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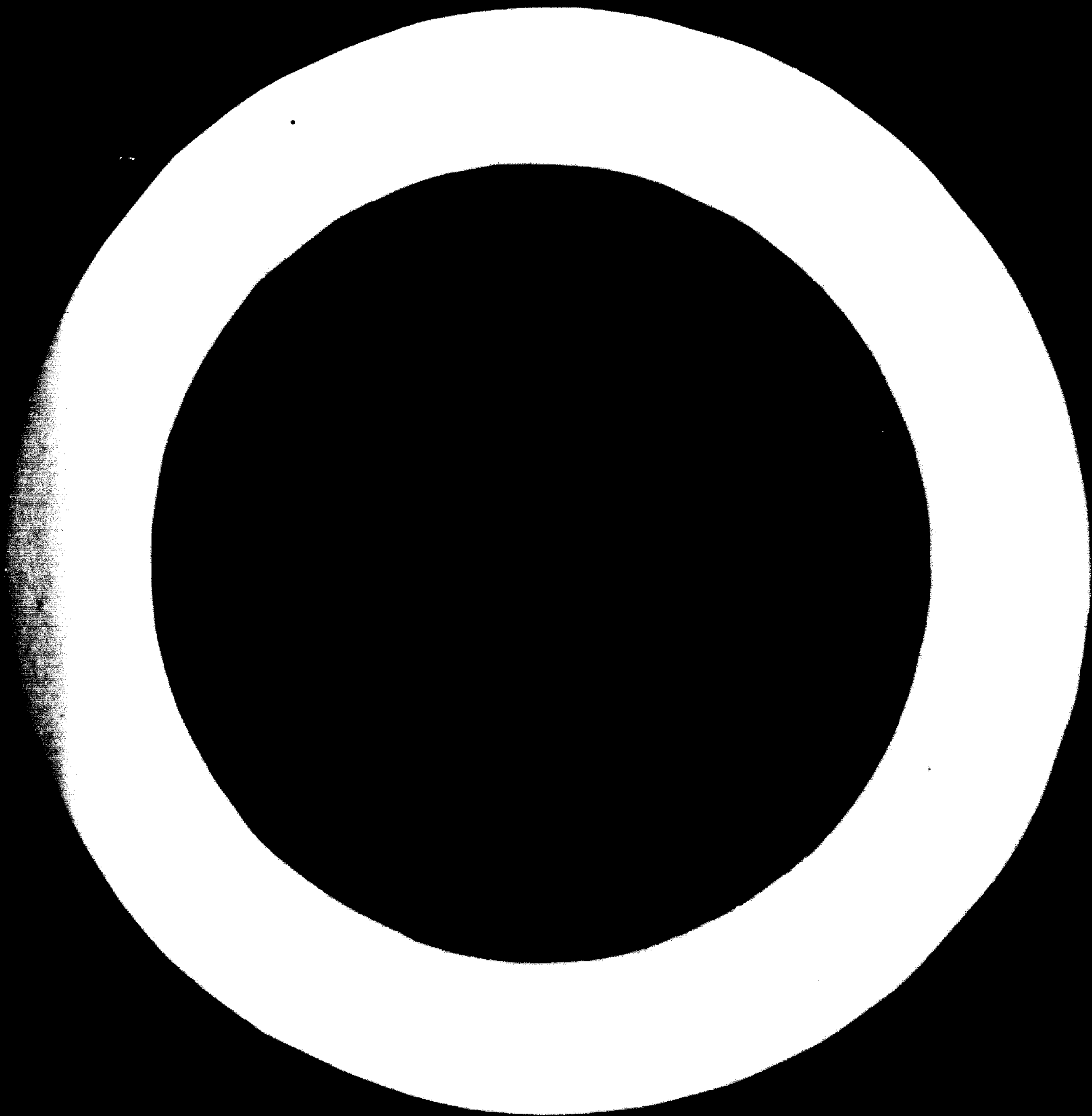
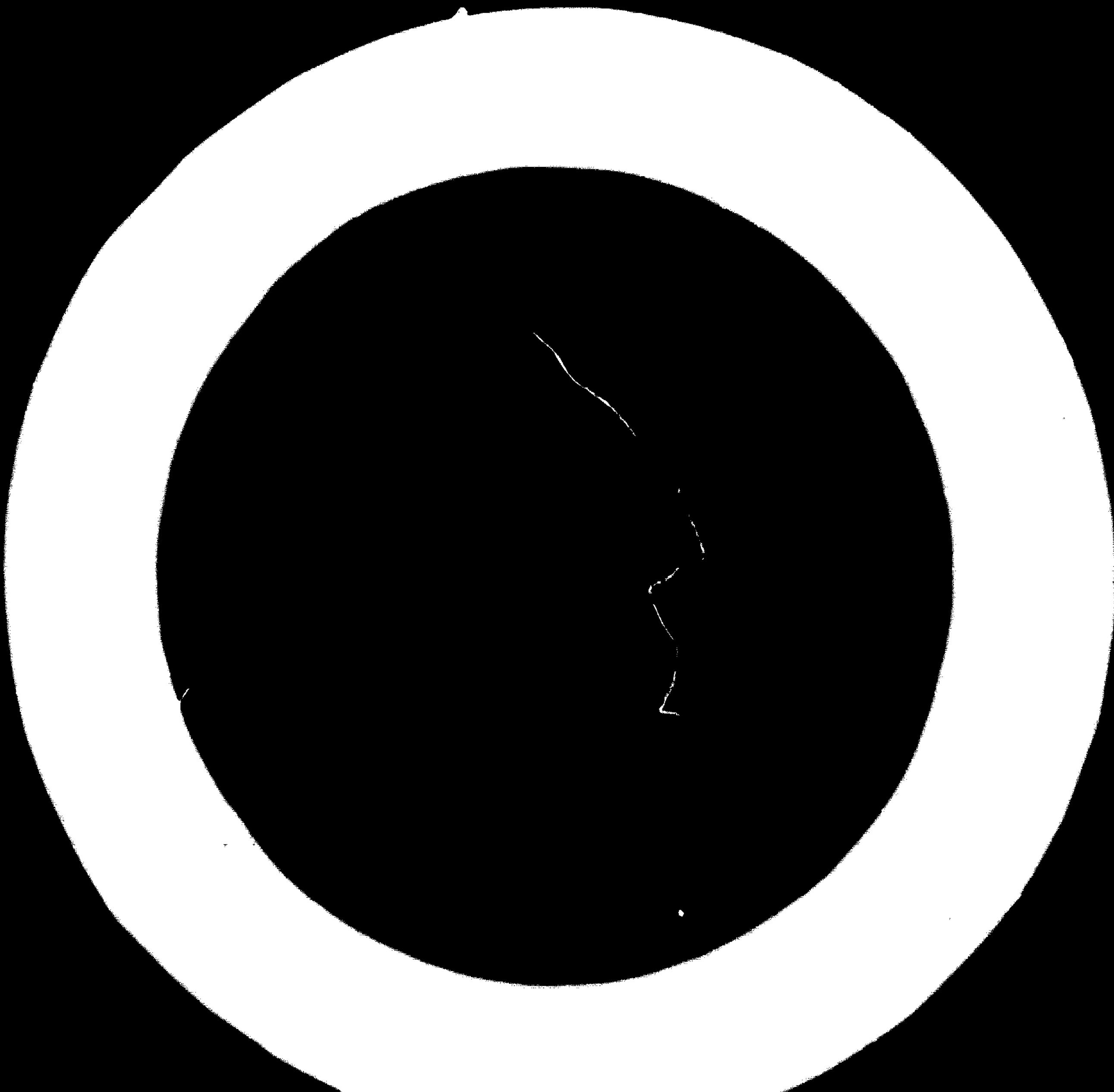
DEVELOPMENT OF METALWORKING INDUSTRIES IN DEVELOPING COUNTRIES



Development of Metalworking Industries in Developing Countries



UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
VIENNA

Development of Metalworking Industries in Developing Countries

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FOREWORD

The United Nations Centre for Industrial Development (CID) organized the Interregional Symposium on the Development of Metalworking Industries in Developing Countries, held in Moscow from 7 September to 6 October 1966.

The activities of CID have been transferred to the United Nations Industrial Development Organization (UNIDO), which was established under General Assembly resolution 2152 (XXI) of 17 November 1966 and which superseded CID as of 1 January 1967.

The final report of the Symposium has been issued as a separate publication;[1] the present publication contains papers presented at the Symposium. The material is divided into three parts. Part One contains papers dealing with the current state of metalworking industries, while the papers presented in Part Two concern economic aspects of the development of those industries. Part Three comprises the papers which deal with technological developments in metalworking industries.

In general, the papers are presented in the form in which they were submitted. Corrections have been incorporated and some minor editorial changes have been made. In some instances, the papers contained in Parts One and Two have been condensed.

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[1] "Report of the Interregional Symposium on Metalworking Industries in Developing Countries" (Sales No.: E. 68. II. B., $US 2.00).

EXPLANATORY NOTES

The following symbols have been used throughout the report:

A full stop (.) is used to indicate decimals.

A comma (,) is used to distinguish thousands and millions.

A slash (/) indicates a crop year or financial year, e.g., 1965/1966.

Use of a hyphen (-) between years, e.g., 1963-1966, signifies the full period involved, including the beginning and end years.

References to "tons" indicate metric tons, unless otherwise stated.

References to "dollars" indicate United States dollars, unless otherwise stated.

Symbols of United Nations documents are composed of capital letters combined with figures. Mention of such a symbol indicates a reference to a United Nations document.

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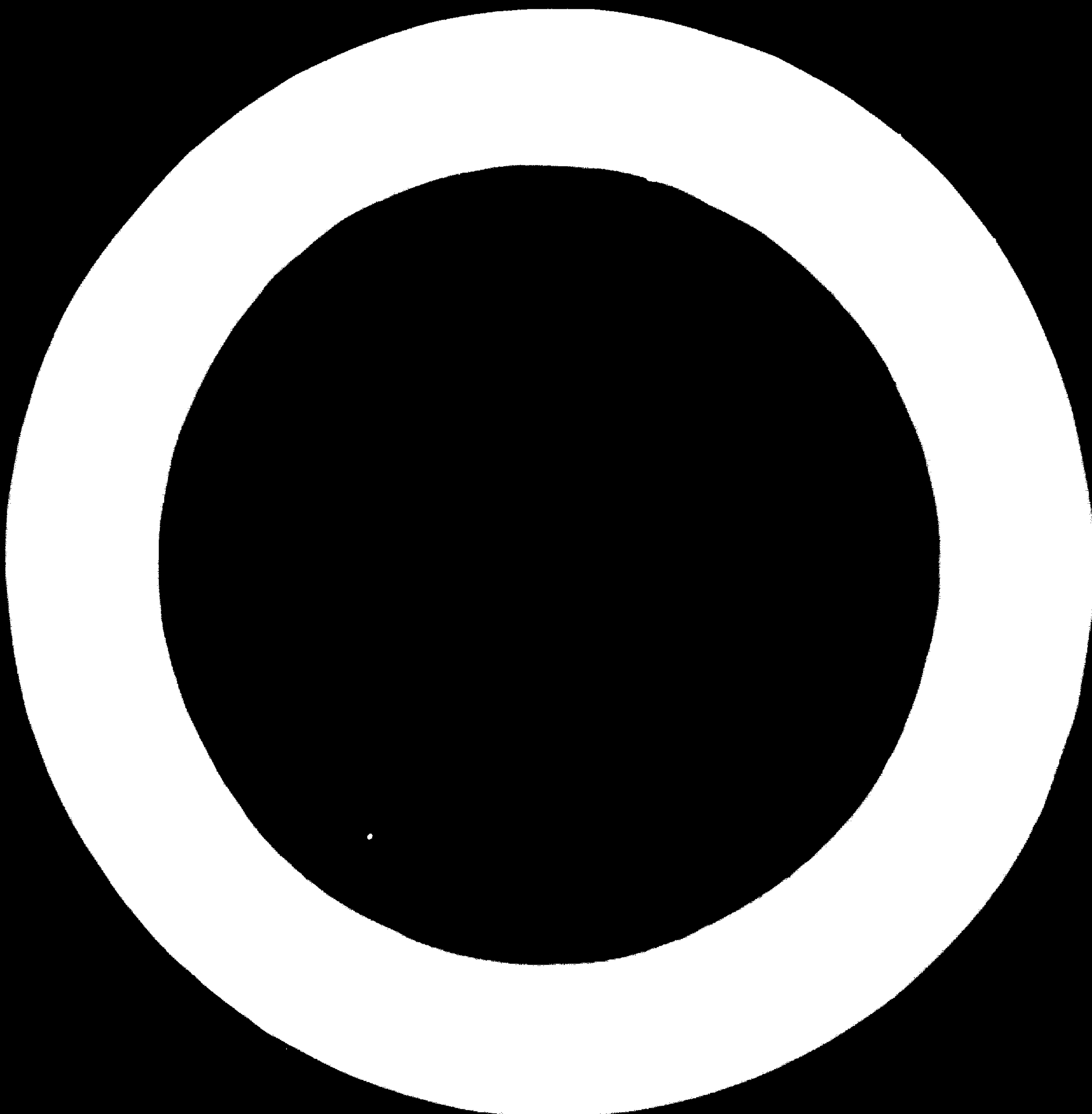
THE STATE OF METALWORKING INDUSTRIES



CURRENT DEVELOPMENTS IN METALWORKING

P. A. Sidders, Chief Associate Editor, **Machinery and Production Engineering**, *London*

Introduction

The output of a nation's machine-tool industry provides a significant indication of its degree of industrialization. Before the Second World War, machine tools were produced primarily by a few European countries and the United States. An important feature of the post-war period has been the spread of machine-tool production to countries that, at one time, were considered to be importers. This world trend will undoubtedly accelerate.

There is difficulty in obtaining reliable data on machine-tool output but, roughly, world production in 1964 was valued at slightly more than £1,700 million, and the estimated output for 1965 was £1,800 million. Output figures (in millions) for the six leading machine-tool-producing countries for 1964 (with estimated values for 1965 in parentheses) are: United States, £430 (£510); USSR, £284 (£280); West Germany, £273 (£284); United Kingdom, £122 (£143); Japan, £109 (£104); and France, £83.5 (£82.5).

The importance of Japan as a machine-tool producer reflects the great expansion in Japanese engineering industries since 1945. Other countries which at one time were regarded mainly as importers enjoy noteworthy positions. China (mainland) is thought to be building machine tools worth £25.2 million a year, although estimates are based on scanty information. Spain, with an output (in millions) of £18.2 in 1964 (estimated 1965 output, £20.9); Brazil, £11.3 (£10.8); Romania, £9.17 (£9.35); Hungary, £9.7 (£10.1); Argentina, £5.8 (£9.3); and Yugoslavia, £3.1 (£3.35), were predominantly agricultural, but are becoming increasingly industrialized.

Particular attention is drawn to India which established the machine-tool industry as one of the bases for planned industrialization. India now is the fourteenth largest producer of machine tools in the world, with an output in 1964 that was valued at £15.8 million (estimated 1965 output, £19.8 million).

Although developing countries must be concerned primarily with the more basic types of machine tools and production techniques, they should keep abreast of the advances in highly developed equipment and processes and use them wherever practicable. In many instances, the latest machine tools and metalworking methods will enable such countries to make the most effective use of scarce raw materials and, of even greater importance, skilled engineers and technicians.

For example, by making use of numerically controlled machine tools, such skill that is available can produce control tapes for a large number of machines, thus providing for quantity output of complex workpieces with only semi-skilled labour. In this connexion, attention may be drawn to a United States company which has sixty employees and seven fully tape-controlled machines with automatic tool-changing facilities as well as other numerically controlled equipment. The machines are operated on a three-shift basis, six days a week, and all the necessary control tapes are prepared by only four skilled programmers, unaided by a computer.

The application of numerical control to machine tools and the provision of improved facilities for setting and changing tools are among the most important developments in metal-cutting equipment during the past ten to fifteen years. At the same time, other significant, although less spectacular, advances have taken place and should be investigated by any country embarking on a programme of industrial expansion. These developments may conveniently be classified into a number of broad groups concerned with raw materials, casting processes, metal cutting, metal forming and welding.

Raw materials

Certain developments in steel production are directed towards reducing the cost of the metal and facilitating continuous casting and other processes. A technique known as spray steelmaking has been developed whereby hot metal direct from a blast furnace is refined on a continuous basis to provide a base material for a wide range of steels. The molten metal is poured into the plant where it is mixed with oxygen and powdered lime to form a fine spray; the refined metal is collected in a container at the bottom of the plant from which it can be withdrawn continuously. Molten slag is withdrawn from above the refined metal and the gas that results has fluxing properties so that, after it has been cleaned, it is fed back through the lime input system. The technique, on a pilot scale, has produced a variety of steels by the addition of alloying constituents in the plant; a production unit was commissioned.

Another development has been continuous vacuum degassing, now in commercial operation for the production of high-quality alloy steels. Molten metal is drawn into the vacuum chamber and the degassed steel is delivered into a ladle or ingot mould.

Both these processes have been used to supply metal to continuous casting plants and such arrangements have great potentialities for the future. In one instance, the continuously cast lengths of steel are cut into billets and then extruded by the Ugine Sejournet process which uses glass as a lubricant; the heated billets are forced through a die to produce lengths of profiled material. It has been used for the production of steel sections of a wide variety of shapes including gears and turbine blades, and the process is particularly suitable for the production of sections in small quantities and in materials that are difficult to roll.

Continuous casting is being used for making lengths of steel, in a modified H-section, which are subsequently rolled to produce structural girders. This procedure eliminates a number of early rolling stages, and girders of different sizes can be rolled from one cast section. The mechanical properties of such girders are equal to those produced by conventional rolling.

Computers are being applied to the control of rolling mills and a fully automated installation is now in operation for press forging. The forging presss and the work manipulator are controlled and adjusted by a pegboard programme unit, the length and size of the work is continuously monitored and provision is made for automatic tool changing to suit the forging stages.

Casting

In the field of conventional casting, there is increasing use of expanded foam plastic patterns for castings required in small quantities. Such patterns are left in the mould and when the molten metal is poured the pattern melts and gasifies. Coring is unnecessary and the use of such patterns can facilititate the production of complex, one-off castings such as are required for special-purpose equipment.

In more conventional foundry work, glass fibre patterns now are used and the application is likely to grow substantially in the future, particularly for the production of large castings. Such patterns are considerably lighter than those of wood, leading to substantial reductions in labour costs. The technique is being developed to permit the production of a mould and a core from one pattern.

In die casting, a material has been introduced for the production of soluble cores and is used for the production of water-cooling passages in cylinder heads, for example. The core material can be dissolved readily after the casting has cooled, so that the production of complex internal forms is greatly facilitated.

Die casting under vacuum conditions is increasingly applied to the production of components, particularly to those required to have high density, good surface finish and thin walls. A new Bulgarian die-casting process has been developed which holds considerable promise for the production of castings free from porosity and of high surface finish. During the casting cycle, counter-pressure is applied to the metal entering the die to prevent the entrainment of gas and to ensure that the casting is of high density.

Metal cutting

The most important metal-cutting developments have been the widespread introduction of numerical control and provisions for automatic tool changing. These two trends have led to the development of the "machining centre", to which reference will be made later, and equipment of this type currently represents the peak of machine-tool design.

Such machines are built by an increasing number of manufacturers, and their use is likely to grow substantially. They offer particular advantages for the production of complex components in small batches, and they can substantially reduce the lead time before a new product can be placed on the market.

The importance of machining centres must not detract from other machine-tool developments, particularly in the application of numerical control.

Continuous-path numerical control is being applied to planing machines to engage the feed and rapid traverse motions of the table, to vary the feed rate, and to control the movements of the cross-rail, the cross-rail tool boxes and the side tool boxes. Profile planing is possible under tape control, also skip planing for machining pads and facings.

There is an increasing tendency to provide high-power milling heads and the necessary low table speeds on planing machines so that they can be used either for planing or milling. Another important trend is to swivelling tool-holders which can be used for cutting in both directions of table travel, with the necessary drive-system modifications to permit the same speed for the forward and reverse motions of the table. This arrangement allows a workpiece to be rough machined with the swivelling tools and simultaneously finish planed with a broad tool in a conventional clapper box.

Planing machines with milling facilities should not be confused with plano-milling machines, now used for much that was at one time done by planers. Plano-milling machines will undoubtedly be used more in the future, although planers still will be required for certain specialized applications such as rail planing. Plano-millers now are provided with cutter heads of increasingly greater horsepower than hitherto. Machines are available with programme control arrangements and in some instances tape control, and this trend should grow in the next few years.

Lathes

Numerical control is being applied on an increasing scale to lathes of all types, particularly in the United States. Usually, the control system is of continuous-path type employing punched tape and, in many instances, provision is made for the use of quick-change tool-holders which may be set away from the machine. Certain lathe makers are building machines with turrets on the cross-slide to hold a variety of tools which can be brought into use as required during the cutting sequence and under tape control.

Although numerical control usually implies the use of punched tape, certain machines are being built with different arrangements. For example, one lathe has a plugboard arrangement for programming the required cycle of movements; the associated traverse lengths are set up on dials. It will be appreciated that this system provides for point-to-point control only, but investigations have indicated that 80 per cent of the work performed on centre lathes does not involve contouring.

In Europe, greater interest is being shown in the application of numerical control to copying and multi-tool lathes. One of the latest machines of this type has two infeeding slides and a vertical profiling slide with an indexing tool-holder. Tooling is pre-set and it is claimed that the change from one type of workpiece to another is confined virtually to the substitution of a new control tape. Programming is relatively simple, and the machine is suitable for short runs.

Numerical control has been applied in an interesting manner to a French lathe which incorporates a conventional profiling slide and an independent tape-controlled tool slide with a four-station turret. Intricate components can be rough machined under tape control and then finished to fine limits under template control.

A German company has developed a complex family of programme- and tape-controlled lathes of unit construction. These lathes can be provided with various drive arrangements—one or more profiling slides which can be fitted with tool turrets, one or more infeeding slides and an independent drum-type turret. The most advanced machine of this type has three tape readers to control a drum turret, an infeeding slide and a profiling slide with a six-station turret.

The programming of a tape-controlled lathe is relatively simple and the application of such numerical control arrangements to straightforward turning work is fully justified. Setting-up time is greatly reduced and the loss of production time when a skilled turner has to check dimensions and reset tools repeatedly is completely eliminated. Moreover, a group of tape-controlled lathes can be tended by one unskilled machine loader. It is not likely that tape-controlled lathes will supplant conventional copying lathes for work required in large quantities, but it is envisaged that one tape-controlled lathe could produce masters for a battery of copying lathes.

Capstan lathes and automatics

Plugboard control has been applied to capstan and turret lathes for a number of years and proprietary systems now available can be applied to a wide range of lathes. One system can control virtually any type of machine tool and other production equipment, and similar arrangements controlled by tape are also available.

A number of chucking automatics are being built with plugboard control and, on one machine, spindle speeds, feed rates and all functions of the machine can be preselected. The traverse motions of the tool-carrying turret are controlled by removable trip and stop drums which can be set away from the machine with the aid of simple fixtures, thus expediting change-over from one job to another.

In order to reduce setting time, provide greater flexibility of operation and permit a large number of spindle speeds and feed rates during a machining cycle, many established chucking automatics are being arranged for numerical control, usually by means of punched tape. A machine-tool builder in the United States has applied an ingenious system to a two-spindle vertical chucking automatic, and this system can be used to control a variety of other types of machine tools.

The arrangement uses a multiple master cam of non-metallic material, which controls the machine through a closed-loop hydraulic system. The cam is produced on a specially developed, tape-controlled milling machine provided with a continuous-path system, and one such cam milling machine can provide control cams for many associated automatics. This arrangement should be capable of considerable extension in the future and provides all the advantages of numerical control without expensive electronic equipment on each controlled machine.

Any expensive production equipment, such as numerically controlled machine tools, must not be allowed to stand idle for long. A number of machine builders have introduced equipment whereby the cutting tools can be set in their holders far from the machine, so that when a blunt tool has to be replaced there is only a short interruption in operations. Such provisions are likely to be adopted extensively in the future and at least one universal type of setting equipment is now available. This equipment is based on an optical projector and can be fitted with adaptors designed for the type of machine for which a tool is to be set. Tools can be set to high standards of accuracy and in most instances no further adjustment is necessary after they are mounted on the machine tool.

Milling and multioperation machines

Most builders of milling machines now provide machines with plugboard or tape control, and the former arrangement usually suffices for straight production operations, whereas the latter is generally applied to more complex work such as profile milling. An increasing number of multioperation machines is being built with provisions for milling, drilling, boring and similar duties, either with tool-carrying turrets or with some simple automatic tool-changing systems. many such machines are also being arranged for tape control.

One interesting turret-type machine, with the turret arranged horizontally, is of unit construction. A variety of operations can be performed in a prearranged sequence and the cutter speeds and feed rates can be preselected for each turret spindle. The unit construction of this machine has permitted the building of special high-production units with a number of turrets around an indexing table to allow a very large number of operations to be performed on complex workpieces.

Automatic tool changing as applied to multioperation machines is usually restricted to replacing a single tool at a time, such as a drill or milling cutter, but a German company has developed a machine for multiple drilling and tapping operations with provision for changing complete multispindle heads. Up to six multiheads can be stored in a magazine unit at one side and a second magazine unit can be provided.

The term "machining centre" has been applied to the more complex multioperation machine tools, and machining centres are now being built by a number of makers in the United States, and by a few elsewhere. Basically, the term relates to a machine designed to perform multiple operations on a fully automatic cycle including tool changing in accordance with programmed instructions, with provision for presenting two or more faces of the work to the cutters without disturbing the work on its support. The most advanced unit of this type has tape control of the complete machining sequence including movements of the cutter head vertically and transversely, and the work towards and away from the cutter spindle; rotation of the work table through 360 degrees and inclination of the table from the horizontal to the vertical; automatic tool changing; and selection and engagement of the spindle speeds and feed rates. One United States company makes five sizes of machining centres of various degrees of complexity. Another United States builder produces a machining centre for which the tool magazine moves with the cutter head. This arrangement allows tools to be changed without disturbing the co-ordinate setting of the head, an advantage when a number of concentric bores have to be machined to high standards of accuracy.

In order to overcome the difficulties associated with automatic tool changing, certain companies are building machines similar to machining centres but with arrangements for producing holes of different sizes with one tool. One such arrangement provides for automatically displacing a single-point tool radially. Another employs tape controlled planetary milling, although this machine still is being developed further. The maker has also constructed equipment for control tape production directly from an enlarged scale layout which is traced mechanically.

A similar arrangement has been developed by a control equipment manufacturer and comprises a special drafting machine with a probe unit coupled to a co-ordinate measuring system. Signals from this system are fed to a tape-punching typewriter which also allows information to be incorporated in the tape manually. The punched tape is fed into a computer and the data is processed to produce a machine control tape. Associated equipment allows a drawing to be made from the machine control tape for checking and other purposes.

Grinding equipment

One of the most significant grinding machine developments was the introduction of the "controlled force" technique in 1963. With this, a specific pressure is applied to urge the abrasive wheel towards the work instead of advancing the wheel at a pre-set feed rate as in conventional grinding. It is claimed that this procedure ensures repeatability of work size throughout a batch, regardless of initial diameter or hardness variations; "spark out" can be eliminated from the grinding sequence, wheel life is extended and vibration is reduced. The technique has been applied principally to grinding machines for ball-bearing races, but it should have great potentialities in connexion with very accurate grinding operations.

Numerical control is being applied to grinding machines on an increasing scale, and one United States machine has a system for automatic control of work diameter. Information relating to the various diameters of a stepped component is fed into the control equipment by means of standard punched cards or by setting dials, and the machine is particularly effective for grinding multidiameter parts in small batches. A German system provides for control of work diameter and wheel position, when grinding stepped shafts, from data which is fed into the unit by groups of decade switches. This equipment governs the rapid approach and roughing stages of the cycle and is used in conjunction with a caliper-type measuring unit which controls the removal of the last 0.004 in. of metal.

Generally similar facilities are provided on a Japanese cylindrical grinding machine, and it is claimed that shafts with up to five different diameters can be ground as quickly as on a multiwheel machine.

A very important development in connexion with the production of small parts is the introduction of machines for grinding such workpieces from solids. Fully automatic machines, with arrangements for feeding bars of hardened work material, have been developed in Germany and the United States. This production technique should find increasing application in the future. Output rates are high, often three times those obtainable with conventional production methods. Check-valve needles, for example, are being ground from hardened steel bars at a rate of 240 an hour to tolerances of 0.0005 in. and finishes of 8 microinches.

Increasing interest is being shown in the use of hydrostatic bearings for grinding spindles, particularly those employing compressed air. A British company is building a range of spindles with air bearings for converting existing grinding machines, and such spindles have been applied to both internal and external grinding. Greatly improved standards of surface finish, accuracy and wheel life are obtained; a specific surface finish is obtained with a wheel of coarser grit than when a conventional spindle is employed.

Electrolytic grinding has been in use for some years, and an electrolytic honing machine has been developed in the United States. By combining the high metal removal rate of electrolytic machining with the controlled surface generation of honing, it is possible to remove metal at rates that are up to 300 per cent higher than those obtainable with conventional honing. This method of honing has been used for such diverse materials as cemented carbide and cast iron, and there is negligible heating of the work. The process was in its infancy, but it will assume increasing importance within the next few years.

Gear production equipment

In gear cutting, a copying system has been developed for use on hobbing machines to permit the production of crowned, spherical and tapered gears. A template, or former, causes axial motion of a linear transducer which is incorporated in a stylus unit arranged to rise and fall with the hobbing head of the machine. Electrical signals from the transducer are applied to control an electric motor which drives a ball screw connected to the work-slide of the machine; corresponding movements of this slide produce the required form on the gear teeth.

Hydraulic motors are being used increasingly for the drive systems of machine tools because of their small size for a given power output. A United States builder of gear-cutting equipment is fitting such motors to the cutter heads of his hobbing machines to provide a particularly compact design with stepless speed variation.

It is generally appreciated that cutting techniques are not the most efficient methods for converting raw materials into finished products, and greater attention is being paid to metal forming processes. The production of gears by rolling has been utilized effectively in the USSR for many years, and this method of gear production is being investigated and applied elsewhere. This technique not only makes the most effective use of work material but also produces teeth of greater strength for a given pitch than can be obtained by cutting, and the teeth produced by rolling are of high accuracy and surface finish. Equipment for rolling gear teeth in unheated blanks or bars has been developed by Swiss and German machine-tool builders, and a machine for hot rolling is under development in Great Britain. Gears are also being produced by rolling on existing spline and serration rolling machines.

A new type of gear-finishing machine, employing a tungsten carbide cutter which resembles a master gear, has recently been introduced in the United States. The cutter is mounted at an angle of five to twenty degrees to the workgear and is rotated in phase with it by a drive system that incorporates change gears. The cutter is advanced axially across the width of the workgear from which metal is removed from the teeth by the cutting edges on one side face of the cutter. In contrast to conventional shaving, the new method permits the removal of much greater amounts of metal so that larger errors can be corrected and the output rate is high.

Sawing machines

Improved techniques for cutting billets from bar material are available and include so-called "cut machining" and friction sawing. With the former process, a specially compounded grinding wheel is used to cut through materials, including hardened alloy steel, at high speed without softening the work or producing large burrs; machines can be supplied with wheels of 36 in. diameter. Friction sawing utilizes a circular, hollow-ground alloy steel disc, with a cutting edge of special form; the cutting action is very rapid, and an 8 × 4 in. rolled steel joist, for example, can be cut through in seven seconds.

Photoelectric control has been applied to bandsawing machines for sawing from a drawn outline. A typical machine has two rotary tables, one for the work and the other for the drawing, which are connected by gearing so that they rotate in unison. Feed motion is imparted to a compound slide on which the tables are mounted, in accordance with signals from the photoelectric follower system. It is claimed that contours can be followed to an accuracy of 0.001 in., and material up to 16 in. thick can be cut.

Transfer machines and link lines

Although transfer machines are still built and widely used, there is a trend towards the employment of link lines: standard machine tools linked together by work handling and storage equipment. Product changes can be accommodated more readily and the machines can be regrouped if required. Particular interest has been shown in link lines in the USSR where a range of standard machines has been developed for this purpose; free-standing workloading and magazine units for incorporation in such lines have been developed also.

Machine-tool builders elsewhere are becoming increasingly aware of the significance of link lines, and certain current machine tools are designed to facilitate work loading and handling. A German company, for example, has built a link line comprising a number of standard front loading automatic chucking lathes, and a special purpose drilling and boring machine connected by an overhead conveyor to standardized hydraulically operated loading and unloading units. A similar line of a number of standard vertical turning and boring mills and a special inspection machine, have been built by an Italian maker.

A Swiss builder of copying lathes has introduced standardized automatic loading equipment for use on his machines. The equipment is of two types, one for handling billets cut from bar and the other for forgings, and provision is made for adjustment to suit a wide range of component sizes and lengths. Quick adjustment can be made so that the equipment can be employed for the automated production of parts in small batches.

Metal forming

As has already been intimated in connexion with gear production, increasing interest is being shown in metal-forming techniques with a view to reducing the amount of machining required to produce a finished product, and to provide improved physical properties. Reference has been made to programme-controlled forging in connexion with raw materials, and programme control is also being applied to the production of finished forgings for shafts and spindles. A Swiss builds machines which forge the work by the action of three hammers that are moved radially relative to the work while it is traversed axially and rotated. The latest machines of this type have plugboard control for engagement of the various machine motions, and trip plates to control the lengths and diameters of the various portions of the work. Forgings up to 43 in. long by 3.5 in. diameter can be produced to an accuracy of ± 0.012 in.

A somewhat similar technique has been developed in the USSR whereby a heated bar is passed between three sets of rolls. These rolls may be of cylindrical or back-tapered form and are mounted on inclined shafts. Separation of the rolls is controlled by a template and follower and the rolls are fed in and out to produce the required diameter steps or contours on the work.

Another interesting hot-forming process in use in the Soviet Union employs rolls with a spiral form, between which the heated bar of work material is passed. The material is progressively formed by the grooves in the rolls and long lengths of formed bar may be produced for convenience of subsequent machining, or a sharp edge at the side of the final groove in each roll may cut the component from the bar. Forgings for bearing races and bicycle hubs are produced by the former method, using a mandrel and tubular work material; blanks for bearing balls are produced by the latter arrangement.

Work is being carried out in many parts of the world in connexion with high-energy rate forming, and a number of such machines are commercially available. Certain of these machines operate on the principle of releasing a volume of gas under very high pressure to react on pistons connected to the ram and platen of the forging machine. Equipment recently developed in Great Britain and now going into production makes use of the controlled combustion of a petrol-air mixture, the gaseous products of combustion providing the driving force for the ram. This arrangement greatly simplifies the construction and operation of the machine, and the cycling time of less than two seconds allows repeated forging blows to be made.

Among the advantages of high-energy rate forging may be mentioned the large displacements of metal that can be obtained in one forging cycle, so that parts of considerable complexity can be produced without draft and to close dimensional tolerances; the lower cost of forgings as compared with those produced on drop-hammers or forging presses of equivalent power; and the elimination of massive foundations, such as are required for the latter equipment.

Reference has already been made to the Ugine-Sejournet process, one of a number of extrusion techniques, the use of which is now widening. Cold extrusion of non-ferrous metals has been effectively employed for many years and steel components are being produced by this method in increasing variety and numbers. Recently, research has been undertaken in connexion with hydrostatic extrusion, and equipment for this technique is now commercially available.

The technique provides for the application of fluid, usually oil, under high pressure to a chamber that contains the billet of metal to be extruded, one end of the billet being engaged with the extrusion die. Pressure applied all over the billet surface by the oil forces the work material through the die to produce a length of metal bar of the required cross-section. Metals that are too brittle to be formed by any other procedure can be extruded by this technique, and it is possible to produce clad extrusions by using a core of one metal within a tube of another. The work material can be coiled, before it is inserted into the chamber of the extrusion equipment, when very long bars of small diameter are to be produced.

In more conventional presswork, there have been a number of advances in press design. A recently built United States press of 30 tons capacity operates at speeds up to 600 strokes per minute and has an aluminium alloy ram guided by ball-bearing ways, provision being made for pneumatic counterbalancing. A Danish company has developed a hydraulic drawing press of particularly compact design. The ram is housed in the lower part of an inverted-U frame, and moves vertically upwards during the working stroke. Both side members of the frame are bifurcated and a cross-head moves between them. This unit is supported by hydraulic cylinders and is secured in the working position at the bottom of its travel by massive locking bolts. The blank-holder cylinders carried on the cross-head have only a short stroke, so that the volume of oil displaced is very small and pre-filling is not necessary. Moreover, very high pressure can be applied to the work material by the blank-holder to allow a stretch-forming action during the last part of the ram travel. This press is a radical departure from conventional press design, and should have an important influence on future press development.

Another unusual press design was originated in Sweden and is intended for cold forging, closed-die forging, coining and other applications that require very high forces. The design is based on a built-up frame of cast or forged members, which is reinforced by winding around the frame a continuous mantle of high-tensile steel wire. These presses are built with ratings from 1,000 to 20,000 tons.

Turret presses, for multiple operation work, are available with tape control systems for selecting the sequence of operations and the tools and also for positioning the work.

Electrical and Other Metalworking Techniques

Spark erosion is well established as a metalworking process and is being applied to the production of tools, dies, gauges and components in heat resistant and stainless steels and other materials difficult to machine. Development work is proceeding in the USSR, the United States and Europe, and certain makers of jig borers now build machines with spark erosion heads.

Ultrasonic drilling has been employed for many years for piercing holes of square and other shapes in brittle materials. Recent developments in ultrasonics have been concerned with combined ultrasonic and electrolytic machining and combined ultrasonic and spark-erosion. This work is still in its early stages but holds promise for the future. The application of ultrasonic vibration to grinding wheels has resulted in higher rates of metal removal and improved surface finish.

Electrochemical machining, that is, the removal of metal by electrolysis in a manner the reverse of electroplating, is now increasingly used for working materials difficult to machine by conventional techniques, such as heat and corrosion resistant alloys. Typical components for which electrochemical machining has been used are turbine blades, and substantial economies have been achieved. Very large installations are now in operation, and components of considerable size and complexity are being worked. A recent investigation is concerned with machining a bulkhead in Rene 41 alloy of 5 ft internal diameter and 3 in. thick; it is estimated that conventional machining would have required 3,775 hours, whereas 195 hours are required for electrochemical machining.

Magnetic forming makes use of the rapid discharge of stored electrical energy from a bank of capacitors to produce a pulsed magnetic field around a coil. As a result, an induced current is caused to flow in the opposite direction through any electrically conductive material in close proximity to the coil. The induced current reacts against the magnetic field to produce an intense force and, if the coil surrounds the work, the latter is deformed. This process has passed out of the experimental stage and magnetic forming machines are commercially available. Magnetic forming is being used for expanding and shrinking tubular components, forming flat workpieces and assembly operations. In one application, it is being employed to form an aluminium shell around a small electric motor. Aluminium, brass, copper, steel and molybdenum are among the metals that have been handled by this process.

Explosive forming is being used commercially for such diverse operations as forming stainless steel plates for dentures and producing large pressings for aircraft and space vehicles. This technique involves the explosion of a charge adjacent to a metal blank that is clamped against a die within a tank of water. A shock wave is produced which forces the metal into intimate contact with the die and the die contours are reproduced to a high standard of accuracy.

Welding

Electron beam welding is assuming increasing importance as a production process, particularly in connexion with components for aircraft and aero-engines. The electron beam is the most intense source of heat available at a usable power level. It can be applied to join metals that are normally considered to be unweldable. Because of the power density and the process of metal fusion, greater penetration with substantially reduced heat input can be obtained than is possible by conventional welding techniques.

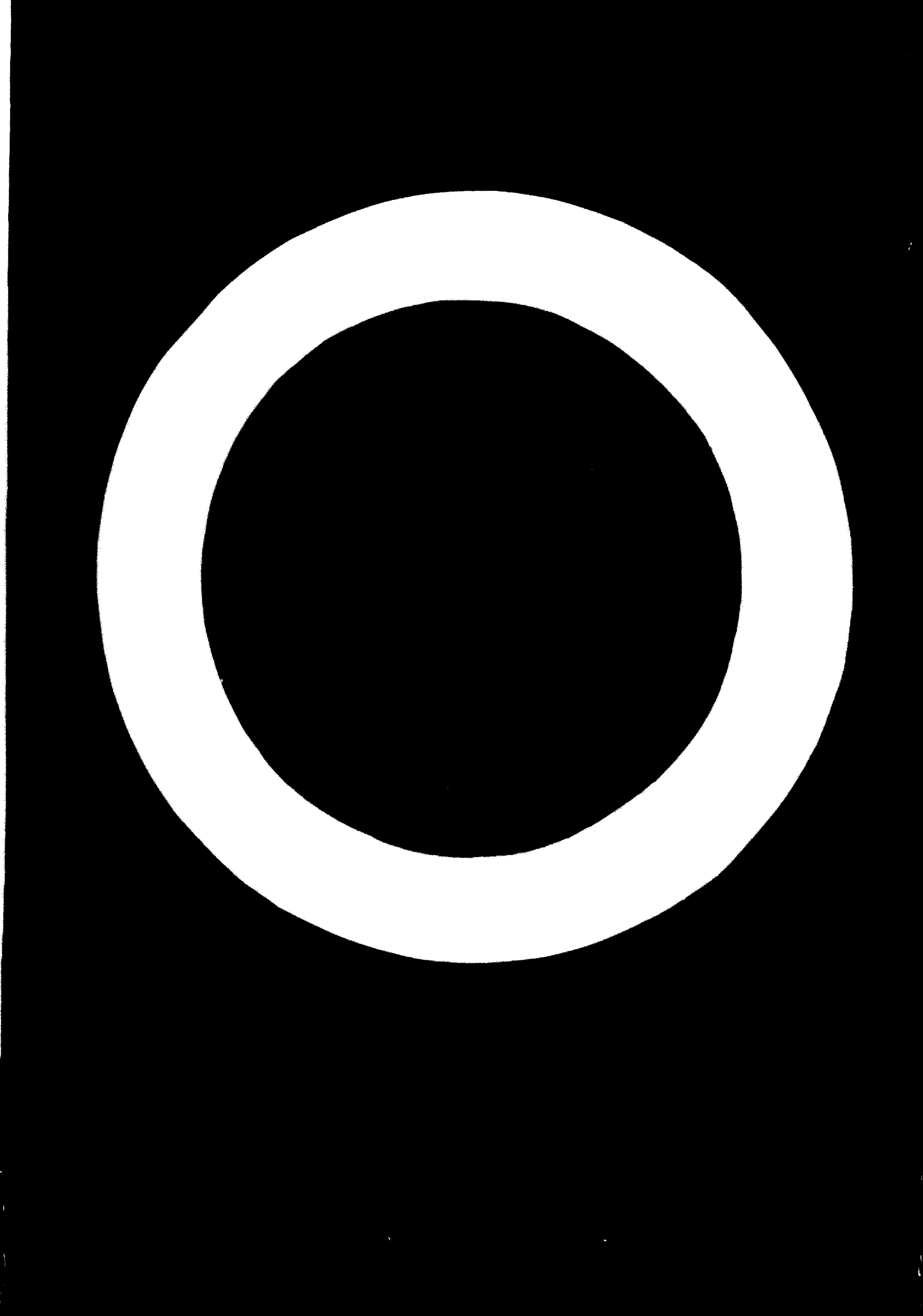
The depth-to-width ratio with electron beam welding may be as high as 20 : 1, as compared with 1 : 1 for the argon arc process, and the heat input with electron beam welding is about 5 per cent of that required for the latter process. Thermal distortion is reduced, shrinkage of the weld during solidification is small, and weld cracking is decreased when the electron beam technique is employed.

Electron beam equipment of considerable size is available, for example, with a vacuum chamber 5 feet in diameter by 6 feet long; "in air" electron beam welding guns are now being used for specialized applications such as welding long steel pipes.

Friction welding machines, which operate on the principle of generating heat by bringing two surfaces into contact at a relatively high speed, are now built by a number of makers. Friction welding permits joining dissimilar metals, such as aluminium to stainless steel and copper to aluminium, on a completely automatic cycle. A typical machine has capacity for work up to 1.5 in. diameter by 36 in. long; one component of a welded assembly is held stationary, whereas the other is rotated at speeds up to 2,000 rpm. The two components are brought into contact under conditions of controlled pressure and time to effect the weld, and provision is made for automatic loading and unloading.

Electro-slag welding was developed in the USSR and is widely employed for making joints in very thick steel plate, particularly where large amounts of filler metal are required. Metal can be deposited by this process more quickly than by any other known technique, and the electro-slag process is readily adaptable to automatic working. The process is now being used for joining plates with thicknesses exceeding 15 in. but is not considered suitable for material less than 1.5 in. thick.

It should be stressed that development and invention in metalworking is continuous, and is not limited to any one country so that, in certain instances, new advances may have been made during the time when this paper was prepared and when it is read.



MACHINE-BUILDING TECHNOLOGY

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TECHNICAL PROGRESS IN MACHINE BUILDING

Science and technology

Technological advances in the productive sectors of society are resulting in greater industrial and economic transformations than during all past stages of development put together, including the periods of discovery and industrial application of steam and electric power.

Rapid development of the so-called fundamental sciences, physical, technical, mathematical, chemical and natural, and the achievements of atomic physics and electronics have opened a new epoch in the development of techr ›logy, increasing the rates of industrial development.

The characteristic and distinguishing feature of the present stage of technological progress is a more rapid application of scientific discoveries into industrial production. If formerly tens and hundreds of years elapsed between scientific discoveries and wide-scale industrial application, now these periods are reduced to several years. Thus, for example, the discovery of the principle of generating focused beams of light (laser) took place slightly more than ten years ago. And at present laser methods have already obtained industrial application in communications, medicine and materials processing.

Especially vigorous development is taking place in the creation and industrial application of a wide range of synthetic materials.

Scientific discoveries radically changing the nature of industry and technology gave life to the appearance in the recent ten-year period of new branches of industry such as electronics and atomic energy.

Branches of industry producing household equipment and chiefly using the achievements of electrical engineering and chemistry are the most rapid in development.

As a rule, the industrial significance and economic effectiveness of all scientific discoveries and results of research is expressed mainly in new materials, new technological schemes and products possessing new and better qualities as compared with the old.

The rates of economic development of any country and especially of the developing ones depend, at present, on the speed with which scientific discoveries are transformed into actual schemes, technological processes and equipment and how widely they are employed in the country.

It is understood that scientific discoveries and technical achievements must be used for the development of productive forces and for making the life of the population more comfortable.

The fact that actually almost all the scientific and technical achievements in all branches of industry and agriculture are realized through machine equipment and instruments is a characteristic peculiar to technological progress.

This is the special role and significance of machine building, the basis for technically re-equipping the country's economy and the means for speeding up the technological reconstruction of industry and for increasing the national income.

General tendencies in development of machine building

Contemporary machine building is fulfilling, in general, two basic functions. First and foremost is the production of means of production, i.e. of equipment and instruments for production of various types of products. The nomenclature and the technical parameters of industrial equipment manufactured by individual countries are determined by the specific peculiarities of the economy and especially raw materials resources, by the size of the territory and the number of the population, by national traditions in trends of trade, and the existing and the prospective level of industrial development.

The second and the more increasing peculiarity of machine building is connected with the creation of so-called consumer equipment: radio and television sets, means of communication, refrigeration equipment and means which make household labour easier (vacuum cleaners, floor polishers, etc.).

If the first branch of machine building is developing in individual countries, in special channels, taking into account these peculiarities, then the second branch is of importance not only to the industrially developed countries but also to all others including the developing ones.

Under the current conditions of communication and association, the problems of supplying markets with sufficient quantities of cheap and high-quality consumer items are an urgent problem of every state. This acquires special importance for the developing countries which for a long historical period could not make full use of the achievements of contemporary society in improving the standards of living because of some economic and other reasons.

It is quite natural that the demands for, and the assortment of, consumer goods will be determined both by the economic and climatic conditions of each country

But a considerable part of this variety is sold also in the world market.

When analysing this variety, it is necessary to estimate and weigh carefully the conditions in each country as well as the scale of development of machine building both for the industrial machinery and consumer equipment.

The assortment of modern machines and equipment is measured in millions. Technique is constantly developing and improving. The common characteristic of the development process anywhere is to increase the speed of production processes. This is expressed in continuous and sufficiently intensive growth of working speeds (in aviation, for example, speeds in the past twenty-five years have increased, excluding rocketry, from 200–300 km per hour to 1,000–3,000 km and more).

High-speed working processes and continuity of production processes became necessary and largely possible through automation and automatic control.

The tendencies of development of machines directly affect the technology of machine building which should create conditions making it possible to manufacture in sufficient quantity and variety with the least labour.

Thus, for example the application of electroerosion made it possible to manufacture curved and shaped holes and to meet design requirements for machines. The use of ultrasonic and laser techniques made it possible to produce materials with great precision and of practically any strength, thus creating the conditions for the use of new designs of machines.

Thus the development of machine building and instrument construction are closely related to the development of machine-building technology.

Peculiarities of machine-building development in developing countries

The industrial development of machine building and the use of equipment under contemporary conditions may be divided into three basic stages in the developing countries.

The first stage is the importation of machinery from more developed countries.

The second stage is the organization of maintenance and repair of the machinery.

The third stage is the organization of a country's production of machinery for its own use.

A developing country's decision on whether to import machines, produce its own, or some combination, must be based on its needs.

Today, not a single country, even the most developed one, can produce sufficient quantities and keep up the technical level of all the machines required; all are forced to import a considerable amount.

It is most probable that the economically expedient organization of production of industrial equipment in individual countries should be limited to those types of machines which are necessary for the development of the main branches of the economy and which draw on the country's natural resources. But there are many examples when some developing countries started to produce machinery from imported raw materials and successfully competed in the market. This is done to increase employment and national income.

International division of labour is already a fact and will increase as the economic relationships develop and become stronger, involving to an increasingly greater degree the industrially developed countries.

Technical and economic abilities of individual countries already show the advantages of producing certain types of machines more economically in one country than another. These peculiarities should be considered by the developing countries both at the first stage when solving the problems of import and especially at the third stage when organizing their own production.

The solution to the problems of the second stage, maintenance of machinery, is more complicated.

Practice shows that maintenance and repair of automobiles, refrigerators, radio and television sets and other equipment by the exporter may be acceptable at the first stage only. It is evident that in the course of development it is more economical to create national maintenance and repair facilities which will make it possible to render service both to the industry and to the public.

The third stage is the creation of national machine building, taking into account all ramifications.

Economic calculations prove the expediency, especially in the large developing countries, of creating in the shortest period national machine-building production of industrial equipment and consumer goods for its own use and for export.

It is very probable that within the next decade there will be all types of production scaled from mass to job ork. Consequently, it is necessary to develop technology and to procure equipment bearing this in mind.

Effect of industrial development on machine-building technology

In what way does modern industrial development influence machine production?

First, in the change of raw materials to be processed.

The variety of metals and alloys is continuously enlarging and these metals are stronger and more heat- and chemical-resistant.

Ceramics, hard minerals, plastics and other synthetics are more broadly used. However, based on all the factors, it is difficult to expect that in the next ten-year period the volume of plastics used in machine building will exceed 5–6 per cent of the total quantity of materials. Metals and their alloys will remain the basic construction materials for machine building.

Second, this influence is reflected in the dimensions of machines. The tendency towards classification of equipment by size has become more important recently. There is also a tendency to increase sharply the sizes of machines in metallurgy and transport (railroad, aviation, freight and passenger) and to miniaturize machines used in electronics and medicine.

Machine-building technology now must be more flexible and be capable of producing items weighing several thousand tons and items whose weight is measured in thousandths of a gramme.

Third, what is increasingly attracting the attention of scientists and industrialists is the demand for higher quality precision, stability and reliability of production equipment.

One should expect that the demands for precision will grow with the increase in production capacity.

But already the physical barrier of precision is clearly visible. Thus, in the aviation, bearing and means of control industries, there is the necessity to manufacture individual parts with a precision measured by parts of a micron, that is, where permissible error approaches the size of a molecule.

Large expenditures of labour and means to ensure such high precision now become an obstacle for the further development of some designs of machines. That is why the clearly outlined tendency of moving from machines with large kinematic speeds and dynamic loads to units with rotating and quickly moving parts to stationary equipment distinguished by a complete absence of rotating and moving mechanical elements is a natural phenomenon. The evolution from propeller to jet engines, the direct generation of electricity by chemical or heat methods without the use of mechanisms, may be referred to such a tendency.

But if in the sphere of power supply, transport and some other types of machinery the transformation into stationary units may be expected within the next decade, then in the spheres of the basic means of control a considerable decrease of demand for precision is not yet observed.

That is why the most important problem in the development of machine-building and instrument-making technology is the problem of precision and reliability of operation.

This actually determines the special role and significance of the machine-tool building industry, the heart of machine building. The technical level and scope of development of the machine-tool industry determine the level and the pace of development of all machine-building and metal-processing industries and deeply affect the development of the country's economy as a whole.

Basic developmental rules of machine-building technology

The technical level of machine-building technology is first of all determined by the quality of the material to be processed, dimensions and form, productivity, machinery and equipment and the scale of production (from piece-work to mass).

Use of raw and semi-finished products

The cost of initial materials reaches 50–70 per cent and more of the cost of manufacture, particularly so in batch and mass production. Wages are 20–35 per cent, and in a number of branches (instruments, bearings) are only 10–15 per cent or less. That is why the materials factor is so important. This factor may be determined by:

$$K_m = \frac{Q_i}{Q_m}$$

where: K_m is the material factor
Q_i is the weight of the machine
Q_m is the weight of the initial materials.

Experience shows that the losses of metal at all stages of production constitute 20–30 per cent or more in mass production and 35–40 per cent or more in batch or piece-work production.

There should be given greater attention to improving precision in initial operations so that there is less to do in final stages.

Experience shows that only 30–35 per cent of the initial weight of metals is delivered as finished parts to the assembly line.

Modern methods are only now beginning to be applied to improve this ratio. The level of consumption of materials should be increased soon to 80–85 per cent in the machine-building industry. This will make it possible to bring about 50–60 per cent of the original metal weight to the assembly line.

In the current world market, the cost of raw materials is low compared to the cost of manufactured parts. The analysis reveals that the established ratios of prices in a number of cases do not correspond to the actual expenditures of labour and are chiefly determined by the conditions of obtaining these types of products. There are cases when some raw materials produced in economically backward countries with low wages are priced unjustifiably low as compared to highly priced machinery from industrially developed countries with high wages.

It is probably wrong to be guided by the market prices, but the decision should be based on the analysis of exact cost of social labour both for obtaining the raw materials and the manufactured products.

Continuous processes

The ever-growing tendency of shifting from discrete to continuous processes is a peculiarity of the main trend in technology. The index of continuity may be estimated by the following equation:

$$K_c = \frac{T_w}{T_o}$$

where: T_w is the time of useful work of equipment
T_o is the total working time.

The estimation of these indices may be referred both to the working shift and to a long period (month, year) of work.

The total working time consists of the useful operation time, auxiliary time, manual time, adjustment time, idle time, etc.

The existence of discreteness, though the present objective conditions make it possible to fulfil many processes by theoretically continuous methods, is a characteristic of machine-building production at all stages. Especially unfavourable is the ratio of time of useful work to total time in press forging and metal cutting. The useful time of metal forming constitutes only 2–3 per cent of the entire cycle of the operation. On metal-cutting machine tools the useful time of cutting is 50–60 per cent of the entire cycle and for such types of equipment as turning lathes it does not exceed 20–40 per cent.

These unfavourable proportions prove that the main attention is paid to the problems of increasing productivity of the working process proper and not to increasing the degree of continuity when designing machines.

Possibilities of practical improvement of the index of the continuity degree may be illustrated by two examples: application of periodical rolling methods in which the degree of continuity of the working process may be brought to 70–80 per cent makes it possible to increase productivity 15–20 times as compared to presses of the same capacity; substitution of centre grinding processes by centreless grinding makes it possible to increase the continuity degree from 50–60 per cent to 85–95 per cent and the productivity of the process two to three times.

In general, the increase of the continuity degree may be achieved by an over-all speeding up of auxiliary movements of working parts of a machine, by the reduction of the number of consequent movement elements or by performing auxiliary movements with the working movements at the same time.

Experience shows that this combination is the most effective. The development of equipment and technology should ensure reduction of nonproductive expenditures of working time as compared to the reduction of time for accomplishment of useful work.

Degree of concentration

There are two ways to organize productive processes. One is differentiation based on the maximum division of complex technological processes into simple elements for which special equipment is designed. The other is concentration based on the maximum combination of technological operations to be performed in a single unit.

Differentiation of technological operation, which made it possible to apply comparatively simple equipment and less skilled personnel prevailed at the first stages of development of machine building and especially of mass production. But based on economic factors such as demand for a large amount of equipment, working site and personnel, differentiation gave way to more effective methods based on application of complex units in which the concentration of various technological operations is fulfilled to the maximum degree.

The ideal method of manufacturing machine parts, not considering technical and economic possibilities, is manufacturing the part on a single machine in one pass. In a considerable number of cases the expedient degree of concentration is practically achieved by multitool and multiposition machine tools and the continuous process. When estimating the practicality of such decisions it is also necessary to take into account that, in the conditions of identical expenditures of auxiliary time, their total value will be less if there will be more technological operations performed on one unit.

The degree of concentration is expressed as:

$$K_k = \frac{l}{n}$$

where: n is the number of consecutive operations in manufacturing of the part.

In machine building this coefficient is equal to 0.2–0.3, which means that the part is subjected to three to five operations.

It is a little more difficult to solve the problem of manufacturing precision parts, when the parts must undergo consecutive finishing operations.

Accelerating the working process

There is a trend to accelerate working processes by increasing machine speeds and pressures.

Mechanization and automation

Statistical analysis in a number of countries shows that only a third of the increase in labour productivity is related to the increase of machine productivity while two-thirds of the increase in labour productivity is related to automation.

A stronger and stronger tendency to use automated equipment and automated systems is noted in batch and mass production.

The degree of automation of individual operating machines may be defined by the following equation:

$$K_a = \frac{t_a}{t_o}$$

where: t_a is the time of automated operations
t_o is the total time of the cycle.

Wider use of electric and electrohydraulic controls is being applied along with traditional means of automation of operating machines through mechanical distribution devices (chiefly in automatic turning lathes). Development of numerical control systems is of a special significance for batch production.

The proportion of automated equipment in mass production is as high as 80–95 per cent and the further increase of such automation is connected to introduction of transfer machine lines and gradual transfer to complex automatic systems. The proportion of automated equipment in batch production is 20–30 per cent. Further increase in the degree of automation in batch production is connected with design of flexible, quickly readjusted automatic machines equipped with standardized, sufficiently universal devices for clamping, rotation and removal of machine parts.

Wide-scale introduction of grouped methods of treatment is of great significance for creating economic conditions for introduction of automatic equipment into batch production. Correct choice of similar technology, tools and sequences of operations make it possible to cut significantly the time for their resetting and to increase the size of the batch. The use of numerical control equipment is the best way to increase the degree of automation in small batch production and in heavy machine building.

When solving problems of labour efficiency in machine building it is also necessary to take into account the fact that along with the production workers there are many categories of workers indirectly involved such as transport and warehouse workers, inspectors, dispatchers and accounts, etc. In some cases this category of workers is as high as 30–40 per cent of the total number employed. Under modern conditions it is impossible to estimate the level of technology only through the degree of automation of the basic production equipment, but it is essential to consider this problem by taking into account all the people involved in the production.

This problem may be most effectively solved by creation of complex mechanized continuous lines in batch production and complex automatic lines and shops in mass production.

The development of computers and automatic control raise the problem of creating automatic systems of production in the industry.

The practical solution of these problems requires raising the numbers of skilled personnel.

Experience shows that the idea that the demands for skilled personnel will be decreasing with automation and the development of technology has been rejected by practice.

Highly skilled personnel possessing the necessary skills and knowledge to maintain complex equipment are necessary.

This problem is especially important for the developing countries. The opinion that developing countries should be chiefly orientated towards the simplest types of machinery because of the absence of well trained and skilled staffs is not confirmed by either the economic or the social aspect. It is evident that no less time is required for training a highly skilled turning or milling machine operator than for training a skilled mechanic. The difference in both cases is only in the general educational level.

Stability of processes

The most important qualities of technological equipment and processes are reliability, durability and stability in operation. Generally the stability index may be expressed by the following:

$$K_{st} = \frac{t_c}{t_o}$$

where: t_c is the continuous operation time
t_o is the total operation time.

It is necessary to maintain the stability of working parameters as long as possible during the operation. This is especially important for metal-cutting operations where the tool life is relatively not very high.

The most effective solution of this problem is through application of automatic control directly to the workpiece which is machined.

The second and the no less important problem is to insure high reliability of operation of all machine elements. To increase the reliability and durability of machines, the engineers are facing the problem of discovering objective means of rapid estimation of the preset durability and reliability of individual parts, separate mechanisms and of the whole machine.

It is necessary to analyse all factors, though in some cases one or several may be decisive, when solving engineering problems of machine building.

Some peculiarities of development of machine-building technology at basic process stages

Rolled stock

Rolled stock manufactured by metallurgical enterprises was, is and remains to be the basic construction material for machine building.

Rolled stock constitutes about 60 per cent of the entire amount of materials used in machine building.

It is necessary to mark, along with these facts concerning the assortment of materials for machine building caused by the peculiarities of technical development, the continuity in technical development. Various types of bent and shaped profiles of higher rigidity make it possible to make miscellaneous, comparatively complicated designs of machine parts; these are becoming more widely used along with the traditional rolled shapes. Application of such types of rolled metal makes it possible in a number of cases to do without any treatment of metal in machine building. The proportion of the rolled shapes and bent profiles should soon be 5–7 per cent of the total amount of rolled metal supplied for machine building, according to experts.

There is a recent tendency, based on the specific demands of machine building, to increase the manufacture of high precision types of shaped metal (with a precision of 5–10 microns) for manufacture of such parts as spline shafts. These precise profiles find wider and wider application in machine building in spite of the labour-consuming operations when rolling and pressing.

The general tendencies of changing to the continuous processes find their reflection in rolling of metal and fabrication of the volume blanks by continuous methods, by the so-called periodic method instead of forging or stamping. Such mass-produced parts include ploughshares and mouldboards, bearing rings, crankshafts and many other types of parts.

Though now the proportion of blanks manufactured by the periodic rolling method is comparatively small it is expected that this method will be developing very intensively in the near future and it is necessary to take it into account when solving the problem of blank supplies in machine building.

Bi-metallic rolled stock, in which the corrosion resistant layer is connected with usual cheap types of construction steel, and rolled stock with plastic coating are used more widely in a number of machine-building branches, and first of all in those where there is a demand for corrosion-resistant equipment. The application of bimetallic rolled stock and the rolled stock with plastic coating makes it possible to use cheaper materials and to reduce finishing expenses in machine building.

A more intensive shift from sheets to rolled stock in coils is characteristic of new developments in machine building. The rolled stock in coils varies in thickness from several microns to 3–5 and more millimetres. Application of rolled stock in coils instead of sheets makes it possible to lay it out more rationally and to solve the problem of automated methods of metal forming.

Welding

Welding is the most progressive technique in machine building.

Achievements in very effective linking of parts by welding in combination with the increasing assortment of rolled stock supplied for machine building lead to a continuous increase in the use of welded constructions.

In the total volume of blanks the welded constructions constitute 25–30 per cent.

Carbon dioxide welding which makes it possible to automate the process quite easily and ensures the welding speed up to 180–200 and more metres per hour is being more widely used for welding frame-type constructions. High mechanical strength is achieved when using carbon dioxide welding and in the majority of cases there is no need for thermal treatment.

Application of molten slag arcless electric welding has great prospects.

Wide application of friction welding is noted for joining different and difficult-to-weld parts. Friction welding for joining comparatively large surfaces (6,000 by 10,000 mm and larger) is now possible. Friction welding is most widely used in tool, car and tractor industries. Experiments in creating methods to weld practically unweldable materials by any other methods (for example, ceramics, wood with metal) are now being successfully carried out. Welding in vacuum by means of electronic beams is being applied in instrument making. In such branches of industry as instrument making, electronics and electrovacuum equipment may facilitate welding various kinds of hard-to-weld materials.

Creation of high-quality synthetic glues makes it possible to use glued and glued-and-welded constructions instead of the welded ones on a sufficiently wide industrial scale. The wide use of glued-and-welded constructions is observed in a railroad car building (for projection-spot welding), when welding tubes (projection-roller welding), and in the automotive and aviation industries (spot welding).

Impulse methods connected with the use of high energies find application in the sphere of welding (chiefly the explosion method), for example, for facing large surfaces in a single operation. This method also may find application for facing hydroturbine blades, when making bi-metallic blanks and in chemical machine building.

Metal forming

Metal forming is one of the basic methods in machine building for manufacture of blanks. About 30–40 per cent of the entire volume of processed material is pressed and forged.

The most widely used method of cutting blanks is cutting them with disc saws and hacksaws, leading to considerable losses of metal reaching more than 15–20 per cent. That is why the development of the so-called loss-free or low-loss methods of cutting blanks by chopping them on presses, or cutting them with thin abrasive discs mechanically or electromechanically is a characteristic trend in improving the technology of blank cutting.

The second trend in decreasing the unjustified losses of metals is the attempt to obtain blanks approaching as close as possible to the weight of stamped and forged parts.

The problem of so-called seamless stamping which specialists of many countries are trying to solve depends much on the precision in weighing the material to be stamped. This problem may be solved by using, for chopping and cutting blanks, numerical control making it possible to weigh the material precisely.

Reduction of metal losses caused by the heating of blanks is achieved through acid-free heating and through rapid heating by high-frequency currents. In some cases the method of rapid heating makes it possible to combine in one unit the processes of heating and plastic deformation.

Fabrication of blanks by free forging is the most widely used method. In spite of all the advantages of free forging, this method also has some disadvantages. Besides the low productivity, the precision of fabrication of blanks is extremely low and does not exceed for average sized forgings 2–3 mm and that is why, when processing the blanks fabricated by the free forging method, the losses of metal are as high as 40 per cent and higher. The solution of the problem of obtaining by the free forging method high precision blanks, will be accomplished through numerically controlled hammers which make it possible to make the forging with a precision up to 0.1 mm.

Thus, this ancient method may find new life in the manufacture of accurate blanks. So only its own disadvantage remains: comparatively low productivity.

Higher precision of blanks manufactured by stamping and pressing methods is first of all achieved through effective methods of fabrication of accurate dies and press forms and methods of press form restoration and also through dies and press forms made of durable materials. Electrocorrosion and electrochemical treatments for these purposes make it possible to change radically the character of technology of die fabrication, to restore them rapidly and to use dies of very strong materials including a wide assortment of hard alloys.

It is also necessary to note the second tendency in the development of volume forging: an attempt to shift from the methods of plastics deformation connected with previously heated blanks to the methods of manufacture of volume cold blanks. Application of these processes makes it possible to avoid losses caused by heating of materials and the expenses of heating.

The problem of obtaining very accurate blanks including those manufactured by methods of cold plastic deformation may be successfully solved through use of impulse methods connected with application of energy at high speeds and pressure.

Magnetic and explosion forming, electrohydraulic effects for plastic deformation and other methods are being widely used in a number of machine-building branches of many countries.

Many efforts are being made to find effective fabrication methods of such things as gears and spline shafts by rolling.

The problem of cold knurling of accurate gears with a module of up to 1.5 mm, and of spline shafts without any finish required as well as rough treatment by hot knurling of large module gears is practically solved today.

Rotation forging for making axle parts (crankshafts, etc.) is more widely used in batch production.

The shift from monoposition machines to the multi-position ones which make it possible to fabricate complex parts by a sufficiently productive method without intermediate annealing is a characteristic tendency in sheet stamping.

Methods of thin plastic deformation instead of the grinding effect are more widely applied along with the above-mentioned methods of knurling, threading and worming.

In addition, the methods which are widely used include: generating processes; reeling by means of rollers and balls; arbour pressing; vibration knurling of inner and outer cylindrical and flat surfaces and riveting.

Accurate blanks of comparatively small sizes for large batches and mass production are more economically fabricated from powder by pressing and caking. Application of metaloceramics makes it impossible to manufacture parts from compositions which it is difficult or impossible to obtain as alloys.

Automation in regard to feeding or removal of blanks, use of automatic control systems for heat treatment or machining itself is common in metalworking processes.

Castings

The proportion of castings made from ferrous and nonferrous materials constitutes 30–35 per cent including pig iron casting, 15–20 per cent; steel casting, 70 per cent; and nonferrous metal casting up to 5 per cent.

Tendencies to reduce the share of pig iron casting noted in the past ten years have slowed down.

This is explained by the cheap raw materials and by the creation of new effective methods of manufacturing accurate cast blanks and means which made it possible to mechanize and automate these processes.

The method of fabricating rods and castings by using liquid mixtures is a comparatively new method which became popular in a short time. This method is used along with the older methods of fabrication of accurate blanks in shell forms. This method makes it possible to fabricate sufficiently accurate blanks, makes simpler the technological process of preparing the moulds and does not require complex equipment.

The proportion of accurate castings in machine building constitutes at present about a third of the total production, including the castings manufactured by precision methods, 10 per cent of production.

The common disadvantage of the existing technology of casting is the disproportion between the technical level of technology and foundry equipment.

Problems of effective manufacture of precise moulds are the centre of attention of casting specialists. But as is known, the complex of casting production involves such labour-consuming processes as preparation of mixture and mould materials, preparation of liquid metal and its casting, cleaning and chipping of castings, thermal processing and painting of castings. Underestimation of the complexity of casting moulds leads to too much heavy manual labour. This is especially true for chopping and cleaning of castings. That is why efforts are directed to finding effective methods for solving these problems.

Ultrasonic and electrohydraulic methods of cleaning castings are being used along with the widely employed methods of hydraulic and shot-blasting processes. Plasma cutting, cutting by means of thin and very strong abrasive discs, etc., is being widely used to remove sink-heads, chiefly from steel castings. In batch and mass production this problem is most effectively solved by construction of complexes of mechanized and automated systems for all technological stages of casting.

The fact that the technology and production methods of casting are chiefly determined by their weight and volumes of production and to a smaller degree depend on the actual construction forms is an objective and favourable factor of successful development of casting. This makes it possible to create highly mechanized enterprises with application of up-to-date technology in highly mechanized plants. It is quite natural that the most effective solution may be achieved in conditions of specialized production based on optimal capacities.

Metal cutting

No tendency to reduce the proportion of metal cutting is observed in spite of intensive development of fabrication of precision blanks by plastic deformation or casting. This is explained first of all by the fact that some reduction of expenses connected with the removal of excessive metal during rough operations is compensated by the necessity to involve new operations to achieve the ever-growing demands for precision of fabricated parts. That is why the primary attention is given to the problems of development of metal cutting which finally determines the quality of products.

Increasing cutting speeds is mainly related to materials and cutting tools. An assortment of various hard alloys makes it possible to increase speeds up to more than 300 m a minute.

Application of multiedged hard alloy inserts for cutting tools, milling cutters and reaming instruments makes it possible to cut down cost of production.

The standard wolfram high-speed steels recently became less used than cutting steels based on cobalt, vanadium and molybdenum. These new types of tool materials are 1.2–2 times more resistant than the standard wolfram types and make it possible to operate at higher speeds: up to 120 m per minute instead of 25–40.

New types of materials and first of all diamonds are being widely used along with the perfected links and materials of abrasive tools which make it possible to polish at a speed of 50–100 m per second, chiefly in finishing operations, because of industrial applications of synthetic diamonds.

An expert estimation reveals that the efficiency of the cutting process through a combination of speed, load and the length of the contact for almost all kinds of technological equipment, may soon be doubled or more. This requires special attention when designing metal-cutting equipment and when solving problems connected with the increase of the degree to continuity of processes as the analysis of the operation cycles of the last models of many metal-cutting machine tools reveals tendencies to decrease the useful operation time within the limits of the cycle leading to a considerable decrease in the efficiency of the production process.

The problem of ensuring the necessary accuracy of metal-cutting treatment by more economic methods is basic to compiling and estimating a technological process.

Recent research has revealed the common rules of alteration of accuracy and has determined the basic trends which will make it possible to control the accuracy.

The scope of factors determining metal-cutting accuracy consists of the precision of fabrication, rigidity and vibration resistance of machine tools and durability of elements determining the kinematic accuracy of the tool position with respect to work.

Other factors are: change of conditions in the process of treatment, thermal deformations, errors in measuring and changes of dimensions of cutting tools caused by wear.

The practical solution of this problem is to create durable, high-quality, strong machine and cutting tools.

But the complete solution of this problem and especially for high-precision operations (5–10 microns and less) is creation of systems of adjustment which affect all elements: machine tool, clamp, cutting tool and work.

Taking into account the entire complex of factors connected with obtaining the necessary accuracy throughout a continuous period of operation, it is necessary to regard positively the attempt of many companies to create the necessary tolerances, i.e. to fabricate equipment with considerably less error for this type of treatment.

The safety margin of the tolerances makes it possible to obtain the pieces with required accuracy for a long period of time.

Taking into account the conditions of unautomated production characteristic of the present stage of machine building in many developing countries, the wide application of active control for all finishing operations will be of a limited nature and it is necessary to envisage the up-to-date means of control to measure the parts after machining.

Multimeasuring fixtures are very effective for batch production. It is necessary to use instruments which will make it possible to test in a complex the entire scope of basic parameters.

Electrophysical and electrochemical machining

Electrophysical and electrochemical methods of machining are being more widely used for both rough and especially accurate finishing operations.

Basic disadvantages of electrospark machine tools, intensive wear of tools and low efficiency, have been eliminated in a comparatively short time.

The efficiency of the latest models of electrodischarge machines is as high as 15,000 mm^3 a minute and the wear of the electrode is reduced to a fraction of 1 per cent. The efficiency of ultrasonic and electrochemical machine tools has increased manyfold. The tendency to combine diamond treatment with electrochemical and chemical treatment is especially fruitful.

The peculiarity of chemical treatment methods, which makes it possible to remove very thin layers of metal, makes them very good prospects for precise treatment of flat and shaped surfaces. Studies in light beam and electron beam technology are very promising for the progress of machine building.

Conclusions

The achievements of science and technology are increasing machine-building productivity.

In the course of establishing machine-building plants in developing countries, it is extremely necessary to use all modern achievements and practice.

The methods and means of production accepted for practical use should be based on deep economic analysis and the perspectives of development should be taken into account.

Methods and equipment for machine-building production are determined by objective technical and economic laws governing the development based on the product design and the scale of production.

More profound studies and development of specialized production and particularly production of blanks and standard parts are the most effective initial means of development.

When studying and determining the nature of machine-building and metal-treating branches of industry planned for developing countries, it is expedient to study machine-building branches dealing with the production and processing of the most efficient types of domestic raw materials and the assortment of machine-building products for everyday life.

The problems of employment in the developing countries, increase of national income and well-being of the people may be solved effectively on the basis of highly efficient methods, equipment and production organization, not through the use of low-output machines.

Successful introduction and development of up-to-date machine building in the developing countries depends much on the rates of training of engineers and technicians possessing the necessary knowledge of modern technology, and skilled workers who are required to operate the up-to-date equipment.

MANUFACTURE OF INDUSTRIAL MACHINERY AND EQUIPMENT IN DEVELOPING COUNTRIES[1]

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INTRODUCTION

A study of the manufacture of machinery and equipment necessary to increase the production capacity and productivity in the production of goods and services was undertaken by the United Nations Centre for Industrial Development (CID) to develop appropriate methods for transferring technology and formulating development policies in this field. It became clear at an early stage of the investigation that the promotion of the manufacture of industrial machinery must be viewed as a part of the development of the metal-transforming industry as a whole. The latter, together with chemicals, is the most dynamic among all manufacturing industrial branches, not only in volume of production but also in scientific and technological development. This report summarizes such facts and findings which seem to merit consideration, even though the investigation was at a preliminary stage at the time of writing.

The first phase of the investigation reviews the principal facts concerning the development of industrial machinery and equipment manufacture in less industrialized countries of Africa, Asia and Latin America in order to permit the examination of the scope of national, regional and international promotional actions in this field. The findings and conclusions must be considered preliminary and provisional because of the general scarcity of relevant statistics, the limited time and resources devoted to the study so far and because it was necessary to complete it without direct investigation in any of the developing countries. However, the basic facts and possibilities concerning the field can be outlined with a reasonable amount of certainty.

The importance of industrialization in the economic and social development of countries is now unanimously recognized. The views strongly held earlier that such countries might develop through specialization in primary production are no longer sustained. The debate now concerns the proper choice of industries to be developed. Some views, for instance, emphasize the importance of relative scarcities of capital and labour. This, if accepted as a general rule of choice, would give strong priority to (some) consumer goods industries, and limit the development of engineering industries in general and the manufacturing of industrial machinery in particular. The debate, of course, does not concern the desirability of producing machinery and equipment, but, only its feasibility and economic justification or, in other words, the economically sound timing and priorities at different stages of economic development.

Metal-transforming (or engineering) industries account for almost 30 per cent of the world industrial production (measured in terms of value added) and for about a third of the total manufacturing production. Metal transforming has been among the major industrial branches experiencing the most important increase in production since 1938[2] (see table 1). The increase has been even more important in less industrialized countries than in the industrialized. Nevertheless, the share of less industrialized countries in the total production of metal products was only 3.9 per cent in 1958, the lowest among all major industrial branches.

Table 1

INDEX NUMBERS OF INDUSTRIAL PRODUCTION IN 1962 (1938 = 100)

	Industry total	*Mining*	*Manufacturing*	*Metal products*
	ISIC 1–3,51	*1*	*2–3*	*35–38*
Industrialized countries......	300	178	302	460
Less industrialized countries..	372	520	325	600
Share of less industrialized countries in total production in 1958 (percentage)......	10.4	25.2	8.9	3.9

STRUCTURE AND PATTERN OF ENGINEERING INDUSTRIES IN DEVELOPING COUNTRIES

The developing countries can be classified into three distinct groups, as far as the present degree of develop-

[1] Industrial machinery and equipment comprises goods produced by different sectors of the engineering (metal transforming) industry, classified by the International Standard Industrial Classification (ISIC) as *Manufacture of Machinery, except Electrical Machinery* (ISIC 36), *Manufacture of Electrical Machinery* (ISIC 37), *Manufacture of Metal Products, except Machinery and Transport Equipment* (simple metal products or simple metal manufactures) (ISIC 35), *Manufacture of Transport Equipment* (ISIC 38), and *Manufacture of Professional, Scientific, Measuring and Controlling Instruments* (ISIC 391), which are utilized as means of production in identical processes for transformation or handling of materials, for ancillary activities, etc. The corresponding classes of the Standard International Trade Classification (SITC) are: *Machinery, other than Electric* (SITC 71), *Electrical Machinery, Apparatus and Appliances* (SITC 72), *Manufacture of Metal, N.E.S.* (SITC 69), *Transport Equipment* (SITC 73), *Professional, Scientific and Controlling Instruments, Photographic and Optical Goods, Watches and Clocks* (SITC 86).

[2] United Nations, *Monthly Bulletin of Statistics*, August 1963, Special table A: Index numbers of industrial production, excluding USSR and Eastern Europe.

ment of their engineering industries is concerned. Statistical indicators in absolute figures seem to be more characteristic in this respect than *per capita* ratios. The available statistical data of the countries in question fit reasonably well in the following pattern which can be considered as characteristic in spite of overlapping or deviation in the case of some countries and/or some indicators.[3]

The different categories indicated in table 2, industrialized countries and the three groups of developing countries, *viz*, countries with already developed and diversified engineering production (group I), countries with engineering production at an initial stage (group II), and countries with no engineering production or with

In less industrialized countries with already developed engineering industries (group I), the share of simple metal products is substantially higher (20–30 per cent can be considered as typical), with a tendency to decrease as engineering production increases. While in developed countries, the production of non-electrical machinery is generally more important than that of electrical machinery (typically 30–40 per cent higher); in group I, the production of electrical machinery is as much as two times more important than that of non-electrical machinery. In groups II and III, the share of simple metal manufactures is even higher (typically 35–40 per cent for group II and more than 50 per cent for group III) according to statistics that are available. The share

Table 2

ENGINEERING INDUSTRIES IN INDUSTRIALIZED AND LESS INDUSTRIALIZED COUNTRIES: SELECTED INDICATION OF DEVELOPMENT

	Engineering industries			*Engineering goods*			
	Number engaged (thousands)	*Percentage in total manufacturing (value added)*	*Total yearly steel consumption (thousands of metric tons)*	*Percentage imports in domestic consumption*	*Percentage exports in domestic production*	*Value added in engineering production (millions of US dollars)*	*Value added in total manufacturing (millions of US dollars)*
Industrialized countries	more than 200	25–30 or more	1,000 or more	10–50	20–50		
Less industrialized countries with:							
I. Developed and diversified engineering production	more than 200	15–20	1,000 or more	50–75		400–800	2,000–5,000
II. Engineering production at initial stage	20–50	8–12	400–800	80–90		50–100	400–1,000
III. No engineering production or engineering restricted to repairs and simple metal manufacture	20 or less	8 or less	400 or less	85–100		up to 50	up to 400

Sources: Annex I. OEEC, *The Engineering Industries in Europe 1960*; United Nations: *Production and Export of Mechanical and Electrical Engineering Goods* (ST/ECE/ENG/1), Geneva (1960); *The Industrial Development of Peru* (E/CN.12/493) (1959); and national statistics of India, Mexico, Argentina, Brazil, Colombia, Pakistan.

engineering production restricted to repairs and simple metal manufactures (group III), can be considered as successive stages of industrial development, at least as far as the engineering industries are concerned, characterized by distinct internal structures of total engineering production as measured by the shares of the main engineering branches. The similarity of this internal structure is particularly definite in the case of industrially developed countries, although they differ in the size of their engineering industry or their economy as a whole, the share or amount of imports or exports of engineering goods, etc. The typical structure of the engineering industry in industrialized countries is:[4]

Simple metal products	*Machinery except electrical*	*Electrical machinery*	*Transportation equipment*	*Instruments, watches and clocks*	*Total*
6	33	24	33	4	100

[3] See table 3 for detailed statistics.

[4] The subsequent data are mainly based upon the sources indicated in table 2. Since different statistical sources differ as to the system of classification or content, (e.g., value added or deliveries), they are not fully comparable. However, with necessary corrections, they reflect reasonably well the proportions of the subsectors of the engineering industry.

of the total production of machinery (electrical and non-electrical) which is very low or even non-existent in group III, increases with the progress in the stage of development and is more than 50 per cent in the typical structure for industrialized countries. Industrial machinery and equipment is produced essentially by the sectors "machinery except electrical" and "electrical machinery" which produce, of course, also for other sectors of the economy, mainly for agriculture, commerce and households.

The share of industrial machinery is generally higher in the case of more developed countries.

The available information seems to indicate that the three categories of developing countries present distinct problems requiring distinct measures for the development of engineering industries in general and for the manufacture of industrial equipment in particular. Four countries, India, Argentina, Brazil and Mexico, belong to group I, characterized by an already important manufacturing industry, with the total number of those engaged being well over a million and, as a part of it, with already diversified manufacturing of industrial machinery and equipment.

Steel production, already appreciable in these countries, is expected to increase further at a quick pace and to essentially satisfy the increasing domestic consumption (except in the case of Argentina) in the foreseeable future, bringing into existence the most important base of domestic supply of raw materials for, among others, the engineering industry. This group is distinctly separated from the next, according to all meaningful economic indicators in absolute numbers, such as value added and/or number of persons engaged, both in total manufacturing and in metal-transforming industries, steel production and consumption, etc.

Group II (with some ten countries, e.g. Chile, Colombia, Indonesia, Pakistan, Venezuela) is characterized by a manufacturing industry engaging about 200,000–500,000 persons, by an accordingly lower engineering production and by the manufacture of machinery and equipment, restricted to some relatively simple items. Steel production is at a beginning stage (or sometimes practically non-existent) in the countries of this group, but their steel consumption of about 400,000–800,000 tons already opens a possibility, especially where foreseeable increase is also taken into consideration, of economically justified domestic steel production.

This circumstance is actually reflected in the economic plans or provisions of several countries in the group. However, it is generally not planned to satisfy the domestic consumption by domestic production to an extent exceeding 70–75 per cent in the next ten to fifteen years. Groups II and III are less clearly separated and the latter is less homogenous, comprising countries with an already appreciable amount of manufacturing together with countries in which there is barely any manufacturing at all. However, this group is characterized by an absence altogether of engineering production or by engineering production restricted to simple metal manufacturing and repair work and without (or with a negligible amount of) machinery production, by low steel consumption and by rather remote prospects of a substantial development of domestic steel production.

The three groups described above can be interpreted as a simplified scheme of a normal pattern of the development of the engineering industry in less industrialized countries, this development being an integral part of the over-all process of industrialization.

The pattern in question can be considered as characteristic only in the case of less industrialized countries, implying by that the existence of and the close connexions with industrialized areas. In this context, there is evidence that the two major and interdependent factors determining the degree and the rate of development of the engineering industry are the size of the demand for engineering goods (which is largely determined by the home market in the countries in question) and the supply of raw materials, mainly steel products.

The development of domestic production of engineering goods largely takes the form of a process of substitution by domestically manufactured goods of goods produced by the handicraft (cottage) industry or of imported goods. Among the engineering products, the domestic manufacture of simple metal products is technically possible and economically sound already, with the relatively small size of the economy. Design and production processes are relatively simple; the requirements, from the point of view of skills, education and training of the labour forces, are not too demanding.

Owing to the nature of the demand and the uniformity of products, a scale of production is easily attained where domestic manufacture can operate with lower costs and higher productivity than the handicraft industry, arriving at a generally higher and more uniform quality of products. Further economies of scale are not so overwhelming in cutting costs and in increasing productivity as to make the domestic industry non-competitive when compared with units operating on a much larger scale in industrialized countries. With some products fabricated mainly from metal sheets, such as containers, stoves, etc., the high costs of transport (as compared to the costs of transport of raw materials) give relative advantages to the domestic industry. Repair work of already installed machinery or, frequently, of transport equipment is obviously necessary at a very early stage of economic development. Both simple metal manufactures and repairs are to be viewed also as preparatory activities by introducing similar machinery and providing training in the skills necessarily involved in a subsequently more complicated machinery production.

With an increase in the size of the economy in group II expressed in a higher demand of both consumption and capital goods and characterized by a higher output of the manufacturing industry (which was found to be of about $400–$1,000 million in value added), the manufacture of more complicated machinery goods becomes economically possible. The greater share of electrical machinery, when compared with the engineering industry of industrialized countries, is due to the similar advantages mentioned for simple metal products, specifically the relative simplicity of the production process and the uniformity of products.[5] The production of industrial machinery proper is not yet important.

Further increase in the size of the economy, characterized in group I by value added, in manufacturing, of about $2,000–$5,000 million, creates an important demand in machinery and, consequently, the production of industrial machinery proper, power-generating equipment, metalworking machinery, and special industrial machinery such as paper, textile, leather, food processing and chemical machinery. However, even countries of group I are characterized by a less important share of industrial machinery in engineering production than are the developed countries.

Collateral to this normal pattern, it can be said as a very rough approximation of the complicated development process that the manufacturing of engineering products of standard design and serial (or mass) production appears at an earlier (or lower) stage than individual manufacturing of machinery and equipment according to individual design. The whole development of engineering industries is influenced by the availability of domestic raw materials, mainly of steel. While a total self-sufficiency in steel products is obviously not

[5] This, of course, does not apply to heavy and special electrical machinery.

necessary, and often not even advantageous, the lack of domestic supply adequate to the level to be attained may slow the development of the engineering industry.

THE PLACE OF ENGINEERING INDUSTRIES IN INDUSTRIAL DEVELOPMENT

It is almost impossible to give a universally meaningful statement concerning the priorities to be assigned to single economic branches in the process of industrial development of developing countries. Every case has to be analysed and investigated separately. Several methods of approach are known.

From the point of view of a country's economy as a whole, the main criteria of choice are based on or related to the impact of the resources to be devoted to investment, on foreign exchange earnings and expenditures and on manpower resources. The capital intensity (capital/output ratio) of the average of the engineering industry as a whole is near the average of total manufacturing: lower than that of metal-producing or chemical industries and higher than that of most light industries.

The foreign exchange effect depends largely on the proportion of domestic raw materials. If this is important, the engineering industry ranks high in foreign exchange earnings or savings. Finally, it is well known that the engineering industry is labour-intensive.[6] This feature is generally considered as an advantage in less industrialized countries: an advantage somewhat counterbalanced by the high requirements needed in regard to the skills and education of the labour force. It must be mentioned that this industry exercises a very active and dynamic outside influence, utilizing and at the same time generating a very important part of the new scientific and technological knowledge which, through different channels, has an important impact on the level of technological development not only in the industry but also in other economic branches.

The manufacture of industrial machinery and equipment should be viewed as a part, even one of the most difficult and complicated parts, of the engineering industry.

Such production is technically feasible in developing countries as a considerable and growing amount of industrial equipment is actually produced in all countries of group I and some countries of group II. The economic impact of the domestic production of industrial machinery in economic development is decisive and can hardly be overstated. It has been shown[7] that there are (rather theoretical and abstract) possibilities of substitution among import of grain, import of fertilizers, installation of a fertilizer plant and installation of a machine-building factory to produce the machinery of the fertilizer plant: all result in the same availabilities of grain. The alternatives involve foreign exchange and total expenditures of the following proportions:

	Expenditure		
	Foreign	*Domestic*	*Total*
Grain import	1,000	—	1,000
Fertilizer import	270	—	270
Fertilizer plant	100	150	250
Machine-building factory	20	10	30

This example, certainly an over-simplification of the complex problem of substitution, shows clearly, however, not only the advantages of domestic production by the very important saving of expenditure in general and foreign exchange expenditure in particular, but the two main difficulties: the need of domestic capital and of skilled and experienced manpower in this connexion.

In the example, the grain is ready for consumption, but the fertilizer has to be ordered at least two years in advance of the crop season; in addition, it has to be distributed and utilized effectively, operations which require a considerable amount of competence. To build the fertilizer plant implies an investment of four to five years ahead of the availability of grain and, in order to establish the machine-building factory, the investment is required eight to ten years in advance, with the correspondingly higher requirements concerning the skills of the labour force to operate the plants and concerning other supplies, and obviously with some sacrifices of domestic consumption till the investment will pay off in increased production of grain.

The availability of industrial machinery and equipment is obviously a prerequisite of industrial development. It is equally obvious that it is neither possible nor desirable to produce domestically all industrial equipment in a developing country. The most appropriate share of domestically produced industrial equipment is not investigated in this study, but it must be noticed that official development plans and other studies (e.g. studies prepared by regional commissions of the United Nations) often indicate the necessity of considerably increasing the domestic manufacture of industrial machinery in order to increase the share of domestic production.

In framing economic policies for industrial development, it may be useful to consider the manufacture of industrial machinery and equipment in the framework of the engineering industry as a whole and to bear in mind the normal pattern of development, since this reflects basic economic and technological relations. However, it may be fully justified to plan a different pattern; for instance, to develop the production of non-electrical machinery in advance of the normal pattern. This would, of course, assume that full consideration has been given to the capability of the planning agency to implement the plans and of the prospects of efficient international co-operation

PROMOTION OF THE MANUFACTURE OF INDUSTRIAL MACHINERY AND EQUIPMENT

The available information on the promotion of the manufacture of industrial machinery and equipment (already existing or to be developed) in less industrialized countries, together with experience gained in indus-

[6] Compared with the average of the manufacturing industries in terms, for example, of the capital labour, output labour ratios, or the shares of labour costs in the value of output. There are, of course, considerable differences among subsections of the engineering industry.

[7] United Nations, *Economic Survey of Europe in 1959*, chapter VIII.

trialized countries indicate that appropriate scientific and technological knowledge and know-how and the increase in the scale of operations should be considered as the most important fields of action. According to the available information on capital output and capital labour ratios, it seems that the burden of investment costs is less crucial here than, for example, in the chemicals or metal-producing industries. A smooth and organic growth, requiring only small investment resources at the beginning of the development period, is also possible.

The labour force of the industry from the skilled or even semi-skilled worker to the engineer or the scientist contributes by far the most important part to the factor of knowledge. From this point of view, the problem is identical to the problem of training.

An important part of the manufacture of industrial equipment in developing countries, principally as far as more complicated machinery is concerned, is extensive co-operation with some industrialized country, from contracts to blueprints, from know-how and training of the personnel to establishing subsidiary companies. Technological knowledge obtained by these means is very natural, useful and often the only possibility open to a developing country. However, an excessive dependence on foreign sources of technological information may, at a higher level of development, also cause adverse effects, e.g., slowing down the process of adaptation of product design and production methods to local conditions, or lessening the possibilities of competing in foreign markets.

The most important means for influencing the effectiveness of operation in the field in question, with regard to costs and productivity and even partly with regard to technical achievements, is the increase of scale of production.

The economies of scale do not result mainly from an increase in the volume of production if this is achieved only by a proportionate increase in the diversity of production (i.e., by producing completely new items), though several overhead costs will decrease even in this case. However, economies of scale result much more from a relative increase in the scale of production: by a shift towards serial (or batch) from individual production; by the increase of seriality, and by a shift towards mass from serial production. This means an increase in identical or similar items produced or operations performed at the same time on the same machine or equipment, with the same tool or instrument, according to the same design, etc.

In this context, there are wide possibilities of increasing the scale of operations, even within the limits of a given volume of production and/or a given size of final demand. The most important methods put forward are standardization, co-operation among different factories (subcontracting) and concentration on the production of widely utilized parts (and/or raw materials). It is to be noticed that all these methods are generally utilized in the engineering industries of developed countries.

The scale-increasing effect of standardization is exercised by all its forms, from in-plant standardization through special industry-wide standardization to national standardization. The first intends to reduce the variety of similar parts and components within one plant, the second has the same effect within a whole industry (machine building, in this case); the third has to reduce the diversity of final products through agreement between suppliers and consumers. It is probable that due to the very large number and variety of parts and components utilized in machine building, the second kind of standardization has the most important impact on the economies of scale of the industry as a whole.

In machine building in general (except in mass production), a part of the special equipment, e.g., machine tools producing large and heavy parts, is never utilized to full capacity when operated only for one particular factory. In order to utilize more effectively such equipment which is often very expensive and complicated, different factories may co-operate through a system of subcontracting, which can be developed as a useful and general method to ensure effective utilization of plant facilities and skills within the industry. A high proportion of parts, components, raw materials or accessories in machine building are identical, similar or produced by identical production processes, while the amount required by a single factory is below the limit permitting the operation of plant facilities with advanced and highly productive technologies. The method proposed in such cases, principally for castings and forgings, is the concentration of the production into a few, well-equipped plants serving a large number of factories.

These methods involve principally technical problems and problems within the engineering industry. To ensure the uniform utilization of productive facilities, there is a need for economic forecasting, and planning and co-ordination among industrial branches. Otherwise, it may happen that periods of overloading alternate with periods of idling, especially in heavy engineering and in view of the rather restricted demand in developing countries.

Even in the case of optimal utilization of the indicated methods it seems improbable that engineering industries of developing countries could attain a satisfactory scale of operations without an active participation in the international division of labour, i.e., without exports. The size of the engineering industries of developing countries belonging to group I is comparable, at least in regard to the number of those engaged, to that of the smaller industrialized countries. But, while exports of the former are insignificant, the latter export about 50 per cent of their engineering production and import as much or more, with the resulting economies of scale due to the possibilities of narrower specialization of the domestic production. For countries belonging to group III, pooling of their resources and planning on a subregional or regional scale can be considered as a prerequisite even at the initial stage in the manufacture of industrial equipment.

The complicated problems of finance, tariffs, goodwill, etc., of the export promotion of machinery are not investigated here. However, some remarks concerning the importance and possibilities of export promotion seem necessary. Co-operation of developing countries seems to be an easier way to promote exports of machinery than exporting to industrialized areas. The higher labour-intensity of machine building is an advantage to exporting machinery as far as the competition with industrialized countries is concerned. The potential demand in developing countries, taken together or by regions, is important enough to permit a sharp increase in the production of industrial machinery in the countries in question.

An ECLA study[8] reviewing the equipment required for the projected expansion in 1961–70 of the petroleum, electric, steel, cement and paper and pulp industries, found the share of equipment that could be made by domestic industry at about 80 per cent of the total at prices competing fairly well with imported equipment. Another ECLA study put the share of domestic production in machine-tool consumption for 1967–71 to 65 per cent (against 38 per cent in 1955–61). The industries are representative of the heavy industry as a whole. Machinery and equipment for light industry is obviously easier to produce. If we accept the Brazilian figures as an indication of the share of domestic production and assume increasing co-operation between developing countries, it seems reasonable to admit the possibility of a share for domestically produced industrial machinery and equipment for 1975 of about 60–70 per cent.[9]

The importance of machinery exports cannot be evaluated only by the foreign exchange earnings. Exporting always raises the industry's effectiveness regarding costs as well as technical achievements. Export must be viewed as a major incentive to the development of industrial machinery and equipment production. The importance of this is not measured only by its output but rather by its impact on the whole course of industrial development.

The influence of the present dependence of engineering industries, in developing countries, on foreign sources for the technological knowledge and know-how, together with the role of subsidiaries of foreign firms in this respect, needs to be investigated. It is often easier to import technological knowledge than to develop it in the country. On the other hand, there are indications that plants being set up mainly to surmount tariffs on foreign exchange barriers, and being subsidiaries or licensees of a foreign enterprise, have no general policies favouring the extension of their activities towards export.[10]

Need for research

In order to give substantial and immediate help to developing countries in the development of engineering industries, a detailed and comprehensive investigation of the technical and economic aspects of the present situation of this branch seems necessary. To avoid the abstract generalization of the widely known experience of industrialized countries or the excessive simplification in the description of the local problems of technological development, extensive information has to be gathered in the field in at least some of the developing countries. Information connected with technical and economic problems in industrialized countries is readily obtainable by the use of the generally good statistics, books, articles, and teaching materials, or of the practical experience of most specialists.

All this information, however, is scarce when it concerns the problems of developing countries. This aspect is even more important for engineering industries than, for example, for the fertilizer, aluminium or steel industries, where methods of production and the pattern of (possible) output are determined by the existing equipment, the alteration of which is generally a difficult and costly operation. The metal-transforming industries, the technological processes and their combination to produce a given output, as well as the design of products, are less determined by the existing equipment which can be more easily changed and developed.

In a local survey, attention has to be focused upon the problems of countries with less developed engineering industries (groups II and III) and the clarification of the following problems: volume and pattern of the existing and foreseeable demand for engineering goods, conditions of supply of raw materials and parts for the engineering industry, available production facilities and the possibilities of improving their utilization, comparison of actually utilized technological processes with technological processes in industrially developed countries, possibilities of increasing the scale of operations by standardization and subcontracting and the availability of a skilled labour force necessary to adapt and develop production technologies and product design.

Simultaneous with this investigation in the developing countries, and utilizing its results, attempts may be made to study:

(a) The equipment and technological processes to be utilized in foundries and forges, which serve a great number of machine-building factories, as an important means to improve productivity and quality in the production of raw materials;

(b) The possibilities of utilizing such technologies and processes, which permit substantial savings in skilled manpower (even at the cost of additional utilization of highly skilled or engineering manpower, e.g. numerically controlled machine tools);

(c) The adaptation and further development of the methods of forecasting, planning and co-ordinating of engineering industries, including the utilization of (mathematical) programming models, in order to improve the over-all utilization of productive capacities. It is furthermore proposed to devote special attention to the problems of the engineering industry in work projects already on hand such as those on repair shops, standardization, second-hand machinery, and in the field of training and management.

[8] *The Manufacture of Industrial Machinery and Equipment in Latin America I. Basic Equipment in Brazil* (E/CN.12/619/Rev.1), Sales No.: 61.II.G.2.

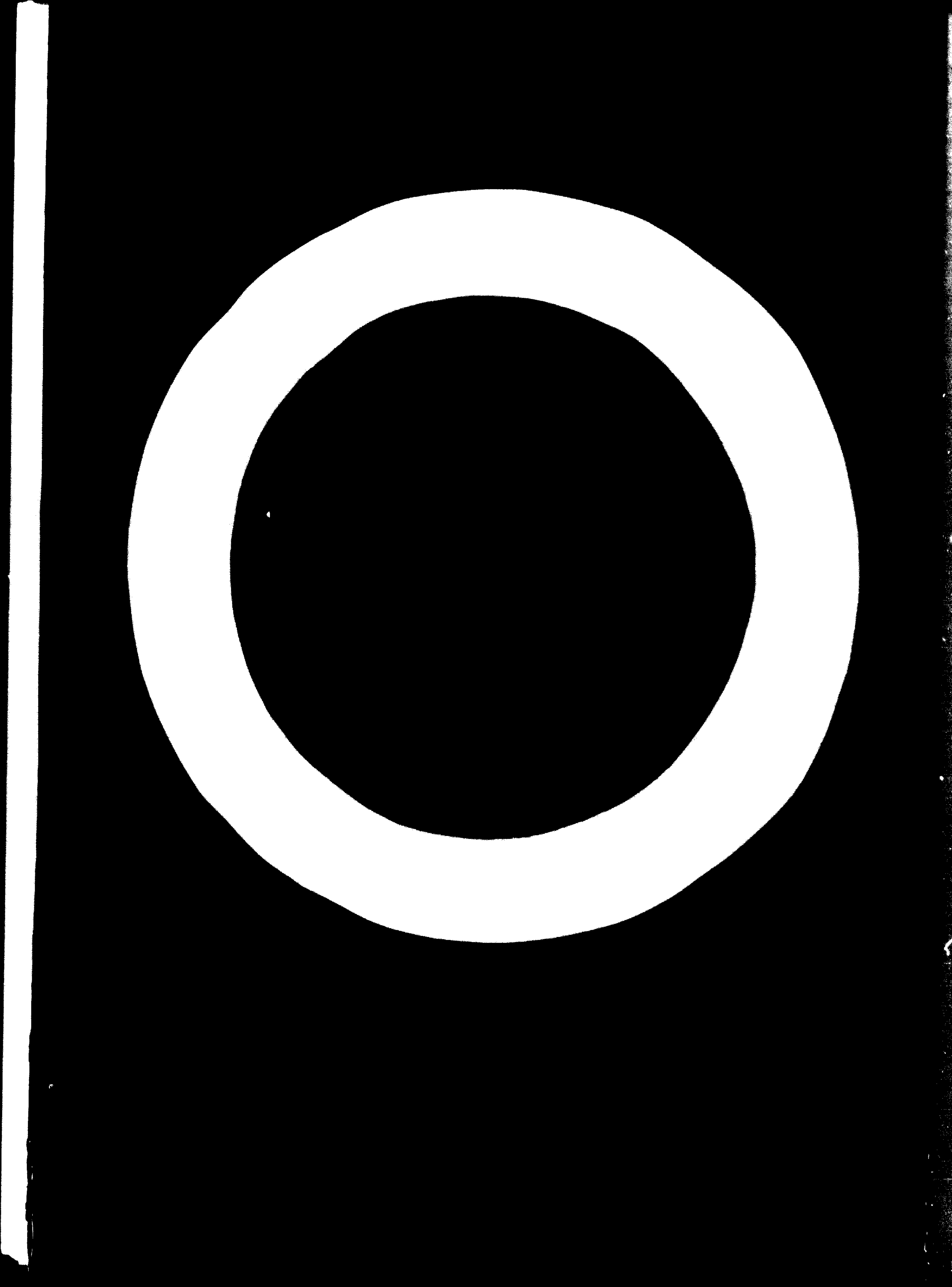
[9] This figure is not to be considered as a forecast of the probable share of domestically produced industrial machinery which has not been investigated here. A study, Projection of Demand for Industrial Equipment, prepared by the Centre for Industrial Development and published in *Bulletin on Industrialization and Productivity* No. 7 (1964) put the probable share to about 25 per cent.

[10] *Problems and prospects in the export of manufactured goods from the less developed countries*, United Nations Conference on Trade and Development, E/CONF.46/P/2.

Table 3

DEVELOPING COUNTRIES: SELECTED STATISTICAL INDICATORS OF INDUSTRIAL DEVELOPMENT

Country	*Value added in million dollars*		*Share of metal products in total manufacturing (per cent)*		*Steel*		*Number of persons engaged in total manufacturing (thousands)*
	All manufacturing ISIC 2–3	*Metal products ISIC 35–38*	*Value added*	*Number engaged*	*Production (thousand metric tons)*	*Consumption (thousand metric tons)*	
			GROUP I				
India	4,701.8	753.3	14.5	12.9	4,071	5,154	1,820.5
Brazil	3,643.8	645.2	14.3	11.5	1,843	2,701	1,547.0
Mexico	2,994.9	557.0	14.3	13.8	1,728	1,840	1,478.0
Argentina	2,412.7	480.0	20.7	25.3	441	2,379	1,411.0
			GROUP II				
Turkey	1,012.6	100.1	7.4	10.9	282	549	295.3
Venezuela	886.6	85.9	6.1	6.0	—	448	137.8
Pakistan	803.1	101.6	8.6	11.6	9	192	397.9
Colombia	685.2	70.8	8.0	12.6	176	405	236.8
Chile	643.4	71.1	9.7	13.3	363	506	216.5
Korea (Rep. of)	571.6	58.5	9.9	10.3	61	...	260.6
United Arab Republic	497.6	44.6	6.0	7.0	—	373	260.8
Philippines	447.6	53.3	10.7	11.2	—	504	228.4
Indonesia	—	—	10.9	11.6	—	439	334.5
Iran	—	—	—	—	—	351	...
			GROUP III				
Peru	367.6	28.4	6.1	7.8	—	246	116.3
Federation of Rhodesia and Nyasaland	356.4	57.4	24.6	22.4	60	244	109.6
Cuba	351.8	—	—	—	277	...	...
Algeria	341.4	66.1	22.0	20.2	—	402	146.7
Uruguay	313.7	57.6	—	18.9	—	86	191.4
Morocco	303.1	50.8	19.0	—	—	152	...
Thailand	253.5	—	—	10.3	—	257	189.8
China (Taiwan)	253.1	39.7	6.1	8.2	198	287	173.0
Burma	181.8	—	2.8	3.6	—	...	120.9
Ceylon	180.6	32.2	23.6	36.0	—	89	49.9
Ecuador	121.2	—	1.5	1.7	—	...	30.4
Syria	92.6	—	—	—	—		...
Guatemala	71.7	—	3.9	6.9	...		27.6
El Salvador	48.3	—	4.1	3.8	...		60.3
Honduras	41.1	—	2.8	3.0	...	...	20.1
Nicaragua	31.1	—	1.3	2.1	...	...	18.9
Paraguay	24.2	0.3	3.7	5.3	...		34.3
Ethiopia	23.2	—	...	...	—	...	20.0
Nigeria	—	—	5.4	—	...	182	
Tunisia	—	—	...	...	...	79	12.9
Ghana	—	—	9.3	13.8		67	21.7



WORLD MACHINE-TOOL PRODUCTION WITH SPECIAL REFERENCE TO DEVELOPING COUNTRIES

Secretariat of the United Nations Centre for Industrial Development

INTRODUCTION

Within the metalworking industry, the machine-tool industry plays a key role in the expansion of world industrial production since every branch of manufacture, whether durable consumer goods or machinery and equipment, is dependent on metalworking machinery.

This report presents a preliminary study of the current position of the industry in its global context and in the context of the developing countries.

Three conclusions emerge: world production has risen rapidly since the Second World War; production is carried out largely in small to medium establishments; and, production is concentrated in the industrial countries.

The developing countries, if China (mainland) is excluded, contributed less than 2 per cent of the total production in 1962. Even this was accounted for by only a few countries.

Such a concentration leads to a high volume of international trade and the total dependence of a large number of developing countries on imports of machine tools for industrial production. World exports of machine tools have been rising rapidly; between 1955 and 1962, they increased threefold in value.

Consumption of machine tools in the developing countries, although increasing, is still below 10 per cent of the world total. Several observations are made in the study of the problems of meeting the increasing requirements of the developing countries. First, foreign exchange difficulties make it necessary that some portion of the national requirements of the developing countries is met by establishing domestic production, perhaps of simpler tools at the beginning. On the other hand, the variety of machine tools needed is so great that reliance will have to be placed on imports to supply a substantial proportion of the requirements. In either circumstance, it is imperative that adequate facilities for the repair and maintenance of machine tools be established by the developing countries as a matter of urgency. Other matters to be considered are the establishment of centralized metalworking units (shops or plants), specialization and large-scale production of more universal tools (such as bolts, nuts, screws and other fasteners) to economize on producing equipment, and the possibilities of importing second-hand machine tools.

THE ROLE OF THE MACHINE-TOOL INDUSTRY IN INDUSTRIALIZATION

The machine-tool industry is unique in that it produces machines which form the basis for the production of all modern machinery, devices and tools for industry, transport and agriculture. The industrial development of a country is dependent, to a considerable extent, on the number of machine tools it possesses, their age, quality and technical state.

It is recognized that one method of indicating the level of industrial development of a country is by the output of machinery and other equipment as a percentage of total output of the country. This can be seen from a comparison of the output of machinery and equipment as a percentage of total industrial output in highly developed industrial countries such as Czechoslovakia, 34 per cent; Eastern Germany, 33 per cent; France, 38 per cent; Germany (Federal Republic), 39 per cent; Soviet Union, 22 per cent; United Kingdom, 40 per cent, and the United States, 34 per cent, with countries at a lower level of industrial development, such as Burma, 2 per cent; Chile, 5 per cent; Pakistan, 3 per cent; Peru, 1 per cent; Philippines, 4 per cent, and Rhodesia and Nyasaland, 2 per cent.[1]

The machine-tool industry has a key role to play in the expansion of the production of capital goods at any stage of industrialization. It may be particularly important in developing countries whose capacity to import is limited. During the process of industrialization, developing countries often suffer a shortage of foreign exchange at the same time as they desire to increase their rate of investment. Currently, there is no single branch of the manufacturing industry in which a high proportion of metalworking machinery is not used. There is a close connexion between a country's level of industrial development and the technical and economic structure of its machine-tool industry.

A developed machine-tool industry is a relative latecomer to a developing country since it depends on the demand of a developed domestic metal-transforming (engineering) industry, or the development of an export market for its output. The production of other than the simplest machine tools, moreover, requires the existence of a highly skilled labour force. Consequently, machine-tool industries existed until recently only in the highly industrialized countries, and these remain the suppliers of machine tools to the developing world.

It will be shown, however, that the industrial countries

[1] *Production and Export of Mechanical and Electrical Engineering Goods*, United Nations, Geneva (1963), p. 3 (figures are for 1960, except Chile, 1957; Philippines, 1956; Pakistan, 1953; Burma, 1953; Rhodesia and Nyasaland, 1953; Peru, 1954); and *World Economic Survey, 1961*, United Nations, N.Y. pp. 28–29.

are also the largest importers of machine tools and that the development of a national machine-tool industry does not necessarily lead to a decline in imports of these tools.

In developing any sector of the national economy, continuous technical progress and the rise of labour productivity are accelerated by advanced machinery and techniques. The rate of industrialization and technical progress in the highly industrialized countries are partly dependent on the progress of their machine-tool industry which could be considered as the heart of the machine-building industry. Indeed, the cost of metalworking machine tools, foundry and woodworking machinery and equipment constitutes approximately a half of the total expenditure for equipment, or about 20–25 per cent of all capital expenditure involved in the building of a mechanical or machinery manufacturing plant in industrial countries.[2] This alone indicates the role of the machine-tool industry in an industrial economy and in the machinery production industry in particular. It is important, therefore, to make an early analysis of the possibilities which exist for the establishment of a machine-tool industry in developing countries, to determine the appropriate scale of production, and what types of machine tools it would be best to produce.

Although the establishment of a machine-tool industry presupposes the existence of metal producing and engineering industries, it is important that the possibilities for the establishment of a machine-tool industry should be examined by developing countries, along with other plans for industrialization.

Definition of the machine-tool industry and classification of machine tools

The term "machine tools" is widely used to describe a group of machines which are used in the metalworking industry to convert the raw material of the metal-producing industry or other products into different machine parts of various shapes and dimensions.

The term can include different categories of machinery depending on the country, language or even the subject under discussion. It has a number of different interpretations even in English, excluding such a broad definition as "tool worked by machinery, not by hand"[3] or a more precise definition such as "power driven machine designed for shaping solid work by tooling either by removing material (as in a lathe or milling machine) or by subjecting to deformation as in a punch press".[4]

In practice, there is no standard rule indicating which machines are included in the category of machine tools. In one country, the category includes only metalworking machine tools, in another, woodworking machines and stoneworking machines are also included. In a third country, metal-cutting machine tools and woodworking machine tools are included in the category "machine tools", but metal-forming machine tools form another group of machines.

[2] *Economic Gazette*, No. 32 (105), 10 August 1963, USSR.
[3] *Concise Oxford Dictionary*, 1960.
[4] *Webster's Third New International Dictionary*, 1964.

In two well-known classifications, the Brussels Nomenclature for the classification of goods in customs tariffs (1955 and 1964) and the United Nations Standard International Trade Classification (SITC), the term "machine tools" is used in its widest sense and applies to metal cutting, metalworking and woodworking, as well as to machines for working stone, ceramics, concrete, and some other mineral materials and cold glass. In specialized technical and economic literature, however, as in the present study, the term "machine tools" is used in its narrowest sense in which only metalworking machine tools are included.

Metalworking machine tools include a large variety of types which differ in size, means of control, purpose for which they were designed and scale of production. There are more than thirty different classes of metalworking machine tools built in more than 1,500 sizes and types to meet different needs.

According to the shaping method used, metalworking machine tools are divided into two major groups, one of which is metal-cutting machine tools and the other metal-forming machine tools.

The former includes lathes, drilling, boring, grinding and polishing, milling, broaching, gear cutting and grinding, planing, sawing, shaping, slatting and several others; the latter includes bending, forging, presses, shearing, sheet and plate-working machines, thread-rolling machines and several others.

This division is determined by the kind of metalworking process. Almost every kind of machine tool mentioned above can be further divided according to the design fixtures and the surfaces to be machined, such as vertical, horizontal, radial, floor or table type, internal, surface, single- or multi-spindle, single- or multi-heads, capstan, centre, bench or pedestal, single or double column, single or double action, friction or hydraulic action, etc.

Metal-cutting machine tools are divided by the degree of accuracy of their performance: normal accuracy, precision, etc. Machine tools can be either general all-purpose machine tools or specialized for a particular product or particular type of production. In this respect machine tools can be automatic, semi-automatic, combined into automatic transfer machine lines and/or with numerical control.

Classification of machine tools by size and weight is also important. The weight of an ordinary machine tool does not exceed 10 metric tons. The weight of heavy machine tools is between 10 and 100 metric tons. Machine tools which exceed 100 tons should be considered as particularly heavy or unique.

Grinding and gear-cutting machine tools are exceptions. In this case, heavy machine tools weigh from 10 to 60 tons and particularly heavy machines weigh more than 60 tons.

It is possible that any particular machine part could be produced by a large range of machine tools, but only a few of these could produce it efficiently and only one would be the best choice for the particular job. That is why it is important to have a scientifically constructed standard international classification to facilitate international trade and customs requirements and the selection of the correct machine tool for a particular purpose.

For convenience, a classification usually uses some form of code, which gives a number to class, group or subgroup of machine tools. As a first step, a national classification is essential, but the creation of an internationally accepted standard classification of machine tools would be of considerable benefit to all nations. This could be discussed at forthcoming international seminars or symposia on the problems of engineering industries.

WORLD PRODUCTION OF MACHINE TOOLS

As a preliminary step in the study of this industry, this survey is to review the world pattern of production and trade in machine tools and relate the development of the industry to the level of industrialization. "Within the machine-building industry (however), machine tools are perhaps the most difficult to study. The great variety of types and models produced, the possibilities of interchanging them in carrying out a given job, the constant technical improvements which are being introduced and the varying levels of automation that can be obtained all combine to introduce great analytical complexities"[5] in the examination of this industry. The findings, therefore, must be considered provisional, as there is a great scarcity of relevant statistical material, and much that is available is of dubious accuracy.[6] It is possible, however, to present a reasonably accurate picture of the world industry and to highlight some of the considerations in an attempt to promote its expansion in developing countries.

Before the Second World War, the production of machine tools was largely in the hands of the United States, a few European countries and Japan. Destruction in the war left the United States as the major producer, but recovery in the other producing countries has been rapid indeed. The value of world production increased by 76 per cent between 1955 and 1962, which was greater than the increase in either the value of total world manufacturing (ISIC 2 3) or in metal products (ISIC 35 38) during the same period.[7] The largest country increases have been in Germany (Federal Republic), 142 per cent; Soviet Union, 136 per cent; Japan, 1,900 per cent; Italy, 325 per cent; mainland China, 276 per cent, and India, Argentina and Brazil with 1,200 per cent, 280 per cent and 527 per cent respectively.[8]

In 1962, the value of world production of machine tools reached $4,300 million. The United States produced 19.6 per cent of the world's machine tools; Germany (Federal Republic), 19 per cent; the Soviet Union, 16.4 per cent; the United Kingdom, 8.7 per cent; Japan, 6.4 per cent; France, 5.4 per cent; Italy, 4.3 per cent; Eastern Germany, 3.7 per cent; Czechoslovakia, 3.2 per cent, and Switzerland, 2.9 per cent.

These ten largest producers of machine tools together produced 89.6 per cent of the total value of world production of machine tools in 1962. There are at present about thirty countries which together produce 99 per cent of total world production of machine tools. Ten years ago this number was half of what it is today. With a few exceptions, all countries of Europe, including Spain and Portugal, and India, Argentina, Brazil and other countries of Asia, Africa and Latin America now have their own machine-tool industry.

In spite of the growth of the machine-tool industry in developing countries, their share in the value of world production of machine tools remains negligible: 3.6 per cent of the world production of which China produced 1.9 per cent, India and Argentina about 0.6 per cent each and Brazil a little more than 0.5 per cent.

The world production pattern as between industrial and developing countries has not changed. Three countries, the Federal Republic of Germany, the United States and the Soviet Union still produce more than half the value of the world's machine tools. In 1964, they produced 57 per cent, the ten largest producers 90 per cent, and all others only 10 per cent.

A comparison of the production of machine tools *per capita* gives another interesting picture. The production of machine tools *per capita* of twenty-one countries is given in table 1. The table shows this indicator for 1960 and 1962, and the change in absolute and *per capita* production during this period. All countries shown in the table, except China (mainland), increased their production of machine tools *per capita*.

The highest rate of increase occurred in Japan with 360 per cent; the next four are Brazil with 237 per cent; India, 228 per cent; Belgium, 177 per cent, and Italy, 168 per cent. The Federal Republic of Germany, the Soviet Union and the United States achieved 141 per cent, 115 per cent and 109 per cent respectively.

In 1962, Switzerland had the highest value of produc-

[5] United Nations, *Report of the United Nations Seminar on Industrial Programming, São Paulo, Brazil (4 15 March 1963)*, p. 23 (Sales No.: 64.II.B.8).

[6] The statistics available on the machine-tool industry present important shortcomings. Data on output are scanty. The lack of a standard international classification system and the great variety of machine tools available has made the presentation of consistent world figures difficult.

Unless otherwise indicated, the data on imports and exports of machine tools used here has been taken from the United States Department of Commerce, Business and Defense Services Administration, *World Trade in Machine Tools*, 1955-58 and 1959-60. Some countries have been precluded from the analysis because of insufficient data. The export and import data compiled by the Department has been "derived from the exports of countries making significant shipments of machine tools". Import data was derived from the export figures of the countries of origin to avoid the wide variations in the methods of reporting imports. Only data from the principal exporting countries was used, so that complete world coverage is not available. The Department of Commerce estimates that the resulting error is less than 5 per cent and is relatively constant. National currencies have been converted to United States dollars at the official exchange rate or, where necessary, the rate ruling in the world market.

The major source of production data was the *American Machinist*, 1964 Production Preview, Special Report No. 546 (29 January 1964). These figures must be considered as approximate only. Their source was a private report by the European Committee for Co-operation of the Machine Tool Industries.

Export data calculated from this published information on the percentage of national production exported does not agree with the United States Department of Commerce data on exports of machine tools.

[7] World, including USSR and Eastern Europe. Percentage increase 1955 1962, in value of total manufactures, 37 per cent; in metal products, 41 per cent. United Nations *Monthly Bulletin of Statistics*, August 1963; Special Table A; Index numbers of industrial production, excluding USSR and Eastern Europe.

[8] For production figures see Annex I at end of chapter.

tion of machine tools *per capita* with $22.40; the Federal Republic of Germany $15.20 and Czechoslovakia and Eastern Germany $10.40. At the same time, the value of India's production of machine tools was less than US 6 cents *per capita*, which is 0.003 per cent of that in Switzerland.

The concentration of production in the industrial countries has contributed to the establishment of a highly developed trade pattern, as most of the developing countries are dependent for their supply of machine tools on imports from the industrial producers. The development of the trade in machine tools has also been due to the structure of the industry, particularly in the United States and Western Europe.

The structure of the machine-tool industry in the main capitalistic countries has not changed markedly since then. It can be seen for the United Kingdom in table 3 in which the structure of the British machine-tool industry for 1935-1955 is given, and in table 4 where the structure of the United States machine-tool industry in 1958 is shown. Detailed industry data is unavailable since then, but it is known that in England in 1959 there were more than 300 firms consisting of 1,130 establishments in 340 of which ten or fewer persons were employed.[9] In the United States in 1963 there were 413 establishments with twenty or more employees and the total number of employees was 73,779.[10]

This type of industry structure in the United States and Western Europe has led to the growth of tightly knit national trade associations and a resistance to the implementation of a standard international system of classification.

Table 1

PRODUCTION OF MACHINE TOOLS *PER CAPITA* IN 1960 AND 1962

Country	*Population in millions*		*Production of machine tools* per capita (*in US dollars*)		*Increase in production between 1962 and 1960 (1962 as a percentage of 1960)*	
	1960	*1962*	*1960*	*1962*	*Production*	*Production* per capita
Switzerland	5.4	5.7	19.7	22.4	120	114
Germany (Federal Republic)	54.0	54.8	10.8	15.2	148	141
Czechoslovakia	13.7	13.9	9.8	10.3	108	102
Eastern Germany	17.2	17.1	8.3	9.7	112	117
United Kingdom	52.7	53.4	5.1	7.1	142	139
France	46.5	47.0	3.4	5.4	159	154
Sweden	7.5	7.6	4.3	5.3	125	126
United States	179.3	186.6	4.4	4.6	109	109
Italy	49.4	50.2	2.2	3.7	172	168
USSR	208.8	221.5	2.9	3.35	119	115
Belgium	9.2	9.2	1.9	3.3	170	177
Hungary	10.0	10.1	2.5	3.2	128	128
Japan	93.4	94.9	0.8	2.9	375	360
Austria	7.1	7.1	1.5	2.0	136	137
Poland	29.7	30.3	1.66	1.73	119	105
Netherlands	9.6	11.8	1.1	1.55	169	141
Argentina	20.0	21.4	1.16	1.2	109	107
Canada	18.2	18.6	0.77	0.81	109	105
Brazil	71.0	75.3	0.131	0.31	250	237
China (mainland)	582.6	700.0[a]	0.13	0.11	100	085
India	435.0	449.4	0.025	0.057	238	228

Sources: *World Trade in Machine Tools*, United States Department of Commerce, *Machine-Tool Survey*, McGraw-Hill, New York; *Statistical Yearbook, 1963*, United Nations, New York.
[a] Proximate.

STRUCTURE OF MACHINE-TOOL INDUSTRY IN INDUSTRIAL COUNTRIES

In the United States and Western Europe, the machine-tool industry was mainly founded by superior individual craftsmen who developed their product principally by personal ingenuity and established family operations. With the gradual modernization of the industry, and the proliferation of types and sizes and the increased complexity of machine tools, the average size of the firms increased. The industry, however, is still characterized by a relatively large number of small manufacturers compared with their customers in other engineering industries. Manufacturers specialize in a few or perhaps only one particular line, with some firms even specializing in particular sizes or qualities of their individual line. Table 2 shows the size of establishments in the United States, France and the United Kingdom at the end of the war.

WORLD TRADE IN MACHINE TOOLS[11]

Specialization is a marked feature of the machine-tool industry internationally. This means that a substantial volume of imports is normal even in those countries where the industry is most developed.

Following the Second World War, the United States was the major world supplier, but the recovery of trade in machine tools has been even more rapid than that of

[9] Surveys of British Industry, No. 6. *The Machine Tool Industry*, Far East Trade, Supplement (Nov. 1959).

[10] *A Guide to the McGraw-Hill Plant Census*, McGraw-Hill, New York (1963).

[11] See Annex II at end of chapter.

Table 2

STRUCTURE OF MACHINE-TOOL INDUSTRY IN FRANCE (1949), THE UNITED STATES (1947) AND THE UNITED KINGDOM (1947)

France			*United States*			*United Kingdom*		
Size of establishments (number of persons employed)	*No. of establishments*	*Percentage*	*Size of establishments (number of persons employed)*	*No. of establishments*	*Percentage*	*Size of establishments (number of persons employed)*	*No. of establishments*	*Percentage*
0–49	60	50.0	0–49	431	57.9	1–49	104	46.4
50–99	30	25.0	50–99	95	12.8	50–99	38	17.0
100–249	16	13.4	100–249	106	14.2	100–299	55	24.6
250–499	8	6.6	250–499	53	7.1	300–499	13	5.8
500–999	6	5.0	500–999	34	4.6	500–749	3	1.3
1,000–2,499	—	—	1,000–2,499	20	2.7	750 or more	11	4.9
2,500 or more	—	—	2,500 or more	5	0.7			
Total	120	100.0		744	100.0		224	100.0

Source: ECLA, *The Machine Tools Industry in Brazil: Background Material for the Programming of its Development* (1962), E/CN.12/633, p. 69.

Table 3

STRUCTURE OF THE MACHINE-TOOL INDUSTRY IN THE UNITED KINGDOM IN 1935, 1947 AND 1955

Size of establishments (no. of employees)	*1935*				*1947*				*1955*			
	Establishments		*Employees*		*Establishments*		*Employees*		*Establishments*		*Employees*	
	No.	*Percentage*	*Total*	*Percentage*	*No.*	*Percentage*	*Total*	*Percentage*	*No.*	*Percentage*	*Total*	*Percentage*
11–24	17	13.8	304	1.4	49	22.0	1,050	2.3	55	20.0	986	2.2
25–49	31	24.7	1,118	5.3	55	24.6	2,570	5.6	70	25.4	2,520	5.6
50–99	28	22.9	2,124	10.0	38	17.0	3,610	7.9	56	20.4	3,852	8.7
100–199	23	18.8	3,065	14.6	42	18.7	7,380	16.3	38	13.8	5,092	11.4
200–299	11	9.0	2,713	12.9	13	5.7	4,100	9.1	20	7.3	4,838	10.8
300–499	3	2.5	1,221	5.8	13	5.7	6,430	14.2	20	7.3	7,472	16.7
500–749	3	2.5	1,846	8.7	3	1.4	2,240	4.9	4	1.4	2,347	5.2
750 or more	7	5.8	8,691	41.3	11	4.9	18,050	39.7	12	1.4	17,645	39.4
Total	123	100.0	21,082	100.0	224	100.0	45,430	100.0	275	100.0	44,752	100.0

Source: The British Machine Tool Industry, Machine Tool Trades Association, London (1958).

Table 4

STRUCTURE OF THE MACHINE-TOOL INDUSTRY IN THE UNITED STATES OF AMERICA IN 1958

Size of establishments (no. of employees)	*No. of establishments*				*Average employment per establishment*	*Value of shipments*	
	Metal-cutting machine tools	*Metal-forming machine tools*	*Total*	*Percentage*		*Thousands of US dollars*	*Percentage*
1–4	213	60	273	29.8	2	9,093	9.0
5–9	99	41	140	15.3	7	13,326	1.4
10–19	84	43	127	13.9	14	24,063	2.4
20–49	88	65	153	16.7	32	65,881	6.6
50–99	47	30	77	8.4	70	78,489	7.9
100–249	48	31	79	8.6	160	179,484	18.0
250–499	21	10	31	3.2	351	161,453	16.2
500–999	17	9	26	2.8	757	263,626	26.4
1,000 or more	10	2	12	1.3	1,275[a]	202,088	20.2
Total	627	291	918	100.0	80	997,503	100.0

Source: United States Department of Commerce, Bureau of the Census, *1958 Census of Manufactures*.
[a] Estimated. For metal-cutting alone, 1,739.

production. Between 1955 and 1960, the percentage increase in the value of world exports of machine tools was 71.6 per cent, compared with an increase of 35.1 per cent in the value of production. This increase in trade has also far outstripped the rate of growth of the value of total world exports.

Table 5

TRENDS IN WORLD EXPORTS 1955–1960 (INCLUDING EASTERN EUROPE AND THE USSR)

(millions of US dollars, f.o.b.)

Year	*All commodities*[a]	*Machine tools*[b]
1955	93,700	439
1957	111,800	641
1960	127,700	753

[a]*United Nations Yearbook of International Trade Statistics* (1962), table A.
[b]United States Department of Commerce, Business and Defense Services Administration, *World Trade in Machine Tools* (1955-58, 1958-60), Washington, D.C.

By 1955, the United States had fallen to second place, behind the Federal Republic of Germany, as a world exporter; it has remained there since. These two countries exported 28 per cent and 30 per cent, respectively, of total machine tools in 1960, with the United Kingdom the third largest exporter with 10 per cent. Switzerland exported 9 per cent of the world total; Czechoslovakia, 5.8 per cent; Italy, 4.8 per cent, and France, 4.5 per cent.

All other exporters contributed less than 8 per cent of the total, but included in these are a number of smaller countries which exported more than 50 per cent of their production. (For example, Austria, Belgium, Netherlands and Sweden.) In some countries, domestic demand fostered the development of special skills and know-how, and the product pattern of exports reflects the product pattern of production.

In others, however, export demand has resulted in the specialization in the production of certain types of machine tools which are less related to the pattern of domestic demand. Further analysis of this question would require data on the proportion of output exported for different kinds of machine tools.

The degree of international specialization is indicated by the value of imports as a percentage of exports of the major exporting countries (see table 6). Between 1955–60 only six countries, the Federal Republic of Germany, the United States, Czechoslovakia, Switzerland, the Soviet Union and the United Kingdom imported less than they exported. Imports of all other countries were larger than exports. This is particularly true of Japan whose average annual imports were ten times its exports between 1955 and 1960 and, in 1958 alone, fourteen times exports.

Belgium, the Netherlands and Switzerland exported nearly three-quarters of their annual production during the period of 1955-1962. Czechoslovakia, Austria and Sweden exported about two-thirds of their production during the same period. The Federal Republic of Germany and Hungary exported about half.

World exports of machine tools in 1960 were directed in more than sixty countries but approximately 50 per cent of total world exports have been taken by the major exporting industrial countries themselves.

The world's largest exporters of machine tools are also among the leading importers. In 1962, for example, the Federal Republic of Germany was the largest exporter and the second largest importer.

Table 6

IMPORTS AS A PERCENTAGE OF EXPORTS OF MACHINE TOOLS

(in United States dollar value)

Country	*Percentages*					
	1955	*1956*	*1957*	*1958*	*1959*	*1960*
Germany (Federal Republic)	18.2	16.4	13.7	13.6	19.2	25.4
United States	11.8	15.1	16.5	14.2	20.3	13.5
United Kingdom	85.5	111.4	71.9	63.9	60.1	77.7
Switzerland	27.3	38.2	37.9	33.2	27.8	26.4
Czechoslovakia	5.4	10.6	18.4	24.9	14.2	1.9
Italy	182.3	154.9	145.2	97.0	73.3	113.9
France	256.6	300.9	368.5	421.0	216.7	158.0
USSR	40.3	38.8	79.7	33.8	109.4	261.0
Sweden	150.0	100.1	87.1	84.3	124.9	146.7
Belgium-Luxembourg	119.2	105.5	102.1	89.5	85.9	105.9
Netherlands	360.4	329.6	349.8	250.3	260.6	304.6
Japan	362.8	391.0	970.6	1,452.6	1,074.2	991.9
Denmark	109.2	99.8	98.0	125.4	239.5	191.1

Source: U.S. Department of Commerce, Business and Defense Services Administration, *World Trade in Machine Tools* (1955–1958; 1959–1960).

Table 7

VALUE OF TOTAL IMPORTS AS A PERCENTAGE OF TOTAL EXPORTS OF THE MAJOR MACHINE-TOOL EXPORTING COUNTRIES

1955	*1956*	*1957*	*1958*	*1959*	*1960*
52	55	55	48	50	58

Table 8

MACHINE-TOOL EXPORTS FROM EUROPEAN COMMITTEE NATIONS AND THE UNITED STATES

(in percentages)

Destination	*Eur. Com. nations* 1960	1961	1962	*United States* 1960	1961	1962
European Committee nations[a]	45.5	51.5	56.3	44.1	44.2	41.0
Other European nations	6.5	6.2	4.6	0.9	1.8	1.2
Eastern Europe	7.5	6.7	6.2	0.1	0.4	0.1
Africa	3.5	2.9	2.9	0.9	0.9	0.8
North America[b]	7.0	4.5	4.5	12.5	6.7	9.7
Latin America	9.5	8.6	7.3	17.3	15.8	15.6
Asia	16.0	16.2	15.0	21.5	27.7	26.6
Oceania	5.0	3.2	2.3	2.7	2.5	5.0

Source: American Machinist (9 December 1963).
[a] European Committee nations' exports to other European Committee nations.
[b] United States exports to Canada.

The main direction of the flow of machine-tool exports can be seen in table 8 for the two groups of larger exporters, the twelve nations of the European Committee[12] and the United States in 1960–62.

If the imports taken by the smaller industrial European countries of Austria, Spain, Finland, Poland, Yugoslavia, Hungary and Eastern Germany, and the semi-industrial countries of Canada and Australia are added to those of the major machine-tool exporting countries (see table 9), only about 30 per cent of world trade in machine tools is with the developing countries.

Table 9

MACHINE TOOLS: VALUE OF IMPORTS OF DEVELOPING COUNTRIES AS A PERCENTAGE OF THE VALUE OF TOTAL WORLD EXPORTS

1955	*1956*	*1957*	*1958*	*1959*	*1960*
28	27	28	36	32	27

Table 10

AVERAGE YEARLY MACHINE-TOOL CONSUMPTION OF SELECTED COUNTRIES DURING 1957–59

(in US dollars)

Country	*Million dollars*	*Percentage of world consumption*	*Country*	*Million dollars*	*Percentage of world consumption*
United States	685.7	24.20	China (mainland)	59.5	2.10
Soviet Union	482.6	17.00	Brazil	46.0	1.65
Germany (Fed. Rep.)	274.5	9.75	India	34.2	1.20
United Kingdom	224.9	8.00	Argentina	30.3	1.10
France	198.9	8.10	Mexico	8.7	0.30
Eastern Germany	92.7	3.30	Venezuela	5.2	0.10
Japan	88.3	3.10	Turkey	3.1	0.10
Czechoslovakia	87.1	3.05	Colombia	1.54	0.055
Switzerland	59.5	2.10	Iran	1.36	0.050
Italy	58.7	2.05	Philippines	0.99	0.035
Canada	50.9	1.85	Peru	0.93	0.030
Poland	37.4	1.35	Indonesia	0.79	0.025
Sweden	29.8	1.05	Iraq	0.39	0.015
Australia	26.4	0.95	Ethiopia	0.11	0.005
Netherlands	18.9	0.65	Ghana	0.04	0.002
Hungary	17.1	0.60			
Austria	14.8	0.55	Developing countries		
Belgium	13.8	0.50	Total	193.15	6.8
Finland	3.9	0.15	Total, included countries	2,532.25	94.1
Industrialized countries			Other countries[a]	165.0	5.9
Total	2,465.9	87.3	World total	2,824.05	100.0

[a] Other industrialized countries for which similar data was not available included Denmark, Spain, Yugoslavia, Norway, Portugal and Romania, total consumption of which is not likely to exceed $1 million a year.

In recent years over half of this remainder has been taken by the more industrialized of the developing countries: Brazil, Argentina, India, mainland China and Mexico. (In 1960: 4.3 per cent; 3.9 per cent; 2.3 per cent; and 1.5 per cent, respectively.)

It is clear that the production and trade of machine tools is confined very largely to industrialized or industri-

[12] The European Committee for Co-operation of Machine Tool Industries. Members: Austria, Belgium, Denmark, Federal Republic of Germany, France, Italy, Netherlands, Portugal, Spain, Sweden, Switzerland and United Kingdom.

alizing countries and that the production and even use of machine tools, except for simple repairs and maintenance, presupposes a certain level of economic development and industrialization.

World machine-tool consumption

The value of machine-tool consumption is another important indicator of the level of industrial development and the rate of a country's industrialization. In table 10, the average annual consumption of selected countries between 1957 59 is given. This period was chosen because the data was available only for those years. The ten major consumers are also the ten main producers of machine tools. Their total annual consumption was approximately 80 per cent of world annual consumption between 1957-59. The thirty-four countries which are shown in the table consumed approximately 94 per cent of the remaining consumption.

America and Asia. Consumption in Africa is negligible. Consumption in the highly industrialized countries of Europe during the five years presented in table 11 is approximately sixteen times larger than that in Asia during the same period.

The relationship between the production and consumption of machine tools and the level of industrialization

Countries can be divided into two broad groups. The first group includes those countries whose machine-tool industries are developed to the point where their exports make a significant contribution to world trade in this commodity (over $US 5 million) or comprise over 30 per cent of their production. Included in this group are the United States, Europe and the USSR. Japan is a borderline case but has been included here because of the size of its domestic industry. The second group includes

Table 11

ANNUAL *PER CAPITA* MACHINE-TOOL CONSUMPTION

(in US dollars)

World region or countries	*1958*	*1959*	*1960*	*1961*	*1962*
12 countries of European Committee for Co-operation of Machine Tool Industries	3.57	3.57	4.47	5.77	5.84
USSR and countries of Eastern Europe	2.36	2.46	2.87	3.20	3.27
United States and Canada	2.74	2.86	3.24	2.80	3.06
Latin America	0.56	0.63	0.70	0.76	0.79
Other European countries	0.46	0.60	0.70	0.88	0.72
Asia	0.18	0.18	0.23	0.37	0.42
World average	0.90	0.90	1.14	1.32	1.42

Source: European Committee for Co-operation of Machine Tool Industries.

African countries consume the least machine tools. Consumption in Ghana, with a population which could be compared with such European countries as Sweden, Czechoslovakia and Austria, for example, is negligible compared with these countries. The value of machine-tool consumption *per capita* also gives some idea of the industrial level of a country or group of countries. Average annual consumption *per capita* between 1958 and 1962 was $US 4.64 in the twelve countries belonging to the European Committee for Co-operation of Machine Tool Industries.[13] It was $US 2.96 in North America, $US 2.83 in Eastern Europe, $US 0.68 in Latin America, $US 0.27 in Asia and about $US 0.1 in Africa. The world average annual consumption *per capita* was approximately $US 1.1 during 1958-1962. Table 11 gives the annual *per capita* machine-tool consumption for several groups of countries.

As can be seen from table 11, annual *per capita* machine-tool consumption in the highly industrialized countries of Europe and the United States is very high compared with that of the developing countries of Latin

all other countries, the distinguishing feature of which is their lack of machine-tool exports.

Countries in the second group can be further divided into three subgroups. Subgroup I includes semi-industrialized countries such as Canada and Australia which have a developing machine-tool industry, but still depend largely on machine-tool imports, and the value of whose machine-tool exports are less than $5 million (actually less than $1 million). These countries have a developed engineering industry with more than a million persons engaged in manufacturing, and virtually all their steel consumption is provided by the domestic industry. *Per capita* figures for gross domestic product and value added in manufacturing are as high as the industrial countries, indicating a high level of economic development and welfare.

Subgroup II includes the industrializing countries of India, Brazil and Argentina. The machine-tool industries in these countries have the same characteristics as those in subgroup I. The industrial sector, however, is not as developed in subgroup II as in I, the total value added in metal products being less than 50 per cent of that in subgroup I. These countries, particularly Argentina, are also more dependent on steel imports to meet consumption

[13] Austria, Belgium, Denmark, Federal Republic of Germany, France, Italy, Netherlands, Portugal, Spain, Sweden, Switzerland and United Kingdom.

requirements. The main difference between subgroups I and II, however, is in their levels of general economic development as measured by *per capita* GDP and *per capita* value added in manufacturing.

Subgroup III is clearly distinguished from the previous subgroups. The machine-tool industry is negligible or non-existent, consumption requirements being met from imports. The engineering industry is similarly undeveloped, and there are less than 400,000 engaged in total manufacturing. These countries are also characterized by low levels of living as measured by the general economic indicators of *per capita* GDP and value added in manufacturing.

It is clear from this classification that the machine-tool industry is a late-comer in the process of industrialization and the scope for the expansion of the industry in developing countries is very great. In both the semi-industrialized countries of subgroup I, and the more highly developed of the developing countries in subgroup II, the consumption of machine tools is still primarily met from imports. Consumption, except of simple tools for repairs and maintenance, is dependent on a developed engineering industry as exists only in the few more industrialized of the developing countries such as India and Brazil. It is also clear that the existence of a machine-tool industry is not correlated with general economic development as measured by *per capita* gross domestic product, but rather with the absolute size of the industrial sector.

The process of development of the machine-tool industry has in the past involved the gradual substitution of domestic production for imports, beginning with the least complex types of tools. If the experience of the industrialized countries is repeated in the developing areas, however, the absolute value of machine-tool imports will not necessarily decline. As a country's production increases, so will the value of its exports as it tends to specialize in the production of certain types of tools, at the same time maintaining its imports of other specialized tools. It can be expected that the increased development of the machine-tool industry will increase the volume of world trade in this field.

Conclusions

Developing countries' share in world machine-tool production

During the past decade, Europe and the United States continued to consolidate their position as the world's leading machine-tools producing areas. In 1964, the total value of machine-tool production was estimated at $4,700 million, an increase of 6 per cent over the 1963 total of $4,400 million and almost double that of 1955. As in previous years, three countries accounted for over 50 per cent of world machine-tool production in 1964: United States (25 per cent), USSR (17 per cent) and Federal Republic of Germany (15 per cent). The share of all the developing countries in world machine-tool production remains only about 8 per cent and the share of individual developing countries is still very small (for example: India 0.8 per cent, Brazil 0.67 per cent). In contrast with the relative stability of other countries, Japan's production has grown rapidly from 0.55 per cent of world production in 1955 to 6.5 per cent in 1964. During this period, Japan moved from fourteenth to the fifth largest machine-tool producer.

Share of developing countries in the world trade of machine tools

Only imports of machine tools into developing countries can be discussed, as their exports are negligible (less than 0.03 per cent of the total world exports). Their share of world imports is also comparatively small. Table 12 shows the distribution of world imports of machine tools from the main exporting countries (United States and Europe), the exports of which represented 85-88 per cent of total world export between 1955 and 1962.

The industrial regions include practically all countries of Europe, North America, Japan and Oceania. Japan is excluded from Asia, so the figures for Africa, Latin America and Asia include only developing countries. It can be seen that the industrialized countries absorbed between four-fifths and three-quarters of world exports during this period. Even though the average annual rate of increase of imports by the Latin American and Asian countries was higher than that of the industrialized countries during this period (Asia, 19 per cent, Latin America, 16 per cent, industrialized area, 15 per cent), the share of world imports did not increase perceptively.

In 1962, the share of world imports of machine tools reached 9.5 per cent in Latin America and 6.4 per cent in Asia. The average annual increase of machine-tool imports into Africa was only 8 per cent over the period but its share of the total world machine-tool imports was only 2.4 per cent in 1962. Annual machine-tool imports into developing countries was not stable during this period, and the accumulation of imported machine tools in the developing countries was a fraction of the accumulation in industrial countries (in Latin America, a seventh less, in Asia, a ninth and in Africa, a twenty-seventh.[14]

Developing countries' share in the world consumption of machine tools

The low rate of production and import of machine tools into developing countries has produced a low level of consumption of machine tools as compared with that in developed countries. This gap widened during the past five years since world machine-tool production increased at an average rate of 12 per cent *per annum* while the developing countries reduced their imports, which form the main share of their consumption, and even decreased their production in some years.

Imports into Asia and Latin America were lower during 1960-64 than during the 1955-59 period. The average annual increase of imports into Latin America was only 3 per cent during 1960-1962 compared with 26 per cent during 1955-1959. For Asia, these figures were

[14] See table 12, total for 8 years.

Table 12

SHARE OF WORLD MACHINE-TOOL IMPORTS FROM THE UNITED STATES AND THE MEMBER COUNTRIES OF THE EUROPEAN COMMITTEE OF MACHINE-TOOL INDUSTRIES, OF THE INDUSTRIALIZED AND DEVELOPING COUNTRIES IN 1955–1962

(in millions of Swiss francs)

	Imports of				
	Industrialized countries (Europe, North America, Japan and Australia)	*Africa*	*Latin America*	*Asia (Japan excluded)*	*Totals*[a]
1955					
Value	1,524	66	180	105	1,881
Percentage	81.0	3.5	9.5	5.6	100.0
1956					
Value	1,812	75	184	168	2,243
Percentage	81.0	3.2	8.2	7.5	100.0
1957					
Value	2,182	94	234	255	2,767
Percentage	79.0	3.4	8.5	9.1	100.0
1958					
Value	1,981	89	366	281	2,721
Percentage	72.0	3.3	13.5	10.3	100.0
1959					
Value	1,943	81	424	255	2,705
Percentage	72.0	3.0	15.7	9.4	100.0
1960					
Value	2,465	85	375	337	3,265
Percentage	75.0	2.6	11.5	10.3	100.0
1961					
Value	3,313	101	406	352	4,222
Percentage	78.0	2.4	9.7	8.0	100.0
1962					
Value	3,986	115	462	310	4,865
Percentage	82.0	2.4	9.5	6.4	100.0
Total for eight years:					
Value	19,170	706	2,631	2,063	24,669
Percentage	77.5	2.7	10.7	8.4	100.0
Average annual percentage increase	15.0	8.0	16.0	19.0	15.0

[a] The simple addition of the columns may not give the amount appearing under the heading "Totals" because of rounding.

Table 13

THE RATIO OF CONSECUTIVE YEARLY VALUES OF CONSUMPTION, PRODUCTION AND IMPORTS OF MACHINE TOOLS, DEVELOPING COUNTRIES AND WORLD TOTAL DURING 1955–1964

The ratio of consecutive yearly values of:	*1956/1955*	*1957/1956*	*1958/1957*	*1959/1958*	*1960/1959*	*1961/1960*	*1962/1961*	*1963/1962*	*1964/1963*
Production of machine tools by:									
Brazil	1.13	1.12	1.11	1.13	1.60	1.99	1.25	1.34	1.00
India	1.19	2.21	1.21	1.18	1.78	1.94	1.25	1.15	1.25
China (mainland)	1.11	1.10	2.02	1.44	1.05	1.00	1.00	—	—
Argentina	1.84	1.66	1.08	1.06	1.00	1.14	0.96	—	—
Developing countries	1.32	1.52	1.35	1.20	1.36	1.74	1.11	1.12	1.06
World production	1.25	1.04	0.85	1.06	1.29	1.16	1.12	1.06	1.06
Import of developing countries of:									
Africa	1.14	1.25	0.95	0.91	1.05	1.19	1.14	—	—
Latin America	1.04	1.27	1.56	1.16	0.88	1.08	1.13	—	—
Asia (Japan excluded)	1.60	1.53	1.10	0.91	1.32	1.04	0.88	—	—
All developing countries	1.26	1.35	1.20	0.99	1.08	1.10	1.05	—	—
World import	1.19	1.23	0.98	0.99	1.21	1.29	1.16	—	—

8 per cent and 28 per cent, respectively, and for Africa, 13 per cent and 6 per cent. Africa has shown a relative increase but its share of the total imports of machine tools into developing countries is only about 12 per cent. Table 13 gives the percentage yearly increase of production and imports of the world and the developing countries.

Machine-tool requirements in developing countries

The process of industrialization cannot be accelerated without an increase in the stock of efficient machine tools at the disposal of developing countries. Table 14 gives an indication of the number of machine tools at the disposal of selected countries. The determination of the

Table 14

MACHINE-TOOL INVENTORIES AND NUMBER OF PERSONS EMPLOYED IN THE METAL-TRANSFORMING INDUSTRIES IN SELECTED COUNTRIES

Country	*Number of machines*	*Number of persons employed (thousands)*	*Number of persons per machine*
United States of America	2,200,000	4,616	2.1
Soviet Union	2,350,000	4,539	1.9
United Kingdom	1,100,000	3,049	2.8
Federal Republic of Germany	1,300,000	2,419	1.9
France	500,000	1,078	2.2
Italy	363,000	595	1.6
Japan	750,000	1,350	1.8
Brazil	152,000	353	2.3
Chile	12,000	44	3.6

quantity of machine tools that would be required by a developing country during a given period is a very complicated problem which involves the analysis of the whole programme of industrialization of the particular country. Regardless of the procedure and method used, it is clear that a census of the metalworking industry and an inventory of the machine tools available in the country should be undertaken. The findings would provide valuable information which could help to determine the machine-tool requirements of the country.

A study of the consumption of the quantity and types of various machine tools used in the different manufacturing industries of developed and developing countries should also be undertaken. This could provide a prototype for a rough estimate of the requirements of machine tools in planning industrial development. On the basis of such surveys, some specific models for determining the quantity and types of machine tools required for the manufacture of particular products could be prepared for the use of the developing countries in the programming of their development.

Obtaining machine tools during the process of industrialization

The importation of machine tools and the establishment and development of a machine-tool industry require the expenditure of foreign exchange. Attention should be paid to a consideration of both the importation and production of machine tools, but a number of other measures can also be taken which could help to meet the increasing demand for machine tools during the early stages of industrialization.

The first is the establishment of adequate facilities for the repair and maintenance of machine tools throughout the country. The useful life of machine tools can be quite long, as the experience of the developed countries shows (see table 15). The longer their life the greater the possible accumulation of machine tools at the disposal of developing countries.

Second, the establishment of centralized metalworking shops (or plants) which could be equipped with such machines as tool-room machines, gearworking machine tools, jig-boring machines and others, to do jobs for smaller metalworking firms which could not afford to operate such specialized machine tools. Such co-operation would permit a reduction in the number of expensive machine tools and more efficient use.

Table 15

USEFUL LIFE OF MACHINE TOOLS IN DIFFERENT TYPES OF PRODUCTION

Group	*Type or scale of production*	*Product manufactures*	*Average useful life of machine tools*
I	Mass	Passenger cars, refrigerators, radio and television sets, etc.	8 years
II	Large batch	Vehicles, transport equipment, machine tools, industrial equipment of different plants, etc.	20-22 years
III	Small batch	Maintenance, repair	24-28 years
IV	Job	One or several items produced at a time; small-scale industry	to 40 years

Third, developing countries should promote specialization in the metalworking industry from its beginning. State or privately owned specialized plants for the production of bolts, nuts, screws and other fasteners, as well as for small tools, forgings, castings and pressing and other products may be established. Such plants could use mass and large batch production equipment and by this means reduce the quantity of machine tools required in the country if the same tools were produced by a number of small factories.

Fourth, the importation of second-hand machine tools should also be considered if a market for such machine tools exists in the developed countries.

The establishment of the machine-tool industry

Some developing countries, such as Argentina, Brazil, China, India and the United Arab Republic have already established their own machine-tool industry. A study of their experiences should be undertaken and made available. This would be an important contribution. Countries which plan to establish a machine-tool industry must take account of the linkage with other industries. The existence of a number of well-developed industries is a prerequisite for the establishment of a machine-tool industry.

Initially, a developing country may contain machine-tool repair shops and plants, woodworking machine-tool plants and other existing mechanical works. Centralized repair shops or plants, initially established for the purpose of serving the metalworking industry, could later be developed into producing machine tools. This would encourage the accumulation of the necessary experience and skills. Another problem in developing countries is the training of designers who could develop their own machine tools. It would probably be necessary initially to purchase licences for the production of foreign machine tools. Invitations could be extended to foreign machine-tool firms to assist the developing countries in the establishment of machine-tool industries.

Organization of maintenance and repair of machine tools

The provision of maintenance and repair services must be emphasized. The problem of the reliability of machine tools is of increasing importance in all countries because the development of modern machine tools is characterized by an increasing degree of automation, horse-power and speed. Imperfect organization and methods of machine-tool repair increase maintenance and repair costs which can often exceed the original cost of a machine tool (see figure 1).[15]

Research into developed countries' experiences in the field of the maintenance and repair of machine tools, carried out by the Experimental Scientific Research Institute for Machine Tools, Moscow (ENIMS) since 1959, shows that the organization of centralized repair shops and plants in a country has significant advantages over sending machine tools back to the manufacturer for repair. Research has shown that the labour time in specialized central repair plants is about 40 per cent of the labour time in the production of a comparable new machine. The production cost in the case of centralized repair in the USSR is 20–25 per cent less than that of existent practice.[16]

In developing countries where industry is centralized, it provides favourable conditions for the introduction of centralized repair plants. It would not only reduce costs but allow the use of more modern methods and require a smaller number of highly skilled personnel.

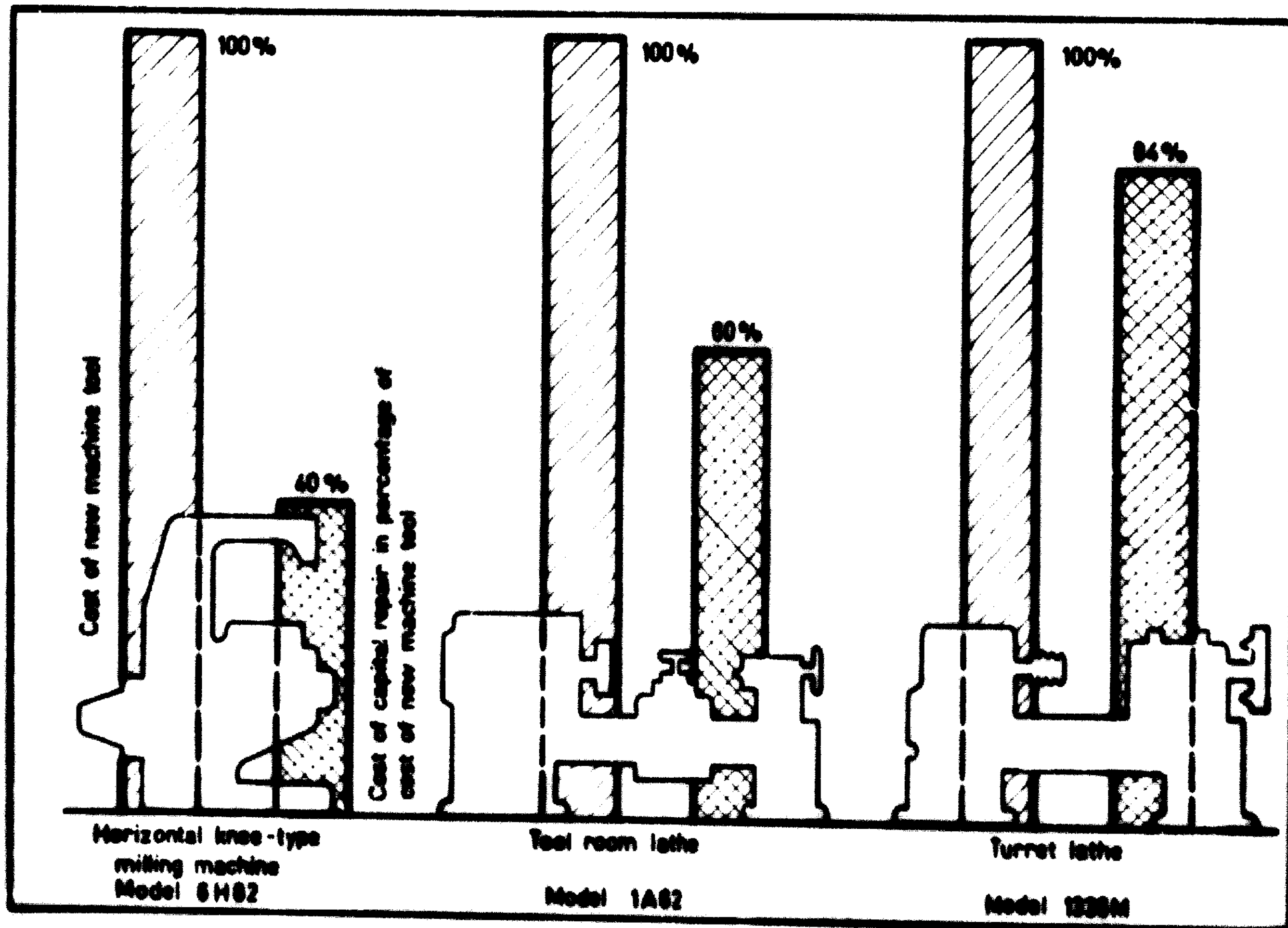


Figure 1

COMPARATIVE COST OF NEW MACHINES AND COST OF CAPITAL REPAIRS

[15] *Reliability of Metalcutting Machine Tools* by Prof. A. S. Pronikov and Prof. A. M. Dalsky, Moscow Workers Publishing House (1965), p. 5.

[16] *Organization of Centralized Repair and Modernization of Machine Tools*, ENIMS (1961).

It may be suggested also that a special organization dealing with the problems of the machine-tool industry should be set up in developing countries. Depending on requirements of such an organization, it could be established as a special centre or as a department within the framework of a technological institute. Such an organization could consider the problems involved in the importation of machine tools, their design, preparation and the training of the necessary labour.

ANNEX I

Production of machine tools

(in millions of US dollars)

Country	*1955*	*1956*	*1957*	*1958*	*1959*	*1960*	*1961*	*1962*	*1963*	*1964 (estimated[a])*
United States	984	1,293	1,189	628	650	788	792	857	920.0	1,160.0
Soviet Union	336	382	440	510	510	602	649	718	760.0	790.0
Germany (Federal Republic)	343	418	452	412	466	563	706	831	753.8	725.0
United Kingdom	211	236	278	238	229	267	336	379	319.7	340.0
Japan	13.9	23.2	39.4	57.9	61.4	125.3	232	278	292.6	304.6
France	127	130	159	174	134	160	188	234	224.0	220.0
Czechoslovakia	74	81	93	116	122	134	132	139	195.0	207.3
Eastern Germany	69.5	93	116	133	139	144	151	160	165.0	[b]
Italy	44	60	54	57.5	61	110	185	187	194.5	126.0
Switzerland	81	86	93	93	102	107	116	127	120.5	121.4
China (mainland)	20.9	23.2	25.5	52.1	75.3	79	79	79	[b]	[b]
Poland	28	39.4	36.4	39.4	40.5	45.2	47.5	53.8	[b]	[b]
Sweden	27.3	32	30.8	33.6	27.8	32.4	38.5	40.5	49.0	46.0
Hungary	18.5	18.5	20.9	22.0	24.3	25.5	29	32.4	30.0	[b]
India	1.6	1.9	4.2	5.1	6	10.7	20.4	26.0	30.0	37.8
Australia[c]	6.0	6.9	7.3	6.8	5.9	7.2	7.3	6.2	34.0	35.0
Brazil	3.7	4.2	4.6	5.1	5.8	9.3	18.5	23.2	31.0	31.0
Canada	11.6	12.5	13.2	11.6	13.9	13.9	13.9	15.1	23.0	25.5
Argentina	6.7	12.3	20.4	22	23.2	23.2	26.6	25.5	[b]	[b]
Belgium	12.3	15.1	15.3	14.8	13.7	17.6	23.9	30.1	25.3	24.1
Austria	5.1	6.5	7.2	6.3	7.4	10.2	11.4	14.1	13.1	14.0
Netherlands	7.0	8.1	7.6	7.9	7.9	10.4	14.8	18.3	11.1	11.6
Total	2,432.1	2,982.8	3,106.8	2,646.1	2,726.1	3,285.1	3,817.8	4,274.2	4,277.6[d]	4,282.7[e]

Sources: *American Machinist*, 1964 Production Review, p. 126. Except for: Germany (Federal Republic of) (1958), from *The Financial Times*, *Review of Industry*, London; Japan (1960), from US National Machine Tool Builders' Association, *Survey of Foreign Machine Tool Markets*, p. 106; and Australia, from Australian Industries' Development Association, *Director Reports*, No. 145 (August 1964).

[a] *American Machinist*, 1965 Outlook, p. 133.

[b] Figures are not available.

[c] Year ending 30 July.

[d] Total production without China (mainland), Poland, Argentina, but excluding Spain ($US 27.0 million); Romania ($US 19.0 million); Denmark ($US 9.6 million) Yugoslavia ($US 8.8 million) and Portugal ($US 1.8 million). World estimated production for 1963 was $US 4,400 million.

[e] Total production without Eastern Germany, China (mainland), Poland, Hungary, Argentina, but including Spain ($US 50.0 million); Denmark ($US 9.9 million), and Portugal ($US 3.5 million). World estimated production for 1964 was $US 4,700 million.

ANNEX III

World exports of machine tools, 1955-1962

(thousands of US dollars)

Country	1955 Value	1955 Per-centage	1956 Value	1956 Per-centage	1957 Value	1957 Per-centage	1958 Value	1958 Per-centage	1959 Value	1959 Per-centage	1960 Value	1960 Per-centage	1961 Value	1961 Per-centage	1962 Value	1962 Per-centage
All machine tools																
Germany (Federal Republic)	128,222	29.2	158,675	30.9	199,853	31.2	199,018	32.4	200,838	32.6	224,517	29.8	360,000	31.0	391,000	29.30
United States	125,088	28.5	141,659	27.6	182,258	28.4	165,118	26.9	145,504	23.6	209,640	27.8	305,000	26.3	342,000	25.60
United Kingdom	52,601	12.0	58,741	11.5	76,485	11.9	65,332	10.6	63,241	10.3	78,922	10.5	94,200	8.1	117,000	8.80
Switzerland	45,017	10.3	48,573	9.5	58,299	9.1	52,016	8.5	59,216	9.6	69,018	9.2	88,300	7.6	97,800	7.40
Czechoslovakia	15,055	3.5	19,066	3.7	24,147	3.8	30,581	5.0	41,905	6.8	43,848	5.8	92,500	7.9	97,400	7.30
Italy	14,632	3.3	19,110	3.7	24,620	3.8	25,213	4.1	26,466	4.3	35,993	4.8	57,400	4.9	78,500	5.95
France	17,245	3.9	18,412	3.6	21,041	3.3	13,418	2.2	26,112	4.2	33,841	4.5	50,500	4.4	71,500	5.40
Soviet Union	8,892	2.0	9,892	1.9	9,582	1.5	18,090	2.9	20,200	3.2	13,796	1.8	45,400	3.9	57,400	4.30
Sweden	11,357	2.6	15,808	3.1	17,980	2.8	19,991	3.2	10,352	1.7	13,920	1.8	25,800	2.3	24,300	1.82
Belgium-Luxembourg	9,596	2.2	11,277	2.2	11,768	1.8	11,467	1.9	10,403	1.7	11,497	1.5	18,800	1.8	23,700	1.78
Netherlands	4,323	1.0	5,675	1.1	5,785	0.9	6,028	1.0	6,007	1.0	6,539	0.9	11,200	1.0	14,300	1.07
Japan	3,176	0.7	2,745	0.5	4,380	0.7	2,816	0.5	3,071	0.5	7,506	1.0	9,300	0.8	11,300	0.85
Denmark	3,667	0.8	3,654	0.7	4,996	0.8	4,785	0.8	3,374	0.5	4,164	0.6	[a]	[a]	5,700	0.43
Total, all countries	438,871	100.0	513,287	100.0	641,204	100.0	613,873	100.0	616,689	100.0	753,201	100.0	1,158,400	100.0	1,331,900	100.0

Country	1955 Value	1955 Percentage	1956 Value	1956 Percentage	1957 Value	1957 Percentage	1958 Value	1958 Percentage	1959 Value	1959 Percentage	1960 Value	1960 Percentage
Metal-cutting machine tools												
Germany (Federal Republic)	86,017	27.0	113,005	29.9	143,364	31.6	138,861	32.5	142,048	32.6	161,742	30.5
United States	87,006	27.3	99,089	26.2	118,766	26.2	100,464	23.5	81,738	18.8	127,774	24.1
United Kingdom	40,222	12.6	44,525	11.7	51,855	11.4	44,907	10.5	46,905	10.8	53,499	10.1
Switzerland	39,616	12.5	43,524	11.5	49,132	10.8	45,320	10.6	51,169	11.8	59,632	11.2
Czechoslovakia	11,807	3.7	14,953	4.0	18,938	4.2	24,968	5.8	33,524	7.7	35,078	6.6
Italy	11,634	3.7	15,885	4.2	20,169	4.5	20,008	4.7	20,803	4.8	27,251	5.1
France	12,963	4.1	13,868	3.7	14,599	3.2	10,032	2.8	19,637	4.5	26,668	5.0
Soviet Union	7,247	2.3	8,701	2.3	7,797	1.7	15,485	3.6	18,252	4.2	10,430	2.0
Sweden	7,505	2.4	9,166	2.4	11,066	2.4	9,972	2.3	7,175	1.6	9,768	1.8
Belgium-Luxembourg	5,601	1.8	7,238	1.9	7,858	1.7	7,913	1.9	6,990	1.6	7,195	1.4
Netherlands	2,936	0.9	3,437	0.9	3,673	0.8	3,757	0.9	3,543	0.8	4,661	0.9
Japan	1,987	0.6	1,502	0.4	2,014	0.4	1,331	0.3	1,380	0.3	4,511	0.8
Denmark	3,511	1.1	3,495	0.9	4,805	1.1	4,710	1.1	2,296	0.5	2,844	0.5
Total, all countries	318,053	100.0	378,308	100.0	454,036	100.0	427,728	100.0	435,460	100.0	531,053	100.0
Metal-forming machine tools												
Germany (Federal Republic)	42,205	34.9	45,670	33.8	56,489	30.2	60,157	32.3	58,790	32.4	62,775	28.3
United States	38,082	31.5	42,650	31.6	63,492	33.9	64,654	34.7	63,766	35.2	81,866	36.9
United Kingdom	12,379	10.3	14,216	10.5	24,630	13.2	20,425	11.0	16,336	9.0	25,423	11.4
Switzerland	5,403	4.5	5,089	3.8	9,167	4.9	6,696	3.6	8,047	4.4	9,386	4.2
Czechoslovakia	3,248	2.7	4,113	3.0	5,209	2.8	5,613	3.0	8,381	4.6	8,770	4.0
Italy	2,998	2.5	3,225	2.4	4,451	2.4	5,205	2.8	5,663	3.1	8,742	3.9
France	4,282	3.5	4,544	3.4	6,442	3.4	3,386	1.8	6,475	3.6	7,173	3.2
Soviet Union	1,645	1.3	1,191	0.9	1,785	0.9	2,605	1.4	1,948	1.1	3,366	1.5
Sweden	3,852	3.2	6,642	4.9	6,924	3.7	10,019	5.4	3,177	1.8	4,152	1.9
Belgium-Luxembourg	3,995	3.3	4,039	3.0	3,910	2.1	3,554	1.9	3,413	1.9	4,302	1.9
Netherlands	1,387	1.0	2,238	1.7	2,112	1.1	2,271	1.2	2,464	1.4	1,878	0.8
Japan	1,189	1.0	1,243	0.9	2,366	1.3	1,485	0.8	1,691	0.9	2,995	1.4
Denmark	156	0.1	159	0.1	191	0.1	750	0.1	1,078	0.6	1,320	0.6
Total, all countries	120,819	100.0	134,979	100.0	187,168	100.0	186,145	100.0	181,229	100.0	222,148	100.0

Source: United States Department of Commerce, Business and Defense Services Administration, *World Trade in Machine Tools*.

[a] Figures not available.

THE DEVELOPMENT AND PLANNING OF METALWORKING INDUSTRIES IN THE ECAFE COUNTRIES

Secretariat of the United Nations Economic Commission for Asia and the Far East

INTRODUCTION

The ECAFE countries are at different stages of development in the metalworking industries and the general economies. The degree of development of the metalworking industries is similar to the relative degree of industrialization in these countries. By world standards, the manufacture of metal products and engineering goods in the region may be insignificant. Viewed, however, from the standpoint of the over-all industrial growth in the ECAFE region, significant progress has been made in manufacturing metal products during the past decade. This progress has raised industrial output and also increased employment.

Only a few countries have achieved a relatively high degree of industrial development and these are also the major producers of metal and engineering goods. Japan may be compared to the highly advanced countries in Europe and the United States. India has made an impressive advance in the capital intensive metalworking industries. Australia has, in recent years, made remarkable progress in the diversification and expansion of heavy and light engineering goods. New Zealand is almost self-sufficient in the production of agricultural machinery (except tractors) and also has made considerable progress in the production of miscellaneous engineering goods. Export capacities for metal and engineering products have developed rapidly in these countries.

Countries such as Burma, China (Taiwan), Hong Kong, Indonesia, South Korea, Pakistan, the Philippines, Malaysia and, to a lesser degree, Thailand and Iran have made some progress in developing metalworking industries. They have increased the production of durable consumer goods such as metal manufactures, appliances, utensils, building and hardware and accessories. The manufacture of small engines, complete units of simple agricultural machinery and food-processing machinery meet part of the domestic demand. The assembly of transport equipment such as motor cars and bicycles has increased considerably in some countries.

The other countries, namely Afghanistan, Brunei, Cambodia, Ceylon, Laos, Nepal and the Republic of Viet-Nam, have included in their development plans schemes for more rapid industrialization; but higher priorities have been given to power development, mineral resource exploitation, and increased production in agriculture and its related activities.

In some of the countries, small metalworking industries are also being established and or are in the early stages of construction. Many of these countries have workshops for miscellaneous repair services of machinery used in construction, mining and in agriculture. The trend is to expand these workshops and diversify production for greater utilization of the existing facilities. Also under active consideration are new metalworking industries for manufacturing farm implements and tools, assembling tractors for farm mechanization, establishing small foundries and shops for manufacturing pumps for irrigation purposes and for manufacturing household utensils, building hardware and common appliances in small establishments.

POSITION OF THE METALWORKING INDUSTRIES[1]

The relative importance of the metalworking industries may be assessed by the percentage share of these industries in the total manufacturing output, by their contribution to employment and by added value in the process of manufacture. The percentage share, as of 1962, of the metalworking industries to the total manufacturing output in the countries of the region show wide variations, e.g. 16.4 per cent in Australia, 22.5 per cent in New Zealand, 7.1 per cent in China (Taiwan) and 14.4 per cent in India.

The percentage share in the total manufacturing employment shows similar variations, e.g. 24.9 per cent in Japan, 25.2 per cent in New Zealand, 12.4 per cent in China (Taiwan), 16.7 per cent in India and 24.4 per cent in Australia. In added value, the percentage share of the metalworking industries was: Philippines 8.8, Korea 8.1, New Zealand 22.5 and Australia 20.3.

Many of the countries in the ECAFE region have a low level of economic and industrial achievement, as there has been no large-scale application of scientific and technological advances to agriculture and industry. Now they are beginning to realize that their positions can be improved by modern techniques. An essential requisite for solving the basic economic problems of these countries is a planned change in the economy to bring about a high rate of growth which can be sustained in the years to come. This target, though difficult, is by no means unattainable. However, in implementing this plan it may not be necessary to follow the precise staging and techniques to which the highly advanced countries owe their success.

It is evident that a proper assessment of the existing social and economic conditions, the present industrial status and other inherent problems must be made in

[1] *Statistical Yearbooks 1963-64*, Australia, China (Taiwan), Japan and New Zealand.

order to achieve the best results. An exhaustive analysis of government policies and programmes and a host of techno-economic factors must be undertaken before deciding the kind of industry which will have growth opportunities in the coming decade.

The ECAFE region has more than half the population of the world in less than a sixth of the earth's land area[2] and also a tremendous rate of population increase. Consequently, the need for increasing the productivity of the people as well as improving the economy of the countries by industrialization is of utmost importance. The proper growth of metalworking industries is one of the key factors in achieving this end. This region is labour-abundant, but capital is scarce; hence, the development of labour-intensive metalworking industries is eminently desirable.

While the percentage shares of metalworking industries in the total manufacturing outputs of countries of the region have substantially increased during the past decade, they are still low compared to standards in other parts of the world. For example, the share ranges from 27 per cent to 30 per cent in Czechoslovakia and Belgium; and from about 35 to 40 per cent in the United States and the United Kingdom. The share in employment ranges from 22 to 25 per cent in the Netherlands and Poland; and from about 30 to 37 per cent in West Germany, the Soviet Union, Denmark and the United States. These high percentages reflect these countries' positions as major exporters of metal products.

Trends of production, demand and delivery of metal goods[3]

In the relatively more advanced countries such as Japan, the domestic production of metal goods in the mechanical and transport equipment groups is over 50 per cent of the total demand. In China (Taiwan), South Korea, Pakistan and the Philippines, a very high percentage of the demands for mechanical machinery is supplied by imports. The existing capacities of metalworking industries in the latter countries have been developed primarily to meet the domestic demands for durable consumer goods.

Progress has been achieved in the manufacture of household utensils and appliances such as metal containers, household furniture, office equipment and a host of other miscellaneous hardware and fittings. Manufacture of components and parts of oil and sugar mills, textile machinery (jute and cotton) and complete units of food-processing machinery has been developed in some of these countries. Manufacture of selected tractor parts (rollers and linkages) and assembly of tractors has been started in some countries. The manufacture of agricultural machinery and the assembly of automobiles have also reached moderate levels of production. Export markets have been developed for a few items of durable goods such as sewing machines, bicycles and pumps, utensils and appliances.

[2] ECAFE report of Asian Population Conference, December 1963.
[3] Country studies for Asian Conference on Industrialization, 1965.

In a few countries, the high increase in production of passenger cars, commercial vehicles and bicycles in the past few years has been one of the highlights of the metalworking industries. Japan has strengthened its position as one of the world's major exporters of passenger cars and commercial vehicles.

Australia recently began exporting passenger cars. In India, cars are being manufactured for the domestic demand and imports are banned. In the Philippines, Pakistan, Malaysia and Thailand, assembly units are turning out passenger cars in increasing quantities. The production of bicycles in India and China (Taiwan) is considerable and these countries can export part of their production. Manufacture of sophisticated and precision machinery is confined mainly to a few countries in the region, namely, Japan, China (mainland) and India and, to a growing extent, Australia and Pakistan. Complementary basic industries have been or are being developed in some countries.

Factors determining rate of growth

The rate of growth of metalworking industries in the ECAFE region from 1953–1964 was relatively higher than that of the developed areas of the world. This growth has been reflected in corresponding changes in the economic structure of some of these countries. It is well known that in many of these countries, the limitations of the domestic market represent an inhibiting factor in their industrial growth. The creation of large markets through such means as economic integration and reciprocal trade agreements, therefore, presents opportunities for encouraging the growth of industrial output. Past experience has also demonstrated the importance of international technical co-operation in industrial growth. While shortage of capital has been singled out as one of the most important factors in hindering industrialization, attention has been focused in recent years on such factors as lack of trained manpower. International technical assistance thus has played and will continue to play an important role in alleviating these basic shortages.

Degree of utilization of existing facilities

While the outputs in the branches of the metalworking industries producing durable goods have increased progressively, there are certain sectors in some of the countries where the capacity of machinery and equipment has not been fully utilized. The lack of continuity and inadequacy of the supply of essential raw materials such as pig iron, steel sheets, special steel products, alloys and nonferrous metals have limited the output. This is attributable among other causes to the foreign exchange shortage for purchasing these materials from abroad. Indigenous production has not kept pace with the increasing demand. There is evidently a need for establishing new basic facilities for the production of these essential raw materials to meet the expanding demand and to utilize fully the productive capacity of the existing metalworking industries.

Export promotion

Most of the metal goods produced in the region are meant primarily to meet domestic demand with the exception of Japan, India and Australia. The promotion of exports is, however, being encouraged to generate foreign exchange to supplement the inadequate foreign exchange earnings of their primary export products. As an example of the effect of export incentive, the export of metal products in India has increased from Rs. 96.3 million in 1962 to Rs. 128.5 million in 1963. Similarly, Hong Kong and China (Taiwan) have developed new export markets for some metal goods. The opening of new markets in the more advanced countries for some of the metal products produced in the developing countries will also help the growth of the metalworking industries.

Trends of investment

Continued expansion in output can only be achieved with considerable investment both in the establishment of new industries and the improvement of existing facilities. Most of the important metalworking industries of the region are of recent origin. The trends and characteristics of investment vary from country to country. In the case of Japan and India, the great portion of the investment has been channelled to capital intensive metalworking industries. In Pakistan, the Philippines and China (Taiwan), investments have been concentrated on light metalworking industries. However, the present and future development plans of these countries include investment in heavy metalworking industries.

Employment

The employment trends in the metalworking industries in most countries of the region, particularly in the machinery and transport groups, indicated a rapid growth in the more advanced countries (Japan and Australia) and a steady growth in the other countries from 1956 to 1963 (1958 = 100).

The index of employment in Japan in machinery industry rose from 81.5 in 1956 to 187.5 for 1963. In transport equipment the indices rose from 86.4 to 156 and in metal products the increase was 72.6 to 206 for the same period. In Pakistan, the machinery branch index rose from 132.3 to 171.1. In Australia, the metal industries (machinery, etc.) increased from 96.6 in 1956 to 121 in 1963. In China (Taiwan), the machinery group increased from 94 to 105 and the transport increased from 99 to 169. In Indonesia, the index for machinery increased from 85.5 to 105.8 and for transport from 101.4 to 107. In the Philippines, the machinery index rose from 68 in 1956 to 70.3 in 1963.

Prices

Available statistics do not permit a breakdown in absolute figures or percentages of the principal cost price factors and their trends in the metalworking industries as a whole or their main branches. Undoubtedly, raw materials and semi-finished products and salaries and wages are the most important factors. Transportation and distribution costs, investment and interest rates are also important. Wages have increased in the metalworking sector in the less advanced countries by about 40 per cent since 1955. In Japan, there was an increase in wages of about 50 per cent from 1955 to 1962. The cost of raw material imports, particularly the cost of steel products, has had a great influence in the price structure of the finished metal goods in some ECAFE countries. Except in Japan, the costs of producing metal products in ECAFE countries are relatively higher than in the major producing countries in the world, particularly those which use mass-production methods.

There are, however, consumer goods and machinery items such as sewing machines, bicycles, simple agricultural implements and simple castings and metal furniture which can be produced competitively in the ECAFE countries. The relatively cheaper wages in ECAFE areas, coupled with the application of modern technology and the use of efficient machinery, has made it possible to manufacture some of these goods competitively. Improved methods of organization and know-how will further reduce production costs.

Trade in metal products

Statistical data of world trade in metal goods show an increasing magnitude of trade among the highly developed countries and a continued increase in imports by the less developed areas. There has been, if at all, a very insignificant complementary export trade of metal products to the highly developed areas. The small value of exports from the ECAFE countries reflected the relatively unindustrialized state of their economies.

Concluding observations

The pattern of development of metalworking industries within each of the more advanced countries of the region is generally similar. Minimal facilities for manufacture of agricultural implements and hardware items gradually gave way to the establishment of more sophisticated workshops for the maintenance of imported machinery and equipment. Then followed a long period of development of skills in the use of imported tools and semiprocessed materials until a stage was reached when components and complete units could be manufactured for agriculture, food processing, transport and construction.

The next step was to set up facilities for processing imported steel ingots into bars, sections, sheets and wire, and ultimately to produce steel and other metals from indigenous raw materials. A tremendous impetus was given to this development by the growing use of motor vehicles. The maintenance of a wide variety of imported vehicles presented special problems and required specialized equipment and skills. Local production of replacement parts paved the way to the supply of original equipment components to vehicle assembly plants and hence to the complete local manufacture of cars, trucks and tractors. This whole process of development of metalworking industries in the more advanced countries of the region took place during a period of up to seventy years.

The urgent need to provide immediate employment for a rapidly expanding population which has become aware of better standards of living does not permit any prolongation of the industrialization of the less developed countries.

Limitations in both natural and physical resources may not necessarily be a great handicap for developing metalworking industries. Hong Kong is a good example of a country which has developed an industrial economy with a minimum of natural resources. Most of the ECAFE countries are labour-abundant but short of capital resources and it is therefore of interest to note that these countries could develop satisfactorily by the establishment of labour-intensive and economically viable metalworking industries. These small-scale industries are naturally preferable because their needs for capital and markets are small. Successful development along these lines will be conducive to the establishment of larger scale enterprises. However, it is stressed that such industries should be properly co-ordinated and fitted into the over-all industrialization of the country and, moreover, of the region.

The establishment of common facility centres, comprising tool room, heat treatment, electroplating, inspection and testing of materials and components in relatively dense industrialized areas of developing countries, would go a long way in strengthening the industrial base of the country and also improving the quality of the products. Where this process is uneconomical, such as in rural areas, the use of mobile workshops is recommended. These would be useful also for training and demonstrations.

Several countries have already made arrangements for the exchange of study and observation teams in metalworking industries. The scope of such exchanges could be extended usefully. It would be particularly valuable if arrangements could be made for trainees from the less developed countries to receive in-plant training in some of the newly established metalworking factories in other countries. This would provide them with varied experience in some of the practical problems encountered in the establishment and operation of new factories.

There is room for better co-ordination between the educational system and the specific needs of industries in the region. In addition, it is suggested that engineer tradesmen and managerial staff require periodic refresher courses or advanced training to keep pace with industrial progress.

The problems facing the developing countries of the region are lack of adequate domestic capital, shortage of foreign exchange, insufficient technical know-how, raw materials, trained technical and managerial personnel and industrial research and development facilities.

Obviously these problems could be solved by international co-operation. Forms of such co-operation include financial equity participation, licensing agreements, technical assistance, consultant services and a re-examination of international trade and investment policies. An example of this would be the preferential duty treatment of goods exported from developing countries.

In addition to the above forms of assistance, advantage may be taken of offers from countries outside and within the region, in the form of consortiums, aid programmes and loans from governments and other financial institutions. Another feature of international co-operation in promoting industrialization in the region is in the establishment of large enterprises which will result in low unit-production costs.

The economies of scale should not be lost sight of when setting up plants, especially those which are capital-intensive and which require large markets. Such plants may require assistance from other countries inside and outside of the region. The recently established Asian Development Bank may be one of the main sources of financing for well-conceived projects of this type.

A STUDY OF THE INDIAN MACHINE-TOOL INDUSTRY

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Introduction

The Indian machine-tool industry, which in status and sophistication is second only to Japan among the ECAFE countries, has a big gap to bridge towards self-reliance despite its progress during the past decade.

In 1965, the import of machine tools accounted for $US 88.64 million in spite of the foreign exchange situation; domestic production was $55.59 million.

Almost all the teething troubles have been solved but the problems of attaining maturity are still many. Some account of the industry, particularly the aspects which have contributed to its rapid success in the initial period and some of the main problems which at present hinder its further development, will perhaps prove useful to other developing countries in the ECAFE region.

Past performance

General survey

It is not proposed to deal here with the whole history of the Indian machine-tool industry. Nevertheless, a brief description of its performance for the last decade may illumine certain salient features contributing to the rapid progress of the industry. Having built the infrastructure solidly, the industry is now well poised to take a big leap towards specialization, diversification and sophistication.

During the First Five-Year Plan (1951-1955), the Indian machine-tool industry verily was in its infancy, with hardly three major units producing machines of accepted standards of accuracy. The manufacture was then primarily of low-priced machine tools meant for repair workshops, training institutes, etc.

Essentially, the requirements of the engineering industry were met through imports. Out of the total machine-tool demand of about $42 million during 1951-1955, imports accounted for almost $36 million as against domestic production of hardly $630,000. However, the position of the industry changed for the better during the Second and Third Five-Year Plans as can be seen in table 1.

The industry, as is clear from the statistics, has shown its capacity for an accelerated growth. From a production of hardly $2.27 million in 1956, the output shot up to $55.59 million during 1965, multiplying by almost twenty-five in ten years; the percentage of domestic production to the total requirement rose from 11.44 per cent in 1956 to 38.54 per cent during 1965. The capital investment in the industry, which stood at hardly $2 million in 1956, increased to $77 million in 1965.

Investment in industries

Investment in the industrial sector, which during the First Five-Year Plan was $650 million, rose to $2,900 million and $5,000 million during the Second and Third Five-Year Plans respectively. A detailed study of the capital base of the organized industry and commerce in India indicates that if the targets are realized by the end of the Fourth Plan (1970-71), the public sector (Government-owned) and the private sector will contribute investments in the order of $12,000 million and $12,300 respectively in industry and commerce. The total invest-

Table 1

Indigenous production and imports of machine tools—1956 to 1965

Year	Total requirement	Imported	Domestic production	Per cent imported to total requirement	Per cent domestic to total requirement
	(in millions of US dollars)				
Second Plan					
1956	19.85	17.85	2.27	88.56	11.44
1957	35.68	30.75	4.93	86.18	13.82
1958	37.44	30.28	7.16	80.88	19.12
1959	43.03	34.29	8.74	79.69	20.31
1960	56.27	43.96	12.31	78.12	21.88
Third Plan					
1961	66.25	50.86	15.39	76.77	23.23
1962	76.53	54.69	21.84	71.46	28.54
1963	98.44	66.16	32.28	67.21	32.79
1964	147.53	97.77	49.77	66.26	33.74
1965	144.23	88.64	55.59	61.46	38.54

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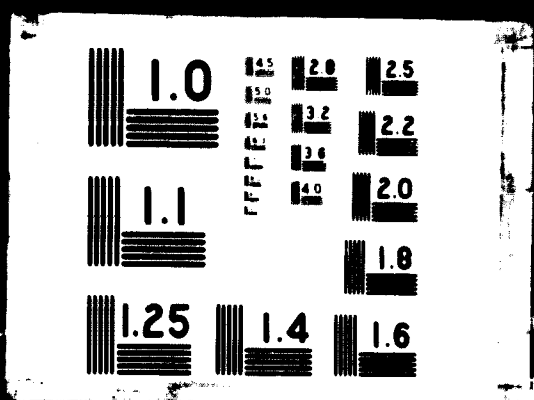

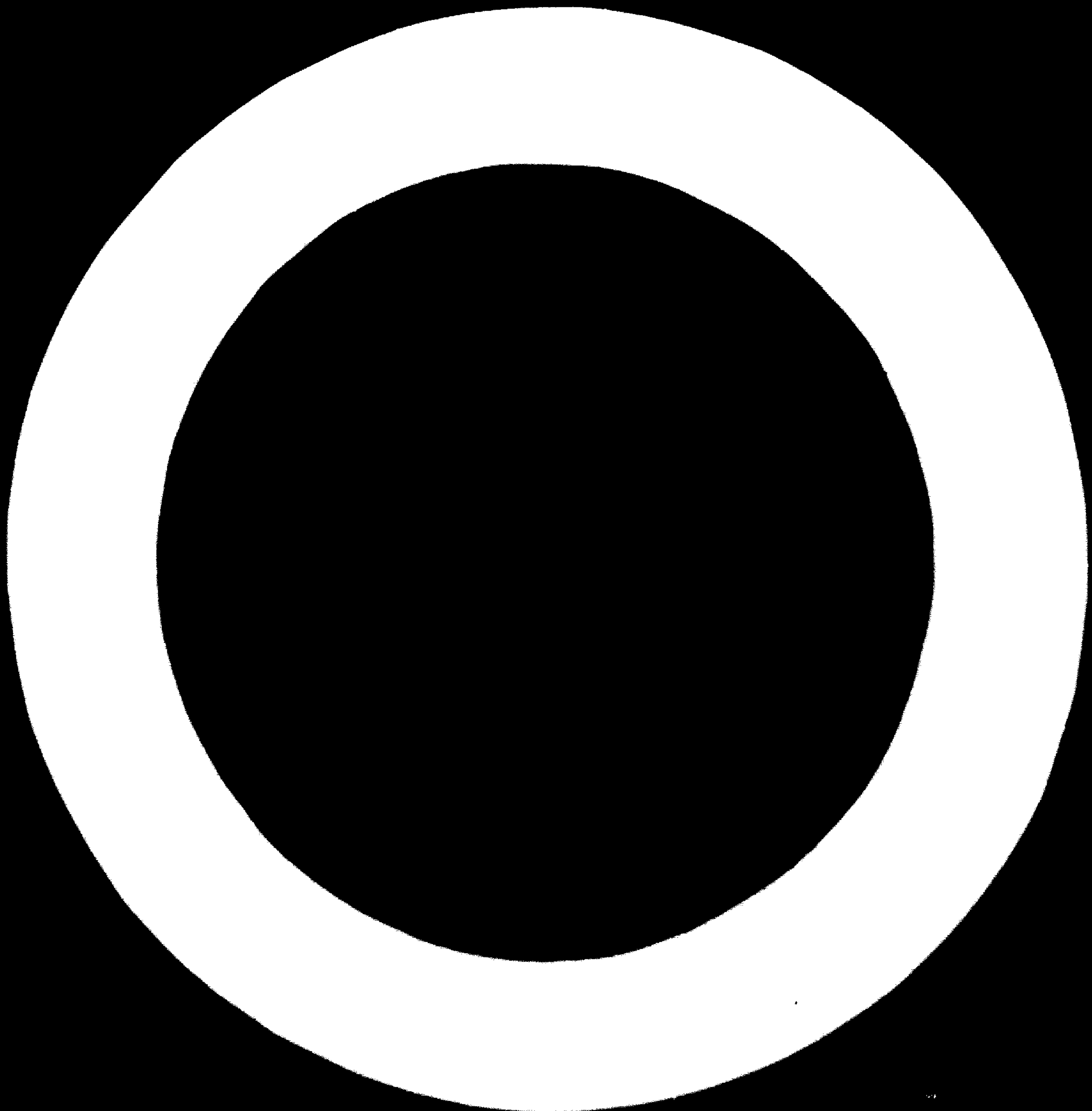

MAIN TRENDS IN DEVELOPMENT AND ORGANIZATION OF DESIGNING AND RESEARCH WORK IN MACHINE-BUILDING INDUSTRIES OF DEVELOPING COUNTRIES

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INTRODUCTION

Science is assuming an ever-increasing importance and governs, to a large degree, the progress and standards of organization of modern production. The rates of industrial development would be considerably lower, while greater effort and more money would be spent if it were not for the scientifically based organization achieved through research, which is carried out in all modern fields of production and marketing. Of special importance is the proper organization of research in the metalworking industries, where the cost of the means of production is very high. It is necessary to make large expenditures on up-to-date equipment which will be efficient only if the entire production process is duly organized, the tools and fixtures are of good quality, the speeds and feeds are chosen correctly and the servicing workmen are highly skilled. Each of these problems involves a series of other problems whose solution requires highly skilled operators, technicians, engineers etc. The urgent problem currently facing the developing countries is the lack of properly trained craftsmen and engineers.

It is only natural that the organization of designing and research machine-building establishments should be based on the standard achieved by a particular industry in one or another country. Such an organization is planned to provide the developing country with what it needs in this field with the minimum expenditure and with research and designing workers being used in the best way possible. With the development of a machine-building industry, the trained personnel should be qualified in more specialized trades, while the research and designing machine-building centre should gradually be divided into a number of specialized independent research establishments set up for servicing those machine-building branches which have been developed in a particular country.

The most important integrants of this process are: training nationals of the country as research and designing personnel; instructing them in more and more special branches of machine building; and raising the grades of such personnel. This calls for close links between the research establishments and technical colleges of the country, especially at the beginning stages of development of the industries.

At the first stage, much importance should be attached to providing help to industrial enterprises in mastering foreign-made equipment, solving certain technological problems, designing and tools and accessories and attachments, adjusting the machines and their controls etc.

With the industry gaining strength in the country and with the development of machine-building by nationals, new problems will receive priority, for example: working out designs by nationals of the country for certain machines; elaborating technological processes for their manufacturing; providing research work aimed at investigating the performance of the machines; perfecting the technological processes performed by them; seeking ways to raise the efficiency of the machines constructed.

The structure of the research and designing services proceeding from the machine-building prospects may be described as follows:

(a) *Stage I.* A training technical institute whose laboratories and skilled personnel render assistance and give advice to the industrial people on some questions;

(b) *Stage II.* A United research machine-building centre which is independent of the training institute (college). This centre designs machines for the entire machine-building branch, investigates the processes and studies some of the mechanisms at the request of enterprises, renders technical assistance in mastering complicated foreign-made equipment and foreign technological processes and supplies the enterprises with technical and economic information on the latest achievements in the fields concerned. The personnel of the research institute take part in the work done by the engineering colleges;

(c) *Stage III.* A united metalworking centre and individual centres in machine-building branches which produce equipment for processing and mining industries. This centre is specialized in certain types of machines, while its laboratories are engaged both in technology and in the creation and investigation of special types of equipment. They also render assistance to industrial enterprises;

(d) *Stage IV.* Research centres servicing individual machine-building branches and designing and research services established at enterprises. Such centres concentrate on investigating promising technological processes, control systems, machine units and components. The centres also supply information to those who are interested. The designing services of the enterprises are given practical tasks in the creation of new machinery and the supervision thereof.

Each particular country will proceed from its own level of development when selecting its research and designing services. An analysis of experience gained by the countries shows that the above-described methods of organizing research and designing jobs have a practical application under the following levels of development of industries.

The figures shown in table 1 are, to a large extent, arbitrary and can provide only an approximate idea. Depending upon the conditions found in each particular country, certain departures from the data in the table may be expected. When reading the table, one should bear in mind that the lower quantities prove to be more realistic in the countries with State planning practices, while the higher ones are more characteristic of the countries with more highly developed private initiative. The reason for this is that, in the first case, all the country's specialists gather in one centre and service the enterprises of the given industry. In the other case, many specialists, from 50 to 75 per cent, are scattered among individual enterprises; the research centre proves necessary only for a well-developed industry and is used for tackling the most difficult problems which are beyond the capacity of an individual company and call for the concentration of efforts in related sciences.

It may prove useful if several countries of a common economic region organize united centres for the benefit of all of them, until their industries reach a high level of development.

I. Laboratories of training institutes

Along with training qualified craftsmen, the polytechnical colleges can be considered primary units capable of rendering technical assistance to the industries. Such assistance may take the following forms:

(*a*) The enterprises may consult the laboratory on calculations; designing and maintenance of the machines, their controls and drives; manufacturing processes; designing of jigs and fixtures; labour organization etc.

(*b*) The laboratories may fulfil some orders of the enterprises related to workability of materials, machining rates, manufacturing processes and tools, jigs and fixtures to be used, machine adjustment, drives and controls etc.

(*c*) The laboratory may make up reference tables or other reference materials on various questions;

(*d*) Suggestions on standards and standard specifications may be prepared;

(*e*) The laboratory may work out, make and adjust instruments;

(*f*) Workmen at the enterprise may be instructed in maintenance rules and the handling of complicated machines and instruments.

Table 2 shows a representative structure of an institute with such laboratories. The names of the departments of the processing and mining industries are arbitrary. Actually, such chairs will vary from country to country.

Table 1

Level of country's development	*Organization of research (type of establishments)* Training institute (college) with laboratory	Machine-building research centre	Metalworking research centre	Specialized metalworking centres
Number of machine tools (thousands)	Less than 10	10–50	100–200	More than 500
Estimated national annual production of machine tools (millions of dollars)	Less than 5	5–10	15–50	More than 100
Estimated annual production of machine tools *per capita* (dollars)	Less than 0.1	0.1–0.5	1.5–2	More than 3.0

Table 2

Representative structure of a polytechnic institute

Mining industries department	*Processing industries department*	*Metalworking technology department*	*Machine components department*	*Drives and controls department*	*Technical measurement department*
Oil, gas and oil equipment laboratory	Textile technology and equipment laboratory	Metal-cutting laboratory	Machine components and mechanical drives laboratory	Electrical engineering laboratory	Metrology laboratory
Machine work and equipment laboratory	Food technology and equipment laboratory	Stamping laboratory	Hoisting and mechanical handling equipment laboratory	Hydraulics laboratory	Mechanical, electrical and electronic measurement laboratory
		Heat-treatment laboratory			

pending upon the particular industries for which ecialists are being trained.

The metalworking processes department and its boratories would be responsible for solving practical sks faced by the developing country.

It would be advantageous if the machine-components epartment had either two laboratories, as shown in ble 2, or one laboratory if experts were lacking at the oment and those available could not devote themselves o more specialized subjects. A laboratory for mechanical-handling equipment could serve as a primary unit which would subsequently train specialists in construction machines, loading machines for seaports and roads, road construction machines, mechanical handling etc.

The name "Drives and controls department" is rather arbitrary. This department would attract electrical engineers, engineers on electrical motors and controls, and specialists on hydraulic pumps and hydraulic drives for machines. Since such drives are to be found in a great variety of machines and all of them have very much in common, it would be expedient if, at first, the laboratories were closely connected so that practical tasks could be solved comprehensively and reasonably economically.

One cannot very well imagine the production of modern machines without first solving a number of measurement problems and those of inspection of individual components and assemblies. It follows, therefore, that due attention should be paid to developing the means of linear and angular measurements; this is usually done by the metrology service. Of no less importance is the measurement of other values: force, pressure, liquid consumption, amperage and voltage, power, speeds, acceleration etc. The latter tasks would be the domain of the other laboratory, which should provide uniform measurement practice throughout the country and should supervise the condition of measuring means used at the enterprises. The laboratory would also render necessary technical assistance should an enterprise encounter a complicated type of measurement calling for some special devices (measuring noise, vibration etc.) or it were in need of a scientific approach to obtain correct results (measuring wear and tear, thermal strains etc.).

Brief as the foregoing list is, it shows the wide scope of the problems which could be handled by the laboratories for the benefit of enterprises.

Each laboratory may employ from five to fifty people.

II. United research machine-building institute

A united research institute can deal with a wide variety of problems. In addition to the jobs done by the college laboratories, such an establishment can carry out the nvestigations described below.

A profound study can be made of the technology of the processing and mining industries developed in the given country. The objectives of such an investigation would be o adapt the experience gained by the rest of the world o local conditions, to search for new economic and fficient processes, to utilize by-products, to improve echnological equipment and study the best conditions or its maintenance and repair, and to develop new articles nd processes.

The institute may undertake the development of metal-working processes as a part of comprehensive problems while concentrating particularly on heat treatment as related to properties of materials, blanking operations, forging and casting. More attention will be given to machining the parts by cutting, especially to finishing processes, large-batch manufacturing on production lines, assembling and adjusting machines etc.

The institute may become the first establishment in the country to work out its own designs of machines for the most important industries, farming and transport machinery. With this aim in view, its organization should include a designing office. This will, in turn, be subdivided into offices according to the types of machines whose production is planned in the country (e.g., textile machines, food-processing machines etc.). Such an organization will allow the designers to use their abilities to the best advantage. It will also facilitate the training of young specialists by permitting them to share in the creation of efficient units and mechanisms of machines, and in the working out of designs with good manufacturing qualities; by teaching them the rules for assembling and adjusting the machines, and the methods for achieving planned capacities; and by their observation of the instruction of production people in correct working methods and the reasonable management of production. Gathering the designers, at the first stage, within one centre will allow correct provision of the enterprises with standards and standard specifications for parts, components and basic parameters of machines, which are indispensable prerequisites for organizing centralized manufacturing of the parts common to most machines. This will conserve the means for both making new machines and maintaining the existing ones through an essential decrease in the prime cost of machine components by reducing, in the first place, the number of fixtures required and, secondly, through the better methods which are possible under the conditions of centralized manufacturing.

Technical tasks concerning the further improvement of components and units should be entrusted to special sections under the guidance of one department. One of the laboratories should be concerned with mechanical parts or elements for drives, e.g., fixtures, fittings, geared and belt drives bearings, reduction units, speed and feed change gear-boxes etc. It will render skilled assistance in this field to enterprises and to sections of the institute, while designing, calculating, testing and adjusting all these devices. The other laboratory should be engaged in similar work, but its field will be electrical motors, which will include not only motors, but also controls, electrical apparatuses, rules for mounting and maintaining electrical equipment and energy systems. This body will be a basis for further development of most branches of the electrical motor manufacturing industry and of power engineering, and will later provide a basis for creating an independent organization having more specialized tasks in this particular field.

The field of the third laboratory will be hydraulics, hydraulic engineering and hydraulic drives, which currently comprise a well-developed branch and are applicable in a wide range of industrial and farming machinery. Development of machine building is largely dependent upon hydraulic drives, whose moderate-sized and comparatively light-weight power units provide considerable working efforts. Because of their flexibility and high reliability, hydraulic controls are preferred to electrical ones under difficult working conditions.

Modern methods for the design of machines are based on a profound theoretical knowledge and employment of computers. Since these problems are specific, while the regularities of computation practice are common to many machines, it will be quite reasonable to gather computing specialists and means at one centre with the capacity to service all the sections of the institute and thus to fulfill the orders of the enterprises. Such a centre should employ specialists in metal fatigue and strength, dynamic-load calculations, vibrations, stability and automatic adjustments, calculations of optimal processes, mathematical statistics and probability theory subjects which find application in many modern industries.

The measurement service should be duly organized from the very outset. The measuring laboratory will be responsible for introducing uniform basic physical measuring units throughout the country and, especially for ensuring that the enterprises use uniform measures and that their measuring equipment operates properly. To this end, the laboratory should be equipped with accurate measuring means which have been declared fit for work after being compared with the appropriate standards.

Other important tasks which will be faced by the laboratory will include working out the correct methods for taking measurements, giving certificates for various items in industries and helping the enterprises to take measurements calling for special instruments and highly skilled operators.

Table 3 shows an approximate organizational structure of the centre, giving a general idea of how such a centre can be organized. Local conditions will, no doubt, call for some alterations in the structure. At first, when the centre employs a staff of 100 persons or fewer, the laboratory can function with four departments. With the extension of the centre, its structure will be subject to further differentiation.

The activity of the research centre will be fruitful if it is given a pilot enterprise which can build the products according to the institute's blue prints and make necessary stands and instruments. In this way, the centre will be able to introduce all possible improvements into the design of a new machine and the models intended for the industries will be thoroughly tested before being suggested for operation at enterprises. This will contribute to smooth co-operation between the research centre and the enterprises. The staff of the pilot enterprise should correspond to that of the research centre, and the enterprise should be equipped with facilities allowing production of the main machines while reasonably utilizing the help of the industrial enterprises.

With the growth of the country's industry, the centre will gradually extend. At some stage, when the staff of the centre is about 1,000, it should be divided into a number of specialized research organizations, while independent centres will be established for servicing the producing and mining industries. One of the first independent centres to be isolated from the others will be the metalworking research institute.

III. Metalworking Research Institute

Table 4 shows an approximate structure of such a centre. At this centre, the specialization will go further and investigation into certain types of metalworking processes will be undertaken.

The technological department will employ specialists in metal cutting, who will study cutting rates and workability as related to various metals and the elaborate manufacturing processes to be applied in the production of

Table 3

Representative structure of a united machine-building institute

Technological department of industries	*Metal-working technology department*	*Designing office*	*Units, drives and controls department*
Textile manufacturing process laboratory	Machine-cutting process laboratory	Textile machines: designing office	General machine-building units and components laboratory
Food-manufacturing process laboratory	Forging and casting process laboratory	Food machines: designing office	Electrical equipment and instruments laboratory
Electric-motor manufacturing process laboratory	Metals, heat-treatment and welding laboratory	Hoisting and road-construction machines: designing office	Hydraulics and hydraulic-drives laboratory Engineering calculations and machine-testing laboratory
Hoist and road-construction manufacturing laboratory	Plastics, oils, paints and electroplatings laboratory	Metal-cutting machines, forging and casting equipment laboratory	Metrology and measuring means laboratory
		Standards and scientific information office	

Table 4

REPRESENTATIVE STRUCTURE OF A METALWORKING RESEARCH INSTITUTE

Metalworking technology department	*Designing office*	*Units, drives and controls department*	*General metalworking department*
Metal-cutting laboratory	Metal-cutting machines: designing office	Standardized units laboratory (couplings, bearings, reductors, guides)	Laboratory for business conditions and engineering and economic studies
Forging laboratory	Forging presses: designing office	Electrical motors and controls laboratory	Standards, patents and information office
Metals, heat-treatment and welding laboratory	Tools and dies: designing office	Hydraulic drive, apparatus, lubrication and filters laboratory	Machine calculation and testing laboratory
Casting-technology laboratory	Casting, heat-treatment and welding equipment: designing office	Jigs, fixtures, accessories and attachments laboratory	Metrology and measuring means laboratory
			Plastics, paints, electroplating and chemical laboratory

machine parts—casings, bodies, gear-wheels, bushings, sleeves, levers, brackets etc.—as well as of special parts ordered by enterprises. This body will also have specialists in the forging and casting processes. The laboratory should undertake further development of metals and heat treatment, as the scope of its investigations grows.

At that stage, the designing office will have designers who are concentrating on metal-cutting machines, while others will specialize in forging equipment. A special group should be set up to deal with cutting tools and dies: this group will not only design and improve the all-purpose tools, but will also handle the special-purpose tools ordered by the factories. Still another group will deal with heat-treatment and casting equipment.

The department of units, drives and controls will, for the most part, retain its structure, but it also will become more specialized. Thus, the electrical-engineering laboratory will no longer deal with power-plants: instead, it will concentrate on developing motors for metal-cutting machines and their controls. This will encourage the automation of many processes and the independent tackling of more complicated problems. The laboratory for hydraulic drives will devote itself solely to developing and improving the hydraulic drives used in metal-cutting machines. The drives will be constantly improved, the operation of the systems will be made more stable and more attention will be paid to lubrication and oil-cleaning, and to other questions.

It will then be necessary to organize a laboratory for jigs, fixtures and accessories, which will work out the designs for the centralized manufacturing of all-purpose jigs and fixtures, and which will fulfil orders of certain enterprises for special jigs and fixtures and similar articles.

The department of general metalworking problems will be occupied with solving the problems common to the entire metalworking branch. This department will collect information on machine tool building practices throughout the world, and on specifications of machines, price lists, costs and performance, as well as other economic and technical data required for the proper orientation of those who develop the equipment for the metalworking industry in a particular country while basing it on economic and technical considerations.

The standards laboratory will study the experience gained in industrialized countries, analyse the features pertaining to the country concerned and use the data obtained from these studies to prepare the standards and permissible norms valid for the particular country. This laboratory also will supply the industrial enterprises with generalized and selected information materials on the most important achievements of each particular enterprise.

The laboratory for calculating and testing should render assistance to the enterprises in making the most complicated calculations requiring special knowledge in the theory of elasticity and strength of materials, vibration theory, stability theory and automatic adjustment, or in the event that the calculations require the use of computers. The same laboratory should help the enterprises to test and to examine thoroughly new machines, its role being mainly in working out the necessary methods and in supplying the enterprises with the instruments needed for the purpose.

The measurement laboratory will fulfil both the assignments of the institute and the orders of the factories, helping them to solve their measurement problems.

The quality of the metalworking equipment is largely dependent upon the proper selection of varnishes, paints and grades of electroplating, and on the methods used for coating the machine surfaces therewith. This is especially true for tropical countries. The same requirements apply to the selection of plastics, protection slushing and films to prevent the parts from corrosion and to ensure their good appearance. All these problems are a source of work for a special laboratory.

Thus, the structure of the research centre reflects the main problems to be solved. The staff of an institute can vary from 150 to 600. It is very important that the pilot enterprise should be attached to such an institute, the staff of the latter being approximately equal to that of the institute. The pilot enterprise will have to construct the machines designed at the institute.

IV. Research institute of metal-cutting machines

With the further development of industry, and especially of the metalworking branch, in a particular country, with a rather developed machine tool industry having about ten factories, it may prove reasonable, especially with an aim of employing the best designers available, to establish a special institute of metal-cutting machines.

Table 5 shows a representative structure of such a metal-cutting institute. One alternative way is to set up a few other research centres; thus, in addition to the institute of metal-cutting machines, a centre of forging and metal-cutting machines can be established, whose activities will cover more than one production sphere.

The main feature of the structure shown in table 5 is deeper specialization of engineers, technicians and researchers.

At this stage, a laboratory engaged in the entire complex of technological problems involved in the production of machine tools, along with laboratories of metals and heat-treatment, and of measurement will deal with the problems peculiar to machine tools. Thus, more importance will be attached to the problems intimately associated with machine tools, i.e. to stabilizing the sizes and shapes of parts and to raising their wear resistance, while less attention will be given to such problems as strength of materials.

The designing office will comprise a few laboratories specializing in certain groups of metal-cutting equipment. It is essential that one compartment should unite the specialists engaged in improving some types of machining jobs (turning on a lathe, boring, milling, etc.) and the specialists designing the equipment intended for performing such operations. There is no doubt that there must be close everyday links based on creative activities of the specialists of the two groups if the institute is to aim at achieving appreciable advances in various types of machining.

Jigs, fixtures and tools provide sufficient reason for setting up a separate laboratory since similar jigs and fixtures and tools can be applicable to various types of machines and are based on some common subjects, such as the material from which the tools are made, heat treatment, the geometry of the tools' lips as a factor of the material to be worked, tool grinding etc.

The laboratory of machine units and components will be concerned with its own problems, as in the previous case.

The staff of the department of general machine tools building problems will concentrate on approximately the same questions studied in the similar department of the metalworking centre, but the problems referring to metal-cutting machines will be given priority.

In this case, a pilot plant will also be necessary, so that the machine tools designed at the institute may be constructed under the direct supervision of the institute.

The staff of the institute should be at least 200 people.

V. Relations between research institute and industrial enterprises

Organizing research centres is the first step to be taken on the path of development of engineering services in industry. With the development of production and the quantitative growth of engineers and technicians, care should be taken that not only are research centres organized but also that the enterprises' services are established and that this comprise designing and technological offices directly at the plants. These services should gradually take over the management and provision of routine production. Such services will, of

Table 5

Representative structure of a research institute of metal-cutting machines

Technology department	*Designing office*	*Units, drives and controls department*	*General machine tool building department*
Machine tool building technology laboratory	Lathe machines and technology laboratory	Laboratory of standardized units (spindle bearings, guides, couplings, reductors)	Laboratory for investigation of business conditions and engineering and economic data
Machine tool metals and heat-treatment laboratory	Boring machines and technology laboratory	Laboratory of electrical motors and controls for machine tools	Machine calculation and testing laboratory
Metrology and measuring means laboratory	Milling and planing technology and machines laboratory	Hydraulic drives and lubrication laboratory	Standards, patents and technical information office
	Abrasion technology and machines laboratory	Cutting tools, jigs and fixtures, accessories and attachments laboratory	
	Gear-cutting technology and machines laboratory		

›urse, receive help from the research centres when ·ealing with the construction of new promising machines, ›lving most complicated designing and technological ›roblems, investigating in machines, adjusting intricate ›ontrols etc.

It will be found that various activities of the research ›entre will prove helpful for enterprises. To what degree ›he enterprises will be interested in the institute's activities ›nd in what way they will pay for the jobs done by it will depend upon each particular type of activity. The latter ›an be classified as follows:

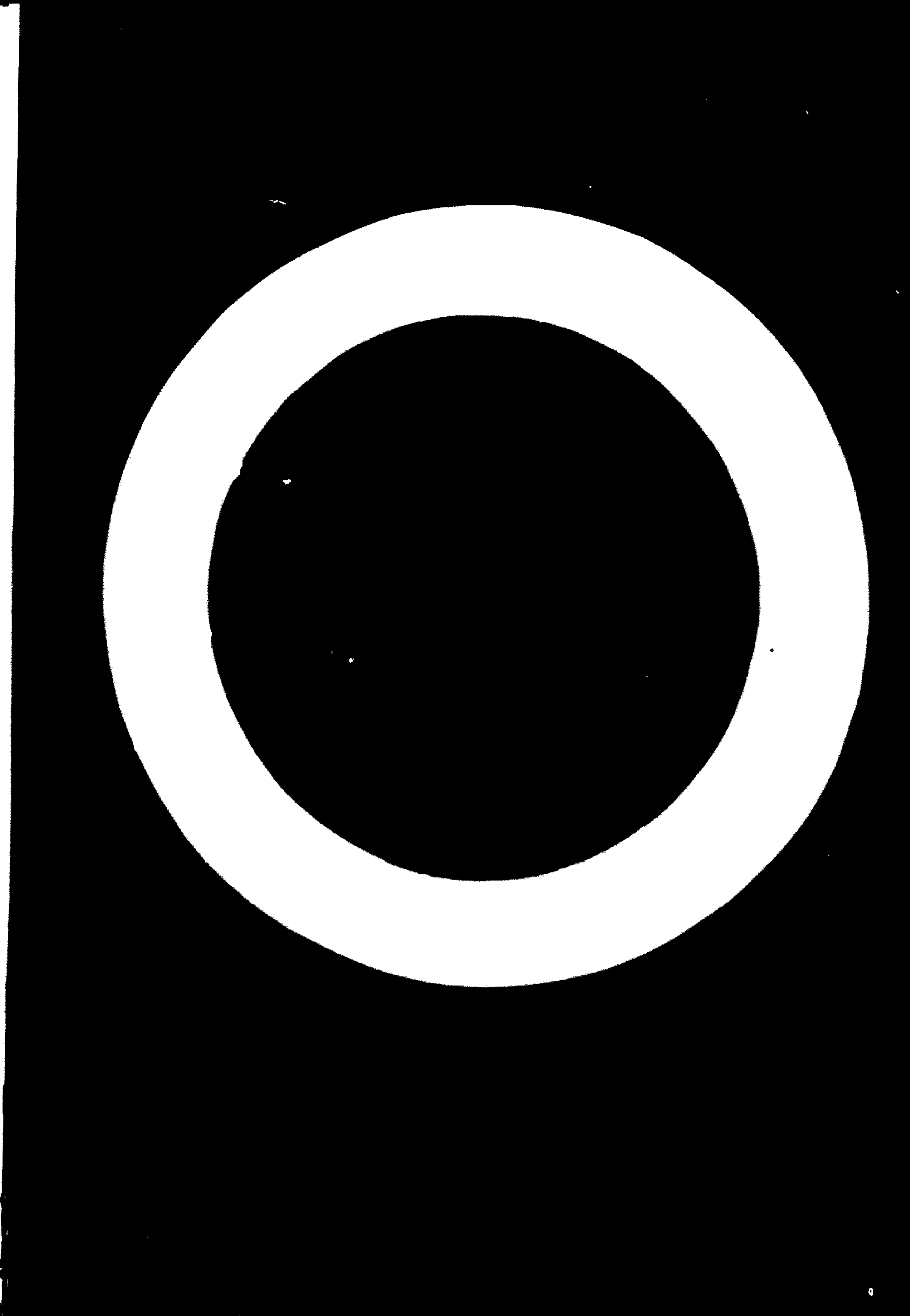
(*a*) General information on business conditions of the world machine-building industry, achievements in machine building, standards and norms assumed for the basic parameters and general calculation methods; working out of general-purpose units and components, working out of cutting rates etc. All these problems are of interest to the machine-building branch as a whole and, as such, must be financed either by the Government or by certain State establishments supervising the given branch, or else by collected fees if the enterprises are affiliated to some association and the research centre is a part of it;

(*b*) Investigation into development of a certain group of machine tools which are produced by a few enterprises of the country, designing of units for this group, new technological processes, new tools or jigs and fixtures etc. These problems concern only certain enterprises and, as such, must be financed by their joint efforts;

(*c*) Finally, some jobs may be confined to the products and machining methods found at one enterprise only. These jobs should be financed by the enterprise concerned.

In this connexion, an important question may be posed: is the information collected necessary only for the one who has ordered it or is it of interest to other enterprises which did not finance the collection of the information in question? In the latter case, the information may, in the author's opinion, be supplied to non-paying enterprises only if consent is granted by the payers.

The author of this paper does not claim to have given exhaustive and definite answers for such a complicated problem as economic and efficient organization of engineering services in industry. However, the organizational structures, approximate duties of personnel and lists of tasks which can be found in the present paper are made on the basis of experience gained by some countries through the successful application of the principles discussed above. Proceeding from this, one may maintain that the suggested structure of the research centres can ensure proper and reasonable methods of solving the problems discussed. The methods suggested in this paper are flexible enough to be adapted to the specific features of industrial development pertaining to any developing country.



ORGANIZATION OF FACILITIES FOR REPAIR AND MAINTENANCE OF INDUSTRIAL MACHINERY AND EQUIPMENT

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INTRODUCTION

Technical progress in machine building and metalworking can be said to be characterized by a considerable increase in the speeds and temperatures of working processes and an increase in variable loads and complexity of design, in order to ensure added accuracy of manufacture and faultless operation of machines.

The last ten years have brought an increase of from two to two-and-a-half times in the accuracy of mechanical treatment. Turning and grinding of medium-size parts to 10 and 1 microns, respectively, are common, and, in some cases, grinding accuracy of up to a fraction of a micron has also been reached.

Since the accuracy of manufacture of parts depends, to a great extent, upon the finish of the operating surfaces, increased requirements have been put upon the surface finish of the manufacturing machine. At the current time, an accuracy of up to 2-3 microinches should be ensured in many cases.

Any further development necessarily calls for a further increase of accuracy of mechanical treatment and finishing of parts' surfaces. At the current rate of development, it is expected that in the coming ten years there would be a twofold or threefold reduction in these allowances.

The particular problem is being solved by the perfection of the methods of parts treatment by cutting with tools of new materials and with new precision machines, as well as through the employment of maximum automation and mechanization.

To satisfy the demands made of mechanical engineers, machine building engineers are incessantly improving the designs of metalworking machines along the following lines: an increase of static and dynamic rigidity; accuracy of working and part-adjusting motions; automation, mechanization and control during machining; reliability and service life, parts fitness for repair; and improvement of the technological process.

The second trend is the extension of technological possibilities of the machine.

Deeper drilling, broaching or milling is now being effected by the provision of multiple-position turrets, additional upper carriages and other arrangements on automatic lathes of the single-spindle type. In addition, multiple-spindle turret facilities make it possible to process parts from both sides during the same operation.

At the current time, six- and eight-spindle double-indexing automatic lathes are widely used, the double index giving the advantage of simultaneous machining of two different parts on the same lathe.

While designing, major consideration is given to the reduction of the auxiliary time. This problem is being solved by increasing the speeds of idle displacements; utilizing mechanized means of clamping and fixing of blanks; the introduction of multiple-position toolholders; and using automatic loading arrangements and resetting facilities, as well as by using other arrangements intended for active control of the parts' dimensions. It is envisaged that the accuracy of the parts' machined surfaces would be checked by various built-in measuring instruments. Besides controlling the process of machining, these instruments would also be used for discarding machined parts as required.

Constant attention is also being paid to design improvements in progressive, high-production, multiple-tool and multiple-position machines. Particular attention is being given to multipurpose, abrasive, broaching, turret and vertical cutting lathes; semi-automatic and fully automatic machines of all the groups and purposes; specialized and unit machines; and heavy-duty and precision machines for new kinds of machining. The share of the machines of the above-mentioned kinds and purposes in machine-building has been significantly increased.

Automation and mechanization of machines are being effected in the following two basic directions. All high-production machines used for mass and large-scale production are so designed and manufactured that they they can be easily installed as "built-in" components of automatic lines. These machines are equipped with arrangements for a pre-selective speed-change system, variable speeds and feed control, and automatic changing of cutting tools.

Automatic lines of resetting automated machines, equipped with normalized transport facilities, loading, control and metering devices, have found a wide application in mass and large-scale production.

On the other hand, in small-scale and piece production, there is a tendency towards the use of machinery equipped with arrangements facilitating dual control, by programme and by automatic cycles.

Programmed control over metalworking machines is becoming one of the most effective means of automation of small-scale and serial production, as it permits the solution of control problems by the position of the tool in relation to the part under processing and to the cycle of the machine operation.

Some of the most important advantages of machines with the programmed control are:

(*a*) Rapid resetting for processing another part;

(*b*) Reduction in the cycle of technological preparation;

(*c*) Simplification of technological rigging and reduction in operational costs;

(*d*) Increase in machining productivity at the expense of reduction of auxiliary and main time for machining;

(*e*) Reduction in the number of rejects as a result of possible mistakes of operators.

Since machines with programmed control have a higher degree of automation, as compared with multi-purpose machines, it stands to reason that a higher degree of accuracy and rigidity be given to these machines.

The sphere of application of machines with programmed control is rather extensive. The particular type of equipment makes the machine universal and flexible, when mastering new production units under conditions of small-scale and serial production. Processing of parts on machines with a programme control is characterized by a high degree of concentration of operations, and automatic lines consisting of machines with a programmed control will find wide application in the near future.

The up-to-date technological equipment of the mechanical-engineering and metalworking enterprises requires a more qualified maintenance. Both the operation and repair of such equipment have become highly complicated.

The perspectives of the development of metalworking and expansion of the spheres of application of new processes and new equipment require that paramount attention be given to the improvement of the equipment utilization rate and, consequently, to the problem of organization of equipment operation and its repair.

Technical progress in mechanical engineering is constantly presenting new problems of the personnel of various repair agencies, the said problems having a final goal of maintaining, with minimum expenditure, the equipment in a serviceable state.

Thus, the exceptional role of repair agencies in modern mechanical engineering is explained by the introduction of extremely complicated equipment, the intensification of machining modes and the increased level of mechanization and automation of production processes, as well as by the considerable expenditure allocated for maintaining the equipment in a serviceable condition.

1. Concept of reliability, service life and repairability of equipment

Much attention is given to repairability of parts in the mechanical engineering and metalworking industries.

The problems of reliability, service life and repairability may be equally related to the designing, technological, operational and economic aspects.

The reliability, service life and repairability of machines are taken into consideration while working out the designs, are ensured in the course of equipment manufacture and are maintained during operation.

A. *Reliability*

Reliability is a property of the machine and it has a probable character. Reliability is probability of the fact that under certain conditions of operation the machine will function satisfactorily for a sufficiently long period of time for its use to become effective. Reliability is characterized by regularly appearing faults and is considered to be one of the most important quantitative characteristics of machine quality.

Faultless operation of the machine within the prescribed period of time may be regarded as a quantitative estimate of reliability of a general-purpose metal-cutting machine. In the above-stated case, the numerical value of reliability is determined from the time interval during which the machine is likely to function satisfactorily, *tp*, and from the total time of machine idling, *tnp*, owing to preventive maintenances, emergency repairs and additional setting-up of the machine. Besides, the numerical value is also characterized by the coefficient of readiness:

$$\eta = \frac{tp}{tp + tnp} \qquad \text{(Equation 1)}$$

It is also important to optimize the degree of machines' reliability. The higher the technical standard of the equipment designing and manufacture, the higher will be the degree of its reliability and, accordingly, the greater will be the expenditure of means and the labour consumption, which will, after all, determine its high production cost.

Since the increase of reliability will require certain material expenses, it cannot be obtained for nothing. At the same time, the increase of the degree of machine reliability will, evidently, bring down the repair and operational expenditures.

The minimum of curve *x* (see fig. 1) summing up total expenses, including purchase of the machine, and its repairs and operation, C_2, determines the degree of reliability which is likely to be the optimum from the point of view of the customer.

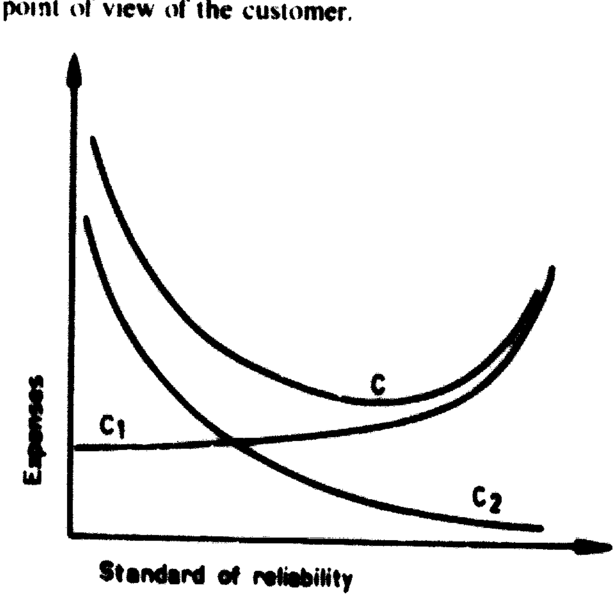


Figure 1

Determination of optimum degree of reliability equipment reliability is assuming an ever-greater importance in automatic lines where synchronously operating machines are combined by means of a transport facility. The probability of faultless operation for automatic lines and complicated equipment is of paramount importance. In this case, the service life of the equipment is pushed to the background.

B. *Service life*

Service life is characterized by the duration of a machine's operation under certain operating conditions until the serviceability of the machine is completely exhausted and the machine is ready to be sent for overhaul or to be scrapped.

Total operation of the equipment throughout its operational period (until it is damaged or requires an overhaul) is considered to be a quantitative characteristic of the equipment's service life.

Metal-cutting machines should be related to the category of multiple-action and recoverable systems which are periodically repaired in order to restore their operational characteristics. After repair, the systems become serviceable again. However, no machine can be reconditioned perpetually. The time will come when further operation of the machine will turn out to be uneconomic and its replacement will be urgently necessitated.

For determination of the optimum service life of the equipment until the approximate date of its replacement, in addition to the expenses on the equiment purchase, and its repair and maintenance, there should necessarily be taken into account the factor of technological obsolescence of the equipment, that is to say, when the operated equipment can no longer be compared to other equipment which is similar in purpose, but which has far better working indexes, namely, in its efficiency, reliability and service life.

Prior to replacement of the equipment, it is necessary to compare the specific production cost per unit during the period under review, of both the equipment which is to be replaced and that equipment which is to replace it.

Here, the original cost of the machine should be taken into account along with the current operating expenses (monthly wages of workers, repairs, electric-power consumed and the tools used).

The following equation can be used for the particular comparison:

$$3e = \frac{3ct + \sum_{i=1} 3pi + \sum_{i=1} 3\epsilon i}{\sum_{i=1}^{n} Qi} \qquad \text{(Equation 2)}$$

where: $3e$ = specific expenses per unit of production;
$3ct$ = purchase price of the machine and cost of its mounting;
$\Sigma\, 3\, pi$ = repair and maintenance expenses;
$\Sigma\, 3\, \epsilon i$ = wages of workers and cost of electric-power consumed and the tool used;
$\Sigma\, Qi$ = total quantity of articles manufactured during the period under consideration.

The solution of the problem is a matter of some difficulty, since the values included in the above equation vary in time. Thus, figure 2 shows the variation of specific time wastes relating to one repair unit required for repair and interrepair maintenance of the universal machine, depending upon its service life.

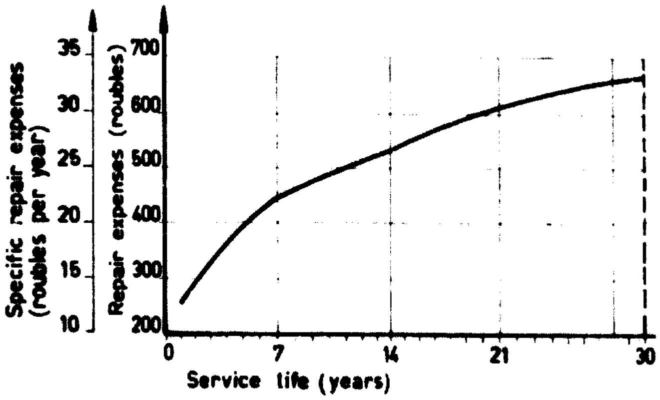


Figure 2

DEPENDENCE OF REPAIR EXPENSES UPON SERVICE LIFE OF THE MACHINE

C. *Repairability*

Repairability characterizes fitness of the machine for any repair and technical maintenance. Time required for reconditioning of the machine is considered to be the basic criterion of repairability.

The estimate of repairability may be carried out by the following characteristics: convenience in mounting and dismounting of units; convenient access for technical inspection with the objective of preventing, detecting and correcting the malfunctions; and possibility of rapid replacement of the parts which are most subjected to wear.

Reliability, service life and repairability are considered to be the main criteria for determination of the technical state of the machine.

II. FUNDAMENTALS OF PLANNED PREVENTIVE MAINTENANCE OF EQUIPMENT

In the course of operation, machines lose their working capacity mainly because of wearing and destruction of separate parts or of their surface layers, as a result of which the equipment becomes less accurate, in addition to the decrease in the machines' power and efficiency. Restoration of these most important operational characteristics of the equipment can be achieved by repairing the machine. The replacement and repair of worn-out parts, as well as the adjustment of mechanisms, should also be carried out in the course of the machine repair.

The experience of the Union of Soviet Socialist Republics over the years, which has been transferred to other countries, has proved that it is preferable to carry out the maintenance of equipment on a planning and preventive basis. Planned and preventive maintenance is carried out in accordance with a definite system adopted by industry in the USSR in 1932.

Rational organization of equipment repair in the Soviet Union goes as far back as forty years. The first researches for improvement of equipment maintenance began in 1923 in the Oka mountain district (the Urals) and were conducted by A. G. Popov. In that same year, the planning principle in maintenance was adopted in the Soviet Union.

In 1931, A. G. Popov published his work, *Rationalization of Maintenance in the Plant*, in which he generalized the results of the research works he had carried out at various plants. In his work, A. G. Popov set forth three basic—and very valuable—principles relating to the organization of repair works:

(*a*) Repair should be carried out so that the equipment can be kept serviceable for a continuous period of time;

(*b*) Repair should be preventive by its nature and should be planned deliberately.

(*c*) During equipment repair, replacement of parts should be effected, proceeding from the deliberately determined life of the parts.

Within approximately one year, that is to say, in 1932, the planned maintenance of equipment became popular in all the machine-building plants of the Soviet Union. The planned maintenance is carried out on the basis of an elaborated after-inspection maintenance system. The particular system implies the following principle: Instead of equipment maintenance, inspections are planned to determine the technical state of the equipment, upon which this or that type of maintenance of equipment, including the time required for its accomplishment, is planned, depending upon the inspection results.

Organization of planned maintenance of equipment on the basis of the after-inspection system is comparatively simple and has two basic advantages: (*a*) it ensures the possibility of organization of preparation for fulfilment of maintenance works; and (*b*) it ensures timely maintenance of the equipment, thus preventing the machine parts and units from disastrous wear as a result of continuous operation of the equipment.

In the meantime, the practice of employing after-inspection maintenance systems in the machine-building industry has revealed a number of major short-comings, e.g., the estimate of inspection results is of a subjective character. Determination of the type of maintenance and the time required for its fulfilment, proceeding from the inspection results, is accompanied by the introduction of essential amendments into the deliberately elaborated monthly and annual plans of maintenance works.

In 1940, a more improved method of organization of maintenance works was elaborated in the USSR—a system of planned and preventive maintenance.

On the basis of generalization of the experience of industry and research works, the system of planned and preventive maintenance has been constantly improved and specified.

In 1955, a system of maintenance and rational operation of technological equipment, common for all the machine-building enterprises of the Soviet Union, was finally formulated and approved. This system embraces the basic varieties of equipment used in machine-building enterprises: metal-cutting, woodworking, pr[illegible] forging, foundry, lifting and transport (includ[illegible]g hydraulic and electrical parts).

The work, *Common System of Planned and Prevent[illegible]e Maintenance and Rational Operation of Technologi[illegible]l Equipment of Machine-building Enterprises*, was first published in 1955. In 1964, the fifth edition of the book was published; 120,000 copies of it have been printed and circulated.

At the current time, the basic statements of this system are thoroughly checked and are practised well enough in the industry.

The system of the planned and preventive maintenance has also found wide application in Czechoslovakia, Eastern Germany, the Federal Republic of Germany, Poland and some other countries.

This system implies a combination of organizational and technical measures concerning the maintenance and repair of equipment, carried out in conformity with a deliberately elaborated plan having the objective of ensuring faultless operation of the equipment. The system of the planned and preventive maintenance envisages the execution of routine inspections and planned repairs (minor, medium and overhaul) after each unit has worked out the prescribed hours of operation.

The repairs and the maintenance works envisaged in the system are preventive by their nature. Thus, the basic tasks of the planned and preventive maintenance of the equipment can be formulated as follows:

(*a*) Maintaining the equipment in a serviceable state throughout its service life;

(*b*) Ensuring the rational operation and maintenance of the equipment;

(*c*) Increase of service life of parts and mechanisms in order to cut down the expenditure for spare parts and to reduce the number of planned maintenance operations;

(*d*) Reduction of tasks of a labour-consuming nature and the decrease of total repair costs, along with the increase of their quality.

The machines may possess a high reliability and may be operated for a continuous period of time, provided the system of the planned and preventive maintenance is properly organized in the enterprises.

Planned and preventive maintenance of technological equipment includes its maintenance also.

Maintenance includes the operations to be done during interrepair maintenance, inspections, checking for geometrical accuracy, washing and changing of oils in the equipment housings.

A. *Maintenance*

Interrepair maintenance includes control over fulfilment of the equipment operating instructions listed in the technical manuals of the manufacturing plants, mainly those relating to the control mechanisms, guards and lubricating facilities. It includes also the timely elimination of minor faults and the adjustment of mechanisms. Interrepair maintenance is carried out during the stretches of time when the unit is inactive so as to avoid disturbing the production process. Such maintenance i[illegible] carried out by the workers servicing the units and, in some cases, by the personnel of the shop repair agency on duty (mechanics, electricians, lubricators etc.).

Interrepair maintenance of automatic lines is carried out either daily or less frequently, depending upon the purpose of the line. If the line is operated during two shifts, maintenance will be carried out during the non-working shift: and if the line is operated during three shifts, then the maintenance will be performed in the space of time between the two shifts. Maintenance of automatic lines is carried out by the personnel and operators who are responsible for setting up the machine.

Inspection is carried out for the purpose of checking the state of the equipment, eliminating minor faults and determining the scope of preparatory works to be fulfilled during the nearest planned maintenance.

Inspections between the planned maintenances of the equipment are carried out by "locksmiths" with the participation of the personnel servicing the particular equipment.

Checking for geometrical accuracy is carried out at regular intervals after the planned maintenance and in accordance with a special schedule established for precision and finishing equipment.

All types of the equipment which operate in dirty conditions should be washed.

The list of units and assemblies to be washed is determined by the department of the chief mechanic of the enterprise, in accordance with the requirements set forth in the manufacturing plant manuals and with the account of conditions under which the equipment is going to be operated.

Washing is performed by "locksmiths" during technological pauses in the operation of the unit, nonworking shifts and days off so as not to avoid disturbing the production process.

Oil change is performed in accordance with a special schedule for all equipment with centralized and housing systems.

B. *Repairs*

The system of the planned and preventive maintenance envisages three basic repairs, namely, minor, medium and overhaul.

The scope of each of these repairs makes it possible to compensate for the wear of separate parts and mechanisms which have been operating throughout the interrepair period.

Minor repair is a kind of planned maintenance during which the worn-out parts are either replaced or reconditioned, or the mechanisms are adjusted, thus ensuring normal functioning of the unit until the forthcoming planned maintenance.

Medium repair is a kind of planned maintenance dealing with the partial disassembly of units, the overhaul of separate units, the replacement and reconditioning of a considerable number of worn-out parts and the assembly, adjustment and testing of the equipment under load.

Overhaul is a kind of planned maintenance during which the unit is completely disassembled, worn-out parts and units are replaced, base and other parts and units are repaired and the equipment is assembled, adjusted and tested under load.

In the course of medium and overhaul repairs by adjustment of co-ordinates, the geometrical accuracy of the equipment and the power and efficiency should be restored for the period until the planned repair – medium or overhaul.

The comparative labour consumption nature during the overhaul and medium and minor repairs is characterized by the ratio 1 : 0.6 : 0.16. The labour consumption nature of "locksmith" operations is 2.3–2.5 times higher than that of machining operations.

The interrepair cycle is a combination of repair and routine operations performed during machine operation in the period from date of commissioning until the overhaul, or in the period between the two successive overhauls. The structure of the interrepair cycle is determined by the sequence of the repair and routine operations, as well as by the priority of their fulfilment.

Thus, the structure accepted for universal metal-cutting machines consists of two medium repairs (C), six minor repairs (M) and nine inspections (O). The particular structure may be lettered and put down in the following way: H–O–M–O–M–O–C–O–M–O–M–O–C–O–M–O–M–O–K, where H – new machine and K – overhaul.

The structure of interrepair cycle envisages twenty-seven inspections for complex and automatic line equipment since the probability of faultless operations with these equipments is of utmost importance.

Other types of equipment have different structures of repair cycles. Thus, two medium repairs, three minor repairs and twelve inspections are envisaged for the forging hammer.

The interrepair period is the period of machine operation between the two successive repairs.

The duration of both the interrepair cycle and the interrepair periods can be determined, depending upon the type of equipment and the conditions under which the equipment is being operated. The durations of the interrepair cycle and interrepair periods are given in the hours actually worked out. However, said duration may also be determined from the number of calendar shifts (by introducing a correction factor for the equipment as it stands idling) or by using any other value indicating the number of working cycles of the equipment (number of machined parts).

The duration of the interrepair cycle is determined by the service life of the location and the most important parts which can be repaired or replaced during complete disassembly of the machine in the course of its overhaul.

The duration of the interrepair period depends upon the service life of the basic, mostly loaded, parts of the mechanisms (gear-wheels, splined shafts etc.). The increase of the duration of interrepair periods increases the degree of utilization of the equipment and reduces the repair expenses (see fig. 3). In the meantime, a wide interrepair period may bring about emergency machine idlings, as, in this case, the limit of wear of several parts may take place before the nearest planned repair.

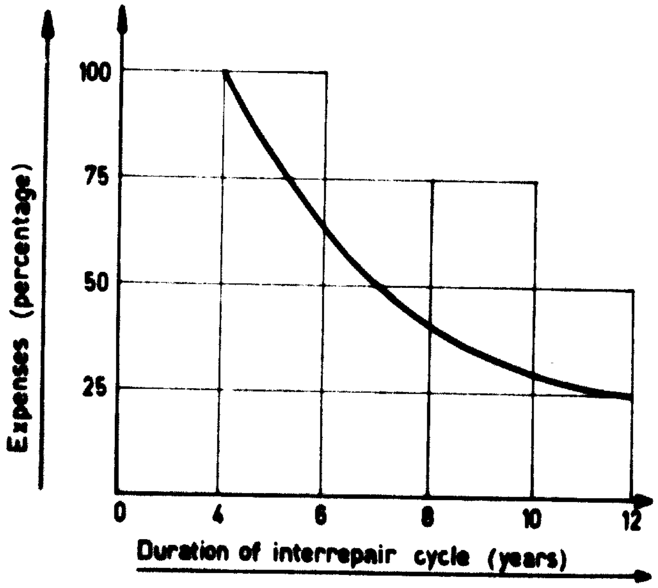


Figure 3

VARIATION OF AVERAGE ANNUAL REPAIR AND MAINTENANCE EXPENSES PER REPAIR UNIT

The shorter the interrepair period is, the more frequently will the repair operations alter and the greater will be the possibilities for repair or timely replacement of the defective parts (to ensure the full use of parts' service lives up up to the ultimate permissible values). However, the possibility of fulfilment of various repair works is connected with the equipment idlings, whereas frequent assembly and disassembly of the mechanisms, without a sufficient reason, adversely affect the operation of mated parts in the mechanisms.

To reduce idlings of machines when under repair, it is necessary to have a sufficient stock of spare parts in depots. The spares include those parts which are used for replacement during the interrepair maintenance and the planned repairs (minor, medium and overhaul).

Knowledge of the nomenclature of wearing parts and their service lives will permit the timely purchase or manufacture of the required spare parts, so as to have them in depots at all times.

The duration of the interrepair cycle (T) in actual hours is determined from the following equation:

$$T = an \cdot au \cdot ay \cdot acm\, A \cdot \quad \text{(Equation 3)}$$

where

an, au, ay, acm = coefficients characterizing the conditions of operation

A = constant. For metal-cutting machines, it is accepted to be 24,000.

Changing of the conditions under which the equipment is being operated should correspondingly involve a change in the duration of the interrepair cycle. A number of coefficients are introduced for taking into account the influence of the various conditions under which the equipment is operated upon the duration of the repair cycle.

In serial production, the equipment is operated more intensively than in the case of piece production; and i[illegible] mass production, the equipment operates more stre[illegible]ously than it does with serial production.

Coefficient *an* takes into account the influence of th[e] character of production. With the machine bei[ng] operated in mass and multiple production, the value of *an* is accepted to be 1.0; in series production, it is 1.[illegible]; and in piece production, 1.5.

When machining steel and non-ferrous metals, the bed guides, lead screws and other parts and mechanisms of the machine are less contaminated than when machining cast-iron, whose disintegrated chip is known to contain a large quantity of abrasive particles. Coefficient *au* is introduced to take into account the influence of the material under machining. For the machining of cast-iron and bronze materials, the value of *au* is accepted to be 0.8 and for structural steel, 1.0.

The influence of the application of abrasive tools for processing machine parts, as well as the general dustiness of the production premises, is taken into account by common coefficient *ay*. The value of *ay* for equipment operated under normal conditions in the mechanical shop equals *ay* = 1.0; and *ay* for the equipment installed in a separate building protected from soiling is 1.3.

Since the share of the machine time (when operating heavy-duty and precision machines) which falls to the time of total unit operation is less than when operating normal machines, another coefficient, *act*, is introduced to take into account the conditions of operation of heavy-duty and precision machines. For multipurpose machines having a weight of about 10 tons, *act* = 1.0; for heavier and larger machines, *act* = 1.4.

Table 1 gives the approximate durations of interrepair cycles for metal-cutting machines used for two-shift processing of ferrous metals.

The degree of complication of the unit repair and its repair peculiarities are estimated by the categories of repair complicacy.

The category of equipment repair complicacy depends upon the design and technological peculiarities of the equipment. As initial data for establishing the category of equipment repair complicacy, one should take the technical characteristics tabulated in the machine logs (accuracy, weight, degree of automation, complicacy of mechanisms etc.).

The more complex the machine is and the greater its over-all dimensions and weight, the higher will be the accuracy obtained on the machine and the higher will be its category of repair complicacy.

Thus, for instance, a screw-cutting machine with a maximum working diameter of 400 mm and a maximum take between the centres of 1,000 mm, is referred to repair complicacy category 11. The labour consumption required for its overhaul constitutes 250 hours for the "locksmith" operations and 110 hours for the machining operations.

A boring machine with a boring bar 85 mm in diameter is referred to the category 18 of repair complicacy. The single-frame jig-boring machine whose over-all table dimensions are 320 × 450 is referred to the category 2[illegible] of repair complicacy. The labour-consuming nature of

Table 1

DURATION OF MACHINE OPERATION UP TO OVERHAUL

Type of production 1	*Machines* 2	*Weight characteristics of machines* 3	*Duration of machine operation up to first overhaul* 4
Mass and multiple	Normal accuracy	Light and medium, having a weight of about 10 tons	5.5 6.5
		Large and heavy, having a weight of 10-100 tons	7.5 8.0
Serial		Light and medium, weighing up to 10 tons	7.0 8.0
		Large and heavy, weighing 10 100 tons	9.0 10.0
Mass and multiple	High accuracy	Light and medium, weighing about 10 tons	6.0-7.5
		Large and heavy, weighing 10 100 tons	8.0-10.0
Serial		Light and medium, weighing about 10 tons	8.0-9.0
		Large and heavy, weighing 10-100 tons	10.0-12.0

its overhaul is 500 hours for "locksmith" operations and 220 hours for machining operations.

III. ORGANIZATION OF REPAIR WORKS

Fulfilment of repair works in a brief space of time and with the minimum expenditure of means can be obtained if such works are organized in the most rational way and ensure:

(*a*) The technical preparation of production of works on technical maintenance and repair;

(*b*) The planning of all kinds of works to be carried out during technical maintenance and repair;

(*c*) The application of progressive technology of repair and mechanization of handwork;

(*d*) The availability of the necessary spare parts and units before the repair works have begun.

As a production base for fulfilling operations on the maintenance and repair of the equipment, there should be a repair and mechanical shop, as well as repair bases in the production shops of the industrial enterprises operating the equipment.

The repair and mechanical shop manufactures those spare parts which cannot be purchased or whose purchase is inexpedient from the point of view of economy. In addition, the overhaul and medium repairs of equipment, as well as its modernization, can be carried out in a centralized way in the repair and mechanical shop.

To perform these works, the repair and mechanical shop should be outfitted with the necessary repair facilities. Table 2 describes an approximate set of the minimum equipment to be found in the repair and mechanical shop.

The repair bases are entrusted with a mission of fulfilling all the works concerning the technical maintenance of equipment, including minor repair. In some enterprises, however, the shop repair bases also perform the medium and overhaul repairs.

A repair team of "locksmiths" is usually entrusted with the task of fulfilling repair works in the shop repair bases. The whole equipment of the production area or shop is appointed to this repair team, which is also responsible for the repair and maintenance of machines of various models. Thus, idlings of the equipment will be reduced, due to the general personal interest of the whole repair team. Furthermore, the repair works are carried out without removal of the machines from the bed plates and, thus, the duration of machine idling, while under repair, is shortened. However, this particular form of organizing the labour of the repair men has significant disadvantages, since there is no specialization and this influences the labour productivity and the quality of repair.

Table 2

LIST OF EQUIPMENT OF REPAIR AND MECHANICAL SHOP OF MACHINE-BUILDING PLANT

Description of equipment 1	*Model* 2	*Basic data* 3
Screw-cutting engine lathe	1K62 1G620	Swing over bed: 400 mm Takes between centres: 710; 1,000; 1,400 mm Number of spindle speeds: 23 Range of spindle speeds: 12, 5 2,000 rpm Number of cross-feeds: 42 Range of cross-feeds: 0.07 4.16 mm/rpm Power of main electric motor: 10 kW Weight of machine: 2,160; 2,300; 2,400 kg
	163	Swing over bed: 630 Takes between centres: 1,400; 2,800 mm Number of spindle speeds: 24 and 22 Range of spindle speeds: 10 1,250 rps Range of speeds: longitudinal feeds, 700 mm/rpm; cross-feeds, 250 mm/rpm

Table 2—continued

Description of equipment 1	*Model* 2	*Basic data* 3
Screw-cutting engine lathe	163	Power of main electric motor: 14 kW Weight of machine: 4,350 and 4,500 kg
Universal milling machine	6M82	Working dimensions of the table (over-all width × over-all length): 320 × 1,250 mm Maximum travel of table: longitudinal, 700 mm; cross, 250 mm; vertical, 330 mm Range of distances from the axis of spindle to the table surface: 30–410 mm Maximum angle of table turn: ± 45 degrees Number of spindle speeds: 18 Range of spindle revolutions per minute: 31.5–1,600 Range of table feeds: longitudinal, 25–1,250 mm/min; cross, 25/1,250 mm/min; vertical, 8–400 mm/min Power of main electric motor: 7 kW Weight of machines: 2,800 kg
Vertical milling machine with a swivel head	6M12N	Working dimensions of table (over-all width × over-all length): 320 × 1,250 mm Maximum travel of table: longitudinal, 700 mm; lateral, 260 mm; vertical, 420 mm Range of distances of vertical guides up to the middle of the table: 210–170 mm Angle of swivel-head turn rightwards and leftwards: ±45 degrees Number of spindle speeds: 18 Range of spindle revolutions: 31 ÷ 1,600 minutes Range of table feeds: longitudinal, 25–1,250 min/min; cross, 25–1,250 mm/min; vertical, 8–400 mm/min Power of main electric motor: 7 kW Weight of machine: 3,000 kg
Horizontal shaping machine	7M36	Maximum and minimum slide movement: 150–700 mm Maximum distance from the cutter-support surface to the machine (spindle travel): 840 mm Working dimensions of table surface (over-all width and over-all length): 450 × 700 mm Maximum table movement: horizontal, 700 mm; vertical, 320 mm Maximum vertical travel of the cutting head: 200 mm Range of table cross-feeds per double movement: 0.25–5 mm Weight of machine: 3,200 kg
Slotting machine	7A420	Maximum travel of slotting ram: 200 mm Diameter of table operating surface: 500 mm Maximum table movement: longitudinal, 500 mm; cross, 400 mm; circular, 360 degrees Maximum angle of cutting-head travel: 90 degrees Number of double movements of slotting ram per minute: 40; 64; 102
Slotting machine	7A420	Ranges of longitudinal and cross-table feeds per double movement of slotting ram: 0.1–1.2 mm Power of electric motor: 2.8 kW Weight of machine: 2,100 kg
Vertical drilling machine	2H125	Maximum diameter of drilling: 25 mm Maximum spindle movement: 175 mm Working dimensions of table: 350 × 350 mm Spindle travel: 260 mm Range of spindle speeds: 165–2,300 rpm Range of spindle feeds: 0.104–0.837 mm/rpm Power of main electric motor: 2.2–2.8 kW Weight of machine: 600 kg
Radial drilling machine	2H55	Maximum diameter of drilling: 50 mm Maximum spindle movement: 350 mm (spindle travel); 1,600 mm Range of spindle speeds: 30–1,700 rpm Range of spindle feeds: 0.05–2.2 mm/rps Power of main electric motor: 4.0 kW Weight of machine; 4,100 kg
Surface-grinding machine	3671M	Maximum dimensions of the ground articles: 630 × 200 × 320 mm Cross movement of table: 235 mm Range of longitudinal movement of table: 70–710 mm Operating dimensions of table (over-all length × over-all width): 630 × 200 mm Range of cross automatic feed of table per movement: 0.2–4.0 mm Dimensions of grinding-wheel: 250 × 75 × 25 mm Power of main electric motor: 3.4 kW Weight of machine: 1,900 kg
Cylindrical grinder	3A161	Maximum dimensions of the work to be set up on machine: diameter, 280 mm; length, 700 mm Power of main electric motor: 7 kW Weight of machine: 3,800 kg
Gear-milling machine	5K32A	Maximum outer diameter of wheels cut by machine: 300 mm Maximum modulus of teeth of wheels cut by the machine: for steel, 10 mm; for cast-iron: 12 mm Power of main electric motor: 7.5 kW Weight of machine: 7,000 kg

IV. Specialization and Centralization of Repair Works

The technical standards and organization of metal-cutting equipment repair in the industrial enterprises operating the equipment are subject to the conditions of piece production and the use of the means and forces of these enterprises and, as a rule, fall below the standards for manufacturing the equipment at the plants.

Figure 4 shows the dynamics of alteration of labour consumption required for manufacturing a new screw-cutting engine lathe and that required for its overhaul.

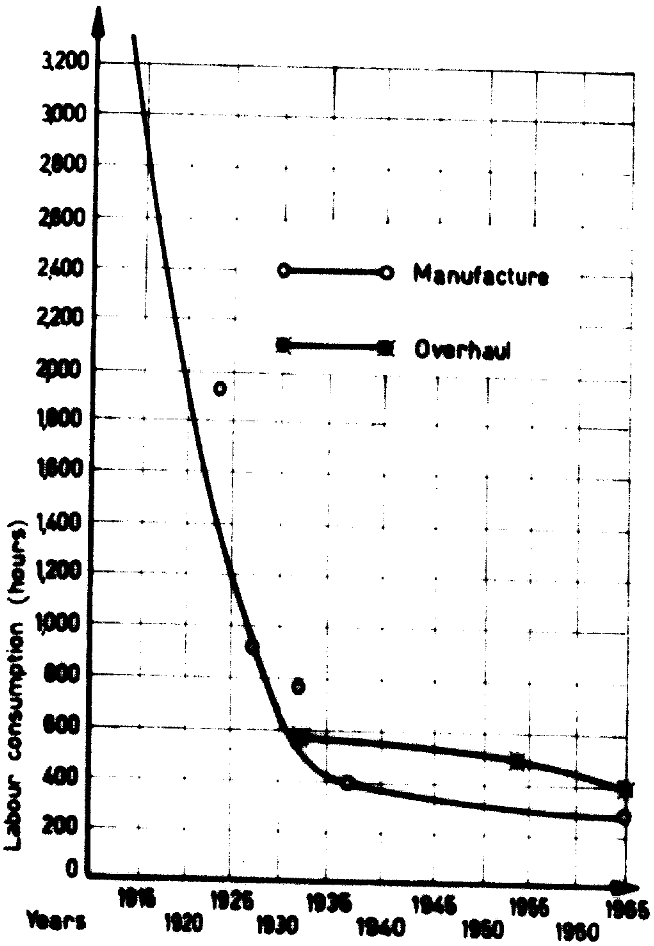


Figure 4

VARIATION OF LABOUR CONSUMPTION REQUIRED FOR MANUFACTURING AND FOR OVERHAUL OF SCREW-CUTTING ENGINE LATHE WITH 200-MILLIMETRE SWING OVER BED AND 1,000-MILLIMETRE TAKES BETWEEN CENTRES

Repair technology sharply differs from the technology which is accepted at the manufacturing plant. Wide nomenclature of the equipment under repair and rare repetition of the models make the application of special technological rigging ineffective; manual works predominate in the course of repair works; and, therefore, many of the technological processes used in the manufacturing plant turn out to be unprofitable and practically unacceptable under repair conditions. This particular factor adversely affects the fulfilment of repair works.

The complicacy of preliminary technical preparation during fulfilment of a single repair work may bring about considerable idlings of the equipment as it is being repaired. In the course of a single performance of repair works, the equipment of the repair and mechanical shop has proved to be insufficiently utilized. In connexion with this, it becomes reasonable to change the organization of repair works in the industrial enterprises.

Specialization and centralization are considered two of the most progressive trends in the organization of repair works in the industry. Both centralization and specialization create favourable conditions for progressive technological processes, as well as for rational organization of the production.

At the current time, specialization and centralization are being widely applied and may be carried out either within the enterprise which operates the equipment (inside-plant) or outside it.

Specialization and centralization of repair works on an enterprise level may be carried out by way of:

(*a*) Concentration of works to be performed in the repair and mechanical shop during the overhaul and medium repairs of the equipment and in making up special teams for the repair of common-type equipment. For instance, teams may be organized for the repair of grinding machines, turret lathes, semi-automatic and fully automatic lathes etc.;

(*b*) Making up teams with a limited sphere of repair duties (repair of hydraulic systems, repair of conveyors etc.);

(*c*) Organization of centralized performance of machining operations in the repair and mechanical shop.

Concentration of the overhaul and medium repair works for the common types of equipment presents an opportunity for properly equipping the repair team with universal and special appliances and for mastering the repair technology.

With centralization inside the plant, it is reasonable to ensure the concentration of several commonplace machines, as far as the repair time is concerned. For this purpose, it sometimes becomes necessary to shift somewhat the time-terms of the repair works.

Organization of repair during which all kinds of works are carried out by the personnel operating the equipment of the industrial enterprise is not yet the optimum plan. It is more effective to carry out the overhaul and medium repairs of the equipment in a centralized way either in equipment-manufacturing plants or in specialized repair plants.

For outside-plant centralization and specialization of repair works, there can be effected two basic forms of organization of repair works, namely:

(*a*) Organization of repair works ensuring fulfilment of the overhaul and medium repairs in the equipment-manufacturing plant, in which case the technical maintenance and minor repairs will be performed by the repair and mechanical shop and shop repair bases of the industrial enterprise which operates the equipment;

(*b*) Organization of repair works ensuring concentration of the overhaul works in the shops and enterprises which are especially designed for fulfilment of repair works.

The following are the repair works which it is advisable to carry out in specialized repair enterprises or specialized repair shops:

(*a*) Overhaul and medium repairs of the widely distributed models of universal metal-cutting machines;

(*b*) Manufacture of spare parts (which cannot be received from the manufacturing plant) for all kinds of repair works;

(*c*) Repair of precision and heavy-duty machines with departure to the enterprise's consumers.

Organization of the centralized repair of precision and heavy-duty machines is explained by the fact that transportation of precision machines is not advisable from the point of view of economy, since it will require a large expenditure of means and a waste of time for its assembly. In the meantime, heavy-duty machines are practically non-transportable.

Furthermore, during the centralized repair of complex and precision equipment, every favourable condition is created for the repair works to be performed on a high technical standard and with the wide utilization of various means and methods, ensuring both the mechanization of the repair works and obtaining high accuracies.

For centralized repair, it is advisable that the common types of machines be concentrated for repair during those definite calendar periods which create favourable conditions for the technical preparation of the repair works and, more particularly, for the manufacture of spare parts.

The following advantages can be obtained through the centralization of repair works:

(*a*) Reduction of labour consumption required for repairing machines and manufacturing spare parts and units;

(*b*) Reduction of cost price of parts and units for repair, at option of increasing labour productivity and decreasing the norms of metal expenditure.

(*c*) Increase of labour productivity while performing repair works;

(*d*) Reduction of the number of machines engaged in the repair of basic technological equipment;

(*e*) Extension of the interrepair cycle at option of increasing the quality of repair and reduction of machine idlings because of inferior quality of repairs.

During the centralized repair of the equipment, special shops may be organized for the reconditioning of worn-out metal and labour-consuming parts.

Specialization and centralization of repair works may reduce the expense of equipment repair by 25–30 per cent, while equipment idlings while in repair may be reduced five or six times. They may, in addition, ensure the provision to the industrial enterprises of the spare parts required for all kinds of repair works and will, therefore, assist in the increased quality of repairs.

When repairing the equipment in a specialized enterprise, it is advisable to combine the repair of the equipment with its modernization. It is advisable to effect modernization of the equipment simultaneously with the overhaul of medium repairs. Combination of the overhaul with modernization brings down the expenses, since the volume of "locksmith" disassembly and assembly operations is considerably reduced, as is the time of equipment idlings.

Modernization, depending upon the technical trend, is known to be of two kinds:

(*a*) General technical modernization ensuring the execution of a complex of measures aimed at the increase of technical status of the operated equipment by way of approximating its technical and operational characteristics to up-to-date machines used for the same purpose.

(*b*) Technological (target) modernization ensuring the equipping of the machines with various arrangements and mechanisms, as well as modification of their designs in order to solve certain technological production problems, introduce advanced technological processes, automate the equipment and effect automatic progressive assembly and mechanized lines using the modernized machines.

Modernization of equipment may be effected only if it is of economic value. An estimate of the economic effectiveness of the equipment modernization should be carried out by way of comparing the cost of the modernization of the machine and its subsequent operation with those of the purchase and operation of a new machine having an improved design. It would be wrong to estimate modernization by way of comparison of these expenses before the equipment modernization and after it.

An exchange fund should be provided in the enterprises for centralized repair of equipment. In this case, the machine accepted for repair would be replaced with the one already repaired and, thus, the equipment idling would be reduced to two or three days. The number of machines which would be required for the exchange fund can be determined from the following ratio:

$$n = \lambda \frac{m \cdot t}{300} \qquad \text{(Equation 4)}$$

where:

- n — number of machines in the exchange fund;
- m = number of machines annually accepted for repair;
- t = duration of machine repair (days);
- λ — coefficient accounting for irregularity of machines' acceptance for repair.

Enterprises for the centralized repair of equipment may also have a narrow specialization in the types of machines to be repaired, as well as in organization of specialized enterprises for the centralized repair of the group of engine lathes, the group of milling and drilling machines, the group of grinding machines and the group of gear- and spline-milling machines.

In specialized enterprises, it is advisable to carry out the repair of equipment on the basis of the line production system.

In the mechanical shops of specialized repair enterprises, it is advisable to organize individual manufacture of separate parts and units. The mechanical shops of specialized repair enterprises may be provided with high-efficiency equipment.

The "locksmith" and assembly sections should be equipped with various assembly and disassembly appliances and with stands for stationary testing and running-in of the equipment units.

. Recommendations for organization of centralized repair

With the centralized repair of equipment, the quality of repair can be substantially increased. The technical standard of repair is determined by the operational characteristics of the equipment after being repaired and the ability to preserve these characteristics in operation and for a continuous period of time. In the course of fulfilling the centralized repair of the machine, the following recommendations should be taken into account in specialized enterprises:

1. While repairing the machine, do not effect any design modifications that might adversely affect their technical characteristics (power, efficiency or the factor (of economy) as compared with the characteristics of the manufacturing plant;
2. It is advisable to combine the overhaul and medium repairs with the modernization of theequpiment. However, the problem of equipment modernization should, in each particular case, be thoroughly considered from the economic point of view and should be co-ordinated with the customer;
3. The machine which has been accepted for repair should undergo inspection and testing for accuracy. The inspection results will be entered on the acceptance certificate.

   When disassembling a machine under repair, the parts and units should be assorted as follows:

   (*a*) Serviceable parts, which have no defects that might adversely affect their operation while the machine is active and which have maintained their dimensions or have insignificant wear;

   (*b*) Parts which are worn and have defects that can be eliminated by various reconditioning methods, including subsequent mechanical treatment of the faulty parts;

   (*c*) Parts to be replaced, i.e. those which are worn and have defects whose elimination is either impossible or economically impractical;
4. The materials for parts to be manufactured during the repair of machines should conform to the technological charts of the machine-building plants;
5. Manufacture of new parts to replace those which are worn out should be performed in a strict conformity with the dimensions, allowances and other instructions given in the charts;
6. Assembly of the machines under repair should ensure the faultless operation of all the mechanisms and should be performed in accordance with the requirements listed in the assembly charts;
7. The lubrication and cooling systems of the machine handed over to the using organization after being repaired should ensure normal feed of oil and coolant;
8. The scope of works on the machines' overhaul (medium repair) includes repair of the entire electrical equipment mounted on the machine or in separate cabinets, in addition to the repair of the machine's electric wiring;
9. The machine which has already been repaired should be subjected to outside finishing, painting and ornamental finishing of all the machined surfaces of parts;
10. After being repaired, each machine should be provided with a name-plate indicating the plant which repaired the machine and the date of its output;
11. Each machine, after being repaired and handed over to the using organization, should be subjected to an acceptance test, the latter being carried out in the following order—visual inspection, idle-run test, testing under load and in operation, testing for accuracy and testing for rigidity.

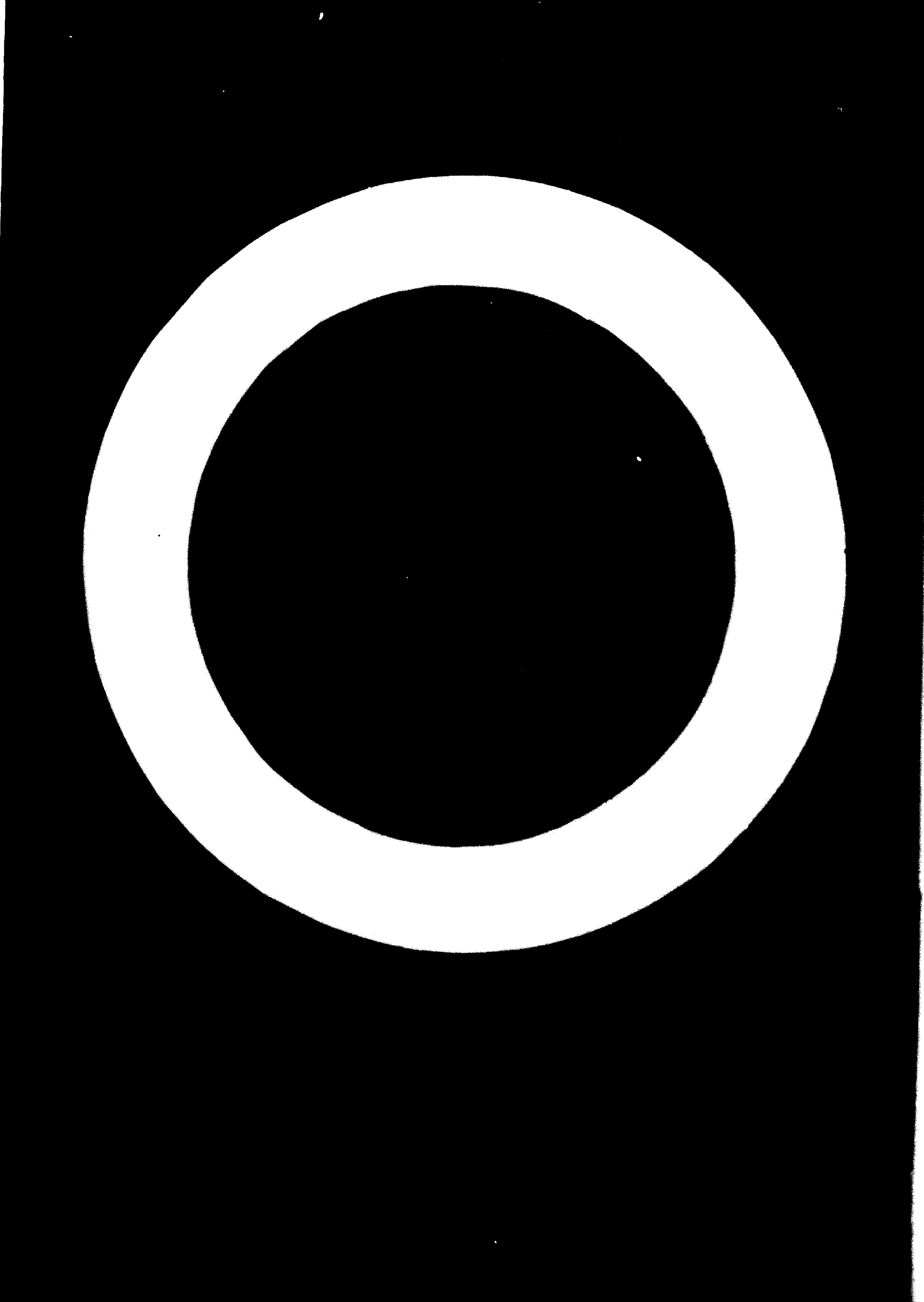
B. *Testing*

When testing at idle run, both the quality of repair and the correct interaction of machine parts and units are checked, for testing of the main motion mechanisms should be carried out in all the spindle speeds and that of the feed mechanisms, at all the feed values.

Testing under load has an object of checking for the correct functioning and interaction of all the units under normal conditions of operation, as well as for the faultless operation of all the mechanisms (electrical and hydraulic apparatus systems of lubrication and cooling).

After machine running-in at idle run and under load testing, its geometrical accuracy should be checked, in addition to checking the accuracy of the parts to be treated on the machine.

The results of testing should not be lower than those envisaged in the standards or technical specifications of the manufacturing plant.



REPAIR AND MAINTENANCE OF MACHINE TOOLS IN DEVELOPING COUNTRIES

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INTRODUCTION

Machine tools, together with welding equipment, occupy a special position in relation to other machinery, such as that used in the textile industry, transport, light industry, printing and so on. Machine tools are used to produce parts of other machines, i.e., to manufacture new machines and instruments, and to repair existing ones.

A country's stock of machine tools—its technical level, structure and condition—to a considerable extent determines the national productive capacity and ability to solve technical and economic problems independently.

The structure and growth of the machine-tool stock are closely connected with a country's level of industrialization. As the country develops, it continues to use general-purpose machine tools of normal accuracy, but it makes increasingly extensive use also of precision tools, automatic tools and lines, specialized tools for specific branches of mechanical engineering and heavy tools for parts of large machines.

Thus, table I shows the number of types of machine tools put into production in the Union of Soviet Socialist Republics since the establishment of a domestic machine-tool industry. These figures indicate how the need for machine tools has grown in the Soviet Union as its industry has developed.

Table I

NUMBER OF TYPES OF MACHINE TOOLS IN SERIES PRODUCTION IN THE USSR

Categories of machine tools produced	*1932*	*1937*	*1940*	*1945*	*1950*	*1955*	*1957*	*1965 (planned)*
Precision	—	4	7	9	41	109	115	180
Automatic and semi-automatic	7	42	87	40	115	250	295	650
Specialized	6	39	54	47	141	346	370	620
Heavy	3	5	29	12	90	247	180	420
Total, all types	47	190	320	150	384	788	900	1,500

Given a stock of machine tools, the problem arises of how to use them most efficiently and to extend their service life as long as possible. This can be achieved only through the organization of a special repair and maintenance system.

This is a very serious problem, for modern machine tools are highly complicated machines which include precision devices, hydraulic and electrical systems, high-speed and power transmission systems and automatic and control devices.

The functioning of a machine tool's units and mechanisms depends, to a considerable extent, upon the methods used to operate, maintain and service it.

If insufficient thought is given to these methods, great waste of resources and, most important, of foreign exchange, can result. Such waste is due to two factors which arise when individual units and mechanisms are taken out of service prematurely.

First, there is an increase in the amount and, accordingly, the cost of repair work. Often the repairs may entail the importation of spare parts.

When the failure occurs in a complicated precision part, such as a precision lead screw, the bushings of a jig borer, a reading mechanism or the like, it is not always possible to repair and recondition it locally. This may be avoided by adequate methods of operation and servicing.

Secondly, wear and breakdowns increase idle time in repair and reduce the tool's use coefficient. Consequently, extra machine tools have to be acquired to do the same amount of work, and shop space has to be increased correspondingly.

Furthermore, improperly repaired and maintained machine tools may fail to meet their technical specifications, particularly as regards accuracy.

Thus, it is important not merely to acquire a stock of machine tools, but also to maintain it in efficient condition, which can be done by applying a repair and maintenance system and by developing methods of increasing the reliability and durability of equipment.

It is important to train national personnel armed with modern technical ideas in this field.

I. ECONOMIC ASPECT OF THE MAINTENANCE AND REPAIR OF MACHINE TOOLS

Expenditure on the repair and maintenance of equipment accounts for a considerable proportion of production costs.

Research has shown that every year approximately 10 per cent of the stock of technical equipment undergoes a major overhaul; 20–25 per cent, an intermediate overhaul; and 90–100 per cent, a minor overhaul.

The loss of time and resources involved in keeping the stock of machine tools in good order is substantial, depending to a great extent upon the methods of operating and servicing the machines and the technology and organization of maintenance. For example, in an average-size or small enterprise, the cost of major overhaul alone is normally up to 60 per cent of the cost of a new machine in the case of medium-size turning lathes, up to 40 per cent in the case of universal milling machines and up to 75 per cent in the case of capstan lathes. It must also be remembered that prior to the major overhaul, a machine tool undergoes two intermediate overhauls, each of which takes about half as much labour as a major overhaul, and six minor overhauls, each of which takes about one-quarter as much labour as a major overhaul.

In addition, machine tools are periodically checked for accuracy, lubricated and given preventive treatment.

Thus, the cost of maintaining and servicing a machine tool during one maintenance cycle (i.e. up to and including the major overhaul) is greater than the cost of a new machine, and if maintenance and repair are badly organized, it can be several times greater.

A factor of no less importance in evaluating the economics of maintenance is the idle time lost by equipment during the various kinds of overhaul.

As an example, one may consider the periods of forced idleness for maintenance work on screw-cutting lathes and cylinder-and-core grinding machines of average size and complexity of design. These data are taken from the standards for machine-tool maintenance applied in the Soviet Union (1), under which maintenance of all equipment is carried out in accordance with a special system known as the "planned preventive maintenance system".

The figures given in table 2 are for maintenance teams working a single shift and indicate how many days a machine tool must remain idle for the given type of maintenance.

Table 2

IDLE TIME OF MACHINE TOOL DURING VARIOUS TYPES OF MAINTENANCE, WITH MAINTENANCE TEAM WORKING ONE SHIFT

(*Days*)

Type of maintenance	*Lathe*	*Cylinder-grinding machine*
Major overhaul	11	18
Intermediate overhaul	6.5	11
Minor overhaul	2.75	4.5
Accuracy checks	1	1.5

As was stated above, under the current maintenance system a machine tool undergoes two intermediate and six minor overhauls before its major overhaul. Accordingly, the number of days which a screw-cutting lathe, for example, will lose for maintenance from the time it is put into operation until its major overhaul is completed (i.e. over the period of the maintenance cycle) will be:

$$11 + 6.5 \times 2 + 2.75 \times 6 \approx 40 \text{ days}$$

A machine's operating life before major overhaul, and similarly between intermediate overhauls, depends, to a large extent, upon the methods of operation. For example, a screw-cutting lathe working single shifts at a series production factory and turning out steel parts to a normal degree of accuracy will have a working life of four to nine years before major overhaul.

If the machine tool runs for eight years before major overhaul, it follows that the time lost for maintenance will amount to an average of five days a year. If the shop has sixty machines with the same average maintenance complexity as a screw-cutting lathe, the total idle time will be 300 days, i.e., the maintenance crew will have to work steadily all year round on maintaining the machines (not allowing for lubrication and preventive and other measures).

If, because of insufficient attention to operating methods, the maintenance cycle is four years, the relative volume of maintenance work will be twice as great.

These figures show that great attention must be given to methods of maintaining and operating equipment. It is necessary to know why a machine tool loses its efficiency, as well as the methods by which its reliability and durability can be increased; in maintaining equipment, up-to-date technological processes and methods must be applied. In addition, the equipment maintenance system must be so organized as to act in advance to reduce the progressive wear of equipment, bring maintenance costs to a minimum, and ensure the proper preparation and planning of maintenance work and the efficient use of equipment.

II. CAUSES OF LOSS OF EFFICIENCY IN MACHINE TOOLS

In approaching machines and mechanical systems, the classical sciences, such as mechanics, attempted to idealize the conditions in which they functioned. The errors and inaccuracies caused in the actual performance of a machine by component wear, temperature deformation, defective materials, technological factors etc. were viewed as aberrations from the performance of the perfect machine and as undesirable and fortuitous phenomena.

Modern science, particularly cybernetics, takes a different view of the errors in a given system. Errors and inaccuracies in a machine's execution of an assigned programme (e.g., a technological process) are regarded as a natural feature of any real system. The need thus arises to investigate the sources and causes of adverse influences acting on machines and to study the machines' reactions to them.

A machine cannot be completely isolated from the effects of its environment, nor can it be isolated from the influence of the processes going on within itself as it functions.

A. *Influence of energy*

The units and working parts of a machine tool in an industrial shop are subject to the influence of energy in all its forms, which affect its technical performance.

Mechanical energy is not only transmitted through the

.rious working parts of the machine as it performs the given technological process, but also acts on the machine as a whole, in the form of vibrations transmitted by other equipment running in the shop, vibrations generated as the machine is fed material and so on

The forces at work in the machine are the product of both the technological process and such forces as those arising from friction in kinematic couples or inertia in moving parts. These forces cannot be strictly defined since the very nature of their occurrence is bound up with complex physical phenomena.

It is, indeed, this degree of indefiniteness of the influences at work that gives rise to the errors and inaccuracies in the operation of mechanical systems. Furthermore, even a constant force produces wear, deformation and fatigue, i.e. causes a component's parameters to change with time.

Thermal energy affects machine parts as a result of fluctuations in shop temperature, the operation of driving gear or electrical equipment, or heat generated during the cutting process.

These phenomena also affect the operation of both individual working units and the entire machine. Studies have shown, for instance, that as little as two hours' exposure to the sun (at mean latitudes) of the face of a cylinder-and-core grinding machine produces a shift in the table guides, causing the table to deviate 45 microns from true linear displacement. Performance can be affected even more by the heat generated in electric motors, bearings, gear-boxes, hydraulic systems etc. Thus, oil heating in the hydraulic systems of power heads in standard-unit machine tools can increase oil losses and decrease feed. As a result, the duration of the working cycle in the machine or automatic machine line spontaneously increases and productivity falls. It is practically impossible to make accurate allowance for thermal effects.

Chemical energy also has an effect on machine performance. Air containing moisture and aggressive elements can cause corrosion in various machine parts. Emulsion used to cool a tool may drip onto essential machine parts, especially the electrical system, causing premature failures.

Electromagnetic energy in the form of radio waves electromagnetic oscillations) permeates the space around a machine and may affect the performance of the electronic apparatus, which is being increasingly employed in modern machine tools.

Thus, all forms of energy attack the machine and its working parts, initiating a great many undesirable processes and creating conditions making for technically inferior performance.

B. *Reversible processes affecting efficiency*

Before dealing with the methods by which these harmful influences may be combated, it is appropriate to examine briefly the processes that cause a machine to lose its working efficiency.

Some processes occurring in a machine and affecting its performance are reversible, since they alter the parameters of parts, units and the entire system within given limits, without tending to cause progressive deterioration.

The most typical example of a reversible process is the deformation of machine parts and units which occurs under the influence of external or internal forces. The sources of deformation in machine tools include not only deformation of the parts themselves, but also deformation at surface junctions, e.g., slideways, bearings and other linkages. Deformation of parts and junctions alters the relative positions of machine units, including the position of the tool and the workpiece. The result is a loss of precision, the machine's most important technical feature. When the forces change, so does the deformation; and when the stress is removed, elastic recovery takes place and the machine parts return to their original positions. It is for this reason that the deformation process is regarded as reversible.

If circumstances arise in which the forces change periodically and very frequently, vibration of the machine units occurs, i.e. rapid deformation changes of minor magnitude. Vibration also seriously affects the quality of work. It usually results in inferior surface finish.

Another example of a reversible process is the temperature deformation of machine parts and units.

Heat production in the cutting zone or in friction couplings and ambient temperature variations lead to temperature deformations which alter the original positions of machine units and consequently reduce precision. Thus, observation of the position of a lathe spindle has shown that after some hours of operation (three to seven hours) the spindle is gradually displaced, owing to the heating-up of the headstock face. The displacement reaches 20 to 120 microns and then stops, a certain degree of heat exchange being established. After the machine has been switched off, the spindle gradually returns to its former position.

Machine tools can sometimes be adjusted to reduce inaccuracies due to temperature deformation, but this makes their operation more difficult.

Accuracy of work is particularly affected by temperature deformation in precision units and framework members.

C. *Irreversible processes affecting efficiency*

Whereas reversible processes occurring in a machine tool lower its efficiency, as compared with its potential performance in the absence of deformation, temperature effects and the like, irreversible processes result in the progressive deterioration of the machine's performance with time.

The most typical irreversible processes in machines are wear, corrosion, the gradual redistribution of internal stresses and creep (the slow building-up of deformations).

The most important cause of loss of efficiency in machine tools is wear of machine parts. Wear is the result of a process of gradual change in the dimensions of the surfaces of machine parts under the influence of friction. The process of wear arises out of numerous complex physical phenomena occurring on the friction surfaces of machine parts.

As the surfaces interact, they deteriorate and give off minute particles. At various points of contact, the temperature rises, changes occur in the structure of the surface layers and there develop chemical processes and processes connected with the molecular attraction of the contiguous materials.

The most common types of wear met with in machine tools are the following.

Abrasive wear, in which abrasive particles found on friction surfaces attack the surfaces by cutting or scratching and produce tiny chips. The particles usually enter the lubricating fluid from the outside and travel with it to the friction surface, but they can also be produced by wear in the couple itself, or they may be hard structural components at one of the abutting parts. In many cases, therefore, abrasive particles cannot be completely eliminated from the friction surfaces of machine parts. Even with efficient oil filtration and the isolation of friction surfaces, conditions for abrasive wear continue to be present (2).

Fatigue in surface layers manifests itself in the scaling of minute particles of metal from the contact surfaces of machine parts. The appearance of fatigue in the surface layers does not mean the complete breakdown of the part, but there is usually a speeding-up of the destructive process (gradual chipping).

Plastic deformation (warping) of surface layers is usually manifested in a displacement of the metal beyond the contact surface. It occurs as a friction, accompanying the process of wear, and in the absence of relative sliding motion. This type of failure is typical of materials having plastic properties.

In practice, the various kinds of surface deterioration develop concurrently, rarely occurring in pure form. To each type of friction surface there corresponds a basic form of deterioration, determined by the mechanical properties of the material, the lubricant, the magnitude of the stresses applied, the operating speed and other factors.

All processes occurring in a machine, whether reversible or irreversible, affect its performance, causing errors, reducing the quality of the technological process and necessitating periodic overhaul.

III. Principal Methods of Increasing the Durability and Reliability of Machine Tools

A machine tool's reliability and durability are the indicators of its performance as a function of time: that is to say, they define the magnitude and nature of the changes in its main characteristics which take place in the course of its operation. A machine tool must have high initial qualitative and quantitative indicators, but that alone is not enough to make it an efficient machine. Those indicators must be maintained in the course of its operation.

A. *Durability*

The durability of a machine tool is its ability to carry out its operational functions with minimum expenditure for the replacement of worn parts, readjustment, repairs and servicing. The smaller the total money and time spent on maintaining the efficiency of the machine tool throughout its period of use, the greater its durability (3).

As the indicator of a machine tool's durability, one may use the coefficient of durability n_D, which equals the ratio of the operating time to the sum of the operating time and the time the machine is out of action for repair

$$\frac{T_o}{T_o + T_2} = \frac{1}{1 + \sum_{i=1}^{n} \frac{\tau_i}{T_i}} \quad \text{(Equation 1)}$$

where:

T_o is the operating time of the machine tool;

T_2 is the time the machine tool is out of action for repair;

T_i is the service life of the nth part or unit of the machine tool;

τ_i is the time (amount of work) required to repair the nth part or unit, including dismantling, reassembly and adjustment;

n is the number of repairable parts of the machine tool.

The coefficient of durability may vary from 0 to 1. The higher its value, the more durable the machine tool.

The time the machine tool is out of action depends upon the service life of its component parts and units and the amount of work required to repair them.

Stoppages of the machine tool which lower its coefficient of durability may have the following causes: breakdown of individual parts, loss of efficiency of drives and mechanisms, changes in the initial service characteristics of the machine tool (precision, freedom from vibration), and so forth.

The coefficient of durability should be calculated on the basis of the machine's entire period of operation, or, at least, of a period equivalent to the length of its maintenance cycle (the length of time before a major overhaul becomes necessary).

B. *Reliability*

The reliability of a machine tool is the indicator of its ability to carry out its functions continuously for a given period of time.

Uninterrupted operation is an important requirement for modern industrial equipment. Flow-line methods of production, where the work is transferred from machine to machine, and automatic production lines make it essential for every unit to operate without interruption.

The reliability of a machine tool is determined on the basis of indexes of probability. It may be defined as the probability (p) that the machine will operate without breakdown for a given length of time under normal operating conditions. If the probability that a machine tool will operate for one year without breakdown is $p = 0.95$, for example, this means that out of a large number of machine tools of the model in question an average of 5 per cent will lose its efficiency in less than one year of operation.

What does "loss of efficiency" or, as it is called in reliability theory, "failure" mean in relation to machine tools? Does a "failure" occur, for example, when it becomes necessary to change a drive belt or adjust a clutch?

The meaning of "failure" must be defined in the light f analysis of the operating and servicing methods used r machine tools of the given type. Brief "interventions" y the operator in the work process and the adjustment f the machine tool, when provided for in the servicing nstructions and resulting from the relative imperfection f the machine tool itself, should not be included under he heading of "failures" (breakdown).

Thus, for example, the adjustment and replacement of tool, the adjustment of individual mechanisms and preventive maintenance are included in the standard unning adjustments and between-overhaul servicing of nany modern machine tools.

The more highly perfected a machine tool is, the fewer such "legitimate" stoppages it will have and the more suitable it will be for continuous operation. Thus, in order to assess the reliability of a machine tool one must take into account all interruptions of its operation (stoppages) which are not provided for in the servicing plan.

The most convenient period of time to select for the operation of the machine tool with a given degree of reliability is the period between two scheduled overhauls. The higher the guaranteed probability of operation without failure, (*p*) is, the more reliable the machine tool.

Of great importance for machine tools is reliability from the point of view of output quality, i.e., from the point of view of ensuring the desired precision of machining and quality of surface finish.

The production reliability of a machine tool, which is an index of its capacity to continue to satisfy the qualitative requirements of the production process for a given length of time, can also be evaluated from the probability that the machine tool will satisfy those requirements throughout the period between overhauls or for the period before intermediate overhaul, at which any loss of precision by the machine tool is made good.

The reliability and durability are the characteristics which define a machine tool's capacity to realize its technical potential in actual operation, its serviceability and its degree of perfection.

C. *Methods of combating harmful influences*

To improve the reliability and durability of machine tools, it is necessary to combat the harmful influences which result in loss of efficiency.

The designer, the technician and the operator always have at their disposal a number of ways of achieving high indexes of reliability and durability.

First of all, the machine must have high resistance to external influences. The units and mechanisms which make it up must be sufficiently sturdy, must be built on the frame principle, must have the smallest possible number of members etc., so that they will withstand loads, undergo the least possible deformation and be as free as possible from vibration. Wear-resistant anti-friction materials must be used for friction couples, while all points of friction must be protected from dirt and thoroughly lubricated. Observance of these rules lays the foundations for good wear-resistance.

The causes of possible failure must be borne in mind in the design of the entire machine tool and its units, and precision mechanisms must be protected from shocks and other influences (4).

The correct placement of driving gear, symmetry of design and the use of materials with low coefficients of linear expansion help to improve a machine tool's resistance to temperature deformations.

Corrosion is combated by protecting the machinery with special coatings and paints and by the use of additives in oils and coolants.

The above-mentioned and other similar measures will result in the production of highly perfected machine tools of advanced technical performance.

The latest advances in mechanical engineering, materials and chemistry (lubricants and plastics) are continually being brought into use in up-to-date machine construction.

The possibilities of combating harmful processes are not unlimited, however. There are no completely wear-resistant materials, it is practically impossible to exclude all but liquid friction in all mechanisms and there are no materials which do not suffer deformation and do not change their dimensions with temperature fluctuations.

When it is also borne in mind that the sources of internal and external influences on the machine tool remain and that increasingly exacting demands are being made as regards output quality, it will be seen that the above-mentioned methods of combating harmful influences, while essential, are inadequate, being limited by the level of development of one or another field of technology—for example, by the possibilities of producing wear-resistant materials.

The second way to increase the reliability and durability of machine tools is to use the most highly rationalized methods of operating and maintaining equipment.

The method of operation of a machine tool determines, to a great extent, its rate of wear and the rate of development of other processes resulting in loss of efficiency.

Systematic supervision of the functioning of the machine tool and of the lubrication of its moving parts, prompt adjustment of its various mechanisms, regular care and protection from accidental blows and damage are all essential conditions if the machine is to have the durability for which it was designed.

The system of planned preventive maintenance in operation in Soviet factories embraces not only overhaul operations proper, but also a complex of preventive operations which form part of the interoverhaul servicing system.

Both the machine-tool operator and the members of the maintenance staff (fitters, greasers, belt-drive servicemen and electricians) take part in the interoverhaul servicing operations.

Interoverhaul servicing includes checks to ensure that the equipment is in good condition, that it is being operated correctly, that necessary adjustments are being made and minor faults corrected, and that proper lubrication is maintained.

In addition, the services included in the periodic overhauls, such as cleaning, changing the oil and flushing the lubrication system, and checking the equipment for precision and rigidity, also help to create proper conditions for correct operation.

In the operation of equipment, the protection of friction surfaces from dirt is of great importance. The protection of friction surfaces from atmospheric dust, abrasives and chips from the work material considerably affects their wear-resistance. It is particularly important to protect the surfaces if the surrounding atmosphere has a high abrasive content. For example, when polishing machines are in operation, abrasive particles from the polishing discs accumulate in great quantities in the air and on the surfaces of the machines.

In such working conditions, therefore, rational operating procedures are extremely important, i.e., changing and filtering of lubricants, protection of mechanisms from abrasives, removal of dust from the working area, removal of the products of grinding and polishing, e.g., by magnetic separation, etc. (5).

The nature of the material being worked is an important factor in the fouling of the machine surface. When cast-iron is worked on lathes, milling machines or other machine tools, damage is caused by scale or particles of grit falling onto the mechanisms; in the case of aluminium alloys, the harmful elements are hard aluminium oxides. Thus, the rate of wear of lathe slides in light machining operations, even with shields (which only partially protect the slides), is three to four times higher in the machining of aluminium alloys than in that of steel or cast-iron parts.

This demonstrates the need for more effective ways of protecting the slides in the machining of aluminium.

In some factories, machine tools may be seen operating without slide shields, the slides being protected only by felt padding. Measurements have shown that in such cases slide wear is two to three times greater.

In machine-tool operation, therefore, careful attention should be given to the use of various protective devices to prevent the fouling of key parts (6).

It is of great importance when operating machine tools to ensure that the lubrication system functions without interruption.

Defects in the lubrication system may cause accelerated wear and the breakdown of key parts of the machine. For example, if the flow of oil to the spindle of a polishing machine is cut off, not only are the sleeve bearings damaged, but the spindle is often heated to the point where heat cracks appear on its surface and it breaks down. While working with machine tools, operators have noticed that abrasive and other dusts in a state of suspension in the air settle on the bed guides and combine with the oil to form an abrasive mixture.

This accelerates the process of wear, especially if the machine with oiled slides has been idle for a time. The extent of wear may increase by 30 per cent. For this reason, experienced workers clean the slides thoroughly at the beginning of their shifts, particularly after non-working days.

Wear depends upon the hardness of the abrasives falling into the lubricant. In ascending order of abrasive capacity, these particles may be rated as follows: steel and cast-iron filings; scale; grit; and cutting partic[les] from polishing discs.

It is also desirable when operating machine tools [to] check the wear of their key parts, particularly the slid[es]. This may be done with special wear gauges developed [in] the USSR (3, 7), which measure precisely the amount [of] wear of the slides in industrial operation. The extent [to] which deterioration can be corrected depends upon [the] methods and technological processes employed [in] machine-tool maintenance. In wear-resistance, accura[cy] and other characteristics, reconditioned parts or units should be as good as new ones.

The system of maintenance should be so organized that the restoration of the efficiency of equipment requires a minimum expenditure of time and resources.

A third way of improving and maintaining the technical characteristics of a machine tool is to isolate the machine from harmful external influences. This method is particularly applicable in the case of precision machines which are required to turn out a high-quality product.

Thus, in order to reduce temperature deformation, precision machines are placed in special temperature-controlled rooms or shops equipped with special devices to maintain the desired temperature, usually 20 C. For example, co-ordinated boring machines, which are required to be exceptionally accurate in performance, are generally operated in temperature-controlled rooms; where that is not possible, each machine is placed in a separate room, where it can be better isolated from temperature changes, dust in the atmosphere and the vibrations of other machines.

Insulating machines from vibrations is also one of the methods of increasing their precision. Many machine tools and other machines and equipment operating in any part of a factory subject the bed on which they rest to periodic stresses. The resulting vibrations are transmitted to other machine tools and if they reach a certain degree of intensity and frequency, they can lower the quality of performance of the latter substantially. The usual method of insulating machine tools from vibrations is to set them on individual beds, 2–3 metres deep in the case of medium-sized precision machines and up to 5–6 metres deep in the case of some heavy and special-purpose machines.

Although placing the machine tool on an individual bed considerably improves its resistance to vibration, the process is a laborious one and makes it difficult to move the equipment about in the shop. To an increasing extent, therefore, machine tools are being placed on special resilient supports or vibration dampers. The resilient component consists of steel springs or grids, plastic packing, rubber, cork etc. If they are given the proper degree of rigidity, they damp vibrations transmitted from other machines and equipment.

Devices for removing dust from the air and strict atmospheric-dust control are other widely used means of improving the accuracy of performance of machine tools. In some cases, there are standards which specify the permissible quantity of dust particles per cubic centimetre of air. This procedure not only is essential in connexion with the manufacture and assembling of certain key parts f instruments, but also helps to maintain the efficiency f the machine tools themselves, since it considerably educes the quantity of abrasives which can fall on their riction surfaces.

Isolating the machine tool from temperature changes, ibrations, dust and other external influences increases its fficiency, but this method has its limitations also.

First, internal causes of error remain, for example, the heat generated by the working mechanism of the machine tool, abrasive particles produced by wear of the machine's parts and vibrations produced by cutting and by the operation of the mechanisms of the machine itself.

Secondly, complete isolation is difficult to achieve because external influences are variable and, to a certain extent, indeterminate in nature. Thus, the intensity and character of external vibrations affecting the tool depend upon the operation of other machines and vary quite widely, while insulation from vibration is most effective only for vibrations of certain frequencies.

Thirdly, the very principle of isolation from external influences stems from an old non-cybernetic view of mechanical error as something which can be eliminated.

For these reasons, there has been a growing tendency in recent years to use a fourth means of improving the efficiency of today's complicated machine tools, namely, the use of special mechanisms which automatically regulate the parameters of the machine. The use of these mechanisms makes it possible to maintain the fundamental characteristics of the machine over a long period of use, through interaction with the environment, through the automatic reaction of the machine to changes in its operating conditions. A complicated machine should possess the function—similar to that of a living organism of automatically recovering its lost efficiency.

Such mechanisms are already being used on machine tools, ranging from the simplest devices which automatically eliminate gaps produced by wear, break the kinematic circuit in case of overloading and ensure uniformity of stresses within the mechanisms, to systems which restore accuracy of performance, replace worn-out tools, react to the effects of temperature etc. For example, the following controls are coming into use: automatic regulation of the kinematic precision of the rolling chain in gear-cutting machines; automatic regulation of the thickness of the oil layer in the slides in vertical boring and turning machines; active control and automatic minor adjustments in polishing machines; automatic elimination of vibration and imbalance in lathes; automatic compensation for wear in the tables of certain types of machine tools; and other self-regulation systems (8).

These automatic regulation systems are opening up broad prospects for the development of reliable and long-lasting machines, but they require that even closer attention be given to the methods of maintaining and operating them. The more complicated the equipment used and the better its quality, the more important the correct organization of machine-tool servicing and maintenance becomes.

V. Need for dependability and continuity of service of machine tools meant for use in developing countries

The indexes of dependability and continuity of service of a machine tool are the most important characteristics of its quality. They determine the duration and stability of the tool's retention of its initial parameters (precision, output, ease of maintenance, efficiency etc.), its adaptability to different operating conditions and the continuity of service of separate mechanisms.

Insufficient dependability and continuity of service involves a considerable increase in expenditure for the maintenance and repair of machine tools, especially under intensive use of the equipment and in unfavourable operating conditions. In quite a number of developing countries, comparatively strained conditions of exploitation of technological equipment prevail. Such conditions are accounted for by the high humidity and temperature, fewer opportunities for the production and acquisition of spare parts and for the repair of machine tools, the more frequent employment of less well-qualified workers and the absence of production within the country of the types of machine tools being used.

In the case of the developing countries, therefore, it is especially important to give consideration to all the major aspects of the problem of the dependability and continuity of service of machines and machine tools, as this is the only way to minimize the expenditure of time and means involved in breaks in the normal operation of machines.

In the Soviet Union, this problem is given serious attention. There are planning and large-scale implementation of measures aimed at raising the dependability and continuity of service of machines of different types. The development of scientific-research works in this field, the theoretical elaboration of the problem and the analysis and summing up of data on the exploitation of machines permit the formulation of sound means and the use of different methods to increase the operating capacity of machines.

A. *Special methods of creating lasting units*

When designing and modernizing machine tools, as well as when assessing their working capacity, it is essential to take into account all the major possibilities of improving the dependability and continuity of service of their various units and parts. There are well-known methods for prolonging the life of parts—for example, the use of wear-resistant materials, increased precision in the machining of separate parts, the lubrication of surfaces and prevention of their soiling.

Nevertheless, in order to improve the wear-resistance and to prolong the life of different parts and mechanisms, it is essential also to employ special principles of designing and calculation, which are briefly described below.

1. *Principle of minimum influence of wear on working capacity of mechanism*

In order to design lasting machines and machine tools, it is essential to select for a mechanism that design scheme in which the wear of interconnexions only minimally affects its normal operation. The value of interconnexion wear does not yet, in itself, characterize the degree of break in the normal operation of a mechanism; that is, with the same wear, mechanisms of the same kind may, in one case, cease to operate normally, while, in another case, they may continue to operate for a long time.

In the Soviet Union, the principle outlined above is taken into account in the development of new machine tool designs: when arranging the main units of a machine tool and analysing the acting forces, e.g., in multiple-tool semi-automatics, internal-grinding machines etc.

2. *Principle of uniform wear*

A break in the normal operating of mechanisms which is brought about by wear often depends not so much upon the extent of wear as on the non-uniformity of its distribution on the surface of friction. For example, non-uniform wear along guide screws results in a decrease in the accuracy of movement of rests or beds; non-uniform wear among the contour of the cam gear distorts the character of conveyed movement; non-uniform wear of straight-line motion guides adversely affects the accuracy and vibration resistance of machines. When designing the main machine elements which are subject to friction, the designer must strive to reduce the non-uniformity of wear and thus to create conditions under which the mechanism will retail its working characteristics for a longer period of time.

Wear, temperature deformations, violations of the lubrication régime etc. lead to the deterioration of the original parameters of a machine tool. The usual methods of combating these phenomena, e.g., compensation of wear and removal of gaps, only partially correct the indexes of a machine tool.

The most progressive method is one which involves the creation of special mechanisms to restore automatically the characteristics lost and to remove possible disturbances. In the Soviet Union, the work is conducted along these lines. As a result, mechanisms have been developed for the automatic correctional setting-up of machine tools in case of tool wear, rise of cutting force, disturbance in the smoothness of motion of rests and beds, wear of guides etc.

The equipment and machines incorporating the principles described above will, other conditions being equal, work longer and require less expenditure for their repair and maintenance.

VI. Testing of Technological Dependability of Machine Tools

In order to assess the dependability of a machine and the probable continuity of its service, special tests should be conducted to obtain an objective evaluation of the machine's qualitative indexes. In the case of machine tools, such tests should, first of all, aim at assessing the precision of their work throughout the period of their use. In the USSR, methods of testing the technological dependability of metal-cutting lathes are being developed.

The technological dependability of a machine tool is its capacity to retain the qualitative indexes of the technological process (precision of machining and quality of surface) during a given period of time. When machine tool is exploited, its qualitative indexes, which are affected by different processes, gradually change.

It is essential that a new machine tool should not only give the required precision in machining, but also that it should retain it within the specified limits during the interrepair period. To attain this precision, technological dependability tests should be conducted. These tests are designed, first, to assess the reserve in the precision of machining possessed by a given machine tool and secondly, to give some prognosis as to the period of time during which that reserve will be present. When conducting such tests, one must evaluate the probability of faultless (from the point of view of precision) operation of the machine tool for the given period of time—usually during the interrepair period or until the average repair.

Processes of varying speed result in a change in the various parameters—geometric, kinematic, force, precision etc.—of a machine tool, which leads to precision failures.

Rapid processes, such as vibration by cutting and relaxation vibration by friction in the guides, lead to dispersion of sizes of machined parts and to errors in the initial setting-up of the machine tool.

Processes of average speed, such as temperature deformations of machine-tool units and tool wear, lead in time to displacement of the initial level of setting-up of a machine tool.

Finally, slow processes, such as wear of guides and warping of frames and posts, lead to worsening of the geometric indexes of a machine tool and, as a result, to a distortion of form of machined parts, as well as to change or errors in the initial setting-up and an increase in the zone of dispersion of sizes of machined parts.

When testing the technological dependability of a machine tool, it is essential, following specially devised methods, to assess the change over time of its initial qualitative indexes under the influence of processes of varying speed, i.e. to determine how the precision reserve is spent during the machining of parts with given allowances. This test will yield objective indexes of a machine tool's technological dependability and provide a basis for finding the most rational methods of improving it.

For such a test, one selects a typical part with the most characteristic demands as to shape and size to be attained by machining. The régime and methods of machining are fixed, proceeding from the most difficult operating conditions for which the machine tool was calculated.

The calculation of technological dependability and the test of the machine tool's parameters are conducted using methods based on the theory of probability, as the dispersion of sizes of machined parts and the processes accompanying machining are incidental values, or functions. Let:

X = size of a machined part (incidental value)
t = time of work of the tested machine tool
δ = allowance for machining
D_{min}; D_{max} = allowed minimum and maximum sizes of the part (i.e., $\delta = D_{max} - D_{min}$)

The value of the initial setting-up of a machine tool (X_H) has a dispersion range (A_H), which, by the normal law of distribution, can be expressed by $A_H = \sigma \cdot \sigma_H$, where $\sigma \cdot \sigma_H$ is the root mean deviation of the setting-up error.

In addition, an instantaneous dispersion of sizes of the machined part takes place (dispersion range $A = \sigma \cdot \sigma$).

The required level of the initial setting-up of a machine tool with a given parameter (D) will be:

$$X_H = D_{min} + \frac{A_H}{2} + \frac{A}{2} \quad \text{(Equation 2)}$$

or, when adding by the theory-of-probability method and the law of Gauss:

$$X_H = D_{min} + 3\sqrt{\sigma^2 + \sigma_H^2} \quad \text{(Equation 3)}$$

When assessing the precision possibilities of a machine tool, it is essential to assess also the error in shape, $\Delta\phi = X_{max} - X_{min}$, as the difference between the maximum and minimum sizes of the machined part. The shape error depends upon the initial inaccuracy of a number of machine-tool units. Thus, for example, inadequate roundness of the part depends first of all upon the inaccuracy of the spindle unit, specifically of the spindle bearing.

Errors of shape in length depend upon the inaccuracy and wear of machine-tool units, e.g., guides, which affect the motion of the rest as to its parallelism to the axis of the part rotation. Shape errors involve also the expenditure of a part of the total allowance on machining (δ).

Some time after the machine tool begins operating, a displacement of the initial level of setting up, caused by average speed processes, takes place. For the readjustment period t_1 (changes or readjustment of tool) or for the period of stabilization of temperature deformations, the precision indexes of the machine tool deteriorate by some value (Δm).

It should be kept in mind that function $X_H(t)$, which determines the value of Δm, is incidental, and it is essential, in the process of testing, to assess its average value (the mathematically expected value) and dispersion parameters.

Then, taking into account the initial inaccuracy of the machine tool, the action of rapid processes and the displacement of the setting-up level caused by average speed processes, one finds the precision reserve, δ_T, allowing slow processes equal to:

$$\delta_T = \delta - (A + A_H + \Delta\phi + \Delta m) \quad \text{(Equation 4)}$$

or, adding to the theory-of-probability method:

$$\delta_T = \delta - \left(\sqrt{\left(\frac{A}{2}\right)^2 + \left(\frac{A_H}{2}\right)^2} + \sqrt{\left(\frac{A'}{2}\right)^2 + \left(\frac{A'_n}{2}\right)^2} + \Delta\phi + \Delta m\right) \quad \text{(Equation 5)}$$

Here, possible changes of dispersion ranges A and A_H by the end of the interadjustment period are taken into account.

Accuracy reserve δ_T will be exhausted after some period of time: $T = nt_1$. This will result from: (*a*) The enlargement of range A caused by the enlargement of gaps in the joints, changes in rigidity and other characteristics influencing rapid processes (vibration etc.); (*b*) the enlargement of range A_H caused by wear of machine-tool units; (*c*) an increase of $\Delta\phi$ caused by wear, warping and other phenomena in a number of units (e.g., non-roundness increases with wear of the spindle-bearing races and errors of shape in length increase with wear of rest guides); and (*d*) an increase of Δm, owing to redistribution of internal stresses and deformations in machine-tool parts which lead to an increase of their "pliability" when irregularly heated, to an increase in the speed of dimension wear of the tool, with the increase of vibration etc.

These changes can be determined by long operation testing. For a particular machine-tool design, however, the data obtained will, as a rule, lose actuality because the design will become obsolete by that time.

Therefore, technological-dependability tests should be brief and should be aimed at determining the precision reserve (δ_T) and the precision reserve coefficient ($K_T = \frac{\delta}{\delta_T}$) for the main parameters of the machine tool being tested.

The value of K_T is a very important characteristic of the technological dependability of a machine tool.

In order to prognosticate the decrease in the accuracy of a machine tool in the course of time, owing to wear of its base units, it is essential to calculate the shape of the worn surface and to assess its influence on the accuracy of machining. Such calculations have been devised by the author of the present paper.

In evaluating the average speed of wear and its dispersion, on the basis of operating conditions and data of wear tests of materials, it is possible to calculate, with a sufficient degree of probability, the duration of operation of a machine tool with the required precision of machining, as well as the probability of its faultless operation.

For modern machine tools, the technological-dependability test is an indispensable part of the complex testing which permits the assessment of the major technological parameters of the tool and which provides the beginning data for the most effective improvement of its design.

VII. Organizational principles for machine-tool maintenance and servicing systems

In order to keep equipment permanently in working order with the minimum expenditure of time and resources, it is necessary to institute a maintenance system with strict rules concerning the basic measures to be taken for this purpose.

In the Soviet Union, a uniform planned preventive-maintenance system has been especially formulated and is applied in all branches of industry. This system, which is now thirty years old and which has been steadily improved, has shown its great possibilities and the correctness of the underlying organizational principles.

The basic principles of the planned preventive-maintenance system are as follows:

1. All operations necessary to keep equipment in working order are divided into two groups:

(a) Servicing in the intervals between overhauls, which includes regular checking of the equipment and correction of faults, preventive measures, adjustment of mechanisms and occasionally replacement of quick-change parts;

(b) Periodic overhauls, which are carried out in accordance with a plan laid down in advance and which represent the bulk of maintenance operations.

2. Periodic overhauls, in accordance with the plan, are subdivided into various types, depending upon the scale of the operations. There are usually three types of overhaul: minor (type I); intermediate (type II); and major (type III).

A machine tool which has undergone major overhaul must be able to meet all the basic demands placed upon a new tool.

3. All overhauls of a particular model of machine tool under the plan are carried out at regular intervals, the intervening periods being called "intervals between overhauls". The length of the interval is one of the main characteristics of the maintenance system and depends upon the type of machine tool and its operating conditions.

4. The maintenance system also fixes the pattern of the maintenance cycle, i.e., the number of planned overhauls and the order in which they are carried out. Most machine tools now have a cycle of nine planned overhauls, in the following order: I-I-II-I-I-II-I-I-III.

This pattern is the same for all types and models of metal-cutting lathes and all operating conditions. The period of time over which it is completed, i.e. the period from one major overhaul to the next, is known as the maintenance cycle.

5. The expenditure of labour for a given type of overhaul is indicated by the number of machine-hours and man-hours allocated for it under the plan.

The relationship between the volumes of major, intermediate and minor overhaul work is the same for all machine tools.

6. Machine tools are broken down into different categories according to their degree of complexity. Each category is assigned a conventional coefficient which compares the labour consumed by a machine tool in that category with the amount consumed by a standard tool. The tool taken as the standard was a general-purpose turning-lathe of average complexity, whose labour consumption is indicated by a complexity coefficient R = 10.

7. The standard values for the volume of overhaul work are average figures and are used to plan the total volume of overhaul work in a workshop or enterprise. Deviations are allowed for, depending upon the actual state of a machine tool when overhauled.

The basic idea behind the principles underlying the maintenance system is that by establishing a maintenance cycle with a permanent pattern, preserving the average ratios between the volumes of work involved in the different types of overhaul and comparing different types of equipment by placing each in a maintenance complexity category, it is possible to plan maintenance in advance and to calculate the labour, equipment and time required.

On the other hand, the system allows for the variety of equipment and working conditions to be found in industry. It provides for different intervals between overhauls, allows for deviations from the average values for labour consumption and lays down a whole complex of preventive measures to prevent sudden breakdowns and cumulative wear.

Standard rates have been worked out in the Soviet Union for determining the expenditure of labour in maintenance of technological equipment (1). From the standard rates it is possible to calculate in advance the periodicity of maintenance, the amount of time and resources to be expended on it, the amount of labour and equipment required, the cost of maintenance operations, the quantity of spare parts and other necessary data.

The standard rates are drawn up in such a way that the labour consumption in the overhaul of each unit of complexity is determined; this value is then converted for the tool in question. Thus, according to the 1962 rates, the time to be spent per maintenance unit should not exceed the figure shown in table 3.

Table 3

STANDARD RATES FOR LABOUR CONSUMPTION IN MAINTENANCE OF TECHNOLOGICAL EQUIPMENT

Overhauls and preventive maintenance operations	*Number of hours* Mechanics etc.	*Number of hours* Machine tools
Cleaning	0.35	—
Checking accuracy	0.4	—
Minor overhaul (I)	0.75	0.10
Intermediate overhaul (II)	4.1	2.0
	16.5	7.0
Major overhaul (III)	26.0	10.1

Thus, the labour consumption ratio for planned overhauls is:
I : II : III 6.1 : 23.5 : 36.1, or approximately 1 : 4 : 6.

These standard time rates are intended for planning and calculating the labour force required. In order to determine from them the number of hours required for maintenance of a given model of machine tool, the figures given must be multiplied by the complexity coefficient for the machine tool concerned.

For example, in the case of a thread-grinding machine with complexity coefficient R = 17, 17.(26 + 10.1) = 615 hours which should be planned for major overhaul, 400 hours for intermediate overhaul and so on. The standards give examples of how to make the calculations and tables of complexity coefficients for different types and models of machine tools.

Table 4 gives the most characteristic complexity coefficients for certain types of machine tools.

The length of the maintenance cycle (in hours) is calculated from formulae in which the operating conditions of the tool are expressed by empirical coefficients.

For metal-cutting lathes the value of T can be calculated from the formula:

$$T = 24{,}000\, \beta_1\, \beta_2\, \beta_3\, \beta_4 \text{ hours}$$

Table 4

CHARACTERISTIC COMPLEXITY COEFFICIENT, SELECTED MACHINE TOOLS

Type of machine tool	Complexity coefficient
1. Lathes, medium size	9-13
2. Heavy lathes	17-19
3. Vertical drilling machines	3-8
4. Radial drilling machines	6-12
5. Open-side jig borers	20-35
6. Horizontal borers, medium-sized	16-18
7. Cylinder-grinding machines	10-15
8. Gear-cutting machines, medium-size	10-12
9. General-purpose horizontal milling machines	8-14
10. Planing machines, medium-sized	12-15

where β_1 is the coefficient for the type of production, with values $\beta_1 = 1$ for mass and large-series production, $\beta_1 = 1.3$ for series production and $\beta_1 = 1.5$ for small-series and unit production. The coefficient β_2 relates to the type of material worked on the machine tool, with values $\beta_2 = 1$ for structural steel, $\beta_2 = 0.7$ for high-strength steel, $\beta_2 = 0.75$ for aluminium alloys and $\beta_2 = 0.9$ for cast-iron and bronze. The coefficient β_3 relates to operating conditions, with values $\beta_3 = 1$ for normal operating conditions, $\beta_3 = 0.7$–0.8 for dusty and humid conditions, $\beta_3 = 1.1$–1.2 for high-precision tools in machine-shop conditions and $\beta_3 = 1.3$–1.4 for tools housed separately. The coefficient β_4 relates to the size of the machine tool, with values $\beta_4 = 1$ for light and medium-sized tools, $\beta_4 = 1.35$ for heavy tools and $\beta_4 = 1.7$ for especially heavy and special-purpose tools.

The formula for the interval between overhauls (t), with nine planned overhauls per cycle, is $t = \frac{T}{9}$ hours.

When equipment is worked on a single-shift basis, its rated annual working time is 2,000 hours.

The interoverhaul period can be determined roughly from these functional relationships and then corrected in accordance with the specific operating conditions and methods.

Suppose, for example, that it is necessary to determine the duration of the maintenance cycle for a heavy turning lathe (complexity coefficient $R = 17$, $\beta_4 = 1.35$) working two shifts in small-series production conditions ($\beta_1 = 1.5$). The tool processes mainly high-strength steel and cast-iron $\left(\beta_2 = \frac{0.7 + 9.0}{2} = 8.0\right)$ and humidity in the workshop is very high ($\beta_3 = 0.7$).

$$T = 24{,}000 \times 1.5 \times 0.8 \times 0.7 \times 1.35 = 27{,}000 \text{ hours,}$$

or

$$T = \frac{27{,}000}{2 \times 2{,}000} = 7 \text{ years}$$

$t = 9.5$ months—the interoverhaul period.

On the basis of these data, the machine's maintenance schedule can be drawn up and the labour consumed and the time spent idly in maintenance can be determined as shown above.

There are three main systems of maintenance at industrial enterprises—centralized, decentralized and mixed.

Under a centralized maintenance system, all maintenance work is carried out at the factory with the labour and resources of a chief mechanical engineer's section and its maintenance machine shop. This kind of organization is typical for plants with a small amount of equipment.

Under a decentralized maintenance system, all kinds of maintenance operations—interoverhaul servicing and periodic overhauls, including major overhauls—are carried out under the direction of shop mechanics by so-called "shop maintenance units", which are general maintenance squads. The maintenance machine shop under the chief mechanical engineer carries out only the major overhaul of complex units. In addition, it manufactures and reconditions equipment parts for the shop maintenance units when this requires special technology.

Under a mixed maintenance system, all kinds of maintenance, except major overhauls, are carried out by shop maintenance units and major overhauls (and sometimes intermediate overhauls of large assemblies) are handled by the maintenance machine shop.

A. *Scope of each type of overhaul and determination of the service life of machine-tool parts*

The scope of the planned periodic overhauls depends upon the design of the machine tool and the conditions under which it is operated.

A minor overhaul entails the replacement or reconditioning of a small number of worn parts, the adjustment of the machinery and checks to see that the machine tool is in satisfactory condition and that its lubrication system is functioning properly.

An intermediate overhaul entails a greater amount of maintenance work, including the partial truing of the machine tool and the restoration of any precision which has been lost. It is carried out without removing the machine tool from its bed.

A major overhaul entails the complete restoration of the efficiency of the machine tool. The tool is normally completely dismantled and degreased, and its parts are sorted, on the basis of measurements and visual inspection, into three categories.

The first category covers serviceable parts which do not need reconditioning and are fit to serve for another maintenance cycle.

The second category covers parts which require reconditioning because of surface wear, deformation or other reasons. The most suitable reconditioning process is specified for each part (e.g., building up the part by welding, chromium plating or other methods, grinding to the reconditioned dimensions etc.).

The third category covers parts which it is impossible or uneconomic to recondition. Such parts are replaced with new ones made to the same technical requirements. Typical parts which fall into this category are roller-contact bearings, friction clutch plates and so forth. In order that the various parts may be correctly sorted into categories and their suitability for further service in the machine tool properly evaluated, it is essential to set maximum permissible limits of wear for them and to establish their service life.

This is an extremely complicated matter, as the parts of any machine tool have to satisfy the most varied requirements. So far, no completely satisfactory method of calculating maximum wear levels has been developed.

The criteria (characteristics) of the maximum wear of machine-tool parts may be divided into two groups.

The first group comprises criteria relating exclusively to the proper functioning of a given assembly or part. This covers such cases as the breakage of parts as a result of wear (the teeth of slow-speed worm gears); the wearing away of the case-hardened layer, resulting in a sharp increase in the rate of wear (the slide blocks of link gear); and the breakdown of liquid friction (slider-type bearings). In many cases, however, the functioning of an assembly cannot be considered in isolation from the functioning of the mechanism or the machine tool of which it is a part.

The criteria in the second group relate to the performance by the machine tool or mechanism of the functions for which it is intended. The most typical criterion of this group, as far as machine tools are concerned, is precision of machining.

Table 5, for example, gives lists of figures calculated by the author which show, for various degrees of machinery precision, the maximum wear of lathe slides on the basis of practical overhaul and operating experience.

In order to determine the service life (T) of a part, it is necessary to know the nature of the wear process in the part as a function of time and the maximum permissible value of wear (U_{max}). As, in the majority of cases, normal wear takes place at a constant rate (γ = constant), then for known values of γ and U_{max} the service life of a part will be:

$$T = \frac{U_{max}}{\gamma} \qquad \text{(Equation 6)}$$

The value of the rate of wear (γ) is determined either on the basis of measurements or from operating experience with the machine tools of the type in question.

Formula (6) for determining the service life of machine-tool parts is applicable to parts which are replaced only when they become unserviceable, i.e. when their wear has reached the value U_{max}. Quick-change parts which are replaced when the machine tool is serviced between overhauls fall into this category.

In the case of parts which are reconditioned or replaced during the periodic planned overhauls, the acceptable values of wear (U_o) will be equal to or less than the maximum permissible values (U_{max}), as the parts must not become unserviceable in the interval before the next overhaul. If the interoverhaul period, i.e. the period between two planned overhauls, is T_1, then over that period of time the wear of the part will increase by an amount γT_1. The maximum acceptable amount of wear (U_o), after which it is essential to replace or recondition a part at the current periodic overhaul, will therefore be:

Table 5

MAXIMUM WEAR OF LATHE SLIDES PERMITTED FOR VARIOUS DEGREES OF PRECISION

Maximum permissible variation in diameter of workpiece (microns)	*Class of precision at d 50–80mm*	*Maximum permissible wear of slides (millimetres) when turning workpieces with lengths of up to:*					
		25	*50*	*100* (*millimetres*)	*200*	*300*	*400*
13	1	0.16	0.08	0.04	0.02	0.013	0.01
20	2	0.24	0.12	0.06	0.03	0.02	0.015
30	2a	0.40	0.20	0.10	0.05	0.035	0.025
60	3	—	0.40	0.20	0.10	0.07	0.05
120	3a	—	—	0.40	0.20	0.13	0.10
200	4	—	—	0.65	0.32	0.21	0.16
400	5	—	—	—	0.65	0.43	0.32

(measured at the point of greatest wear) which will permit those precision requirements to be satisfied. The figures in the table show only the reduction in precision due to wear of the slides, and do not take into account the influence of other factors (such as the rigidity of the slide rest, the spindle and other parts and wear of the cutting tool).

This table shows that there is a direct connexion between the permissible wear of the slides, on the one hand, and the desired precision of machining and the dimensions (length) of the workpieces, on the other hand.

When the workpieces are short and a large allowance is made for variations in their diameter, the permissible wear may be very considerable. However, operational and overhaul considerations and the need to avoid vibration of the slide rest make it inadvisable to allow the wear to exceed 0.2 mm.

In many cases, the maximum permissible wear of key parts of each model of machine tool can be established

$$U_o = U_{max} - \gamma . T_1 \qquad \text{(Equation 7)}$$

Bearing in mind that $\gamma = \frac{U_o}{T}$ (where T is the service life of the part before overhaul) one obtains:

$$U_o = U_{max} - \frac{U_o \cdot T_1}{T} \qquad \text{(Equation 8)}$$

whence:

$$U_o = \frac{U_{max}}{1 + \frac{T_1}{T}} \qquad \text{(Equation 9)}$$

If a given periodic overhaul is the Kth since the last overhaul of the part, then the service life of the part will be $T = KT_1$ and the formula for calculating the acceptable wear will take the form:

$$U_o = \frac{K}{K+1} U_{max} \qquad \text{(Equation 10)}$$

For example, a part has a case-hardened layer 0.8 mm in depth and the maximum permissible wear is U_{max} = 0.65 mm (80 per cent of the depth of the case-hardened layer). Should the part be reconditioned if, when measured at the third periodic overhaul, its wear is found to amount to 0.55 mm?

If one calculates U_o according to formula (10):

$$U_o = 0.65 \frac{3}{3+1} = 0.49 \text{ mm}$$

The part must therefore be reconditioned; although its wear is less than U_{max}, it will not last until the next periodic overhaul.

If the maximum permissible amounts of wear and the service lives of the main parts of the machine tool are known, the scope of the various types of overhauls can be defined more accurately, the durability of the machine tool increased and the cost of maintaining it reduced.

VIII. Theoretical bases for establishing the main parameters of a maintenance system

The main parameters of a maintenance system are a maintenance-cycle pattern which is applicable to all machine tools and an interoverhaul period which takes into account the special features of the equipment and the way it is operated.

The maintenance-cycle pattern and the interval between overhauls must be such that through fuller utilization of the service lives of the machine-tool parts and assemblies, other things being equal, the equipment is idle for overhaul for the shortest possible time and expenditure on its overhaul is kept to the minimum.

In order to select the best values for these parameters, it is necessary to determine how their values influence the durability of the machine tool—the coefficient η_D (see formula (1)).

When using formula (1) in connexion with periodic overhauls, it must be borne in mind that:

(*a*) The periodicity of overhauls will be defined by the minimum service life (T_1) of the parts subject to periodic overhaul;

(*b*) At each overhaul, all parts whose service life will expire before the next overhaul must be replaced.

In order to analyse the maintenance-cycle pattern, all machine-tool parts which are subject to periodic overhaul must be divided into groups according to length of service life.

Each group comprises parts whose service life (T_i) is within the range $n_i \cdot T_1 \leq T_i < (n+1)T_1$, where n is the ordinal number of the group of parts in question and T_1 is the minimum service life, which determines the periodicity of overhauls. For the nth group of parts, the periodicity will be $n.T_1$, as parts of the first group will be overhauled after T_1 hours, parts of the second group after 2 T_1 hours and so forth. The number of groups of parts (n) overhauled at the periodic overhauls is determined from the relation $n = \frac{T_{max}}{T_1}$ where T_{max} is the service life of the most durable part.

If the maintenance-cycle patterns used are analysed from this point of view, more advantageous variants than the nine-period pattern may be found.

It is a fact that although the pattern shows the first two periodic overhauls as being of the same type (minor overhauls), this is an index only of their average scope. In reality, these two overhauls will be different from each other, as after the period T_1 (the period between overhauls), the first-group parts will be overhauled, while after the period $2T_1$ both the first-group and the second-group parts will be overhauled. The amount of overhaul work carried out on the second occasion will, consequently, be greater, although both are classified as minor overhauls, and the time and resources allocated for them are identical.

Similarly, it can be shown that the volume of overhaul work involved in the first and second intermediate overhauls in the cycle will be different in each case.

In the interest of more accurate planning of maintenance, it is therefore desirable that there should be not three, but four, types of overhaul (the fourth type being termed a complete overhaul).

As the author's calculations show (3,6), it is more advantageous from the point of view of reducing the idle time of equipment to use a six-period pattern with a I-II-III-II-I-IV cycle and a ratio of volumes of overhaul work of I: II : III: IV = 1: 2: 4: 6.

The change to a cycle pattern with four types of overhaul requires a higher level of maintenance organization and will constitute a further development of the maintenance system.

Attempts are now being made in the Soviet Union to introduce optimum maintenance-cycle patterns which take into account the work which has been done in this field. The existing maintenance system, which has been of great economic value to industry, will thus be further developed and perfected.

The length of the period between overhauls (T_1) is that basic parameter of the maintenance system which reflects the special features of the equipment in question and the nature and intensity of its operation.

The length of the period between overhauls must be determined after the maintenance-cycle pattern has been selected; it is, therefore, the second task in establishing the basic parameters of the maintenance system.

The aim in determining the length of the period between overhauls and the maintenance-cycle pattern must be to achieve the highest possible durability of the equipment. The optimum period will be that which, other things being equal, gives the highest coefficient of durability (or the minimum loss of machine time on overhauls, which amounts to the same thing).

The main consideration in selecting the optimum period between overhauls ($T_1 = T_{opt}$) is to establish such a ratio between the amount of work carried out at the periodic overhauls and the amount carried out in the course of servicing between overhauls as will make possible the minimum expenditure of labour on overhauls in the given conditions.

When the length of the interoverhaul period is extended, a larger number of parts will be replaced in the course of the servicing between overhauls. As a result of this, the durability of individual parts will be more fully utilized during the servicing interval, but the amount of assembly and disassembly will be increased.

On the basis of these considerations, the author proposes the following formula for calculating the optimum interval between overhauls:

$$T_{opt} = \frac{1.8}{K}\cdot\left(\frac{\tau_k}{\tau_1} - 1\right)(\beta - \sqrt{\beta^2 - 1})\cdot T \quad \text{(Equation (1))}$$

where T is the length of the actual interval between overhauls established in practice; K is the number of overhauls in the cycle (K = 6 or K = 9); τ_k is the actual time required for a complete overhaul (in hours) for a length of cycle K.T; τ_1 is the actual amount of time required for a minor overhaul (in hours); $\beta > 1$ is a coefficient which indicates the increase in the amount of time spent on the overhaul of machine tool parts and assemblies in the course of interoverhaul servicing because of increased assembly and disassembly work.

β is normally between 1.5 and 3. This formula permits the calculation of the value of $x = \frac{T_{opt}}{T}$ which is an index of the advisibility of lengthening or shortening the period between overhauls in the given operating conditions; i.e. it makes possible more accurate correction of the value of T established from the norms.

The coefficient β greatly influences the value of T_{opt}.

If the time spent on assembly and disassembly work can be reduced by using quick-change parts and introducing wear-compensation adjustments, the interval between overhauls can advantageously be lengthened.

If changes are made in the overhaul and operating conditions of the equipment, the interoverhaul period should also be adjusted accordingly.

Improvements in overhaul methods, in the durability of the individual parts and in the design of machine tools will be fully effective in increasing the durability of the equipment, provided that the main parameters of the maintenance system—particularly the maintenance-cycle pattern and the length of the interoverhaul period—are correctly selected.

IX. Organization of Maintenance Services at the Plant

The organization of maintenance work at the plant must provide for the execution of all technological processes necessary for maintenance operations, the receipt of spare parts from the machine-tool factory and the overhaul of individual assemblies or machine tools at special maintenance centres.

The organization of maintenance, as shown abov depends upon the types and number of machine tools .. the plant.

The plant's maintenance machine shop usually comprises the following sections or units: (*a*) a machine-too section; (*b*) a fitting shop; and (*c*) a welding shop. I large maintenance machine shops there is a furthe department for restoring and increasing the wear resist ance of parts, with sections for metallization, chrome plating, cementing, heat treatment etc.

The machine shop is headed by a superintendent, who is subordinate to the factory's chief mechanical enginee and the various sections or units are headed by foremen under the shop superintendent. Under the latter's authority also are a technological office, a planning office and other administrative units.

Shop maintenance units, as has already been shown, form part of production shops. Their purpose is to carry out interoverhaul servicing and to perform individual repair work on all the various types of equipment installed in each workshop. The scale of operation of a shop maintenance unit depends upon the system of maintenance followed at the plant.

Under a centralized system of maintenance, in which work is carried out exclusively with the labour and resources of the appropriate workshops of the chief mechanical engineer's section, the shop maintenance unit is responsible only for interoverhaul servicing. Where the workshops of the chief mechanical engineer's section have insufficient work, they are also made responsible for interoverhaul servicing.

Under a decentralized system, the shop maintenance units carry out interoverhaul servicing of mechanical equipment and all types of overhauls, except major overhauls of the most complex units. They are also responsible for interoverhaul servicing and minor and intermediate overhauls of electrical and diesel equipment.

Under a mixed maintenance system, major overhauls of production-shop equipment are carried out by mechanical and electrical repair shops.

The Model Regulations recommend the establishment of shop maintenance units in workshops where the total number of maintenance and repair operations runs to upwards of 600–700. In small workshops, independent maintenance units are not set up. Such shops are served by so-called "central district units" (one unit for several shops), which are headed by district mechanical engineers who are subordinate to the chief mechanical engineer.

Central district units are staffed by squads of fitters, who are attached to production sections, bays or shops. The size of each squad is established according to the labour requirements for the projected maintenance operations given on an annual schedule and for carrying out the interoverhaul servicing of the equipment assigned to the squad.

In choosing the particular system of maintenance for the factory as a whole, account is taken of its effect on the structure of the central maintenance-service apparatus—the chief mechanical engineer's section. With a decentralized system of maintenance, when the bulk of the work is undertaken by the shop maintenance units, it is dvisable to augment the latter's planning and accounting staff and correspondingly to simplify the structure of the central maintenance-service apparatus, making the latter responsible only for the methodical direction and supervision of the shop maintenance units' work.

The structure of maintenance services in the chief mechanical engineer's section also depends upon whether there is an independent chief mechanical engineer's section at the plant. If there is such a section, one of its functions is to ensure the correct use and planned maintenance of all power equipment.

An independent chief power engineer's section is usually set up at large plants which have a great deal of equipment and which use substantial quantities of power. In factories using small amounts of electricity and having small power installations, a combined chief mechanical engineer's and power engineer's section is formed, which includes a power-engineering office and is responsible for the work of the electrical and diesel shops.

In plants with large numbers of machine tools of the same kind and in mass production factories, it is advisable, in order to reduce machine idle time during repair, to carry out repairs by the unit system.

The essence of the unit system of repair is the removal of machine-tool units requiring repair and their replacement with spare units, either previously repaired, rebuilt or newly purchased. In metal-cutting machines, such interchangeable units include the headstock, the apron and the carriage saddle, the drive mechanism, the spindle-casing, the grinding and turret heads etc. The range of interchangeable units and interchangeable parts must be made more and more comprehensive, and the rebuilding (repair) of these units and parts must be centralized.

In addition to the unit system, there is the successive-unit system of repair and overhaul, in which the units of the assembly are overhauled in a particular sequence during normal breaks in the operation of the equipment. During meal-breaks and on rest-days and non-working shifts, different units requiring overhaul are dismantled and their worn-out parts replaced.

The successive-unit system is particularly well suited for the repair of standard-unit machine tools and other tools for which the various subassemblies are individually designed (9).

The more equipment is standardized and the more its individual units and assemblies are unified, the simpler will the organization of maintenance services become. It is expedient, therefore, in equipping any given factory, to use the minimum number of machine-tool contractors.

In the Soviet Union, efforts are now being made on a broad front to produce machine tools in various technological versions and types on a single base, to standardize regular machine parts and assemblies, and to unify construction. These measures not only reduce the cost and increase the quality of machine-tool production, but also substantially simplify their repair and maintenance.

X. Technical problems of machine-tool maintenance

In the maintenance of machine tools and other equipment, the correct choice of the technical processes to be used to restore the impaired efficiency of the various units and parts is important.

This is a somewhat complex problem, for several reasons: first, the range of repairable parts is extremely wide; secondly, the parameters of the parts have to be fully restored in repair and, in many cases, increased wear resistance and toughness are called for; and, thirdly, expenditure on repairs and idle time during repair must be kept to a minimum.

In addition to the ordinary methods of mechanical machining, extensive use is made of electroplating, metal-improvement processes, pulverization and other technical processes to restore the dimensions of the worn parts (10).

Processes to harden the surface of parts and increase their wear resistance and fatigue strength are used also. These processes include heat and thermo-chemical treatment, electric-spark surface toughening and surface toughening by rolling and shot-peening.

In repairing equipment, it may also become necessary to modernize individual units, to replace some materials by others and to economize in the use of non-ferrous metals. In some cases, therefore, bimetallic parts have to be made—e.g., slider bearings, worm wheels and lead screw nuts using bronze for the friction surface and steel or cast-iron for the main body of the part. Metallo-ceramic parts are also used—for example, iron-graphite bushings and plastic parts (11). All this calls for special equipment and skilled labour.

In the repair of machine tools, particular attention has to be given to the technical processes for reconditioning or repairing certain parts, since their quality determines the precision of the machine tool.

Normally, the most labour-consuming operation is the repair of machine-tool slides, since these determine the precision of movement of the basic units of the machine and the accuracy of their relative positions.

The technical processes for repairing worn slides are varied, and, depending upon the circumstances, may be carried out by machining at the lathe, by the use of suitable appliances or by hand.

The machining of slides by planing, milling or grinding is the most exact and productive method of reconditioning worn slides. However, its use is not infrequently limited by the factory's lack of machine tools of suitable size and adequate precision.

The repair of bed slides with the help of suitable appliances necessitates no special equipment; the appliances used for the purpose are of simple construction and can be made at any machine-building plant. But the drawback of this method is its high labour consumption as compared with machine work, since treatment with appliances normally takes place at a lower tempo and usually necessitates a certain amount of manual labour in preparing the setting bases and some rather labour-consuming work in installing and setting up the appliance. Nevertheless, it is often preferable, because it can be carried out at the site of the machine tool, so that the bed does not have to be dismantled and reassembled, and time is saved on transporting it to the repair shop and back. This method is best suited to the repair of particularly large bed slides.

The repair of slides by hand (powdering, scraping etc.) is the most labour-consuming and outmoded method, and is permissible today only in one of the following cases: (*a*) when the wear on the slides is so slight that hand reconditioning requires less time than mechanical methods; (*b*) when the equipment for mechanical treatment (machine tools and appliances) has not yet been obtained or made.

The Soviet Union has developed portable appliances for grinding and clean planing machine-tool slides in the process of repair, mechanized scraping tools and technical processes and methods for machining slides with the use of machine tools (10). Model technical processes have also been developed for repairing spindles, lead screws, precision worm couples and other key machine-tool parts.

The overhaul of the hydraulic equipment of machine tools presents special features of its own, including technical processes characterized by the use of precision and finishing work in the repair of hydraulic cylinders (honing) and hydraulic pump parts (grinding) and by checking to ensure precise clearances and relative positions in reconditioned parts returned to use.

Units are assembled with the help of universal and special appliances ensuring correct and efficient assembly.

In order to ensure accurate assembly, it is necessary to apply the theory of dimension sequences and compensators (12), since the method used to restore precision can then be selected on rational grounds; e.g., one can regulate or adjust the part, use trial and error or fit a compensator in one of the members of the subassembly.

Great importance for high-quality assembly attaches to the checking and testing of the machine tool after an overhaul.

In addition to the familiar tests for geometrical precision, efficiency, machining precision and surface quality obtained, methods of checking to determine the quality of separate subassemblies are also being introduced into the practice of machine-tool overhaul.

One may mention first the rigidity standards and methods of checking the rigidity of machine tools which have been worked out in the Soviet Union (13). For example, in the case of lathes, a load is applied to the spindle and tailstock into which the mandrels are inserted. Force is created with the help of a special dynamometer, which exerts pressure on the mandrel at an angle of 60° from the horizontal (in the direction of total cutting thrust). Under the standards applied for normal precision lathes, the permissible displacements of the slide rest in relation to the mandrel are as in table 6.

By means of rigidity testing, one can ensure a high repair quality and detect any couplings requiring more careful adjustment.

In the case of gear-milling, thread-grinding and other precision machines, it is also desirable to check the kinematic accuracy of the mechanisms linking the rotation of the blank to the movement of the tool. For this purpose, universal and specially developed tools are used.

The use of technically advanced repair and testing processes is essential to the achievement of high efficiency and economy in the overhaul of machine tools.

Table 6

Maximum machining diameter of machine tool (millimetres)		100	200	400	800	1,600
Force applied (kilogrammes)		70	200	560	1,600	4,500
Maximum displacement in relation to mandrel (millimetres)	Spindle	0.04	0.10	0.21	0.47	1.05
	Tailstock	0.05	0.13	0.27	0.61	1.40

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RESEARCH FOR THE MACHINE-TOOL INDUSTRY

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INTRODUCTION

The business of the machine-tool industry is to make machine tools, and research for the machine-tool industry must, therefore, have two main objectives: (*a*) to facilitate the design and manufacture of machine tools; and (*b*) to improve existing machine tools and develop new ones.

But machine tools are not manufactured as ends in themselves; they are essentially means to a wide variety of ends. Machine tools are made in order to make possible the manufacture of other machinery—power-stations, rolling-mills, typewriters, motor-cars etc.—and the design of machine tools, must be determined largely by the requirements of the production engineers responsible for their use. Thus, the scope of research for the machine-tool industry is ultimately determined by the manufacturing requirements of modern industry. It includes problems associated not only with metal-cutting machine tools, such as lathes and drills, but with metal-forming machines, such as presses and forging machines and with new types of machine tool, such as electrochemical machines. It probably should also include work on some types of casting machines and machines for powder metallurgy, all of which can be regarded as possible alternative manufacturing machines. The aim of research for the machine-tool industry can, therefore, be stated as being to help the designer of manufacturing machines to meet the manufacturing requirements of his customers.

Even if the customers' needs could be completely satisfied and were to remain unchanged, research would still have a part to play in making it easier and cheaper for these needs to be met. New materials, new techniques and new methods of design can all be used by the machine-tool designer in his efforts to meet his customers' requirements. Thus even though many of the basic types of machine tool used today were already in existence 100 years ago, research on their performance and construction can still be justified in terms of the contribution it can make to reducing the resources required for their design and manufacture.

Of course, the needs of users of machine tools do not remain unchanged. Today's machine tools must be more accurate, more versatile and more economical to use than their predecessors were, while, at the same time, they are required to work at higher speeds and on a wider variety of materials. The improvements have been achieved by the development of greatly improved structures, mechanisms, control systems and machining techniques, and it is to further improvements of the same kind that much current machine-tool research is directed. Although the older types of machine tool are continually being improved, they are still unable to meet all the needs of the modern production engineer. New machining processes are necessary to meet the requirements of technologically advanced industries, such as the aerospace and nuclear-power industries, which base their designs on the use of materials which are difficult, if not impossible, to machine in the conventional way. And even in the mass production industries, economic considerations emphasize the need for manufacturing processes which do not involve the wastage, as swarf or scrap, of large proportions of the raw material purchased. Improved versions of the older types of machine tool have, therefore, been supplemented by entirely new machine tools—electrochemical machines, high-energy forging machines and even, for some purposes, electron-beam and laser machines.

Conventional metal-cutting processes, which depend upon plastic deformation and shearing of the workpiece material, have been studied for many years and, although they are not yet fully understood, a considerable body of data is available on which to base the design of machine tools. Little information is yet available, however, about the mechanism of machining by lasers, for example. Thus, although the successful design and operation of these newer types of machine tools still depends upon basic research on structures and mechanisms, it requires, in addition, the backing of considerable research into the fundamentals of the processes themselves.

Nevertheless, whether it is intended to facilitate the design of a conventional machine tool or to develop a new machining process, the results of research must eventually be incorporated into a machine tool. And the research is successful only if the machine tool is itself successful in production conditions. Much, but not all, of the research and development required for the production of a new machine tool can be done by the machine-tool maker, or in government and other laboratories. But the successful development of a new machine tool requires also a substantial contribution from users and, indeed, the rate at which new machine tools and processes can be developed and applied probably depends more upon users than upon the manufacturer. Machine-tool research, if it is to be fruitful, must be accompanied by equally basic studies in production engineering. The quality and quantity of production engineering research must keep pace with the considerable recent growth of research for the machine-tool industry, and the economics and organization of manufacturing must, therefore, be added to the list of topics for study.

In practice, the way in which a machine tool is used can be as important a factor in determining whether or not it is successful as the quality of the engineering that has gone into its design. Thus, studies of all aspects of machine-tool utilization, including ergonomics, also form a vital part of machine-tool research.

It is obviously impossible, in a single paper, to describe completely all the problems and procedures of machine-tool research. In this paper, therefore, some of the main problems of current interest will be described in relation to their background, and an indication will be given of the way in which the problems are being tackled and of some of the results obtained.

The work described is based mainly on that of the Machine-Tool Industry Research Association (MTIRA), a co-operative research association working for the machine-tool industry in the United Kingdom of Great Britain and Northern Ireland.

I. Machine-tool structures

The functions of the structure of a machine tool are, first, to support the workpiece and cutting tool; and, secondly, to allow relative motion of prescribed kinds between the tool and the workpiece. Furthermore, accuracy must be maintained even when the structure is subjected to the forces required to machine the workpiece. Thus, the structure must not only be geometrically accurate, it must also have high stiffness to permit it to resist deformation by cutting forces. A structure which is stiff enough for this purpose will, almost invariably, also be strong enough to support the workpiece.

It is convenient to discuss separately the problems of geometrical accuracy and stiffness, and although the examples quoted in this section refer mainly to metal-cutting machine tools, the principles discussed apply also to all other types of machine tool.

A. *Accuracy*

Fundamentally, accuracy must be built into a machine tool; surfaces must be flat and perpendicular or parallel to each other, slides must move along straight lines and spindles must rotate about defined axes. All this must be achieved by accurate manufacture, and the main contribution of research has been to the techniques of measurement.

As standards of accuracy of machine tools have increased, particularly on larger machines, with the spread of numerical-control systems, it has become increasingly difficult to measure the performance of the completed machine tool with an accuracy comparable with the resolution of the measuring scales on the machine. This problem has recently been eased considerably by the development of portable laser interferometers, and this instrument is a good example of the way in which research in fields which are apparently remote from machine-tool technology can be applied to the benefit of the machine-tool industry. (Reference has already been made to the use of solid-state lasers f[...] machining operations; a further development of las[...] research is discussed in a subsequent section.) Th[...] high degree of coherence in the light emitted by a singl[...] mode gas laser permits fringes to be formed between tw[...] beams of light even when their optical-path lengths diff[...] considerably. With suitable corrections for temperatu[...] and atmospheric pressure, therefore, lengths of up to 5 metres can now be measured to an accuracy better than 1 part in 10^6.

Thus lasers, discovered only in 1961, are already in routine use for calibrating machine tools that could not be checked to the required accuracy in any other way (see figure 1).

The availability of this instrument makes possible the calibration, under workshop conditions, of both large and small machine tools with an accuracy hitherto attainable only under standards-room conditions. Although much remains to be learned about the practical application of machine tools of laser interferometry, it seems likely that this new technique will have an immediate beneficial effect on the performance of the more accurate machine tools and, at the same time, will stimulate research into methods of achieving still greater accuracies.

As mentioned above, it is the application of numerical-control systems to large machine tools that has been mainly responsible for the growing need for more accurate calibration of the linear displacements of the moving parts of machine tools. With manual operation, small adjustments to correct residual inaccuracies can always be made by the operator but, as yet, these same adjustments cannot be carried out automatically, although the development of adaptive control systems for machine tools (which are discussed later) may eventually make this possible. At the current time, however, although numerically controlled machine tools are capable of a higher degree of repeatability than are manually operated machines, they can achieve the same absolute accuracy in practice only if they are inherently more accurate or if they are controlled from the actual machined dimensions of the workpiece, rather than from the relative positions of tool-holder and work-table, as is more usual. This requires some form of "in-process" gauging to measure workpiece dimensions immediately behind the cutting tool. Pneumatic gauging systems are already being applied in this way for the control of cylindrical- and disc-grinding machines, and versions suitable for use on lathes are now being developed. Mechanical systems for measuring the diameter of large bores by rolling a disc around the periphery are also used. Other methods of in-process gauging which are currently being developed include the electronic measurement of the dimensions of an image of the workpiece projected on to a television camera tube, and the optical straight-edge system shown in figure 2, which illustrates yet another possible application of lasers to machine tools.

Until quite recently, one could not expect a machine tool to machine to an accuracy better than that of the machined surfaces in the machine tool itself—slideways,

Figure 1

LASER INTERFEROMETER CALIBRATOR USED BY MACHINE-TOOL INDUSTRY RESEARCH ASSOCIATES FOR CHECKING THE ACCURACY OF A MACHINE TOOL

bearings etc. However, the growing use of hydrostatic bearings for slideways and spindles means that this is no longer true. A slide supported on a film of oil under pressure will, because of the integrating effect of the oil film, move along a line which deviates from the straight appreciably less than the actual slideway surface. Similarly, a spindle supported on hydrostatic journal bearings can rotate with less eccentricity than is present in the bores of the journal bearings. Research on hydrostatic bearings (which are discussed more fully below) has thus led to the possibility of using a machine tool to produce a series of further machines, each of which is more accurate than the last.

It is also possible, using a recently developed type of hydrostatic bearing pad (see figure 3) to correct automatically for gross errors in the straightness of slideways by causing the slide to follow a path defined by a beam of light. An arrangements of photocells detects any deviation of the slide from the desired path and corrections are effected by increasing or decreasing the thickness of the oil film between the slide and slideway. The stiffness of the system normal to the plane of sliding is now determined by the gain in the error-control system. Although research on this subject is continuing, the system would currently appear to be practicable only in special circumstances. However, the possibility of obviating all need for accurate machining of machine tool surfaces by using optical means of guidance and serve systems to provide the required structural stiffness is an attractive one.

Hydrostatic slideway bearings have the additional advantage that, as there is no metal-to-metal contact during sliding, there is no wear. Moreover, as explained above, a small amount of wear does not necessarily affect the accuracy with which the slide moves. With adequate lubrication and properly fitted slideway covers, wear can often be reduced to negligible proportions. It is still sometimes necessary, however, to operate slideways without protection and, in general, it is necessary to take account of the possibility of wear of slideways

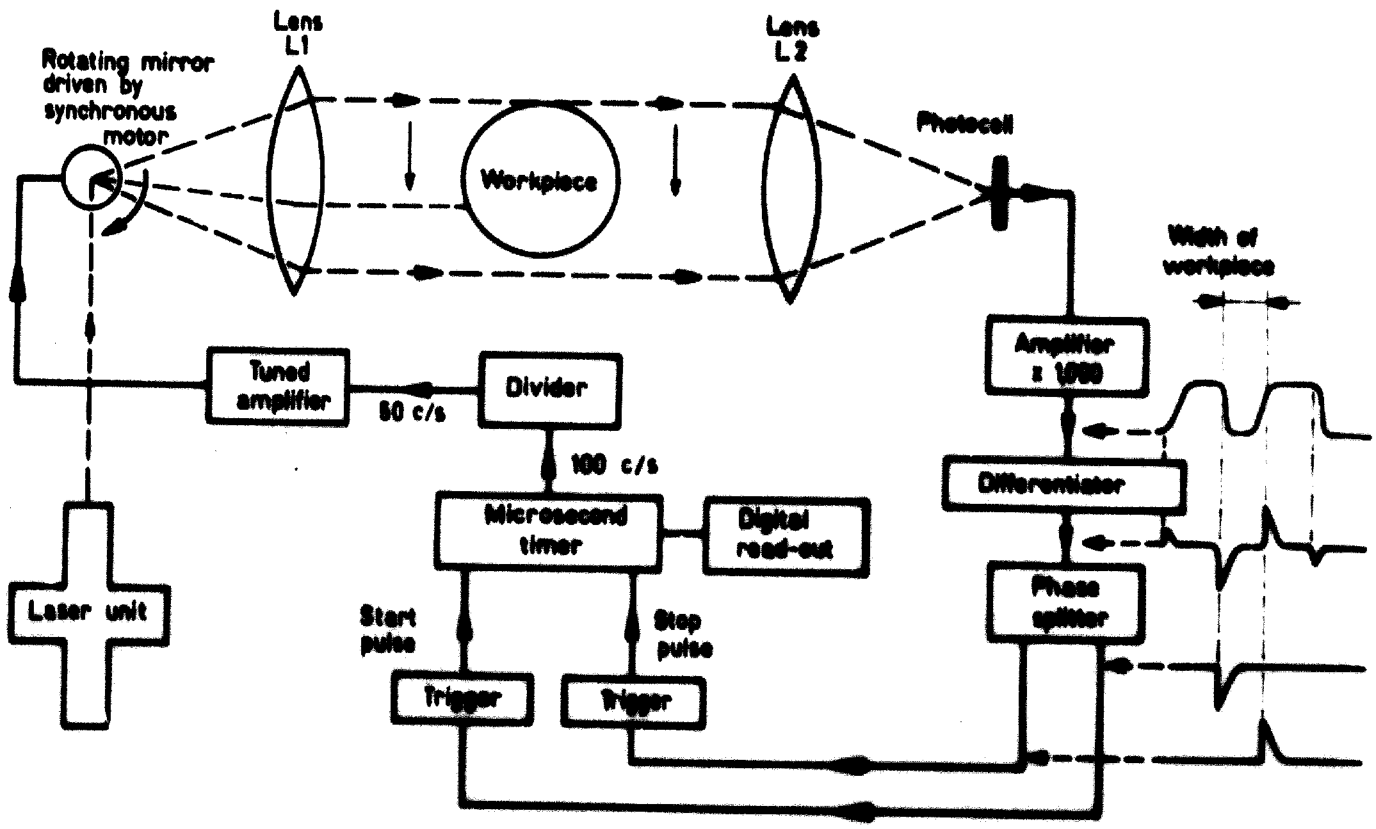

Figure 2

USE OF A LASER FOR IN-PROCESS MEASUREMENT OF WORKPIECE SIZE

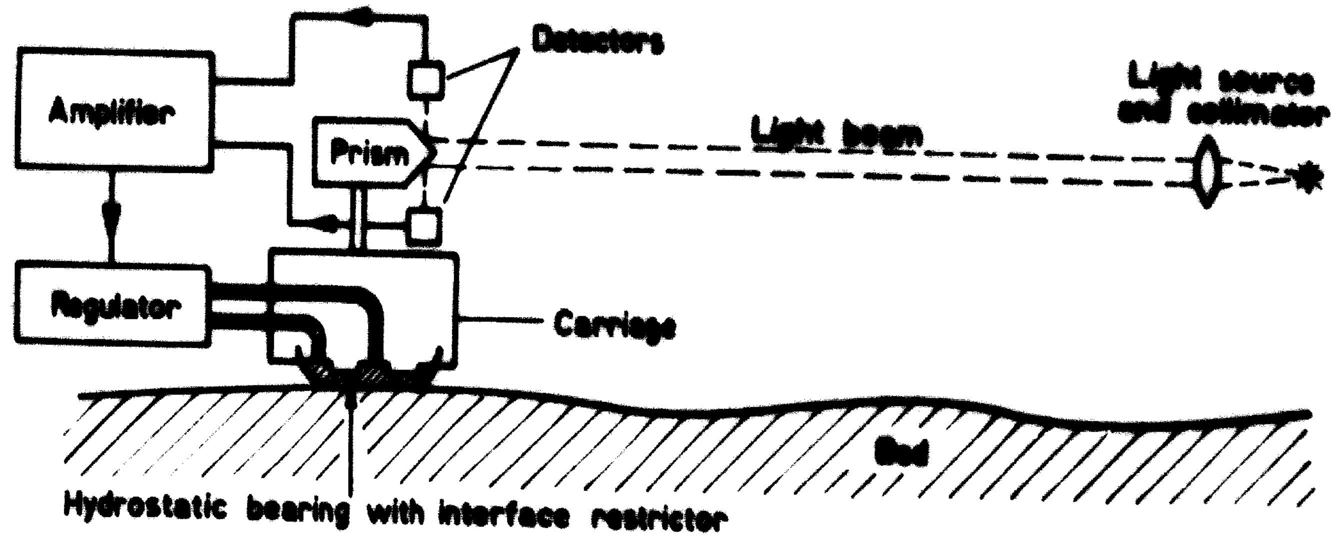

Figure 3

AUTOMATIC CORRECTION OF ERRORS IN MACHINE-TOOL SLIDEWAYS BY VARYING THE THICKNESS OF THE OIL FILM IN A HYDROSTATIC BEARING hich operate under conditions of boundary or hydrodynamic lubrication. If wear of slideways is likely to be experienced, care should be taken to position the slideways in such a way that wear has the least effect on the accuracy of machining. For example, by supporting a machine tool slide on three sliding surfaces arranged so that the normals to the surfaces interesect at a point, any rotation of the slide as a result of wear of the surfaces is minimized. Figure 4 shows a practicable arrangement of three surfaces which approximately meets this condition.

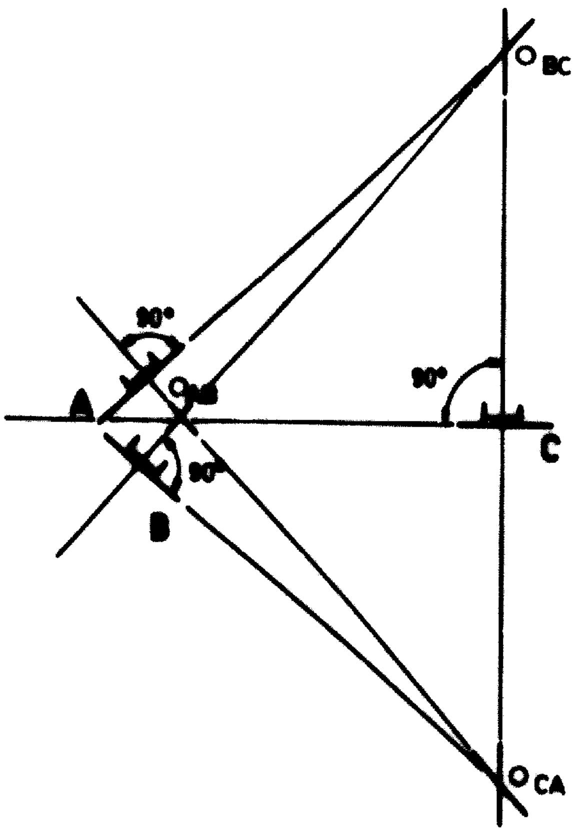

Figure 4

A PRACTICABLE ARRANGEMENT OF SLIDING SURFACES WHICH APPROXIMATELY SATISFIES THE RULE FOR THE MINIMUM EFFECT OF WEAR

Such an arrangement might be used to support the saddle of a lathe and if, in addition, the axis of the lathe spindle passes through the point of intersection of the normals, then wear will produce only a tangential displacement of the cutting tool, which will have little effect on the accuracy of the machine tool. In practice, it would probably be sufficient to arrange that the lathe spindle was on a line joining the point of intersection of the normals and the point of the cutting tool.

Similar considerations can be applied to determine the best geometrical arrangement of slideways for other kinds of machine tool.

B. *Stiffness*

The cutting forces which tend to distort a machine tool structure do not remain constant, even under nominally uniform cutting conditions. Interrupted cutting conditions or variations in workpiece properties can give rise to alternating components of cutting force superimposed on the steady forces, and the alternating forces will produce forced vibrations of the structure which may result in a wavy surface on the workpiece. A machine-tool structure must, therefore, be not only statically stiff so as to resist deformation by steady forces, but also dynamically stiff in order to prevent alternating components of cutting force from giving rise to large amplitudes of vibration. Since it is impossible to know the frequencies of all the alternating components of force (although there will usually be components at the frequency of revolution of the spindle and at cutter tooth frequencies), it is usually desirable to make the natural frequencies of vibration of machine-tool structures as high as possible so as to minimize the chances of excitation of vibrations of large amplitude. In general, therefore, the objective of a high dynamic stiffness is usually interpreted as meaning a high natural frequency. Damping is also important, however, and at resonance the effective stiffness is determined mainly by the damping in the structure.

In some circumstances, when the damping in the structure is small, energy can be fed back from the main drive to build up and sustain vibrations of the structure at a frequency approximately equal to the natural frequency of vibration. Such "regenerative chatter" vibrations can be of large amplitude and, in addition to leading to poor surface finish, may even lead to actual damage to the workpiece, cutting tool or machine structure. The theory of chatter vibrations, has been extensively discussed in the literature, but although the phenomenon is reasonably well understood, it is still not easy to design from first principles a structure that can be guaranteed not to chatter.

The accuracy of movement of a machine tool is normally assured by some form of acceptance test, and it would be useful for both makers and users if the actual machining performance of a machine tool could be tested in a similar way. Dynamic acceptance tests would include noise level, power available at the spindle etc., but they would be really useful only if they provided a measure of the inherent resistance of the machine tool to chatter. The difficulty is to devise an objective and meaningful test, as small differences in stiffness and damping can have a great effect on performance. A machine tool may perform satisfactorily with one workpiece and cutting tool, but unsatisfactorily with other workpieces and tools, even though these may be essentially similar to the first.

Even when a machine tool is known to be unsatisfactory in respect of chatter behaviour, it is not always easy to say just how it can be improved. Increasing the static stiffness may help, but this could have the opposite effect by bringing the natural frequency of the structure into near coincidence with an exciting frequency. Indeed, it is often possible to improve the machining capabilities of a machine tool by reducing its stiffness in a particular direction. In general, however, the best way of reducing liability to chatter would undoubtedly be to increase the damping in the structure, although this is not easily achieved since the sources of damping in machine structures are not yet fully understood.

The inherent damping in cast-iron or steel structural members is only a small proportion of the total damping, although it is possible to increase the damping in welded-steel structures by the use of a laminar construction, in which there is a relative movement at the interface when the structure deflects. Sand or concrete filling can also increase the damping of a structure, although there is little quantitative information available. Joints certainly contribute a large proportion of the damping, presumably by friction when the joint surfaces move in relation to each other. Increasing the relative movement will increase the damping, but only at the expense of reducing the static stiffness. Oil films, such as those which are formed in hydrostatic slideways, are capable of dissipating energy as the thickness of the film varies cyclically and are thus potential sources of damping. The damping effect increases rapidly as the frequency increases, but, unfortunately, so does the stiffness of the oil film (see figure 5). At frequencies greater than a few cycles per second, therefore, the oil film is probably as stiff or as stiffer than the rest of the structure, so that alternating forces will produce little variation in thickness of the film and there will be little contribution to the damping. The problem of finding effective ways of increasing the damping in machine-tool structures therefore remains to be solved.

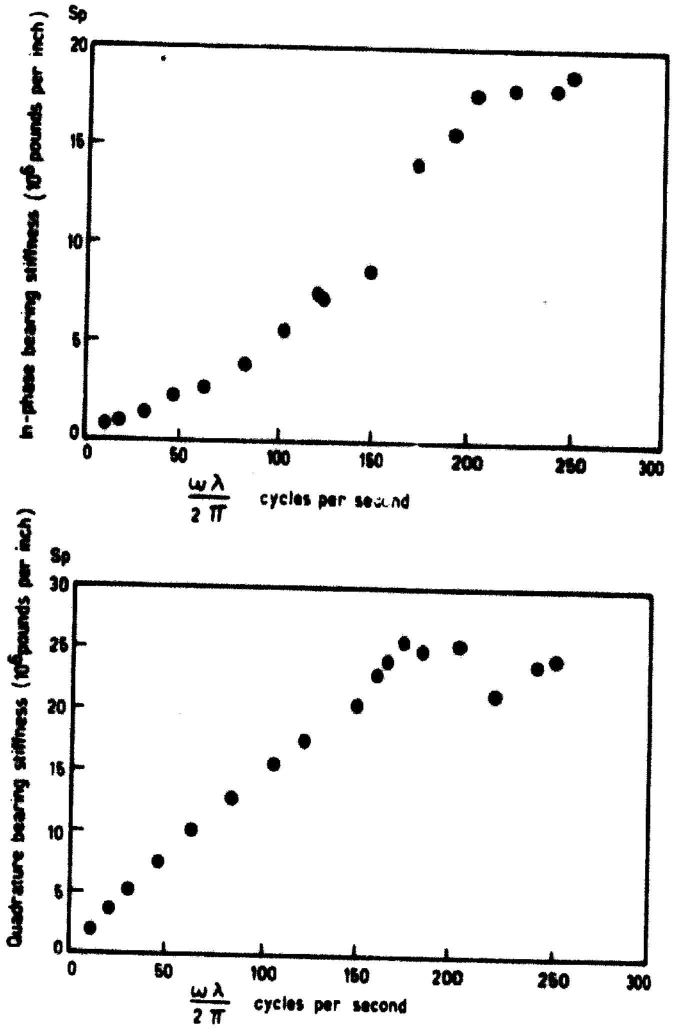

Figure 5

IN-PHASE AND QUADRATURE STIFFNESS OF A HYDROSTATIC THRUST BEARING WITH AN 0.04-MILLIMETRE OIL FILM

Until more is known about the dynamic behaviour of machine-tool structure, it is probably best for the designer to aim at producing structure with high static stiffness and high natural frequencies of vibration. This means, in practice, that the stiffness has to be achieved using as little structural material as possible. Michell structures—orthogonal pin-jointed frame structures so proportioned that the stress is constant everywhere—can be shown to have the maximum stiffness to a given set of forces for a given weight of material. The saving in weight can be appreciable (see figure 6) and these structures would seem to be a good approximation to

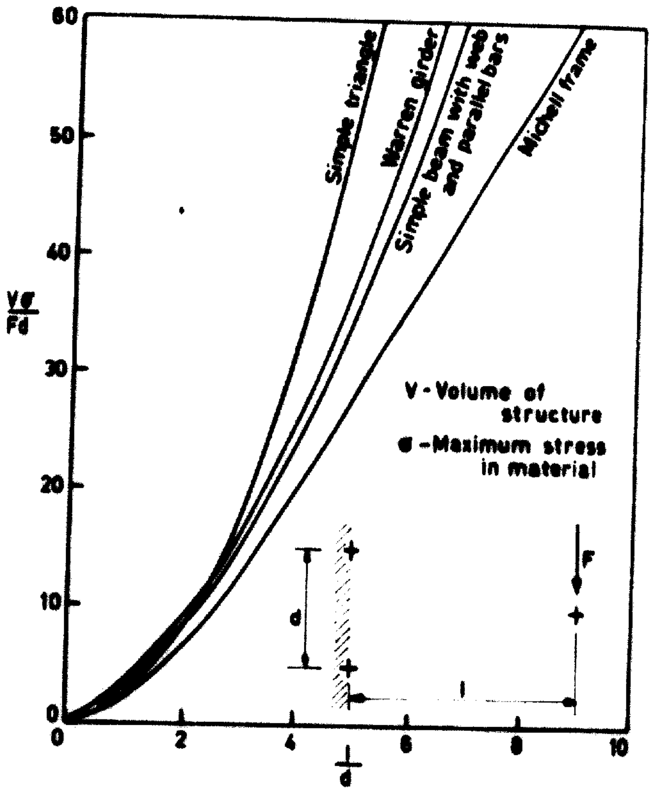

Figure 6

COMPARISON OF THE VOLUMES OF DIFFERENT TYPES OF CANTILEVER STRUCTURE

structures of high natural frequency. Unfortunately, Michell structures can, as yet, be specified only for simple two-dimensional sets of forces, although research to extend their range of application is continuing. Moreover, practical continuous structures can only be approximate to true Michell structures.

For the time being, therefore, machine-tool structures must be designed using more empirical methods. Structures which are stiff to bending, torsional and shear forces are required (the need for shear stiffness is often overlooked, but deflections due to shear can represent a large proportion of the total deflection of some structures), although the relative magnitudes of these forces will vary from one machine tool to another. In general, it is best to base the design on a structure which has maximum torsional stiffness since such a structure usually has good bending and shear stiffness also (see Figure 7).

A major problem is the need to prevent local distortion and to ensure that the material of the structure is, as far as possible, uniformly stressed. Simple structural models are often useful for showing up weaknesses and for suggesting ways of stiffening a structure. Weak regions, such as can be caused by holes, must be stiffened by properly placed ribbing, and arrangements must be made for spreading point loads.

be fed into the computer along with other information about the structure. (Models can include joints also, but care is necessary in scaling the joint parameters if reliable results are to be obtained.) The computation can also, to some extent, take into account the stiffness of the oil film in the hydrostatic slideway bearing, but further work is still required on the interaction between the structure and the oil film. The difficulty is that particularly when the thickness of the film is small the oil film is very stiff and, under alternating loads, the pressure in it may cause local distortion of the sliding surfaces. In turn, such distortion alters the thickness and stiffness of the oil film.

With many machine tools, particularly the larger ones, it is not economic to make the bed of the machine stiff enough to allow the machine to be used without attaching it to a foundation. It is then necessary to ensure that the machine tool is attached to its foundation in such a way that the stiffness of the foundation block is fully utilized. Since it is usually necessary also to allow for differential settlement of the foundation, and for changes in its shape and size with temperature and humidity, the choice of the method of attachment of the machine tool to the foundation requires some care.

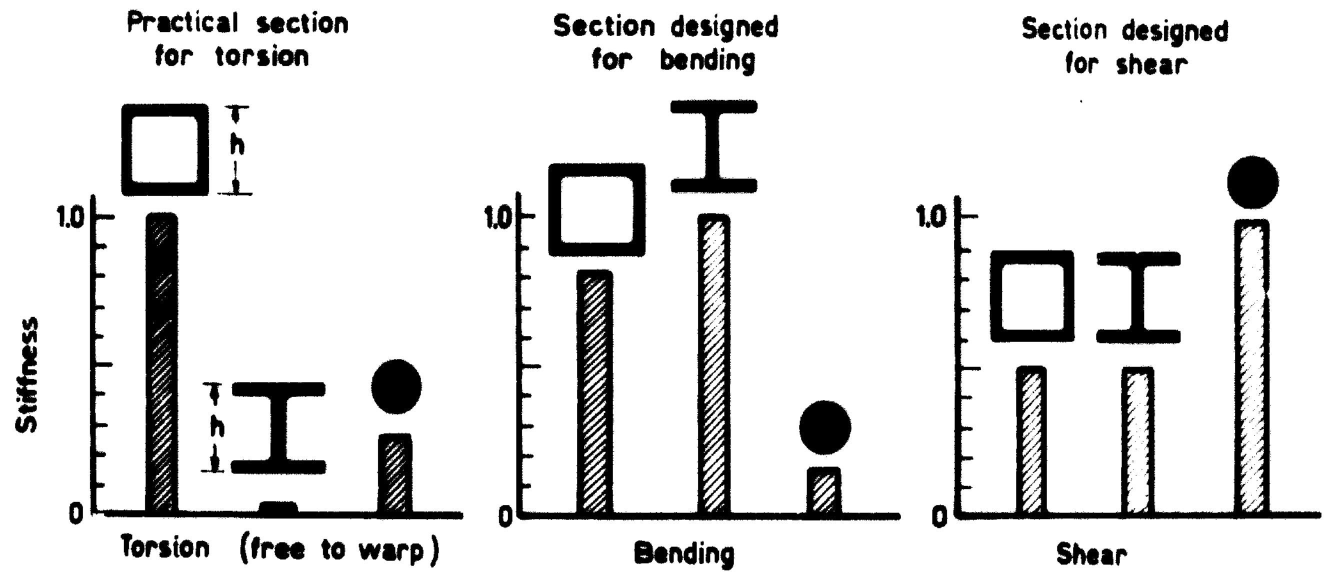

Figure 7

RELATIVE STIFFNESS OF VARIOUS SECTIONS IN TORSION, BENDING AND SHEAR

Tests on models are also often used for predicting the stiffness of full-scale structures. More recently, however, as a result of research, it has become possible to use computing techniques for predicting the static and dynamic stiffnesses and modes of vibration of proposed structures. It is necessary to represent the proposed structure by a lumped-parameter model and to describe in reasonable detail the shapes and sizes of the various structural elements. Once this has been done, however, stiffnesses, mode shapes and natural frequencies of vibration can be determined by using the programme prepared for this purpose. The effects of proposed modifications to the structure are easily calculated also. It seems likely that the use of computer techniques in this way will gradually replace model tests for the study of the dynamic behaviour of structures.

Joints can contribute a large part of the total compliance of a machine-tool structure and their effect must be taken into account in any consideration of structural stiffness. Studies of joint behaviour have shown the importance of interface pressure and surface finish of the joint surfaces, and it is now possible to predict the effective stiffnesses of simple joints. This information can

II. MATERIALS AND TECHNIQUES

If, however, the foundation has to be regarded as an integral part of the machine-tool structure (and this is usually the case when static or dynamic stiffness is involved), it is reasonable to consider integrating the design of machine tool and foundation by making the machining bed in concrete. A few machine tools with concrete structural members have already been produced, but doubts about the long-term stability of the material have tended to inhibit the wider use of this method of construction. Recent measurements indicate, however, that if proper precautions are taken, it should be possible to achieve the necessary stability. The possible advantages of concrete as a structural material for machine tools include reduced cost, reduced transport charges because large structural elements can be cast on site, and, possibly, increased damping. A full assessment of the use of concrete in this way cannot be made, however, until more data are available on stability and damping capacity.

Although cast iron is still the most commonly used material for machine-tool structures, fabricated structures are being used to an increasing extent and offer economic advantages in some circumstances, particularly when the shape can be chosen to take advantage of the increased modulus of elasticity of steel, as compared with that of cast-iron. The possibility of introducing additional damping into fabricated structures has already been mentioned and the ease with which modifications can be made to fabricated structures is also relevant. Modular (s.g.) cast-iron, whose properties are intermediate between those of steel and ordinary grey cast-iron, is also worth studying as a possible structural material.

For obvious reasons, plastic materials are not frequently used for the structural members of machine tools, but are increasingly used for non-load-bearing components. Laminated plastic inserts impregnated with PTFE are used as slideway materials, as are various soft non-ferrous alloys.

III. Mechanisms

Although stiffness is the main criterion in the design of the structural elements of machine tools, relative movement of structural members—slides on slideways or spindles in journal bearings—is often necessary and bearings, both plain and journal, are important elements of machine tools. The usual requirements are for stiffness perpendicular to the direction in which movement is to be permitted and little resistance to movement in the desired direction.

The simplest and cheapest slideway bearings are plain lubricated bearings, and much effort has been devoted to examining lubricants and the shape and finish of sliding surfaces in attempts to reduce wear, reduce friction and eliminate stick-slip effects. Reproducible and relevant results are not easily obtained in tests of this kind but special oils and laminated plastic impregnated with PTFE, or soft metal surfaces sliding on hardened-steel or cast-iron surfaces have permitted the manufacture of low-friction, wear-resistant slides and slideways, with controllable friction characteristics. The advent of numerically controlled machine tools has, however, accentuated the need for slideway bearings requiring even lower forces to move the slides, and rolling-element bearings of various types have been developed to meet this need. But the stiffness normal to the plane of sliding is not easily obtained without pre-loading, which increases the effective frictional force opposing movement.

Hydrostatic slideways, in which the sliding surfaces are supported by a film of fluid—oil or air—under pressure, offer many advantages. The film of fluid can be made very stiff to forces normal to its plane, but it offers little resistance to sliding motion and the effective frictional force (viscous) increases with velocity so th there is no danger of stick-slip effects. Moreover, t integrating effect of the film of fluid means that the sli moves along a line which can be more nearly straig than the slideway itself.

The fluid used may be gas (usually air) or oil. Air h the advantage of not requiring collection after use, but expensive to supply at the pressures and volumes require and has little damping capacity. Oil is cheaper to suppl and it can provide damping of motion in and normal to the plane of sliding; furthermore, hydrostatic slideways using oil are easier to design than those using gas. The main disadvantage of oil is the need to collect it after use and to keep it free from contamination with cutting or other fluids.

Hydrostatic slideways are made stiff normal to the plane of sliding by supplying oil to the slideway pockets (see figure 8) *via* some form of restriction. Any tendency

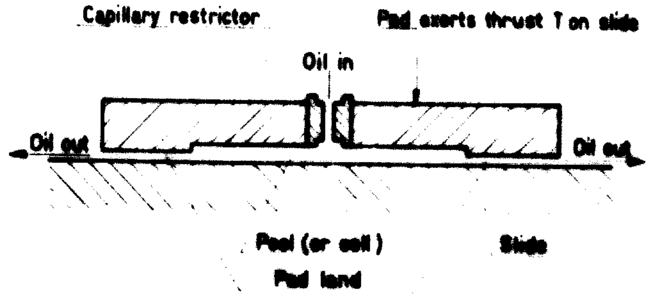

Figure 8

Cross-section of hydrostatic thrust pad

for the thickness of the oil film to decrease, say, when the load changes is opposed by the resultant increase of pressure in the oil film, the thickness of which thus tends to stay constant. The simplest forms of hydrostatic slideway use capillary restrictors, but more elaborate diaphragm-controlled restrictors have been developed. With the latter, the pressure in the oil film varies the resistance of the restrictor in such a way that even greater stiffness can be obtained. Single-sided hydrostatic slideway bearings ofter suffice, but there are many advantages in using opposed pairs of pads. These will not only support loads in both directions, but can be made with greater stiffness than can single-sided bearings. Moreover, their stiffness is less dependent upon the load carried.

Hydrostatic slideway bearings are relatively easy to design and make. There are, however, many variables involved and the development of procedures for optimizing the design has involved much research. The relations between stiffness (and load) and restrictor resistance and oil-film thickness are complex (see figure 9); it is also necessary to consider the area available for the bearing pads, the oil-supply pressure and the minimum allowable gap (oil-film thickness). Account must also be taken of the heat generated and the pumping power required; and, in general, it is not possible to minimize both these quantities simultaneously. Therefore, the final design must always be some kind of

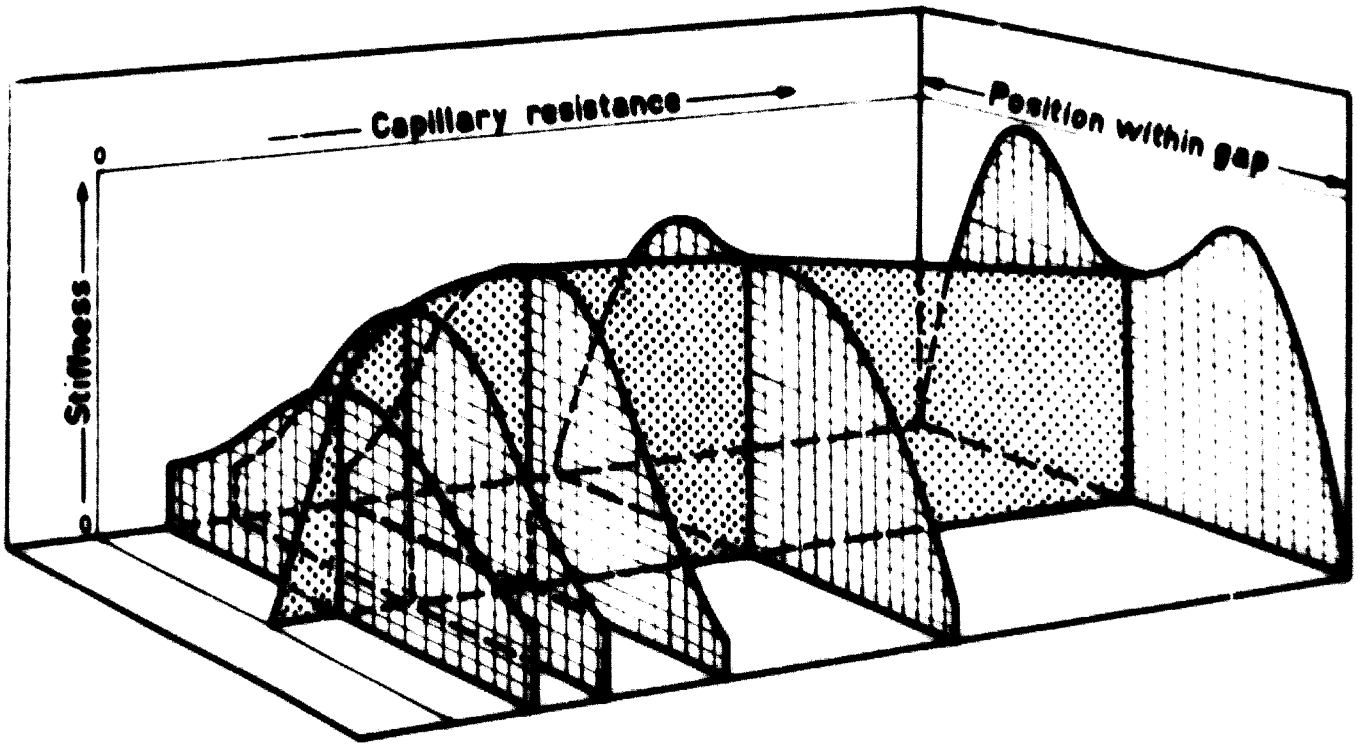

Figure 9

STIFFNESS CONTOURS FOR A TYPICAL HYDROSTATIC PAD-PAIR

compromise, but with all the data available in a readily usable form, the designer can easily choose a design which best suits his conditions. The preparation of design data of this kind for hydrostatic bearings and other mechanisms and structures is an important objective of research for the machine-tool industry. In the United Kingdom, the Machine Tool Industry Research Association prepares "MTIRA notes for designers", which present in analogue (graphical) form the results of extensive computations to permit designs to be optimized for any given conditions.

A similar approach is adapted to the design of hydrostatic journal and thrust bearings, although the number of variables involved is even greater than for plain sliding bearings and the problems are correspondingly more complex. However, studies of the phenomena involved have led to an understanding of the behaviour of these bearings (see figures 10 and 11) and to the development of design procedures which permit optimization for any given conditions. Conventional rolling-element journal bearings can be pre-loaded to give the required radial stiffness at low speeds, but pre-loaded bearings cannot be run at high speeds because the heat generated in the bearings would cause seizure. Unless, therefore, arrangements are made to remove the pre-load as the speed increases, it is not possible to achieve uniform stiffness over a wide speed range. This is, however, easily achieved with hydrostatic journal bearings. Moreover, accurate, stiff bearings of large diameter can be operated up to speeds which present considerable difficulties for conventional rolling-element bearings.

Nevertheless, most machine-tool spindles still rotate in rolling-element bearings and research has led to the development of highly accurate bearings of this type. The performance, in respect of accuracy of rotation and stiffness, of machine-tool spindles with rolling-element bearings depends not only upon the bearings themselves, but also upon the way in which they are mounted in the machine tool. An inaccurately machined bearing housing can cause loss of stiffness, overheating and inaccurate relation. Furthermore, the design of the housing and the way in which it is attached to the rest of the machine-tool structure play a large part in determining the effective stiffness of the bearing.

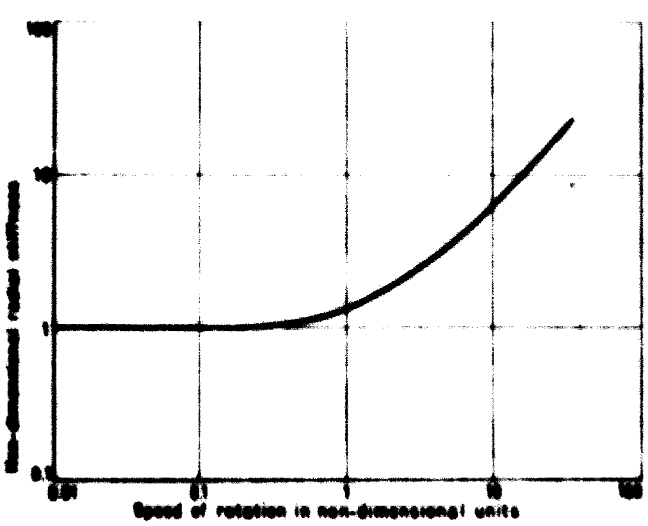

Figure 10

EFFECT OF ROTATIONAL SPEED ON THE RADIAL STIFFNESS OF A HYDROSTATIC JOURNAL BEARING

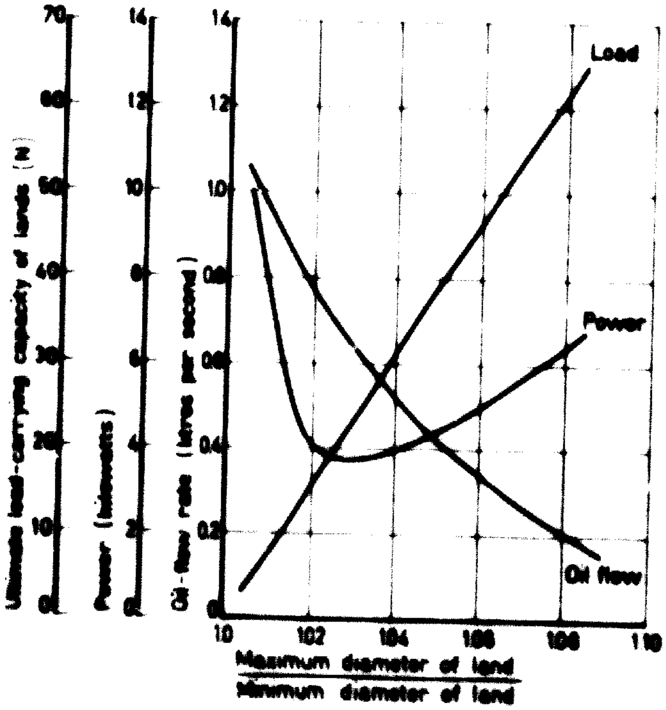

Figure 11

EFFECT OF WIDTH OF LAND ON THE ULTIMATE LOAD CAPACITY, OIL-FLOW RATE AND TOTAL POWER REQUIREMENTS OF A HYDROSTATIC THRUST BEARING

Whatever the type of bearing used, the stiffness of the bearings must be properly matched to that of the spindle if full advantage is to be taken of both. Before the optimum design can be produced, it is necessary to have full knowledge of the stiffness of bearings and spindles. Here again, the use of a computer to calculate the necessary relationships (which can then be presented in graphical form) makes it possible to present the designer with all the information necessary to enable him to produce the optimum design. Occasionally, however, it may not be possible to achieve the optimum design in practice because of lack of space or other practical considerations, but if the designer knows just how much he is sacrificing by not having optimum conditions, he is in a better position to make the necessary decision.

IV. Drives

A. *Spindle drives*

For a given input power, high spindle speeds mean low torques and therefore small forces, whereas low spindle speeds involve large forces and high torques. At low speeds, therefore, the power that can be utilized by a machine-tool spindle is limited by the stiffness of the size of the driving motor. The ideal power speed characteristic for a machine-tool drive is, therefore, of the form shown in figure 12, i.e. a constant torque at low speeds and a constant horsepower at high speeds.

For small variations of speed about a given speed, however, it is not always clear whether a constant-torque or a constant-power characteristic is to be preferred. Direct drive by a variable-speed hydraulic or electric motor usually gives the first type of characteristic, whi[le] the conventional gear drive is of the second type. Wi[th] the first type of drive, if the resistance experienced by th[e] tool-point varies, e.g., with interrupted cuts or because [of] variations in workpiece properties, the cutting speed wi[ll] decrease so as to keep the cutting force constant, wherea[s] with the second type of drive, the speed will tend t[o] remain constant and the cutting force will increas[e] correspondingly. Under these conditions, the effects o[f] the characteristics of the spindle drive on surface finis[h] and tool wear do not seem to have been investigated. Th[e] constant-torque drive would seem to be less hard on th[e] cutting tool, although most designers and users o[f] machine tools think that they need a constant-horsepowe[r] drive.

Although there is ample evidence (see figure 13) that most users of machine tools do not make full use of the spindle speeds available, the economic advantages of being able to choose the correct speed for each application can be considerable. Continuously variable-speed drives tend to be more expensive than gear drives, but when allowance is made for all the savings associated with the omission of a gear-box and for the added convenience afforded both the designer and the user, the extra cost may not be very great. For some operations, e.g., facing operations on a lathe, the extra cost can certainly be justified.

At the current time, most machine-tool spindles are driven, *via* systems of gears or belts, from a constant speed alternating-current electric motor. It is usual for the spindle speeds available to cover a wide range (100:1 is not uncommon) in very small steps, in order that the correct cutting speed may be available for any tool and workpiece combination. Thus, spindle drives may involve several gear trains and sometimes a belt drive also. Both the total compliance and the total inertia of the drive can, therefore, be high and its torsional natural frequency low, so that torsional vibrations of relatively large amplitude can easily be set up if the cutter-tooth frequency happens to correspond to a harmonic of the resonant frequency. Torsional vibration in a spindle drive will

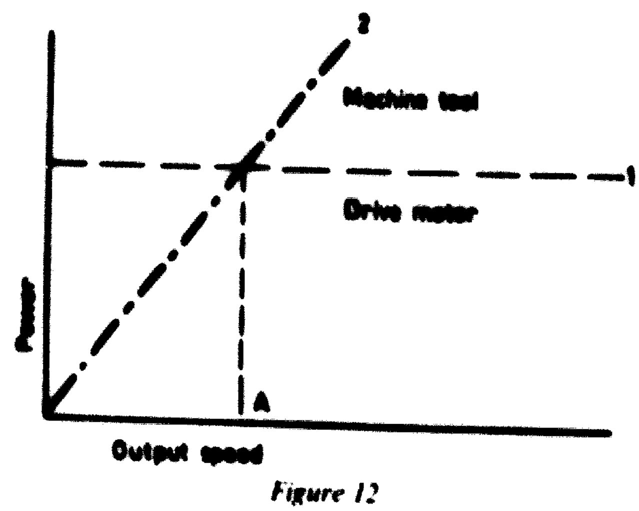

Figure 12

IDEAL POWER SPEED CHARACTERISTIC FOR MACHINE-TOOL DRIVE

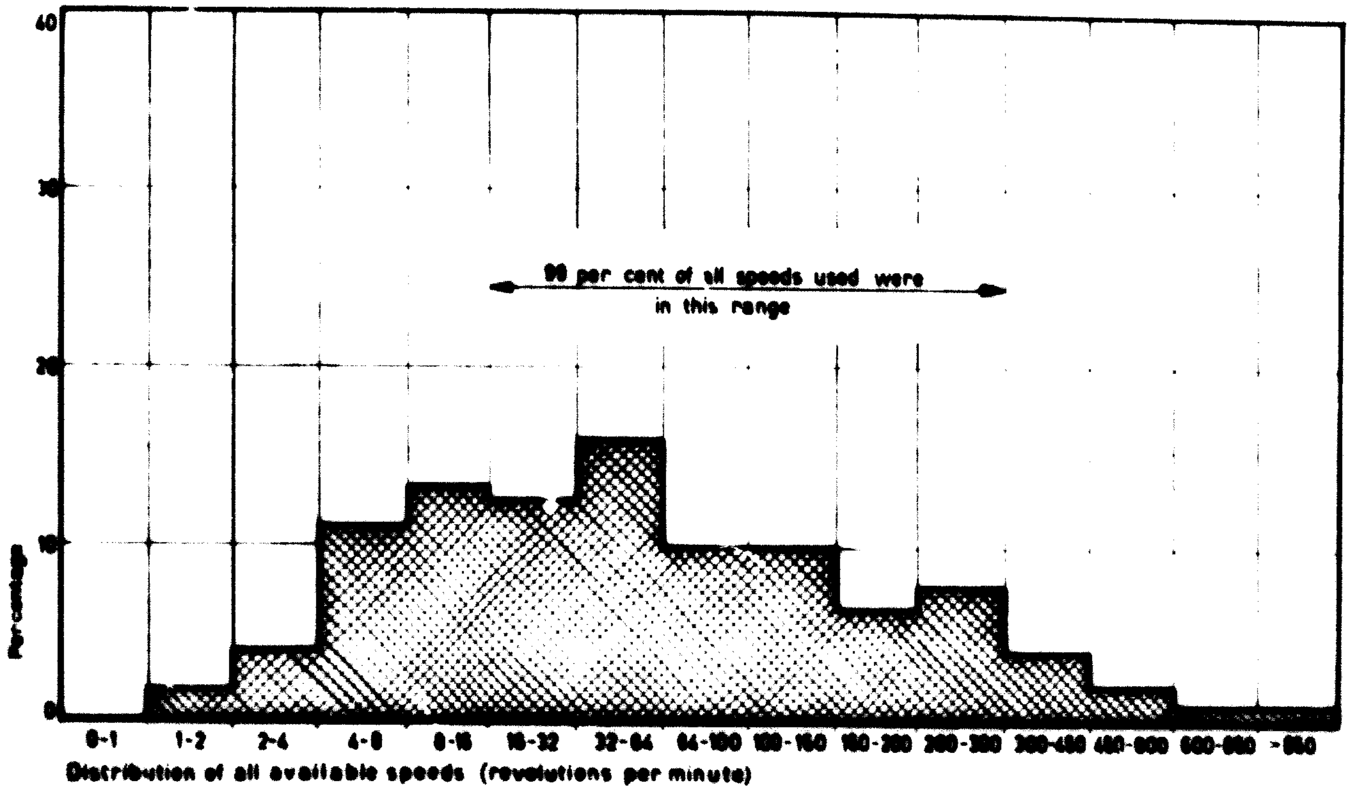

Figure 13

DISTRIBUTION OF AVAILABLE SPINDLE SPEEDS ON A GROUP OF HORIZONTAL BORING MACHINES

cause the cutting speed to vary cyclically, but it may or may not affect the surface finish of the workpiece. It is possible, however, for coupling to occur between torsional vibrations of the drive and vibrations of the machine tool structure. In those circumstances, torsional vibrations can contribute to machine-tool chatter. Knowledge of the torsional characteristics of spindle drives, gear and belt is therefore important to permit the design of drives with the desired characteristics.

These are only a few of the problems concerning the choice of spindle drives and spindle speeds. The full answer requires the development and use of adaptive-control systems which will optimize cutting conditions continuously. The criterion for optimization may be productivity, surface finish or minimum cost. Experimental adaptive-control systems with provision for the continuous measurement of cutting force, tool temperature, tool wear etc., and with a computer which continuously optimizes feeds and speeds, have already been built. Adaptive-control systems of this kind are currently uneconomic for general use, but the time may soon come when they control the operation not only of individual machine tools, but also of complete manufacturing units.

In the meantime, however, there is considerable interest in continuously variable-speed drives for machine tools. Hydraulic motors and direct-current electric motors are often used, and the growing use of silicon-controlled rectifiers for speed control of electric motors should increase the use of continuously variable-speed drives for machine tools. In particular, frequency-changing circuits using silicon-controlled rectifiers should make possible the use of induction motors for a wide range of speeds.

Power-dividing transmissions, in which differential gears are used to extend the range of a small-ratio variable-speed unit (see figure 14) are of interest for machine-tool spindle drives because, depending upon the actual arrangements adopted, almost any desired power speed characteristics can be obtained. In the particular version shown in the figure, the variable-speed unit operates in the usual way in the low-speed range, but at higher speeds only part of the input power flows through the variable-speed unit, the remainder being transmitted by the high-efficiency differential gear. The transition from one stage to the other is effected by means of a two-way clutch operated when there is no speed difference between the output shafts of the two stages.

A. *Feed drives*

The major problem with feed drives is not their power-handling capacity, but the natural frequency of the table drive system. This presents little difficulty on manually operated machine tools, but it can be a source of trouble on numerically controlled machine tools where the speed with which a slide or table can be positioned or made to follow a given path is limited by the band width of the servo-system. If the natural frequency of the table drive system lies within the band-width of the servo-system errors can arise as a result of the phase changes associated with resonance and, in extreme cases, the system can become unstable. If, therefore, numerically controlled

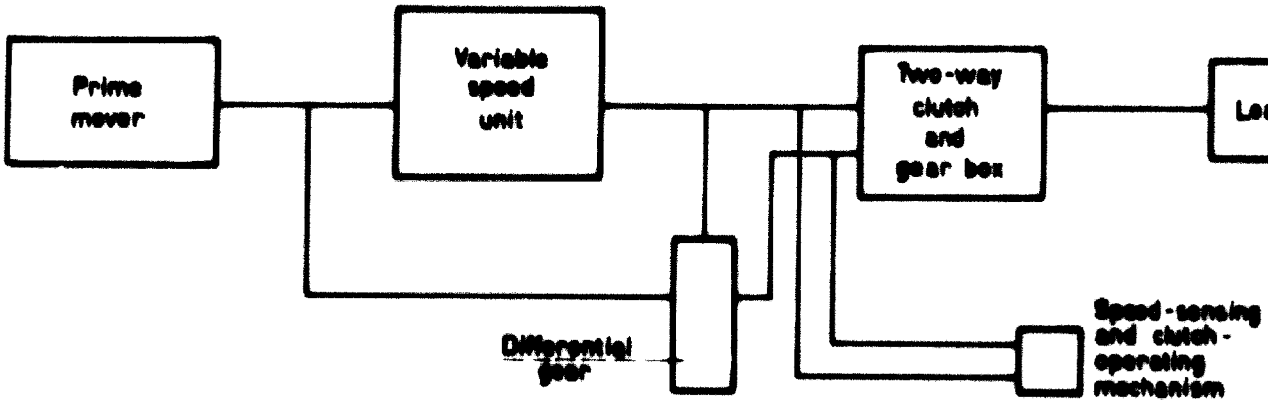

Figure 14

COMBINED SERIES: SHUNT DRIVE

machine tools are to be capable of following or of being positioned at high speed, the natural frequency of the table drive system must be made as high as possible.

In the case of ram drives, the natural frequency is essentially that of the mass of the table and workpiece, together with the spring formed by the column of oil in the ram. Clearly, when the product of the mass and the length of the ram is large, a high natural frequency can be obtained only with a ram of large diameter. The larger the diameter of the ram, however, the greater the required flow of oil into the ram for a given rate of linear movement and, thus, the larger the valve required to control the oil flow. As the diameter of the ram is increased, therefore, a point is reached at which the speed of response of the system is determined by the response time of the valve.

Attempts to overcome this difficulty have included the development of a drive in which a short-stroke ram for rapid, short displacements is combined with a rack-and-pinion drive for larger, slower movements—i.e. a system of two short-stroke rams acting in a step-by-step fashion; a system of short rams acting on a series of inclined planes; and the efflux drive (see figure 15) in which oil supplied under pressure to one of two pairs of pockets produces a force on the slide.

In the case of lead screw drives, the lead screw itself forms the spring and, by increasing the diameter of the lead screw sufficiently, the natural frequency of the table on the lead screw can be made as high as is desired. Although practicable, lead screw drives can be made for greater values of the mass stroke product than is possible with ram drives. There comes a point, however, as the diameter of the lead screw is increased, at which the effective inertia of the lead screw itself exceeds that of the table and workpiece so that the response time tends to be limited by the inertia of the lead screw.

It might be mentioned in passing that it is not only structural resonances within the control loop (such as that of the table and its drive) that restrict the band-width of the servo. Resonances outside the loop, for example, that of a counterbalance weight or, more significantly, of the machine tool and its foundation block on the "springy" soil (which may occur at a frequency as low as 10c/s), must also be considered. The difficulty of raising these resonant frequencies has already been mentioned and alternative methods of permitting greater servo band-width have to be considered. The inclusion of compensating elements and subsidiary control loops allows some increase of band-width without instability in the presence of structural resonances (see figure 16), but more elaborate types of control system are probably required to eliminate this problem entirely.

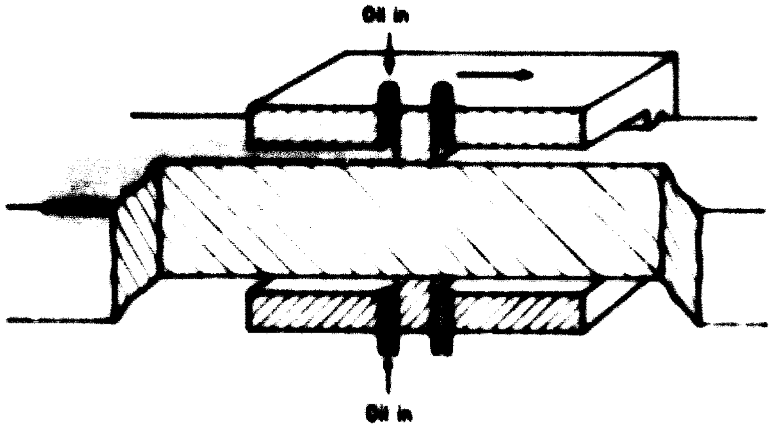

Figure 15

EFFLUX DRIVE

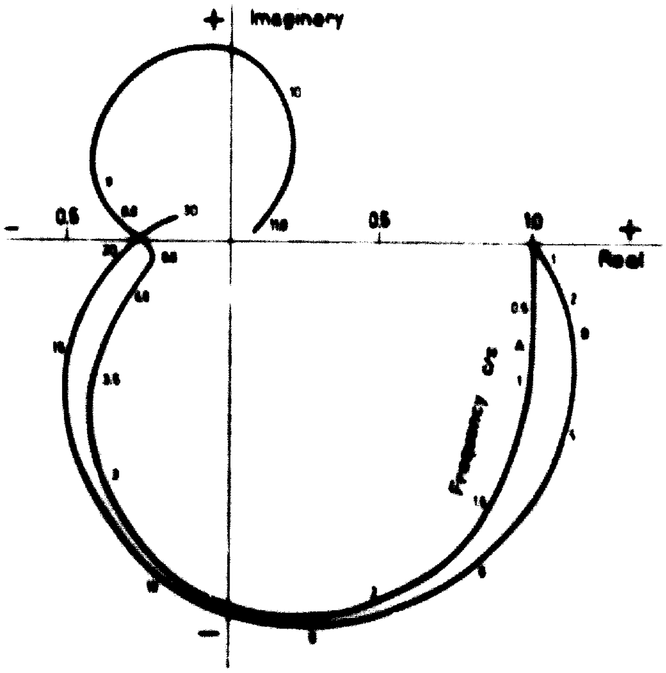

Figure 16

FREQUENCY RESPONSE OF CONTROL LOOP INCLUDING POORLY DAMPED STRUCTURAL RESONANCE AT 10c/s

A high natural frequency is not, of course, the only requirement of a feed drive; stiffness, absence of backlash and low friction are important also. For lead screw drives, the recirculating ball nut has proved a useful way of meeting these requirements, which are particularly important on numerically controlled machine tools. However, backlash can be eliminated only by increasing the pre-load and thereby, at the same time, increasing frictional resistance. The answer would seem to lie in the application of hydrostatic lubrication to lead screw nuts. A film of oil under pressure between the mating surfaces of lead screw and nut virtually eliminates friction and, properly designed, is stiff and exhibits no backlash. Design data are available, but the problem of manufacturing the nut to the tolerances required still presents difficulties.

V. Ergonomics

Even numerically controlled machine tools have to be set up manually, although, of course, the extent to which the operator participates in the operation of the machine is very much greater in the case of manually operated machine tools. Aspects of the design of machine tools to which the science of man-machine relationships—ergonomics—can contribute include the positioning, shape and characteristics of control levers and knobs, the design of control panels, the design of scales and scale readers and the layout of legend plates and the design of symbols (see figure 17). Figure 18 shows the difference, in terms of the speed of operation and the ease of learning, between a conventional legend plate and a plate designed for the same purpose but based on ergonomic principles.

VI. The utilization of machine tools

Although research to provide designers with the data they need for the layout of machine tools and for the design of structures, mechanisms and control systems is undoubtedly important, the design of a machine tool really begins one stage farther back. It is first necessary to know what function the machine tool is required to perform. For special-purpose machine tools, such as those incorporated in transfer lines, the question is relatively easy to answer (although even with this kind of machine tool it is not always clear just what feeds and

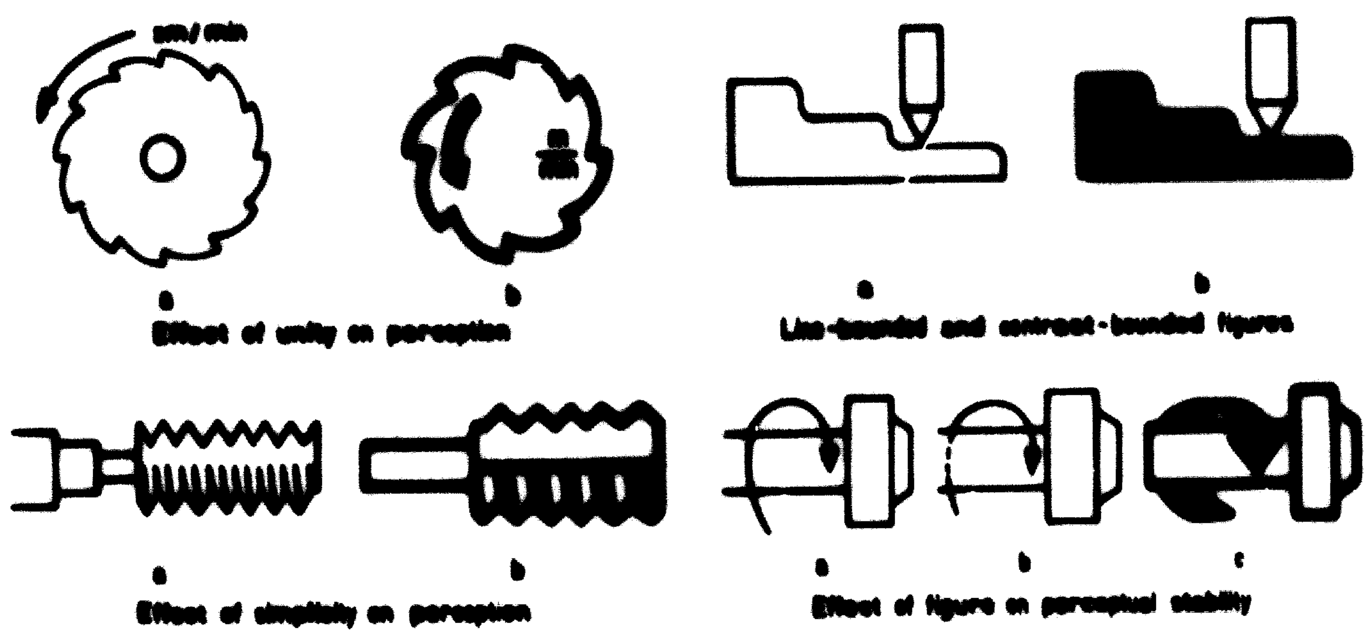

Figure 17

PRINCIPLES UNDERLYING THE DESIGN OF SYMBOLS FOR MACHINE TOOLS

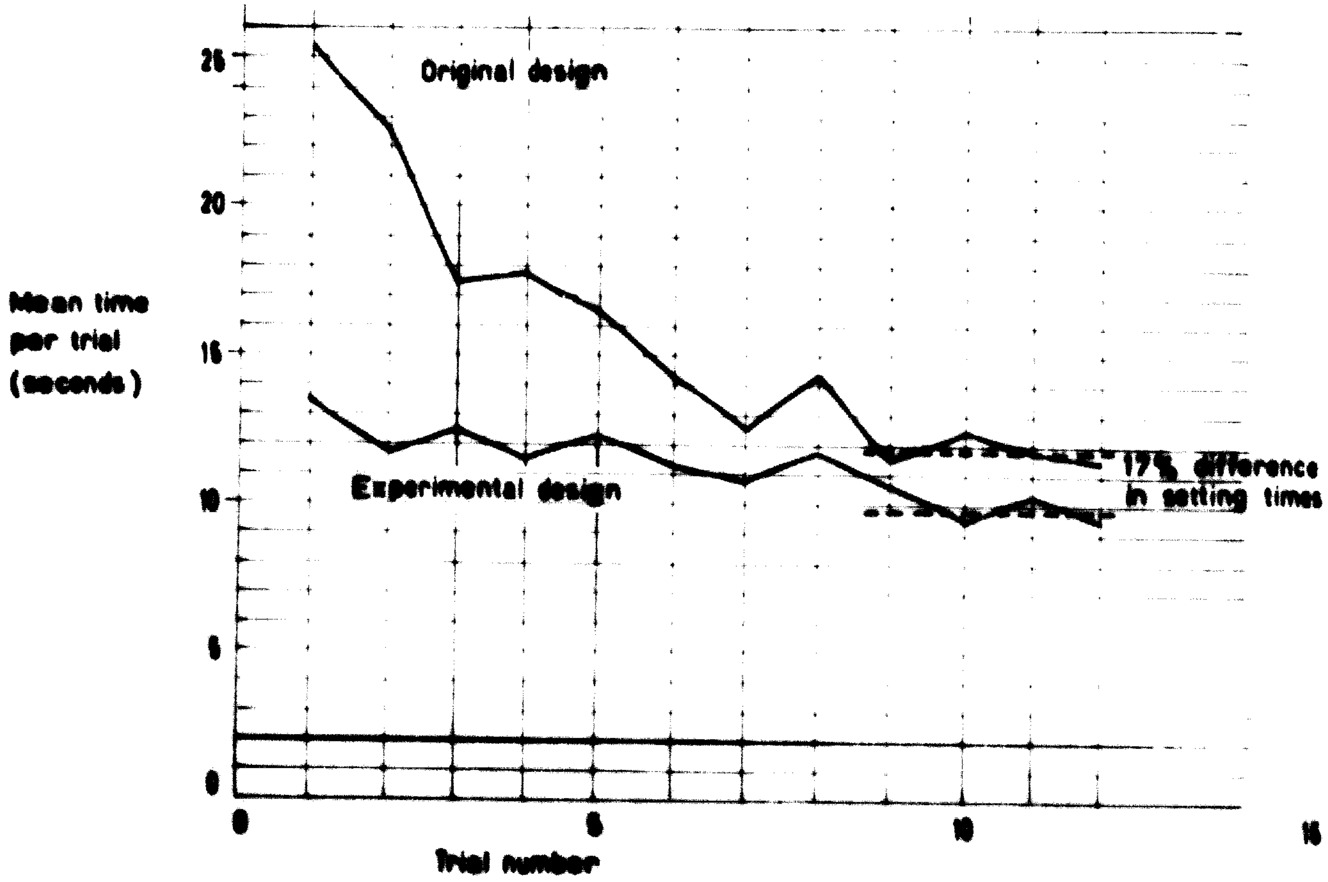

Figure 18

TIME REQUIRED FOR SETTING UP A LATHE GEAR-BOX, USING TWO DIFFERENT DESIGNS OF LEGEND PLATES

speeds will be required). But general-purpose machine tools are used for such a wide variety of work that they have to be designed so that all the facilities that users may require can be incorporated. There is, however, a growing body of evidence that general-purpose machine tools are ill-matched to the purposes for which they are used. Figure 19, for example, compares the facilities available on a large number of machine tools in a number of workshops with those actually used. It is probable from these and many similar results that if machine tools could be properly matched to the real requirements of users, the equivalent capital value of the plant required for machining (taking account of the reduction in complexity and size of the machine tools, of the reduced workshop area and of the reduced costs of heating etc.) could be reduced by about 30 per cent. In the United Kingdom alone, the sum involved would be more than £250,000. In practice, of course, not all of this saving could be realized, but even a 5 per cent saving would be well worth while.

This problem, like so many others, requires full co-operation between users and makers of machine tools. Users should analyse their requirements carefully, on the basis of studies of the actual components to be manufactured, and should not over-specify their requirements. It might then be possible for machine-tool makers, knowing that all the facilities ordered would actually be required, to produce a small range of standard machines which would meet most requirements, so that the current need for extra equipment on nearly all machines could be greatly reduced. The problem requires research into the pattern of shapes and sizes of components and study of the way in which they should be manufactured, i.e. into the optimum machining conditions. Such studies could also lead to even greater standardization through the introduction of machining on the family-group system, whereby different components of essentially similar shapes are machined together. The fact that components can thus be machined in larger batches greatly facilitates their manufacture.

Studies of the way in which machine tools are actually used can also point to other ways of increasing their effectiveness. For example, figure 20 suggests that the provision of better measuring and handling facilities could greatly increase the utilization of centre lathes.

Any work on the economics of metalworking processes must obviously include studies of the use of numerical control and similar automatic systems. Although the greatly increased capital cost of numerically controlled machine tools can be justified when they are properly used, the techniques currently available for deciding when the capital expenditure would be justified are often inadequate. Research for the machine-tool industry must, therefore, include studies of the economics of manufacture and must include co-operation with management and accountants.

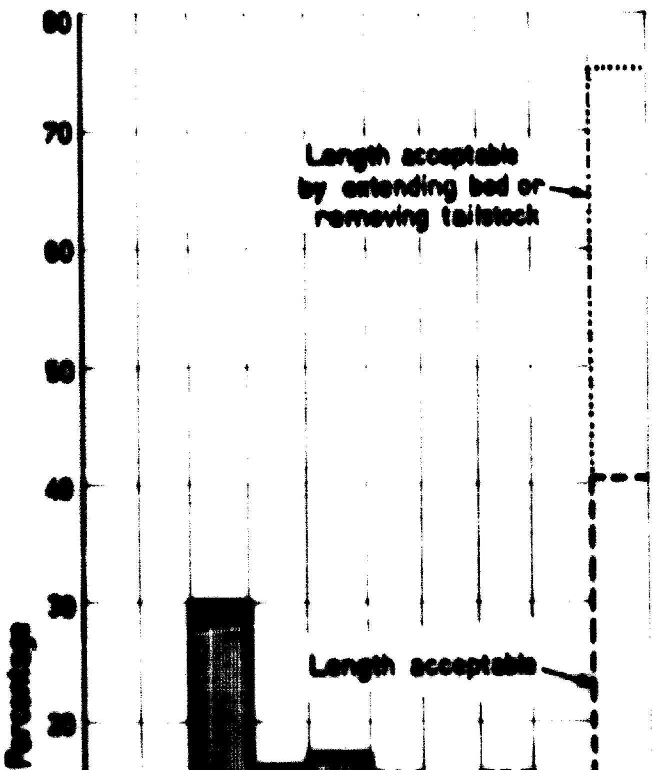

Figure 19

HORIZONTAL BORING MACHINES: COMPARISON OF ACTUAL LENGTHS OF WORKPIECES WITH THOSE ACCEPTABLE

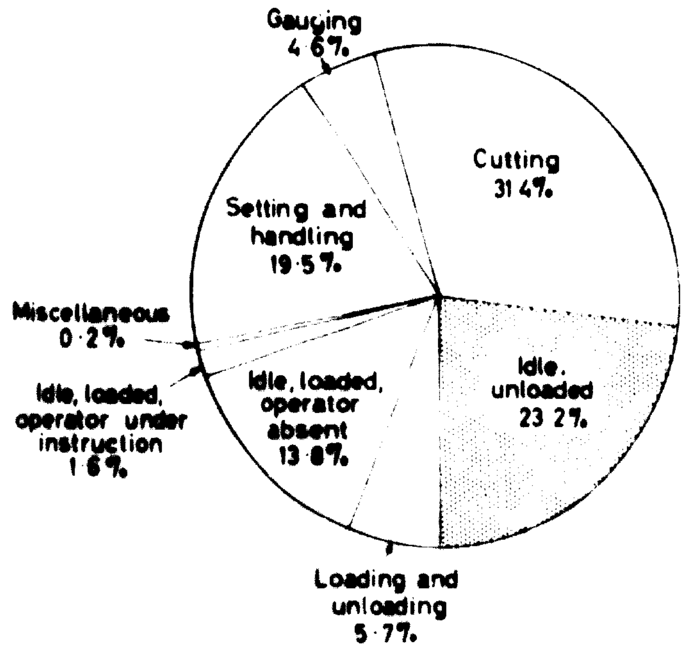

Figure 20

CENTRE LATHES: PROPORTION OF TIME SPENT IN DIFFERENT OPERATIONS (PERCENTAGE)

VII. AUTOMATIC CONTROL

In order to increase productivity faster than the rate at which the amount of skilled labour available will increase and in order to make the best use of skilled labour of all kinds, there must be greatly increased use in future of automatic controls of all kinds. Although, in the context of machine tools, automatic control is coming increasingly to mean numerical control, it must be realized that numerical control, as it is currently understood, is neither the beginning nor the end of automatic control of machine tools. Mechanically operated automatic machine tools and auxiliary equipment have been used for many years, and such recent developments as static switching, electric, hydraulic and pneumatic logic units etc. have greatly increased their flexibility. The current trend is exemplified by the programme-sequence controlled lathes of the capstan and automatic type, although essentially similar, but simpler, systems are in use on transfer lines, conveyor systems and on other machine tools. Information about the operations to be carried out and the sequence in which they are to be performed is fed to the control system by punched paper tape or punch cards, or by setting up electrical connexions by switches or plugs. Switches on the machine signal the completion of each operation, and the resulting electrical signals from the input system and the machine are interpreted by the logic units which control the operation of the machine. Control systems of this kind were originally based on electromagnetic units, but continuing research has led to the emergence of systems based on cold-cathode tubes, solid-state semi-conductor devices and, more recently, fluid-logic elements of hydraulic or pneumatic nature.

Programme-sequence control systems differ from numerical-control systems in that they select only discrete functions—particular feeds, speeds or tools; they do not control the dimensions of the workpiece, which are determined in the usual way by fixed stops on the machine. With numerical-control systems, however, the dimensions of the workpiece are determined by numerical information fed to the machine together with the required process information, the position of the moving parts of the machine tool being measured continuously by suitable transducers. Research for numerically controlled machine tools can be considered under three headings.

A. *Control systems*

In addition to the development and improvement of transducers—optical gratings, inductosyns and resolvers, digitizers etc., there is scope for the development of control systems with improved characteristics in respect of ease of programming. The problem of improving following speeds and response times has already been mentioned.

B. *Mechanical design*

The absence of a human operator to make correcting adjustments imposes special design requirements on numerically controlled machine tools. Most of these — high stiffness, low friction etc. — have already been mentioned and it is worth noting that many of the design features that have been developed to meet those special needs (hydrostatic slideways, recirculating-ball lead screws etc.) have also been incorporated in conventional machine tools. In general, too, there is a higher degree of reproducibility of numerically controlled machine tools and this also involves greater care in design. Satisfactory results can be assured currently only by more or less individual fitting of the control system to the machine tool. It should, however, ultimately become possible to make both machine tools and control systems to specifications which will ensure their mutual compatibility. Accuracy, inertias, natural frequencies and frictional characteristics of the machine-tool structure could be specified and controlled to agreed limits. At the same time, the accuracy of measuring transducers, the gain and phase characteristics of the control loop and other features of the control system could also be specified. It should then be possible to ensure that any control system meeting the specification would function satisfactorily on any machine tool which also met the appropriate specification. Much research is needed, however, before this desirable end can be achieved.

The possibility of using an automatic-control system to correct errors in straightness or alignment has already been mentioned. In a rather similar way, the use of in-process measuring systems for actual measurement and control of workpiece dimensions during machining is now being developed. At the current time, deflections of the machine tool or workpiece during machining are outside the feedback control loop and cannot, therefore, be corrected. Good mechanical design of the machine tool and care in setting up the workpiece can minimize, but cannot eliminate, these errors. Particularly when high standards of accuracy are required, therefore, there is a need for in-process measurement of actual workpiece dimensions.

C. *Part programming*

The problems of part programming — the preparation of instructions for numerically controlled machine tools — are too complex to discuss at length here, but the facility with which machining instructions can be programmed will influence very considerably the extent to which numerically controlled machine tools are used.

In some parts of the world at least, numerical control is now well-established, and although its future development requires research into programming languages and techniques and also into the way in which numerically controlled machine tools should be used, the improvement of the machine tools themselves probably depends more upon machine development than upon research. Likely directions for the future development of numerically controlled machine tools include:

(*a*) The development of multiple-axis machines and suitable programming languages and techniques to facilitate their use for die-sinking and similar operations;

(*b*) The development of photogrammetry as a means of supplying to the machine tool the information about a prototype component;

(*c*) Extension of programme-sequence controlled machine tools to full numerical control, the development of simplified systems for straight-line machining and the development of systems to permit one numerical control system to operate a number of machine tools;

(*d*) Combination of numerical control with electro-erosion or electro-chemical machining for dealing with difficult-to-machine alloys.

There are, however, other types of automatic-control systems demanding the attention of the scientists and engineers in machine-tool research. At the current time, cutting conditions, such as feeds and speeds on numerically controlled machine tools, have to be determined in advance. They must, therefore, be chosen conservatively and unless the programme is intended for one machine tool only, they must take account of any variations which may exist between machine tools. With a manually operated machine tool, on the other hand, the operator can, if necessary, make continual adjustments to ensure accuracy, surface finish or maximum productivity. There is, however, no reason why the machine tool itself should not perform the same function and, by occasional or continuous monitoring of its performance, keep itself adjusted in the optimum manner. This is adaptive control which, in its most complete form, involves the continual making of small variations in one or more of the quantities to be controlled, noting the result on the chosen criterion — surface finish, productivity etc. — and continually optimizing the values of the controlled quantities (see figure 21). Systems of this kind could be applied to individual machine tools in order to minimize costs or to maintain accuracy or surface finish; they could also be applied to control an entire workshop or manufacturing process. Adaptive control can be considered quite independently of numerical control but the fact that, with a numerically controlled machine tool, the exact state of the machining operation is known at any instant greatly facilitates the application of adaptive control.

Simpler forms of adaptive-control systems are also possible and have already been applied to some machine tools. One of the simplest merely involves measuring the machined dimension and then making, automatically, a second operation to correct any error that may be detected. Such a system could, until systems of in-process measurement have been fully developed, be applied with advantage to the machining of workpieces which deflect appreciably under the cutting forces imposed on them. Adaptive-control systems could also be used to ensure that the feeds and speeds used for machining are correctly chosen to optimize productivity or surface finish. As with in-process measurement, however, the successful application of adaptive control requires the development of measuring techniques for the continuous measurement of workpiece dimensions, surface finish, cutting forces, tool wear etc.

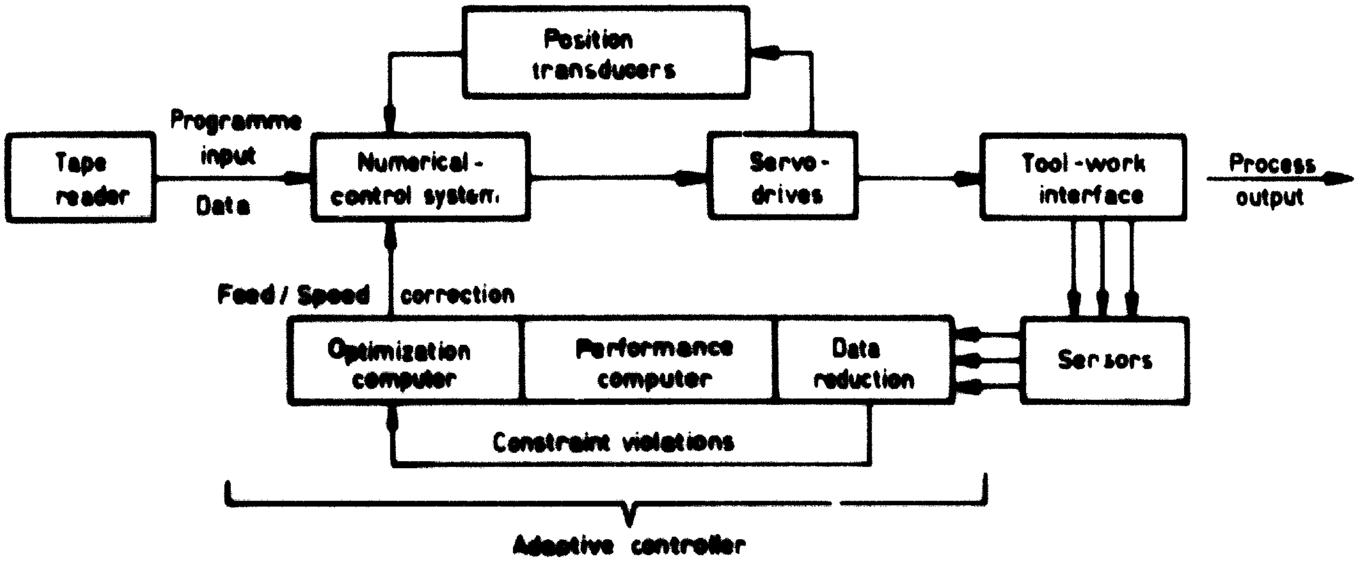

Figure 21

ADAPTIVE CONTROL SYSTEM

The use of computers and other numerical aids to engineering design, although not a problem peculiar to the machine-tool industry, is, nevertheless, closely associated with the use of numerically controlled machine tools. Examples have already been given of ways in which computers have been and can be used by or for the machine tool designer, but there remain many directions in which further research into their application is required. Numerically controlled drawing machines and computer-aided design systems of the "sketch-pad" type (in which the designer is in full and continuous communication with a computer *via* an electronic sketch-pad) represent the two extremes and there are many intermediate possibilities.

VII. MANUFACTURING PROCESSES

Although a distinction can always be drawn between the machine tool and the tool which actually changes the shape of the workpiece, it will be clear that the design of a machine tool must be considerably influenced by the characteristics of the cutting tools with which it will be used. The study of metalworking processes of all kinds must, therefore, be considered when discussing research for the machine tool.

There is a long history of research into the mechanism of metal-cutting and the subject was being studied long before research, as distinct from development, was begun on machine tools. In the course of this work, much has been learned about the mechanism of chip formation and tool wear although practical machining has benefited very little from it, the considerable advances in metal cutting that have been made during the last years — increased speeds, improved cutting-tool materials and design, better cutting fluids etc. — having been made on a mainly empirical basis. Although work on cutting forces, tool temperatures, frictional phenomena and deformation processes in the cutting zone still continues in many centres, it now seems unlikely that work on the current lines will contribute significantly to the development of metalworking processes, and a new and more fruitful approach is urgently needed.

Measurements of cutting forces under steady conditions have provided a picture of the effects of tool geometry, cutting speed etc. on the forces required in various machining processes, and this provides a basis for the mechanical specification of a machine tool. The dynamic characteristics of the cutting process, as affected by cutting speed, depth of cut, tool geometry etc. are just as important as the dynamic characteristics of the machine-tool structure in determining the performance of the machine tool. Relatively little detailed information is available, however, about cutting forces under the more usual non-steady conditions, i.e. when the chip thickness is varying continuously either because of the geometry of the workpiece itself or because the machine tool is vibrating.

But even if basic research in metal cutting seems unlikely to produce useful results, there is considerable scope for making better use of the large amount of empirical data that now exist on cutting forces and conditions. Not only are the optimum feeds, speeds and depths of cut for different machining operations and materials rarely used because of lack of information or lack of attention to the economics of machining, but considerable experimenting with tool geometry is often required, even when machining conventional materials, before acceptable conditions can be obtained. And with the increasing use of harder and tougher alloys the problem is continually increasing.

The pioneer work of Taylor on wear of cutting tools led to the development of a relationship between speed and tool wear which, although still not fully understood, has proved very useful and could, with advantage, be more widely used for determining optimum machining conditions — feeds, speeds etc. More recently, work on the physical and chemical reactions in the high-temperature region near the tool-point and on the effect of inclusions in the workpiece materials, has suggested the possibility of considerable improvements in tool life.

Perhaps not surprisingly, still less is known about the mechanism of the grinding process although recent work has made significant contributions. As with metal-cutting, however, grinding processes (including lapping and honing) have been developed empirically and recent developments high-speed grinding and the use of grinding for stock removal (abrasive machining) have been made in the same way.

Of metal-forming processes, forging is perhaps the oldest, but it has recently been shown that greatly improved results can often be obtained by forcing the metal to deform rapidly. Under these conditions, plastic deformation takes place simultaneously in most regions of the workpiece and cracks are less likely to develop than when the deformation takes place slowly. High-energy forging is, therefore, a possible method of making components that could not be successfully forged in the normal way. Extrusion processes (forward, backward or combined) have long been used for shaping light-alloy parts, but, recently, extensive research has permitted the process to be used to produce steel components also.

The advantages of forming as opposed to machining are: (*a*) less wastage of material as swarf, chips etc.; (*b*) reduced production time; and (*c*) better mechanical properties as a result of the way the material has flowed during forming (see figure 22).

Of course, not all components can be produced by forming, but if the problems of die life could be solved and more was known of the economics of the processes, it seems likely that many components now produced by machining could be made by a forming process. An even more recent development is the use of investment casting for producing components in steels and other metals. Cast components usually require even less finish-machining then do formed components; and, of course, both processes produce components with much less wastage of material than is involved in machining. As yet, however, neither process is used on a really large scale and there are many technical problems to be solved before this is possible. But even more important, perhaps, is the need for studies of the economics of these and other manufacturing processes to establish the conditions in which each should be used.

There is an increasing trend towards the wider use of materials which are tougher and harder than the conventional mild steels and non-ferrous alloys, and which retain their hardness and toughness at high temperatures. All conventional metal-cutting, grinding, forming, forging etc. processes rely essentially on plastic deformation of the workpiece material caused by pressure against a harder tool. The harder the workpiece material, the more difficult it becomes to find tools that will behave satisfactorily. These new materials are, therefore, difficult to machine by conventional methods and it is not possible to cut them at the rates which were possible with the materials that they have replaced (see figure 23). The search has begun for new methods of machining and particularly for methods that are independent of the hardness or toughness of the workpiece material.

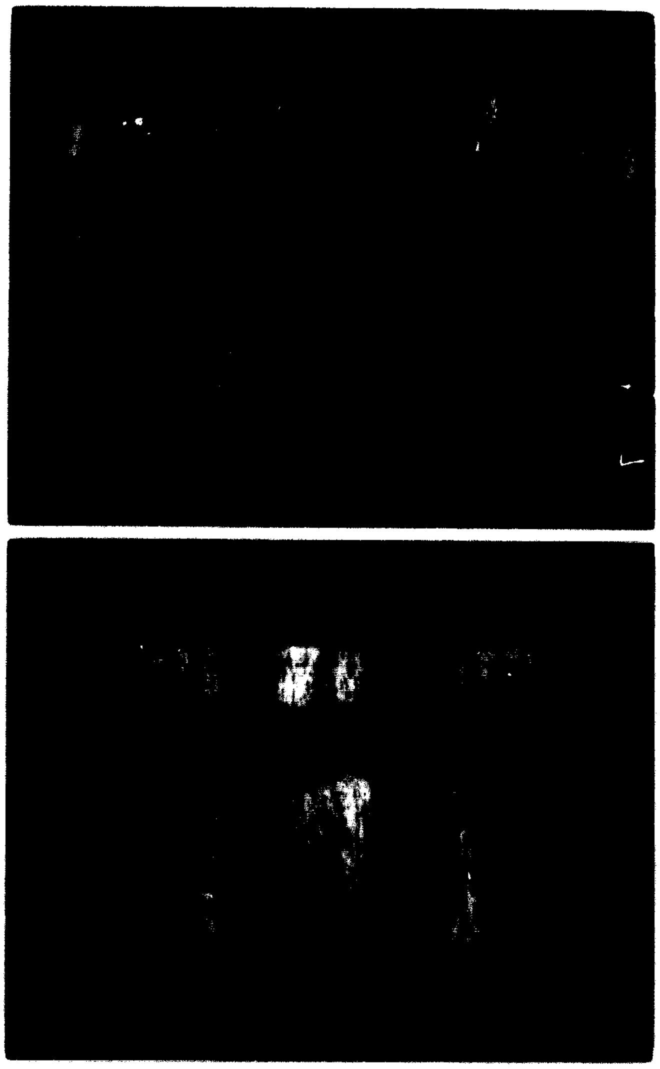

Figure 22

GRAIN STRUCTURE IN COMPONENTS PRODUCED BY TURNING AND BY FORMING

The traditional way of machining hard materials is, of course, to use an abrasive process since the form of the tool used in such processes permits much greater wear rates to be tolerated without loss of accuracy. Special abrasive methods have also been developed for making fine cuts in very hard and brittle materials, particularly glass and semi-conductors. These include:

(*a*) Abrasive jet machining in which a fine high-velocity jet of air carries fine abrasive particles which, on impinging on the workpiece, cause material to be removed;

(*b*) Ultrasonic machining in which a shaped tool is vibrated rapidly against the surface of the workpiece, a slurry of fine abrasive particles flowing between the tool and the workpiece. The impact of the tool causes small particles to be chipped off the workpiece.

Even abrasive machining, however, is much slower with harder materials and the high rate of tool wear limits its application. The newer methods of machining that are now being developed avoid this difficulty by

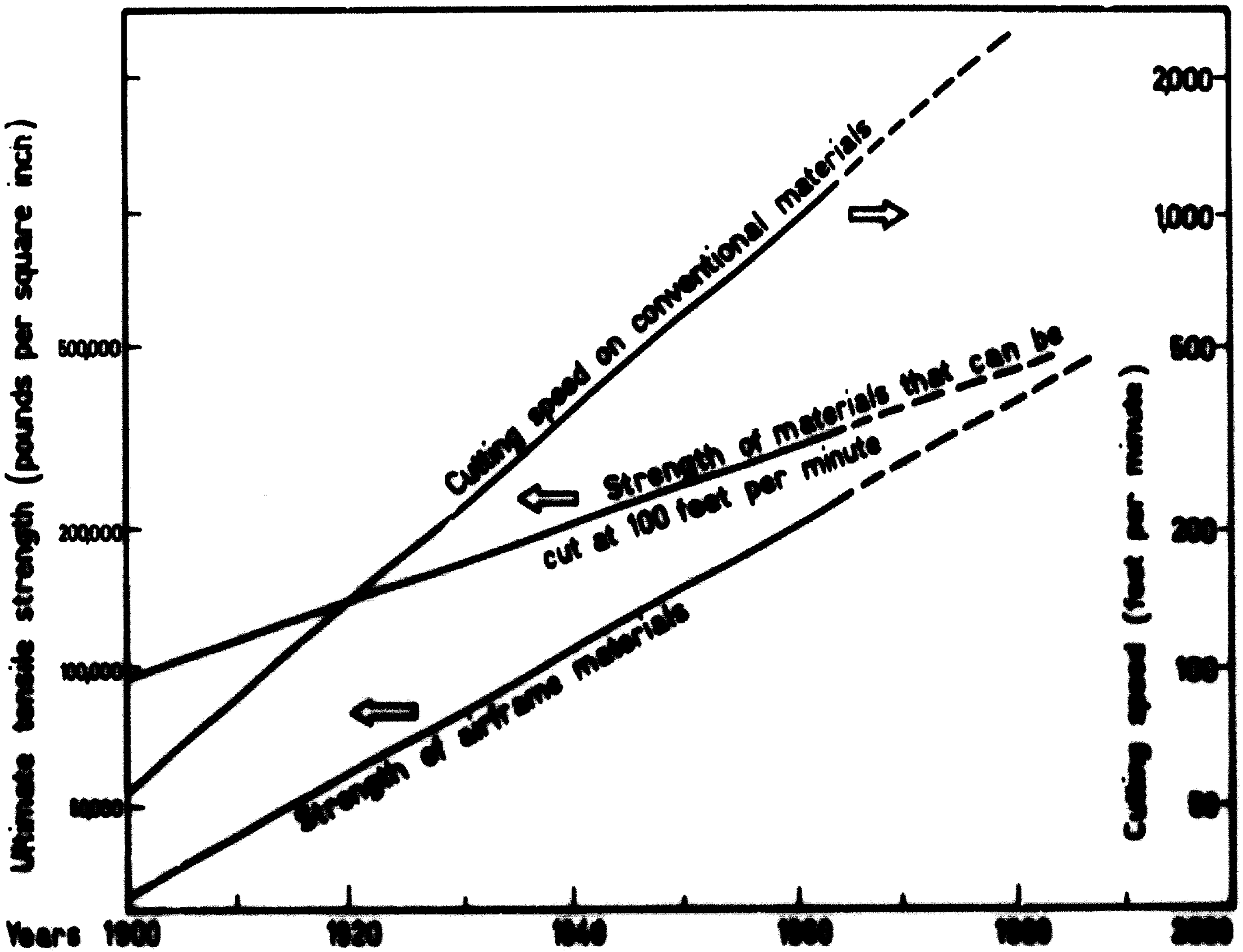

Figure 23

DEVELOPMENT OF NEW MATERIALS LEADING TO SLOWING DOWN OF RATE OF METALWORKING

NEW METHODS OF MACHINING

	Maximum rate of metal removal (cubic inches per minute)	Power consumption (horsepower per cubic inch/minute)	Cutting speed (feet per minute)	Penetration rate (inches per minute)	Accuracy: Attainable (inches)	Accuracy: At maximum rate of metal removal (inches)	Typical machine: Input power (horsepower)	Typical machine: Cost (pounds)
Turning	100	1	200	—	0.0001	0.005	30	3,000
Grinding	50	10	10		0.0001	0.005	20	5,000
Plasma jet	10	20	50	10	0.01	0.1	200	4,000
Spark-erosion	0.3	40	—	0.5	0.0005	0.005	10	5,000
Electrochemical	1	100	—	0.5	0.002	0.005	200	10,000
Ultrasonic	0.05	200	—	0.02	0.0002	0.001	20	750
Electron beam	0.0005	10,000	200	6	0.0002	0.001	10	30,000
Laser	0.0003	60,000	—	4	0.0005	0.005	20	2,000[a]

[a] Source only.

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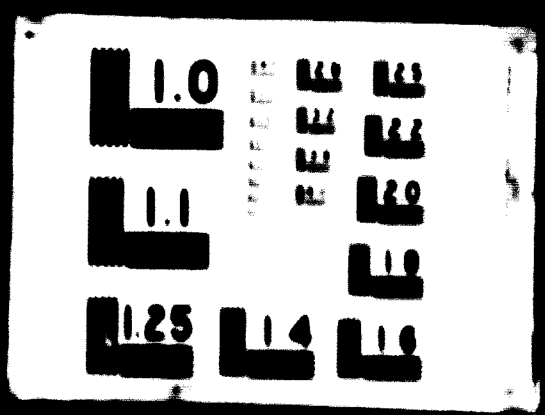


relying on quite different processes for shaping the workpiece. Two main processes are involved—chemical processes, in which the material of the workpiece is removed atom by atom by chemical action; and thermal processes, in which the material of the workpiece is melted and vaporized. A summary of the characteristics of the principal methods available is given in the table on page 541.

A. *Thermal methods*

Thermal processes depend essentially upon achieving a high concentration of energy on a small area of the workpiece so that the temperature of a small volume of the material is raised sufficiently high for that small volume to be melted and vaporized while leaving the remainder of the workpiece relatively unaffected. Power densities in the range 10^4–10^{12} watt cm^{-2} can be achieved. (A power density of 10^{12} watt cm^{-2} is equivalent to putting the output of several large power-stations through an area of 1 square centimetre.) Even though these power densities are achieved for only a small fraction of a second, the local temperature of the workpiece is thereby raised to 10–20,000 K. The main forms in which thermal methods of machining are practised are:

1. Plasma torch

The use of an oxygen-hydrocarbon flame for metal cutting is not new, but the development of plasma torches, in which the temperature of the flame is increased by electrical energy, has greatly extended the applicability of the technique. Materials which could not be cut economically with conventional flames can now be cut and, furthermore, the increased power densities obtainable with plasma torches permit rough turning and gouging operations to be carried out also. The accuracy currently obtainable is not high, but it can be expected to increase.

2. *Electro-erosion*

Electro-erosion is currently the most widely used of the new methods of machining. The energy necessary to raise the local temperature of the workpiece is supplied electrically by passing electric sparks or arcs through a dielectric fluid between a shaped tool and the workpiece. Material is removed from both anode and cathode but, for reasons which are not yet fully understood, it is possible to arrange for most of the material to be removed from one or other, and thus to arrange for a cavity complementary to the shape of the tool to be formed in the workpiece (see figure 24). Although each pulse of current may produce only one spark and, therefore, remove metal from one small region to the workpiece only, succeeding sparks will pass at other parts of the workpiece. A typical pulse rate is 400–200,000 c/s, so that over a period of a few minutes, metal is removed more or less uniformly from all parts of the workpiece close to the tool. As machining proceeds the tool is fed towards the workpiece, the distance of closest approach being maintained at about 0.01 mm, so that eventually material is being removed over the whole area of the workpiece exposed to the tool.

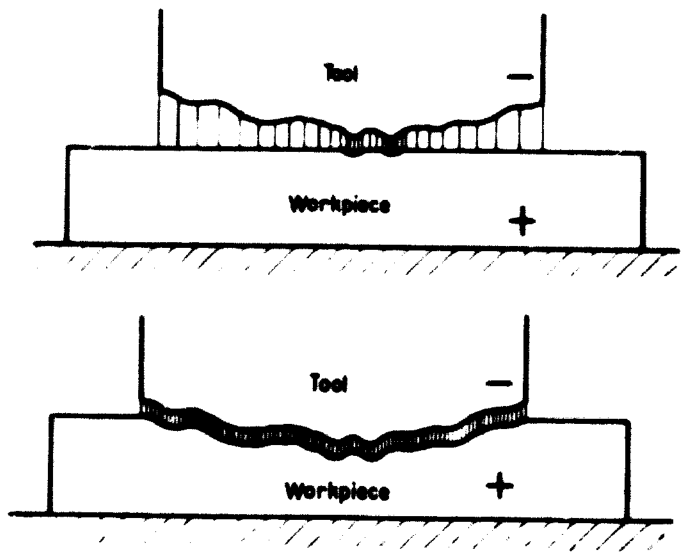


Figure 24

CAVITY FORMATION BY ELECTROCHEMICAL AND ELECTRO-EROSION MACHINING

Problems requiring solution are:

(*a*) A full understanding of the mechanisms of electro-erosion;

(*b*) Choice of tool material for minimum wear;

(*c*) Choice of circuit conditions—amplitude, shape and frequency of current pulses—for optimum metal-removal rate and tool wear;

(*d*) Reduction of damage to the workpiece surface and improvement of surface finish;

(*e*) Development of scanning systems, perhaps with numerical control, for generating three-dimensional cavities with a small electrode.

3. *Electron beams*

The energy of a beam of high-velocity electrons is converted into heat when they impinge on a solid target and, since the beam can be focused on to a very small spot (diameter less than 5μ), very high power densities can be obtained. The position of the beam can be controlled electrically by means of deflecting coils so that fine intricate shapes can be machined automatically by suitably deflecting the beam.

The advantages of electron-beam machining are that fine intricate cuts can even be made in materials like evaporated metal films which are less than 250 Å thick. The disadvantages are that the workpiece must, at the current time, be enclosed within the vacuum of the electron-beam tube and the fact that the relatively high capital cost and the limited power available make the method unsuitable for bulk removal of metal.

An electron-beam machine for machining purposes may have a total beam power of only a few hundred watts, but much larger machines, with powers up to 10^4 watts, are used for welding. Very clean, reliable narrow welds can be made in material up to 10 cm thick, including materials which are difficult to weld in the normal way. Although it is usually necessary to enclose the workpiece within a vacuum chamber, even this is unnecessary on the latest machines.

4. *Lasers*

The characteristics of the light emitted by lasers are such that it can be focused on to a spot of very small diameter and, as high-energy pulses of short duration can be produced, very high power densities can be obtained on small areas for short periods of time. As with an electron beam, machining to the desired shape is achieved by moving the focused beam in relation to the workpiece.

Current applications of lasers for machining are rather similar to those of electron beams, the main differences being that with a laser the workpiece does not need to be in a vacuum chamber and that the position of the electron beam can be controlled electrically. Progress in the development of lasers is, however, so rapid that it is difficult even to speculate on the future of laser machining techniques. Until very recently, the necessary high-output energies could be obtained only by the use of "giant-pulse" techniques with solid-state lasers, the mean output power being limited mainly by the low efficiency of the laser. The recent development of high-output gas lasers of high efficiency have materially changed the picture, but as yet little information is available on the machining capabilities of this type of laser.

B. *Chemical methods*

Chemical methods of metal removal have been practised for a long time, e.g., pickling of metal sheets, but chemical etching (sometimes called chemical milling) has recently been developed as a selective metal-removal process for reducing weight or for producing complex shapes in thin materials. Regions where chemical attack is not desired are protected by a suitable coating, which may be applied only where it is required, or applied overall and then selectively removed by manual or photo-exposure techniques to expose the appropriate regions of the sheet.

Electrolytic action as a means of removing metal was first proposed more than thirty years ago and was developed at about that time for removing asperities and thus producing a flat polished surface—electropolishing. It has since been applied to assist the removal of metal in grinding and honing, and also for bulk metal-removal. The rate at which metal is removed by electrolytic processes is independent of the hardness or other physical properties of the workpiece and depends only, according to Faraday's laws, upon its chemical composition and the quantity of electricity passed. For the most usual workpiece materials, the rate at which metal is removed is about 1 mm^3 per minute per ampere of current flowing.

In electrolytic honing, the normal mechanical honing action (which, by virtue of the rotating and reciprocating motions involved, is intermittent on any portion of the workpiece) is augmented by electrolytic action on those portions of the workpiece not in contact with the abrasive stones. If desired, the final cuts can be purely mechanical to give the characteristic honed surface. In electrolytic grinding, however, the electrolytic action takes place parallel with and at the same time as the normal grinding action. An electrically conducting grinding-wheel is used, current being passed from the wheel as cathode to the workpiece as anode.

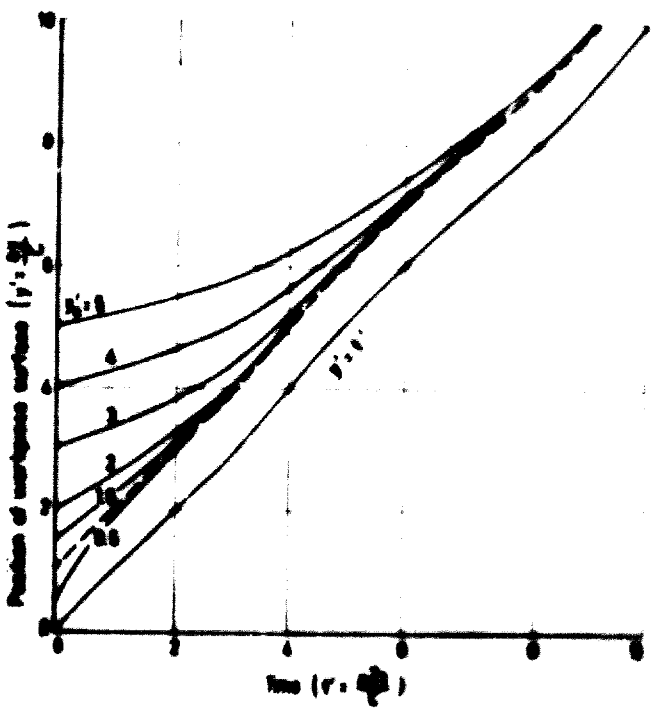
In both processes, electrolyte usually a salt solution is fed to the gap between anode and cathode, which is maintained at the desired value either by control of the surface of the grinding wheel (the amount by which abrasive particles protrude above the conducting matrix, or, in the case of graphite-bonded wheels, the structure and composition of the wheel), or, in honing, by the position of the electrodes with respect to the surface of the honing stones. In both electrolytic honing and electrolytic grinding, however, most of the metal is removed electrolytically, thus giving increased production rates and less wear of the abrasive, while the geometry of the finished surface is controlled essentially by the mechanical dimensions and characteristics of the abrasive stones or wheels. Electrolytic action can also be used to augment ultrasonic machining in a similar way.

In electrochemical machining proper, however, all the metal is removed electrolytically. Current passed through an electrolyte between a shaped tool and a workpiece will concentrate in the region of closest approach (see figure 24) so that, in time, the surface of the workpiece will become approximately complementary to that of the tool. The distance of closest approach is kept approximately constant, either by actual control of the gap or by keeping constant the potential applied across it. In these latter circumstances, the gap tends to a constant value, any deviation leading to an increase or decrease in current, which quickly restores the gap to the equilibrium value (see figure 25). If conditions (electrolyte, tool material) are properly chosen, there need be no wear of the tool.

Some of the possible ways of applying electrochemical machining are shown in figure 26. Most of the current applications are for shaping or deep-hole drilling operations on gas-turbine blades. The process is, however, also being used for a wide variety of miscellaneous applications, again mostly with high-temperature alloys, and there would seem to be some scope for a numerically controlled electrochemical cavity-sinking machine for machining complex shapes in tough materials.

To summarize, the new methods of machining that seem to offer most promise for the future are electrochemical machining and the use of lasers. As far as lasers are concerned, it is too early to say much about the research that is needed for their application since there is still so much to be done to develop lasers which have the required output powers and which are both cheaper and more efficient than those currently available. But it is possible to discuss briefly the research problems associated with electrochemical machining:

(a) *Electrochemistry.* Little is known of the nature of electrolytic phenomena when the current densities are as large as those normally used in electrochemical machining (200–300 amp cm^{-2}). More knowledge of the mechanisms involved would help in the solution of all the following problems;



Note: With a constant applied potential and a constant feed rate, the gap between tool and workpiece in electrochemical machining always tends toward the equilibrium value, whatever the initial gap may be. In the units used, the equilibrium gap is 1.

Figure 25

TENDENCY OF GAP BETWEEN TOOL AND WORKPIECE IN ELECTROCHEMICAL MACHINING, WITH A CONSTANT APPLIED POTENTIAL AND A CONSTANT FEED RATE

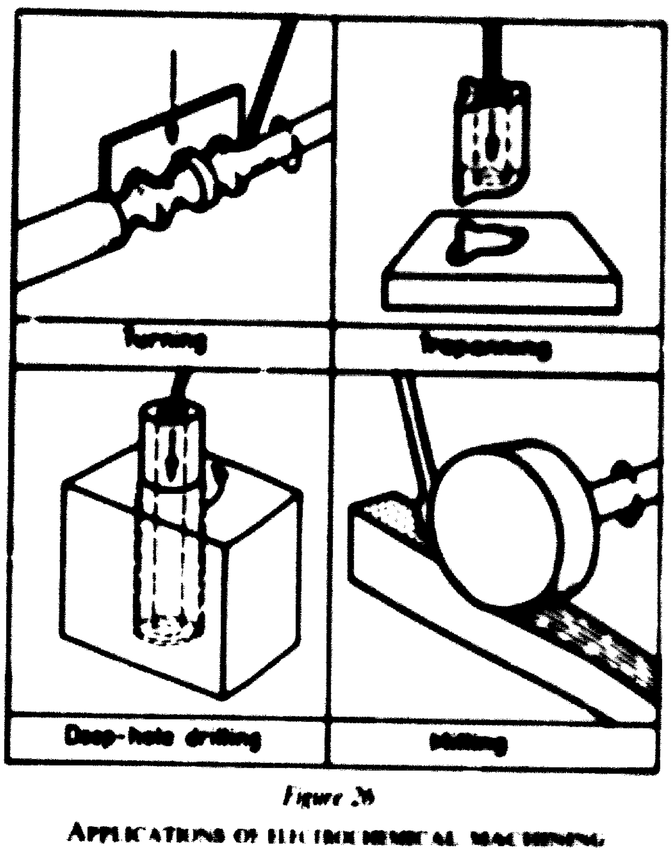


Figure 26

APPLICATIONS OF ELECTROCHEMICAL MACHINING

(b) *Tool design.* Even under ideal conditions, the workpiece shape is not exactly complementary to that of the tool. To produce a given workpiece shape, the required tool shape is that equipotential which, at the appropriate distance from the workpiece, produces a current density which is uniform over the surface of the workpiece. The problem of determining the desired equipotential line, which is probably the most important outstanding problem of electrochemical machining, can be tackled by analogue methods, digital computation or by trial-and-error methods.

(c) *Gap control.* Closely associated with the problem of tool design is that of control of the size of the gap between tool and workpiece, both having a direct influence on the accuracy of machining. Although control of the potential across the gap will always maintain an equilibrium gap, this remains constant only if the conductivity of the electrolyte does not vary. In practice, changes in the temperature and composition of the electrolyte cause its conductivity to vary, and alternative approaches to the problem of gap control are now being considered. These include direct control and also indirect control by measurement of electrolyte conductivity.

(d) *Electrolyte flow.* In order that it shall continue to be possible to pass large currents through the electrolyte in the narrow (0.05–1 mm) gap between tool and workpiece, the electrolyte in this region must be continually replenished. In practice, this usually means that electrolyte must be made to flow rapidly between the electrodes, and the need for this rapid flow of electrolyte brings several problems:

(i) Large pressures are required to force the electrolyte through the gap and these produce large forces tending to separate the electrodes. A pressure of 60 N cm^{-2} acting on an area of, say, 100 cm^2 produces a separating force of 6,000 N, and if the machine structure is not stiff, the resultant deflections will, as with conventional machine tools, influence the accuracy of machining by causing the gap between the electrodes to vary.

(ii) Tools must be designed in such a way that the electrolyte can be pumped through the gap, but also so that the holes necessary for this purpose produce the minimum of interference with the required surface.

(iii) The Joule heating associated with the passage of electric current through an electrolyte causes the temperature of the electrolyte to rise. The temperature of the electrolyte will increase from inlet to outlet (see figure 27), and the resultant variation in conductivity complicates the problem of tool design.

(iv) Turbulent flow of the electrolyte is necessary if large currents are to be passed, but persistent eddies tend to cause machining marks on the surface of the workpiece.

(e) *Electrolyte.* Although, in principle, any ionic solution will serve as the electrolyte for electrochemical machining, in practice, the following considerations are involved:

(i) cost;

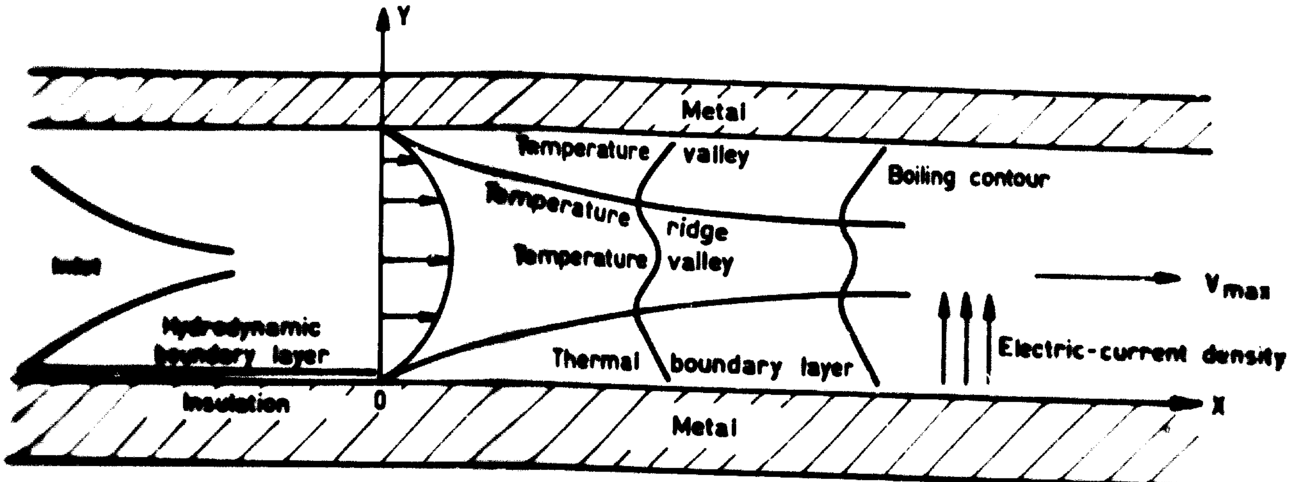


Figure 27

THEORETICAL TEMPERATURE AND FLOW CONDITIONS IN THE GAP BETWEEN TOOL AND WORKPIECE

(vii) **Conductivity**: most of the electrical power required for electrochemical machining is dissipated as heat in the electrolyte;

(viii) **Corrosion**: the electrolyte should not corrode the workpiece or material of the machine;

(ix) **Surface finish**: although the reasons are not fully understood, the surface finish obtained by electrochemical machining varies greatly with the electrolyte used;

(x) **Filtration**: both the form in which the material removed from the workpiece exists in the electrolyte and the effect that it has on its properties are important.

VIII. THE ORGANIZATION OF MACHINE-TOOL RESEARCH

It may be useful to conclude this review of some of the research problems of the machine-tool industry with a short discussion of the way in which research is organized.

The border line between research and development is never clearly defined and is probably even more indistinct than usual when machine-tool research is involved. The improvements that took place in machine tools between 1850 and 1950, say, obviously involved considerable effort, but since, with a few notable exceptions, little of this led to any systematic collection of information of general applicability, it can perhaps be best regarded as development rather than research. This distinction between research and development is a useful one to bear in mind even if it is not universally applicable.

This paper has not been concerned with development work, important though that may be, but with the wider and more general problems of research which, if the information gained is to be really useful, must be tackled at a fundamental level. Only the very largest individual manufacturers of machine tools can afford the necessary effort to basic research, which must, therefore, usually be carried out in co-operative, educational or state laboratories.

Prior to 1950, the amount of real research of interest to the machine-tool designer was very small. In the United States of America valuable work was done on the metal-cutting process, and in Germany, the foundation for more subsequent work on machine-tool structures was laid. Since 1950, however, interest in machine-tool research has increased rapidly and an appreciable proportion of the research effort of most industrial countries is now devoted to machine-tool problems.

The pattern varies from one country to another. In the United States of America most of the research is done privately by machine-tool manufacturers, often with support from the state for specific projects. In addition, some universities have always shown an interest in the subject and the amount of university research is now increasing. In Eastern European countries and the Union of Soviet Socialist Republics, machine-tool research tends to be concentrated into one or a small number of large state-supported institutes whereas in the United Kingdom and in Western Europe, private research by machine-tool manufacturers is combined with co-operative research in research associations, state laboratories and educational establishments.

As the amount of machine-tool research increases, there is a danger that too large a proportion of the effort available will be devoted to empirical problems and not enough to fundamental studies. The mathematics involved in the analysis of real situations such as are found in machine-tool problems can be difficult, but the rapid spread of electronic computing techniques is doing much to alleviate the difficulties.

In general, a theoretical analysis of the physical phenomena involved, augmented by experiments to determine numeric values or to check conclusions, is likely to be of far more use in the long run than attempts to draw general conclusions from a large number of *ad hoc* experiments, although the latter approach is usually much easier. Isolated measurements of various phenomena can, of course, be very useful in the development of a particular machine. Unless, however, they are made systematically, i.e. with proper control of all the variables and on a sufficiently wide basis for the results to be generally applicable, taking account of all or most of the variables involved, they are unlikely to be generally useful and may, indeed, be misleading.

This point is conveniently illustrated by reference to work on slideway lubrication. There are innumerable references in the literature to measurements of coefficients of friction between slides and slideways, account being taken of lubricant properties, sliding speed, method of preparation of the surfaces etc. Some of the measurements were made on actual machine tools, and these undoubtedly helped in determining and specifying operating conditions for those machines. Other measurements were made on specially constructed rigs, but although a small amount of useful information was obtained in this way, the results have not been found to be generally applicable and it remains impossible to predict with any certainty just how any particular machine-tool slide will behave under given conditions. The reason for this became clear when it was realized that the frictional behaviour of the slide depends upon the shape of, and pressure in, large numbers of small wedge-shaped oil films which form between the sliding surfaces. The shapes and other properties of these wedges obviously depend upon the character of the surfaces, but they depend also upon the constraints applied to the sliding members. For example, the frictional behaviour when the surfaces are constrained so as always to remain exactly parallel can be expected to be different from that observed if a small amount of tilting is possible.

There is no substitute for real understanding of the physical phenomena involved and although, as this paper has tried to illustrate, the range of problems facing those engaged in research for the machine-tool industry is very wide indeed, the benefits to be gained from such an understanding can also be very great.

SOME PROBLEMS IN THE APPLICATION OF RESEARCH IN THE MACHINE-TOOL INDUSTRY

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Introduction

Today there is great awareness of the problems in the relationship between research and its industrial application. These problems are a constant topic for discussion and there is a good deal of information on the subject—information from which one can draw conclusions as to the methods that should be applied in order to gain useful results. If, however, a particular industry is actually to make use of this information, it must know how to extract those parts which are relevant to that industry.

Before entering fully into the subject of this paper, the author would like to make a few remarks based on his experience as an industrialist. First, it should be borne in mind that economic growth depends upon such factors as the resources which are available, in terms of finance and human skill. It depends also, however, upon a chain of factors which, beginning with basic research, leads to applied research and technological development before culminating in economic growth. It is on this basis that one must study the problems of the relationship between research and its application in industry.

One must remember also that the number of scientists who are working alone is decreasing and that research is becoming more and more a group activity. This opens up all the possibilities inherent in collaboration between different scientific disciplines, but it also opens the way to the dangers of bureaucratization of a human activity which, by its very nature, is refractory to organizational pressure. On this point, it is worth while mentioning the results of the work done by the Organization for Economic Co-operation and Development (OECD), which, at the instigation of the International Institution for Production Engineering Research (CIRP), has worked out methods for promoting joint research between various European laboratories.

Again, one should remember that the incorporation of research into the framework of an organization always results in some upsetting of traditional administrative procedures. Such questions as the following arise. How will the scientific and commercial staffs co-operate? How can the research activity be reconciled with the financial objectives of the organization? At what level will research policy be related to the over-all policy of the organization?

Most persons consider research a positive investment that will eventually pay for itself. There are still, however, those who consider money spent on research as money wasted. Why do these opposing viewpoints exist? In the author's opinion, it is essentially because investment in research entails far greater risks than does investment in more tangible things, such as production equipment. Research does not necessarily produce results that can be commercially exploited and, indeed, the paths taken by research do not necessarily lead to any useful result at all.

If, however, one could know in advance what research paths to take, there could not, in fact, be any research and, as a result, no products better than others.

It is appropriate also to discuss briefly what can be called the "natural industrial pattern" of a region or of a country. In this regard, one must be very careful because one's conclusions can so easily be completely at variance with the facts. Generally, what appears to be a natural state of affairs is merely the result of a particular effort maintained over a number of years. Industrial patterns are the result of the energies, desires, abilities and feelings of social responsibility of those in charge of the industries that go to make up the industrial pattern; this applies as much to centrally planned economies as it does to free-enterprise economies. The continued success of these patterns, however, will depend upon the results of research into the organizational structures required for the attainment of the necessary levels of efficiency.

I. The Role of Innovation

Research cannot be regarded as something which is well defined and which appears the same to all men. The scientist thinks of it as a matter of increasing human knowledge, while for the technologist, it is something which leads to improved processes and new products.

Whatever the research philosophy may be, the results of research will, in time, affect the general economic situation, and the interrelation of research, industry and the general economy should never be overlooked by those who have to plan technological research.

Why is scientific and technological research so important? Frequently, the temptation is to consider that it is unnecessary and that it is sufficient to watch from a distance the evolution of things as brought about by others.

Unfortunately, this is not the case. It is, in fact, only by innovation that one can open new markets and improve the economy. If a firm, or a group of firms, wants not only to maintain its turnover but also to increase it, it is essential that it should innovate in some realm. It must be kept in mind, however, that it is necessary to have more than one string to one's bow, especially if the one listed is not very strong. Innovation is beneficial not only in design, but also in production, distribution and advertising.

To summarize, innovation is the means for making a product more attractive than its competitors. It creates the difference that convinces the customer he is getting the best value for his money.

Now, it has to be acknowledged that the current rate of progress is much more rapid than it has been in the past, and the more elaborate a product is, the more difficult it is to improve. Moreover, the production facilities required are much greater and the costs much higher.

Consequently, any research organization should attempt to make itself as efficient as possible. Research calls for every kind of knowledge, relating as much to physics as to human behaviour. The efforts exerted by man to master nature compel him to rethink his relationships with his fellow men and to return to the study of the functioning of his mind, the role played by his emotions and the causes of his behaviour and attitude. This is why it is useful to analyse, at the level of working methods, the mental processes of scientists and those whose role it is to develop the results of their research.

II. THE VARIOUS STAGES IN ESTABLISHING A RESEARCH PROGRAMME

The establishment of scientific or technological research programmes, the choice of objectives and of the means for attaining them, require consideration of both the known and the unknown factors. Before reaching any major decision, one must, as far as possible, attempt to see into the future and systematically to evaluate the various likely possibilities. It is only in this way that one will be able to establish what will, in fact, be useful programmes of research.

How should one go about choosing our research objectives? Here, one should more or less systematically follow what is in itself a research programme, a programme having a number of stages, of which the most essential are the following:

(a) The selection by top management, from all the various possibilities, of the general field of research and the broad lines to be followed therein. To do this wisely one must be able to foresee, to some extent, the changes that will come about in the economic situation, for it is necessary, at all costs, to avoid putting outmoded products onto the market. Further, there must be a good knowledge of the current stage of technology so that, from a knowledge of the state of scientific research, one can assess the probable changes that will come about in the technological situation. These two requirements can only be met if a team spirit, with all that it implies in the way of openness, fair play and honesty, exists between the laboratory director and his staff.

(b) The second stage is the selection of particular ideas within the general field. It is not sufficient to choose a field of research capable of yielding useful results: one still has to actually obtain results. Therefore, only those ideas which can be clearly expressed should be retained. The research staff themselves should be associated with this second selection and classification so that their own ideas add to those under consideration. At this stage also, specialist help from outside may be useful. It is obvious that although all can contribute to the generation of ideas, only the research staff can give detailed expression to them. It is the author's opinion, however, that a broad knowledge of the general factors involved, in addition to the purely scientific ones, can facilitate their task in this.

(c) The last stage consists of fixing relative priorities for the various parts of the programme. This is by no means management's least important task, if all the work is to end together, a necessary condition for efficient research. Unfortunately, planning scientific research is practically impossible because planning means defining not only the aim, the means and the stages, but also the times allowed for them. This can only be achieved for those operations to which known techniques can be applied. Nevertheless, if in applied research the target is clearly defined, it is possible, to some extent, to programme successive experimental stages.

After the initial establishment of a research programme, it is necessary to consider its periodic revision. Steps taken previously should be objectively reconsidered from the points of view of:

(a) Changing the tempo of the work, or stopping it temporarily or permanently.

(b) Maintenance of the same tempo.

(c) Transference to other laboratories for further development.

(d) Transference to other undertakings for industrial exploitation.

As was mentioned earlier, research does not necessarily produce results that can be commercially exploited. Is this fact to be regretted? In the author's opinion, it is not, because it is possible to learn in many ways, and failure is not always as fruitless as one imagines, particularly if one is aware of the causes.

III. WORKING METHODS USED IN RESEARCH AND PRODUCTION

Experience has shown that in order to form a link between research and production, it is first useful to analyse the working methods of both the scientist and the production engineer. This is most important if one is to understand their respective points of view.

It enables one to find the proper steps to be taken in order to ensure continuity between laboratory work and manufacture of the finished product.

A. *Similarities between the work of the scientist and that of the production engineer*

Is there, in fact, a similarity between the work of a scientist and that of the production engineer? The author believes that there is, because the engineer must constantly resort to scientific theories, even though he is mainly concerned with practical circumstances.

However, just as improvement in manufacturing techniques can be said to depend upon advances in science, these advances themselves may have been made possible by progress in practical manufacture and there is, in fact, a constant interaction between the progress of science and the improvement of manufactured products.

Both the designer and the scientist use imagination and seek truth, precision and objectivity. The engineer must, as the scientist does, consider that there must be a rational explanation of the discrepancies he observes in the phenomena he predicts on the basis of physical laws; they cannot be simply the result of whimsical construction. Furthermore, in extreme cases, he must check to ascertain whether the laws he has applied are really applicable in the domain explored.

B. *The scientist's mental processes*

How does the scientist go about his work? He generally proceeds in three stages.

(a) *Observing*. This is usually done by examining those phenomena that the research worker himself chooses, consciously or unconsciously, depending upon his curiosity, awareness, patience and experience. At this stage, the role played by instrumentation is by no means negligible, for it enormously widens the scope of the senses and allows one to make exact measurements.

(b) *Hypothesizing*. In the second stage, the scientist formulates hypotheses and makes experiments with a view to verifying them. Hypotheses are the product of creative imagination and of the application of calculations to new phenomena etc.

(c) *Testing*. Scientific thought accepts only knowledge that can be proved by experiment and observation. The research worker must, consequently, always submit his ideas to experimentation and be ready to modify or change them according to the results of his experiments. Needless to say, this experimentation must be organized on the basis of carefully developed theories and is an intimate fusion of the practical and the theoretical.

C. *Professor Gonseth's point of view*

Dr Gonseth, late professor of higher mathematics and of the philosophy of science at the École Polytechnique Fédérale, in *Zurich*, corresponding member of the Institut de France, considered that there are really four stages to the scientific method:

(a) *First stage*: emergence of the problem. The researcher recognizes the general problem. In the case of the experimental sciences, this recognition comes from observation.

(b) *Second stage*: working out of the hypothesis. No research will progress without an inventive mind and a creative imagination.

(c) *Third stage*: proving of the hypothesis. In the experimental sciences, this proof must obviously come from practical experimentation.

(d) *Fourth stage*: recapitulation. The research worker integrates the results from stage three into the general problem.

In the author's opinion, the omission of this fourth stage is often the cause of disappointments and of misunderstanding between scientists and management, and it creates a kind of barrier that is not always easy to cross. When a research worker has isolated a problem, he tends, quite naturally, to solve it for himself alone and rarely concerns himself with the effects that his findings may have on the whole research programme. Indeed, it is questionable whether he can be expected to without a wide knowledge of market demand, production potentials and proposals for future developments.

In view of the above-mentioned problem, it is appropriate to discuss the methods that, in the author's opinion, should be applied in order to exploit profitably the results of research.

IV. EXPLOITING THE RESULTS OF RESEARCH

Experience has shown that the transference of research results into the workshop is likely to be the major obstacle to their successful exploitation. Results of work which has been enthusiastically undertaken may never achieve concrete form, leading to discouragement for both research workers and management. On this subject, the report of the First European Regional Symposium on Research Administration and Organization states:

"In applied research, the transference of results from laboratory to workshop is a constant, delicate and complex problem. We think it advisable to outline the essential features of the proposed solutions for it is at this stage that research work finds its justification. This transference takes place either when the research programme comes to an end or when a coherent set of results has been obtained."

There are two solutions which can be applied either singly or together, i.e. the creation of pilot plants and/or the introduction of "research and production engineers". In the author's opinion, however, it is advisable to add a third solution for the machine-tool industry, namely, the introduction of "research and development engineers". Such engineers form a link between research and manufacture. They play an important part for the reason that a machine, even though manufactured with advanced technical means, will never be worth more than the design principles on which it is based.

A. *Pilot plants*

The above-mentioned Symposium report continues as follows:

"The question is how to pass from small-batch to quantity production under totally different environmental and processing conditions.

"The technical difficulties of such an extrapolation are too well known to dwell on. Nevertheless, there are some remarks which must be made. It is absolutely necessary that the research worker or research team 'follow' the process under transference in its peregrination from the laboratory to the pilot plant and from the pilot to the main production plant.

"The laboratory engineer must, before any actual manufacturing has begun, form a team with the engineer in charge of the pilot plant. Close co-operation is most important for making a satisfactory start. It can be relaxed as the pilot activity increases. The procedure must also be followed when passing from the pilot to the production plant, and a reverse procedure, if the production schedule is not attained and it is necessary to return to the beginning again.

"Two points deserve attention:

"The advantage of having the pilot plant located within, or as close as possible to the laboratory, because perfecting industrial techniques is more difficult than shifting them from place to place.

"The advantage, equally obvious, of allowing those who carried out the laboratory studies to help run the pilot shop, in order to avoid a 'break in psychological involvement' and the loss of a great part of the benefit of previously established human relationships."

B. *Research and production engineers*

With regard to research and production engineers, the report states:

> "In order to make the transference from the laboratory to the workshop, certain engineers responsible to the production departments may be used to assure a permanent link between the laboratory and the workshop concerned.
>
> "These engineers will preferably be chosen from experienced laboratory staff in order to have the problems clearly revealed. They are, furthermore, propagandists for scientific ideas in the workshop.
>
> "Let us close this chapter by pointing out that the recommendations it contains relate to a major link in a firm's organization that ties the applied research to the use of its results in production."

This may be an astonishing point of view, but it is justified in those instances where a drastic modification of production techniques is called for. The extent to which an organization can profit from research in general depends upon the extent to which it carries out its own research and employs production engineers capable of exploiting it.

C. *Research and development engineers*

It is advisable to stress again that in an industry the role of the university-trained engineer is to form the link between research and that industry. For this reason, it is worth while examining the working methods used by engineers, whether or not they have to deal with the construction or manufacture of machine tools, in order to show the similarities and differences between their work with respect to that of the scientist—using Professor Gonseth's theses (see chapter III, section C).

1. *Emergence of the problem*

A very wide range of problems is encountered in the construction of machine tools. They may result from discussions with customers, from personal observations, from practical tests or, and this is frequently the case, from manufacturing costs which are considered too high. They can concern the operational convenience of the machine and the safety of the operator, as well as improvements in output and accuracy.

The engineer must not neglect one problem in favour of another. He must first observe the phenomena and the environmental conditions in which they arise. Observation is the objective recording of facts without trying to modify them. This observation is not sufficient. Measurement is needed in order to gauge the importance of the problems. Measurements allow one to evaluate the order of magnitudes involved and to decide on the advisability of envisaging new developments.

A point worth noting is that it is the accuracy of the measuring means which limits the detectability of the phenomenon sought. Charles-Eugène Guye rightly says that "it is the scale of the observation which creates the phenomenon", that is to say, the phenomenon changes in accordance with the scale on which it is considered.

2. *Establishment of solutions*

While the scientist tends at this stage to formulate hypotheses, the engineer looks for means to solve the problem in terms of his knowledge. In both cases, however, imagination is the mainspring for their thoughts. The means differ, but the intellectual processes are the same.

The engineer often complements the inventor and the scientist. His mission is to give the most favourable construction to a technical concept. He uses imagination to obtain several solutions, which he then examines for validity. According to the nature of the object to be given a practical form, he will orientate his efforts towards appropriate solutions and, today, engineers have at their disposal widely different techniques for solving the same problem.

Louis Armand, a well-known French engineer, a member of the Académie Française and author of *Plaidoyer pour l'avenir*, says that the engineer of the future will have to change his "knowledge store", on an average, three times during his life. In the present author's opinion, however, the term "change" is too strong; it is, rather, a matter of adding to and extending one's store of knowledge.

It is in choosing from amongst the above-mentioned techniques that the university-trained engineer must show his skill. Because of this, he must, throughout his career, keep abreast of technical developments.

Having a wide choice of techniques at his disposal, the engineer, who uses and masters his imagination, progressively reaches the point where he knows in what manner he will be able to give shape to his initial ideas. Then, his faculty for imagining the material aspect of things comes into play. He must possess the faculty of concentration in order to force his nebulous imaginings to take a form sufficiently concrete and precise for transmission to others.

Owing to the difficulty of obtaining technical perfection and scientific rigour, the solution the engineer selects is often a compromise between contradictory requirements. Indeed, when one considers the range of different techniques available, one sees that the ability to decide between them is not the least of the qualities that an engineer must possess. In this decision-making, sketches, drawings and calculations obviously play an important part in fixing the engineer's thoughts.

3. *Verification of the solution adopted*

In order to be in a position to verify that the proposed design meets the requirement, it is generally necessary to carry out one or more tests, and perhaps to build a prototype; such prototypes are often made in the machine-tool industry. Before reaching this stage, however, the engineer must examine his solution from two different aspects:

(*a*) The technical aspect, so as to see whether the proposed design really is an improvement on the previous design;

(*b*) The commercial aspect, since even the best concept, from the technical point of view, is useless if a market cannot be found for it.

If the engineer concludes, alone or with specialist aid, that the solution he suggests is the right one, the time has come to pass onto manufacture. The engineer must then be able to show managerial ability, as he will, on occasion, be called on to supervise the various personnel in the mechanical, optical, hydraulic, electrical and electronic fields, who are concerned in furthering the solution. He must care about costs and, consequently, about the manufacturing processes and assembly methods.

Then, once the drawings are completed, they are sent to the workshop and, finally, the engineer can see the fruit of his thoughts taking shape. His feelings of paternity with regard to what his imagination has led him to develop grows and he waits confidently for the first trial.

At this stage, the engineer often finds difficulties arising, for he comes up against the engrained habits of the workshops. What seemed to him an improvement turns into a complication, then to a nuisance and, finally, to an obstacle. The prototype is considered by the shops to be something difficult to produce; they consider that they have neither the necessary tooling nor the required information for its manufacture. Consequently, the engineer must be a good psychologist and leader, or enjoy the total support of the management. Nothing is more comforting for the engineer than seeing other people, at all levels, taking an interest in "his" prototype and showing their willingness to aid him in its development.

A real team spirit is essential because many different specialists are now concerned in the development. At this stage also, the production staff must study possible improvements and simplifications of the manufacturing and assembly methods. Operating, testing, dismantling, inspecting and retouching are repeatedly carried out until the machine is ready to be delivered to the customer or is ready for manufacture on a production basis.

4. *Re-examination of the solutions: their incidental effects*

In principle, the incorporation of a new development in a machine tool or an instrument must result in an improvement, but the secondary effects of this incorporation must be considered, for they can, in some instances, prove to be quite disturbing. This re-examination is the analogue, for the research and development engineer, of the scientist's reintegration of his results into the state of knowledge at the beginning of his research: Professor Gonseth's fourth stage.

In spite of all tests, results obtained under production conditions can sometimes be different from those obtained from even the best prototype. All engineers encounter difficulties which did not occur during manufacture and testing of the prototype and which give rise to serious problems as soon as quantity production begins.

At this point, the author would like to make some comments based on his experience as a designer of measuring machines and machine tools. First, improvements in the concept or in the manufacturing methods of a machine tool often result in a price increase. The user wonders whether this increase in price is worth the higher performance. His criteria of judgement are not always the same as those of the engineer. The likelihood of the new concept becoming a commercial success must be examined with the sales department. It may then be necessary to abandon a technical improvement in favour of a lower price, hoping that in future a simplification of the design will allow quantity production to be undertaken economically. Furthermore, the prototype often does not provide enough information as to the life that can be expected from the various separate parts of the machine. Here, one can at least say that the fewer the number of assemblies or components, the safer the functioning, and the lower the specific pressures between the moving parts, the least wear.

Without dwelling too long on reliability of operation, the author would like to point out that the methods used in the development of missiles are possibly applicable. In industry, it is necessary, above all, for a producer to keep an eye on the troubles the customers may encounter with his machine and to make certain that this information is passed back to the engineers concerned. This kind of long-term feedback is indispensable in acquiring the necessary experience and skill required for building better "the next time". In the case of the machine tools, this approach assures the quality and regularity of the production by lessening the down-time required for repair and maintenance.

With regard to more scientific matters, in very high-precision machine tools, one sometimes encounters difficulties which seem quite extraordinary. It is as if the physical laws did not fit one another. One must keep in mind, however, that a physical law aims at describing, in a manner as precise and as quantitative as possible, the relationships between phenomena in a particular system. But it is a formulation which is more or less exact, according to the accuracy of the instruments used in its establishment. A result of this is that one may apply certain laws in optics, forgetting that, ultimately, it is the constitution of the retina that limits the resolving power of the eye; or, further, one may apply Hooke's law, which states that the deformation of material is proportional to the force it is subjected to, forgetting that it is not valid for very small forces, especially if they are torsional.

There is no discussion here of oil films, for all of the author's recent observations have been most perplexing and not open to interpretation at this time. The realm of physical laws is a limited domain, poorer than the real one, and to this domain must be added factors that were neglected when it was established. This is precisely why applied research is necessary. It results from one's inability to fully grasp the problems.

V. Time Required for Research

It is appropriate to mention some factors which affect both production and research equally. First, management looks forward to receiving positive results from research work at relatively short notice and is often disappointed by the long time spent in working out a new solution. It must, however, be recalled that the more closely a product nears perfection, the more difficult it is to improve it, as the influence of secondary effects becomes more important.

For example, in 1961, the Conférence Générale du Metre decided to change the definition of the Metre. It is now defined in terms of a Krypton 86 wave length instead of being the length between two lines engraved on a platinum-iridium bar. But, if with the latter, it was necessary accurately to know its temperature, the use of the new standard requires one to know the composition, the temperature and the barometric pressure of the air in order to determine its refractive index. It may be seen, therefore, that the change from the old to the new definition introduces a wider range of dependence upon external physical conditions, and the control of these conditions and the determination of their effects are not always easy and may entail lengthy side studies.

Another point is that the techniques applied in industry are often the result of accumulated experience: they have been progressively developed, sometimes empirically, sometimes on a more scientific basis, but they have seldom been systematically investigated. It is obvious that the change-over from methods founded on empirical knowledge that may be hundreds of years old cannot be effected within a few weeks. The skill and experience of one's predecessors cannot be abruptly replaced by scientific method. It is necessary to decide on the methods of analysis, to determine the problem and to study the effect that a new solution may have on the other factors involved, and for this one requires not only intelligence and knowledge, but also time.

The author has often wondered what factors affect the time for getting something new into production. Obviously, if the new item is only a matter of several detail modifications, it will be easy to predict accurately the required time, but the question is quite different if a complete change is involved. It may be preferable to return to research and completely revise the project rather than to alter a product already in production. It is clear, however, that one must refrain from seeking exaggerated perfection and that one must bear in mind that any object produced today is marked with obsolescence with regard to the future.

Conclusion

Today one must add knowledge of the mutual processes of research and production people and a number of methods have been developed for [illegible] to a satisfactory relationship between them. In the author's opinion, this knowledge must be used to the fullest possible extent if the results of research are to contribute effectively to the economic growth of industry.

Selected References

[illegible]

SOME MAJOR PROBLEMS IN THE INTRODUCTION AND MASTERING OF DIGITAL CONTROL AT MACHINE-BUILDING PLANTS

If one does not consider the above-mentioned firms, for which the introduction of progressive equipment is obligatory, it will be correct to assume that unless measures are taken, there is a risk of witnessing a relatively slow progress in the expansion of machine tools with digital control either because the majority of manufacturers are not yet willing to part with the setting system and classical machine tools which are in good condition, or because they have insufficient amortization to buy programme-controlled machine tools irrespective of their price. The introduction of the new equipment is very slow, as a result of the following circumstance. It is possible to understand manufacturers when they produce small batches of machine tools with digital control before organizing their large-scale production. On the other hand, the consumer refrains from introducing a costly novelty until the advertised machine tool receives good recommendations in operation. One sees, therefore, two approaches which counteract each other and which present a serious obstacle to the increased application of machine tools with digital control.

There is no doubt that digital control will win recognition, for progress does not stop. But the question is how many years will be required if no measures are taken to urge manufacturers to modernize their existing equipment.

It should be mentioned that many industrially developed countries have taken a number of measures to the benefit of new equipment. Data on this subject have been collected and are given below. These data, which, it should be noted, are incomplete, refer to Belgium, France, the United Kingdom of Great Britain and Northern Ireland, and the United States of America. The information was supplied by both official organs and persons connected with such organs.

Belgium

In Belgium, which currently does not have any designers of machine tools with digital control, a series of lectures on the subject (given by Professor Peters) was organized at the Institute of Mechanics of Louvain University. The lectures were sponsored by the Centre de Recherches Scientifiques et Techniques de l'Industrie des Fabrications Métalliques (CRIF).

These lectures on digital control were read during the "Louvain days of February 1966" and were accompanied by an exhibition of the equipment and demonstrations of its operation. The purpose of the "Louvain days" was to acquaint Belgian machine-tool builders with the equipment designed for digital control, through demonstrations of its operation. As a result, it was recognized that it was necessary to develop propaganda about digital control to prepare for its acceptance.

The "Louvain days" demonstrated the good co-operation between CRIF, Louvain University and the manufacturers or persons supplying digitally controlled equipment (machine tools and fixtures). Machine tools with co-ordinate digital control and machine tools for longitudinal machining were the only ones exhibited.

Finally, an experimental workshop of digital control was established at Louvain University, which planned to commission, by the end of this summer, a drilling machine with an Xlo-Burgmaster turret equipped with a three-spindle digital-control system of the Hugues type.

One of the tasks of the above-mentioned experimental workshop was to render actual assistance to Belgian machine builders by demonstrating the advantages of the new equipment where small-batch production is involved. The Belgian manufacturers will join the ranks of digital-control supporters when the facts have convinced them of its advantages.

France

In France, the Délégation générale à la Recherche scientifique et technique (DGRST) joins in the efforts of some groups who are interested in the digital-control firms, for example, the efforts of the Centre d'Etudes et de Recherches des Machines-outils (CERMO).

The Laboratoire Central de l'Armement (LCA) has organized, in its department of applied mechanics, an experimental workshop for studies of digital control and for inspection of machine tools purchased by the technical department of ground weapons for the equipment of their objects.

The Groupement pour l'Advancement de la Mécanique Industrielle (GAMI) has recently established, together with the Association Française de Régulation et d'Automatisme (AFRA), a working group called "digital control", whose task is to facilitate the development of methods of digital control of machine tools and the allied branches of technique (programming, computers).

The above-mentioned group intends to make use of every possible measure which will ensure the development of numerical control, namely, the following:

(*a*) To assist in establishing contacts between representatives of those branches of engineering which are participating in the development of digital control, e.g., mechanics, electronics, automation, programming, automatic methods of calculation, mechanical treatment etc.;

(*b*) To provide information to the designers and the users of digital-control systems by means of publications, seminars, demonstration, lecture courses etc.;

(*c*) To contribute to standardization in the field of digital control and to help the official institutions working in this trend;

(*d*) To establish contacts between national and international organizations associated with digital-control problems;

(*e*) To promote the inclusion of digital-control problems in official educational programmes;

(*f*) To develop interest in programmed control among leading industrial figures and among people of industry in general.

United Kingdom

An exhibition completely devoted to machine tools with digital control was organized by the Machine Tools Trade Association (MTTA) in London in May 1966. The purpose of the sponsors of the exhibition was to advertise digital control to attract representatives of interested branches of industry.

In addition to this exhibition—the first attempt in the world in the field under consideration—it was decided to organize regular "open weeks" to enable the manufacturers of the machine-building branch to visit machine-tool works and to become convinced that these enterprises give an example of the profitable use of equipment with digital control when manufacturing their products.

A periodical, *Metalworking Production*, reported that a British Numerical (digital) Control Society was established in London in July 1966. The Society's purpose is to inform its members on economical, technical an pother aspects of digital control for the popularization and expansion of the new technology and its application.

On the other hand, the Government, taking into account the difficulties encountered at the introduction of digital control (costly equipment and unwillingness of the consumers to take the risk of introducing new equipment, which is associated with the solution of a number of problems), intends to adopt the following measures, which were disclosed by the Minister of Technology at the opening ceremony of the above-mentioned exhibition:

(*a*) To sign a contract for the purchase of pilot batches of new machine tools to support the manufacturers and to publish the test results of those machine tools obtained by individual consumers. The first four orders, totalling £500,000, were distributed between the Churchill, Ferranti and Molyns firms;

(*b*) To envisage a sale with a test period, which will give the consumer a possibility of returning the machine tool to the manufacturer within six to twenty-four months after its installation if its operation turns out to be unprofitable. In such cases, the consumer will pay only a definite fee, depending upon the time the machine tool has been in operation and a definite compensation—a sort of compulsory, although reduced, fee—to avoid possible misuse on behalf of the consumer, who, in normal conditions, purchases the equipment "for eternal use". Any machine tool returned to the manufacturer is to be repaired at the expense of the National Research Development Corporation, a State institution, whose budget for these purposes is £1 million.

It is also necessary to note that research in the field of digital control has been subsidized for a number of years by the Government and has been entrusted with the Industrial Research and Development Authority (IRDA) and with the following universities and official technical centres: Nel, Glasgow University, the College of Aeronautics at Cranfield and Birmingham University.

Among the most important works are the following:

(*a*) Exploration of possibilities of machine tools with digital control;

(*b*) Testing of an experimental sheet-bending press with digital control for bending sheets used for sheathing ships, including studies of the spring-back of sheets after their stamping and studies of residual stresses occurring in cold stamping;

(*c*) Studies of static and dynamic rigidity of hydraulic follow-up systems;

(*d*) Testing of a highly sensitive mechanism of high rigidity for hydraulic feed; an analogue computing device for prognosticating dynamic characteristics of mechanisms was built in the course of testing;

(*e*) Comparative testing for accuracy of various setting devices for pre-set co-ordinates (the weight of the travelling table, persistence and rigidity of the feeding mechanism and the friction and free play of the moving parts were taken into account).

Some interesting results were published in technical literature and were read as public lectures at the annual September Conferences of International Machine-Tool Design and Research, which are held alternately in Manchester and in Birmingham.

United States of America

The initiative of the first theoretical research in the new control system, which was undertaken at the Massachusetts Institute of Technology, belongs to the Government of the United States of America, the country in which digital control was first devised (1948–1953). The Government's order for the manufacture by 1956 of new machine tools, which made it possible for the designers working on this problem to carry out the necessary tasks in creating prototypes without concern for monetary questions, was of major significance. These facts were of great interest to the members of the French delegation of digital-control specialists upon the occasion of their visit to the United States of America in 1964, on behalf of the French syndicate of machine-tool industry designers.

Another outstanding fact is that when the Seneca Vocational High School in Buffalo (New York) foresaw the demands of the industry, it installed in April 1966—with the Government's support and in addition to the School's existing equipment with simple digital controls—a three-spindle milling machine of the Gorton type (valued at $50,000) for contour treatment, so that specialists might be trained in the sphere of programmed control.

Still another important detail to be mentioned is that only those enterprises which are equipped with machine tools with digital control are given government orders to fulfil.

II. Suggested Measures

No matter how necessary and useful the above-mentioned expressions of initiative are for speeding up the introduction of digital control into industry, they may turn out to be insufficient if no measures are taken to ensure their simultaneous effect.

It would have been in the interests of the mechanical-production enterprises, whose higher efficiency is of essential significance, to have provisions for "national plans" directed towards the widest application of machine tools with digital control.

It is necessary to draw a clear line between contour and co-ordinate digital controls, and linear control, where all the machining is accomplished along the trajectories, which are parallel to the guides of the machine tool.

The contour digital-control system is very complex and expensive, and it is used by firms who are interested in the newest equipment, which, in the majority of cases needs no advertising. Furthermore, the problems of the contour control system differ from those of the co-ordinate system. Thus, the continuing development of contour control depends greatly upon the progress in an important and wide field of computing techniques.

Digital control according to pre-set co-ordinates, which is simpler and much less expensive, corresponds (and this is the advantage) to 90 per cent of the demands of the industry. Thus, it is clear that this control system should receive concentrated efforts at the very beginning.

The application of digital control raises economic, financial and technical problems, whose scale exceeds the framework of machine-tool building.

Considered below are those measures which, it seems, should be given priority and which appear to be the most effective.

As a first measure, it is recommended to popularize digital control and to prepare people for its introduction. Good results could be achieved by presenting films of demonstrations of machines with such controls, in order to attract the largest possible number of consumers.

Propaganda by the machine-tool designers themselves would be very effective also. In fact, the designers present a business-like example by studying in their laboratories the possibilities of the maximum use of machine tools with digital control, informing others of the results obtained using various means and, above all, demonstrating their achievements. In the United States of America, where about 7,000 machine tools with programmed control are in operation, the machine-tool industry is using a comparatively large share of them, if one takes into account the proportion of machine-tool building in relation to other branches of machine building. With the exception of one firm which manufactures aircraft engines, a machine-tool manufacturer has the largest number (sixty-two) of machine tools with digital control. Furthermore, many important enterprises in the United States of America have commissioned works in which the majority of machine-tool parts are produced on machine tools with digital control.

According to the statistics in the United Kingdom, the machine-tool plants have concentrated from 18 to 20 per cent of all machine tools with digital control operating in that country, while the output of those plants is only 3 per cent of the entire output of mechanical enterprises.

During the exhibition in May 1966, the firm of Kearney Trecker willingly demonstrated, upon request of interested persons, the operation of its plant near London. Kearney Trecker is now machining the beds for milling machines in seventeen hours (sixty-five hours were formerly required) by using Milwaukee-Matic machine tools with digital control; the above-mentioned part is machined in two operations.

It would have also been very useful to publish the most interesting results obtained by those industrial firms which use or test digitally controlled machine tools.

There is no doubt that the suggested measures will help to promote in the near future the widest scale of use of the new types of machine tools and will build up the demand, thus justifying a larger production of the above-mentioned machine tools than the level which is now contemplated by the designers.

The second measure suggested is to render assistance in research and designing, and in the purchase of machine tools with digital control and appropriate equipment.

Assistance on behalf of the Government when buying digitally controlled machine tools should take place at the stage of adjustment and commissioning of new enterprises to have the maximum effect. If such assistance is not yet being rendered, it should be made available in the very near future.

Thus, it would be useful to supply machine tools with digital control to the system of technical education and to the largest possible number of vocational schools. For the beginning, it would be possible to limit these to simple machine tools, for example, drilling machines with manual programming.

Thirdly, it is recommended to render assistance in the commissioning and further equipment of experimental laboratories, one of the tasks of which would be to provide technical assistance to manufacturers in the period of commissioning the digitally controlled equipment, for example, consultations on the expediency of the planned capital investment.

Designing bureaus which are projecting machine tools are ready-made experimental laboratories for consumers, provided they are well equipped.

In addition, it is important that some official institution, such as the machine-tool building scientific research centre in France (CERMO), should render technical assistance to consumers (programming, commissioning of new enterprises etc.) at the stage of adjusting and commissioning.

III. Conclusions

The magnitude and the urgency of the problems raise the question of governmental support for the interested mechanical enterprises in order to promote the success of the new technique of digital control and for rendering assistance to machine-tool designers. It is very important to ensure co-ordination of the efforts of State institutions and private firms which are interested in developing this technique and in the perspectives of development of mechanical production of the country in question.

In conclusion, it should be remembered that the sphere of application of digital control is not limited by those enterprises where machining is obligatory. As soon as there is a possibility of interpreting mathematically any mechanical process, there is a possibility of controlling it by a computer. As an example, one may refer to the device for balancing, pairing or sorting, paper-making machines etc. Digital control is also used in other non-mechanical branches of industry—e.g., metallurgy (control over blast-furnaces and rolling mills) and the oil industry (refinery of oil products).

In the near future, the all-sided automation ensured by digital control may pose a number of problems which differ from the problems of today, as follows:

(*a*) Training of necessary skilled staff;

(*b*) Introduction of new requirements into the programmes of technical education;

(c) Retraining of the personnel who fall in reserve. This is a cardinal problem, whose solution will require the help of the Government and which was not considered in the present paper as it was beyond the scope of the topic.

The spheres of machine-tool building and mechanical production have considerably expanded, which is another reason for the necessity of co-ordinating, at the highest possible level, any activity. Recently much has been said about the new successes achieved in mechanical production:

(a) Equipping machine tools with [illegible]

(b) Application of digital computers for optimization of machining conditions;

(c) Application of self-adjusting systems for automatic control of machine tools in the process of machining;

(d) Direct transfer from the designer's idea to the command for fulfilment without making conventional drawings and compiling an operation plan (probably the day is not far ahead when the man would learn to introduce a written information into the machine and then he would be satisfied to give the information in an oral form).

But these perspectives should not hide the problem of today, i.e. the maximum profitable application of every possibility of using digital control for machine tools.

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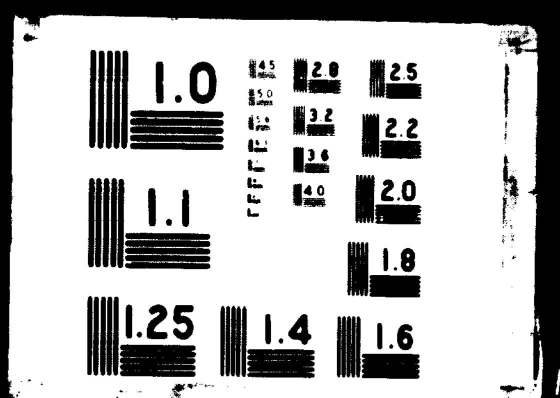


ment (equity and long-term loans) in sixty-six major industrial undertakings, by the Government alone, stood at about $4,300 million at the end of 1964 65. Out of these investments, the total of the sixty-six public sector undertakings stood at $3,963 million distributed broadly as:

Table 2

	Value in millions of U S dollars	Percentage
Land	55.65	1.4
Building	508.62	12.8
Plant and machinery	2,015.79	50.9
Other miscellaneous assets	443.52	11.2
Capital work in progress	939.54	23.7
Total	3,963.12	100.0

It can be seen that the Government's investment in plant and machinery of the magnitude of $2,015.79 million, the major part of which was committed during the past ten years (1955 to 1964) in these major industrial undertakings in the public sector alone, has undoubtedly given tremendous impetus to the machine-tool industry in India.

Another significant contribution to the Indian machine-tool industry has been that of the Hindustan Machine Tools Ltd. (HMT), Bangalore, a Government undertaking engaged in manufacturing several varieties of modern medium-heavy precision machine tools. Table 3 shows that 42.38 per cent of the total 1965 domestic production of machine tools was by HMT.

Foreign collaboration and domestic designs

The industry, in a span of hardly ten years, has been able to diversify its production and to produce a wide range of machine tools of modern designs. Besides the general purpose machine tools such as lathe varieties, there recently have been introduced turrets and capstans, shapers, radial and pillar drills, milling machines of various types and sizes, grinding machines (universal, cylindrical and surface), tool and cutter grinders, and new designs in single spindle automatics, vertical turret lathes, gear shapers and heavy-duty planing machines, and all-electric milling machines.

In the course of the next year or two, newly designed gear hobbers, high production copying lathes, automatic lathes, multispindle automatics, and drum turrets are planned for domestic production. In fact, a stage has now been reached when most of the general purpose machine tools are being manufactured in the country.

The most significant feature in recent years has been the commencement of manufacture of special purpose machine tools, transfer lines and similar machines by HMT. Thus, a trend to the manufacture of more sophisticated types of machine tools of higher productivity and suitable for mass-production industries such as automobiles, scooters, tractors, bicycles, electric motors and pumps, has set in.

This has been possible mainly because of the industry policy to enter into agreements for designs and technical co-operation with well-known foreign firms. The Government, which in fact initiated such an arrangement through HMT, set the rapid pace for development which, but for this policy, would have suffered seriously.

One of the main reasons for the outstanding success of HMT has been its ability to diversify its range of products quickly. This has been possible on account of the firm's co-operation with almost all the highly industrialized countries in the world for securing designs, manufacturing rights and technical know-how and has been one of the significant factors contributing to the rapid growth of the Indian machine-tool industry. From 1955 until May 1966, as many as 105 agreements were made with ninety firms from almost all industrialized countries for the licensed manufacture of various machine tools.

Table 3

DOMESTIC PRODUCTION OF MACHINE TOOLS AND PERCENTAGE OF HMT'S PRODUCTION TO TOTAL DOMESTIC PRODUCTION 1956-1965

(In millions of US dollars)

Year	Total domestic production	HMT'S production	Per cent HMT production to total domestic production
1956	2.27	0.65	28.46
1957	4.93	2.51	51.00
1958	7.16	3.72	51.98
1959	8.74	4.13	47.20
1960	12.31	6.53	53.06
1961	15.39	8.94	58.08
1962	21.84	11.64	53.27
1963	32.28	18.25	56.54
1964	49.77	19.67	39.52
1965	55.59	23.56	42.38

In this process of world-wide collaboration for securing designs and technical know-how, the Indian machine-tool industry has certainly benefited greatly in developing its own design talents. Although today it cannot be said of the industry that it has reached an advanced stage in evolving original designs of machine tools of highly sophisticated types and of heavy- and extra heavy-duty machines it has, without doubt, proved that a nucleus of design talent has been created in the country. The industry is to some extent now capable of evolving its own designs of general purpose machine tools. In fact, more advanced types of designs have also been attempted and produced successfully: for example, pre-selection headstock centre and turret lathes and all-electric milling machines.

Government assistance to the industry

One other factor which has accelerated the growth of the Indian machine-tool industry is the assistance it has enjoyed at the hands of the Government. In the economic planning of the country since independence, the machine-tool industry has been given a high priority, particularly in the Second and Third Plan periods, as the main plank on which the modern industrialization is built. India committed itself to rapid industrialization and development of key and heavy engineering industries and its machine-tool industry therefore had to be encouraged by the Government.

Although there are no special concessions given to the Indian machine-tool industry in direct and indirect taxes or monetarily, the industry does enjoy a higher priority and consideration in the Government's planning, industrial licensing, allocation of scarce foreign exchange and issuance of import licences.

Protected market

Chronic and acute shortages of foreign exchange appear to be the main reason for the Government's restrictive policy on imports of machine tools. There is a positive support and incentive given to the domestic machine-tool industry through the Government policy of banning imports of certain types of machine tools which are being produced in sufficient numbers in the country. Thus, whether it is the paucity of foreign exchange or the intentional policy of the Government to ban the import of certain types of machine tools, both these factors account for the creation of almost a protected market. Although in many ways it is not a healthy feature for the industry to enjoy the preferential and non-competitive position continuously, the situation has helped the industry to establish itself firmly. The industry has not been resting idly on this protective cushion, but has been making efforts to diversify its products to satisfy the growing needs of the nation's engineering industry for different types of machine tools. There are also many machine-tool producing units in the country with an overlapping programme of production, thus generating, to some extent, a spirit of competition for improving quality, designs, performance standards and deliveries, and keeping check on the spiralling prices of machine tools, which has become the alarming feature of the Indian industry and trade today.

Demand forecast

General survey

In spite of the fiscal year 1965–66 being a very depressing period for the Indian machine-tool industry, it is considered only a temporary recession. Demand for machine tools should improve considerably during the Fourth Five-Year Plan. If this forecast does come true, the machine-tool industry will once again face the problem of gearing itself to the rising demands which the industry has never been able to meet in the past. Even in the lean year of 1965–66, imports of machine tools were 61.46 per cent of the total requirements. Close examination of the imports and production statistics for the past ten years (see table 1) clearly indicates the inability of the industry to catch up with the demand and although the percentage of imports to the total requirements has slowly and gradually been decreasing, imports have been consistently going up from year to year.

Report of the Working Group on Machine Tools

Forecasts of demand for machine tools during the Fourth Five-Year Plan (1966–1970) have been attempted by two agencies and although their findings vary and are even disputed by other experts, all are unanimous on one point: demand for machine tools during the Fourth Five-Year Plan is bound to outstrip national production. The report of the Working Group on Machine Tools (Group VI), appointed by the Government, estimates the demand for the graded machine tools by number of units at 173,000 for chip-removing types valued roughly at $942.9 million and other metalworking machinery at $235.2 million for the Fourth Plan. Details of the estimated demand for machine tools of chip-removing types from year to year are shown in table 4.

Table 4

Estimate of machine tools for 1966-70

(*Average annual increase 13%*)

Year	*Number of units*	*Average price ($)*	*Value (in millions of US dollars)*
1966	26,700	4,366	115.5
1967	30,200	4,803	147.0
1968	34,100	5,284	180.6
1969	38,500	5,811	222.6
1970	43,500	6,392	277.2
Total	173,000		942.9

The Working Group further estimated that the machine-tool industry's capacity and production would reach a level of only 85 per cent and 75 per cent, respectively, of the total demand which, based on performance in the past, is certainly an ambitious target. Table 5 shows the targets of capacity and production in 1970 for machine tools and other metalworking machinery, set by the Working Group.

Table 5

Targets 1970

Items	*Capacity*		*Production*	
	number of units	*value (in millions of US dollars)*	*number of units*	*value (in millions of US dollars)*
Machine tools for domestic consumption.	37,000	237.3	32,600	207.9
Machine tools for export.			1,500	8.4
Metalworking machinery.		37.8		33.6
Total		275.1		249.9

Forecast by the National Council of Applied Economic Research

A most comprehensive and systematic study of the demand for machine tools was made by the National Council of Applied Economic Research (NCAER), New Delhi. The NCAER has evaluated the demand for machine tools based on the "end-use" method in which a complete inventory of the machine tools installed in the country during 1963 was estimated by types, categories and sizes of the machines. It is estimated that there will be an additional total demand for machine tools valued at $1,281 million (graded, $1,215.06 million and ungraded, $65.94 million) and in number of units, 526,000 machine tools (348,499 graded and 177,501 ungraded) for 1964 70.

The findings of the above two exercises vary in some degree (Working Group's estimate for Fourth Plan Period: $1,178.10 million and rate of demand by 1970, $346.50 million a year; NCAER'S estimate: total demand for 1964 to 1970, $1,281 million and rate of demand by 1970, $258.30 million a year). But the fact remains that in view of the industry's inability to meet the demands for machine tools, large-scale imports will have to continue.

MEASURES TO BRIDGE THE GAP

General survey

India still has to depend upon heavy imports to meet the gap in the domestic supply of machine tools. Though the ratio of internal production of machine tools to imports has gone up from 13 per cent in 1956 to over 62 per cent in 1965, the value of imports in absolute terms has increased from $17.58 million to $88.64 million over the same period. The heavy imports year after year made constant inroads into the foreign exchange reserves of the country.

The revised Fourth Plan Memorandum laid down a capacity of $231 million and a production target of $210 million to be achieved by 1970-71, the last year of the Fourth Plan, for the organized sector of the machine-tool industry as against the Third Plan's capacity and production targets of $78.96 million and $63 million, respectively. Even if it is assumed that the Fourth Plan targets would be met at the production level of $231 million a year by 1970-71, requirements for machine tools in the same year are estimated at $294 to $315 million, resulting in a shortfall of $84 to $105 million worth of machine tools a year which will have to be met through imports, according to both the Working Group and the NCAER.

It is not necessary for any country to plan for 100 per cent self-sufficiency in machine tools. This is not practical or feasible as there are so many types, sizes and designs. But following are some of the recommendations for the industry's continued growth towards self-reliance.

Export

In any highly industrialized country, the imports of machine tools, even with a high degree of self-sufficiency, are still about 20 to 30 per cent of the total requirements. But this is more than compensated by exports. In India, however, until very recently, there were no tangible exports of machine tools. Also, no serious attempts seemed to have been made both by the industry and the Government in this respect, perhaps because of their concentration on encouraging national production.

Table 6 shows the export of machine tools during the Third Five-Year Plan.

Table 6

MACHINE-TOOL EXPORTS FROM INDIA

(Including metalworking machinery)

Year	*Value in US dollars*
1961	162,889
1962	223,618
1963	199,677
1964	248,849
1965	291,338

As can be seen from the table, attention seems to have been paid recently to this vital aspect and an export target of $21 million a year within the next five to seven years was set by the Board of Trade at a meeting in New Delhi on 30 April 1966. The importance of exports, apart from maintaining equilibrium in trade balances among countries, has a special significance in the case of non-traditional items such as machine tools. When the products of one country are exposed to the world market, there are many indirect gains for the industry. For one, the product, to be competitive, necessarily calls for better quality, efficient manufacture and superior design. The Indian machine-tool industry, to keep pace with the advanced countries, must expose itself to the world market to remain progressive, aggressive, cost conscious, quality conscious and price conscious.

Though exports of Indian machine tools to the highly industrialized West may sound like "carrying coals to Newcastle", closer examination has, however, disproved this myth and market surveys carried out by some prominent Indian manufacturers do hold promising prospects for the future. It is therefore necessary that every effort is made by the Indian machine-tool industry to export a portion of its products abroad continuously.

Need for diversification

In view of the severe restrictions imposed by the Government in issuing import licences, sometimes customers have had to accept not, ideally, what was needed for a particular operation or process, but what was available in the country. This position has been changing and the recession in the machine-tool market has, in a way, been a blessing in disguise for the customer in that he could advantageously dictate his requirements to some extent and select his machine tools. In order not to lose the customer, the manufacturer must now give him the machine he needs with accessories and tooling on a competitive basis. If there is no demand for a particular machine tool, the manufacturer should have a sufficient flexibility to switch to the other types which are in greater demand.

It is in such circumstances that the ability of the manufacturer to diversify the production programme pays a dividend. One who can without much delay meet the diversified needs of a customer will eventually succeed, particularly when the market changes from the seller's hand to the buyer's. Indian machine-tool makers thus have a long way to go in this direction and very soon they will have to gear up their methods and organization and be flexible in diversifying their programmes of production to satisfy the customers.

One of the main difficulties in the machine-tool business is an inherent high degree of diversification which sometimes is likely to retard the growth. It is perhaps easier to evaluate the country's over-all requirements of machine tools from period to period in terms of volume and value. It is not even difficult to split up this demand into main categories, such as lathes, drilling machines, boring machines, milling machines, grinders and gear-cutting machines. What has been the most difficult problem for the estimators is to guess what different designs, types and sizes of machine tools will be needed by the engineering and manufacturing industries. This depends so much on the techniques, methods of production and processes, etc., of the end users of the machine tools that it is practically impossible to furnish a ready reckoner for the individual machine-tool manufacturers to adopt a particular pattern of diversification.

It is more for the machine-tool makers themselves to intelligently forecast and adapt their programmes of production and diversify them to suit the market demands. It could be suggested that to counteract the disadvantages of a high degree of diversification, the machine-tool manufacturers should specialize in a certain family of products and diversify within the family itself. That is to say, if one is making turning machines, he is best advised to include in the range other types of lathes: centre production, capstan, turret and even automatic lathes and, for the milling machine manufacturer, to include other types of milling machines such as production millers, tool room millers, duplex millers, knee and bed-type millers, die sinkers, etc.

Raw materials and supporting ancillary industry

Machine-tool manufacture involves specialized raw materials such as heavy-duty castings, alloy steels, steel castings, forgings, special bronze, plastic material, etc. Requirements of raw materials are specialized and these have to be so if products are to be of high quality and performance. If the domestic machine-tool industry is to progress on the same lines as elsewhere in the highly developed industrial world, manufacture of all these essential raw materials has to take priority and should be established in the country as quickly as possible.

One other serious disadvantage facing the machine-tool business in India is the relatively slow development in the supporting and ancillary industries which supply hundreds of highly specialized bought-out parts and other proprietary items such as ball bearings, special electric motors, switch gears, Ward Leonard sets, electro-magnetic clutches, programme control equipment and other electrical, hydraulic, pneumatic and electronic equipment needed for modern machine tools.

Modern designs

The domestic machine-tool industry has, in the past decade, made definite contributions and met some of the specialized needs of the engineering industry. This has been, to a large extent, possible through the purchase of designs from abroad and production of the machines under licence. Although this has been and still continues to be an essential feature of the development of the machine-tool industry in India, it is absolutely necessary for the manufacturers of machine tools to evolve their own modern designs.

To achieve this it is important to train machine-tool designers systematically and give them encouragement and scope. Every machine-tool entrepreneur should devote part of his resources to this basic need so that his own designers could closely associate themselves with the work of machine-tool research centres in the country and abroad and be able to design the required machine tools. This calls for sustained efforts but, though long and tedious, it is a "must" for the progressive development of the machine-tool industry.

India today, to some degree, is self-sufficient in medium- and light-duty machine tools of the general types. The country, however, is not manufacturing highly sophisticated heavier and modern machine tools such as transfer line machines, multispindle automatics, jig borers, machine tools for automatic production, machine tools with numerical controls and heavy- and extra heavy-duty machine tools. India is not even producing some of the basic machine tools such as horizontal boring machines, gear hobbing machines, multispindle automatics and drum turrets, although recently certain licence agreements have been concluded for the manufacture of some of these machines.

The Government of India has set up, in collaboration with Czechoslovakia, the Heavy Machine Tool Plant, a unit in the complex of the Heavy Engineering Corporation Ltd., Ranchi, to produce heavy and very heavy machine tools such as horizontal boring machines, size 160 mm and above, radial drills, size 80 mm and above, heavy-duty lathes (1,000 mm swing and above) and heavy vertical boring mills. But until this unit goes into production, all similar machine tools have to be imported. By and large, it may be said that India's future imports will be for more and more heavier types and for modern designs of machine tools.

The trend appears to favour single and special purpose machines and machine tools to do specific operations. The modern trend in the highly developed countries abroad is towards machine tools designed for automation, transfer line machines and for the production of machine tools with automatic repeat cycle systems and positioning and measuring by numerical controls. The domestic machine-tool industry has to think in terms of producing these designs soon if it is to meet the increasingly specialized demand for machine tools without having to depend upon large-scale imports.

Metal-forming machines

Taking up types of machines, the high proportion of metal-cutting machines is evident. But the trend in the highly industrialized countries to higher proportions of metal-forming machines, nearly 24 per cent in the United

States as against 16.5 per cent in India, can be explained by the fact that production of durable consumer goods, the components of most of which are formed, is more pronounced in these countries.

The production of metal-forming machines in India is far from satisfactory and, compared to industrialized countries abroad, is very poor. Modern heavy-duty presses of capacities varying from 100 to 5,000 tons for the automobile, shipbuilding, aircraft, refrigeration equipment and domestic appliances industries are not yet made in the country and all have to be imported. The need for early development of this vital wing of the metalworking industry is great in India. Somehow, progress in this vital branch of the metalworking industry in India has been very slow and a few of the items, mostly presses, press brakes, forging machines and shearing machines which are produced in the country today, cannot be termed as very modern. Hence, not only is it necessary to improve the design and quality of metal-forming machines currently produced in the country, but there is equally an urgent need to diversify the production of these machines in the country to include the other essential types of metal-forming machine tools.

Machine-tool research

If the Indian machine-tool makers are to meet the growing needs of the domestic manufacturing industry, they will have to concentrate on the applied research in production technology and development of machine-tool designs. This is evident from the rapid and spectacular progress that has been achieved by all the European countries, the United States and the USSR in all industrial fields and especially in machine tools. Unlike the USSR, Czechoslovakia, Poland and the German Democratic Republic, where research is concentrated in the Government-operated and financed agencies, the Continental and United States programmes rely to a large extent on the contribution of the private builders made directly or through their national associations. Similar initiative should come forth from the Indian Machine-Tool Manufacturers' Association.

The Government of India, with the assistance provided by the Czechoslovakian Government, has set up a machine-tool research institute, the Central Machine-Tool Institute, in Bangalore. Many more machine-tool research institutes are needed in the country and it should not be for the Government alone to take initiative in these matters. It should be more in the interest of the machine-tool builders themselves not only to take active part in such sponsored ventures but substantially to guide and finance the work towards progressive modernization of the industry.

THE METALWORKING INDUSTRIES IN LATIN AMERICA

Secretariat of the United Nations Economic Commission for Latin America

The mechanical industries, including under this term the manufacturers of metal products, machinery and equipment, as well as electrical and transport material, represent almost 17 per cent of the total manufacturing industry in the region. With an aggregate value of some $4,000 million, its contribution to the formation of the gross domestic product is slightly more than 4 per cent. In terms of employment, this activity maintains a labour force of nearly a million persons, or 15.6 per cent of the total occupied in the industrial sector of the area.

In view of the different levels of development in Latin American countries and the particular conditions of each of them, it is understandable that when taken individually they present great differences regarding these statistics as shown in table 1. In this respect, it should be pointed out that although the figures are sufficiently illustrative, they do not provide further information on the situation among the countries. These statistics should therefore be taken with certain reserve; in many cases, particularly in the medium and smaller countries, they represent services and mechanical maintenance rather than proper production. The scarcity and unreliability of available data is partly justified by the relatively short history of this activity in the region and the low degree of specialization existing in many mechanical plants.

The over-all evaluation of the mechanical industry, as shown in the table, evidently characterizes an activity which has reached a certain size and importance and is merely a reflection of the influence of the larger Latin American countries, Argentina, Brazil and Mexico, which together account for 90 per cent of the mechanical industries of the region. In these countries, import substitution of durable consumer goods has attained high levels and great progress has been made in the production of capital goods.

In the other countries, on the contrary, the limitation of national markets and other factors that will be mentioned later on have constituted serious obstacles for the expansion of this activity. In both groups of countries disequilibrium and maladjustment can be observed, in the evolution of the mechanical industries, which are an impediment to complementation and integration within the framework of a regional scheme.

In the larger countries, development has been rather spontaneous, leading in certain production lines towards an excessive concentration of manufacturers, with the consequent loss of the advantages of specialization or ill use of installed capacity; in others, this development has resulted in a shortage of supply of intermediate and semi-processed products. Furthermore, the rapidity with which this expansion process has been carried out has not permitted an accelerated adoption of the adequate institutional measures which should accompany the evolution of this activity. Among these are the training of labour and technological research.

On the other hand, medium and smaller countries present, in a greater or lesser degree, sharp deficiencies in their productive structure, a markedly backward technology and an almost complete lack of adequate mechanical infrastructure. In addition to this, in almost all

Table 1

MECHANICAL INDUSTRIES AND THEIR COMPOSITION IN SELECTED LATIN AMERICAN COUNTRIES, 1964

(*Percentages*)

	Participation of the mechanical industry		*Composition of the mechanical industries*			
	in the gross domestic product	*in the manufacturing industry*	*ISIC 35 metal products*	*ISIC 36 machinery other than electrical*	*ISIC 37 electrical machinery and equipment*	*ISIC transport material*
Argentina	8.5	26.3	25.1	24.3	12.8	37.8
Brazil	4.3	17.4	14.5	19.8	22.4	43.2
Colombia	1.7	9.4	38.1	9.3	25.8	26.8
Chile	2.4	12.5	37.3	19.3	19.3	24.1
Ecuador	0.9	5.2	37.5	12.5	12.5	37.5
Mexico	3.4	13.8	28.6	9.0	32.5	29.8
Peru	1.2	6.7	40.0	10.0	16.6	33.3
Uruguay	3.7	17.4	20.2	20.2	27.7	31.9
Venezuela	1.2	9.1	25.3	3.4	14.9	56.3
Others	0.6	3.6	31.1	12.6	8.4	47.9
Total Latin America	4.0	17.0	23.7	18.7	20.2	37.4

of these countries no plans or specific programmes exist for the development of this sector. Aside from economic and cost considerations, the possibility of starting the production of mechanical products, especially those which are particularly suitable for integration, is basically linked to prior knowledge of a series of procedures and manufacturing techniques which in turn require a significant supply of qualified manpower for practical and efficient application. Both conditions, technology and personnel training, are not easily or quickly acquired and demand a minimum training period, especially in the case of export products which must fulfil more exacting technical and qualitative specifications.

Domestic production provides nearly 60 per cent of the consumption of mechanical products in the area. This appraisal of the average situation in Latin America is certainly influenced by the strong participation of the larger countries of the region, which have been able to satisfy a great part of the consumption of both durable consumer goods as well as capital goods. In the medium and smaller countries, national production supplies consumer needs in varying proportions, which are in any case inferior to those for the larger countries, with the aggravation of a productive lag in relation to the latter vastly exceeding the one which would derive from the direct comparison of the sizes of the respective markets or other economic indicators.

The degree of expansion generally has been lower than the possibilities offered by their own markets, notwithstanding their limited size; the course followed by the mechanical industries has been disconnected, lacking orientation and a definite economic policy to foster development. As a reflection of all this, a series of weaknesses may be observed starting from the infrastructure to the very organization of firms.

On the evidence, it follows that these countries are seriously handicapped in their desire to enjoy, over a short period, the benefits of a regional integration of this activity and that they meet internal difficulties in resisting competition from the more advanced countries of the area.

This situation must be corrected in order to avoid a further accentuation of the existing differences which, besides separating these countries from the advantages of a common market, might even hamper their own process of internal economic development. The manufacture of exportable products could have more far-reaching importance for the future of the smaller countries than for the larger ones since, apart from reasons deriving from a trade balance deficit, the maintenance of strong and sustained industrial growth rates requires the concurrence of external markets to complement those national ones which, by themselves, do not have the capacity for it.

The development of the mechanical sector has been sustained to a great extent as a result of the increased activities of services and industrial maintenance and the starting of assembly activities for durable consumer goods and, to a lesser degree, the manufacture of certain mechanical products of simple construction for a ready market.

The future prospects of these countries are therefore closely connected to their formulation of adequate plans for the growth of the industries mentioned, the correction of their structural deficiencies and the elimination of their technological gaps. This should be done in such a way as to equip the industries with the necessary means of production to enable them, in addition to supplying the domestic market satisfactorily with the products that should be manufactured locally, to place themselves on a technical level which allows them to reach complementation or integration agreements with the other countries for the manufacture of more complex mechanical products. Such products will undoubtedly constitute a substantial part of future regional trade and some countries are already engaged in the formulation of national plans for the development of the mechanical sector with this orientation in view.

The studies carried out by ECLA in Uruguay and Venezuela,[1] as well as those in Colombia and Ecuador, reveal that the countries, in order to reach the goals envisaged, should follow different orientations in accordance with the stage and course their mechanical industries have attained up to now. Thus, for example, in Ecuador, Colombia and Venezuela where imports are fundamental for the supply of mechanical products (in Ecuador more than 80 per cent and in Colombia more than 70 per cent), import substitution would seem the most convenient attitude for the creation of this infrastructure and raising of the proposed technical level. In the case of Uruguay, with a more advanced process of import substitution which it would not be advisable to continue because of the size of its market, it has been estimated that the elevation of its technological level should be obtained on the basis of what already exists. Furthermore, in view of its geographic location and peculiar manpower characteristics, consideration should be given to the specialized manufacture of certain light mechanical precision products whose production in the area is just beginning or incomplete. This would mean launching a movement of effective national specialization to satisfy the Latin American market.

The programme outlined for Venezuela involves only import substitution for internal consumption with the sole aim of raising its technological level. At a later stage, once new manufacturing techniques have been incorporated, trained personnel is available and the country has familiarized itself with the processes of mechanical production, other activities oriented towards the Latin American market can be considered. In this respect, Venezuelan national organizations are undertaking a study for the creation of a specialized centre for longer-term manufacture of heavy machinery to supply the region.

It is only natural that in the field of construction of basic industrial equipment and machine tools as well as of capital goods in general, the major advances in the region should be apparent in countries with greater

[1] La industria mecanica del Uruguay; un programa para su recuperación y desarrollo (E/CN.12/743); La industria mecánica de Venezuela; un programa de sustitución de importaciones para su desarrollo (E/CN.12/737).

domestic markets. The studies in Argentina and Brazil[2] regarding the manufacture of equipment for basic industries have established that in these countries such manufacture has reached significant proportions in supplying present consumption of these goods and that a certain manufacturing capacity, sufficiently ample to cover a substantial part of the demand forecasts, is available for 1970 as shown in table 2.

Table 2

PROPORTION OF BASIC EQUIPMENT DEMAND WHICH SHOULD BE SUPPLIED BY NATIONAL PRODUCTION BETWEEN 1961 AND 1970

(Percentages of value)

	Argentina	*Brazil*
Petroleum refining and petrochemicals..		
Petroleum and gas exploitation and distribution	89[a]	65
Electrical energy generation	22	86
Steel industry	45	77
Paper and pulp	84	89
Naval construction	75	..[b]
Cement	..[c]	62

[a] The high percentage indicated results from the inclusion of pipe for the development and distribution of petroleum and gas that were not considered in the case of Brazil, and which during the period covered by the study should rise to nearly 68 per cent of the value of the required equipment.

[b] This sector was not included in the study, but it is known that the capacity of the Brazilian naval industry is sufficient to meet the needs of the country and that the national parts incorporated into ships actually built amount to 75 per cent of the value.

[c] This sector was not considered in Argentina because at the time of the study the cement industry was already undergoing an expansion of considerable size.

The problem of these countries in connexion with the supply of a high percentage of the greater future internal demands is an improved utilization of the existing manufacturing capacity, the investments for which should not be particularly significant. Nevertheless, a series of measures should be adopted to eliminate certain obstacles which limit their development at both the national and the regional market levels.

Almost all of them originate in the absence of a development programme, either at a general or sectoral level. Lack of goals, ignorance of the domestic market and its future evolution and, in general, absence of a definite economic policy to stimulate and help the development of this manufacture (for while it is strictly mechanical with regard to supply, on the side of demand it is intimately linked to the industrial and economic growth of the country) are the principal causes that explain the situation in which this industry has evolved.

As a consequence, the incorporation of new manufacturing techniques has been slow; the training of qualified personnel at all levels has been rather circumstantial and according to the needs, since the existing training programmes have not included a timely appraisal of the factors which would orientate them to quantities and specialities required in the future. Installed capacity is often badly distributed between intermediate and final products and, among the latter, excessively concentrated in a few lines of manufacture; its utilization has been generally deficient because of the irregularity of demand which accumulates in certain periods, even surpassing the local manufacturing capacity, while in the other it is totally absent. Finally, the credit and financing systems have not been constructed organically to provide for the needs of this manufacture. Regarding this aspect, various measures have been taken towards finding a solution to the problem.

Thus, in Brazil for example, with the collaboration of international credit organizations and the complementation of domestic and foreign resources, a financial fund has been established for the acquisition of industrial machinery and equipment which covers up to 60 per cent of the value of the transaction for a period of two to five years. On the other hand, the Inter-American Development Bank has dictated a ruling on the financing of intraregional exports of capital goods designed to place the Latin American exporter in a position competitive with suppliers from other areas.

The manufacture of machinery and equipment for basic industries is a rather heterogeneous sector and includes a wide and varied range of products, which makes it difficult to enter into general considerations equally valid for all of them. However, these products can be separated in two major categories: those which, because of their more or less widespread use in many activities, are produced in large series and constitute standard or catalogued products such as pumps, valves, electric motors, etc., and those which are specific of a certain manufacture, generally "made to order".

Although many of the preceding considerations may be applied to both groups, the majority refer to the last category of products. These products constitute an important part in the supply of industrial installations and, at the same time, form an activity of a complex operational structure which requires for its efficient development and operation the co-ordinated action of a series of measures.

Machine tools, on the other hand, integrate another type of capital goods whose manufacture in Latin America has achieved considerable progress in meeting demand, particularly in Argentina and Brazil, though in smaller proportions than basic equipment.[3] The figures in table 3 show the levels of supply and their structure in both countries. It may be verified that, besides the fact that Brazilian production is slightly higher than in Argentina, no outstanding differences exist between the two countries in product composition, at least at this aggregate level, which reveal tendencies towards specialization in either of the countries.

In both cases, lathes and drills represent nearly 80 per cent of the units manufactured in the category of metal-cutting machines, and presses slightly more than 70 per cent of metal-forming machines. The evolution followed in these countries has been similar and presents many characteristics in common, it has been possible to establish from studies in those countries.

The development of this sector is limited by the same factors for basic industrial equipment, but here they present different shades and have repercussions that in

[2] Estudio sobre la fabricación de equipos industriales de base en la Argentina (E/CN.12/629); Fabricación de equipos básicos en el Brasil (E/CN.12/619).

[3] *Las máquinas-herramientas en la Argentina* (E/CN.12/747); *Las máquinas-herramientas en el Brasil* (E/CN.12/633).

many cases compromise more seriously its evolution. As indicators of the background against which this activity must develop, the following can be pointed out: the heterogeneous nature of demand, the highly competitive market, the technical and research requirements for its construction, the time and capital needed to launch new models and the difficult competition with international production centres.

In Argentina as well as in Brazil, both industries have developed under the same stimulus, that is, the demand for machine tools for factory maintenance activities. In this field, technological and manufacturing needs are not as rigorous as those of production machinery. These countries are facing the transition from this stage to the construction of more complex machines. This will require the joint action of the manufacturers as well as the national authorities in order that the necessary technical, economic and institutional measures be adopted. An action within the regional framework would be highly positive and necessary in order to consolidate this activity leading it towards greater specialization.

The degree of development achieved in Argentina and Brazil has been the result of the initiative and the isolated efforts of a greater number of manufacturers who possessed neither an adequate knowledge of the market as a whole and its evolutionary trends, nor a general orientation which would enable them to better their investments and efforts. Neither did they have the backing of a definite policy to stimulate and promote development. As a consequence of this, its present state is characterized by a weak structure with great preponderance of small and medium industries (in Argentina, almost 91 per cent of the establishments have less than fifty persons) which do not count with the technical and economic means sufficient to face by themselves the construction of more complex machinery. There is an accentuated concentration of manufacturers on a similar type or model of machine, thus losing the benefits of specialization and of production on a larger scale, as well as a backward line of production, each time more distant from actual market requirements.

It is true that these general considerations on the sector are not entirely applicable to a small number of enterprises which are outstanding because of the technical level, the quality of their products and the effort displayed to satisfy demand requirements. Such enterprises can be classified as proper manufacturers with many of the characteristics and aptitudes for meeting demand requirements and participating in export markets.

Table 3

MACHINE-TOOL PRODUCTION IN ARGENTINA AND BRAZIL

(*Weight in tons*)

Machines	*Argentina*				*Brazil*			
	Number	*Per cent*	*Weight*	*Per cent*	*Number*	*Per cent*	*Weight*	*Per cent*
A. *Metal cutting*	10,256	100.0	6,601.0	100.0	12,693	100.0	8,222.9	100.0
Lathes	3,580	34.9	3,927.4	59.5	4,638	36.5	5,265.0	64.0
Milling machines	248	2.4	345.9	5.2	278	2.2	289.8	3.5
Drilling machines	4,558	44.4	763.7	11.6	5,311	41.8	794.9	9.7
Boring machines	116[a]	1.1	77.2[a]	1.2	—	—	—	—
Planers, shapers and slotting machines	729	7.1	997.0	15.1	937	7.4	1,369.4	16.7
Threading machines	42	0.4	24.6	0.4	53	0.4	35.0	0.4
Gear cutters	14	0.1	28.0	0.4	—	—	—	—
Saws	366	3.6	113.3	1.7	1,296	10.3	342.4	4.2
Grinding machines	457	4.5	278.9	4.2	79	0.6	57.1	0.7
Tool grinders	146	1.4	45.0	0.7	101	0.8	69.3	0.8
B. *Metal forming*	1,236	100.0	3,936.3	100.0	2,813	100.0	4,986.0	100.0
Presses	95	73.2	2,912.9	74.0	2,139	76.1	3,890.0	78.0
Forging hammers	2	0.2	15.9	0.4	7	0.2	24.8	0.5
Other metal-forming machines[b]	329	26.6	1,007.5	25.6	667	23.7	1,071.2	21.5
Total	11,492		10,537.3		15,506		13,208.9	

[a] Majority are machines for reconditioning internal combustion engines.
[b] Bending and forming, punching and shearing machines.

This group constitutes the nucleus that is entering into the construction of production machinery, i.e., specific machines for larger-scale manufacturing, in contrast to the more universal type produced today. Nevertheless, they have not been indifferent to the consequences resulting from the ignorance of the market and its future prospects, the lack of credit and the absence of a national policy for such development.

The outlook for future growth and the attainment of a larger share of the supply of domestic requirements, as well as a more favourable position in foreign markets will depend to a large extent upon the removal of these structural and technical obstacles.

Machine tools constitute a field of multiple possibilities for interchange and regional complementation. The great diversity of types and models together with their respective variations, as well as the different quality levels these machines attain in their construction (according to destination and future utilization), enables the existence of specialized factories. This situation is confirmed by the steady trade in machine tools which is observed among countries in which this industry is highly developed. Latin America, with a market that can be estimated at some $250 million to 1970, with a present production not exceeding $50 million and lacking a great quantity of machine types, offers sufficiently attractive possibilities to justify a detailed analysis of the future of this production line.

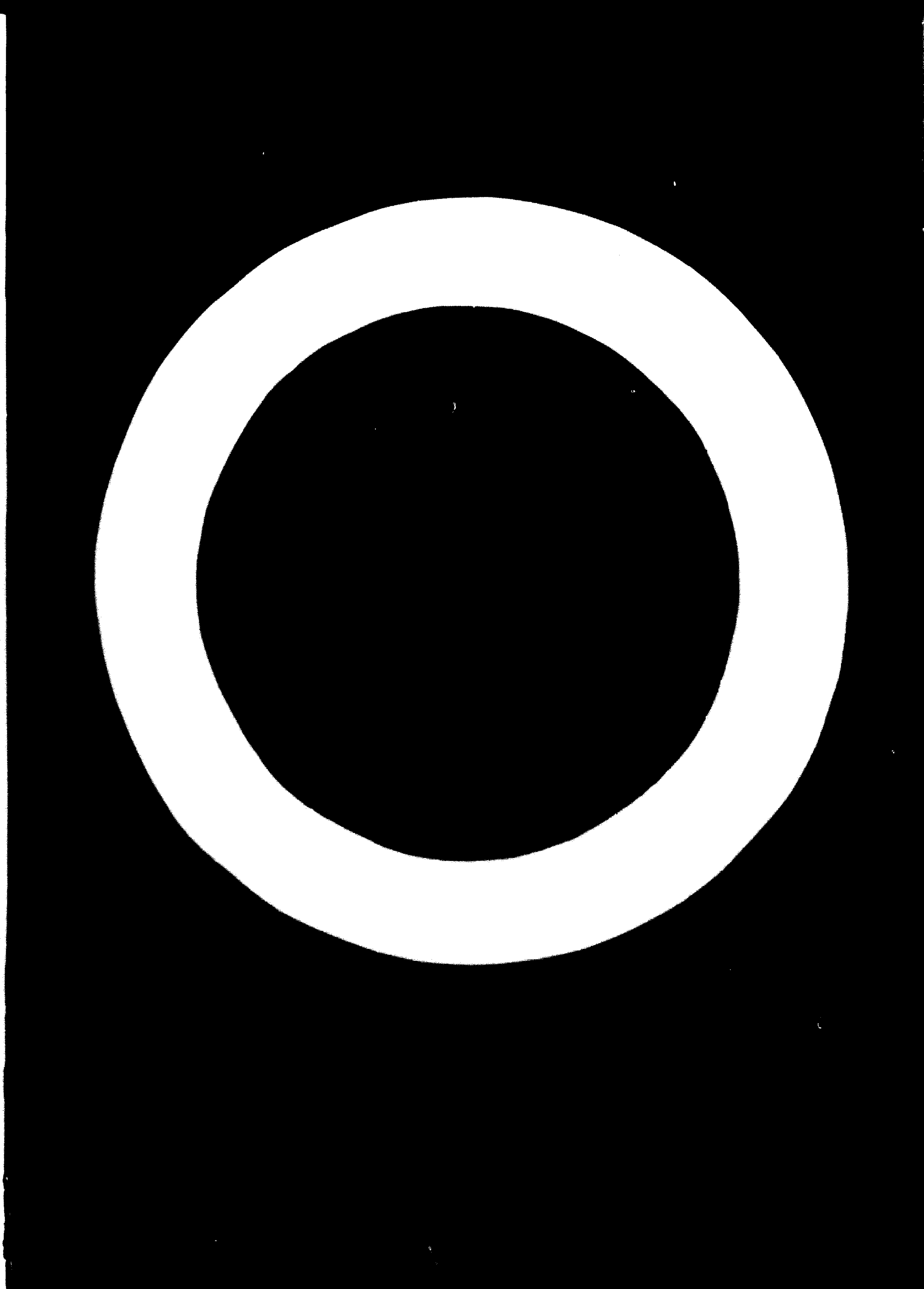
Moreover, some Latin American countries have a textile machinery industry ofimportance while others are in the process of establishing one, with well-defined plans for the future. This branch of mechanical manufacture is under study, particularly by ECLA, and data collected until now point out that the present installed manufacturing capacity in four countries, Argentina, Brazil, Colombia and Mexico, should supply nearly 60 per cent of the region's total demand.

While regional manufacturers started production through improvisation of designs, it was not long before they gained sufficient technological knowledge to compete with popular brands. Once the necessary technical basis was laid and minimum standards of quality were achieved, they could obtain from traditional manufacturers licences for the construction of already well-known models.

With the exceptions of Mexico and Colombia in which industry is at an initial stage although with well-defined plans for the future, the other countries (Argentina and Brazil) which together make up almost 80 per cent of production have used in recent years only 20 per cent of their potential productive capacities. Under these conditions, they were able to keep going only because of the flexibility of production, characteristic of the mechanical industry, which allows factories to reorientate their work.

The need to modernize the textile industry as soon as possible is evident and the regional textile machinery industry could play an important role in this process. A preliminary estimate of global needs for renewal of Latin American textile equipment results in a figure close to $480 million of which this industry could supply approximately two-thirds during the next five years, especially in such items as spindles, looms, and finishing machines.

However promising this situation may be for the textile equipment industry, certain difficulties emerge which, if not overcome, will force the sector to continue its functions without a work programme and consequently without any prospects for expansion. It should be pointed out that the textile and the textile machinery industries, while closely linked by common interests, have not apparently found a harmonic work formula. They lack the proper orientation and, above all, the necessary technical assistance in engineering and finances which would permit them to join those efforts which are scattered throughout both sectors.



THE METAL-TRANSFORMING INDUSTRY IN VENEZUELA: AN IMPORT SUBSTITUTION DEVELOPMENT PROGRAMME

Secretariat of the United Nations Economic Commission for Latin America

INTRODUCTION

Venezuela's national development plan for 1963–66 established goals for the various economic activities, with a view to an annual average growth rate of 7.9 per cent in the gross domestic product. This programme assigns the metal-transforming industries an outstanding role in the expansion of the manufacturing sector, within which their projected rate of development is the highest.

The initial object of study was to consider the metal-transforming sector's practical possibilities of meeting the goals established under the National Plan (Plan de la Nación). Serious deficiencies in the structure of the industry were noted, as well as a lack of specific plans for metal-transforming activities. It was for these reasons that the sector did not fully respond to the incentives provided by the Government and was unlikely to succeed in reaching the goals set up under the plan.

Now emphasis is on the correction of structural defects rather than on fulfilment of the plan's objectives. To this end, a development programme is outlined for the metal-transforming sector, designed to fill the technological gaps and thus gradually create a sectoral infrastructure which will enable the metal-transforming industry to improve its competitive position both on the domestic and on the world market and to undertake more complex lines of manufacture in the future.

The National Plan directs that in the promotion of new industrial activities the policy should be primarily one of import substitution and that "in this connexion the sectors producing intermediate and capital goods hold out the best prospects".

In 1962, imports of metal-transforming products amounted to 309,000 tons valued at 1,731.4 million bolívares, and included a considerable quantity of goods that could feasibly be manufactured in Venezuela. With 1962 as the base year, a preliminary selection of products was made, taking into consideration not only those cases in which import substitution would be possible almost at once, but also those recommendable on account of the technical processes and know-how that would be brought into the country with them. The following were the definitions on which the selection was based:

(*a*) Simple products that could be manufactured in small and medium industrial establishments by means of relatively labour-intensive procedures;

(*b*) Products for which manufacture processes are used that are not yet familiar in Venezuela or that require perfecting, in so far as much techniques could be introduced through medium and small enterprises;

(*c*) Products required for the integration of other activities as inputs in more complex metal-transforming processes.

From the selection thus made it appeared that about 25 per cent of imports in terms of weight, or 23 per cent in terms of value (77,540 tons and 398.1 million bolívares, respectively) could be replaced by domestic production. At a reasonably conservative estimate, this could be reached within four or five years. The programme would be largely implemented through the establishment of new medium- or small-scale enterprises whose organization and operation would be more in keeping with the country's incipient entrepreneurial capacity. This procedure would make it easier to put the programme into effect and at the same time would contribute to the more widespread diffusion of metal-transforming technology and the training of a larger number of workers.

A first evaluation of the programme suggests that its implementation would entail investment in fixed assets amounting to approximately 204.9 million bolívares and a labour force of 7,150 workers, 3,300 of whom would be skilled operatives basic to the programme.

It would be essential to adopt measures and action that would provide the appropriate institutional framework and would include, primarily, organization for the implementation of the programme; mobilization of external technical assistance resources; definition of goals and of industrial policy; establishment of financing and credit systems; and technological research.

Lastly, the metal-transforming industry's prospects under a regional integration plan are analysed with due regard to the objectives envisaged in this development programme and in others prepared in Venezuela for the manufacture of heavy machinery and equipment. The programme has been adopted by the Venezuelan Development Corporation (Corporación Venezolana de Fomento) for the expansion of the country's metal-transforming industries.[1]

THE 1963–1966 DEVELOPMENT PLAN IN RELATION TO THE METAL-TRANSFORMING INDUSTRY

The aim of the National Plan is to raise the average annual growth rate of the gross domestic product to 7.9 per cent in 1963–66, as against the rates of 3.7 and 2.8 per cent registered in 1957–60 and 1960–62, respectively. Although this rate is lower than that attained in 1950–57

[1] See Corporación Venezolana de Fomento, *Promoción Activa*, April 1965.

(9.3 per cent), which was attributable to an exceptionally favourable situation on the world petroleum market, it will necessitate a rapid expansion of the manufacturing sector of the economy. According to the development goals established under the plan, the industrial product should increase during the period under consideration at an annual rate of 13.5 per cent, as compared with 11.6 per cent in the 1950s. Consequently, the volume of additional employment afforded by the manufacturing sector would represent the absorption of 82,100 workers, the annual average being a little over 20,500. The significance of this objective, as is noted in the plan, will be realized "if it is borne in mind that in the whole of the last decade (1950–1960), manufacturing industry created only 84,200 employment opportunities, i.e., absorbed about 7,650 workers a year. Thus the aim is almost to treble the effort made in the past".

The attainment of these production and employment goals will call for a systematic promotion effort on the part of the authorities and for private enterprise energetic use of initiative and determination to outdo previous achievements. "Venezuela's manufacturing industry is entering a phase which, both economically and technically speaking, is broader and more difficult than that ended with the fifties. The stage now reached involves the installation of heavier industries with more complex techniques, some of which will have to compete on foreign markets and must therefore operate efficiently and at competitive costs. Furthermore, the industries already established will have to embark upon a rationalization process designed to raise their productivity and to improve the quality and lower the prices of the goods they manufacture—another complex and ambitious task.

"Concurrently with the diversification of production, effort will have to be concentrated on industrial integration with a view to the introduction of the structural changes required for the more efficient operation of the whole industrial complex. In other words, this implies improving interindustrial relationships", the plan says.

For the promotion of new industrial activities, according to the plan, an import substitution policy would be the most appropriate to pursue and "in this connexion, the sectors producing intermediate and capital goods hold out the best prospects".

An import substitution programme does not preclude the promotion of exports; on the contrary, this should be regarded as deriving from such a programme, and should be the natural outcome of an over-all consolidation and diversification of the manufacturing sector for which the dynamic impetus is generated, in the first place, by a selective import substitution policy.

In the outline of general policy for the promotion of the manufacturing sector as a whole (whose share in the gross domestic product should rise from 16.4 per cent in 1962 to 20 per cent by 1966), the following are the salient directives:

(*a*) Import substitution should be the mainspring for the installation of new activities;

(*b*) The selection of new activities should be directed towards the improvement of interindustrial relationships, with a view to the gradual establishment of a better balanced industrial structure characterized by maximum complementarity of enterprises;

(*c*) In manufacturing activities, products and processes should be introduced which will imply technological progress in industry as a whole, in the sense that their mastery by domestic industry will open up prospects of manufacturing other more complex products for which there will be a gradually expanding domestic market;

(*d*) Absorption of manpower should be maximized through proper selection of the lines of manufacture to be introduced, as well as of the production processes and equipment to be adopted.

The leading role in the expansion of the manufacturing sector falls to the metal-transforming industries. Table 1 sums up the production objectives formulated for manufacturing industry in general and for the metal-transforming industries in particular, these latter being broken down by subsectors corresponding to four major groups (35 to 38) in the International Standard Industrial Classification (ISIC):

(*a*) Manufacture of metal products;

(*b*) Manufacture of machinery (except electrical);

(*c*) Manufacture of electrical machinery, apparatus, appliances and supplies;

(*d*) Manufacture of transport equipment.

From an examination of the goals for these four groups, certain inferences can be drawn.

The annual growth rate of apparent consumption is almost the same (a little over 10 per cent) in the first three groups and more than twice as high in the fourth (transport equipment). But in the period under consideration, the shares corresponding to domestic production and to imports will have to undergo radical changes which will differ from one group to another. It seems likely that between 1962 and 1966 the proportion of apparent consumption represented by imports will decline more sharply in the industries producing electrical equipment (from 82 to 44 per cent) and machinery (from 95 to 69 per cent) than in those manufacturing metal products (40 to 22 per cent) and transport equipment (53 to 30 per cent). In absolute figures, however, the production increments envisaged are considerably higher in the case of transport equipment and metal products.

To judge from these larger increases in the output of the metal products and transport equipment groups, the volume of additional employment in 1962–1966 will range from 15,000 workers in the transport equipment sector to 2,500 in metal products. The expected increase in the number of persons employed in the metal-transforming industries as a whole is slightly over 23,000.

As regards the product (value added) per employed person, the plan estimates that it will be 28,000 bolivares in 1966, compared to 22,800 bolivares in 1962 for manufacturing industry as a whole (excluding artisan industry). The metal-transforming industry should show a value added amounting to 20,800 bolivares in 1966, as against the 19,600 bolivares registered in 1962.

Investment requirements for the expansion of metal-transforming activities are estimated at 640 million bolivares (at 1960 prices), which implies a *per capita* investment of a little over 33,000 bolivares, or rather

Table 1

VENEZUELA: GOALS FOR THE MANUFACTURING AND METAL-TRANSFORMING INDUSTRIES ESTABLISHED IN THE NATIONAL DEVELOPMENT PLAN FOR 1963-66

Item	Years 1960	1962	1963	1966	Variation between 1962 and 1966: thousands of persons	percentage	Annual percentage increase 1962-1966
	(millions of bolivares at 1960 prices)						
1. Apparent consumption of manufactured goods	9,898	11,060	12,738	17,001		53.7	11.4
Products of the metal-transforming industries	1,225	1,393	1,720	2,530		81.6	16.1
G.35 Metal products	573	604	667	899	—	48.8	10.5
G.36 Machinery	35	164	181	244	—	48.8	10.4
G.37 Electrical equipment	88	119	131	177	—	48.7	10.4
G.38 Transport equipment	529	506	741	1,210		139.1	24.4
2. Value of manufacturing output	8,521	10,063	11,476	16,210		61.0	12.7
Products of the metal-transforming industries	535	634	903	1,721		171.5	28.4
G.35 Metal products	309	365	429	699	—	91.5	17.6
G.36 Machinery	6	8	9	75	—	837.5	75.0
G.37 Electrical equipment	18	21	25	100	—	376.2	47.5
G.38 Transport equipment	202	240	440	847	—	252.9	37.1
3. Value of gross product in the manufacturing sector	3,914	4,648	5,320	7,720	—	66.1	13.5
Metal-transforming industries	283	337	432	840	—	149.3	25.6
G.35. Metal products	189	223	263	428	—	91.9	17.7
G.36 Machinery	3	5	6	55	—	1,000.0	82.1
G.37 Electrical equipment	11	12	14	80	—	566.7	60.6
G.38 Transport equipment	80	97	149	297	—	206.2	32.3
4. Value of exports	1,850	2,184	2,367	2,939	—	34.6	7.7
Metal-transforming industries	—	—	—	—	—	—	—
5. Value of imports	3,227	3,181	3,629	3,730	—	17.3	4.1
Metal-transforming industries	690	759	817	809	—	6.6	1.6
G.35 Metal products	264	239	238	200	—	(−) 16.3	(−) 4.4
G.36 Machinery	29	156	172	169	—	8.3	2.0
G.37 Electrical equipment	70	98	106	77	—	(−) 21.4	(−) 4.9
G.38 Transport equipment	327	266	301	363	—	36.5	8.1
	As a percentage of value of apparent consumption						
5A. Imports of manufactured goods	32.6	28.8	28.5	21.9	—	—	
Metal-transforming industries	56.3	54.5	47.5	32.0	—		
G.35 Metal products	46.0	39.6	35.7	22.2	—	—	
G.36 Machinery	82.9	95.1	95.0	69.3	—	—	
G.37 Electrical equipment	79.5	82.4	80.9	43.5			
G.38 Transport equipment	61.8	52.6	40.6	30.0			
6. Employment (thousands of persons)	309.3	323.1	340.5	405.2	82.1	25.4	5.8
Metal-transforming industries	18.0	17.2	21.0	40.3	23.1	134.3	23.7
G.35 Metal products	5.0	0.8	5.3	7.3	2.5	52.1	11.1
G.36 Machinery	0.3	0.3	0.3	2.6	2.3	766.7	71.6
G.37 Electrical equipment	1.0	1.1	1.2	4.4	3.3	300.0	41.4
G.38 Transport equipment	11.7	11.0	14.2	26.0	15.0	136.4	24.0
7. Product per employed person (thousands of bolivares)	12.7	14.4	15.6	19.1		32.6	7.3
Metal-transforming industries	15.7	19.6	20.6	20.8		6.1	1.5

Source: National Development Plan (*Plan de la Nación*) for 1963-66.

more than half the figure for manufacturing industry in the aggregate. This high proportion is of course due to the heavier incidence of the markedly capital-intensive basic and petroleum industries on the over-all figure.

As can be seen from the foregoing data, the hypotheses adopted do not assume any significant increase in labour productivity or, probably, in rates of return on capital and therefore seem realistic, given the brevity of the period covered by the analysis.

CHARACTERISTICS OF THE EXISTING METAL-TRANSFORMING INDUSTRY

The existing metal-transforming industry constitutes the springboard for the sectoral expansion programme propounded below. On its characteristics, in respect to products, organization, plant size, technological progress, manpower supply at the various levels of skill, capital and value added per worker, etc., will depend the nature of the programme and the intensity of the promotional effort. Accordingly, the next step will be to give a brief description of the main characteristics of Venezuela's existing metal-transforming industry, based on the findings of CORDIPLAN's industrial survey (1961) and on the data obtained by means of another survey, much more limited in its scope, carried out by ECLA during the first half of 1964.

The figures presented in table 2 give some idea of the magnitude of the sector as well as of its relative significance within the manufacturing industry. In general terms, the table shows that in 1961 the metal-transforming industries contributed 9.7 per cent of the value added in the whole of the manufacturing sector and provided employment for 22,215 workers, i.e., 14.2 per cent of the personnel employed in industry as a whole, whence it can be inferred that metal-transforming activities have achieved some degree of importance in Venezuela. To this over-all evaluation, however, must be added a few indications of the real significance of these figures and the true structure of the sector.

The first striking point is that fixed capital in this industry accounts for only 4.2 per cent of the total amount registered for manufacturing activity which, by comparison with the level of employment, implies a very low capital density per employed person while at the same time showing that servicing and maintenance enterprises predominate over what may strictly be classed as productive activities in this sector. Secondly, it must be stressed that a division of industrial units by plant size reveals a high proportion of medium and small establishments, especially the latter, which represent about 90 per cent of the units in question and account for approximately 57 per cent of the personnel.

No further evidence is needed to show that the sector as a whole, despite its relative importance within Venezuelan industry from the standpoints of value added and employment levels is, in the first place, seriously underproductive on account of its low *per capita* investment rate and, secondly, handicapped by a structural composition almost of the artisan-industry type, which makes it ill-fitted to tackle or develop the production techniques involved in metal-transforming activities.

If the various branches of the metal-transforming

Table 2

VENEZUELA: THE METAL-TRANSFORMING INDUSTRY IN RELATION TO MANUFACTURING INDUSTRY, 1961

(In millions of bolívares)

	Large-scale industry	*Medium-scale industry*	*Small-scale industry*	*Total*	*Manufacturing industry*	*Percentage share of the metal-transforming industry*
Number of establishments[a]	7	195	1,574	1,776	7,531	23.6
Number of persons employed[b]	2,799	6,724	12,692	22,215	156,938	14.2
Gross value of production	292.7	294.8	278.5	866.0	9,261.5	9.4
Value added	85.2	141.8	160.9	287.9	3,999.4	9.7
Fixed capital[c]	66.3	91.5	106.1	263.9	6,316.0	4.2

Source: Central Co-ordination and Planning Office (*Oficina Central de Coordinación y Planificación*—CORDIPLAN) Industrial Survey 1961.

[a] Reference is made to "industrial units", i.e., to a plant, group of plants or industrial complex belonging to a single owner and situated in one and the same place.

[b] Including, in addition to operatives and employees, other types of workers such as partners, members of the entrepreneur's family and home workers.

[c] Excluding the value of the site.

Table 3

VENEZUELA: DIVISION OF GROSS VALUE OF PRODUCTION AND OF VALUE ADDED, BY MAJOR GROUPS, 1961

	Large-scale industry	*Medium-scale industry*	*Small-scale industry*	*Total*
		Millions of bolívares		
A. *Gross value of production*	292.7	294.8	278.5	866.0
35. Metal products	97.6	56.9	52.6	207.1
36. Machinery	—	11.7	8.2	19.9
37. Electrical equipment	8.4	93.5	46.4	148.3
38. Transport equipment	186.7	132.7	171.3	490.7
B. *Value added*	85.2	141.8	160.9	387.9
35. Metal products	47.4	28.4	24.0	99.8
36. Machinery	—	6.2	4.4	10.6
37. Electrical equipment	2.8	36.4	24.6	63.8
38. Transport equipment	35.0	70.8	107.9	213.7
		Bolívares per annum		
C. *Value added per operative*	40,242	28,029	17,865	23,978
		Thousands of bolívares		
D. *Fixed capital per operative*	31.3	18.1	11.8	16.3

Source: CORDIPLAN, Industrial Survey, 1961.

sector are analysed individually, their operational characteristics become even more patent. From the figures presented in table 3, showing the composition of production in the metal-transforming industry, it can clearly be seen how large a proportion is represented by transport material, more than 55 per cent in terms both of the gross value of production and of value added. This branch is made up of vehicle assembly plants which can be classified among the large and medium industrial establishments, and small and medium repair and maintenance workshops. The former constitute a primary activity using a low proportion (not more than 10 per cent) of domestically manufactured parts, most of which are not products of the metal-transforming industries. Consequently, in terms of value added, the contribution made by these plants in the aggregate is very small and does not amount to as much as 20 per cent of the value of the vehicles assembled. The main activity of the other establishments in this branch is the servicing and maintenance of motor vehicles. A similar situation, although on a more limited scale, is to be found in the manufacture of electrical equipment, where again the enterprises assembling radio sets and other household appliances, and those providing maintenance services and installing electrical fittings, show a heavy incidence. In this group, however, there are sizeable industrial establishments engaged in the manufacture of steel-reinforced electric cables and accumulators.

The group producing non-electrical machinery is almost negligible, with an output slightly exceeding 2 per cent of the whole sector's, and here too the great majority of the establishments concerned are not manufacturing enterprises in the proper sense of the term. The oldest and most important metal-transforming industries in Venezuela are those in the metal products group, outstanding among which are the plants manufacturing metal structures, wire products and other goods for the construction sector. Their installation was motivated by the fact that these lines of manufacture do not require very highly skilled labour.

Because of this structure of production in the existing industry, the productivity and capital-density indexes and the other production ratios deducible from the figures given are of little significance and hardly applicable as a means of quantifying installed production potential and its future prospects. Similarly, the machine-tool inventory at the industry's disposal displays the usual characteristics of an activity primarily concerned with metal-transforming services: a high proportion of metal-forming machines and only a very few cutting machine tools, mainly of the simplest all-purpose type. Accordingly, there is a shortage of manpower at the various levels of skill, and this may constitute a serious obstacle to the development of the metal-transforming sector.

All this clearly testifies to the structural weakness and underdevelopment of Venezuela's metal-transforming industry, and its growth prospects are therefore closely linked to the establishment of new enterprises whose characteristics and structure fit them for definitely productive activities. In this connexion, the contribution of the existing industry, with its marked predominance of service and maintenance workshops and of primary metal-transforming activities, will be very limited.

Evaluation of the programme and determination of the corresponding inputs

In order to evaluate the nation's proposed manufacturing programme, even if only on an over-all basis, and to determine labour inputs and investment, a number of coefficients were established whereby the production goals could be expressed in terms of the inputs required. The coefficients correspond to average manufacturing conditions for the product structure and are based on the findings of various surveys undertaken in Venezuela, as well as on data collected by ECLA in several studies carried out in other Latin American countries.

Once manufacturing projects have been determined at the product level, of course, these coefficients will have to be revised in the light of the scales of production adopted, the plant sizes selected and the manufacturing techniques chosen. But in the case of the great majority of the imported products whose replacement by domestic production is recommended, considerations of technology or scale of operations will not exert much influence in this connexion.

As regards the value of production per operative the average figure for the manufactures proposed was estimated at some 69,000 bolívares, which compares satisfactorily with the findings of the surveys. According to the industrial survey carried out by CORDIPLAN in 1961, the average for the metal-transforming industry was 53,522 bolívares; while the result obtained in the survey made by the Metallurgists' Association (*Asociación de Metalúrgicos*) was about 56,000 bolívares. In view of the fact that at the date in question the metal-transforming industry was operating at low performance levels, it may be concluded that the coefficient adopted is reasonably realistic.

Similarly, these surveys establish densities of fixed capital per operative in the neighbourhood of 16,300 bolívares and 22,500 bolívares, respectively, which are regarded as too low for new activities. In the case of the Guyana Project,[2] average investment works out at 63,000 bolívares per operative, a ratio which, on account of the type of equipment that will be manufactured, corresponds to a high category metal-transforming activity. It was thought that for the type of products under consideration investment coefficients ranging from 25,000 to 50,000 bolívares per operative would be representative, the over-all average thus being 36,000 bolívares.

It can be shown that manpower requirements will amount to 5,722 operatives, and that 204.9 million bolívares will have to be invested in fixed capital (see table 4).

Consistently with this number of operatives, it may be estimated that the total personnel required will comprise about 7,150 employees of whom approximately 70

[2] *Corporación Venezolana de Guyana* (Joint Centre Guyana Project), *Preliminary Programme for the Heavy Machinery Building Complex, Guyana Region*, 162.

will be mechanical engineers and metallurgist and some 210 will be technicians and draughtsmen. It may be reasonably supposed that the skilled operatives will number about 3,300, and that they can be tentatively classified in the following categories:

Metal-cutting machine operatives	1,540
Adjusters	820
Toolmen	200
Foremen	240
Others	500

Since the programme was meant to be carried out within four or five years, it can be seen how great a manpower training effort will be required; no fewer than 800 workers will have to be trained every year. The annual investment figure will not be less than $10 or $12 million, to cover production equipment, construction and other ancillary services.

Raw material inputs were determined by direct reference to the volumes of production established. A point that emerges clearly from this evaluation is the importance of castings for the implementation of the programme, since the volume needed will slightly exceed 20,000 tons, which means that it will account for 30 per cent of the total weight of the products to be manufactured. In order to meet these requirements, the existing foundries will have to be expanded and new ones installed, equipped with plant and techniques that will enable them to satisfy the demands of the new metal-transforming activities.

they will supply has been settled. Transport costs are a factor that will weigh heavily in decisions as to whether some of the proposed lines of production should be integrated or whether certain units should be more widely scattered throughout the country, a matter which will call for careful study.

If this manufacturing programme is evaluated in relation to the existing industry, the progress it will imply is obvious. The following points are worthy of emphasis:

(*a*) Personnel requirements for the manufacturing programme represent 30 per cent of current employment in the metal-transforming industry;

(*b*) The new investment will increase the existing industry's fixed capital by about 80 per cent;

(*c*) The value of production will rise by approximately 50 per cent in relation to its present level.

Furthermore, the new manufacturing activities will indirectly exert a favourable influence, difficult to quantify, on the existing industry, since it will benefit both by the manpower to be trained and by the products to be manufactured, and will thus undoubtedly be an incentive to improve current operational conditions as well as to expand and diversify its lines of manufacture.

Lastly, production ratios bring to light the differences between the two industrial groups as regards the structure of production; the new enterprises call for more capital per employee and also show a higher level of productivity. The low ratio between the value of production and fixed capital indicates pre-eminently productive operational

Table 4

VENEZUELA: MANPOWER AND INVESTMENT NEEDS FOR THE IMPORT SUBSTITUTION PROGRAMME

	Output		Number of operatives	Fixed capital (thousands of bolivares)	Probable number of enterprises
	Tons	*Thousands of bolivares*			
Containers and tinware	9,550	19,560	257	12,850	5–7
Hot-forged and hot-pressed products	8,221	34,982	603	24,120	4–8
Wire products	3,800	6,500	75	2,625	1–3
Primarily stamped products	3,250	16,160	207	7,245	8–13
Small products and parts primarily machined	5,460	25,059	501	15,030	6–12
Boiler shop products and metal structures	5,900	15,948	182	4,550	3–6
Sheet metal work, with or without metal-spinning	11,550	57,522	770	26,950	10–20
Light machinery and machine parts	13,367	108,054	1,544	54,040	20–30
Medium weight and heavy machinery and machine parts	9,532	75,478	1,161	40,632	20–30
Other products	6,910	38,838	422	16,880	5–10
Total	77,540	398,101	5,722	204,925	82–139

In table 4, an indication will be found of the number of enterprises that might be installed to cover the manufacturing requirements shown for each group of products. It is intended merely as a rough guide, and the figures in question cannot be accurately established until the products have been specifically determined and manufacturing costs have been fixed at the product level. As will be noted, many of these enterprises may be integrated in a single unit, but the advantages or disadvantages of this procedure can only be assessed once the possible geographical location of the plants and of the markets

conditions, in contrast with the figure registered for the existing industry, greatly distorted as it is by the heavy incidence of service and maintenance activities.

THE METAL-TRANSFORMING INDUSTRY AND REGIONAL INTEGRATION PROSPECTS

In the main, the immediate object of the study was to formulate a relatively short-term development plan for the metal-transforming sector, with the sole intention of offering a few pointers to possible new lines of domestic production that would help to raise the technological level of the existing industry and to form a metal-transforming infrastructure such as is indispensable for the consolidation of the sector's future development. Thus, the selection of products was essentially based on two considerations deemed fundamental for this preliminary approach: the prevailing techniques used in their manufacture and the volume of the domestic market evaluated through imports. The study of the existing industry, structurally weak, and under-productive, sufficed to suggest that it would be advisable to adopt a development plan directed towards the attainment of certain levels of technological progress and training of skilled workers rather than towards quantitative achievements that would call for a substantial manufacturing effort or would have a powerful impact on the expansion of the gross domestic product. Consequently, in the programme presented here, economic considerations have played a secondary role in the sense that recommendations for the manufacture of new products are not backed by comparative cost studies.

Broadly speaking, this procedure is justified by the convictions that the development of the metal-transforming sector must be a gradual process and that it is impossible to move on to more complex manufactures until certain basic production methods have been introduced and that the vast range of products of the metal-transforming industry, especially durable consumer goods and building materials, includes a large number of articles which entail relatively simple manufacturing processes, which the developing countries should start to produce as they reach more advanced stages of industrialization, and which are the very means of introducing new techniques and manufacturing processes. In Venezuela's case, it could be seen that the metal-transforming sector is lagging far behind, since its manufacturing lines are not in keeping with the country's level of industrialization, the size of its market and the *per capita* income available.

The fact that the volume of the domestic market was the principal determinant of the production targets established for the initial phase of the development of the metal-transforming industry does not mean that no thought was given to the possibilities that would be opened for this activity under a regional integration programme. On the contrary, it was considered that the ultimate objective must be to equip the domestic industry with such production media as will enable it not only to provide the home market with adequate supplies of the products to be manufactured in Venezuela, but also to concert with other countries' complementarity of integration agreements in connexion with manufacture of the more complex products of the metal-transforming industry, which will no doubt be those accounting for a major share of future intraregional trade. Moreover, manufacture for export will be vitally necessary for Venezuela if substantial and uninterrupted rates of industrial growth, which the domestic market alone will be capable of sustaining, are to be kept up over the long term. It must be borne in mind that, in the metal-transforming sector, production for export cannot be undertaken on a makeshift basis or over the short term since, apart from cost considerations, it entails a lengthy process of manpower training and adaptation of techniques before products can be manufactured in conformity with the specifications and quality standards required for this type of trade, especially if they are to be exported for the purpose of complementing metal-transforming activities in other countries.

In this context, short-term export prospects may be described as non-existent, except perhaps in the case of a few products which may be saleable on occasion to neighbouring countries where they are not yet manufactured or where domestic production is insufficient to meet requirements. Such a situation could not be other than temporary. From the standpoint of the development of the metal-transforming sector, this would not represent an immediate obstacle, inasmuch as the domestic market affords opportunities favourable enough for high growth rates to be attained, at least during the next five years.

The solution of the longer term problem has been engaging attention in Venezuela for years, and one of the studies that has been put forward in this connexion is the project for the formation in the Guyana area of a complex for the manufacture of heavy machinery and equipment. The manufacturing lines envisaged in the preliminary project[3] comprise the construction, in horizontally integrated plants, of large machinery and equipment for mining and building, for the petroleum industry, for the transport of materials, for the wood and machine-tool industries, etc. By 1975, according to estimates, the output quantum might be about \$476.4 million (at 1957 prices), of which \$150 million worth would be exported to other Latin American markets and might cover about 21 per cent of domestic demand, which by that year would amount to \$1,535.1 million. At the same time, it is estimated that the medium and light machinery constructed in the rest of the country might represent about \$347.6 million, i.e., nearly 23 per cent of the domestic market. The investment required for the building of this complex would be approximately \$370 million and for its operation about 26,500 workers would be needed.

The decision to locate this complex in the Guyana area is justified in the preliminary project referred to by the existence of an integrated steel mill in this part of Venezuela which, in addition, possesses an up-to-date machining shop and a big iron foundry; by the fact that there is a project for an aluminium plant in the same locality; and by the availability of good transport communications with internal and external markets. The economic justification of the project, in its turn, and the expectation of low manufacturing costs, would derive from the reduction of investment which the location itself would facilitate; from the organization and structure of the complex in terms of horizontal integration, with many services in common and maximum utilization of capacity; and from the considerable economies of scale that would be achieved.

Irrespective of the volumes of demand and investment and the levels of productivity it is hoped to attain figures which in any event will require careful revision, particularly as regards the market for such large machinery

[3] See *Preliminary Programme for the Heavy Machinery Building Complex, Guyana Region*, op. cit.

and the matter of investment. The execution of this project, which calls for such highly developed technical know-how, seems a trifle premature in view of the entrepreneurial and technological conditions prevailing in Venezuela. Probably, when the project was devised, it was thought that the rest of the metal-transforming industry, which from every point of view undoubtedly has a key role to play in the establishment of this complex, would develop on the lines contemplated in the National Plan. But, as previously pointed out, this has not happened for want of appropriate programming in this sector, and in all likelihood, therefore, the Guyana project will have to be postponed or the time schedules and manufacturing programmes will have to be thoroughly overhauled.

In the latter case, the Guyana programme ought not to be carried out in isolation, regardless of the development of the other metal-transforming activities. The mere observation of the evolution of this sector indicates that it is impossible to embark upon complex undertakings in the metal-transforming industry without a certain amount of ballast in the shape of basic know-how and metal-transforming tradition. The building of heavy machinery and equipment of the type which it is intended to manufacture in Guyana constitutes one of the most advanced states in the development of the metal-transforming sector. Because of the constructional complexities and responsibilities it involves, it is not a suitable activity for the training of manpower, especially in the case of Guyana where such training would have to be given almost in its entirety and from the very start. Another aspect of this project which should be subjected to a more careful scrutiny is that relating to the economies of scale which would be achieved, inasmuch as the equipment concerned is of the large and heavy type which is usually made on a unit basis, each piece virtually representing a new project, on account of the modifications that are generally requested by the consumers to suit their working requirements and procedures and also because of the technical innovations which are constantly being introduced in such machinery.

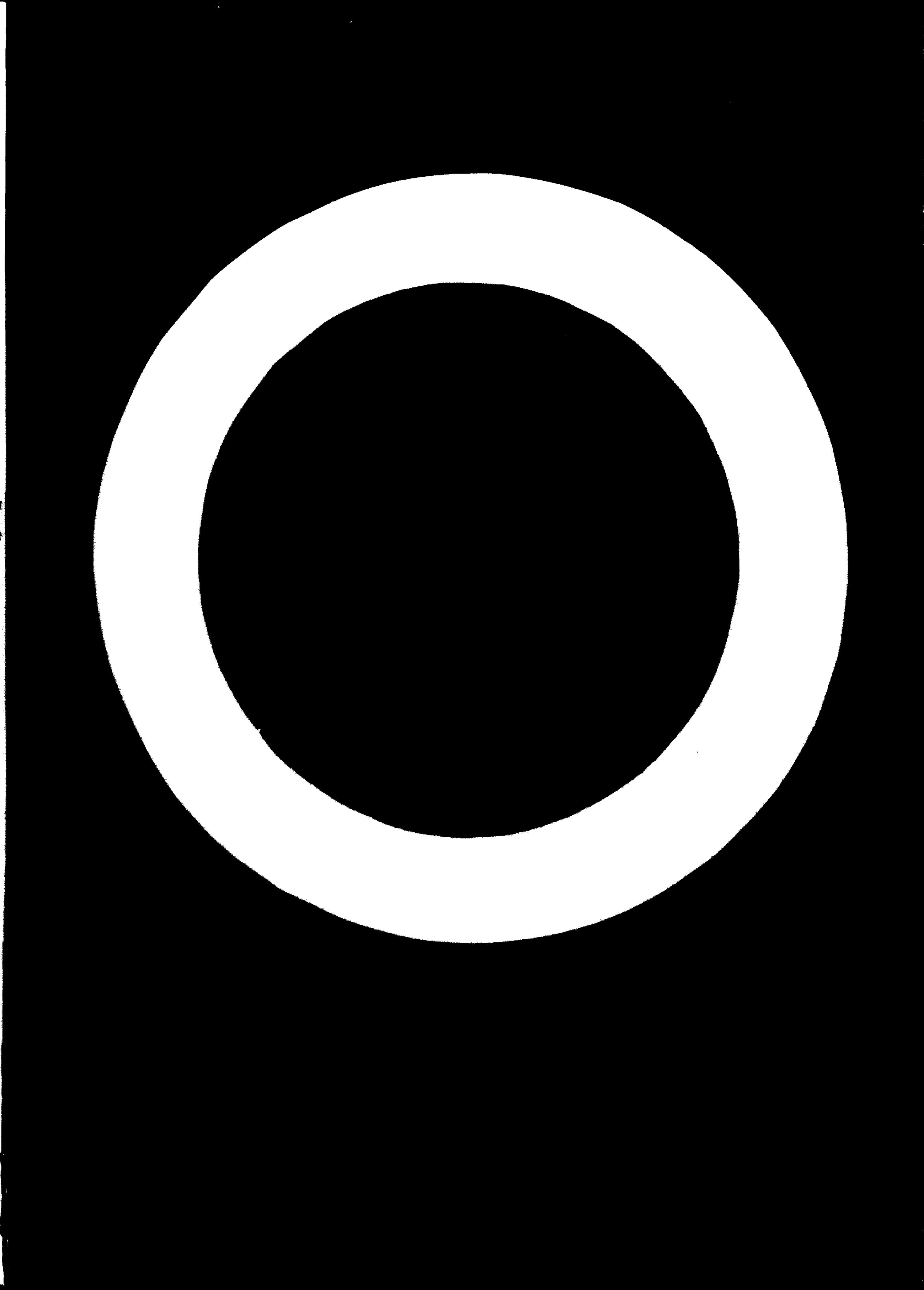
The foregoing considerations give some idea of the tremendous gap between the existing industry and the demands implicit in the Guyana programme, a gap that will have to be narrowed if the project in question is to materialize. In this connexion, the import substitution programme suggested in the present study plays an important role, and constitutes a basis for technical improvements and for the initial phases of manpower training. Nevertheless, other stages will have to be traversed before the final objectives embodied in the Guyana industrial complex can be reached. To prevent the execution of this project from being held up, if in the course of its revision no situations emerge that might cast doubt on the practicability of the targets originally established, the manufacture of some of the products included in the prospective manufacturing lines of the Guyana complex should be started during the stages in question, as an integral part of the national programme for the development of the metal-transforming sector. Special consideration should be given to the production of equipment and accessories for the petroleum industry.

Owing to the exceptional conditions and dimensions of this industry in Venezuela, the metal-transforming sector would do well to undertake the manufacture of products to meet its needs, particularly as many of them are common to other industrial activities, such as the petrochemical industry. The wide variety of products used in this activity, ranging from the simplest, such as flanges and connexions, to the most complex, such as pumps, compressors, etc. makes it possible to graduate the programming of production in accordance with the progress made in technology and in the training of skilled workers. This is an activity for whose products, even in the case of those entailing the simplest manufacturing processes, intraregional export prospects might be very promising, so that steps could be taken to negotiate integration agreements with other Latin American countries. The most attractive feature of the manufacture of equipment for the petroleum industry undoubtedly consists in the fact that the internal market is in itself large enough to sustain an efficient domestic industry and therefore reliance upon external markets would not be necessary.

Another activity which would be worth careful study in the light of this criterion, with a view to its incorporation in Venezuela's plans for the metal-transforming industries, is the motor vehicle industry, especially as regards the manufacture of parts for vehicles. According to 1964 estimates Venezuela's motor vehicle inventory consisted of about 430,000 units, and the number comprised in assembly programmes probably exceeded 40,000 units. Although these figures, especially those relating to assembly work, are not high enough to be described as optimum in countries where the manufacture of motor vehicles is traditional, they may be regarded as satisfactory starting-points for the manufacture of specific parts and spare parts at reasonable price levels.

Apart from the fact that domestic manufacture of spare parts for the maintenance of the inventory might come to constitute a significant import substitution item and might at the same time open up new opportunities for employment and for obtaining technical know-how, it would facilitate the establishment of a programme for the manufacture of motor vehicles, with the corresponding goals for the progressive increase of their domestically manufactured components. Once this activity had been developed for the home market, it might secure a footing in adjacent countries' markets and in those of other Latin American countries where the size of the motor vehicle inventories would not be equally favourable for the establishment of similar industries, or even where domestic manufacture already exists, in view of the wide variety of models in each country's motor vehicle inventory.

To sum up, Venezuela's integration prospects in respect of the metal-transforming industry are closely linked to the formulation of a national development plan for the sector envisaging, in an initial phase, the rapid improvement of the industry's present technological status and the intensive training of skilled labour at all levels. During this stage, the manufacture of simpler products of the metal-transforming activities should be included and initiated. These products would be those which, as pointed out above, not only enjoy significant export prospects but can also rely upon an internal market broad enough to sustain an efficient domestic industry. Over the longer term, when this stage of development had been left behind, consideration should be given to the manufacture of the heavy equipment contemplated in the case of the Guyana complex, if this seems advisable in the light of the revision and verification of the data and the practical conditions for the execution of the project.



THE MANUFACTURE OF MACHINE TOOLS IN ARGENTINA

Secretariat of the United Nations Economic Commission for Latin America

INTRODUCTION

Machine tools will play what might be termed an almost fundamental role in the industrial development plans in which Latin American countries are engaged. This is due as much to the greater production volumes it will be necessary to reach in the future as to the requirements of new production, since the continuation of the import substitution process must impinge primarily on products of increasingly greater complexity and productive requirements.

The increased rate of investment that these development programmes require and the limitations in the foreign purchasing power of these countries confronts the region's machine-tool industry with a serious responsibility: to meet qualitatively and quantitatively the demand which will arise within the next few years.

The manufacture of machine tools in Latin America is at the highest level in Argentina and Brazil as a logical consequence of the larger markets available in these countries. Nevertheless, this activity has in general developed in a disorderly manner and with an almost complete lack of orientation in regard to market size and the nature of demand. It reveals serious gaps in its production structure which place it in a difficult position to face the qualitative requirements of future consumption. This does not mean that the advances during this period lack meaning or significance for the future. On the contrary, the industry in these countries, supplying their markets with an appreciable portion of simple machines (more for maintenance than production), has completed an important stage in its development, thus establishing a base for a more advanced stage.

It is evident, however, that the activity has lacked that characteristic of dynamism and vitality which distinguishes it in the more advanced countries, in the sense of anticipating itself and foreseeing demand requirements. Lacking this dynamism, the industry will go on progressively losing its relative importance since, while demand for the machines that are being made will continue, it will be decreasing relatively within the total because of the greater requirements for more specialized and complex production machines.

These conditions influence the objectives in this study: to provide the framework within which the Argentine machine-tool industry should be developed in the next ten years by a quantitative and qualitative evaluation of the market and to analyse the operating conditions of the industry and to identify the structural changes required to follow forecast demand trends. The Banco Industrial de la República Argentina (BIRA), the Cámara de Fabricantes de Máquinas-herramientas y Herramientas Afines, and the Consejo Nacional de Desarrollo (CONADE) contributed much to this study.

This report is limited principally to the machine-tool industry with regard to machine-tool construction itself, whether they be of the metal-cutting or metal-forming type and exclusively for working metals. The industries complementary to this activity, such as accessories and parts, have not been considered.

Owing to deficiencies in the basic statistics, it was necessary to make estimates to reconstruct the totality of the metal-transforming industries and their operating conditions in order to present a panorama of the machine-tool industry within the objectives of the study. Only when the data of the economic census become available will it be possible to know the real size of mechanical activities and the principal machine-tool consumers. Notwithstanding the preliminary character of this study, it is considered that the result of the research and the conclusions resulting from it concur sufficiently, in order of magnitude, with reality and that corrections in the future will not seriously affect the estimates made here, particularly in regard to the existing industry and the changes which should be introduced in it in the next few years. It should be remembered that the machine-tool field is particularly complex, with numerous and varied problems, which preclude the generalized application of laws or criteria or the attempt to transplant them from one region to another without encountering factors diverse and difficult to assess.

FUTURE MACHINE-TOOL REQUIREMENTS

The analysis of the machine-tool market until 1975 was carried out at the level of three large groups which show appreciable individual differences in the nature of the factors determining demand as well as in the characteristics of the required machines. These three groups were production machines, maintenance machines and replacement. In each group, the point of reference was the number and characteristics of machine tools on hand at the end of 1963. This had to be determined by special surveys at the national level: in the metal-transforming industries, the principal consumers of production machines, and in the remaining manufacturing activities, public services, the fiscal sector and various other activities with respect to maintenance machines.

It was established that in 1963 the national machine-tool sector accounted for 201,700 units, of which 173,100 were in production work and 28,600 in mechanical maintenance and services. The production machine figures reveal an industrial structure in which small- and medium-size establishments predominate and, in consequence, they have small production series. This is corroborated by the high proportion of lathes, drills, shapers and saws, on the one hand, and the relatively low incidence of milling machines, grinding machines and tool grinders on the other. Likewise, it is shown that the machines are relatively new, since units less than ten years old are nearly 55 per cent of the total.

Maintenance machines, as was to be expected, show a high incidence of simple and universal units and a heavy predominance of machines more than ten years old which represent more than 65 per cent of the total.

Requirements of production machine tools were arrived at by a projection to 1975 of the value of the mechanical production as well as the personnel, translating the values in terms of machine tools. In this way, it was estimated that in 1975 the sector would total some 280,700 units, i.e., 74 per cent higher than in 1961, showing an average annual growth rate of 4.5 per cent as against the 5 per cent established for gross domestic product and 7 per cent for the metal-transforming industries.

In regard to maintenance machines, the first approximation was that the inventory would maintain the same proportion during this period in respect to the production inventory, raising the number of units in operation to 46,700 in 1975. Thus, the 1975 total for the inventory would reach 327,400 machine tools and the requirements would be some 125,700 units from 1964 to 1975, both years inclusive. The distribution would be 107,600 machines for production and 18,100 for services and maintenance.

Regarding replacement needs of the inventory, it has been conservatively estimated that only 20 per cent, some 15,600 of the 1963 machines more than ten years old, would be substituted by 1975.

In accordance with these predictions, it is concluded that the total machine-tool demand in the twelve-year period from 1964 to 1975 would reach 141,300 units, 76 per cent of which would arise from the metal-transforming industries, 13 per cent from the maintenance sector, and 11 per cent in replacements, the final percentage corresponding almost entirely to the metal-transforming industry.

The machine-tool industry at present

In order to obtain a more complete background of machine-tool manufacture, a survey of the country's manufacturers was undertaken by means of a personal visit to each establishment. As in other Latin American countries, this activity emerged in Argentina as a result of importation difficulties caused by the Second World War and showed a great expansion during the 1950's, achieving an annual production of almost 10,000 units. Later, and particularly until 1963, an appreciable reduction in manufacturing is evident as a consequence of the contraction of the domestic market. In that year, the activity had declined to where it was represented by 86 manufacturers employing 1,700 persons, with a production of some 5,000 units weighing 5,000 tons.

This activity is located near the most dynamic industrial development centres of the country, which is the reason why nearly 70 per cent are found in the federal capital and the Province of Buenos Aires, the remainder being found in the Provinces of Santa Fé and Córdoba.

During the survey it was possible to prove that not all the enterprises were dedicated exclusively to the manufacture of machine tools and that several maintained other lines of mechanical production. Similarly, it was also proved that the manufacturers preferred to multiply their machine-tool production lines, building several different machines instead of exploiting the numerous variants which exist for a certain type and model of machine. Nevertheless, a certain tendency toward specialization can be seen: in metal-forming machines, for example, there exists a high percentage of enterprises whose production is restricted to machine tools and, within the sector as a whole, nearly 65 per cent of the establishments are dedicated exclusively to the manufacture of only one line of machines. In addition, approximately 55 per cent of the manufacturers contribute no less than 75 per cent of their annual output to the sector.

As to distribution by size of establishment, nearly 91 per cent have less than fifty employees and only three enterprises maintain a staff of more than 100, which is indicative of a structure little suited for the future development which this sector must confront in view of the general rise in demand for more complex machines. In this sense, this distribution would correspond rather to semi-artisan production than to an industry already established or in a growing stage.

The machine-tool inventory in the hands of manufacturers is about 2,000 units. It is relatively new, since 70 per cent of the machines are less than ten years old, and, taken together, offer a favourable composition with an adequate proportion of boring, gear and grinding machines and tool grinders. This situation, nevertheless, is strongly influenced by the larger firms which are equipped with complete assortments of efficient and good quality machines which enable them to manufacture more complex products.

The small enterprises do not have a very complete inventory and subcontract specialized machining services, with the aggravating factor of lacking adequate means for quality control of products farmed out.

During the visits, it was also evident in almost all cases that the good quality of the labour force, often of very limited resources, overcame to a fair extent some of the machining complexities.

Production figures which were possible to reconstruct since 1957 reveal that at that time the national industry had already achieved a significant manufacturing volume, showing a slight tendency toward growth until 1961 when it registered production of 11,492 machines weighing 10,537 tons. Since then, owing to the deterioration of the country's general economic conditions, production fell violently, and in 1963 only 4,767 machines weighing 4,714 tons were manufactured. The cumulative total during this period exceeded 64,000 units weighing more than 55,000 tons. This effort has been a determining factor accounting for the national inventory's maintaining 55 per cent of the machines of less than ten years of age in the metal-working industries.

The products which the industry put on the market have filled an important role in meeting domestic demand, especially in respect of simple and light machines with limited resources and of low unit price. Nevertheless, it should be pointed out that during the passage of these years a certain number of machine tools have made important progress and today show high quality and technological standards, which place them in a very favourable position regarding domestic demand as well as for entry into international markets.

It is interesting to note that during this lapse of time national production displayed activity and speed enough to attend to the most elemental requirements of the market. The average unit weight of machines showed a 32 per cent increase in the metal-cutting category, reaching an average of 644 kilogrammes per machine in 1963. Metal-forming machines have maintained an average unit weight of slightly more than three tons. Similarly, it is possible to see in the composition of manufactured machines a certain trend that is in agreement with expectations for the structure of the future machine-tool inventory: relatively lower production of lathes, drilling machines and shapers, and higher production of milling, boring, threading, grinding and metal-forming machines. Although just beginning, this tendency should increase over the next few years and it is now the task of the sector to consolidate its position by means of more developed machines. This is necessary because staying in the present production line would seriously affect its taking part in meeting domestic demand which, according to predictions, will become steadily more difficult in terms of the complexity and quality of machines.

In regard to the prices of national machines, it is difficult to establish the true level for the various manufactured products in the year of the survey and arrive at any opinions in respect to their competitive position in the international market, even though this by itself is not the decisive reason for determining export possibilities for this type of product. Nevertheless, exports registered in 1962 and particularly in 1963 appear to indicate that the price levels at those times were acceptable in certain foreign markets.

Possibilities of the national industry in the future machine-tool market

In broad terms, it can be said that local machine-tool manufacture contributed almost 85 per cent of the number of machines which were incorporated into inventory in the ten-year period of 1954 to 1963. Regarding weight, the national share fell to 59 per cent and even more if the value is taken into consideration. This came to only 45 per cent. These figures sum up clearly the role which national industry has played in supplying the market and at the same time reveals in a general way a difficulty in keeping up with the increasing technological requirements of demand, national as well as export. It is then evident that the future possibilities of the industry will be closely linked to the changes which must take place in its productive structure and technical potential. These aspects, although not the only ones, acquire especial importance in this stage of the industry's development. An analysis in this sense, based exclusively on past experience of its evolutionary process, would at this time be totally unrealistic. The most determinant aspects for the development of the sector are principally related to perfecting the machines now being manufactured and starting to make new types of machines. For this, it will be necessary to face a reorganization of the small industries, raise the technological level, establish adequate lines of credit and financing and, finally, create an Argentine Machine-Tool Institute which, among other functions, would give drive to and support the development of the activity.

The recommendations and the specific manufacturing programme which have been outlined would not in themselves constitute too ambitious a goal or a task too difficult to accomplish if viewed from the standpoint of time and the number of enterprises which could participate. These, including enterprises now in operation, plus others which will eventually join them, come to around 120 firms. The programme certainly implies important technical responsibilities which in order to be achieved will require great effort on the part of the manufacturers, a fact which could be interpreted as an obstacle to success. Nevertheless, if one takes into account the level reached by national industry, the productive elements with which it is equipped and the quality of workmanship employed and which can be made available, the technical aspect is not to be considered as a limiting or unsalvageable factor. This is especially true when one considers that the possibilities of success will to a great extent depend on the facilities accorded to the sector and the adoption of a stable and well defined promotion policy on the part of the government agencies and, also, on the measures taken within the sector itself to adapt its productive structure to the conditions demanded by the programme.

Once the recommendations and the programme outlined have been carried out (which in practice correspond to increasing the unit weight of the machines and their average value per kilogramme), it is expected that local industry will be able to increase its share of consumption to 65 per cent in weight and 56 per cent in value, its percentage contribution remaining more or less constant in relation to the number of machines. It is also considered that improvement in future production along the lines pointed out would place the industry in an even more favourable export position than that seen until now, and it is foreseen that in the first period to 1970 there will be exports of some 2,000 tons annually, which will rise to about 4,000 tons by 1975. In this way, national production in 1970 should reach 13,500 tons and, in 1975, 22,000 tons. That is, 28 and 110 per cent higher, respectively, than the highest figure achieved in 1961.

To accomplish these goals, the personnel required should rise to 6,900 persons in 1975, that is, almost four times higher than the 1963 work force. A great deal of this increase corresponds to the greater need of indirect personnel to achieve higher productivity, the construction of new models, improving average quality and the manufacture of more technically complex machines. The investment required should come to about $14,350,000, principally for the construction of prototypes of new machine models and for the acquisition of machine tools, both imported and national, to complement the manufacturers' present inventory.

Finally, there is the fundamental role which should be played in the execution of the programme and future development of this activity by an Argentine Machine-Tool Institute dedicated to the study and research of techniques related to the construction and functioning of machine tools. Getting this institute started would bring important benefits to the makers as well as to the users of the machines. For the former, it would help in meeting technical manufacturing requirements and, for the latter, the quality tests carried out by the institute would constitute a guarantee for manufacturing and bring more prestige to products for either the domestic or export market. Aside from the mainly technical functions which would be carried out by the institute, it is also thought that it should actively participate in the orientation of the development of this activity, advising the competent agencies regarding credit which should be given to manufacturers for the acquisition of machinery and production equipment as well as for the study and building of prototypes.

In view of the range of the programme, as well as the effort that must be exerted in order to achieve the goals it contemplates, it is necessary as soon as possible to adopt the measures outlined so that this activity may have an evolution which accompanies and, in a sense, anticipates the needs which will stem from the development of the country's metal-working industries.

THE MANUFACTURE OF MACHINE TOOLS IN BRAZIL

Secretariat of the United Nations Economic Commission for Latin America

INTRODUCTION

The importance of expanding production of capital goods at the present stage of Latin America's economic development, when the capacity to import is severely limited and a high rate of investment must be maintained, is generally recognized. The machine-tool industry has a key role to play in this expansion, since there is no branch of manufacture either of machinery and equipment or of durable consumer goods in which a high proportion of machines for metalworking is not used. Thus, the contribution to the economic development of Brazil made by the industry discussed in this report is of more vital significance than could be deduced from the number of enterprises or the labour employed in the sector.

There is a close connexion between a country's degree of industrial development and the technical and economic structure of the machine-tool industry. In this respect, Brazil is at a transitional stage.

The structure of the Brazilian machine-tool industry today is consonant with the country's requirements up to the present time, predominant among which have been machinery and equipment for maintenance and lines of manufacture which do not call for great precision or long production series. But as a result of Brazil's recent industrial development, there are signs of increasing demand for the more complex and heavier machinery used in more highly specialized branches of manufacture. To meet such requirements, the machine-tool industry will be obliged to supply the market with different products and in order to manufacture these it will have to introduce radical changes both in its technical and economic structure and in its methods of work. It would therefore seem that the industry has reached a decisive phase in its evolution, and needs overhauling and modernization so that it can continue to expand in the forthcoming decade.

However, in view of operating conditions in the industry, it is unlikely that these changes will come about of their own accord in response to the stimulus of market demand. The small- and medium-scale entrepreneurs of whom the industry is chiefly comprised have not sufficient knowledge of the market as a whole, or, more important still, can they foresee the direction in which this market will develop and the new types and models of machinery that will be required by the metal-transforming industry during the next few years. To present a qualitative and quantitative appraisal of the market up to 1971, that is, to define the framework into which the Brazilian machine-tool industry will have to fit during the next stage of its development, is the primary purpose of this report.

Detailed knowledge of the probable future market is an essential prerequisite, but not the only one for the introduction of structural changes in the industry. The latter's possibilities of spontaneous development are restricted by this small size and the difficulties which an incipient industry is likely to encounter in absorbing the know-how available in the more advanced countries.

Clearly, then, deliberate steps must be taken to create institutional conditions which will bring about the necessary transition towards a more balanced industrial structure and greater technical efficiency. These conditions should be conducive, in the first place, to the development of new industrial undertakings in the sector and the consolidation of those already in existence, through agreements on royalties in respect to technical assistance and the manufacture of new models. Secondly, they should be such as to encourage the creation, possibly through a specialized institution, of national technical assistance facilities chiefly designed to help small- and medium-scale establishments in their efforts to modernize, expand and improve technical plant and manufacturing activities.

Another purpose of this study is to indicate current conditions in the industry and the direction in which changes should take place, as well as to suggest basic lines of approach to the establishment of a national institution to provide technical assistance for the machine-tool industry.

Thus, the study covers two aspects of the background material on which development programming for the Brazilian machine-tool industry must be based: a quantitative and qualitative evaluation of the market in the next decade, and an analysis of operational conditions in the industry as it exists in Brazil, with an indication of the changes required.

METHODS OF RESEARCH AND SUMMARY OF MAIN CONCLUSIONS

The term machine tools, in its widest sense, is applied to a group of machines used for cutting, forming, grinding and polishing metals, wood and other materials, and usually classified in two major categories: chip producing (lathes, milling machines, drills, boring machines etc.) and non-chip producing (presses, forge hammers, bending, cutting and forming machines etc.). Those in the second category are also frequently referred to by the general name of forming machines. The definition of machine tools, however, varies from one country to another, so that in practice there is no standard interpretation of the term indicating which machines it should be taken to cover.[1] For this study, machines used for metalworking, whether in cutting or forming operations, are regarded as machine tools.

Given the objectives and scope of the study, intensive field work was required in order to collect the basic data needed for knowledge and analysis of demand for machine tools and domestic production. The study was prepared in close co-operation with the executive board of the Heavy Metal Transforming Industry (GEIMAPE), the Machine Industry Syndicate of the State of São Paulo (SIMESP) and the Brazilian Association for the Development of Basic Industries (ABDIB) which provided the facilities, and with two engineers from GEIMAPE and SIMESP.

This study is the first of its kind in Brazil on machine tools, a sector in which there are many complex problems. It must therefore be regarded as provisional in some respects and subject to reservation. Certain situations, such as those relating to future demand for machine tools or to the average weight of the domestically produced or imported machines which will form the country's inventory in the future, can be evaluated only on the basis of assumptions which, while established on logical grounds and supported by the experience of other countries, are not guarantees. In this connexion, the field of machine tools is particularly complex, and does not seem to be governed by laws or criteria that can be universally applied or extended from one area to another.

A primary concern of this paper is the study of the machine-tool industry's actual construction of machines; complementary industries, such as accessories and spare parts, are not included. Similarly, owing to lack of time and resources for research, no attempt has been made to deal with production of the corresponding tools. These aspects are closely linked to the machine-tool sector and undoubtedly should be tackled in future studies.

Machine-tool requirements

In order to establish machine-tool requirements for the next ten years, consideration was given to the needs deriving from the country's industrial development and to machines for replacement purposes. The basis for estimating the former was Brazil's total stock of machine tools in 1960, which had to be determined by a survey. The inventory was taken in the metal-transforming industries,[2] the loading consumers of the machines, in the State of São Paulo, where almost 70 per cent of these industries' labour force is employed. By extrapolation, this result was extended to the rest of the country, and the machine tools used for maintenance work in other sectors (for example, the textile, food processing, chemicals and rubber industries) were added, for which an estimate was prepared on the basis of the experience recorded in other countries.

[1] In the United States, for example, the term relates only to metal-cutting machines, while in France both cutting and forming machines, for working both metal and wood, are comprised under the heading of *machine-outil*.

[2] Manufacture of metal products; machine industry, excluding the manufacture of electrical apparatus; manufacture of electrical and communications material and transport material industry.

It was determined that the national inventory of machine tools in 1960 was 205,654 units. This inventory displays two interesting characteristics. In the first place, the high proportion of simple universal machines would seem to indicate a typical industrial structure in which activities with low volumes of output predominate; in the second place, it is a fairly new collection of machines in which those under ten years old represent 55 per cent of the total; only 24 per cent are over twenty years old.

From study of each of the various branches comprised by the metal-transforming industries, an estimate of individual machine-tool requirements up to 1971 was calculated on the basis both of growth trends in the past and of projects for developing new activities in the sector and demand prospects in respect to the final goods. Thus, with the inclusion of an estimate of machines for maintenance, it was computed that by 1971 the country's inventory of machine tools would total 369,146 units, i.e., it would exceed the 1960 figure by 80 per cent. This would imply an average annual growth rate of 5.5 per cent, which compares reasonably well with the growth prospects established for the gross domestic product (5.7 per cent a year) and for the metal-transforming industries (10.2 per cent).

In estimating the number of machines for replacement purposes,[3] a conservative assumption was adopted, to the effect that a third of the machines which were over twenty years old in 1960, i.e. 8 per cent of the 1960 inventory, would be replaced in 1971.

By this method, demand for machine tools from 1961 onwards was established at 179,947 units, and after subtraction of the machines incorporated into the inventory in that year the conclusion was reached that requirements for 1962–71 would be 158,826 machine tools.

The existing machine-tool industry

Concurrently with the inventory of existing machines, a survey of the domestic machine-tool industry was carried out. This activity, which started in Brazil during the Second World War in response to the need to supply those internal requirements which were seriously affected by import difficulties, has made striking progress in the past twenty years and especially since 1956. At present, it constitutes an industrial complex of 114 establishments employing about 5,000 persons and producing an annual output of more than 13,000 tons.

Of those establishments, 88.8 per cent are in the State of São Paulo, which clearly indicates that this activity has been linked very closely to the expansion of the metal-transforming industries.

Not all the enterprises are engaged exclusively in manufacturing machine tools; it is common to find them undertaking other lines of metal-transforming production. According to the survey, the proportion of the establishments which manufacture items other than machine tools ranges from 46.5 to 100 per cent, according to the kind of machine. In terms of trade activity, the

[3] The term replacement here relates to the final scrapping of a machine because it is no longer fit to perform any operation, so that the figures indicated represent net substitution requirements.

machine-tool industry's share in the annual invoicing of 62.5 per cent of the enterprises is not less than 75 per cent.

A point worth mentioning related to the breakdown of this group of establishments by size. Three fourths of the enterprises manufacturing machine tools employ fewer than 50 persons, only 7.8 per cent employ between 100 and 500, and only one employs more than 1,000. Such a structure is patently not the most appropriate for coping with larger manufacturing tonnages and with the demands in respect to quality and the range of types which the consumer industries will make the next few years. Consequently, the evolution of this structure towards a breakdown by size which is better adapted to future demand conditions will be one of the essential elements in the development of the industry if it is to secure a larger share in satisfying consumption in Brazil.

The manufacturing enterprises have an inventory of 2,527 machine tools at their disposal. In this connexion, it is of interest to point out that the eight establishments which employ more than 100 persons, 8.9 per cent of the total, own nearly 30 per cent of these machines. This group possesses complete, efficient and up-to-date production equipment, and at the same time the technical knowledge required for the proper use of the machines; and its projects and manufacturing lines keep pace with domestic market requirements and with the constant technological advances in the sector. In marked contrast with the situation of this group is that of the small enterprises whose manufacturing equipment is too light and too incomplete to be satisfactory, while at the same time indirect technical services are neglected.

Market requirements, however, differ sharply in relation to quality, types and prices according to whether the machines are for use in the technically more advanced industries or in the small- and medium-scale establishments whose level of technological development is lower and whose capital resources are very limited. As the national inventory of machine tools grows and with it the demand made in relation to quality, variety and low costs, production technology will be forced to develop, and some of the small- and medium-scale manufacturers will also have to take part in this process.

In relation to volumes of manufacturing output, the data and information afford clear evidence of the colossal effort made by the manufacturers of machine tools since 1956. In fact, in only six years the number of tons produced annually increased by 260 per cent, reaching in the course of that period cumulative figures exceeding 60,000 tons, the equivalent of more than 62,000 machines. In 1961 the industry managed to produce 15,517 units, with a weight of 13,250 tons. This substantial increase in domestic production finds justification in the powerful upswing of demand registered between 1956 and 1961 as a result of the establishment of the motor vehicle industry and the expansion of the various branches of the metal-transforming sector.

Today, the industry offers the market fifty-two types of machine tools in about 150 leading models, which represents a fairly satisfactory situation. Nevertheless, production is not altogether commensurate with the numerical size of the national inventory and its range of types and models; and some machines are poor quality. This is another aspect of development to which the sector will have to devote attention: the task of improving machine quality and gradually increasing the number of models and types in order to maintain some degree of balance between evolution of the inventory and domestic supplies of basic types.

From 1955 onwards, a gradual decrease in the average weight of the machines manufactured (from 1,136 to 854 kg) is observable in this sector, chiefly owing to reductions in the metal-cutting machines which dropped from 960 to 650 kg. Forming machines stood at an average of 1,800 kg. It must be stressed, however, that this decline in unit weight does not mean that the weight of the traditionally heavier types of machines has been reduced, but is attributable to the fact that in the last few years new models have been put out in smaller sizes while at the same time construction of light machines has been intensified to meet the demand deriving from the manufacture of light articles, as well as from the emergence of small establishments. The perfecting of these machines and the incorporation of new types which are missing from the lines of manufacture will be bound to entail a rise in the average weight of domestic products. In this connexion, those machines which show development in respect to models and an increase in weight have secured a larger share percentage in the supply of the market, especially as to lathes, saws, milling machines and presses.

Price levels, broadly speaking, fluctuate around an average of $2 per kilogramme, which may be considered satisfactory. Furthermore, since the export of certain types of lathes and presses has been taking place for several years and interest in purchasing Brazilian machine tools exists in some of the Latin American countries, it would seem that their prices are acceptable.

Prospects for the domestic industry, 1962–71

The interval between 1955 and 1961 was characterized by an exceptional increase in domestic consumption, attributable to the causes just indicated, which was reflected in the installation in Brazil of 158,719 tons of machine tools, equivalent to some 101,700 units, the Brazilian inventory being almost doubled during that period. The domestic industry was not dissociated from this trend, and developed during the years in question at a cumulative annual rate of about 14.7 per cent (in terms of weight), expanding from 5,085.6 tons in 1955 to 13,249.9 tons in 1961. This meant that on an average approximately 40 per cent of consumption in the period referred to was satisfied by means of domestically produced machines, the proportion varying between a maximum of 54 per cent and a minimum of 25 per cent in consequence of marked changes in imports.

However, as already pointed out, this industry's contribution to the inventory consisted of simple, light-weight machines, and both in its structure and in its technical potential it displayed certain deficiencies which assume decided importance in relation to the analysis of future possibilities. If no attention is paid to these technical shortcomings, which must necessarily be remedied if the industry is to develop, a mere study of its evolution in the light of statistical data would be divorced from reality.

On the assumption that the machine-tool industry: (*a*) will develop structurally in such a way that by the end of the period under study from 15 to 20 per cent of its establishments will be employing between 100 and 500 persons; (*b*) will increase and supplement its existing stock of machines; (*c*) will improve upon some of the machines currently manufactured; (*d*) will start production of forty-one new models of machines for chip producing operations; and (*e*) will raise the unit weight by about 300 kg in relation to 1961, the conclusion may be reached that in 1966–71 it will be able to supply about 65 per cent of the domestic market, in terms of weight, and will be in a position to export a substantial proportion of its output. In such circumstances, a volume of production amounting to about 20,000 tons, i.e. 50 per cent more than in 1961, might be expected in 1971; this would cover approximately 70 per cent of consumption, leaving an exportable surplus of about 10 per cent.

To attain these goals, as regards the increase in the volume of production and improved quality and the incorporation of new machine types, machinery that can meet the technical demands involved will have to be available. Success will therefore also depend in part upon the incentives and facilities with which government agencies are able to provide this sector. A rough estimate of the investment which such a programme would entail, solely in relation to the machines that would have to be imported, gives a figure close to $6 million which might be subject to modification according to the quality of the machine tools to be constructed.

To enable the industry to solve the financial problems which the foregoing programme implies, the following would have to be available:

(*a*) Long-term financing for the purchase of heavy machines, all of which would be imported:

(*b*) Medium- and short-term financing for the purchase of lighter machines, most of which would also be of foreign origin;

(*c*) Financing for studies and construction of prototypes of new machine tools.

Given the many complex problems involved in the future development of this industry, structurally and technically, problems whose solution will have to be sought by programmed and co-ordinated effort, it is of fundamental importance that there should be an agency in Brazil which would guide and direct the development of the industry, at the same time rendering the necessary technical assistance, so as to channel it properly into suitable lines of manufacture and enable it to play its role in Brazil's industrialization process as efficiently as possible.

Production of machine tools

The manufacture of machine tools in general began in Brazil during the Second World War. At that time, the difficulties of importing constituted a powerful incentive to the recrudescence of various undertakings in this sector and the emergence of new enterprises, whereby the most urgent requirements could be met, particularly in respect to machines for maintenance purposes.

The war once over, however, with the lifting of import restrictions, and in the face of certain instability of demand for domestically produced machine tools, some industries which a state of emergency and a series of noteworthy efforts had called into being no longer found sufficient inducement to continue in the same branch of manufacture, and changed over to other activities. On the other hand, the metal-transforming industries were progressively consolidated and strengthened until by 1950 an embryo market had been created which held out prospects of significant development. It was thus that machine tools, which until then had been associated mainly with maintenance operations, began to assume importance in the manufacturing process. Interest in local production of machine tools was thus reawakened, so that by 1955 domestic output had exceeded 5,000 tons.

The subsequent establishment of the Executive Group of the Motor Vehicle Industry (GEIA), with the ensuing application of its plans and its dynamic effects on other sectors, should be regarded as the true prelude to the consolidation of a large, up-to-date and diversified machine-tool market such as is in Brazil today: in the seven years preceding 1961, the domestic market absorbed from 90,000 to 100,000 machines.

This new incentive gave rise to new undertakings in addition to those which since the Second World War had successfully withstood critical periods and continued to supply the domestic market. At present, the machine-tool industry comprises about 114 establishments, employs nearly 5,000 persons and produces an annual output which has exceeded 13,000 tons, with an approximate value of $26 million.

The production survey

Owing to the lack of adequate statistical data on the manufacture of machine tools, a survey had to be carried out among the manufacturers operating in Brazil, the number of enterprises totalling, as far as could be ascertained, 114 establishments. This survey was carried out by visits to the factories, and specially prepared questionnaires were used whereby general data could be obtained on the industrial establishments and on the machines in use, as well as on the quantities of each type manufactured since 1955 (in terms of units and of weight), the main characteristics of the machines manufactured, and the entrepreneurs' plans for the future.

Out of the 114 establishments, 104 were classified, including five which in 1961 were perfecting prototypes of machine tools to be put on the market in 1962. The establishments analysed are those in which production of machine tools is either the sole activity or supplementary to other lines of manufacture; excluded are a few of an artisan nature which only occasionally produce a short series of machines, usually of a simple type, for consumers making no great demands for quality and precision. Among those covered by the survey are nine whose activity in this branch of industry represents less than 5 per cent of the value of total sales, and which were excluded from some comparisons.

Thus, the considerations formulated below relate to ninety manufacturers, in regard to geographical distribution and number of machines in use; to ninety-nine where manufacturing data are concerned; and to 104 in respect to the types of machines currently produced.

The domestic machine-tool industry

General characteristics

Location. The data clearly show that the choice of sites for the industrial establishments manufacturing machine tools was closely associated with the expansion of the metal-transforming industries. The State of São Paulo is where 88.8 per cent of these establishments are situated, while the same state absorbs 72 per cent of the domestic labour force in the metal-transforming sectors (see table 1).

Table 1

GEOGRAPHICAL DISTRIBUTION OF ESTABLISHMENTS MANUFACTURING MACHINE TOOLS, 1961

State	Persons employed: Number	Persons employed: Percentage of total	Industrial establishments: Number	Industrial establishments: Percentage of total
São Paulo	4,527	94.7	80	88.8
Rio Grande do Sul	176	3.7	6	6.6
Santa Catarina	40	0.8	2	2.3
Guanabara	37	0.8	2	2.3
Total	4,780	100.0	90	100.0

Within the State of São Paulo, the greatest concentration of machine-tool manufacturers is observable in the state capital itself and in the municipalities of Santo André, São Bernardo do Campo and São Caetano do Sul (ABC), where the proportion is 83.7 per cent, with 67 establishments. In the interior of the state, the factories are mainly along the Jundiaí-São Carlos line, and it is in this area that the highest production capacity per establishment is registered. These enterprises number thirteen and employ 2,437 persons in all, i.e. 51 per cent of the total for the country. Communications between this area and the leading consumer centres are good, and transport of the heavy tonnages produced presents no difficulties.

The plants in the capital and in the ABC area employ 2,090 persons, 43.7 per cent of the total for Brazil, in sixty-seven establishments which are a good deal smaller than those in the interior. From the point of view of expansion, the location of some of these implies serious drawbacks in space both for increasing current production lines and for manufacturing heavier machinery, since adjacent lots are not available and, even if they were, anti-economic investment would be entailed. Decentralization of these establishments in the direction of the outskirts of Greater São Paulo should therefore be contemplated for more efficient organization and layout. This does not apply to the firms in the interior of the state, which, from the point of view of the space for future expansion, are in a more privileged position.

In the south of Brazil, the manufacturers of machine tools in Rio Grande do Sul and Santa Catarina have so far supplied most of the requirements of the local market which, together with that of São Paulo, ranks as the oldest in the country.

The participation of the south of Brazil which at present is modest, since the area accounts for only 8.9 per cent of the total establishments and 4.5 per cent of the total personnel, will increase in the course of the next few years through the operation of various favourable factors which are beginning to make their influence felt. These include the quality of the labour, whose efficiency and low turnover play an important part; the development of local industries; the ease with which technical and commercial contacts with the State of São Paulo can be maintained; and the improvement of communications between the south and the other consumer centres. To judge from the new projects under way and the prototypes already tried out, a dynamic spirit prevails, especially in the Porto Alegre area. As in other countries that have had to tackle the same problems in the past, the decentralization of this branch of the metal-transforming industry is generally a factor making for progress and encouragement.

The factories in areas other than those mentioned concentrate on specialized lines of production or supply the local market.

To sum up, the principal areas in Brazil in which this sector is significant are three: the first is along the Jundiaí-São Carlos line in the State of São Paulo; the second is the state capital and the ABC area; and the third is that part of the Porto Alegre district which falls within a radius of 200 km from the capital.

Structure. Not all the establishments manufacturing machine tools devote their entire efforts to this activity, and other products of the metal-transforming industries appear in their manufacturing programmes in varying proportions. One reason for this is that most of the enterprises first became interested in the production of machine tools when they had already developed a certain tradition in other metal-transforming sectors which they did not wish to abandon; and another is that in some cases the consumers of these machines have themselves begun taking steps to produce them, as is not surprising in view of the rapidity with which the machine-tool sector has increased in recent years. This last category includes five enterprises covered by the survey which in 1961 were engaged in perfecting machine-tool prototypes to be put on the market in 1962.

This situation is clearly reflected in table 2, which presents a breakdown of establishments by their extra- and intra-sectoral activities and by types of machines. It reveals how high a proportion of the establishments classified as manufacturing machine tools maintain other lines of production: from 46.5 to 100 per cent, according to the type of machine concerned. In the table, references to lines of manufacture within the sector relate to different categories of machines, not to the machine

Table 2

ORGANIZATION OF PRODUCTION OF MACHINE TOOLS, 1961

Type of machine	Number of establishments	Production		Breakdown of establishments by activities				
		Tons	Units	One line of manufacture within the sector	Two lines of manufacture within the sector	More than two lines of manufacture within the sector	One or more lines of manufacture outside the sector	Works include foundry
Lathes	24	5,265.0	4,638	16	4	4	16	4
Milling machines	14	289.8	278	7	3	4	9	4
Drilling machines	17	794.9	5,311	5	5	7	13	7
Shapers and planers	18	1,369.4	937	11	4	3	10	7
Threading machines	3	35.0	53	1	—	2	3	—
Cutting machines (saws)	12	342.4	1,296	7	3	2	8	4
Grinding machines	4	57.1	79	2	1	1	3	—
Tool-grinding machines	4	69.3	101	1	1	2	3	—
Presses	22	3,890.0	2,139	15	5	2	12	5
Pneumatic hammers	1	24.8	7	1	—	—	1	—
Machines for sheet	15	1,071.2	667	6	6	3	7	3

specified; in other words, if four of the establishments manufacturing shapers and planers are said to maintain two lines of production, this must be taken to mean that they produce another type of machine tool alongside shapers and planers, rather than that they make two models of the latter. It may also be seen from the table that seventy-two of the ninety-two firms manufacture a single type of machine tool, while the remaining twenty-seven maintain two or more lines of production within this sector.

Of the ninety-nine industrial establishments considered, 62.5 per cent accounted for no less than 75 per cent of this activity's trade transactions; the remaining 37.5 per cent contributed smaller proportions (see table 3).

Table 3

BREAKDOWN OF INDUSTRIAL ESTABLISHMENTS BY PERCENTAGE OF ACTIVITY DEVOTED TO MACHINE TOOLS, MEASURED IN TERMS OF ANNUAL SALES TURNOVER, 1961

Industrial establishments		Manufacture of machine tools (Percentages)
Number	Percentage	
62	62.5	75-100
14	14.2	50-74
8	8.1	25-49
6	6.1	5-24
9	9.1	under 5
99	100.0	

The distribution of these establishments by size constitutes another interesting feature of the activity under consideration. The figures given in table 4 relate to the number of persons employed in the manufacture of machine tools and therefore exclude personnel employed in the manufacture of other products within the same enterprise.

Table 4

BREAKDOWN OF ESTABLISHMENTS MANUFACTURING MACHINE TOOLS, BY SIZE,[a] 1961

Size of establishments (Number of persons employed)	Number of establishments	Percentage	Number of persons employed	Percentage
More than 1,000	1	1.1	1,290	27.0
500-999	—	—	—	—
250-499	1	1.1	402	8.4
100-249	6	6.7	954	20.0
50-99	14	15.6	976	20.4
25-49	18	20.0	580	12.1
10-24	30	33.3	459	9.6
Fewer than 9	20	22.2	119	2.5
Total	90	100.0	4,780	100.0

[a] Excluding nine enterprises whose production of machine tools represents less than 5 per cent of their annual sales turnover. Data as of 31 December 1961.

A comparison between Brazil and other countries in respect to the breakdown of establishments by size reveals the trend of this sector's evolution as a consequence of the increase in the tonnage produced, especially where the smaller establishments are concerned (figure 1, table 5).

Experience shows that a high level of productive efficiency in this sector is beginning to be obtained in factories employing 100 persons or more, where the products manufactured have a certain degree of complexity and a high standard of quality. This would seem to be the case in France, the United Kingdom and the United States, where between 20 and 30 per cent of the factories fall within the 100-500 size range. These percentages apparently remain stable, in association with outputs of about 40,000 to 50,000 tons and more.

The structure of the machine-tool industry in Brazil, where only 7.8 per cent of the establishments under consideration fall within the size range indicated, will have to develop along new lines if output tonnages are to be higher than at present and the demands of the consumer industries with respect to quality and diversity of types

Table 5

BRAZIL AND SELECTED COUNTRIES: PERCENTAGE DISTRIBUTION OF ESTABLISHMENTS MANUFACTURING MACHINE TOOLS

Size of establishments (number of persons employed)	Brazil		France		United States		United Kingdom		
	Number of establishments	Percentage	Number of establishments	Percentage	Number of establishments	Percentage	Size	Number of establishments	Percentage
0–49	68	75.5	60	50.0	431	57.9	0–49	104	46.4
50–99	14	15.6	30	25.0	95	12.8	50–99	38	17.0
100–249	6	6.7	16	13.4	106	14.2	100–299	55	24.6
250–499	1	1.1	8	6.6	53	7.1	300–499	13	5.8
500–999	—	—	6	5.0	34	4.6	500–749	3	1.3
1,000–2,499	1	1.1			20	2.7	750 or more	11	4.9
2,500 or more	—	—	—		5	0.7			
Total	90	100.0	120	100.0	744	100.0		224	100.0

Sources: For Brazil: findings of the 1961 survey; for France, 1949: *Mission aux Etats-Unis de l'industrie de la machine-outil*, November 1949–January 1950; for the United States: *Census of Manufactures 1947*; for the United Kingdom, 1947: A. Garanger, *op. cit.*

are to be met. According to the projections formulated in the present study, Brazil should produce a yearly output of about 20,000 tons by 1970–71, and should therefore aim at remodelling the size structure of the industry so that it more closely approaches that found in the more highly industrialized countries. At this stage, it might be considered that satisfactory progress had been made if by the time the above-mentioned level of production had been reached, about 15 to 20 per cent of the establishments employed more than the minimum of 100 persons, with an average of 200 persons per establishment.

General data for the sector. To give an over-all idea of the sector's production potential, some of the most characteristic data relating to the industrial establishments concerned are:

Number of persons employed[4]	4,780	
Installed capacity	12,571	h.p.
Value of production, 1961	26.5	$ million
Annual *per capita* production	5,544	dollars
Per capita capacity available	2.63	h.p.
Number of persons employed per establishment	53.1	
Installed capacity per establishment	139.7	h.p.
Value of production per establishment	294,000	dollars

[4] Including operatives and technical and administrative personnel.

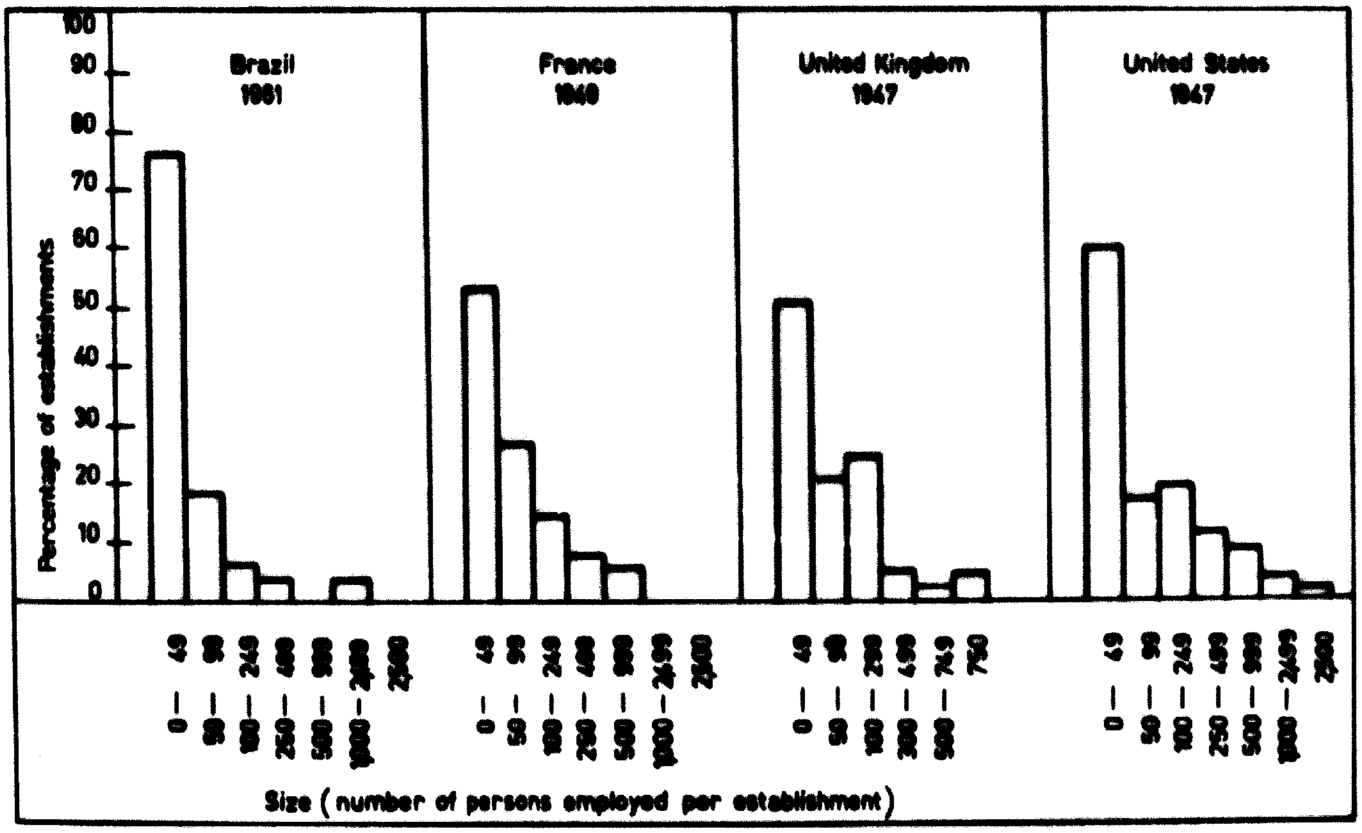


Figure 1

PERCENTAGE BREAKDOWN OF ESTABLISHMENTS MANUFACTURING MACHINE TOOLS IN BRAZIL AND SELECTED COUNTRIES AT A MORE ADVANCED STAGE OF INDUSTRIAL DEVELOPMENT

Prices per kilogramme vary a good deal in the case of domestically manufactured machines, partly because of the different types produced and partly because of the divergent sales methods adopted (through distributors, directly to the consumer, for cash down or on deferred payment terms). Moreover, the continual fluctuations in internal prices and the time lag before exchange rates are brought up to date cause sharp variations in the cruzeiro/dollar relationship. Thus, in order to estimate the value of domestic production, an average price of $2 per kg was adopted.

In view of the heterogeneous sizes of the industrial establishments in this sector, a few remarks must be made on the average values per establishment, since there is one group of enterprises whose size, organization, efficiency and technical level put a considerable distance between it and the over-all averages in question. The eight establishments which employ more than 100 persons together account for 55.4 per cent of total employment and 63.6 per cent of installed capacity, which means that the *per capita* capacity available is about 3 h.p., whereas in the other eighty-two establishments it is only 2.1 h.p. The capacity available per direct operative is even higher in the former group, because of the lower direct/indirect labour ratio. On the assumption that direct operatives constitute about 55 per cent of the personnel employed, available capacity amounts to about 5.5 h.p. per operative, almost twice as much as in the smaller establishments. This advantage is reflected, *inter alia*, in a satisfactory level of production capacity, in contrast with the situation in the other group.

Machine-tool manufacturers' inventories

Table 5 presents an inventory of the equipment used in domestic manufacture of machine tools by the ninety producers whose share in the sector's activity constitutes more than 5 per cent of their annual sales turnover.

In addition, there are sixty-one forming machines installed in these establishments in the aggregate, bringing the total up to 2,527. The firms employing more than 100 persons possess twenty-eight units of this type.

As the size distribution of the enterprises in question is so irregular and the proportion of firms employing fewer than fifty persons is high, it is difficult to make an over-all analysis of this inventory in such a way as to give a faithful interpretation of the machine-tool industry's real situation. The equipment to be found in about 9 per cent of the establishments, representing approximately 29 per cent of the total number of machines, is comparable to that of manufacturers in more highly industrialized countries; most of the remaining firms, in contrast, have only unsatisfactory and makeshift production facilities at their disposal. The eight establishments employing more than 100 persons belong to the first group.

In the case of this group, production equipment is complete, efficient and up-to-date, as can easily be seen from the high figures relating to the use of boring machines, milling machines of various types, threading machines, broaching machines, grinding machines, gear-cutting machines and special machine tools. There is no lack of technical knowledge of the kind required for correct utilization of the machines, and it is thus possible to overcome those machining difficulties which characterize the manufacture of machine tools once the Schlesinger or Salmon standards are the goal.

In addition to the satisfactory equipment situation, jigs fixtures, special tools, and metrological and control instruments are used, both in the intermediate stages of machining and during the final process of assembly, in accordance with the standards referred to above. Consequently, the designs of the machines are more complex, and those manufactured by the group under discussion differ from the rest in that they are more complete, offer better working facilities, have higher power, bigger transmission fields and superior productivity in relation to others of the same type.

It may also be noted that in these enterprises which employ 2,646 persons in all, the proportion of indirect personnel ranges from 30 to 52 per cent, i.e., it is within the limits that should be considered essential for success in this difficult specialty. The manufacture of machine tools of more advanced and complex design calls for more project engineering and research and, consequently, for a greater number of indirect personnel working on the planning of production, quality controls and the making of tools and jigs (table 6).

Lastly, stress must be laid on the marked creative vitality displayed by this group of firms whose projects keep pace with the requirements of the domestic market and the constant technological advances in the sector. Studies aimed at perfecting machine parts, to which the patents registered and experiments with new models bear witness, are commonplace today, and have indeed been so since 1950.

In contrast, the position of the smaller enterprises leaves a good deal to be desired as regards their manufacturing equipment which is lightweight and incomplete, indirect technical services are neglected. This is sufficient indication of the category and quality of the machine tools manufactured.

Hitherto, however, market requirements in respect to quality, types and prices of machine tools have also assumed two very different forms, according to whether the prospective consumers are industries at a more advanced stage of technical development or establishments, usually on a small or medium scale, whose technological level is lower and whose supply of capital is limited.

To meet the needs of the former, the more advanced group of domestic manufacturers is in a position to deliver high-quality goods conforming to the specifications required, within their current lines of manufacture; the latter, on the other hand, preferring as they do machines of low cost (less than $2 per kg as a rule) and hence also low in weight, power and precision are supplied, in the main, by the small manufacturers. Thus, some justification for such producers' limited manufacturing resources is to be found in the nature of market demand, at least to the present.

But as the Brazilian machine-tool inventory approaches 300,000 units, in order to attain low production costs together with an improvement in the quality of the final product it will be essential for the technology of production to develop as well and, consequently, for most of the small establishments manufacturing machine tools to progress along the same lines.

The technical and manufacturing potential achieved by the leading group in this sector, and by the manufacturers of lathes and presses in particular, reaches international standards comparable with those registered in the more highly industrialized countries for manufacturers capable of supplying substantial machine-tool inventories.

The considerable size of the Brazilian inventory, together with its annual natural growth rate of about 5.5 per cent, suggests the need for at least some of the small-scale enterprises to increase their dimensions, with all the structural changes which this implies.

What has been said of the small enterprises and the equipment they use should be regarded rather as a warning for the near future than as criticism. The design of the planer and the work bench. Significant deformation may thus take place in the course of machining.

Other machine tools and equipment which, to judge from the survey, are not usually found among the machining plant of the smaller establishments are: gear-cutting machines of the Fellows and Maag Types, and with gear generators; gear-grinding machines; milling machines for slot axles; grinding machines for grooved shapes; broaching machines for internal grooved shapes; special machines for long thread cutting; heavy drilling machines; grinding machines for long bed rails; dynamic balancers; group of units for tempering bed rails and benches; measuring instruments for testing Schlesinger and Salmon standards.

These machines and equipment usually are essential requisites for the production of good quality machine tools, especially those in the chip producing category. The latter, which also include finishing machines, offer a wider range of types and designs than forming machines; their manufacture calls for a more varied inventory of machine tools. Furthermore, the acceleration of cutting speeds of both rotary and alternating machine tools is compelling manufacturers to use increasingly difficult and complex manufacturing techniques applicable only if special and costly equipment is available.

Table 6

INVENTORIES OF MACHINE-TOOL MANUFACTURERS, 1961

Type of machine	*All establishments*		*Establishments employing more than 100 persons*	
	Number	*Percentage*	*Number*	*Percentage of total*
Lathes	893	36.2	245	27.4
Milling machines	225	9.1	88	39.1
Drilling machines	459	18.6	88	19.2
Boring machines	63	2.6	33	52.4
Shapers and planers	377	15.3	86	22.8
Threading machines	18	0.8	8	44.4
Broaching machines	5	0.2	4	80.0
Gear-cutting machines	55	2.2	38	69.1
Cutting machines (saws)	158	6.4	36	22.8
Grinding machines	136	5.5	64	47.1
Tool-grinding machines	77	3.1	32	41.6
Total	2,466	100.0	722	29.3

comments which follow are valid for most of the small establishments, and afford some justification for such an attitude.

Boring machines, for example, with which heavy asymmetrical parts can be machined at different levels, are replaced by devices which do not permit attainment of the close tolerances acceptable for internal diameters and distances between axles. Again, the very limited use of cylindrical grinding machines for internal and external diameters suggests that series couplings are unlikely to achieve ISO 6 and 7 quality, obviously to the detriment of both surface finish and the precision of the couplings themselves.

Similarly, the problem of machining small and large flats is generally tackled with unsuitable machine tools. Limited use is made of milling machines for which shapers are usually substituted with poor results in production time, precision and quality of surface finish. For machining larger parts, the table planers used, besides offering few facilities, are so light that the weight of the part being machined is disproportionate to the

In the manufacture of machine tools, more perhaps than in other sectors of the metal-transforming industry, the relationship between minimum size of establishment and quality and complexity of product takes precedence over the relationship between size of establishment and series produced.

This, taken in conjunction with the domestic manufacture projections in this study, makes it plain how necessary it is that by the end of the period under study the proportion of machine-tool enterprises employing, on an average, some 200 persons each should be about 15 to 20 per cent, either as a result of the expansion and modernization of the industries already established or by virtue of the installation of new enterprises.

Types of machine tools manufactured in Brazil

In compiling the list of machine tools manufactured in Brazil, the output taken into account was that of 104 firms, i.e. including the five which in 1961 were engaged in perfecting prototypes of machines to be put on the market in 1962. The dimensions represent each machine's maximum working capacity:

Machines for chip producing

(*a*) Bench lathes (diameter, up to 250 mm: distance between centres, 600 mm);

(*b*) Single-pulley lathes (distance between centres, up to 4,000 mm);

(*c*) Engine lathes (diameter, up to 600 mm; distance between centres, 2,000 mm);

(*d*) Medium weight engine lathes (distance between centres, 2,000 to 4,000 mm);

(*e*) Heavy engine lathes (up to 15 tons; distance between centres, 4,000 to 7,500 mm);

(*f*) Extra heavy engine lathes (up to 61 tons; distance between centres, 10,000 mm. There are possibilities of manufacturing these lathes with higher tonnages and longer distances between centres);

(*g*) Bench turret lathes;

(*h*) Hand fed, single-pulley, hexagon turret lathes (spindle bore diameter, up to 2 in.; weight, 1 ton);

(*i*) Hand fed, single-pulley, frontal turret lathes (spindle bore diameter, up to 2 in.);

(*j*) Light hand fed hexagon turret lathes (up to 1.5 tons);

(*k*) Medium weight hand fed hexagon turret lathes (up to 3.2 tons: lathe swing, 500 mm, and length 940 mm);

(*l*) Heavy hand fed hexagon turret lathes (up to 11 tons; lathe swing, 800 mm, and length up to 1,780 mm);

(*m*) Frontal or plateau lathes (lathe swing, 2,500 mm; 5 h.p., and weight up to 6 tons);

(*n*) Special semi-automatic lathes for small parts (up to 2 in.);

(*o*) Automatic lathes with radical slides (spindle bore diameter, up to 1 in.; weight up to 1 ton);

(*p*) Semi-automatic lathes for second operations;

(*q*) Universal bench drilling machines (up to 0.3 tons);

(*r*) Light universal milling machines (up to 0.8 tons and 1.5 h.p.);

(*s*) Universal milling machines with Morse cones No. 4 and 5 (up to 5 h.p., and weight between 1.5 and 3 tons);

(*t*) Milling machines with automatic work cycle (table), simplex and duplex types (up to 3 h.p. and weight 1.5 tons);

(*u*) Hand fed bench drilling machines;

(*v*) Bench drilling machines with automatic feed;

(*w*) Hand fed pedestal drilling machines (diameter capacity up to 1.5 in.);

(*x*) Pedestal drilling machines with automatic feed (maximum diameter 1.5 in.);

(*y*) Multispindle bench and pedestal drilling machines (up to 2 h.p.);

(*z*) Radical drilling machines with arm length up to 1,250 mm (maximum diameter, 25 mm for steel);

(*aa*) Shapers with stroke length from 300 to 1,200 mm, including a hydraulic model;

(*bb*) Table planers (up to 5 h.p.; table 1,000 - 3,400 mm, or over; weight 7.5 tons. Hydraulic models are also manufactured in a smaller size);

(*cc*) Semi-automatic and automatic threading machines for internal threads (diameter, up to 0.5 in.);

(*dd*) Threading machines with flat dies (up to 1.5 in.);

(*ee*) Threading machines with cylindrical die (working pressure up to 20 tons);

(*ff*) Hydraulic broaching machines, simple horizontal type (up to 20 tons);

(*gg*) Alternating saws for metal cutting;

(*hh*) Partially hydraulic alternating saws for metal cutting (up to 12 × 12 in.);

(*ii*) Completely hydraulic circular saws with automatic feed (diameter, up to 130 mm);

(*jj*) Band saws, horizontal and vertical types;

(*kk*) Hand and semi-automatic universal grinding machines, with mechanical and hydraulic controls (distance between centres, up to 1,500 mm);

(*ll*) Grinding machines for flats (table, 135 × 600 mm; up to 3.5 h.p., also with electromagnetic table);

(*mm*) Universal tool-grinding machines;

(*nn*) Special grinding machines for tungsten carbide tools;

(*oo*) Special machine tools for long series composed of machining units up to 5 h.p. One stage or revolving table type;

(*pp*) Axle centerers.

Machines for forming

(*a*) Hydraulic presses (up to 1,600 tons);

(*b*) Eccentric presses, inclinable (up to 100 tons);

(*c*) Eccentric presses, fixed, with intermediate gears (up to 160 tons);

(*d*) Friction presses (up to 400 tons);

(*e*) Pneumatic forging machines (up to 500 kg);

(*f*) Forging machines (up to 150 kg);

(*g*) Drop forging machines (up to 250 kg);

(*h*) Shears (length, up to 3,000 mm; thickness, 0.5 in.);

(*i*) Bending presses (length, up to 3,600 mm; thickness, 5 mm; pressure, up to 75 tons);

(*j*) Machines for cutting shapes, universal type.

The list of variants of the types of machine tools is particularly long in respect to lathes, drilling machines and saws and forming machines in general. It should be taken for granted, for example that, as regards presses, a wide range of capacities is manufactured: from 2.5 tons to a maximum of 100 tons, and the same applies to the other machines. In the categories of chip producing and forming machines, respectively, lathes and presses are the most highly developed and the most advanced from the technical standpoint in respect to types, models, weight and power per unit, quality and productivity. The progress achieved in the manufacturing of these machines during the past decade was so remarkable that for several years exports have been registered; this applies particularly to lathes, which have found a market not only in Latin America and the Middle East, but also in European countries with long-standing traditions in manufacturing machine tools.

Milling machines are important items whose share in the composition of machine-tool inventories is usually about 8 to 10 per cent. Although a great variety of types and models of machines of this kind exists, domestic manufacture is confined to six models. It should be stressed here not only that the manufacturers are lagging behind in this sector, but that the national inventory too is deficient, milling machines being little used in Brazil.

Next in importance to milling machines come grinding machines of which only a few models are manufactured, whereas a wide and varied range is available on the world market. A comparison between the Brazilian inventory and that of other countries reveals an anomalous situation which suggests the urgency of the need to embark upon local manufacture of several basic models. Boring machines and gear-cutting machines are not manufactured in Brazil, and have to be imported.

Generally speaking, the list of the types of machine tools currently manufactured in Brazil is somewhat incomplete in relation to the significance already attained by the national inventory in respect to numbers and variety of types. Nevertheless, considering that the sector is in some instances very young and inexperienced and that the annual volume of output is a little over 10,000 tons, the manufacture of fifty-two types of machine tools in about 150 leading models represents a fairly satisfactory situation.

Given the country's stage of development and the growth projections for the next few years formulated in relation to the various sectors of the metal-transforming industry, the Brazilian inventory will exceed 300,000 units in 1971. Clearly, then, the sector will need to increase the number of models progressively year by year so that some balance is maintained between the evolution of the inventory and the domestic supply of basic types. Otherwise, if Brazil's own technological resources would not suffice to feed the inventory of machine tools, a difficult situation might arise because of the amount of foreign exchange that would be needed to import the requisite machines and the expansion of the metal-transforming industries would be slowed up.

It must be borne in mind, however, that no country is completely independent as regards the manufacture of all types of machine tools, not even those with inventories of over two million machines, and that the necessity for international trade in this field is almost a basic principle. The items concerned, however, are as a rule specialized machine tools, domestic production of which has no attractions from the economic or technical standpoint, and are very seldom the simpler basic types manufactured in longer production series.

Volume of output

The survey of Brazilian production of machine tools presented here, and covering the period between 1955 and 1961, is the first in the country.

The figures for the years 1955, 1956 and 1957 must be regarded as approximate, since in some cases the answers to the questionnaire were incomplete and either the number or the weight of the machines had to be estimated. In any event these estimates do not greatly affect the conclusions.

The findings of the survey with regard to chip-producing machines, forming machines, and the total accumulated during the period 1955–61 are given in tables 7, 8 and 9, respectively.

The tables give a clear idea of the tremendous effort put forth by the manufacturers of machine tools, since in only six years the annual tonnage was increased by 260 per cent, reaching cumulative figures of more than 60,000 tons, and equivalent to more than 62,000 units. This volume of production undoubtedly did much to account for the fact that the Brazilian inventory almost doubled between 1955 and 1961.

The data on the percentage distribution of the machines used for chip producing and for forming operations are worth analysing. During the period 1955–61, the average figures were 79.7 and 20.3 per cent, respectively. In 1960, Brazil's total stock of machine tools, including those used for maintenance purposes but excluding those not inventoried showed a very similar distribution, 78.2 and 21.8 per cent, which suggests that domestic production kept closely parallel to the composition of the total stock as regards the two categories. It must be pointed out, however, that during the period under discussion the proportion of output represented by chip-producing machines showed a decided upward trend, rising from 77.3 per cent in 1955 to 81.9 per cent in 1961. If similar comparisons are made on the basis of the tonnages produced, the position is reversed, and the share of chip-producing machines falls from 65.7 in 1955 to 62.3 per cent in 1961. The explanation lies in the fact that during this period a beginning was made on manufacture of some new types of machine tools (such as grinding machines, tool-grinding machines etc.), in the smaller sizes, while at the same time the manufacture of light machine tools such as lathes and bench drills, shapers and alternating saws was intensified with the aim of meeting the demand deriving from the manufacture of a great many light articles as well as the requirements of small establishments which came into being at that time. Thus, the average unit weight of the machines manufactured dropped from 960 to 650 kg. The unit weight of forming machines was maintained at about 1,800 kg.

While the changes registered in relation to these two major groups of machine tools are broadly indicative of a gradual adjustment of domestic production to internal market requirements, it is interesting to note the much more striking modifications that have taken place within the groups themselves as this industrial activity has gradually developed.

For example, the proportion of output represented by the manufacture of lathes, which in 1955 was 54.6 per cent in terms of units, had fallen to about 30 per cent by 1961. The manufacture of drilling machines has increased to such an extent, more than eight times over in the

Table 7

PRODUCTION OF CUTTING MACHINES FOR CHIP-PRODUCING OPERATIONS

(*Weight in tons*)

Type of machine	1955		1956		1957		1958		1959		1960		1961	
	Number	*Weight*	*Number*	*Weight*	*Number*	*Weight*	*Number*	*Weight*	*Number*	*Weight*	*Number*	*Weight*	*Number*	*Weight*
Lathes	2,443	2,681.9	3,072	3,305.3	2,583	2,814.9	3,149	3,673.9	3,053	3,902.6	3,766	4,295.2	4,638	5,265.0
Bench lathes	—	—	20	2.4	20	2.4	10	1.2	—	—	600	78.0	720	83.6
Engine lathes	1,949	2,382.4	2,444	2,914.1	1,958	2,391.5	2,386	3,067.2	2,341	3,369.8	2,238	3,545.6	2,500	4,196.7
Frontal or plateau lathes	7	42.0	10	52.0	9	54.0	8	48.0	10	56.0	10	56.0	13	62.0
Turret and semi-automatic lathes	487	257.5	597	336.3	579	356.1	708	534.2	670	456.0	849	566.5	1,279	813.7
Automatic lathes	—	—	—	—	6	5.4	12	10.8	12	10.8	24	21.6	76	73.0
Others	—	—	1	0.5	11	5.5	25	12.5	20	10.0	45	27.5	50	36.0
Milling machines	72	42.2	67	42.0	142	77.2	159	143.9	190	168.5	186	187.1	278	289.8
Universal	40	18.0	40	18.0	80	32.0	111	103.0	145	126.6	126	129.8	191	215.3
Vertical	11	5.7	—	—	2	2.3	7	4.6	2	1.4	6	3.0	13	6.7
Others	21	18.5	27	24.0	60	42.9	41	36.3	43	40.5	54	54.3	74	67.8
Drilling machines	614	164.9	1,341	275.2	1,522	2,842.0	2,051	360.0	2,346	430.6	2,809	525.0	5,311	794.9
Bench drills	227	12.1	347	17.8	441	7.9	761	49.4	965	76.2	1,231	164.1	3,590	245.0
Pedestal drills	387	152.8	994	257.4	1,081	256.3	1,290	311.2	1,380	354.2	1,571	411.1	1,707	526.4
Radial	—	—	—	—	—	—	—	—	—	—	1	2.3	5	11.8
Multi-spindle	—	—	—	—	—	—	—	—	1	0.2	6	7.5	9	11.7
Shapers and planers	200	408.4	384	554.7	369	578.8	446	739.5	504	892.6	765	1,079.6	937	1,369.4
Shapers	168	236.1	346	335.7	337	389.8	413	554.5	458	616.6	715	788.1	878	1,027.4
Table planers	32	172.3	38	219.0	31	186.8	33	185.0	46	276.0	50	291.5	59	342.0
Others	—	—	—	—	1	2.2	—	—	—	—	—	—	—	—
Threading machines	19	3.6	18	2.7	25	5.3	36	6.9	28	7.0	45	29.5	53	35.0
Cutting machines (saws)	113	19.5	676	203.1	588	210.1	862	273.9	873	308.6	1,210	387.4	1,296	342.4
Reciprocating saws	113	19.5	634	193.3	518	196.1	678	225.7	560	214.1	740	258.1	817	200.7
Band saws	—	—	42	9.8	70	14.0	184	48.2	313	94.5	470	129.3	478	139.6
Circular saws	—	—	—	—	—	—	—	—	—	—	—	—	1	2.1
Grinding machines	2	3.0	—	—	—	—	44	33.0	61	43.5	46	34.3	79	57.1
Plain	—	—	—	—	—	—	42	30.0	60	42.0	44	31.3	76	53.1
Universal cylindrical	2	3.0	—	—	—	—	2	3.0	1	1.5	2	3.0	3	4.0
Tool-grinding machines	—	—	—	—	—	—	22	22.0	38	38.0	69	50.7	101	69.3
Universal	—	—	—	—	—	—	22	22.0	38	38.0	54	43.2	91	64.3
Special	—	—	—	—	—	—	—	—	—	—	15	7.5	10	5.0
Special machines and machine units for special machining operations	—	—	—	—	—	—	—				47	18	11	41.0
Total	3,463	3,323.5	5,558	4,383.0	5,229	3,970.5	6,769	5,273.7	7,093	5,791.4	8,943	6,606.8	12,704	8,263.9

Table 8

MACHINES FOR FORMING OPERATIONS

(*Weight in tons*)

Type of machine	1955 Number	1955 Weight	1956 Number	1956 Weight	1957 Number	1957 Weight	1958 Number	1958 Weight	1959 Number	1959 Weight	1960 Number	1960 Weight	1961 Number	1961 Weight
Presses	818	1,390.4	1,349	2,336.9	1,146	2,157.6	1,475	2,558.8	1,360	2,465.7	1,820	3,326.3	2,139	3,890.0
Hydraulic	131	86.1	244	158.1	210	116.6	314	181.6	228	226.5	318	488.5	333	510.6
Eccentric	643	1,055.0	1,003	1,720.3	848	1,643.9	1,075	1,989.6	1,035	1,831.8	1,384	2,314.7	1,651	2,734.8
Friction	44	249.3	95	438.9	79	371.9	83	379.2	87	379.4	108	495.1	128	569.0
Upsetters	—	—	7	19.6	9	25.2	3	8.4	10	28.0	10	28.0	27	75.6
Forging machines	1	3.6	1	3.6	1	3.6	6	21.6	5	18.0	9	32.4	7	24.8
Pneumatic hammers	1	3.6	1	3.6	1	3.6	6	21.6	5	18.0	9	32.4	7	24.8
Machines for sheet	196	368.1	301	507.6	250	467.1	317	564.6	354	731.7	473	890.7	667	1,071.2
Shears	71	160.3	124	246.3	114	245.9	139	255.7	160	376.1	248	490.1	346	601.6
Bending machines	98	183.3	134	221.5	94	182.9	128	261.6	133	297.4	131	304.0	182	317.9
Bending rolls	12	12.2	16	17.6	14	15.4	26	27.6	31	33.6	63	71.2	108	126.3
Other machines for sheet	15	12.3	27	22.2	28	22.9	24	19.7	30	24.6	31	25.4	31	25.4
Total	1,015	1,762.1	1,651	2,848.1	1,397	2,628.3	1,798	3,145.0	1,719	3,215.4	2,302	4,249.4	2,813	4,986.0
Total for chip-producing machines	3,463	3,323.5	5,558	4,383.0	5,229	3,970.5	6,769	5,253.7	7,093	5,791.4	8,943	6,606.8	12,704	8,263.9
Total for forming machines	1,015	1,762.1	1,651	2,848.1	1,397	2,628.3	1,798	3,145.0	1,719	3,215.4	2,302	4,249.4	2,813	4,986.0
Total Brazilian production	4,478	5,085.6	7,209	7,231.1	6,626	6,598.8	8,567	8,398.7	8,812	9,006.8	11,245	10,856.2	15,517	13,249.9

Table 9

TOTAL OUTPUT OF MACHINE TOOLS, 1955-61

(Weight in tons)

Type of machine	*Number*	*Percentage*	*Weight*	*Percentage*
Lathes	22,704	36.3	25,938.8	42.9
Milling machines	1,094	1.7	950.7	1.6
Drilling machines	15,994	25.6	2,835.4	4.7
Shapers and planers	3,605	5.8	5,623.0	9.3
Threading machines	224	0.4	90.0	0.1
Cutting machines (saws)	5,618	9.0	1,745.0	2.9
Grinding machines	232	0.4	179.0	0.3
Tool-grinding machines	230	0.4	180.0	0.3
Special machines	58	0.1	59.0	0.1
Total for chip-producing machines	49,759	79.7	37,592.8	62.2
Presses	10,107	16.2	18,125.7	30.0
Forging machines (pneumatic hammers)	30		107.6	0.2
Machines for sheet	2,558	4.1	4,601.0	7.6
Total for forming machines	12,695	20.3	22,834.3	37.8
Grand total	62,454	100.0	60,427.1	100.0

course of the period, that the share of this line of production has risen to 34 per cent as against 13.7 per cent in 1955. The reason lies in the heavy demand deriving from the production of light manufactured goods for which hand drills are generally used, and also in the fact that the use of high output drilling machines such as, for example, the multi-spindle type, is not very common in Brazil.

As may logically be inferred from the low percentage of milling machines both in the Brazilian inventory and in domestic production of machine tools, output of shapers and planers expanded considerably, attaining a figure that should be considered the maximum in percentage terms. As the manufacture of new types of milling machines is consolidated, these will come to predominate over shapers and planers, and the position will thus be reversed.

Outputs of saws increased more than tenfold between 1955 and 1961, which meant that their share in total production rose from 2.5 to 8.4 per cent in that period. This state of affairs is attributable to the widespread use of these machines in maintenance workshops and small establishments, and also, as would seem to be the case with circular saws, to the very limited use of higher yield machine tools.

Production of presses was approximately trebled, but their share too, like that of lathes, dropped from 18.3 to 13.8 per cent.

Despite the substantial increments registered, there is remarkably little manufacturing activity in the field of grinding machines, tool-grinding machines, threading machines and special machine tools, which already represent a considerable proportion of the domestic inventory, although the percentage is lower than in other countries.

The average weight of the machine tools has fluctuated significantly in the course of the period. Worthy of special mention is the progress achieved in respect to lathes, the average weight of which has risen by about 300 kg in the past six years; this was one of the factors responsible for the acceptance of Brazilian lathes on external markets (tables 10, 11 and 12).

Noteworthy, too, is the increase of almost 900 kg in the unit weight of hydraulic presses, although this is not clearly reflected in the over-all average for presses, because the expansion of capacity to manufacture heavier machinery is offset by an increase in output of other types, chiefly eccentric presses, in respect of which domestic industry has for many years been supplying internal requirements of the models and sizes in most general use.

Since the milling machines manufactured in 1955 were simple models, their weight had almost doubled six years later. But this progress must not be regarded as sufficient, since the average weight of these machines recommendable at the country's present stage of industrialization should be in the neighbourhood of 1,500 to 1,700 kg. The introduction of new types will probably permit the attainment of this target in the next ten years.

The heavy consumption of bench drills accounts for a decrease in the average weight of the drilling machine group, which was 150 kg per machine in 1961. Here too the modest share of domestic production may be noted in relation to the heavier types, for example those with capacities of up to 2 in., the pedestal type, multi-spindle drills and radial drills.

The figures for shapers, planers and saws fluctuate mainly on account of the influence of production of the lighter types, demand for which varies greatly. Within these categories, machines of higher capacity and weight have been manufactured in Brazil.

Despite the progress achieved as regards volumes of manufacturing output and the fairly high level reached in 1961, the phase under review might be defined as the formative stage of Brazil's machine-tool sector, on the basis of an over-all evaluation, and in the sense that a considerable proportion of the establishments are equipped to cope with production in terms of quantity rather than of quality. What has been said of the manufacturers' own inventory of machine tools is fairly conclusive in this respect.

Thus, while certain types of machine tools, such as engine lathes, medium weight hexagonal turret lathes and presses have already reached a high level of quality and productivity, many of the other machines are deficient on the technical side. This is because most of the small manufacturers, owing to their limited production facilities, have to make the simplest models. The only advantage of such a situation is the low price of the machine tools which in the last analysis proves anti-economic in terms of productivity.

One obvious result of the production of a large number of simple machine tools is the lack of extrasectoral manufacturing enterprise in supplementary equipment and accessories which are important factors in the development of the machine-tool sector. It must be acknowledged, however, that interest in the manufacture

Table 10

TREND OF AVERAGE WEIGHT OF SELECTED CHIP-PRODUCING MACHINE TOOLS, 1955-61

(*Kilogrammes*)

Type of machines	*1955*	*1956*	*1957*	*1958*	*1959*	*1960*	*1961*
Lathes (excluding bench lathes)	1,098	1,082	1,093	1,170	1,278	1,332	1,322
Milling machines	586	627	544	905	887	1,006	1,042
Drilling machines	269	205	187	176	184	187	150
Shapers and planers	2,042	1,445	1,569	1,658	1,771	1,411	1,461
Cutting machines (saws)	173	300	357	318	353	320	264
Total for chip-producing machines	960	789	759	776	816	740	650

Table 11

EVOLUTION OF AVERAGE WEIGHT OF SELECTED MACHINE TOOLS FOR FORMING OPERATIONS, 1955-61

(*Kilogrammes*)

Machines	*1955*	*1956*	*1957*	*1958*	*1959*	*1960*	*1961*
Total for presses	1,700	1,732	1,883	1,735	1,813	1,828	1,819
Hydraulic presses	657	648	555	578	993	1,536	1,533
Eccentric presses	1,641	1,715	1,938	1,851	1,770	1,672	1,656
Shears	2,258	1,986	2,157	1,840	2,351	1,976	1,739
Total for forming machines	1,736	1,725	1,881	1,749	1,870	1,846	1,772
Average weight of total machine-tool output	1,136	1,003	996	980	1,022	965	854

Table 12

COMPOSITION OF PRODUCTION OF MACHINE TOOLS IN 1955 AND 1961

(*Percentages*)

Type of machine	*In terms of units*		*In terms of weight*	
	1955	*1961*	*1955*	*1961*
Lathes	54.6	29.9	52.7	39.7
Milling machines	1.6	1.8	0.8	2.2
Drilling machines	13.7	34.2	3.2	6.0
Shapers and planers	4.5	6.0	8.1	10.3
Threading machines	0.4	0.3	0.1	0.3
Cutting machines (saws)	2.5	8.4	0.4	2.6
Grinding machines	—	0.5	0.1	0.4
Tool-grinding machines	—	0.7	—	0.5
Special machine tools	—	0.1	—	0.3
Total for chip-producing machines	77.3	81.9	65.4	62.3
Presses	18.3	13.8	27.3	29.4
Forging machines	—	—	0.1	0.2
Machines for sheet	4.4	4.3	7.2	8.1
Total for forming machines	22.7	18.1	34.6	37.7
Grand total	100.0	100.0	100.0	100.0

of highly specialized items is warranted only when the consumer market reaches a certain minimum level. By way of illustration, a list follows of some of the accessories which may be regarded as basic for the manufacture of good quality machine tools with a high productivity, which at present are difficult to find on the market:

Component parts for low-, medium- and high-pressure hydraulic circuits;
Electrohydraulic, pneumohydraulic and electropneumohydraulic equipment;
Component parts for pneumatic circuits;
Electric motors with brakes;
Continuous speed variators, mechanical, electric and hydraulic;
Electromagnetic, pneumatic, hydraulic and mechanical clutches, simple and compound, dry or oil bath types;
Revolving tables with hand dividers;
Hand and automatic high precision dividers for milling machines;
Electromagnetic tables, higher powered than those currently manufactured;
Hydraulic plates for lathes.

If suitable undertakings are to be set up to supplement and support the manufacture of machine tools, the prime requisite is that domestic manufacturers should interest themselves in producing more fully equipped machine tools and duly exploiting the resources offered by semi-automation to improve the productivity of the machines manufactured. This is one of the most important targets to be attained by domestic industry. In addition, as has already been pointed out, the nature of the problems connected with the technological evolution of machine tools is such that, generally speaking, they could not be tackled competently enough by the smaller firms unless they undertake the task of carrying out more advanced projects studied by third parties, or by an agency with the necessary technical qualifications, such as the Brazilian machine-tools institute.

In conclusion, the quality and types of the machine tools manufactured must in future keep up more closely with the increasing needs of the Brazilian machine-tool inventory (table 13), as the more advanced manufacturers have done hitherto, so that definitive consolidation of the sector may be achieved.

As regards price levels in the domestic machine-tools industry and its competitive positions vis-à-vis foreign machine tools, it is difficult at present to put forward conclusive data reflecting the real situation for each machine. In this type of industry, such factors as quality, complexity, and manufacturing characteristics and techniques exert a powerful influence on manufacturing costs and cannot be ignored in such comparisons which as a result become immensely difficult and in some cases even impossible or, if a strictly comparable counterpart cannot be found, virtually devoid of significance. Locally manufactured machine tools show a wide range of prices according to the greater or lesser incidence of these on

Table 13

TOTAL INVENTORY OF MACHINE TOOLS, 1960

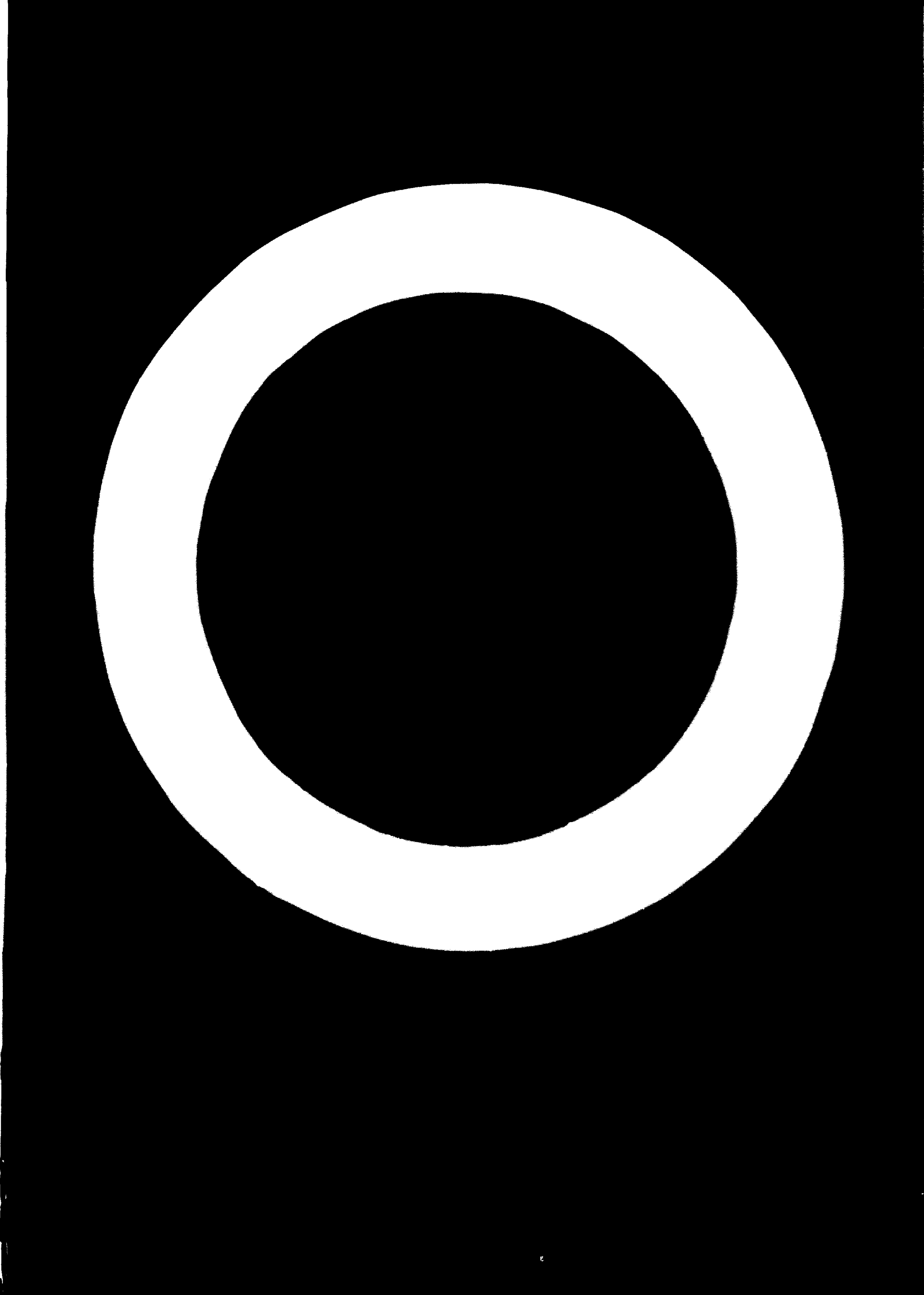
	Major groups					
	I	*II*	*III*	*IV*	*Total*	
Type of machine	*Manufacture of metal products*	*Manufacture of machinery excluding electrical machinery*	*Manufacture of electrical and communications material*	*Manufacture of transport material*	*Number*	*Percentage*
Lathes	11,298	9,860	4,263	15,104	40,525	29.5
Milling machines	884	2,155	572	2,937	6,548	4.8
Drilling machines	7,834	6,067	3,459	9,401	26,761	19.5
Boring machines	83	218	59	597	957	0.7
Shapers and planers	2,653	2,112	724	2,139	7,620	5.6
Threading machines	557	359	332	1,077	2,325	1.7
Broaching machines	38	50	33	510	691	0.4
Gear-cutting machines	[a]	270	36	718	1,033	0.8
Metal-cutting machines (saws)	2,631	1,842	909	3,046	8,428	6.1
Grinding machines	453	1,079	470	2,970	4,072	3.6
Tool-grinding machines	276	542	225	1,183	2,226	1.6
Total for chip-producing machines	26,707	24,563	11,082	39,682	102,034	74.3
Presses	14,140	2,240	4,242	8,191	28,813	20.9
Forging machines	81	54	[a]	382	517	0.4
Machines for forming, bending and cutting sheet	2,348	1,455	1,062	1,135	6,000	4.4
Total for forming machines	16,569	3,749	5,304	9,708	35,330	25.7
Grand total	43,276	28,312	16,386	49,390	137,364	100.0

[a] Fewer than 10 units.

their manufacture, and this would make for unrealistic or meaningless results if a comparison at the level of the broad classification of machine tools were attempted; such an undertaking would have to be carried out in relation to each individual type of machine and for this insufficient data are available, besides which, it would be outside the scope of the present study.

Despite the price differences observable in domestic machine tools, quotations fluctuate, broadly speaking, around an average of $2 per kg, which may be considered satisfactory.

Again, since exports of particular machines, such as certain types of lathes and presses, have been achieved and some Latin American countries are displaying interest in purchasing Brazilian machine tools, it may be deduced that their price levels fall within an acceptable range.



METALWORKING INDUSTRIES IN SOUTHERN ITALY

Vittorio Valletta, Honorary President, FIAT, Italy

The evolution of metalworking industries in Italy's northern section offers no features of immediate interest to the developing countries. But the effort under way towards the industrialization of the southern regions, known as "Mezzogiorno," offers experiences that may be useful to most.

As in these countries, in the Mezzogiorno the *per capita* income is still low, farming the prevalent occupation and industrial activities little developed. Metalworking industries, if numerous small repair and maintenance workshops are excluded, represent a modest part of over-all manufacturing activities. Notwithstanding that there are already in operation some considerably large plants, the metalworking industries of the Mezzogiorno, in *per capita* terms, represent less than 10 per cent of the level existing in the northern industrial triangle (Turin–Milan–Genoa).

While in the Mezzogiorno the local-market oriented industries (standard foods, soft drinks, woodworking) and certain base industries (petrochemicals, steel) have already reached a notable degree of development, the same cannot be said for metalworking. Accordingly, further industrial expansion must be focused on the metalworking industries whose market opportunities may expand at national and international levels, with large labour employment opportunities.

Similar problems and approaches to industrial expansion are found in the developing countries.

The main characteristic of the metalworking industry in these countries is production almost exclusively intended for local markets. In the larger countries, production (assembly and manufacture of relatively simple products) can cover about half the domestic demand, although at high costs; in smaller countries, the metalworking activities concentrate essentially on repair work.

If the development of metalworking industries is to be one of the aims of industrialization in the developing countries, realization clearly entails sales in wider markets. This, in turn, entails the attainment of competitive cost and quality levels.

The problems of competitiveness are still there even when a wider market is achieved through economic integration agreements with other countries. Here again, the Mezzogiorno offers an interesting case study for the developing countries, as it is part of the European Economic Community; its metalworking industries must compete with those of the major industrial concentrations in Western Europe.

Attainment of efficiency and competitiveness at European levels is a central problem of the industrial policy of the Mezzogiorno. Specifically, such policy aims at creating in the new industrial areas of the South those "external economies" of which the metalworking industries of the great industrial centres of the North are benefiting in terms of: effective technical and social infrastructures; skilled labour; interindustry relations.

To foster the establishment of such an environment, "areas of industrial growth" have been mapped out, endowed with the necessary infrastructures and backed by large public works through which they are connected, or soon will be, directly to the major production and consumption areas in northern Italy and the European Common Market. An adequate infrastructure system, especially transport facilities, is one of the very necessary requisites of industrialization.

The problem of local shortage of skilled labour was tackled in the Mezzogiorno through various programmes. In addition to strengthening and expanding primary education in general, special vocational courses were set up by public bodies to give an initial training which is then completed in the factory. To assist businesses in this direction, the Government grants funds to help run interfirm schools organized by industries operating in the same area. This is particularly helpful for the smaller firms that cannot afford to train their own employees.

Screening and training locally hired manpower is perhaps the most difficult of the many tasks that any production plant starting operations in the Mezzogiorno has to handle. Experience teaches, however, that the men learn quickly and well; and if the operation is effectively organized, the time required for local labour training, plant erection and production run-in can be kept within reasonable limits.

Experience in manpower training in southern Italy can, to some extent, benefit developing countries still unequipped with appropriate vocational training systems. Conversely, technical and supervisory personnel should be trained, at least in the early stages of industrialization, in foreign industrialized countries. This offers opportunities for interesting and feasible technical cooperation between developing countries and economically more advanced countries, as well as with international organizations. A successful example of this can be seen in the International Labour Organisation Training Centre at Turin.

Lastly, fundamental importance attaches to the complex industrial interrelations which metalworking industries need and can be provided only in highly industrialized areas.

In these areas, the metalworking industries find the

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specialized firms that provide maintenance and overhauling services for their machinery and equipment; firms that manufacture on order components and assemblies to become part of their end products; stores of industrial standard and catalogued products, and all the specific services required by the industry.

The existence of all these ancillary and supporting activities and services embodies that technological specialization which is the hallmark of the modern metalworking industry. It enables the firms availing themselves of such co-operation to reduce investments in plants and machinery, to attain higher degrees of saturation of equipment capacity, to reduce the rates of skilled labour, to use manpower more efficiently, to keep material inventories down, and generally boost productivity.

It is clear that supporting and allied activities can be established and operated economically only if they have enough customers, and this explains why they developed to a lesser extent in areas where the metalworking industry is still in its initial stage.

This basic problem has been investigated, with actual reference to the Mezzogiorno, in a recent survey conducted for the European Economic Community by ITALCONSULT under the direction of Professor E. Tosco. In its conclusions, the case study proposes for the Bari-Taranto industrial area the promotion at the same time of a number of new major metalworking industries. Such industries would be sized to compete on a European level and tailored to a minimum input demand to support a whole range of tool manufacturers, maintenance and repair workshops, and manufacturing and processing subcontractors, to be themselves sponsored and established in the area. The over-all dimension of such an industrial set-up would justify also the establishment of several other industrial services. For the first time, the industries there established would enjoy, in addition to the customary tax and financing incentives, the basic benefits of that *milieu industriel* that now can be found only in the areas of high industrial concentration.

The study has been approved by the Italian Government and has already entered the promotional phase. The implementation of its recommendations, not unattended by difficulties, is an experiment to be followed with interest by the developing countries that must tackle comparable problems.

Obviously, a distinction should be drawn between countries where metalworking industries are in their early stages and those where they have reached some measure of growth. In the first, an initial nucleus of integrated, up-to-date metalworking industries should be established to become a future pole of industrial development. The major industries of such a nucleus should be selected from those that, while calling for not overly large facilities, and a relatively low rate of skilled labour, would as a whole generate sufficient demand for goods and services to promote and support the most essential ancillary industries.

In countries where mechanical engineering has already made some progress, even if not along well balanced or integrated lines, the current Italian experiment might offer ideas for completing the ancillary industries system by promoting major metalworking industries with high requirements for ancillary materials and services, this in order to attain such structural balance without which no acceptable levels of efficiency and competitiveness can be achieved.

Part Two

ECONOMIC ASPECTS OF THE DEVELOPMENT OF METALWORKING INDUSTRIES

DECISION RULES FOR EQUIPMENT INVESTMENTS IN METAL-PRODUCT INDUSTRIES WITH SPECIAL REFERENCE TO METAL-CHIPPING AND METAL-CUTTING MACHINES

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I. Trends and figures

Productivity ranking (1)

First, we will try to rank the metal-product industries by world regions, according to a productivity criterion. From the United Nations *Statistical Yearbook, 1963*, we obtain a percentage breakdown, by region, of the total value added in the metal-product industries in 1958. Also from the same source, we obtain the percentage breakdown of the total number of persons in the group in the same regions. By taking the ratio of the percentage distribution of value added over the percentage distribution of the number of persons engaged in this activity, a ranking of regional productivity is possible by using the ratio as a productivity indicator.

Productivity in the North American continent, according to our ranking procedure, is highest: in succession come the Soviet Union and Eastern Europe, and Oceania (primarily Australia and New Zealand). Europe (mainly Western Europe) is only in fourth place. Africa and the Middle East, Latin America and Asia (East and South-east), take fifth, sixth and seventh places in the ranking order (table 1).

Productivity ranking (2)

A second productivity comparison will be made by relating index numbers of industrial production for certain industrial activities with the index number of industrial employment. We will compare the individual index numbers among industries per region. In addition, we will take the ratio of the index number of industrial production over the index number of industrial employment as an indicator for labour productivity in a specific year for a certain industrial activity per region. The ratio for 1955 is A; for 1962, B. The same regions as indicated in table 1 are participating in the comparisons. The indices and ratio A are presented in table 3 for ten industrial activities as defined in table 2.

If we compare among industries per region, using the industrial production indices from table 3, we notice that the index for the metal-product industries (ISIC 35–38) has the highest value, compared to all other industry groups, for the following regions: World, Soviet Union and Eastern Europe, North America, Latin America and Asia. For Europe, the index is the third highest and for the European Economic Community it is second.

Looking now at the industrial employment index in table 3, we notice that this industry has the highest value compared to all other industry groups for the USSR and Eastern Europe, North America, East and South-east Asia, Europe and the European Economic Community. For Latin America the index is second highest, and for the world only seventh highest (together with ISIC 23, 24, 29).

This comparison shows that the metal-product industries are of outstanding importance from a production as well as an employment point of view.

Table 1

PERCENTAGE DISTRIBUTION IN 1958 OF METAL-PRODUCT INDUSTRY (ISIC 35–38)

Regions	*Value added in industry*		*Number of persons in industry*		*Ratio 1/2*	*Productivity ranking*
Africa and Middle East ..		0.6		1.3	0.5	5
North America		38.7		17.9	2.2	1
Latin America		1.2		3.1	0.4	6
Asia (East and South-east)		3.1		12.2	0.3	7
Excluding Japan	0.6		6.7		0.1	
Europe		28.7		36.8	0.8	4
E.E.C.	15.6		20		0.8	
F.T.A.	11.5		13.5		0.9	
USSR and Eastern Europe		26.5		27.3	1	2
Oceania		1.2		1.4	0.9	3
Total		100		100		

Table 2

Definition of industry groups

International Standard Industrial Classification (ISIC) number		Description of industry
1	1 3, 511, 512	Mining, manufacturing, electricity and gas
2	20 22	Food, beverages and tobacco
3	23, 24, 29	Textiles, clothing and leather products
4	25 26	Wood products and furniture
5	27	Paper and paper products
6	11, 13, 30 32	Coal and crude petroleum, chemical, coal, petroleum and rubber products
7	14 19 33	Non-metallic minerals and products
8	12, 34	Metal mining and basic metals
9	35 38	Metal products
10	511, 512	Electricity and gas

If we now look at the ratio of index 1 over index 2, ratio A as a kind of indicator for labour productivity, we notice that, for the following regions, this ratio is higher for the metal-product industries than for any other industry group: World, USSR and Eastern Europe (together with ISIC 14–19, 33), East and South-east Asia.

For North America the ratio comes at the third place (behind ISIC groups 51–512 and 11, 13, 30–32). For Latin America the ratio also comes at the third place, for Europe at the seventh place and for the European Economic Community at the sixth place.

From this we may conclude that the growth of the index of industrial production for the metal-product industries has been less than the growth in the index of industrial employment. Of the seven regions distinguished, the industrial index was highest in five and the employment index was highest, also, for five (but different regions) of the seven, but the ratio of the two indices, however, is highest only in three of the seven regions. Table 4 summarizes the results of the ranking procedure.

This gives evidence of the following:

(*a*) The metal-product industry is a labour intensive industry;

(*b*) Mechanization and automation are more limited than in certain other industries;

(*c*) Choices in equipment with different levels of mechanization exist but are presumably not made in an optimal way in many cases.

An optimal choice is not necessarily a choice for the most mechanized equipment. Elsewhere, this author has

Table 3

Productivity indicator A (1961 or 1962; 1958 = 100)

ISIC index ratio[a]		1 3, 511 512 1	20–22 2	23, 24, 29 3	25, 26 4	27 5	11, 13, 30–32 6	14–19, 33 7	12, 34 8	35–38 9	511–512 10
World (1961)											
1		126	115	117	126	122	125	128	126	132	130
2		109	107	106	109	110	102	110	110	106	105
1/2	A	1.16	1.07	1.10	1.16	1.11	1.23	1.16	1.15	1.25	1.24
USSR and Eastern Europe (1962)											
1		150	131	127	151	131	138	159	144	175	160
2		114	105	110	115	111	109	114	115	126	113
1/2	A	1.31	1.25	1.15	1.31	1.18	1.27	1.39	1.25	1.39	1.42
North America (1962)											
1		126	114	120	120	122	126	118	120	134	134
2		104	99	103	102	107	97	103	100	109	99
1/2	A	1.21	1.15	1.17	1.17	1.14	1.30	1.15	1.20	1.23	1.35
Latin America (1961)											
1		119	111	116		122	122	116	116	129	125
2		106	112	98		115	104	103	123	112	—
1/2	A	1.12	0.99	1.18		1.06	1.17	1.13	0.94	1.15	—
East and South-east Asia (1961)											
1		164	121	131		169	141	151	185	245	154
2		117	111	107	117	121	109	114	124	144	—
1/2	A	1.40	1.09	1.22		1.40	1.29	1.32	1.49	1.70	—
Europe (1962)											
1		127	119	115	126	129	133	130	122	131	135
2		108	107	103	107	110	97	107	106	115	105
1/2	A	1.17	1.11	1.12	1.18	1.17	1.37	1.21	1.12	1.14	1.28
European Economic Community (1962)											
1		132	116	119	127	130	141	132	125	138	135
2		108	107	104	103	109	97	105	109	116	104
1/2	A	1.22	1.08	1.14	1.23	1.19	1.45	1.26	1.14	1.19	1.30

[a] Index 1 — Industrial production. Index 2 — Industrial employment.

Table 4

RANKING ACCORDING TO THE HEIGHT OF INDICES AND RATIO A INTER-INDUSTRY PER REGION FOR METAL-PRODUCT INDUSTRIES

Region	Year	Ranking according to height of index of industrial (1) production	(2) employment	Ratio A 1/2
World	1961	1	7[a]	1
USSR and Eastern Europe	1962	1	1	1[b]
North America ..	1962	1	1	3
Latin America ...	1961	1	2	3
East, South-east Asia	1961	1	1	1
Europe	1962	3	1	7
European Economic Community ...	1962	2	1	6[c]

[a] Relative position shared with ISIC 23, 24, 29.
[b] Relative position shared with ISIC 14, 19, 33.
[c] Relative position shared with ISIC 27.

shown that the choice of equipment in the metal-product industries depends on: the wage rate and the interest rate: annual production (size of market), and the homogeneity of production (the size of production runs or lots).

In the second part of this study we will use an atomistic approach, in the sense that we will use highly disaggregated data to explore for which metal-chipping and metal-cutting operations there are choices or no choice in equipment with various degrees of mechanization, and how the optimal choice depends on the variation of such parameters as wage and interest rate and size of lots.

The aim of this first part of our study is only to show some trends and tendencies by comparison with highly aggregated figures.

Productivity ranking (3)

The same procedure as carried out in table 3 for the years 1961 or 1962 was done for the year 1955, yielding ratio B.

Table 5 presents both cross-region ranking and inter-industry per region ranking order.

Noteworthy is the low ranking among industries of the metal-product industries in Europe. Cross-region, the metal-product industries in Europe rank low, especially compared to North America. Some improvements in the efficiency of the group for Europe seem urgent on the basis of this comparison.

Table 5

RANKING ACCORDING TO INCREASE IN LABOUR PRODUCTIVITY INDICATOR FOR METAL-PRODUCT INDUSTRIES 1955–1961(62): ISIC 35 38

Region	Period	Ranking number Cross-region	Inter-industry per region
World	1955 1961	2	1
USSR and Eastern Europe ..	1955 1962	6	5[a]
North America	1955 1962	1	2
Latin America	1955 1961	7	6
East, South-east Asia	1955 1961	3	5
Europe	1955 1962	5	9
European Economic Community	1955 1962	4	5

[a] Relative position shared with ISIC 511 512.

Annual production growth rates

For a number of countries, the average annual rate of growth in the industrial production index of the metal-product industries is computed for the period 1953 1962. Table 6 shows the results. Some countries have amazingly high annual growth rates, such as Japan, 72.22 per cent, Taiwan, 42.59 per cent and Venezuela, 35.29 per cent, to mention only some countries with a growth rate higher than 30 per cent a year. Countries with a lower than 5 per cent annual growth rate during this period are: Argentina, Canada, the United States and the United Kingdom.

Table 6

AVERAGE ANNUAL RATE OF GROWTH, METAL PRODUCTS (PER CENT YEAR) (1958 = 100)

Countries	Index of industrial production 1953	1962	Annual rate of growth 1953 1962
United States	111	135	2.40
Canada	100	115	1.67
Argentina	82	92	1.36
Brazil (basic metals)	72	150	12.04
Venezuela	34	142	35.29
Hungary	80	172	12.78
Czechoslovakia	59	161	19.21
Poland	52	195	30.56
Soviet Union	49	175	25.71
India	40	168	35.56
Japan	40	300	72.22
China (Taiwan)	36	174	42.59
Belgium	79	126	6.61
France	63	126	11.11
Germany (F.R.)	56	139	16.47
Netherlands	72	145	11.27
Italy	70	163	14.76
Sweden	83	126	5.76
United Kingdom ...	83	114	4.15

Comparing the relative positions of the United States and Canada in table 6 with the relative position of North America in table 5, some evidence is found that efficiency increases have materialized, possibly by increased mechanization and automation.

Some further correlations

In trying to interpret the height of the average annual growth rate of the index of the industrial production in the metal-product industry, the average annual growth rate in the index of *per capita* product for the same period was used as an indicator of over-all economic growth, assuming that countries with rapid economic growth would also experience rapid growth rates in the metal-product industries.

Table 7 shows the sample where the dependent variable y stands for the average annual growth rate in the industrial index of the metal-product industry and x stands for the average annual growth rate in the index of *per capita* product. The correlation coefficient is not high, 0.5944, with a standard error of 14.8246.

Table 7

AVERAGE ANNUAL GROWTH RATE OF *per capita* PRODUCT INDEX (x) AND INDUSTRIAL PRODUCT INDEX (y) OF METAL-PRODUCT INDUSTRIES

Countries	x	y[a]
United States	1.10	2.40
Canada	0.91	1.67
Argentina	1.81	1.36
Brazil	3.58	12.04
Venezuela	3.02	35.29
Hungary	5.82	12.78
Czechoslovakia	6.81	19.21
Poland	6.39	30.55
Soviet Union	9.74	25.71
India	1.17	35.56
Japan	11.54	72.22
China (Taiwan)	3.88	42.59
Belgium	2.78	6.61
France	4.37	11.11
Germany (F.R.)	6.96	16.47
Netherlands	3.70	11.27
Italy	6.53	14.76
Sweden	3.83	5.76
United Kingdom	2.17	3.15

[a] See table 6.

Finally, an effort was made to explain y, the average annual growth rate of the industrial index in the metal-products industries, using four independent variables: (*a*) the income *per capita*, (*b*) the size of the population; (*c*) the product of (*a*) and (*b*), and the average growth rate of the index in *per capita* product.

More independent variables were introduced, and the sample size then reduced to fifteen countries due to lack of information. The countries are: United States, Canada, Argentina, Brazil, Venezuela, India, Japan, China (Taiwan), Belgium, France, Germany (F.R.), the Netherlands, Italy, Sweden and the United Kingdom.

A multiple correlation coefficient of 0.8005 was obtained to which the variables of *per capita* income and the average annual rate of growth of the *per capita* product index contributed most. As the size of the market is not only the home market but also the foreign market, the introduction of an appropriate variable for the foreign market would, undoubtedly, have improved the results. Further work is intended to improve the sample and to find the best combination of independent variables.

II. THE ANALYSIS

In this section, we intend to make the analysis from which we will derive decision rules in the last part.

Aim

The aim of the analysis is, as the title of this study suggests, the derivation of decision rules for equipment investments in metal-chipping and metal-cutting machines for a developing metalworking industry.

It is also suggested that there is something to decide, that a choice among alternative equipment types can be made. Everybody who has some experience with the metalworking industry knows that, for many metal-working operations (tasks) a choice among alternative machines does indeed exist. Even the highly aggregated data used in part I suggest the possibility of choices in metalworking equipment. If choices must be made, they should preferably be made in an optimal way and the present study thus should give answers to such questions as: which variables determine the optimum choice in metalworking equipment and how do these variables influence the optimum choice in metalworking equipment?

The practical questions follow directly: which type of analysis must be used to answer the first two questions most adequately and, subsequently, to whom are we going to direct ourselves, to private or to public decision makers? The last question is of importance because, in practical life, optimal choices for private or public authorities may mean different things. For this reason, we state as an additional aim of our analysis that it should yield results from which general rules can be derived, rules applicable to private as well as public decision makers. Hence, the final aim of our analysis can now be formulated: the derivation of decision rules on equipment investments in establishing or expanding a metal-product industries for private and/or public decision makers.

Scope

The scope of the analysis should be broad, in the sense that its results should cover:

(*a*) All countries in the world;
(*b*) All scales of production operation;
(*c*) All types of metal-products industries;
(*d*) All types of decision makers.

In order to achieve this, the analysis must take into account the production circumstances which simulate the real production characteristics for countries in various stages of economic development. To this end a model should be developed in which:

(*a*) Prices of primary inputs (stock and/or flow) can be varied in a discrete way simulating the relative scarcity relationship of capital and labour (and possibly of foreign exchange) for most-highly, highly, semi- and under-developed countries.

(*b*) Lot sizes or production runs (defined as the number of identical parts produced with a single setup) can be varied, simulating small-, medium-, and large-scale production characteristics.

(*c*) A number of production tasks should be defined which vary according to shape, size, and precision, simulating in this way characteristics of all possible types of metal products.

The variations in wage and interest rates can be considered to reflect actual market prices or equilibrium prices, gross or net of inflation. Private decision makers will be inclined to work with market prices, gross of inflation; public decision makers should preferably make use of estimated equilibrium prices, net of inflation.

Type

We now have to decide on the type of analysis that will best meet our previously formulated aims and scope. Best fitted for our purposes is a sensitivity analysis: basically, we want to know how sensitive machine-tool optimality is when certain parameters are varied.

A machine is considered to be optimal if it can produce a given unit of output at lower total capital and labour costs than any alternative machine.

The sensitivity of which parameters on machine-tool optimality do we want to explore? First, of the wage- and interest-rate parameters (parameters are given exogeneously). Economically, the most-highly developed countries will be characterized by a relatively high wage rate and relatively low interest rate, under the assumption that in such countries capital is abundant relative to labour, while under-developed countries will be characterized with a reverse factor-price relationship—that is, a high interest rate and a relatively low wage rate under the assumption that labour is abundant relative to capital. The prices of labour and capital for the middle group, highly developed countries and semideveloped countries, will be set between the extremes of the most-highly and under-developed countries.

The next parameter that will be varied is the size of lots; the variation will be such that all the possible scales of production will be simulated.

The variation of interest rates for equipment capital and wage rates for labour and the variation in size of lots will be called sensitivity analysis A.

The introduction of costs of structures, a type of capital, and the introduction of a variation in equipment prices (e.g., transportation costs for equipment and the application of an equilibrium exchange rate instead of an over-valued official exchange rate causes equipment prices to be higher in under-developed countries) will be explored in sensitivity analysis B. In this analysis, the efficiency rate of labour will be varied under the assumption that, in under-developed countries, this rate, as a result of such factors as less skill and less work discipline, will be lower than the efficiency rate in developed countries.

For the sensitivity analyses we will formulate total-cost functions, where total costs are a function of the equipment price, the interest rate, the labour time and the price of labour, the size of lots and the efficiency rate, from which unit-cost functions will be derived. Hence, as machine-tool optimality is defined as that machine with the lowest total capital and labour cost per unit, we will analyse how the variation of the above parameters influences the machine-tool optimality. As soon as we have established the sensitivity behaviour of machine-tool optimality we can then derive our general decision rules.

As we have now broadly indicated which type of analysis we will apply, something should be said about the level of aggregation on which the analysis will be carried out and which type of data will be applied. The analysis will be carried out at the most disaggregated level possible by applying engineering estimates of time data for metal-machining tasks which are defined for certain shapes, sizes, and precisions. For each task are listed alternative machines capable of carrying it out. Time data for each task on each alternative machine are used; time data consist of piece time (machine time and hand time) and setup time. Tasks are also used as the unit quantity of output; consequently a task unit is defined as an elementary machining operation with a particular shape, size and precision for a specific metal.

By assigning an investment cost to each machine and assuming that this study, as a first approximation, deals with only a one-machine—one-man relation, we know capital and labour requirements (piece times) per task per alternative machine.

By varying the prices of capital and labour in a discrete way, and by varying the lot sizes, we can analyse the price effect and the lot size effect on the optimal machine (sensitivity analysis A). The upper and lower sections of figure 1 illustrate respectively the lot size and the price effects on the total-cost function of one machine. The effect of a lot size increase on the total-cost function of the individual machine, for fixed and given prices of capital and labour, is two-fold:

(*a*) The slope of the curve is affected as the labour requirements per unit of output decrease (the fixed setup time is divided by a larger number of units in the lot);

(*b*) The annual productive capacity of the machine is increased. In a fixed, given number of annual productive machine and man-hours (which are identical under the assumption of a one-man—one-machine relationship) more units can be produced as the production time per unit is decreased by producing larger batches. Note that within each lot size there are constant returns to scale, as can be easily observed in figure 1. Shifting from lot size 1 to lot sizes 2 and 3 causes increasing returns to scale. This latter effect is one of the subjects of investigation.

The unit costs will be measured at the full utilization level expressed in time units on a one-shift basis of the machine. This assumption of full utilization is justified as we think in highly aggregated terms rather than at the level of the individual firm.

It could be argued that the various sizes of firms stand between the individual pieces of equipment and the aggregate output and that, at the firm level, the utilization is not necessarily 100 per cent; however, this author believes that, by varying the lot sizes between extreme boundaries, the variation in "productive utilization" of equipment covers all practical cases.

Figure 1 also shows what happens at the individual firm level, where the indivisibilities of machines are relevant. In an aggregate sense, the indivisibility aspect of the individual machines levels out. For this reason, we measure the lot size effect at the points of full utilization of the machines. Connecting the origin with the points of full utilization of a particular machine for a specified lot size, we obtain straight curves, as shown in the figure.

In figure 1B we illustrate the effect of price changes of capital and labour on the total-cost function of the individual machine for a given, fixed lot size. The annual productive capacity is now constant as the lot size is kept constant. Increasing the price of capital and decreasing the wage rate also has a twofold effect:

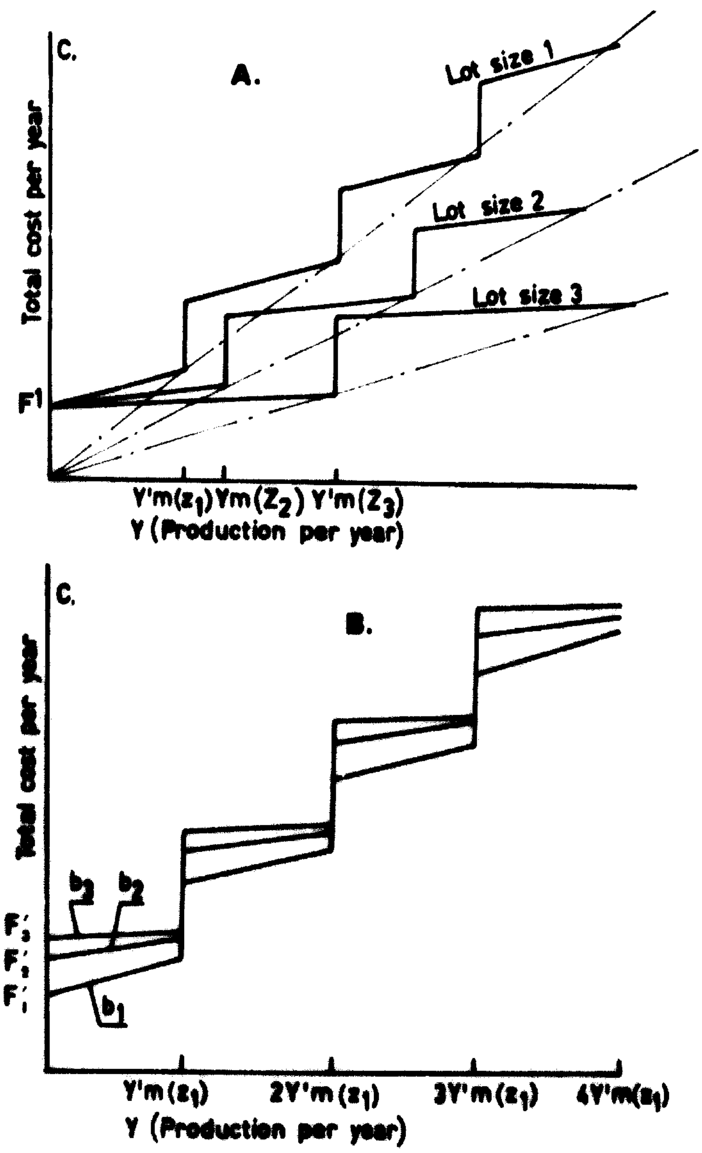

Figure 1

EFFECT OF INCREASING RETURNS TO SCALE ON TOTAL COST FUNCTION FOR ONE MACHINE FOR A GIVEN AND FIXED PRICE OF CAPITAL AND LABOUR

(*a*) The intercept, which measures the fixed cost, increases from F_1 to F_2 to F_3 in our example.

(*b*) The slope decreases as the price of labour is discretely lowered at the same time the price of capital is increased in a discrete way.

Unit cost will be measured at y_m for each capital-labour price set (figure 1B), and at each lot size z_d (z_1, z_2, z_3, etc., figure 1A).

For reasons of simplification, the figure shows only the total-cost function for one machine. In fact, for each individual task, there are as many cost functions as there are economically feasible machines to produce the task unit.

Analysis B is identical to analysis A except for the variations in the parameters mentioned earlier. By comparing the machine optimality in analysis B with the machine optimality obtained in analysis A, the sensitivity of machine optimality to the varied parameters as a group can be observed.

The analyses outlined above can best be characterized by the term sensitivity analyses, as they compare total capital and labour cost per task by keeping certain parameters constant and by varying certain others. From the changes in total unit cost, which lead to changes in optimality, the sensitivity of each parameter or group of parameters can be established.

Assumptions

The assumptions on which this analysis are based are:

(*a*) Complementary or intermediate inputs for each machine per unit of product are the same and consequently omitted. Hence, the analysis counts only the capital (in analysis A only the equipment capital, in analysis B the equipment capital and the capital invested in structures) and labour cost per task unit per alternative machine.

(*b*) It is assumed that equipment is used 2,000 hours a year. Effective utilization, measured in physical output per year per machine, varies considerably as a function of lot size variation. It is assumed that the fluctuations in physical output per year reflect reasonably well the fluctuations in annual capacity utilization in actual production circumstances.

(*c*) The annual potential productive capacity of the machines remains constant over the years and is measured in physical units, in other words, gross benefits remain constant.

(*d*) The lifetimes of all the machines are equal and constant.

(*e*) The cost of capital includes interest and depreciation. The interest rate is assumed constant throughout the lifetime of the equipment. Interest and depreciation are maintained constant per year by applying a capital recovery factor (CRF) in computation.

(*f*) Labour is considered a variable input, but the price of labour remains constant over the lifetime of the equipment. Under these assumptions, benefits and costs are constant over the lifetime of the equipment and there is no need to introduce a discounting procedure in the calculation. Total costs can be computed on an annual basis and remain constant for a given price of capital and labour.

(*g*) The cost functions are linear step functions under the assumption that, for a given lot size, labour inputs are constant per unit of output.

(*h*) Prices of capital and labour are exogenously given. Each set of capital and labour prices is assumed to be representative for a specified geographical area with a certain degree of industrial maturity.

(*i*) For reasons of simplification, we assume that the same task unit is produced the year around, varying the size of lots. In reality, not the same but comparable task units are produced the year around; however, this assumption of a uniform task unit in production simplifies the analysis considerably and does not affect the conclusions.

(*j*) Lot sizes are exogenously given under the assumption that they are dictated to the entrepreneurs by size and composition of demand.

The model

We will now present some of the most essential equations of the model, which all refer to one task unit, *j*. The following symbols are introduced:

- $\bar{c}$ — total capital and labour costs for task *j* on optimal machine
- c^i — total capital and labour costs for task *j* on machine *i*
- k — equipment capital for task *j* on machine *i* for a given lot size z_d
- j — task unit ($j = 1 \ldots 51$); subscripts *j*, however, will generally be omitted: the model refers to one task unit, *j*
- $l^i(z)$ — labour-output ratio for operator on machine *i*, task *j*, for a given lot size z_d
- m — subscript for annual capacity output of a machine
- n — number of shifts
- p^i — piece time on machine *i*
- r^* — price of capital (including depreciation) per year ($h = 1 \ldots 4$)
- s^i — setup time on machine *i*
- w^* — price of labour, per unit of time
- z^* — lot size ($d = 1 \ldots 7$)
- C^i — total capital and labour cost for annual production on machine *i*
- E — highest integral number smaller than U^i (if $U^i = 0$, $E = -1$)
- F — efficiency factors
  - F_a = for illness, holidays, etc.
  - F_B = for allowances for rest and personal care
  - F_y = for general efficiency level inside and outside the factory, to the extent that it influences the productivity of the individual operator (F_y is assumed to be 1 in analysis A)
- H — potential maximum annual number of machine working hours on a one-shift basis
- i — alternative machine, to produce a given task unit (superscript $i = 1 \ldots 5$)
- H^i — efficient annual number of machine working hours
- K — new price of machine *i* capable of producing task *j* in a given year and country, expressed in United States dollars
- U^i_m — degree of utilization at capacity output
- Y^i_m — annual capacity-output level of machine *i* expressed in tasks *j* for a specified shift pattern, lot size, and efficiency parameters (Y^i_m indicates a side condition)

Starting point of the model is a function for total cost:

$$C^i(r,w) = K^i\left[E(U^i) + 1\right] r + \left[l^i(z)\right] Y^i_m w \qquad (1)$$

where

$$l^i(z) = \frac{s^i}{z} + p^i \qquad (1.1)$$

and

$$H^i = F_a F_B F_y H \qquad (1.2)$$

and

$$Y^i_m(z) = \frac{nU^i_m H^i}{l^i(z)} \qquad (1.3)$$

then

$$\left.\begin{aligned} \frac{C^i(r,w)}{Y^i_m(z)} &= \left[\frac{K^i}{Y^i_m(z)}\right] r + \left[l^i(z)\right] w \\ c^i_m(r,w,z) &= \left[k^i_m(z)\right] r + \left[l^i(z)\right] w \end{aligned}\right\} \qquad (2)$$

where

$$\frac{C^i(r,w)}{Y^i_m(z)} = c^i_m(r,w,z) \qquad (2.1)$$

and

$$\frac{K^i}{Y^i_m(z)} = k^i_m(z) \qquad (2.2)$$

then

$$\bar{c}_m(z_d,r_h,w_h) = \min\left[k^i_m(z_d)\right] r_h + \left[l^i(z_d)\right] w_h. \qquad (3)$$

$$d = 1 \ldots 7 \qquad h = 1 \ldots 4.$$

Equation (1) gives the total unit cost equation with definitions of the basic relations in equations (1.1, 1.2, and 1.3).

Equations (2) give two versions of the unit-cost equation, with partial relations further explained in equations (2.1) and (2.2).

Finally, from equation (3), the solution of our problem comes as it states that the total capital and labour cost $\bar{c}$ for the optimal machine is a function of z_d, r_h, and w_h. By varying *d* from 1 to 7 and keeping *h* constant, changes in optimality of machines can be observed, which are due to lot size variation. By varying *h* from 1 to 4 and keeping *d* constant, changes in optimality that are due to price variation can be observed.

The foregoing refers to sensitivity analysis A. For analysis B, only minor changes in the basic model are needed. A new symbol is introduced $\dot{K}^i$, which indicates investments in space requirements needed for worksite around machine *i*; hence, the total investment for machine *i* is ($\dot{K}^i + K^i$). Equation (1.2) is revised as

$$H^i_l = 2F_a\, 2F_B\, F_y\, H \qquad (1.2.1)$$

Finally, instead of K^i, $2K^i$ is used in the equations for analysis B, as the machine investment is assumed as doubled.

Sources and significance of data used

The tasks

So far, we have only occasionally referred to the data. The basic sample was collected in 1955. The sample is complete in so far as it includes all the conventional metal-chipping and metal-cutting machines. The more recently developed numerically or tape controlled metal-

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* The symbols *r*, *w*, and *z* represent continuous variables; we consider only discrete values of these variables, indicated by subscripts *d* and *h*; however, in the model, these subscripts will be omitted in order to simplify the notation.

working machines are not included in the sample. With the conventional machines we mean all the metal-cutting and metal-chipping machine tools excluding electronically controlled machine tools.

As stated, the analysis is on the task level. How representative is such an analysis for the derivation of general conclusions? The point is that, in actual production circumstances, one works with parts. Very seldom does a part require only one machining task. Most commonly, multiple machining tasks have to be carried out on a part. If the time data by task, supplied by our basic sample, can just be added, yielding the same production time requirements as a part analysis could have given, there is no problem. In that case, one simply analyses which basic tasks have to be performed on whatever part one might be interested in and, after having determined the magnitude of the relevant parameters, the conclusions of our analysis are directly applicable.

After a careful investigation on this question, the conclusion is that for eleven tasks, except those involving the lathe family of machine tools, there is no significant difference between task and part analysis. For tasks involving lathing, there might be a difference because in lathes successive steps of mechanization can be distinguished most clearly. This means that, by carrying out a number of tasks in which a lathe is involved, one economizes on production times whenever, because of mechanization, tasks can be automatically changed, in various degrees, without interference by the operator.

For this reason, translating the task analysis into a part analysis will yield production times somewhat high for tasks involving turret lathes and automatic screw machines. However, after several trials with modified time data, our conclusion must be that the above indicated fact affects the outcome of our results in only a minor way.

Task characteristics

Tasks are characterized by shapes, size, and precision. Thirteen shapes, five sizes and three precision classes of the work piece were distinguished, as shown in table 8.

Table 8

CATEGORIES OF TASK CHARACTERISTICS

No.	*Category I: Geometric shape*	*Category II: Size of piece*	*Category III: Precision*
1	Flat surfaces, no contour	Very small	Semi-precision
2	Flat surfaces, external contour	Smatt	Precision
3	Flat surfaces, internal contour	Medium	High precision
4	Cylindrical surfaces, external	Large	
5	Cylindrical surfaces, interior	Very large	
6	Drilled holes		
7	Cylindrical forms, external		
8	Standard screw threads		
9	Standard gear shapes		
10	Complex shapes		
11	Irregular periphery, flat surface		
12	Multiple surfaces		
13	Multiple holes, drilled		

Prices

Four discrete values of h (price set of production factors) are used which can be roughly identified as those prevailing in North America, Western Europe, the semi-industrialized countries, and the under-industrialized countries. A price set is defined as a wage rate and a capital rate that are used in conjunction. The prices are presented in table 9.

Table 9

CAPITAL AND LABOUR PRICES

Region	*Interest rate per year*	*Lifetime of equipment (years)*	*Price set: Capital recovery factor (CRF)*	*Price set: Wage rate in US $/hr*
North America	5	10	0.12950	3.6
Western Europe ...	5	10	0.12950	2.0
Semi-industrialized countries ...	10	10	0.16275	0.45
Under-industrialized countries ...	15	10	0.19925	0.20

Lot sizes

For all tasks, seven lot sizes will be taken into account: 5, 10, 50, 100, 200, 300, and infinite. It is believed that the indicated lot size ranges cover all scales of possible production operations, that is, small-scale, medium-scale and large-scale production.

Efficiency rate

The basic data are corrected by certain allowances for fatigue and delay, varying with the type of machine, the degree of precision and the size of lots. In sensitivity analysis A they reflect normal annual production allowances common in the United States. In sensitivity analysis B, the allowances are doubled under the assumption that, because of differences in skill, differences in internal organization and differences in the organization of the economy at large, only half the efficiency can be obtained from those prevailing in the country with the highest industrial efficiency.

Sample size

Two sample sizes are distinguished. Sample size 1 includes all tasks for which (economical) feasible alternative machines are listed.

Sample size 2 includes tasks for very large pieces (size characteristics, category II, 5) and single observations. By single observations we mean tasks for which no alternative machines, no choice in equipment (or capital intensity or level of mechanization) exists. Sample size 1 includes fifty-one tasks; sample size 2, thirty-seven tasks of which four refer to size 5; and thirty-three to single observations. With the latter term we mean that for these tasks only one machine is listed as feasible and consequently no alternative can be chosen.

Summary for parameter values

In summarizing this section we present in table 10 the numerical values of the parameters that are varied in the analysis.

Table 10

NUMERICAL VALUES OF PARAMETERS

Price variation h	*Price set*	
	Wage rate in US dollars (w_h)	*Capital rate* (r_h)
1	3.6	0.12950
2	2.0	0.12950
3	0.45	0.16275
4	0.20	0.19975

Lot size variation d	*Lot size* (z_d) *(task units)*
1	5
2	10
3	50
4	100
5	200
6	300

As stated, the parameters for sensitivity analyses A and B are the same; however, in analysis B, capital includes the amount invested in floor space; fatigue and personal and work delay allowances are doubled and equipment capital for all machines is uniformly doubled also.

Problem formulation

Sensitivity analysis A

Problem: Separate the influences of the following parameters on the optimum technique:

1. The variation of the prices of capital and labour (respectively r_h and w_h, $h = 1 \ldots 4$).
2. The variation of the sizes of lots (batches or production runs) z_d, $(d = 1 \ldots 7)$.

Given: The given parameters can be divided into two categories:

1. Parameters that are kept constant
   (*a*) Equipment prices for alternative machines i;
   (*b*) Potential maximum number of machine working hours per machine per year;
   (*c*) Time data—for each task j, piece time (p = machine + labour time per task unit), and setup time (s = make-ready time)—for a number of identical task units on each alternative machine;
   (*d*) Shift pattern, degree of utilization, efficiency, etc.
2. Exogenously given, parameters that are varied in a discrete way—e.g., parameters for lot size, wage rate, and capital rate.

Procedure:

1. Find the optimal capital intensity of the machine (k = decision or independent variable) by determining the minimum total capital and labour costs ($\bar{c}$ = dependent variable) per task unit for each machine i.
   (*a*) Compute unit cost by equation (2) for each machine i for each value of r_h and w_h for a given and constant z_d.
   (*b*) Determine $\bar{i}$ by equation (3) for each value of r_h and w_h for constant z_d.
   (*c*) Determine if $\bar{i}$ is changing, giving r_h and w_h different values as $h = 1, 2, 3, 4$, for given and constant z_d.
2. Determine whether or not and to what extent a variation in lot size affects the optimum technique.
   (*a*) Compute equation (2) for each machine i for each value of z_d for given and constant r_h and w_h.
   (*b*) Determine $\bar{i}$ by equation (3) for each value of z_d for given and constant r_h and w_h.
   (*c*) Determine if $\bar{i}$ is changing, giving z_d its values as $d = 1, 2, 3, 4, 5, 6, 7$ for each given and constant r_h and w_h.

Sensitivity analysis B

Sensitivity analysis B is essentially the same as analysis A. Only parameters kept constant in analysis A, such as the equipment price and the allowances for labour, are varied in analysis B. In analysis B, the costs of structures for the worksite of the operator and the machine are included in the capital investment in addition to the price of the machine.

Results

By having discussed the model and the data we are now ready to feed the data into the model:

Labour-output ratios are computed with equation 1.1;
Annual capacity outputs per machine are computed with equation 1.3;
Capital-output ratios are computed with equation 2.2;
Total unit costs are computed with equation 2.
Equation 3 yields the result.

Results of analysis A

(*a*) Price effects of capital and labour occur whenever $\bar{c}$ shifts as a result of varying values of r_h and w_h for each given and constant value of z_d.

(*b*) Lot size effects occur whenever $\bar{c}$ shifts as a result of varying values of z_d for given and constant values of r_h and w_h.

Table 11 summarizes the degree of sensitivity to variation in the lot size parameters and indicates the variation in capital and labour prices for each task. The sensitivity to variation in lot size is defined as follows: for each task, for a given and fixed price set, the maximum number of changes in machine optimality due to lot size variation is equal to the number of economically feasible machines minus one, multiplied by four (the number of price sets).

Table 11

SENSITIVITY CLASSIFICATION TO VARIATION IN LOT SIZE PARAMETER

No. of alternative machines	*Maximum no. of changes*	*Sensitivity classes in number of changes per task in machine optimality*				
		N(none)	*L(low)*	*M(medium)*	*H(high)*	*V(very high)*
1	0	0				—
2	4	0	1	2	3	4
3	8	0	1, 2	3, 4	5, 6	7, 8
4	12	0	1–3	4–6	7–9	10–12
5	16	0	1–6	7–9	10–12	13–16

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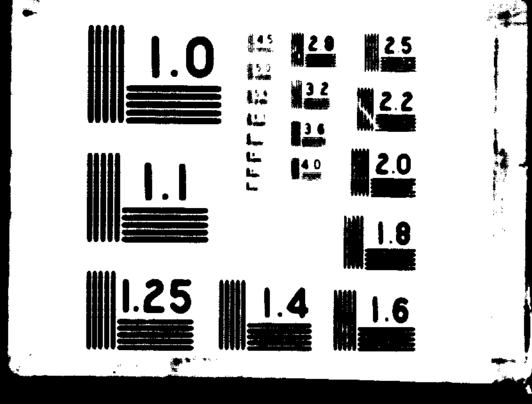


The sensitivity to variation in capital and labour prices is defined below. We distinguish the following optimality patterns, per task for each lot size, due to price variation. Each pattern of four X markings, as listed in table 13, has to be analysed independent of any preceding or following pattern.

Depending on the number of economically feasible machines, we classify the degree of sensitivity to price variation as in table 12.

Table 12

SENSITIVITY CLASSIFICATION TO VARIATION IN CAPITAL-LABOUR PRICE PARAMETERS

Number of alternative machines per task	*Maximum* number of changes in optimal machine*	*Sensitivity degree* N	L	M	H	V
1	—	—	—	—	—	—
2	14	—	≤2	3–5	6–10	≥11
3	21	—	≤4	5–10	11–16	≥17
4	28	—	≤6	7–12	13–20	≥21
5	28	—	≤7	8–14	14–25	≥26

* The number of price variations in the analysis is 4; the number of lot size variations is 7. The number of changes in machine optimality, owing to price variation, depends on the number of alternative machines per task. The maximum number of changes is the number of price variations multiplied by the number of lot size variations.

Table 13

Optimality pattern	*Number of variations in optimal machines for given and fixed za*
X X X X	0
X X X X	2
X X X X	2
X X X X	3
X X X X	2
X X X X	3
X X X X	3

X
    X
  X
X
	4

In table 14, each task is classified according to its degree of sensitivity for lot size and capital and labour price variation. For sample size 2, there is no sensitivity to either lot size and price variation, except for task 52, which shows some sensitivity to lot size variation.

Table 14

SENSITIVITY OF MACHINE OPTIMALITY TO LOT SIZE VARIATION AND CAPITAL AND LABOUR PRICE VARIATION

Analysis A

Task no.	*Lot size variation* N	L	M	H	V	*Price variation* N	L	M	H	V	*Number of economically feasible machines*
1			4						12		3
2			2						6		2
3			2						10		2
4		2							16		3
5					4		2				2
6				6					13		3
7					4	0					2
8					4				8		2
9				3				4			2
10					4		2				2
11					4	0					2
12			12						6		2
13				3					10		2
14	0					0					1
15	0					0					1
16				3				4			2
17					4		2				2
18				5				10			3
19					4		2				2
20			2						10		2
21					4		2				2
22	0					0					1
23					4		2				2
24				5					12		3
25					4				8		2
26				5				9			3
27					8			9			3
28				3					8		2
29		1					2				2
30			2						10		2
31			2						10		2
32			4					10			3
33			2							12	2
34		1								13	2
35			3						12		3
36			3						15		3
37		1								14	2
38	0						0				1
39		1								12	2
40		1								14	2

Results of analysis B

Machine price and efficiency rate effects do occur whenever $\bar{c}$ shifts as a result of doubling the machine price and reducing the efficiency rate of labour, keeping all other parameters and variations in parameters identical to analysis A.

The sensitivity of machine optimality to variation in the efficiency rate and variation in the equipment prices can be determined by comparing the optimality markings in analysis B with those of analysis A. Any change in machine optimality in analysis B compared to analysis A is the combined effect of the variation in the parameter values changed.

Table 15 indicates the sensitivity ranking for each task. For no task is a high or very high sensitivity observed. Considering sample size 1 from the fifty-one tasks, fourteen do not show sensitivity, twenty-six show low

Table 15

SENSITIVITY CLASSIFICATION TO VARIATION IN EFFICIENCY RATE AND MACHINE PRICE

Sensitivity	*Number of changes per task in machine-tool optimality*
None (N)	—
Low (L)	1 or 2
Medium (M)	2 to 7
High (H)	7 to 14
Very high (V)	> 14

Table 16

SENSITIVITY OF MACHINE OPTIMALITY TO MACHINE PRICE AND EFFICIENCY RATE VARIATION

Analysis B

Task	*Equipment prices and efficiency rate variation*					*Task*	*Equipment prices and efficiency rate variation*				
	N	*L*	*M*	*H*	*V*		*N*	*L*	*M*	*H*	*V*
1		2				26		1			
2	—					27			3		
3	—					28			3		
4		2				29	—				
5		1				30		2			
6			6			31		2			
7	—					32			4		
8		1				33			3		
9		1				34		2			
10	—					35		2			
11	—					36			4		
12		2				37		2			
13		2				38	—				
14	—					39		1			
15	—					40		1			
16		1				41		2			
17	—					42		3			
18		1				43		1			
19	—					44	—				
20	—					45			3		
21		1				46		2			
22		1				47			3		
23		1				48		2			
24			5			49			5		
25			3			50	—				
						51		2			

sensitivity and eleven show medium sensitivity. The additional thirty-seven tasks of sample size 2 show no sensitivity to variation of the relevant parameters.

III. DECISION RULES

From the results of the preceding, we can derive decision rules of a specific or a general character. We will first discuss the specific approach, then the general rules for decision on equipment purchases.

Specific procedure

One has first to decide whether analysis A or B best fits the country under analysis. (It was made sure that the omission of structure costs for work sites in analysis A had only a minor effect on the optimality patterns.) For example, because of transportation cost and the extreme scarcity of foreign exchange, an equipment price twice the one prevailing in the United States might indicate an equipment investment better in many countries than the price on the internal United States market. Also, the efficiency of many workers in the newly industrializing countries cannot yet match that of the operators in mature industrialized countries. Although application of double work allowances in analysis B is somewhat exaggerated, in the context of this analysis it is better to overestimate rather than to underestimate the variations. The results of analysis B may then be considered as the least favourable limit, and analysis A as the most favourable limit of efficiency and equipment price variation. By presenting the upper and lower boundaries of machine-tool optimality patterns in this analysis, it is believed that worthwhile insight is supplied, the more so as this refers only to efficiency variation and equipment price variation, while the variations in capital-labour prices and lot sizes cover all possible production circumstances.

Generally speaking, analysis A refers to industrialized countries, analysis B to underindustrialized countries.

The next step for the decision makers is to determine, in detail, the task characteristics of their product mix. Hence, what kinds of shapes do we produce, which piece sizes, and what degree of precision do we need? If the annual product mix is roughly translated into tasks, as defined in this report, an estimate must be made about the average size of lots in which production will be carried out, say, in the next ten years. Also, the trend in the capital and labour prices has to be estimated. As equipment may last for ten to twenty years, we should make an optimal choice not on the production circumstances of today, but on some period that will be more representative in the future. This means, in general, that we have to count on a higher wage rate and a somewhat lower interest rate than the one prevailing today.

General procedure

The more general approach for a decision procedure on machine optimality is to list which tasks are sensitive to which parameters and to make some generalizations from this. This information is useful as a basis for decisions on machine-tool optimality.

Generalizations from analysis A

In table 14, the degree of sensitivity was indicated for lot size variation and for variation into the price of capital and labour for each task. From table 14 we derive table 17. In table 17 we distinguish ten categories of sensitivity for the effect of capital and labour price variation and for lot size variation on machine optimality.

Table 17 also can be aggregated into four major groups: A, B, C and D.

Group A consists of categories a, d and e. These are the subgroups which show a very high, or high, price sensitivity and respectively none, low and medium lot size sensitivity. Hence, the sensitivity to price is predominant in this group.

The practical implication is that, for tasks falling into this group, one should be alert to the level of capital intensity optimal in each country, as one may expect optimality to change for the four capital labour price areas, which we distinguished.

However, as the tasks involved are not very sensitive to

Table 17

SENSITIVITY CATEGORIES FOR PRICE AND LOT SIZE VARIATION ON MACHINE OPTIMALITY

Category	No. of tasks: Absolute	No. of tasks: Per cent	Definition of category sensitivity ranking: Price	Definition of category sensitivity ranking: Lot size	Task no.	Definition of task: Shape	Definition of task: Size	Definition of task: Precision
a		10	Very high	(None) low	34	7	3	1
	5	10			37	8	2	1
					39	9	2	2
					40	9	3	1
					49	12	3	2
					6	2	2	1
			High	(Very) high	8	2	2	3
b					13	3	2	1
	7	13			24	5	2	2
					25	5	2	3
					28	5	3	3
					45	12	1	1
					1	1	2	1
					2	1	2	2
			(Very) high	Medium	3	1	3	1
c	10	19			12	2	4	2
					20	4	3	1
					30	6	2	1
					31	6	2	2
					33	7	2	2
					35	7	3	2
					36	8	1	1
					4	1	3	2
					42	10	4	2
d	2	4	High	Low				
e	2	4	Medium	Medium	32	7	2	1
			Medium	Low	41	9	3	2
f			Low	Very high	5	1	4	1
					10	2	3	2
	7	14			17	3	3	2
					19	4	2	2
					21	4	3	2
					23	5	2	1
					50	13	1	1
					9	2	3	1
					16	3	3	1
g			Medium	(Very) high	18	4	2	1
	9	18			26	5	3	1
					27	5	3	2
					46	12	1	2
					47	12	2	1
					48	12	2	2
					51	13	1	2
					29	6	1	1
h	2	4	Low	Low	43	11	2	2
					14	3	2	2
i			None	None	15	3	2	3
					22	4	3	3
	5	10			38	9	2	1
					44	11	3	2
					7	2	2	2
j	2	4	None	Very high	11	2	4	1

Table 18

SENSITIVITY CATEGORIES AND TASK CHARACTERISTICS

(Analysis A)

Group	Category	No. of tasks	Shapes 1	2	3	4	5	6	7	8	9	10	11	12	13	Size 1	2	3	4	Precision 1	2	3
																				3	2	
	a	5							1	1	2			1			2	3				
A	d	2	1															1	1		2	
	e	10	3	1		1		2	2	1		1				1	5	3	1	5	5	
		17	4	1		1		2	3	2	2	1		1		1	7	7	2	8	9	
	b	7		2	1			3						1		1	5	1		3	1	3
B	c	2							1		1						1	1		1	1	
		9		2	1			3	1		1			1		1	6	2		4	2	3
	f	7	1	1	1	2		1							1	1	2	3	1	3	4	
C	j	2		2													1		1	1	1	
	g	9		1	1	1		2						3	1	2	3	4		5	4	
		18	1	4	2	3		3						3	2	3	6	7	2	9	9	
	h	2						1					1			1	1			1	1	
D	i	5			2	1					1		1				3	2		1	2	2
		7			2	1		1			1		2			1	4	2		2	3	2

lot size variation, there will be not much choice among optimal machines as to scale of operation such as between small, medium and large, within one price area.

In respect to generalization of task characteristics we can state that tasks, which involve shapes 7, 8, 9, 10 and 12 give very high and high price sensitivity and low lot size sensitivity. Shapes 1, 2, 4, 6, 7 and 8 give, also, very high price sensitivity, but now there is also a medium sensitivity to lot size. See table 18 for more details.

Group B consists of categories b and c. The tasks in these subgroups show a high or medium sensitivity to both lot size and price variation. The practical implication is that the optimality of the machines producing these tasks is, for areas with different levels of economic development, sensitive to the various price values of capital and labour and, within each area, sensitive to the scale of operation.

Primarily, shapes 2, 5 and 12 are involved with small piece sizes.

Group C consists of categories f, j and g. The tasks in these subgroups are predominantly sensitive to lot size variation.

Of the eighteen tasks involved in the three categories f, j and g, thirteen concern cases in which only two machines became optimal.

According to our sensitivity classes, when there are four changes because of lot size, they fall in the class of very high lot size sensitivity.

In all these cases a phenomenon occurs that we like to call an optimality break, which means that for all price sets a certain lot size variation causes a uniform shift in optimality. For other tasks, this optimality break occurs in two or three steps. We indicate below for which tasks this optimality break occurs respectively for 1, 2, 3 lot size steps.

The practical implication of this phenomenon is that for certain tasks, anywhere in the world above a certain critical lot size the same machine is optimal, independent

	Task definition			Optimality break due to lot size variation					
Task no.	Shape	Size	Prec.	Lot size z_2	No. of changes	Lot size z_3	No. of changes	Lot size z_4	No. of changes
5	1	4	1	10	1	50	3	—	—
7	2	2	2	—	—	50	4	—	—
9	2	3	1	10	2	50	2	—	—
10	2	3	2	—	—	50	2	100	2
11	2	4	1	—	—	50	4		
16	3	3	1	10	1	50	2		
17	3	3	2	10	2	50	2		
19	4	2	2	10	2	50	2		
21	4	3	2	10	2	50	2		
23	5	2	1	—	—	50	3	100	1
50	1	1	1	—	—	50	3	100	1

of the price variation. For lower lot sizes than a critical range there is lot size and price sensitivity, hence for the smaller scale production processes. Although all these tasks are classified as highly sensitive to lot size variation, the variation itself is concentrated in a narrow range, mostly between lot sizes 10–100. From then on there is no, or very little, sensitivity to lot size, as well as to price variation.

Group D consists of categories h and i. The tasks in these groups show no or low sensitivity to both lot size and price variation. The practical implication is that metalworking tasks within these two sub-groups have to be carried out by the same level of mechanization anywhere in the world.

Generalizing further, we can say that the smaller the workpieces (task units), the lower the precision requirements; the more common the shapes of especially flat, cylindrical and multiple surfaces, the higher the price and lot size sensitivity will be.

The findings for sample size 2, the thirty-seven tasks with no price and lot size sensitivity confirms, in a sense, our generalization based on sample size 1.

In sample size 2, for example, eleven tasks concern very large pieces, nine tasks concern large pieces; eight tasks require high precision, fourteen tasks require precision, and eight tasks concern complex shapes and irregular periphery flat surfaces. Here we find, in general, larger sizes, higher precision requirements and less common shapes which tend to reduce the number of economically feasible machines and consequently the possibility of price and lot size sensitivity.

Generalizations from analysis B

As to variation in the efficiency rate and the price of the machine, we notice from table 16 that no single task shows high or very high sensitivity.

From tables 19 and 20 we may conclude that primarily tasks (sensitivity ranking M) with shape 5 (cylindrical surfaces, interior), shape 7 (cylindrical forms, external) and shape 12 (multiple surfaces) show medium as well as low sensitivity.

Certain tasks (sensitivity ranking L,N) with flat surfaces (1, 2, 3), cylindrical surfaces (4, 5), drilled holes (6, 13), and standard gear shapes (9), show low sensitivity, certain others with the same task characteristics show no sensitivity.

In general, one can say that all tasks sensitive to price variation will be, in principle, also sensitive to a doubling of the equipment price.

Reducing the efficiency rate will favour the more mechanized equipment types relative to the less mechanized equipment types as, with the former, the speed of work is dictated more by the machine. This will, in principle, reinforce the lot size sensitivity. The combined effect of equipment price doubling, which favours the less capital-intensive alternative machines, and reducing of the efficiency rate, which favours the more capital-intensive alternative machines is, to a certain extent, compensatory.

Concluding remark

The general decision rules are necessarily less precise. Most important is: what kind of tasks will be most frequently produced? In part III of this study we have indicated for which kind of tasks one may expect various degrees of sensitivity in machine optimality, for variation in the prices of capital and labour and in lot size (analysis A), and the sensitivity to variation in the price of the machine and the efficiency rate (analysis B). As soon as one, on the basis of this general information, may expect sensitivity, more accurate information can be obtained by following the decision rules outlined in the first section of part III.

Table 19

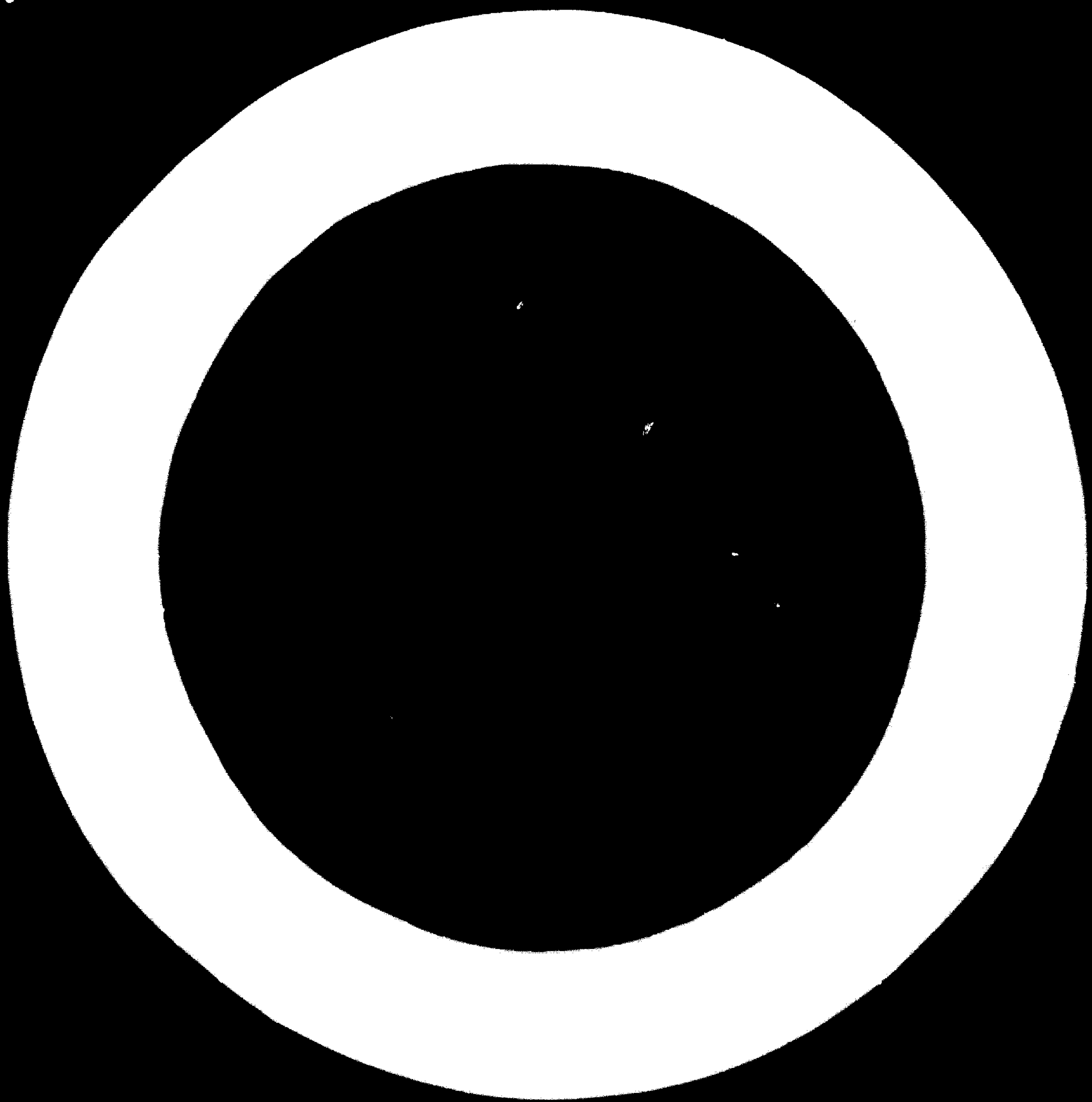
SENSITIVITY CATEGORIES FOR EQUIPMENT PRICE AND EFFICIENCY RATE VARIATION ON MACHINE OPTIMALITY

No. of tasks	Definition of category sensitivity ranking	Task no.	Definition of task		
			Shape	Size	Precision
		6	2	2	1
		24	5	2	2
		25	5	2	3
11	Medium (M)	27	5	3	2
		28	5	3	3
		32	7	2	1
		33	7	2	2
		36	8	1	1
		45	12	1	1
		47	12	2	1
		49	12	3	2
		1	1	2	1
		4	1	3	2
		5	1	4	1
		8	2	2	3
		9	2	3	1
		12	2	4	2
		13	3	2	1
		16	3	3	1
		18	4	2	1
21	Low (L)	21	4	3	2
		22	4	3	3
		23	5	2	1
		26	5	3	1
		30	6	2	1
		31	6	2	2
		34	7	3	1
		35	7	3	2
		37	8	2	1
		39	9	2	2
		40	9	3	1
		41	9	3	2
		42	10	4	2
		43	11	2	2
		46	12	1	2
		48	12	2	2
		51	13	1	2
		2	1	2	2
		3	1	3	1
		7	2	2	2
14	None (N)	10	2	3	2
		11	2	4	1
		14	3	2	2
		15	3	2	3
		17	3	3	2
		19	4	2	2
		20	4	3	1
		29	6	1	1
		38	9	2	1
		44	11	3	2
		50	13	1	1

Table 20

Sensitivity categories and task characteristics (Analysis B)

Sens. cat.	No. of tasks	Task characteristics: Shape 1	2	3	4	5	6	7	8	9	10	11	12	13	Size 1	2	3	4	Precision 1	2	3
M	11	—	1	—	—	4	—	2	1	—	—	—	3	—	2	6	3	—	5	4	2
L	26	3	3	2	3	2	2	2	1	3	1	1	2	1	2	11	10	3	12	12	2
N	14	2	3	3	2	—	1	—	—	1	—	1	—	1	2	6	5	1	6	7	1



ORGANIZATION OF A MACHINERY CENSUS AND USE OF CENSUS DATA WITH SPECIAL REFERENCE TO INDUSTRIALLY DEVELOPING COUNTRIES

***Anderson Ashburn, Editor*, American Machinist**

INTRODUCTION

An inventory, or census, of machine tools and other production equipment used by the metalworking industries is taken in a number of countries. In some countries this has been done only once, in others the studies have been repeated at fairly regular intervals.

All of the studies have certain features in common. This is fortunate because it permits a nation starting such a study for the first time to find reports with which useful comparisons can be made. It also suggests that any country about to plan such a census would do well to follow the general pattern.

The first known national count of production equipment was in the United States in 1925 by *American Machinist*, a magazine published by McGraw Hill Inc. of New York. The editor at that time was Kenneth H. Condit and the general manager was Mason Britton. They developed the concept. The study was directed by William E. Irish, associate editor.

The reason for that first inventory was plainly stated: "For fifty years the *American Machinist* has served the makers and users of metalworking equipment of all kinds. From its first issue it has urged the use of the most modern equipment and the scrapping of obsolete tools. Now, to advice and exhortation, it takes pride in adding actual figures on the extent to which modern equipment is in use. It is hoped that users of equipment of this type will study the figures to make sure that their own equipment is in better shape than the average, and that builders will find in the figures texts for sales arguments to present to ultra-conservative buyers."

The original purpose then was to provide a measure of the degree of modernization in industry. It was obvious that some yardstick was needed for measuring obsolescence and the yardstick chosen was age, with the dividing line being an age of ten years.

The originators recognized that it would be more logical to apply different age standards to different types of equipment or to evaluate the productivity of each individual machine, but they also recognized that neither course was practical. They said that a "survey like this one would fall of its own weight if it attempted to be too precise and in so doing introduced into the questionnaire a mass of complication so forbidding that no one in his senses would attempt to answer it. Furthermore, the task of analysing data based on different standards of machine life would be quite beyond the bounds of practicability."

Although the ten-year yardstick has to be used with understanding, it proved so satisfactory that it has been adopted by the organizers of every other census in which any effort is made to measure modernization.

But even that first inventory had important uses besides the stimulus to modernization. The facts about the distribution of different kinds of equipment in different industries proved different from what most people concerned with industry had thought. It turned out that not nearly so much concentration of specialized machines in certain industries existed as had been generally thought. Thus, the screw-machine products industry had scarcely 6 per cent (in 1925) of the screw machines, the bulk of the machines actually being used to make parts in other industries.

The first inventory also pointed up the problem of a lack of a well-defined distinction between different classifications of equipment. This led to a study of how to classify machine tools. A Subcommittee on *American Machinist's* Questionnaire, in the Durable Goods Industries Committee of the United States Government, was formed. The problems of nomenclature for machine tools will always be with us, but today we have general agreement on most of the older types of machines.

The results of that 1925 inventory were published on 12 May 1927. It may be of interest that they showed that 44 per cent of the equipment was at least ten years old. The total number of machine tools reported in metalworking plants in the United States was 920,000, and the estimated total in the country in all industries was 1.2 million machine tools.

Interest in the inventory was so great that it became a regular part of *American Machinist* operations. That first inventory included sixteen different industrial classifications but did not include any geographic breakdown. The 1930 inventory was made on the same industrial basis but added a geographic split into eight areas.

Basic changes were made in 1935. Division into twenty industrial categories was made and the geographic division was enlarged. This arrangement was continued in 1940 and 1945.

Extensive changes also were made in the fifth inventory in 1949. The industrial and geographic breakdowns were revised and there was an added age category to show equipment more than twenty years old. The geographic pattern was revised again in 1963 but has remained unchanged since then. The industrial division has been refined almost at each new inventory. The most recent inventory, the ninth, taken in 1963 reports on equipment in forty-four industry categories, twenty-four geographic areas, and three age classifications.

The types of equipment studied, and the method of classifying them, have also been changed. In the first inventory 117 types of equipment were charted. A number of peripheral types have since been dropped and other types have been subdivided. Currently, the inventory covers 166.

Many of these changes have been made reluctantly because of the problems they create in comparability of one study with the next. They were made because experience in using the studies or changes in the structure of the machine-tool park made them desirable. Some changes can be made without creating a problem. To subdivide a type of equipment, an industry, a geographic area, or an age period does no harm. It provides more detail, without damaging comparability. Thus, a classification of automatic bar machines can be subdivided into single- and multiple-spindle with no loss of the ability to make comparisons with previous years, but with a clear gain in information. However, if two geographic areas are divided into three along different lines, there is a clear loss in comparability.

Currently, basic changes in the approach will have to be made to accommodate the basic changes in equipment created by the rapid spread of numerical control.

The next country to undertake a comparable study on a regular basis was Japan. The first Japanese census of machine tools was made in 1952. A second was made in 1958 and a third in 1963. I believe it is the current intention to repeat the study at five-year intervals. The Japanese study is made by the Machine Tool Equipment Group, Machinery Statistics and Survey Department, Survey and Statistics Bureau, Ministry of International Trade and Industry (MITI).

The Japanese study gives results for seventeen types of metal-cutting and metal-forming machine tools and for welding equipment. Classifications are by size of plant (six), by type of industry (eight), by area, and by age (under five years, five ten, ten–fifteen, fifteen–twenty, more than twenty years).

France was the next country to undertake the study on a regular basis. The first French study was in 1955 and subsequent studies were made in 1960 and 1965. At the time of this writing, the 1965 report had not yet been issued, so the 1960 report is here treated as the latest. The studies are by the Department of Electrical and Mechanical Industries of the Ministry of Industry.

The 1960 study reports on twenty-four types of metal-cutting and metal-forming machine tools. It covers nine industries and provides a detailed age breakdown. The original study broke ages into five, ten, twenty and thirty years. The second study made it five, ten, fifteen, twenty-five and thirty-five years. The third study will cover five, ten, fifteen, twenty, thirty and forty years. The reason for this approach is that the study is tied to fixed calendar years of acquisition (before 1925, 1926 to 1935, etc.) No geographic breakdown is considered necessary by the French.

There was discussion for some time of a census in Canada, and various groups approached *American Machinist* about enlarging its inventory to include Canada. *American Machinist* felt that such a study should be made by a local organization and offered to assist such an organization in establishing procedures.

The first Canadian census was made in 1958 by *Canadian Machinery and Metalworking*, a magazine published by MacLean-Hunter in Toronto. The procedure was essentially the same as in the United States, except that no area division was made. The study is scheduled for five-year intervals and was repeated in 1963. At that time it covered sixteen industries and 159 types of equipment.

In Italy, a census was made to cover the status of machine tools at the end of 1958. ISTAT (Instituto Centrale di Statistica), the official Government statistical agency, made the study at the request of UCIMU (l'Unione Costruttori Italiani Macchine Utensile), the Italian machine-tool builders' association. It was originally planned to make the study every five years.

The Italian study was extremely detailed. It covered sixty-five types of equipment, fifty-nine industries and ninety-one geographic areas. Equipment was classified into age categories with divisions at five, ten and twenty years. Equipment in all classifications is reported as of domestic or foreign origin.

There was an earlier study made in Italy, in 1938 by ISTAT, but it was not made public.

A similar study was also made in Germany in 1938, but not published. In 1953, a study was made in West Germany by VDMA (Verein Deutscher Maschinenbau-Anstalten), the machinery association with headquarters in Frankfurt-Main. This study has not been repeated.

In 1960, a report on the steps needed to increase productivity in Great Britain was made by a Royal Commission. Known as the Mitchell Report, it recommended that a regular count be made of machine tools in Britain similar to *American Machinist's*.

A McGraw-Hill company in Britain was selected for the work by the Machine Tool Trades Association. The survey was made in 1961 by *Metalworking Production*, published near London.

A second British census was taken early in 1966 and published during the summer of 1966, but was not available when this paper was prepared. That census covers sixteen industries and 174 kinds of equipment. In addition to reporting on age groups divided at ten and twenty years, it reports on whether the machines are of domestic or foreign origin.

The Economic Commission for Latin America (ECLA), an agency of the United Nations, has been instrumental in three censuses. The first, in 1960, was in Brazil and reported on forty-four types of equipment in four industries. No age data was included. This study was made in co-operation with the National Development Council.

A more detailed study was made in Chile in 1962. This included thirty-six types of equipment, fifteen industries, four plant size categories, three areas, and age groups dividing at ten and twenty years. This study was made by the Instituto Chileno del Acero (Chilean Steel Institute).

In 1963, a census was made in Argentina by ECLA in co-operation with CONADE (Argentine National Development Council). At the time of writing, copies of the Argentine study were not published, although some data from it was available. One previous study had been made in Argentina in 1957 by the Chamber of Machine Tools, but it was based only on estimates provided by machine-tool builders. The 1963 study included some 2,000 plants using machine tools.

In addition to the censuses that have been described, most of which are published and made available to plant managers, engineers and others, there are a number of countries in which the governments, often through machine-tool research institutes, conduct periodic censuses of machine tools used by central planning organizations but not made generally available. Such studies are generally similar in nature to the public censuses described here. However, because they cannot be used on a broad basis by plant personnel for evaluating performance or for determining market requirements, their usefulness is limited. They are, therefore, outside the scope of this paper.

To summarize this historical introduction, there are now nine nations which have relatively current censuses of machinery installed in production plants. It may be interesting to note that in three (Canada, Great Britain and the United States) a census is made on a regular basis by a private publishing company. Three others (France, Italy, and Japan) have censuses taken on a regular basis by a Government agency. The other three nations (Argentina, Brazil and Chile) have censuses taken co-operatively by an agency of the United Nations and agencies of the Governments.

Organization of the censuses

Now a closer look at the method of operation of these censuses: Because *American Machinist* Inventory of Metalworking Equipment is the original census, having been taken nine times since 1925, and has set a general pattern for all the others, and also because it is the one with which I am most familiar. I will describe the procedure in some detail and then comment briefly on the variations in the other countries.

The current procedure for a census begins with a careful review of the types of equipment to be included. Suggestions are invited from many quarters—government agencies, marketing consultants, and users and manufacturers of machine tools. All the suggestions are arranged in the order of types of the last previous inventory; then, a group of experienced senior editors reviews each proposal in turn. Consideration must be given to developments in types of equipment since the last inventory, but changes must be held to a minimum to preserve continuity.

The *American Machinist* inventory is confined to plant equipment in the metalworking industries. Note that it includes equipment used for maintenance purposes in these industries and equipment used in toolrooms as well as production equipment. But it does not include machine tools used for maintenance or toolroom work in other industries such as chemical, tobacco or wood, or in transportation or service operations. It has never been felt that the need for accurate information in these areas was great enough to justify the time and expense of collecting the data.

The United States Government has developed a classification system for machine tools, called the "Production equipment code". Similar coding systems have been developed in a number of countries. This system is followed, in selecting the classification of types of equipment, as closely as seems practical. At the time of any given inventory, there always seems to be some significant types for which code numbers have not been developed, and in these cases we depart from the code.

The major problem with the next Inventory is how to integrate data on numerically controlled machines. Several methods have been proposed, but none meets all the requirements.

During the same planning stage, final determination is made on the other classifications. No change has been made in the age classification since 1949. Originally, the inventory provided two categories: less than ten years old and older. No date could possibly be selected on which all machines would suddenly become obsolete, but a uniform standard of some kind is essential.

Because many types of machine tools have considerable useful life after their tenth year, there were pleas to broaden the yardstick. This was done in 1949 when the twenty-year division was added.

It has been suggested from time to time that a five-year measure should also be added, but this is not considered necessary; with data divided into three groups at the ten- and twenty-year marks and with detailed data on the yearly shipments of machine tools available, it is possible to make interpolations of equipment holdings that are accurate enough for most purposes.

Industrial classification is a more difficult problem. Every manufacturer would like to see a classification that included only his plant and his direct and close competitors. Thus he would be able to make studies of his own capability. The tendency over the years has been to provide ever more detailed industrial breakdowns. In the 1963 inventory, the data was broken into nine major industries and these were in turn divided into subgroups to make a total of forty-four separate industry groups on which data was tabulated. These groups follow the Standard Industrial Classification (SIC) format. Geographic classification has not been changed since 1953. A division into twenty-four areas that follow natural trading habits within the country has been developed. This proves satisfactory to most people, though there are always some who would like to see a finer geographic breakdown.

No classification of the data has ever been made on size of plant other than to run small demonstration studies to give an indication of the relationship. Data on size of plant is available, of course, so that such a study could be made.

The method of tabulation that is going to be used should be fully developed during the planning stage and the questionnaire should then be designed to suit it. In the case of the *American Machinist* inventories, the early ones were tabulated with adding machines. Later, ten or a dozen plant reports at a time were summarized by high-speed electric equipment after the data was punched on cards. It has not yet been determined whether the data will be handled by card or by tape for the next inventory. With each change, the form and spacing of the questionnaire has been adjusted to suit the changed methods of tabulation.

The questionnaire is complex, and in the case of a large plant requires much time to fill out. Filling out the forms for the *American Machinist* inventory is, of course, not compulsory. Therefore, the inventory represents an expansion of a sample.

To obtain the sample, questionnaires are sent to each plant, in the metalworking industries, that has twenty or more employees. McGraw Hill maintains a census of manufacturing plants that is used as the mailing list. For the 1963 inventory, this census contained 34,266 plants in the metalworking industries. Repeat mailings were made to all the plants that did not reply. Three mailings were made in all. A total of 7,370 plants returned questionnaires that could be used in the tabulations. These plants represented 21 per cent of the plants in metalworking and employed 27 per cent of the 7,448,000 production workers.

Each questionnaire was classified according to industry (forty-four) and area (twenty-four). Thus, questionnaires were sorted into 1,056 cells. Each of these cells was expanded individually by data processing equipment. Incidentally, in placing the data on cards it was necessary to use one punched card for each type of equipment in each plant. While the cards used for the 1963 inventory were never counted, there were an estimated million.

Expansion is based upon employment ratios. In each cell, containing plants in one industry and one geographic area, it is assumed that there will be a consistent ratio between workers and each type of machine. In addition to the expansion based on size of sample, a small correction is put into each industry, varying for each, to correct for the omission of plants with less than twenty employees.

In addition to a single summary table that reports the total amount of each type of equipment, by age group, tables are prepared and published showing the totals for each industry and for each area. Because this is the form in which most planners in plants would use the data, these tables are given wide distribution through publication in the magazine and through distribution of reprints. For some purposes, it is more convenient to have the data arranged by type of equipment rather than by industry and area; thus, the same data is also assembled into equipment tables. A single table, for example, shows the number of each type of boring machine in each industry and, in each area, by age group. Because these tables present the same data, they are not published in the magazine but are available to those who find this arrangement more convenient.

The 1963 inventory was to represent conditions in January 1963. The first mailing of data forms was in December 1962, with the second and third mailings in January and February. Data collection was complete in March. The results were published in June 1963.

The latest Japanese study covered equipment in the following basic classifications: lathes, drilling machines, boring machines, milling machines, planers, grinders, transfer machines and other cutting types; bending machines, hydraulic and mechanical presses, shearing machines, forging machines, wire forming, die casting, and arc and resistance welding.

Plants are classified into eight industries in the Japanese study: iron and steel, non-ferrous, metal products, machinery, electrical machinery, transportation equipment, precision instruments, and ordnance.

MITI prepares the survey forms and distributes them to local government offices. The local offices hire people to call at the plants with the forms. MITI reports that it surveys all plants with thirty or more workers and samples every sixth plant with four to twenty-nine workers.

The French study is done on a sample basis, expanded by the use of data on the number of workers. The original French study, done in 1955, had considerably more detail in both type of equipment and industry than did the 1960 study. The reason for the reduction seems to have been that "particular difficulties were encountered, coming not only from the inherent imprecision of studies by sample when individual cases offer great disparity, but also from errors concerning the age of the machines, errors made rather frequently, it seems, in answering the poll, and resulting in certain contradictions in the results", according to Henri Ournac, chief engineer, of the Ministry of Industry, in his introduction to the 1960 study.

Because of this problem, the French have undertaken an interesting study to see if it is possible to develop mortality tables (*la loi de riblonnage*) predicting the number of machines that will be kept in service at any given time. The French do not propose to replace the five-year census with the mortality study—they intend to continue and to try to improve the census. However, they feel that with the new law serving as a bridge between the censuses and the annual reports on new machines placed in service, more continuous data on industry would be available. There is also the possibility of using the mortality law, if it can be developed, to forecast future trends.

By far the most complete and detailed census of machine tools I have ever seen is the one made in Italy in 1958. ISTAT reports that it gets data from more than 90 per cent of the machine tool users and it reports in great geographic detail—dividing the country into ninety-one areas. The detail on types of equipment is not as great as in the United States, but the detail on industry and age is greater. Perhaps the work involved in such detail is the reason that the census has not been repeated on the planned five-year schedule.

The Canadian and British censuses are very much like the one in the United States, both in terms of the detail they include and the manner in which they are handled.

The censuses in Latin America are probably more similar to the first census that would be made by any developing nation than are any of the ones we have discussed so far. In each case ECLA, familiar with the *American Machinist* inventory, has provided technical assistance and encouragement.

In Brazil, ECLA actually did the entire job in co-operation with local government agencies. The first requirement for any such census is details on the number, type, size and location of the manufacturing plants. In Brazil in 1960, this information existed only in the State of São Paulo. As a result, the Brazilian census is really a sample study of the State of São Paulo which has afterwards been extrapolated to cover the entire country. Although ECLA has not indicated any intention of continuing the study in Brazil, the Brazilian Association for the Development of Basic Industry (ABDIB) is reported to be planning the continuation of the census on a regular basis.

In Chile, data was first collected by mail, followed by a personal canvas by students at the universities. Altogether, it was estimated that 75 per cent of the industry of the country was covered. All the tabulations were handled by punched card (the people handling the census were following in detail the procedures followed by *American Machinist*). However, details by industry and area were given as reported and only the grand total was expanded to represent the probable total for the entire country.

Utilizing inventory data

As with any basic set of statistics, many uses can be made of the information in a machine-tool inventory. There are four basic groups that can use this data to advantage.

Simple, direct comparisons can be made by the managers of individual plants. This is easiest to do when the plant has retained a copy of the report it has filed on the machines in the plant. This report can be compared with various classifications of the finished inventory.

One of the most effective tools of modern management is to gauge performance of a plant in comparison with other plants of similar nature, using various factors and ratios that can be precisely measured. With the machine-tool inventory, the manager can measure the ratios of new to old equipment, of distribution among various types of equipment and of proportion between workers and machines. In the United States, a number of large companies with multiple plants prepare studies comparing the various plants with each other and with other plants doing similar work.

There have been cases in which such comparisons have revealed that a plant was falling behind in equipment modernization. This may be revealed either by a declining percentage of new machines, by a significant shift by the rest of the industry to new types of machines, or by a sharp difference in the ratio of machines to workers in the plant.

In a period when international trade competition is growing, the plant manager may also find it worth his while to see how his plant stands in comparison with competitors in other countries.

The second group that can make effective use of a machine-tool inventory is made up of firms that manufacture machine tools. Such a study will give a more detailed picture of the nature and location of the markets for machine tools than can be obtained in any other way.

The third group that can use the inventory is made up of the firms that manufacture products used in conjunction with machine tools. These may be cutting tools, holding devices, electric motors, bearings, other parts or accessories, or they may be materials processed by the machines. For all these firms, data on machine tools provides much the same type of information on the nature and location of markets in an indirect fashion that are provided directly for machine-tool builders.

For example, a plant that manufactures dies for thread-rolling machines will find that data on the number and location of thread-rolling machines will be of great help both in planning the distribution method and in evaluating the performance of the people responsible for distribution.

Both of these groups will need data that is detailed as to type of machine and industry classification and (if the country is large) which divides the country into logical areas.

Finally, the data contained in such inventories is valuable for national planning by government agencies and by associations or groups of firms. The data helps measure the direction and extent of changes that are taking place in the production capability of the nation. Such data gains in value as it becomes available at repeated intervals.

On the national level, such data can be of particular value in discovering whether particular industries need additional incentives for development. In the United States, for example, the *American Machinist* inventories have provided evidence that was influential in the revision of tax policy as it related to capital equipment.

Inventory requirements

Any country that plans to conduct a census or inventory of metalworking equipment must start with a list of the plants using such equipment. If a good list does not exist, the first step is to compile one.

In many countries, such a census of manufacturing plants is taken and maintained by the government. In some countries, such a census is also maintained on a continuing basis by a publishing company. It makes no difference what source is used for the list if it is a good one.

The next step is to select the types of equipment that will be covered. A comparison of the lists of equipment used in other censuses, as well as some knowledge of the type of manufacturing done in the country, will be helpful in developing this list.

In selecting the list of equipment it must be remembered that the shorter and more general the list the easier it will be to collect the data. On the other hand, the longer and more detailed the list the more useful and informative will be the resulting statistics. The list must be selected to balance these conflicting requirements.

The method by which the data will be collected should be selected and the method of tabulation should also be determined before the questionnaire is prepared.

In general, the data can be collected by sending a form through the mail, or by individual visits to plants. Usually, a developed country will find the mail satisfactory. If there are particular problems in getting questionnaires delivered to plants or in getting them filled out, the slower and more expensive use of interviewers may be necessary.

Decisions must also be made at an early stage as to which industries will be covered and in what detail they will be reported. All of the existing studies concentrate on those industries that use machine tools as a major factor in making a product—the metalworking industries. They usually include equipment in toolrooms and that used for maintenance purposes in these industries, but they do not generally include the equipment used for maintenance in other industries (such as chemical, food processing and textile) or in service shops.

The reason is two-fold: first, the usefulness of the studies of equipment used for production is much greater than the usefulness of a study of equipment used for maintenance; second, if the study is expanded from a sample, there is a reliable base for expansion of production equipment but not of maintenance equipment.

All of the census studies that are expanded from a sample are extended on the basis of employment on an industry basis. They assume that there is a reasonably consistent relationship between employment and equipment among the plants in an industry. This method seems to work satisfactorily if the sample is large enough. There is no such consistency in the matter of maintenance equipment in non-metalworking plants, however, so there is no reliable basis for a detailed extension of data in non-metalworking plants.

If an area breakdown of the data is to be included, it should be determined before the data collection begins. A good area breakdown, like a good industry breakdown, will not necessarily divide the total into units of about equal size, but will make divisions where there are logical differences in method or approach.

A choice may exist as to how data is to be collected. If it is done by a government agency, it is possible to have nearly complete returns because the agency can compel plants to fill out the forms. If it is done by a private organization and there is no compulsion, it will be necessary to achieve the final results by expansion of a large sample.

Based on the existing examples, the studies made by government agencies obtain larger samples but the ones done privately are done much faster and less expensive. There is no way to gauge the relative accuracy of the two approaches. Experience in these matters would suggest that neither method is entirely accurate but that each is adequate for the purposes.

As more and more nations begin to prepare such reports and publish them for use at home and abroad, our knowledge and understanding of the manufacturing facilities of the metalworking industries in the world will increase and the yardsticks for measuring the performance of individual plants, industries or nations will be enhanced.

THE PROBLEMS AND SIGNIFICANCE OF INDUSTRIAL STANDARDIZATION IN METALWORKING INDUSTRIES IN DEVELOPING COUNTRIES

John E. Wilson, Vice-president for Manufacturing, SCM Corporation

Industrial success in today's world demands careful planning and a broad knowledge of modern manufacturing techniques and practices. It is no longer enough to design a satisfactory product; the manufacturing process itself must be designed so that the product can be made economically enough to be competitive in world trade or locally. Industrial success, whether local or world-wide, is predicated on the capability to produce with economy, whether five or five thousand items are manufactured.

Integral to economical production is the implementation of a system of standards, particularly in the metalworking industry. These standards provide a common unit of reference that enables the industry to produce parts that are interchangeable, a necessity for efficient production, and enables more time to be devoted to creative efforts in determining new product applications.

When a designer can specify a type of screw, nut, or bolt by a number or letter designation that signifies its exact composition and dimensions, his time is then free for more exacting technical work. In one United States typewriter manufacturing plant, for example, the same screw is used forty-six times in one style of typewriter: the designers and production planners need only specify a number. Engineering time that might be spent on individual design for each screw is more appropriately spent on devising better designs and production methods.

By using a number of standardized parts in a product, production costs are kept to a minimum and maximum use is obtained for each part. If each of the forty-six screws in the example was of different design, production costs would be almost doubled. Materials can be purchased at lower costs when the quantity is increased, storage problems are minimized, similar machines can be used to produce the part and similar training can be given to machine operators.

The important role of standards in industry was expressed by Dickson Reck, editor of the book *National Standards in a Modern Economy*:[1]

> "The partnership between science and standards holds the secret to the extraordinary dynamism and productivity of modern industrial technology. This partnership begins at the laboratory door; it pervades all processes of production; it comes to rest only when the goods are used up in the hands of the ultimate consumer."

This paper examines this partnership and provides a knowledge of how standards can help any country in developing its metalworking industry. The paper describes the complex nature of standards and the means through which standards are developed and implemented, stressing the importance of a national set of standards as a necessary ingredient in a successful metalworking industry.

In addition, the paper summarizes the existing sources available to a developing country for use in preparing its own standards system, with the recommendation that this be done at an early date. Libraries throughout the world contain documentation of the standards experiences of other countries, published in several languages. Most of the national standards organizations already in existence provide material, on their experiences in implementing and devising standards, to other countries requesting it.

Some national governments also help developing countries in standardization. The Agency for International Development of the United States Government, for example, sends such aid to countries requesting it.

International organizations also provide assistance. The United Nations, sponsor of this and other symposia in industrialization, plans to increase its work in the field of standards. Plans call for expansion of research and information facilities and technical assistance through meetings, the establishment of standards institutes, the sponsoring of fellowships and assignment abroad of experts.

The United Nations also plans to work more closely with the International Organization for Standardization, a group of fifty-one nations whose co-operative work results in standards which may be used by all to facilitate international trade and to improve local production. Other regional groups, such as the Pan American Standards Committee and the European Committee on the Co-ordination of Standards, also facilitate the implementation of standards by a developing country. The results of the applications of standards to modern industry are thus readily available to developing countries.

The necessity of standards in industry is widely accepted today, after decades of experience. Standards, however, have long been prevalent in all forms of social relationships, much longer, in fact, than they have been used in industrial production.

[1] Reck, Dickson: *National Standards in a Modern Economy* (New York, Harper Brothers, 1956), p. 9.

They are so interwoven in the daily pattern of life that they are sometimes difficult to recognize. Language itself is a type of standard. The words defined in a dictionary must be combined in patterns that are recognizable in order to convey a thought. Without accepted standardization of these patterns, their meanings would not be understood.

Standards of measurement have been used since Man found it necessary to calculate dimensions and distances. At first, the standards consisted of the natural elements, but as civilization became more sophisticated, standards did also. There was no need in antiquity for a standard specifying the number of inches in a foot or centimetres in a metre, but this is a requisite of a modern industrial age.

Standards thus are necessary in all phases of life as models or examples. Their application to modern industry is particularly crucial for, in industry, they represent solutions to problems which continually reoccur. Modern industrial standards provide a guide for design, manufacture, and use of an item by stating specific requirements for acceptability and implementation. Standards describe the item or an action pertaining to it in such a way that misunderstanding is not possible. In addition, a measuring method for conformation is an integral part of the standard.

Standards are written to provide consistency and uniformity for any item at any stage of production, as raw material or as a finished product, and can describe any process involved in production or use. Since standards are essential to producing identical parts that can be interchanged, they are essential to modern metalworking industries which convert metallic materials into parts or products. The artisan who made bows and arrows did not have to be concerned with keeping each set he made consistently uniform, but the factory that manufactures typewriter parts today must ensure that each part of a certain kind is uniform and can be used in place of another like it a task that can be accomplished only if standards are maintained to measure the uniformity.

Industrial standards may be established to encompass a company, an industry, a nation or even a group of nations. Regardless of the intended scope, those standards whose impact in a country is more than company-wide should be co-ordinated through a national standards organization. Also, it is through national standards bodies that representation in international standards organizations is effected.

Much can be gained from a thorough study of the standards systems in effect in the older, more developed countries and of those that result from the work of international groups. These systems took much time to develop and, although certain national specifics must be considered, the developing country can benefit by adapting these standards.

The importance of the early implementation of a standards system cannot be overemphasized. In some cases, an agreement on a standard method is a necessity before industrial development can begin, let alone progress. Standards for a measurement system and electrical power, for instance must be in use before an industry can flourish and survive in today's complex and competitive commercial environment.

How standards are made

The establishment of a standard, whether it be for use in the metalworking industry or another, may be effected through voluntary or compulsory methods. When a voluntary standard is enacted, a manufacturer may decide whether it is in his best interests to use it, determining whether the standard is compatible with his production methods or whether it is not. These standards are usually produced by a body of representatives of trade associations, user groups, engineering societies and the like, on a national, industrial or international level. A compulsory standard, on the other hand, is usually produced by a political or governmental group such as a legislative or administrative body; laws or other regulations mandate using the standard and often impose punishment for not using it.

It is through the employment of a flexible standards system that considers the views and ideas of all concerned that the United States economy and others like it have achieved industrial success. Views are not frustrated by legislative entanglement and the dictates of a small political group; rather, they are accelerated by the free interchange of ideas. In much the same way as information is exchanged at international meetings, the voluntary means of producing standards bring representatives from all groups concerned about a problem together to find an effective solution. All aspects of the problem are considered and a solution that brings each aspect into proper focus results in better products for the consumer at lower costs.

However, the exclusive use of either the voluntary or the compulsory method of standardization does not provide results as effective as does a combination. Voluntary standards stimulate the production of better, less expensive goods for internal and external trade. Compulsory standards, however, provide the best means for regulating facets of manufacturing that concern safety or general public welfare.

In the United States, for example, an existing voluntary standard provides a series of guidelines and rules for industries that want to avoid fractions and use decimals. Those manufacturers that see disadvantages in changing from one system to the other have the choice of not using the standard; however, those who feel the advantages outweigh the disadvantages are provided with a uniform system that has been given careful and thorough consideration. Since this matter does not concern the general public, industries themselves can best determine whether it is to their advantage to implement the standard or whether implementation would increase their production costs too greatly and thus increase the consumer price.

On the other hand, members of the metalworking industry in the United States are bound, by state and federal laws, to provide certain safety features for employees. In most states, for example, the law stipulates that power presses for trimming, forming, stamping or assembling metals must be equipped with guards that keep the operator's fingers out of a danger zone when the press is in operation. These guards may actually enclose the area in which the punch press moves downwards to form the metal or they may provide some means for moving the operator's hands out of the way.

One type of guard actually sweeps the operator's hands away if they are in the path of the ram of the press as it comes down. Another pulls the operator's hands back if they are in the danger zone. A nylon band connected by a cable to the ram of the press is worn by the operator. If he does not remove his hands before the press begins its downward movement, the cables automatically pull his hands back out of the way. Some machines must be equipped with a switch that requires the simultaneous action of both the operator's hands to activate the press. On others, foot treadles that activate the press must be shielded so that they cannot be accidentally struck. In these instances safety, not cost, is the prime consideration and the manufacturer has no choice but to implement the standards.

However, the intent of the law is to safeguard employees, not to handicap the manufacturer by requiring unreasonable expenses for safety mechanisms. Thus, if a law stipulates a certain type of guard and a manufacturer feels that another type would be better, he usually may apply to change the prescribed procedure.

Standards may also be prepared by company management for use within a single company. They standardize methods which have only an internal effect; that is, they make the company's production more efficient. These company standards should always be compatible with existing national and international standards to provide a consistent approach and to make the product as marketable as possible.

Voluntary standards

Voluntary standards usually arise because a group with common interests is able to see that economies, higher quality products, or both can result from adoption of a standard procedure or part. Standardization of certain parts, for example, results in a substantial reduction in inventory and thus effects a reduction in operation costs; commonly used parts do not have to be designed again and again. The resultant economies enable the sale of an item at a more competitive price, and thus make the standard more appealing to the producer.

Moreover, because standards set up only minimum qualifications for a product, they encourage the manufacture of better products. When most manufacturers in an industry agree to conform to certain minimum standards, those whose products do not measure up to these standards will not have consumer acceptance. In addition, manufacturers will be motivated to improve their products beyond the minimum standards in efforts to capture more of the consumer market. When more than one manufacturer produces a product, the consumer compares the qualities and prices of the products before buying. If the consumer can obtain a higher quality product at a comparable price, it is natural that he will choose the better product. Since the manufacturer tries to provide the consumer with what he wants, it follows that better goods will be continually produced.

Sometimes, too, safety acts as motivation for voluntarily establishing a standard. The standard in the United States that provides a numbered identification system for outlet and inlet systems for compressed gas cylinders is an example. Originally a voluntary standard, but now incorporated in many state laws, this safety method involves a relatively simple mechanical device that prevents inadvertent mixing of gases. A number value is assigned for use with a specific gas. A cylinder containing one gas cannot be connected to a line meant for another since each gas has a separate type of connexion. External and internal threads, right-hand and left-hand threads as well as threads of different sizes prevent interchangeability. Because the standard is generally used throughout the industry, a manufacturer can obtain the gas he needs, confident that it is compatible with the connexions already in use in his factory.

Once the need for a standard has been agreed upon, a draft is formulated by a committee of representatives from all of the groups concerned: leaders in design, manufacture, and use. This committee determines what the standard should accomplish, what industrial and geographical areas would be involved, and what conflicting interests and requirements are to be considered. A careful balance between divergent factions should be maintained on the committee for the establishment of a standard that is most effective.

A subcommittee then prepares a draft of the standard and submits it to the committee for comment. Revisions are made and considered, and the revised draft is sent to a broad group of interested individuals and organizations. The committee considers all comments received, making changes in the draft where needed, before voting on a final draft. If approved, this draft would be adopted and made available for implementation. (A detailed explanation of committee workings in a specific voluntary standards organization is in pamphlet PR-27, "The Organization and Work of Sectional Committees Operating under the Constitution, By-Laws, and Procedure of the American Standards Association", available through the American Standards Association, 10 East 40th Street, New York, New York 10016.)

There are some cases in which a voluntary standard may be prepared by a government agency. Because of its unique position, a government may perceive the need for a standard before the industries concerned do or may even be requested by an industry to provide a standard. A period of research and orientation would then ensue in which a competent government engineer familiarizes himself with the situation. He may arrange personal consultations with product producers and users, or he may confer with them by telephone or mail. Once sufficient data has been compiled, he prepares a draft of the standard which is distributed to as many concerned parties as practical for criticism and comment.

In order to make the final draft as universally acceptable as possible, all comments are thoroughly and carefully reviewed. Changes that improve the standard are made in the draft which is again sent out for review and comments. The procedure is repeated until substantial agreement is attained. When a standard is final, it is issued as a government document that may be used by manufacturers.

The group originating a voluntary standard should retain responsibility for it. Periodically, it should be reviewed and changes to keep it up-to-date should be recommended. It might seem that continually revising a standard would impose undue difficulties on the manufacturers, but the experience in the United States has shown that this reviewing and updating actually bring the manufactured object closer and closer to the consumer's ideal. As producers continually improve their product to meet competition, higher requirements in approved standards are compatible with their own facilities.

If changes are necessary to keep the standard consistent with technological, sociological, or other advances, they must be made. Since the manufacturer is constantly improving his product to meet consumer demands, a standard becomes virtually useless if it does not keep pace. Information gained from the practical use of the standard is also of importance in determining changes. Some part of a standard may have appeared usable while it was being written, but field experience may prove otherwise.

When voluntary standards are as successful as they are in the United States, certain conditions must exist. Since adherence is nonobligatory, the standards must be acceptable to many different groups. This necessitates the inclusion of compromises between conflicting desires so that the standard can be widely used. All major interests must be given the opportunity to help in preparing the standard. Even a single negative vote in the balloting for adoption must be given careful consideration and must result in action acceptable to all members of the committee.

In many countries—the United States for one—groups issuing voluntary standards must ensure that they conform to existing laws. For example, voluntary standards in the United States must not be adopted which act in restraint of trade. Manufacturers must not conspire to fix prices, for instance, since this would be unfair to those not included. In other countries, however, such practices are within the limits of the law and are even encouraged. Giant steel cartels are legal in Europe, prohibited in the United States.

It is important, too, that producer and consumer interests are balanced when a voluntary standard is established. The producer wants to keep costs down and sell his goods at the highest prices they can command. The less it costs him to produce an item and the more he sells it for, the greater his profits will be, whether he receives them in monetary form or whether he receives more or better goods through bartering. The consumer, on the other hand, wants high quality goods as cheap as possible. Since the standard provides minimum requirements, the views of both must be reconciled for optimum effectiveness.

The means by which voluntary standards are produced provides a distinct advantage. Because so many interests must be consulted and because all are considered, the standard that is issued is generally more usable and practical than if just one group or agency was responsible for the formulation. There is, in a way, a cross-fertilization of ideas that results in a more complete document. Pooling their ideas, many leaders can formulate a better standard than just one working alone. Often more ideas result when several people meet together. Individual ideas are mutually shared and used, and the proposals by one sometimes trigger new ideas from someone else. The very fact of meeting and discussing a problem together acts as a catalyst for new ideas.

The fact that so many are involved in the production of a standard also means that a selfish proposal has little chance of adoption. A political group, for example, which desired a standard to promote its own interests would be foiled unless the standard had universal merit; only those standards which are truly desired and needed will be adopted.

Since voluntary standards usually arise, in part at least, from manufacturers and those most knowledgeable in the area of technological advances, little time will be lost in updating.

Voluntary standards in no way restrict the adoption of laws to protect public health, safety, and welfare. If a government feels that a voluntary standard does not have enough safety features, it can mandate a standard that does. Likewise, if a private group feels that a governmental standard is not strong enough, it can adopt a stronger one.

Because private manufacturers produce voluntary standards, their businesses remain less affected by government restrictions and controls and, in effect, regulate themselves. New ideas are encouraged and can be quickly implemented when governmental machinery does not have to be activated.

Progress can be accomplished more rapidly in a nonrestrictive environment. The phenomenal achievements made by Japanese industry in such a situation are proof of this. The slow legislative proceedings that institute compulsory standards often hinder a manufacturer. His methods of production are tightly regulated through centralized control. If he wishes to deviate from the prescribed method, a complex legislative procedure must be followed. Knowing this, his incentive for implementing new and better procedures diminishes.

Despite the advantages that diverse interests provide in standard making, certain disadvantages also are inherent. A variety of groups naturally will have a variety of opinions, making a consensus difficult. It has already been noted that the committee promulgating a voluntary standard considers all criticisms and comments. When negative viewpoints persist even after revisions have been made, issuance of the standard will be delayed. A manufacturer, for example, might feel that he must divulge trade or company secrets to release enough information to prepare a standard. Or he may feel that the standard would require quality that would be overlooked by the consumer and thus would not justify higher production costs.

Sometimes a standard will be delayed because a manufacturer feels that advances are being made so fast that the standard will become obsolete before or soon after it is issued. It should be emphasized, however, that voluntary standards are not binding; the manufacturer can offer more than the standard requires, and the consumer can demand more. Voluntary standards are thus less limiting and more adaptable to specific needs.

Since voluntary standards involve compromises, it is doubtful that the perfect standard from both consumer and producer viewpoints could be formulated. Some consumers, for example, might desire a feature that the producer felt added too much to the manufacturing cost. A compromise would have to be reached. The power of public opinion, however, cannot be overlooked. If enough consumers want added quality in the form of extra features, producers would have to yield in some way. Often, several lines of value will be offered. In the automobile industry, for example, it is a common practice to produce several variations of a specific car: some offer merely basic transportation—while others provide added features.

Compromises are also necessary when two or more producers or two or more consumers have differing views. A standard involving "deep-drawing" steel, for example, would have to be acceptable to all users of such steel, whether manufacturers of automobiles, truck bodies or house trailers. The voluntary standard therefore, embodies a usable plan rather than a theoretically perfect one.

Compulsory standards

Implementation of a compulsory standard is mandatory. Neither manufacturing nor consumer interests are given the choice of whether to adhere to the standard. On a national or State level, these standards are usually issued as laws, or as regulations based on laws, and disciplinary action can be taken if they are not used as and when prescribed.

Compulsory standards are usually created by a governing political body or some regulatory group functioning under authority of a law or edict issued by the political body. The standard may be written by an individual or committee appointed by the political body or even by the political body as a whole. Producer and consumer groups concerned may not be consulted and criticisms or comments do not have to be considered. The standards, thus, might not allow for varying interests.

When compulsory standards are used in all areas, they tend to limit innovations. The legislative process is slower than the voluntary and can deter the implementation of better, more efficient standards. Moreover, a governmental group cannot be as knowledgeable about manufacturing techniques as manufacturers themselves; since it is not directly involved in production, a government cannot be aware of all production complexities.

However, compulsory standards have great value for safeguarding the health, safety, and welfare of the public. It is in the best interests of the public, for example, if there is no option allowed for a manufacturer to ignore a standard that establishes the number of emergency fire exits in a building.

In the United States, many safety standards are issued as regulations by agencies established by law which are specifically given the authority to direct operations in a certain area; the Atomic Energy Commission and the Federal Aviation Agency are examples. The Federal Aviation Agency, among other duties, limits the number of hours a pilot can fly.

Numerous local governmental groups are also in operation to set up local regulations. In Los Angeles, California, certain types of products may not be sold unless they meet specified safety requirements. Electrical products, for instance, must be certified that they have been tested for safe operation.

The very basic standard designating systems of measurement is compulsory in most countries. Only confusion could result if there would be no common agreement on the meaning of measurement terms. By standardizing the exact unit of measurement, the government ensures that it has a common meaning whenever it is used.

How standards are used in the metalworking industry

The importance and use of both voluntary and compulsory standards in the metalworking industry is broad and basic, encompassing not only the actual production phases, but also the planning and construction that must precede.

Company standards for internal use enable common references by all departments and facilitate production procedures by eliminating misunderstandings. Standards for use throughout the metal-working industry provide a means for maintaining quality products and encouraging continued product improvement. Moreover, individual companies can benefit from sharing common experiences and jointly solving common problems. National standards provide for common solving of problems that are not peculiar to a single company or industry. Formulating such standards means that an orderly approach to basic issues can be taken. International standards, likewise, provide a basis for trade between countries.

All four levels of standardization company, industrial, national and international contribute much to the development of a metalworking industry.

The extent of standards usage in each area, of course, is predicated on the degree of sophistication and development of the country and the industry. Although total standardization might not be required in the beginning, knowledge of it can facilitate planning for when it will be necessary.

Plant construction

In the United States and in many other countries, State or local laws set requirements for permissible building occupancy; size, location and number of exits; stairwell; fireproofing; exhaust systems; etc.

Without such standards, individual companies would have to design factories incorporating safety features which might or might not be adequate. A tragic occurrence in New York City some fifty years ago led to mandatory State safety standards for fire exits. At that time, a fire in a building in the garment district resulted in many deaths when inadequate exits prevented many of the workers from escaping. Had safety standards been in force at that time, the tragedy could have been avoided.

National electrical standards are extremely important to an industrial nation. Without a uniform system of establishing and using power sources, the task of developing industry is greatly hindered. Likewise, adherence to standards when installing the electrical system of a new factory is essential if the factory is to be able to use the power.

In addition, standards for proper lighting for particular kinds of factory operations facilitate planning and ensure that an employee has sufficient light to perform a task. Emergency lighting procedures should also be considered.

State and national standards regulate certain plumbing facilities, detailing minimum requirements for size and location of rest rooms, screening of exits, washing facilities, and the like. These, of course, must be considered in factory construction. Again, the existence of broad requirements on a national or industrial level facilitates construction planning and ensures at least minimum requirements.

The problem of waste disposal and sewage treatment grows as industrialization increases, and often becomes almost impossible to solve if it reaches serious proportions. National, state, or local standards regulating this phase of industry should be given careful consideration at an early phase of industrial development. Experience in the more developed countries has shown that the time to act on industrial pollution is before it begins. Specified limits and procedures should be agreed upon before pollution becomes a serious problem.

Standards for testing water purity can ensure that enough safe water exists at a proposed site for normal supply requirements and for a reserve supply for fire protection.

Although standards do not usually mandate the temperatures to be maintained by heating and cooling systems, standard practices should be kept in mind when designing the systems. For example, in the United States, northern factories are heated to 72 F., and southern factories are air-conditioned to about the same temperature. In English factories, however, the custom is to heat to 60 F. Heating and cooling thus must be suited to local practices.

Plant equipment

Machine tools selected for the metalworking industry should be built under a standards programme to restrict machine varieties to as few as possible. Investment in the toolroom and production areas is thus decreased, setting up the plant is more convenient and maintenance is easier since fewer kinds of replacement parts are required. Machine tools should be purchased only if they accept standard spindles, tapers, chucks, taps, and dies. Safety standards mandated by state or local governments and used by the equipment builder ensure maximum operator protection. Standards for placement of equipment ensure correct spacing and aisle widths.

Production tooling

Whenever possible, tool designers should make use of standard items such as die sets, dowel pins, nuts, bolts, drill bushings, drills, reamers and cutting tools. This cuts time and money for special designs each time the part is to be used. It is much more expedient to agree upon uniformity in commonly used items and to document the agreement for additional uses. A screw, for instance, can be designated by a series of numbers and letters that indicate all its specific characteristics to anyone who knows the standard. Using a standard item thus frees the tool designer for work on improving tooling equipment and its uses.

Using standardized steel in tool designing ensures uniform machining and heat treating results regardless of the supplier. A standard grade of steel is also less expensive to use, since a steel company can depend upon greater quantity sales and thus produce at a reduced unit cost. Inventory expenses are also reduced since fewer types must be stocked.

Product engineering

Standards facilitate product engineering in the areas of product development, manufacturing drawings, patents, and testing. Product development engineering must take into account product standards established by industries, customer requirements, recognized testing laboratories, and state and federal laws.

Industry-wide consensus is sometimes a prerequisite for product development and design. The United States television industry, for example, found it necessary to agree on standards for frequency, number of frames per second, number of lines per frame, degree of definition and other technical matters before it could present the product to the consumer. This ensured that all receivers regardless of the manufacturer would receive television images from any transmitters built by any manufacturer. Without this standardization, television could not have begun as a commercial enterprise.

Another example illustrates the advantage of early standardization by showing what happens without planning. In 1875, Sholes, Glidden and Densmore, inventors of the first successful typewriter, conceived the keyboard arrangement that is still in common use for the English language. Although their design was based on the frequency of letter usage and the most common character sequences, it gave little if any attention to the arrangement that would provide maximum ease, speed of operation and even loading for the two hands. They made a list of the frequency of juxtaposition with which letters in the language occurred, and the letters which occurred together most frequently were placed as far apart as possible to eliminate key jamming.

For the next ninety years, there were many suggestions for a new keyboard: double keyboards, the arcuate keyboard, the six-row keyboard, the "ideal" keyboard of 1890–1900, the Dvorak keyboard of 1935–1945, and others. In the latter period, serious attention was given to keyboard arrangement from the standpoint of ease and speed of operation. By then, however, it was impossible to effect a change. So the basic typewriter keyboard for the English language is still the straight-row keyboard developed by Sholes almost a century ago. If the policy of standardization by consensus had been known and used then, a more efficient typewriter keyboard would have resulted.

Standards must be carefully considered in the development of electrically powered products. Appropriate changes must be made for domestic and foreign markets allowing for variances in voltages and power outlets. National standards of measurement are also important in the design and calibration of machine tools. A dial calibrated for inches, for example, would have little use if the basic national standard was of a different system.

The development engineer should be trained to make maximum use of standard stock parts, such as screws, nuts, rivets, and ball, roller, and plain bearings, to get maximum use of time, money and materials. For the same reasons, he should use materials that have been manufactured to standards regulating physical properties such as thickness, hardness, and composition. Reducing the total kinds of parts means, too, that replacement parts can be stocked easily throughout a country.

Development engineering must provide for interchangeability by establishing the proper tolerances and specifications for use in manufacturing. The practice of tolerances is well established and is used in accordance with product requirements to maintain interchangeability, quality performance, long life and reliability.

Manufacturing drawings are the communications medium for the metalworking engineering department. The drawings convey detailed specifications such as heat treating, plating, polishing and painting and include special instruction for adjusting, testing, etc. Drawings must be understood easily, completely and uniformly expressed, and as brief as possible. Drawing standards ensure this by setting up a uniform system of drawing sizes, line conventions, lettering, scale, projection, dimensioning, tolerances, surface finish, etc. Preparation of basic drafting standards by the national standards group can smooth the standardization process of companies and industries.

Patent applications and drawings should conform to standard practices regulating format and processing. These standards are often compulsory and are usually issued by governmental sources. In the United States, the Department of Commerce through its Patent Office is the source of patent procedures. If applications are made in other countries which participate in the International Patent Convention, they must be processed according to procedures established by the convention.

In some countries, national or private laboratories test products for performance against established standards. Acceptance by the laboratories assures the customer that the product has passed certain safety and reliability tests. Approved by these laboratories is accepted in some instances instead of approval by local inspectors. An example in the United States is the Underwriters Laboratories which tests electrical products for safety. Although this is a privately operated testing facility, its approval is accepted in all areas in the United States. A similar organization is the Canadian Standards Association which oversees electrical installations and safety features of electrical equipment throughout Canada.

Manufacturing

Almost two centuries ago, the application of interchangeable parts manufacture revolutionized manufacturing practices. About 1800, Eli Whitney, a famed American inventor, began manufacturing muskets for the Government so that the parts could be used interchangeably. Until that time, products were individually made and repair parts had to be specially fitted.

The benefits of interchangeability, however, are lost without the use of standards to measure component uniformity. Standards, in fact, make interchangeability possible. Today, the application of tolerance standards establishing allowable variations is a prime requirement in all companies in the metalworking industry. Tolerances are selected to provide a given function at the proper cost, performance and reliability. Most tolerance standards are established by the individual company to suit a particular product. Generally, the wider the tolerance the less expensive the product; the closer the tolerance the more precise the product and the higher the cost.

Tolerance standards coupled with modern processes and equipment are the basic requirements for low-cost mass production. As an example, the cost of a manual portable typewriter made by hand by skilled mechanics in a model room would be approximately $16,000. After high production tooling and the use of standards, however, the same machine in volume production would cost less than $50.

Work standards in manufacturing engineering establish the time standard for all operations and the method for performing each operation. Adjustment and inspection operations must also be standardized.

Manufacturing specifications detailing these requirements should be expressed briefly and simply, but should be complete and to the point. These specifications protect all concerned: they give management the desired product at the proper cost and protect the workman from unjust criticism if he has followed the specifications.

Purchasing

Purchasing is no longer just a matter of placing an order for goods. A request for three tons of steel means little to a supplier without an exact description of the desired composition, strength, etc. No manufacturer can succeed unless he can be assured of the raw materials he needs at a price that will allow him to produce at a profit. If the materials are of higher quality or of closer tolerances than needed, production costs will rise. If they are of lower quality, product quality will suffer because of frequent breakdowns and repairs.

Using a standard not only results in the acquisition of the right materials, but also in saving time, since the next time the goods are purchased the standard can be used again. Consistency is maintained, and a new description does not have to be prepared.

When a company adopts a standard stock catalogue from which basic supplies are ordered, company decisions are co-ordinated and simplified. Lower inventories result, since fewer kinds of parts are needed and goods can be purchased at the lower rates for quantity buying. Maintenance is simpler, inspection easier and workmanship better. One company, for instance, purchases one type of cold-rolled steel from which it makes almost eighty different parts. The characteristics of the steel are thoroughly known and fewer types of machines are required to manufacture the parts.

Large quantity purchasing helps not only the manufacturer but also his supplier who can produce more and sell at lower costs.

Similar savings can be effected through an industry-wide purchasing standard. For example, United States oil companies were plagued with a common problem involving the purchasing of underground gasolene tanks for use by service stations. Each company had its own type of tank. A meeting involving representatives from all concerned resulted in an agreement on a standard underground tank, thus benefiting both purchaser and supplier.

National standards in purchasing have increased in importance and acceptance as industrial technology has increased. Use of a national standard which is revised periodically can often effect a savings. In one instance, a company discovered that its own internal specifications for steel purchasing were not only outdated but were increasing costs by calling for a type of steel processing no longer in common use. The specification had been valid and even necessary years before, but had no application in modern industry. Adopting an existing national standard resulted in immediate savings.

Production and inventory controls

There are many standard procedures by which a metalworking company can control procurement of materials, manufacture or purchase of parts and production of final units. The procedures depend on the volume of material, parts and units required in a given time. Low-volume production can be handled with a few simple controls, while high-volume production requires sophisticated controls.

A simple system would include such information as lot sizes, reorder points and inventory records. A lot size is the amount of material or parts manufactured or purchased in one order. The size of the lot is established after study of the unit cost, monthly usage and time required to make or buy.

A reorder point is the minimum quantity of material or parts on hand at the time of a replacement order. Reorder points are based on rate of usage and time required to obtain the next order.

Inventory records are maintained showing orders received, withdrawals, and current inventory for all parts, supplies and raw materials.

Control of product quality

At each phase of the manufacturing process, product quality must be carefully checked, a task that can be accomplished only if a basis for evaluation in the form of standards has been documented and agreed upon. This control begins with purchasing of raw materials and continues to a final check of the finished product.

Like all standards, those in purchasing include a means by which incoming goods can be evaluated for acceptability. In the production phase, when raw materials are converted to finished goods, quality standards again provide a means for measuring the goods against an acceptable norm. It should be noted that the standards for quality in manufacturing are somewhat flexible; they allow for some deviation from the tolerances specified in the standard when it is wholly impractical to do otherwise.

The standards for manufacturing product components are generally set a bit higher than really needed to maintain the desired quality of the finished product. Thus, some leeway is allowed to accommodate production problems, and a set procedure is generally established through which all those concerned are notified, in writing, of the plan to deviate from the standard.

Because of these provisions for variances, the standard allows some creativity in the production process. A new way can be tried as an experiment and if it proves feasible and more practical it can be implemented by revising the standard.

Standards must also be used to sample the finished product to ensure that the desired quality is met and that the product performs as desired. Again, certain tolerances should be allowable to provide for the proper balance between the perfect product that the sales unit might desire, and the need for expediting production to keep manufacturing costs at a minimum. Safety features, product use, the cost of replacing parts whose performance is guaranteed, and many other considerations must be made to arrive at a suitable product quality.

Product testing must be performed under conditions comparable to those under which the item is designed to function. A product to be used on a boat, for example, should be tested in a marine environment.

Since it is usually impracticable to test each article, a method must be defined for selecting test specimens. Special care must be taken that the sample is truly representative of the final product. Some raw materials, for example, are purchased in bulk lots and vary in quality at different points in the lots. The test specimen must be made up of a combination of raw materials taken from various parts of the lot purchased.

The role of statistical analyses in selecting test specimens should be carefully considered. Many textbooks explain this concept in detail; in addition, the American Society for Testing and Materials has available several booklets on sampling and probability.

Personnel administration

Personnel administration in metalworking industries includes several responsibilities that make use of established national, industrial and company standards. National and local safety standards apply to guarding machines, plant housekeeping, elevator designs, stairwells, exits, fire hazards, fire alarm and sprinkler systems, ventilating systems, water supply etc.

In larger manufacturing operations, company standards are established for wage and salary administrations. In general, they include job descriptions, job evaluations, labour grades and wages or salaries.

Labour standards are usually established for different jobs by national or local regulation or by the individual company.

It is the responsibility of the medical department to measure the physical fitness of new employees in a company against established standards, to make periodic examinations when required by law and to provide medical attention.

Cost accounting

Company standards are used in factory accounting for controlling and measuring the manufacturing operation. A standard cost representing an estimate of the total cost of producing an item is established before production is begun. Once the item is manufactured, the estimate is compared with the actual cost to determine whether the production is profitable.

An annual operating budget to plan company financing provides a similar measurement for the operation of the company as a whole. Expenses for salaries, supplies, taxes, telephone, rent, etc., are estimated for a yearly period. Later, the actual cost of each item is compared with the budget to determine efficiency.

In addition, factory accounting establishes standard procedures for inventory and operating records. Other audits include accounts payable, payrolls, fixed assets, and expense items.

PROBLEMS OF THE DEVELOPING COUNTRIES

The problem of standardization in the metalworking industries of developing countries is part of the over-all process of industrialization that is often stymied by the political, economic and social environments. Fundamentals such as national language, resources, and technological experience are sometimes not as sophisticated in a developing country as modern technology requires. The obstacles, however, are not dissimilar to those that have faced other nations at similar stages in their development. Once the problems have been identified, the approaches to solving them can be illumined by the experiences of other countries.

The description of standards usage in modern metalworking industries shows that much experience is required to analyse technological areas for standards application. Experience indicates areas in which standardization is an impediment rather than an aid and those in which standardization is permissible but not required. The pace required for industrial success leaves little time for a developing country to develop this experience as some of the older countries did through decades of industrial evolution. Other sources must be consulted if industry is to be developed fast enough to take a prominent place in the industrial world.

The limited number of skilled technicians in developing countries is a handicap in producing a standards programme. However, international assistance is readily available.

National vocabularies of developing countries are often not adequate to express accurately the complex ideas involved in standards. Even more highly developed countries sometimes have difficulty writing standards that are completely accurate and understandable. Interpretation problems could defeat one of the prime purposes of a standard: to ensure uniformity. Special care must be taken to make standards conform despite language inadequacies.

The limited extent to which developing countries have participated in international commerce is a disadvantage in implementing their own standards. Through wide participation, a knowledge of standards use in other countries is obtained as well as an appreciation of the importance of standards to both buyer and seller. This knowledge is beneficial in preparing internal standards and is essential in arranging trade with other countries.

Because metalworking industries are only minimally developed in many countries, widespread support for a national standards programme is often hard to obtain.

Careful analysis will ensure that the standards programme is compatible with the degree of industrial development. It would be foolish for a country to accept standards that are beyond the capabilities of an infant industry; this would only further deter acceptance. Once a proper evaluation has been made, convincing others will be easier.

The information in the following section outlines the sources from which the developing countries can obtain assistance in preparing a standards programme that will benefit metalworking industries.

WHAT IS AVAILABLE TO THE DEVELOPING COUNTRIES?

Formulating industrial metalworking standards is a formidable job for developing countries, but one that becomes easier with the availability of existing standards which can be adapted. Almost all of the standards experience of the world is available to the developing nations. This experience is documented in thousands of published standards in several languages and in numerous technical works, from short papers to books.

The developing countries may procure standards from national standards organizations in many other countries. The American Standards Association automatically sends copies of American standards to more than 160 standards groups in other countries.

The United Nations, through its symposia, is another source of standards assistance. By bringing countries which have established standards systems together with those which do not and by providing a wealth of technical information at these meetings, the United Nations emphasizes the importance of standardization and stimulates the creation of national systems. The proceedings and recommendations of United Nations meetings are readily available in several languages, as are a great number of its other publications dealing with industrialization. For example, a series of manuals, containing technical information about the establishment of new industrial projects has been prepared.

The United Nations Industrial Development Organization is responsible for United Nations activities in standardization. Besides giving technical assistance through meetings and seminars, United Nations aid includes helping establish standardization institutes throughout the world. The Technical Standards National Institute in Paraguay, for example, prepares standards and research dealing with quality in products. Its services are available to the governments and industries of developing countries.

Through the United Nations, some twenty countries in recent years have received assistance through studies made by United Nations experts. The reports from the experts are transmitted through the United Nations.

Training and fellowship programmes in standardization and quality control are also sponsored by the United Nations and are available to any of the developing countries.

Future plans call for an expansion of programmes as well as increased co-operation with international standards groups. These international standards organizations have provisions for helping developing nations to establish standards systems. They include the International Organization for Standardization (ISO), the International Electro-technical Commission (IEC), the International Bureau of Weights and Measures, and the International Commission on Rules for the Approval of Electrical Equipment (CEE).

One of the most influential of these groups in the general fields of industry and engineering is the International Organization for Standardization, a non-governmental body which prepares standards for its members and publishes them in English, French and Russian. Its purpose, as stated in part in its constitution, is to "promote the development of standards in the world with a view to facilitating international exchange of goods and services and to developing mutual co-operation in the sphere of intellectual, scientific, technological, and economic activity". These are voluntary standards. However, because the recommendations represent a consolidated opinion of important trading nations, the standards are especially worthy of note by developing nations who wish to enhance their position in world commerce.

The ISO is comprised of national standards organizations from fifty-one countries who work together to produce standards acceptable to all members to facilitate international commerce. Standards groups representing some nations are voluntary and non-governmental in nature, such as the American Standards Association of the United States; others are governmental, such as the Korean Standards Association, Ministry of Commerce and Industry for Korea. It should be noted that the ISO has made it possible for developing countries who have not yet organized a national standards group to obtain correspondent membership. Upon payment of annual dues, correspondent members may attend any ISO technical meetings and may receive, free, ISO publications to a certain total face value. Additional publications may be purchased at a discount.

The ISO is now considering more than a hundred projects through the work of its active technical committees which are responsible for developing recommendations for international standards. Any ISO member may request that a technical committee be established to consider an international standard. The committee is made up of ISO members appointed on the basis of technical interest. Members who do not wish to participate actively in a project may be designated as observers so that they can be kept informed of the project's progress.

Once a draft has been drawn up by a committee, it is circulated to all member groups for comments. If 60 per cent of the members voting approve the draft, it is sent to the ISO governing council and, if the council approves, it becomes an official ISO recommended standard.

That so many nations with divergent industrial uses and customs must accept the standard means that the intent of ISO standards is to establish minimum requirements. Still, they are beneficial to developing countries for use in international trade or as a guide for preparing national standards. Some twenty-two nations, for example, have been able to work out an international code for boilers with jackets of carbon steel. The code establishes uniform material specifications, rules of construction, methods of inspection and certification. Developing nations which import equipment will benefit from this standard in particular because it provides a common basis for commercial competition.

Preliminary approval has also been given to an ISO recommendation on standards for freight containers. The standard would enable freight containers to be transferred between land and sea carriers without rehandling the contents.

Regional groups have also made significant contributions in standards implementation.

The Pan American Standards Committee (PASC), for example, has brought together representatives of Argentina, Brazil, Chile, Mexico, Peru, Uruguay, Venezuela, United States, Costa Rica, Guatemala, Honduras, Nicaragua, Panama and El Salvador. Their aim is to propose continent-wide standards to stimulate internal and external trade in Latin America. The committee works towards basic standards in fundamental symbols, units and magnitudes; ferrous metallurgy; building materials; electrical engineering; rail and road transportation; textiles, and food and cattle products. It is significant that the PASC has received vital assistance and co-operation from the International Standards Organization, the International Electrotechnical Commission, the American Standards Association and United States industry.

The standards used in the older, more developed countries can be examined through several other means besides active participation in an international organization. Through educational exchange programmes, for example, young engineers can study in countries which have advanced systems of standardization. Often, these young people are given the opportunity to apply what they have learned by working in the country in which they were educated. In this way, they can acquire a practical knowledge of the application of standards in a particular field. Since many of these young people are sponsored by their governments, they can be directed to obtain proficiency in an area such as standards to ensure that information is brought home for use in preparing a national standards system.

The Indian Standards Institution provides training in the field of standards engineering that is open to developing nations; in France, the *Association pour l'organisation des stages en France* and the *Association Française de normalisation* provide group training in standardization.

Since one reason for instituting national standards is to become better equipped for world trade, a developing country can send a commission to study the standards system of a country with which it expects to have commercial relations. If it is feasible for the developing country to make its standards of production compatible with those of another country, the materials it produces will be immediately usable by that country and a basis for trade will be established.

Many of the highly developed countries will sponsor study groups from developing nations, providing information and assistance that can be used for establishing standards for international trade or internal use.

It is also possible for a developing nation to contract with a private consultant for various studies and for recommendations on how to proceed with a programme of national standards. At least one country has already used this means for producing a national bureau of standards.

The developing country, too, can benefit from having its plants established by manufacturers from older, more advanced nations. The manufacturer will bring with him a broad knowledge of standards and a knowledge of how to adapt them.

Although there are many resources at the disposal of developing countries for preparing national standards in metalworking, care should be exercised before standards of other countries are adopted in their entirety. Each country and often each area of a country has special conditions that may have precipitated one or more of the detailed requirements of a standard. If these conditions do not exist in the developing country, conformity to the standard may be difficult and may cause problems rather than solve them.

Voltage requirements for electricity, for example, vary from country to country. A 120 volt, alternating current, 60 cycle appliance can be used anywhere in the United States, but not in some fifty other countries. If a developing nation adopted a standard from a country with a different voltage system without taking the difference into consideration, the standard would be virtually useless. Likewise, a standard for a metal product containing bearings produced for a temperate region would be valueless for a tropical climate.

Each country should therefore carefully determine its standards. For international trade, it must obtain knowledge of the standards of other countries to establish a common basis for buying and selling. For internal consumption, it must develop standards that give its citizens what they need and want and at the same time provide the metalworking industry with standards it can accept practicably. It is important that standards be adopted that will encourage the development of a healthy and profitable manufacturing industry and that will not be a hindrance later.

Conclusions and Recommendations

If developing nations are to achieve the degree of industrialization in metalworking that is required to provide goods for both internal and external consumption, they must have a system of standards. Experience has shown that production methods become harder to change as the industry becomes more complex. A comprehensive study in the beginning phases of industrial development will net fewer costly mistakes. Perhaps an example of the delay caused by a lack of adequate standardization proves this best: the manufacture of the first rotary steam engine in the United States was hindered for almost ten years because its developers were unable to get pistons and cylinders that fitted each other.

The early adoption of standard sizes of metalworking materials will allow the design of many products, based generally on a limited number of sizes of rounds, squares, and other standard shapes; a limited number of thicknesses and widths of sheet, strip, and plate; and a limited number of finishes. Time and money will not be wasted on the constant resolving of common problems. An engineer in company A need not spend time developing a screw that will fit a part provided by company B if both companies adhere to a common standard. By establishing and using a system of national standards, it is possible to ensure that a bolt will match a nut, that an electrical plug will fit an outlet, and that a lamp bulb will screw into a socket regardless of what company manufactures the product or where and how in the country it is used. Engineering time can be more efficiently utilized to provide better products and better product uses, and duplication of effort will be minimized.

A nation's industry will benefit from the exchange of information resulting from discussions for establishing standards. A more adequate and more complete solution will be effected when many are involved in developing it. Problems that may be pending in the future for one company may already be present in another; an information exchange through standards meetings can often provide an expedient means for solving the problems. Sometimes, too, the exchange of information benefits not only the standards problem but also problems in other industrial areas, as standards are so basic and fundamental.

Standards in the metalworking industry are requisite to three basic phases of industrial production: to modern production methods, because they provide for interchangeability and economy; to trade within a country, because they enable consumers in all parts of the country to use a product; and to trade with other countries, because they provide a common basis on which to communicate.

The difficulties of running a manufacturing plant would be compounded immensely if drill shanks came in assorted sizes, if fuses were of non-standard sizes and electrical characteristics, if paint were not uniform in consistency and colour: in general, if standards were not used.

Standards, too, facilitate international commerce. For developing nations, the task of establishing an industry is eased considerably if the necessary goods and raw materials and procedures can be adapted from the experience of other nations. Problems can be alleviated and equipment more readily obtained.

A dramatic illustration of the value of standards in public safety and welfare is the tragedy of the fire that occurred in Baltimore, Maryland, in 1904. A large part of the city was destroyed because firefighting equipment from Philadelphia and New York was unusable: the hose couplings did not fit and the equipment could not be connected to the water lines. The experience of the past may not always provide such clear and dramatic reasons for the early implementation of standards, but a careful study of the past shows the many tangible and intangible benefits that result.

The ultimate goal of standards as expressed by the American Standards Association is "to make life in our machine age simpler, richer, and safer". This truism took decades to gain acceptance in the older, more developed countries. Today's greatest industrial nations have proved the necessity of standards in industrial success, or just for existence in the modern economic structure. All technical analyses have shown that the benefits of standardization spread throughout the economy. The nature of the metalworking industry makes standards especially important in its development.

The knowledge and study of previous mistakes as well as successes will prove beneficial to nations on the brink of modern industrial development today. The pace now will not allow for a long evolutionary process with its lessons of trial and error; the need is immediate and must not be ignored.

CRITERIA AND BACKGROUND INFORMATION FOR PROGRAMMING THE MACHINE-TOOL INDUSTRY

Secretariat of the United Nations Economic Commission for Latin America

Industrially developing nations which are starting the expansion of their traditional industries must evaluate the extent to which capital goods and, within this vast branch, machine tools, should be manufactured in the country.

This problem has not been posed with a view to attaining total national autonomy as regards the elaboration of capital goods, but rather to determine, quantify and qualify the type of domestic effort to be realized in front of global demand, a relationship which should be considered under a certain discipline.

One method of tackling the subject might consist of finding out whether there exists a useful historical correlation between national manufacture of machine tools and the size of the machine inventory used by the mechanical industries.

This should be followed by broad consideration of the predominant characteristics of the products, showing which are the means available to this industry for obtaining specific technical and economic results.

Both methods comprise aspects of diverse natures, not always easy to separate and ponder, as a more detailed analysis would require. In practice, different solutions may be applied to the same problem.

Because machine tools constitute the most significant investment within the mechanical industries (from 50 to 65 per cent of total fixed investment), they have now become the most popular work instrument, as were manual tools in earlier times. It seems therefore convenient to take into account their elaboration in expanding areas, paying attention also to the strategic role they have been acquiring within today's technical and economic evolution.

Thus, first in these notes, an analysis is made of some dynamic factors determining the importance of national manufacture of machine tools and of the magnitude of the inventories operating on the mechanical industries; this indirectly shows an aspect of domestic participation on apparent consumption. The successive sections deal with the industry in charge of the construction of these machines, summing up its peculiar technical problems equivalent to the various stages of development. The last section is about the usually admitted dependency between the machine-tool manufacturer and the rest of the mechanical industry, that dependency increasing in quality, volume and technique as progress is made on the construction of more complex units.

It should be pointed out that the conclusions of this essay must be interpreted as global, because though a great number of the variables in the construction of machine tools have been taken into account, there are still many more. However, once the results of the following preliminary estimates are deemed satisfactory, they can serve as a basis for carrying out the detailed study of one or more specific factors for products of a given design.

THE DOMESTIC MACHINE-TOOL INDUSTRY

Classification of machine tools

Because of the great number of divergent interpretations with regard to the types of machines included as such, machine tools are here defined as metalworking machines in cold and in hot, and the metal-cutting as well as metal-forming machines, leaving aside those for working wood, plastics and non-metallic materials. Within the category of metalworking machines, those indicated in table I have been selected because, though not representing the total means available to the mechanical industry for the manufacture of its products, they constitute a significant majority.

In practice, for the user as well as for the constructor, the denomination of lathes, milling and drilling machines, etc., is too generic, as each category has numerous variables widely differing in outline, controls, productivity, size and other factors. In order to establish an order of magnitude concerning the number of variables applicable to each machine, two criteria have been adopted:

(*a*) Assume for each type of machine, lathes for example, certain variables sufficiently differentiated to individualize the operational as much as the structural and constructive characteristics;

(*b*) Relate each of those variables to four basic conditions of utilization: micro-mechanics, light and current mechanics and medium, semi-heavy, and super-heavy mechanics, which do not exist necessarily in all the variables.

On the basis of these criteria, it has been possible to quantify, for each machine, the most important types and models which together constitute the large family of machine tools in the constructors' vast world supply. Table I shows the results obtained: 1,037 main variants, 776 of which (75 per cent) correspond to the category of metal cutting machines, and 261 (25 per cent) to metal-forming machines.

The information in table I cannot be free from subjective interpretations and, also, from incomplete data regarding some of the variables, in which case figures

Table 1

NUMBER OF TYPES AND MODELS OF MACHINE TOOLS IN THE WORLD MARKET

Denomination of the machines	*Number of types and models*
Metal-cutting machines	
Lathes	106
Milling machines	63
Drilling machines	46
Shapers and planers	32
Threading machines	27
Saws	19
Gear-cutting machines	94
Boring machines	84
Grinding machines	131
Tool-grinding machines	43
Broaching machines	30
Lapping and honing machines	33
Special machines composed by work units	46
Other machines of difficult classification	22
	776
Metalworking machines	
Mechanical presses	75
Hydraulic presses	54
Forging machines	23
Metal-forming machines in cold	24
Machines for sheet	85
	261
Total machine tools	1,037

should be taken rather by default. But even with all the limitations, the data appear acceptable for the purpose.

Another important factor which might have been added in combination with the above figures, to obtain a greater number of variables, is quality. However, at this stage of the analysis, it has been deemed advisable to omit it as inclusion would not alter substantially the determination of an indicator that points out the percentage of national manufacture of the variables in front of their statistical universe, as a function of the numerical value of the machine-tools inventory.

Participation of national manufacture in relation to installed inventory of machine tools

Within the order of ideas mentioned, an endeavour will be made to determine national constructors' possible reactional behaviour, measured in the variety of types and models as a function of the numerical value of the inventory. Conceptually, two different aspects exist simultaneously within an inventory: the serial factor (purchasing power, high population, both, etc.), and the variety and complexity of the mechanical and electromechanical products manufactured. In the measure that these factors are considered to be growing, the one as well as the other will urge for the utilization of more improved technological productive means which in practice will be translated into a progressive increase in the variety of types and models of machines in use. This evolutionary process takes place under different combinations of the elements taken into account, with direct impact upon national industry. This implies admitting *a priori* that to equal numerical values of inventories, different actions may correspond on the part of the constructors. Nevertheless, it does not seem arbitrary to assume that national manufacture of machine tools participates within minimum and maximum limits, susceptible of definition for the various situations.

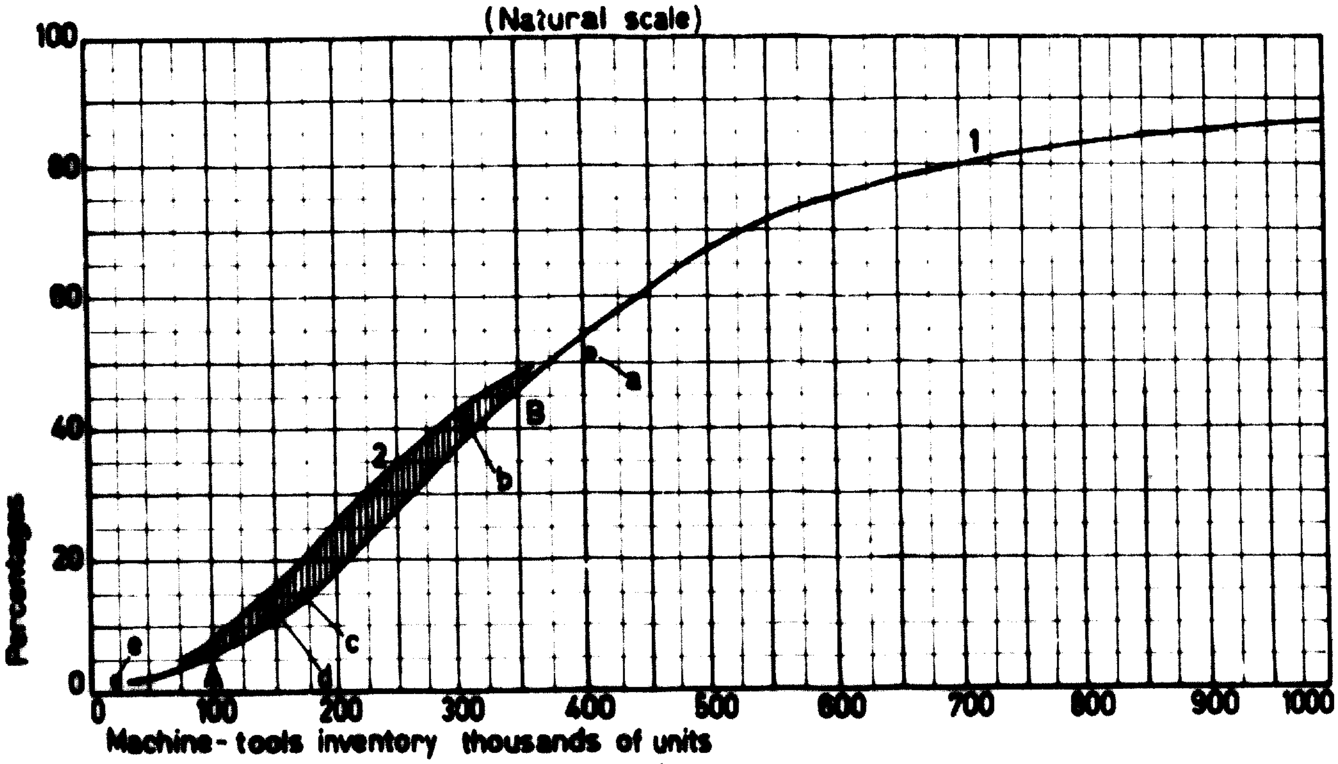
To this end, it has been possible to reconstruct the number of types and models of machines elaborated in some countries, thus establishing percentual relationships with the previously fixed statistical universe. Interest in such an analysis is now circumscribed by knowing the behaviour of supply for countries with inventories of less than 500,000 units.

Almost all the available information derives from studies being systematically carried out in the region by the Economic Commission for Latin America (ECLA) on the mechanical industries in general and especially on machine tools. Figure 1 shows a summary of the data, as well as an interpretation of its trend adjusted to Gompertz' curve (curve 1). It may be observed that in Latin America, when inventories are of less than 10,000 units, no construction activities of machine tools have occurred, a fact which is apparent. But when inventories comprise from 10,000 to 20,000, the first local initiatives are already starting, naturally polarized on the manufacture of simple machines of still deficient quality.

To attain the elaboration of forty to sixty variables of low-cost and low unit-weight machines does not altogether constitute a very significant step towards mastering this difficult technique, and its achievement is generally possible without the support of an important technological infrastructure on the rest of the industry. This first stage of supply of elementary machines, practically abandoned in countries with a high industrialization index, is in great part the result of the strong incidence of small industry and the many artisans who have proliferated in this area due to rather peculiar conditions. At any rate, it is perhaps convenient to accept, as a characteristic sign of underdeveloped countries, the fact of an operational co-existence within the same inventory, of machines with a limited technical capacity and few years use, together with others of medium and elevated category, the first ones in high proportions.

Starting from a given situation of supply, for example forty to sixty variables, or inventories of 80,000 to 100,000 units, this becomes progressively complex as the increase in the variety of types and models implies almost systematically higher standards of quality within an international pattern. In order to reach those qualitative demands, technically well-structured factories and efficient auxiliary industries are required.

Along curve 1, a position that might be called of high national effort is clearly discernible exactly between points A and B. Should this position be related to the Latin American panorama, it would broadly represent the transition from under development to a satisfactory development of the mechanical industries, comprising under the concept of development the serial aspect as well as the diversification of mechanical products. It now seems advisable to admit that especially between points A and B different ways may exist in connexion with the position of supply and that the previous and subsequent situations to these points would present further stability. Such ways would explain, as already said, that not always equal technological potentials correspond to equal magnitudes of inventories, with obvious repercussions upon supply; and also, that the observable differences would derive from those existing between a developed country and another in the process of development. This is clearly confirmed by comparing Argentina's and Brazil's position (less than 200,000 units installed) with dynamism in front of a given inventory. The complementation and refinement of data to be obtained in the near future will confirm whether the limits established in figure 1 through curves 1 and 2 are real and applicable to a great number of cases for countries in the process of development. Attention then will be drawn to the distortions resulting when the structure of machine tools national manufacture is bulky due to exportation of some



Reference:
a – France (1960) – 537 varieties
b – Italy (1958) – 435 varieties
c – Argentina (1963) – 144 varieties
d – Brazil (1960) – 124 varieties
e – Chile (1960), Columbia (1964) – 10 varieties

Curve 1

$$y = 87.4 \; 0.01638^{0.81326^{x}}$$

Where: y = percentage of domestically produced types and models

$$x = \frac{\text{machine-tool inventory}}{35{,}000} - 1$$

Figure 1

RELATIONSHIP BETWEEN THE INVENTORY OF THE METAL-TRANSFORMING INDUSTRIES AND THE PERCENTAGE OF DOMESTICALLY PRODUCED TYPES AND MODELS

that of Italy and France when they had a similar number of machines which served such important sectors as aeronautic construction, that of ships of more than 10,000 tons, and the manufacture of other diversified and complex capital goods not being developed in the two Latin American countries. The machine-tool supply accompanied this process, with a consequent further diversification of types and models than those elaborated by Argentina and Brazil.

This and other examples would be better represented by curve 2 laid out empirically to illustrate those cases in which the behaviour of supply maintains its maximum of its products, a fact which was not taken into account in this preliminary outline.

Starting from situations of more than 500,000 installed units, it is easy to understand that, though the technical problems the constructors must face continue to grow, the magnitude of the market and the infrastructure that should exist in the rest of the industry constitute factors sufficiently attractive that supply adjusts itself to the requirements of internal consumption in an increasing and varying manner.

Despite the fact that the preceding notes do not intend to lead towards the formulation of exact decisions on the problem under analysis, they are explanatory enough in regard to the philosophy to be followed by those countries whose development depends upon significant apparent consumption of machine tools. There could not be important and prolonged expansion of the mechanical industry without a gradually increasing contribution from local industries constructing machine tools. The framing of an even partial attitude of participation in the domestic manufacture of the capital goods in question is of vital importance not only for improving the balance of payment of this item, but also for familiarization with every characteristic problem in the elaboration of machines. Manufacturers must be responsible and offer users the possibility of direct contact.

When dealing with machine-tool manufacture, different stages of supply development will be considered in an indirect manner, that is, showing which qualitative and varying production potentials may be attributed to a specific number of enterprises typified by diverse structures, from the humblest to the well-equipped, generally knowing that such initiatives get consolidated in the measure that the inventory improves in its numerical and technological aspects.

Characteristic problems of machine-tool manufacture

Introduction to the subject

To facilitate research into some general laws, it seems advisable to apply a restrictive criterion to the universe of types and models of machines, selecting those with more homogeneous and similar fabrication problems. The machines used in micro-mechanics, heavy and super-heavy mechanics are thus excluded, incorporating instead the ones used in current, medium and semi-heavy mechanics, which are more popular.

The unit weight of the machines is limited to approximately ten tons; the highly specialized types, such as the jig boring machines, machined units and others, are not taken into account. The same happens with the machines using numerical control programmers, etc. Despite these restrictions, the rest comprise the majority of existing variables in the world market and cover to a great extent the fabrication interests of countries with relatively small demand, concentrated on the most current types of machine tools.

The final objective of this outline is the analysis of global machine-tool manufacturing, trying to frame the technical, practical and economic fields of action of the construction enterprises. At the same time, it is intended to indicate how the "economy of scale" concept, so closely connected to the applicative effects of the machines once they have been installed in the workshops, has a different meaning when referred to the elaboration of those machines.

Unlike other sectors of the mechanical industries where the same product may be elaborated for a long time, machine-tool manufacture, with the exception of some simple types, is constantly evolving in details as well as in general composition, because of the need for more productivity at the same price, weight or power. This situation is reflected in the fabrication series of identical products, reducing them in a sensible manner. Because composition of machine-tool inventories is related to the quality, the variety and the series of products, when development of the mechanical industry starts, the demand for machines corresponds to elementary types for maintenance and fabrication of simple articles. As in this stage of development demand is scarcely diversified in types and models, favourable conditions are present for construction in series, above a hundred, for example, which represents a high scale in machine-tool manufacture on the order of one ton weight. However, while the number of machine tools integrating an inventory increases and new products are launched into the market, a substantial change takes place in the requirements of users who first try to obtain the type of machine best suited from the standpoint of operation technology (more variety) and then, according to the serial size, the most productive machine.

It is difficult to reconcile the interests of a very diversified demand with those of machine-tool construction in important series. Here it must be recalled that, during a period shortly before the Second World War, different production scales of mechanical manufactures were generally attained through the installation of larger or smaller numbers of equal machines. The technology trend prevailing at present, far from eliminating the multiplicity of types and models of machines, tries to find the most adequate solution to the problems. As an extreme, it might be said that for some articles maximum productivity is only achieved by means of special and complex machines, elaborated to order. In other words, the maximum production scale for the users would correspond to the minimum scale for the constructors. This indicates a certain relationship of inverse proportionality between the user's series and that of the machine-tool manufacturer.

In order to condense the peculiar operative conditions upon which the sector must rely, the producers' main problems have been typified through five sizes of machine-tool construction enterprises, assigning to them beforehand the equipment together with direct and indirect labour corresponding to predetermined manufacturing structures to produce a wide variety of types and models of machines. The possibility and convenience of elaborating given types related to each size of enterprise is then examined, considering the greatest possible number of variables in order to synthesize the most characteristic technical and economic problems of the sector.

The first two sizes of enterprise represent embryonic technical situations of an artisan type which are specially useful in countries with low industrialization indices. The last two sizes denote more advanced structures of specialized factories already able to produce complex machines for more demanding and developed markets. The other type of enterprise constitutes a sort of transition from artisan production to production of great industrial significance.

The values assumed as well as the conclusions are always indicative of intermediate situations. The basic data related to the first three sizes of enterprise have been obtained from studies of the machine-tool industries of Argentina and Brazil. Information for the other enterprise derives from some Western European firms.

The method took account, simultaneously, of a vast *ensemble* of products and factories of diverse technical operative characteristics and represents an approach the ultimate objective of which is to favour the formation and selection of basic ideas with regard to the new initiatives frequently emerging from this sector in countries with mechanical industries in the process of development.

Variables

Machine, type, model, accessory

The term "machine" designates a lathe, a milling machine or an eccentric press. The type determines one of the probable variables in the construction of a machine; in milling machines, for example, there are the universal, horizontal, vertical, simplex, duplex, for splines and copying types. In its turn, the model indicates mainly the size of each type and is directly related to work capacity, installed power and other characteristics.

The type and model are usually accompanied by a series of accessories diversified in form, complexity and weight so as to offer greater utilization capacity. Production machine equipment is studied and adapted especially for specific applications such as feeders of pieces. When the producers design, manufacture and supply equipment, they are compelled to involve themselves with the production problems of the user in a much more intense way than the constructor of universal machines. At any rate, the inclusion of standard and special accessories to the normal line of production implies supplementary series of fabrication which overlap the basic problems, thus augmenting the variable factors that affect the producers.

Complexity index

One of the obstacles met in this study is that of classifying and comparing even approximately the difficulties of construction of the great number of machines, types and models in existence. To assert, for instance, that the elaboration of a parallel lathe is easier than that of a turret lathe of the same power, is not always true.

In order that the machines may be comparable by fabrication, it is necessary to introduce an index number *Ic* called "complexity index" which represents the most significant and characteristic quantity of the machining difficulties.

This *Ic* index may be defined as the sum of various categories of simple or compound machine elements, as:

$$Ic = a_1 + a_2 + a_3 + a_4 + a_5$$

where:

a_1 Indicator number of the quantity of gears, internal and external splined profiles, pulleys and flywheels;

a_2 Indicator number of transmission shafts, racks, movement screws and motors. The transmission shafts are related to the bearings and consequently to the precision borers for the bearings and bushes seat;

a_3 Indicator number of the quantity of couplings, clutches, brakes, internal and external levers, all sorts of cams, and other programmers of a kinematic type. This group of elements is indicative of the degree of mechanical automatism attained by the power and control or programming transmissions;

a_4 Number of plane surfaces and slides that support those parts which being either in movement or blockaded are indispensable to determine a work cycle;

a_5, Number of final and intermediate apparatus, filters, pumps and tanks belonging to the circuits of lubrication, refrigeration, pneumatic, hydraulic and mixed;[1]

a_5,, Number of pistons and rotors.[1]

It is obvious that on counting the different parts and pieces from a_1 to a_5 abstraction has been made of the varying degrees of machining difficulty among the elements; but it is also true that the simplification facilitates equationing the problem without altering its nature.

Figure 2 presents the estimated *Ic* indices for some machines; the great *Ic* variation occurring on the same type of machine is observable. On the basis of the estimated results of *Ic* indices for different machine models (without accessories or auxiliary equipments), it is possible to subdivide the variation field of *Ic* into five groups (Ic_1, Ic_2, Ic_3, Ic_4 and Ic_5) which would be equivalent to:

- Ic_1 Kinematically very simple machines;
- Ic_2 Kinematically semi-complicated machines;
- Ic_3 Kinematically complicated machines;
- Ic_4 Machines with complicated kinematic, hydraulic, pneumatic and lubrication circuits;
- Ic_5 The same machines as Ic_4 but with programming of the work cycle through perforated, magnetic band and other advanced methods not dealt with here.

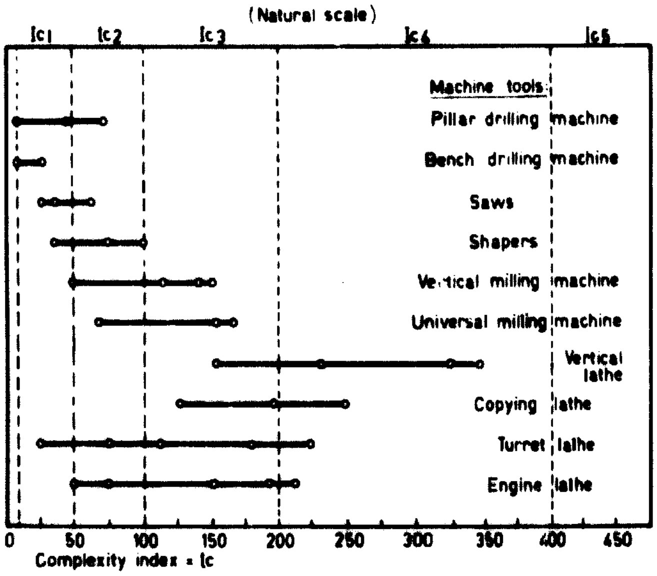
In numerical terms, the four groups could be fractionated as:

Ic_1 from 10 to 50
Ic_2 from 50 to 100
Ic_3 from 100 to 200
Ic_4 from 200 to 400

Weight of machines

The weight of machines is another variable factor which constitutes an important characteristic for the manufacturers. As already demonstrated by practice, at equal complexity the machining of large pieces with a high degree of accuracy is in some ways more difficult than the smaller pieces. Actually, the heavier machines present specific problems of deformation, alignment, perpendicularity and others, proving arduous for the producer despite the implicit admission that when augmenting its size the machine tool loses in precision as compared with the smaller ones.

[1] For a_5, and a_5,, 0.5 of each element is considered when they are bought from third parties, and 2 for those machined by the same producer.



Note: Only a limited number of machine-tool models was considered.

Figure 2 — COMPLEXITY INDEX CORRESPONDING TO SELECTED MACHINE TOOLS WITHOUT ACCESSORIES

Of course it is evident that for each size of enterprise considered further on, the same productive capacity as regards the average weight of machines cannot be assumed, as the heavier ones need a determined managerial infrastructure on equipment, technical experts and transport which can only be found in factories of certain dimensions. Practice suggests then to attribute the maximum weight of the machines they are able to produce to the different manufacturing structures. This limitation is particularly valid and applicable to the small enterprises.

Quality of machines

The quality factor is also a significant variable that should not be ignored when analysing this sector. The verification of the quality of a machine according to Schlesinger and Salmon standards constitutes the most accepted method. It is only by means of such standards that it will be known afterwards whether the machine was manufactured within or outside the specifications. This checking is, however, not sufficient for the purpose of these notes, as no account is taken of the degrees of difficulty the constructor confronts when producing at different quality levels.

It is convenient in the first place to separate the quality of machines into four possible and real classes:

Q_1 Quality of those machines in which the results of the tests are always inferior to the recommendations of maximum error in the standards;

Q_2 Quality of those machines satisfactorily passing only one part of the standards tests or which, owing to inadequate materials or deficient design as a whole or in detail, work with their initial precision for only a short time:

Q_3 Quality of machines always in accord with the standards and in condition to maintain the initial precision for a long time, requiring only normal maintenance;

Q_4 Quality of high precision machines such as the jig boring machines, not included in this outline.

A criterion might be established right away to determine the existing relationship between the final quality of the product and the technical attention to which its components would be subject, taking as an example the number of controls performed on each machined part.

It is a well-known fact that in order to achieve Q_1 quality the use of calibres with a range from 1/20 to 1/50 millimetre is enough: also that the accuracy on the elaboration of couplings or plane surfaces is generally left to the operator. Category Q_2 demands further knowledge on the part of the constructor with regard to metrology, the greater number of measuring instruments and a minimum of quality controls including even the phase of elaboration of pieces. So as to attain category Q_3 manufacturers must make significant efforts, as in general the control of all machining operations is carried out in the section of specialized metrology. Naturally these three cases differ in the instrument utilized, personnel technical level and the indirect hours employed on the quality controls.

Taking now as a point of reference the number of controls the manufacturer usually performs on the components and considering tentatively that the operations may range between 4 to 6 for each part, the result is: for Q_1—one control per piece: for Q_2—from two to three controls per piece; for Q_3—from four to six controls per piece.

These data may also be transcribed thus:

	Q_1	Q_2	Q_3	
one piece of four operations	1	2	4	controls
one piece of six operations	1	3	6	controls

The number of controls reflects in good measure the final result envisaged once the pieces are assembled, as well as that stricter control corresponds to more rigorous design specifications which must be verified.

From another point of view, a certain correlation may be admitted between Q qualities of the machines and ISO work tolerances with regard to the more responsible parts and pieces forming the product. According to information gathered from various producers, that correlation could be approximately: Q_1—quality corresponding to grades 10 and 11 of ISO tolerances; Q_2—quality corresponding to grade 8 of ISO tolerances; Q_3—quality corresponding to grade 7 of ISO tolerances.

To pass from precision degree 7 to degree 8, the field of tolerance of the first piece must be multiplied by 1.56, and from degree 7 to degrees 10 and 11 by multiplying by 4.0 and 6.2 respectively. Supposing now a certain identification among the tolerance degrees and the manufacturing difficulties for obtaining the pieces under consideration, which in practice is partly confirmed, it might be said that other factors being equal, quality Q_1 is 4.0 or 6.2 times easier to obtain than quality Q_3 and 2.6 or 4.0 times easier to obtain than Q_2. If the tolerance criterion is combined with that of the control of pieces with similar values, and adopting intermediate situations, it will be possible to formulate comparisons, which though abstract, lead to the meaning of starting the manufacture of products of different quality.

On the basis of the above it may broadly be admitted that: Q_1 is three times easier to machine than Q_2; Q_1 is five times easier to machine than Q_3; Q_2 is 1.7 times easier to machine than Q_3.

This preliminary equation of the problem has been made with the sole purpose of illuminating how difficult it is in practice to advance on the qualitative field from an inferior quality towards another of international level. Also, that it is not possible to pass from a qualitative situation of elaboration to a superior one without changing the structure of the manufacturing equipment or extending the corresponding technical services.

Size of enterprises

With a view to analysing the sector in its most general aspect, it seems advisable to consider different sizes of manufacturing enterprises from the artisan to a factory with adequate technical resources available for the production of various types and models of machines.

Five typical sizes of enterprises (*Te*) have been selected. The first two (Te_1 and Te_2) with 20 and 50 persons occupied, are characterized by the high percentage of direct or productive hours in relation to indirect or unproductive ones. They dispose of precarious production means and may therefore manufacture simple articles of low quality and low price per kilogramme. These enterprises are justified especially in those consumption areas where the demand for machine tools is still at a primary stage and maintenance and manufacture of metallic devices of elementary composition are predominant. Size Te_3 with a hundred persons, has greater technical capacity than the previous and may elaborate Q_3 machines of low *Ie* index. In this dimension, the proportion of indirect personnel may even reach 28 per cent of all the personnel, favouring the quality of the product as well as the organizational structure. This size, Te_3, represents, however, a stage of transition in the evolution of the enterprises, rather than a well-defined point of techno-economic equilibrium. It is through sizes Te_4 and Te_5 with 250 and 500 persons that more complete manufacturing structures are feasible from a technical and organizational point of view. The percentage of indirect labour increases as referred to Te_5 thus enabling the projection, study, testing and construction of complex products of high responsibility in Q_1 quality.

For sizes above Te_5 not dealt with in these notes, it must be thought that the increase in the number of persons and machines would be related to more important and diversified production volumes rather than to the weight, quality and complexity factors already indicated. Certain observations and results regarding Te_5 may then be valid for these enterprises.

The subdivision of direct and indirect personnel derives from data collected in Argentina, Brazil and Western Europe from enterprises that concentrate their activity on machine-tool elaboration and work exclusively by means of their own designs and research, as shown in table 2 and figure 3.

The lack of a classification that allows for the exact differentiation between direct and indirect personnel might lead to various interpretations. This is the reason why in table 3 the activities here considered as indirect

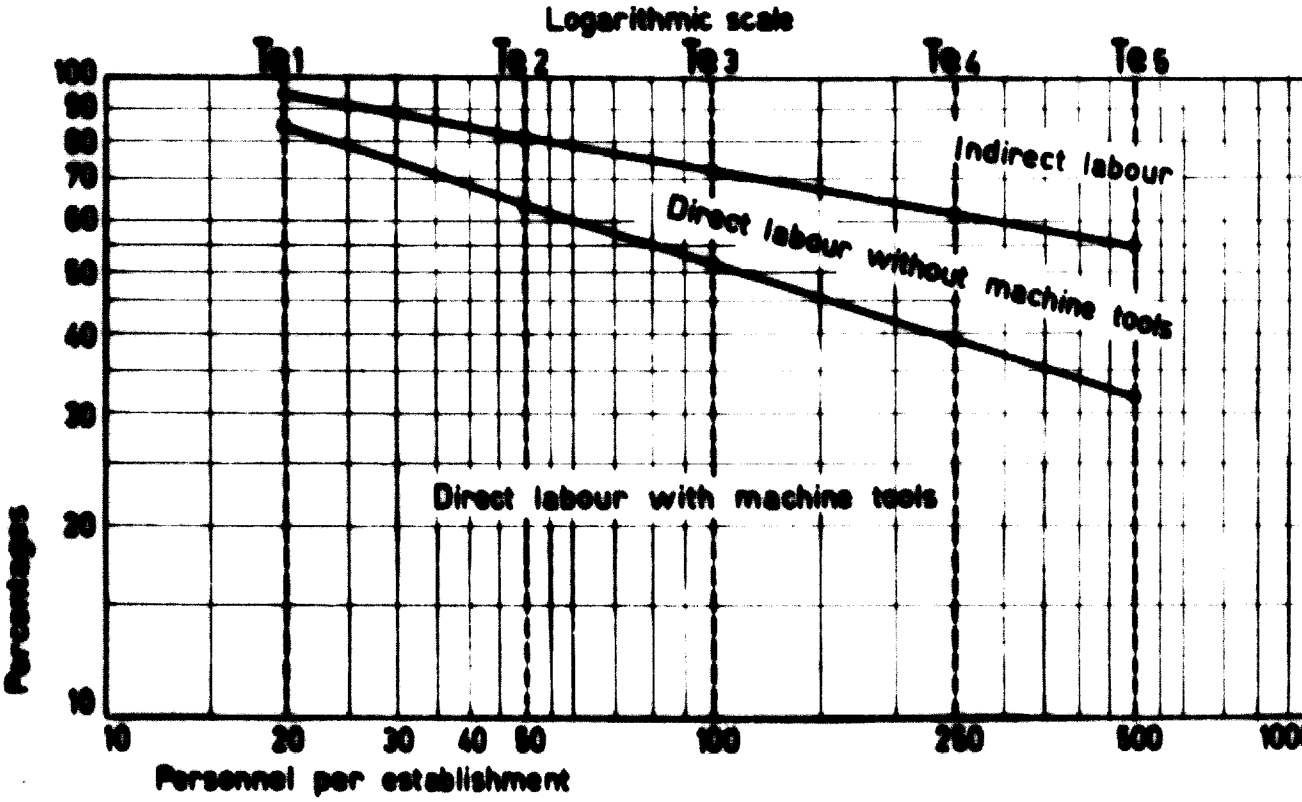


Figure 3

PERCENTAGE DISTRIBUTION OF DIRECT AND INDIRECT LABOUR

Table 2

DIRECT AND INDIRECT PERSONNEL IN THE FIVE SIZES OF ENTERPRISES

		Direct personnel							
		With machines		*Without machines*		*Total*		*Indirect personnel*	
Te	*Total personnel*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*	*Number*	*Per cent*
Te_1	20	17	85	2	10	19	95	1	5
Te_2	50	32	64	9	18	41	82	9	18
Te_3	100	52	52	20	20	72	72	28	28
Te_4	250	98	39	57	23	155	62	95	38
Te_5	500	160	32	115	23	275	55	225	45

have been classified, pointing out the existence or absence in each size of enterprise. The other activities have been taken as direct or productive and are so accounted in order to know the real time of elaboration by pieces, assemblies and machines.

Table 3

DESCRIPTION OF INDIRECT ACTIVITIES

Denomination	Te_1	Te_2	Te_3	Te_4	Te_5
Workshop (workers and foremen)					
Assistant machine operator ...				x	x
Preparation of work on machines					x
Manual internal transports	x	x	x	x	
Mechanized internal transports .			x	x	x
Maintenance	[a]	[a]	x	x	x
Tools	[a]	[a]	x	x	x
Construction of jigs		[b]	[b]	x	x
Tool warehouse			x	x	x
General warehouse			x	x	x
Metrology section				x	x
Baling and packing				x	x
Delivery	[c]	[c]	[c]	x	x
Person in charge of auxiliary services			x	x	x
Foreman	x	x	x	x	x
Labour foreman		x	x	x	x
Workshop (employees)					
Engineers				x	x
Technical office for piecework estimate					x
Technical office for jigs design .				[d]	x
Office for production planning .				x	x
Office for distribution of production cards	[e]			x	x
Co-ordination of purchases ...				x	x
Tests, laboratory and research					x
Office (employees)					
Technical	[e]	[e]	x	x	x
Accounting	[e]	x	x	x	x
Costs			x	x	x
Administration	[f]	[e]	x	x	x
Sales	[f]	[f]	x	x	x
Purchases	[f]	[f]	x	x	x
Exports					x
Management			x	x	x
General services					
Cleaning	[a]	[a]	x	x	x
Conciergerie				x	x
Outside services				x	x
Outside transport				x	x
Guards				x	x

[a] Operations by the same worker who performs productive functions.
[b] Work executed by direct operators.
[c] Uses the same assembly personnel
[d] Elaborated by the employees of the central technical office.
[e] Collaboration of third parties part-time.
[f] Activities personally executed by the owner.

In this way the profound structural differences of the diverse *Te* sizes stand out, and consequently the diverse human technical potentials they have available to operate. Thus, after establishing criteria to define the *Q* qualities, *Ic* complexity indices and *Te* sizes of enterprise, and also taking into account the machines and equipment mentioned elsewhere, it is possible to delimit the most adequate field of action for each industry, using logic compatibility and practical experience as co-ordinating elements among the multiple variables considered.

Table 4 summarizes the most probable situations which may actually happen.

Data registered in table 4 may be transcribed in the following way, bringing out the limit values of *Ic* information of *Q*.

	Ic values for		
Te	Q_1	Q_2	Q_3
Te_1	10-125	10- 62	—
Te_2	10-200	10-100	10- 50
Te_3	100-250	10-175	10-125
Te_4	—	100-300	50-250
Te_5	—	—	100-400

Another observation derives from the work field of the enterprises: that it is necessary to differentiate between the possibility and the convenience of elaborating certain products. This situation is modified according to the size of the enterprise; relating it to the quality factor it might be said that:

Te_1 may manufacture products Q_1 Q_2 —
Te_2 may manufacture products Q_1 Q_2 Q_3
Te_3 may manufacture products Q_1 Q_2 Q_3
Te_4 is only interested in products — Q_2 Q_3
Te_5 is only interested in products — — Q_3

within the previously determined *Ic* complexity indices.

It is understood that Te_4 and Te_5 are manufacturing the products of the smaller enterprises though it does not seem advisable as their prefixed structure would render this uneconomical given their high operational cost. On the contrary, the field of action defined for the first three *Te* corresponds to the maximum technological limits they may achieve as functions of *Q* and *Ic*.

Production series

Among the factors analysed, production series are perhaps the most variable, as in practice they are influenced by innumerable causes. Attention has already been drawn to the fact that the order of magnitude of the series is maintained low even for *Te* enterprises. The diversification of types and models together with the number of different pieces comprising the machines constitute elements so characteristic of the construction of capital goods and of this sector in particular, that they prevent the serial factor from receiving the same approach as, for example, the durable consumer goods.

In order to furnish some arguments on the subject which may be applicable to several producers, the factors indicating the elasticity with which this sector should operate are:

(*a*) During the past fifty years, statistics have systematically shown that in diverse countries the machine-tool demand has almost always been variable in weight and in quantity;

(*b*) Each time, the producer tends to study the most adequate machine for the user's different "economies of scale";

(*c*) As a consequence, the manufacture of complementary and special equipment, sometimes more complicated than the machines themselves, assumes an increasing importance since the constructor will have to take care of them in some way, even if he does not integrate them in his production;

(*d*) In front of a fluctuating demand, the manufacturer shows his interest on the elaboration of different models of the same type of machine, thus ensuring a more regular sale;

(*e*) For the same reason, the producer's preference may be inclined towards the fabrication of more than one type of machine;

(*f*) The elaboration of one type of machine in various models gives the user the impression that the manufacturer has a more thorough knowledge of his field of specialization and that therefore he is not improvising;

(*g*) When manufacture is divided into several models it constitutes a much stronger incentive towards the introduction of structural or marginal modifications and innovations on the products than if the case were of elaborating a unique model, since then it is not necessary to intervene on the whole production;

(*h*) Lastly, it may be said that the construction of one type of machine in more than one model is always a sign of prestige for its manufacturer.

From the above it is apparent that the machine-tool producer should elaborate at least one type of machine in different models which is obviously reflected upon the annual series of fabrication. It may also be added that as a rule this sector tends to fractionate its total production many times in the course of the year, which naturally reduces the order of magnitude of the repetitive series. As a matter of fact, the manufacturer always tries to defend himself against the too low series, on the basis of:

(*a*) Launching the fabrication of small pieces once or twice a year. The storage of such pieces does not involve a significant immobilization of capital;

(*b*) Studying the products in order that the small mechanical pieces are common to various types and models of machines (internal unification);

(*c*) Maximum standardization of pieces bought from third parties (less variety of tools for their applications), including electrical material;

(*d*) Unifying as much as possible diametrical measures, screws, splined profiles, threads, tolerances and pieces of all types;

(*e*) Unifying at a maximum the modules and numbers of teeth of gears;

(*f*) Conceiving the machines as a composition of compact groups and subgroups for the power transmission chain as well as for that of the controls, be they kinematic, hydraulic, pneumatic, of lubrication, etc., which may be joined to a carrying and functional structure having in mind their eventual adaptation to machines manufactured in different models but within the same technical line;

(*g*) Abandoning the traditional idea of incorporating into one-piece structures all the non-powered transmissions, that is, of low potential, to apply them externally. This would simplify in a sensible manner the machining of heavy pieces, giving at the same time more scope for possible modifications;

(*h*) Reducing the use of the unique source of power and installing various motors, giving among other advantages simplification derived from the diminution of distance transmissions;

(*i*) Designing similar pieces to perform the same function with different potentials.

The production means generally utilized on the construction of machines are almost always of a universal type. Consequently, in order that the products may be elaborated within a reasonable number of direct man hours per 100 kilogrammes (Hs/100), the manufacturer

Table 4

Work field of the enterprises

(Average conditions)

	Ic_1			Ic_2			Ic_3			Ic_4		
Size	Q_1	Q_2	Q_3	Q_1	Q_2	Q_3	Q_1	Q_2	Q_3	Q_1	Q_2	Q_3
Te_1	10–50	10–50	—	50–100	50–62	—	100–125					
Te_2	10–50	10–50	10–50	50–100	50–100	—	100–200					
Te_3	—	10–50	10–50	—	50–100	50–100	100–200	100–175	100–125	200–250		
Te_4	—	—	—	—	—	50–100	—	100–200	100–200		200–300	200–250
Te_5	—	—	—	—	—	—	—		100–200			200–400

also is compelled to give maximum attention to the auxiliary production equipment and tools.

The difficulties met when trying to establish a criterion to determine the minimum economic series of fabrication which may be equally valid for the different product levels thus are revealed clearly. The estimate methods adopted for this purpose would only be applicable to homogeneous groups of machines and specific manufacturing situations. Furthermore, in practice, several combinations are offered to the same constructor (produce, for example various types or models of machines, each one with a different series).

As an illustration, some data are transcribed which have been provided by machine-tool manufacturers in connexion with the minimum production series for machines up to five tons. It is understood that these values do not prevail for the total production of the enterprise but only for one or a few types or models of machines.

	Minimum repetitive series (tons)				
Te	5	2 to 5	1 to 2	0.5 to 1	0.5
Te_1			4	9	12
Te_2			5	11	15
Te_3		3	6	14	18
Te_4	3	4	12	20	26
Te_5	4	8	16	24	32

Production of the enterprises

Productive capacity expressed in tons per year

It is possible to estimate the annual tonnage of finished products for each enterprise. Consider on one side, the total number of direct man-hours (Hs) available during one year in each *Te* enterprise and, on the other, the number of direct man-hours necessary to manufacture 100 kilogrammes of product (Hs 100).

Purposely, no specification has been made previously in order to do it now. The activities considered as direct owing to their closer linkage to the Hs 100 are examined herein. These are summed up for each enterprise in table 5.

Table 5

DESCRIPTION OF DIRECT ACTIVITIES

(**M** minimum; **S** scarce; **R** regular; **N** normal)

Denomination	Te_1	Te_2	Te_3	Te_4	Te_5
Cleaning and preparation of cast iron pieces	M	S	R	N	N
Marking	N	N	N	N	N
Operators with direct machines	N	N	N	N	N
Scraping	M	S	N	N	N
Assembly	N	N	N	N	N
Painting	N	N	N	N	N
Break in		M	R	N	N
Final controls according to standards	M	S	R	N	N

The annual production right lines *P* marked as a function of Hs 100 are indicated in figure 4. The extension covered by them is observable as well as the superposition on the tonnage produced between one enterprise and another, which in practice is difficult to admit. Meanwhile, considering that it has been verified that the production per occupied person (direct and indirect personnel) and per year normally fluctuates between

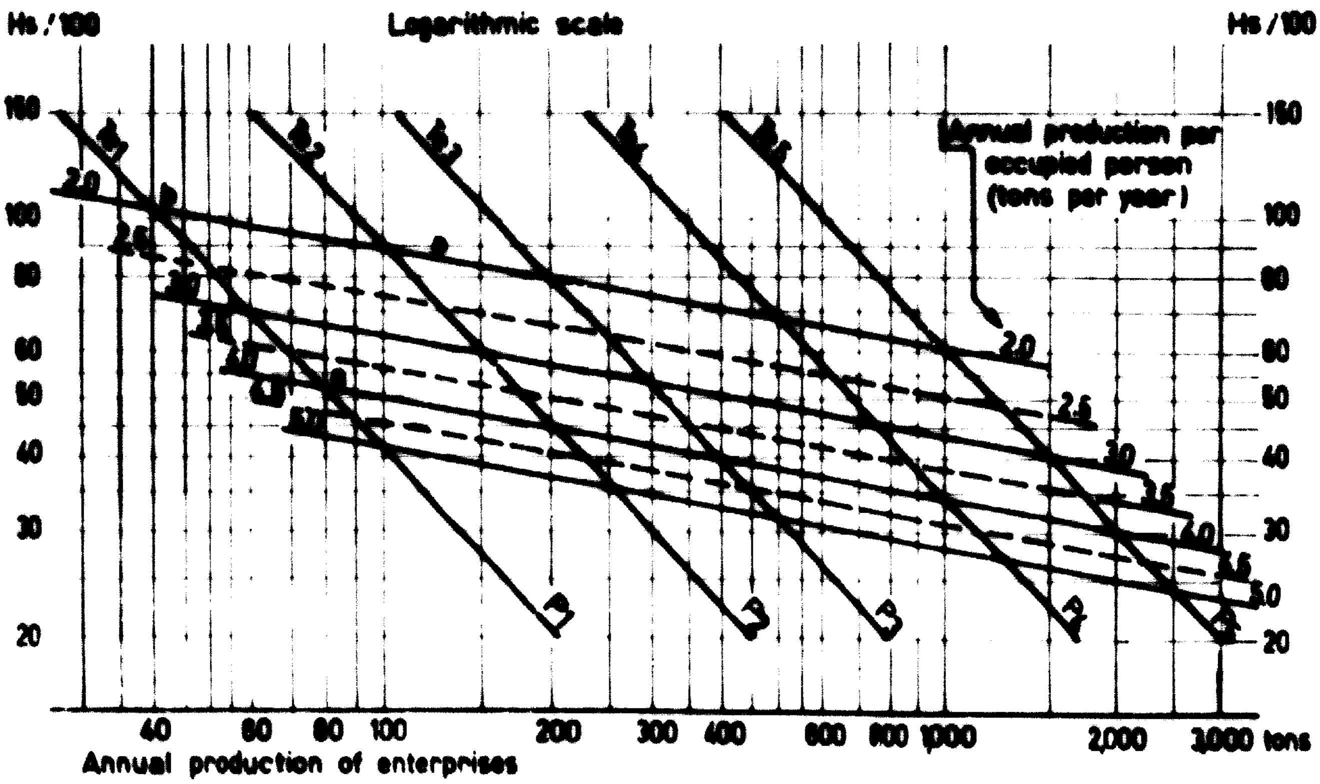


Figure 4

ANNUAL PRODUCTION OF ENTERPRISES AS A FUNCTION OF PRODUCTIVITY

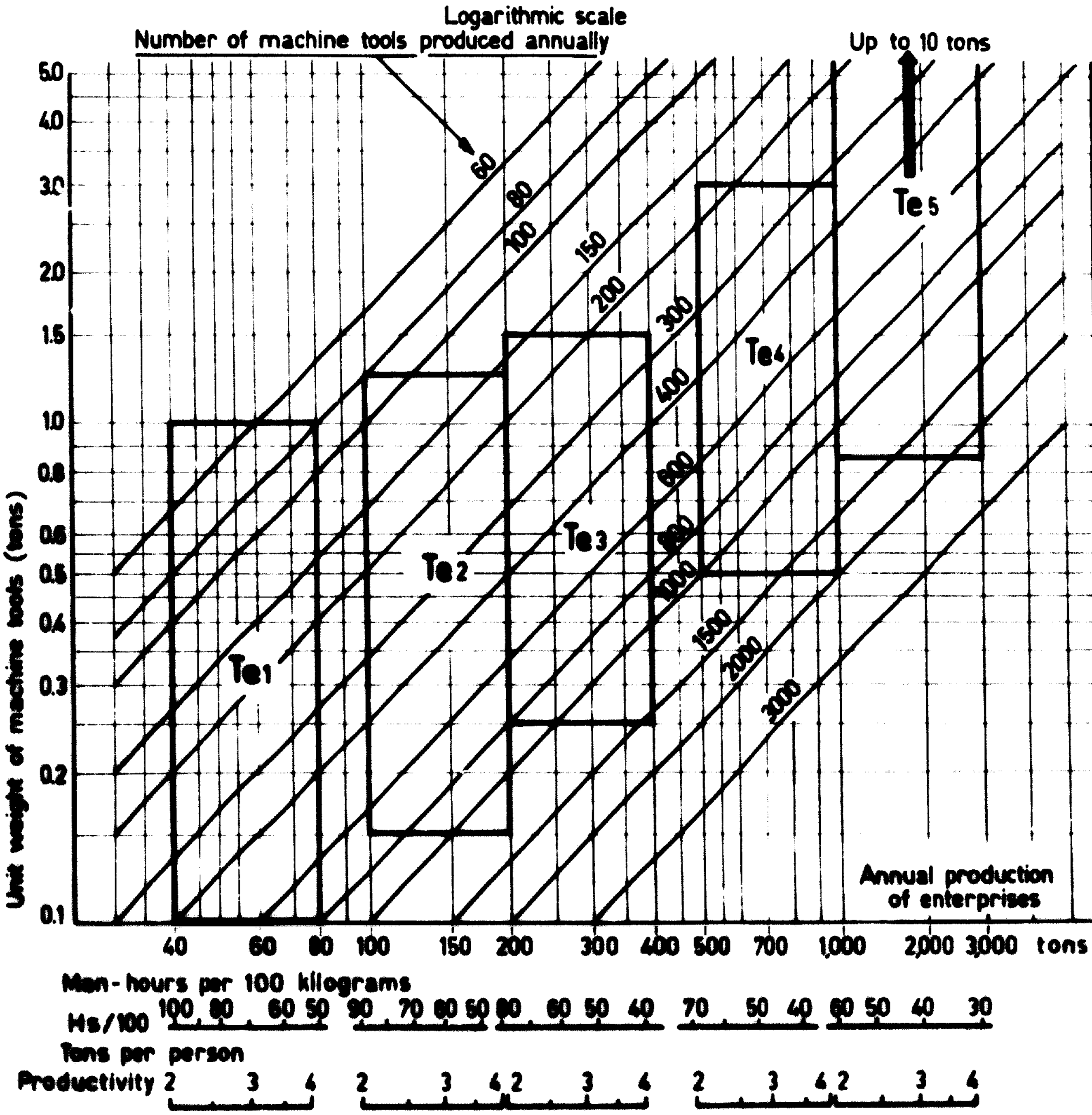


Figure 5 — NUMBER AND WEIGHT OF MACHINE TOOLS DERIVED FROM ANNUAL PRODUCTION

two and four tons, it is possible to delimit the production field of the enterprises. It will then be enough to overlap to the right lines *P* a faggot of right lines *p* representing the different production values per person and per year that, when located between two and four tons, leads to the elimination of production interference between one enterprise and another. The problem thus defined gives a clear idea as a whole, enabling at the same time a glimpse of the panorama presented by those sizes above *Te*₅.

Different observations may be formulated in connexion with figure 4. In the first place, it may be supposed that one goes from *a* to *b* along right lines *P* when the *Ic* and *Q* indices increase. The same happens assuming that *Ic* and *Q* remain constant if bad use is made of machines and installations, or a production is fractionated in too many types and models of machines, or both things at a time. Going from *b* to *a*, the appreciations are equal and opposite. Attention should also be drawn to the fact that 2,200 effective work hours per year have been admitted for each direct person, which is equivalent to one work shift.

Productive capacity expressed in number of machines per year

If a determined weight unit is attributed to machines, it is easy to estimate the number *Te* may elaborate on the basis of already available production data in tons per year.

This situation is illustrated in figure 5 where Hs 100 scales and those of productivity per person have also been adapted for each enterprise. The action field of the enterprises is defined when possibility or convenience limits are established regarding the weight of machines, in accordance with the size of industries and taking into account:

Te_1

(*a*) The means for lifting and for internal transport are exclusively manual, thus making it difficult to remove heavy volumes such as cast iron bodies of machines of more than one ton;

(*b*) The machines used are more adequate for light production;

(*c*) Should the constructed machines weigh more than one ton, their fabrication number per year would be low. In that case, annual invoicing would be subdivided into a few fractions, which is incompatible with the economic-financial structure of the manufacturing artisan;

(*d*) In order to ensure a more regular invoicing, Te_1 should elaborate larger quantities of light products susceptible of being launched into production twelve times a year (monthly frequency);

(*e*) It may be noted that Te_1 has possibilities of producing Q_2 machines only if their unit weight is reduced.

In view of the above, the manufacture of products with a unit weight of more than one ton does not seem advisable for Te_1.

Te_2

Generally speaking, the observations made for the former enterprise are also valid for Te_2.

(*a*) However, unlike Te_1, this enterprise is able to produce Q_3 machines provided their weight is not high, for example up to 0.5 0.75 ton.

(*b*) It seems convenient that when this enterprise elaborates its products in two models, the maximum weight be limited to around 1.25 tons.

Te_3

(*a*) Figure 5 indicates the existence of a wider field of manufacturing possibilities as regards the weight of machines. It is assumed that Te_3 is interested in the construction of at least three models of machines and for that reason the production of machines above 1.5 tons is not desirable.

(*b*) The technical capacity of the enterprise might allow for even heavier manufactures but with Q_1 quality.

(*c*) For financial motives, the launchings should not be fewer than six per year when it is the case of producing only one model; for other cases, eight launchings would be recommended.

Te_4 and Te_5

Within the high *Ie* and *Q* patterns assigned to them, these enterprises permit the most varied conditions of operability in respect of weight and number of machines. The limitations on the unit weight of products for these sizes refer to the minimum weight of the machines they are interested in constructing. Otherwise, should this weight be reduced in extreme, productions would result in less technical and commercial significance in contrast to prefixed structures which are considered normal within the sector.

Repetitive series

By repetitive series of manufacture is understood the results from the division into fractions of the annual production of a given type or model of machine as a consequence of the number of launchings in the course of a year.

Machine-tool fabrication, as with other capital goods, is characterized by discontinuity which derives from the number of times the series is repeated during the year. The most frequent quantity of launchings is in practice exactly one, two, three, four, six, eight and twelve, figures deserving some additional comments.

Generally speaking, launchings of one, two and three times a year are not acceptable for the production as a whole because the circulating capital would in such cases attain excessively high values in comparison with the economic structure of the enterprise, altering costs in a sensible manner.

For Te_4 and Te_5 the most usual frequencies are four, six and eight, while eight and twelve seem more suitable for Te_1, Te_2 and Te_3. Due to a series of variable factors, among them demand which may differ according to the type and model elaborated by a single constructor, different launching frequencies may coexist within a given factory. Hence it becomes practically impossible to take into account all the probable combinations that may occur.

Nevertheless, starting from already known data in figure 6 permits calculation of the magnitude of the construction series as a function of the number of launchings and the quantity of models.

This is of course valid for estimating the average of a manufacturing situation as well as for facilitating some of the combinations which may derive from the subdivision of total annual production for each *Te*.

INVESTMENT AND COSTS

Investment on machines for the five enterprises

Machine tools represent the greatest part of fixed total investment. The number of direct operators working with machines has already been determined for each size of enterprise: as usual, they have been assigned a machine per person. If this relationship is taken as starting-point, it is easy to compile an inventory for each enterprise which although hypothetical may be sufficiently representative regarding the form of operation of the sector. Even if not referred to the construction of given types or models of machines, it must be acknowledged that these conditions are nearer the ideal equipment for the manufacture of metal-cutting machines than for that of metal-forming machines, since the first ones exist in a larger variety of types and models.

The selection of the production equipment is also made, taking into account the factors, quality, complexity and weight of the machines, in agreement with the positions adopted in this outline. Generally, the smaller firms use machines of low price and less technical resources. Te_3 utilizes machines of medium value together with others of inferior quality, while for Te_4 and Te_5 the category of the machines integrating the inventories is of high level in terms of quality, operative resources and prices. Here an almost always valid observation concerning the sector under analysis should be pointed out: As the importance of the series is variable at least between the limits considered, the machines do not differ much from the universal types. Hence, automatic and semi-automatic machines are not included in the manufacturers' inventory. This is easily understood when account is taken of the great variety of pieces and the large number of different operations required by the repetitive series. Standing out once more is the importance that must be attributed to the quality of tools and to a wider use of jigs and special equipment for obtaining low Hs 100 values. This is equivalent to asserting that at parity of Te and Q and with equal equipment and investment, it is possible to achieve different Hs 100 values only through the more or less rational utilization of the auxiliary production equipment which in its turn depends upon the technical, imaginative and creative capacity of the indirect personnel in charge of this task.

It also may be said that if a smaller percentage of indirects is admitted for Te_4 and Te_5, numerically more important inventories than those selected can be conceived. Such would be the case, among others, of enterprises working exclusively or partially through licences of foreign firms, since then the indirect personnel devoted to research studies, product and equipment projects might be replaced by productive personnel once these services would be in the charge of the industry providing the licence. Thus the number of direct hours available in one year could be increased between 15 and 5 per cent over the values adopted. As these cases fall out of the scope of the present outline, they have not been considered further. However, it would not be difficult to adjust the respective corrections within the context of these notes.

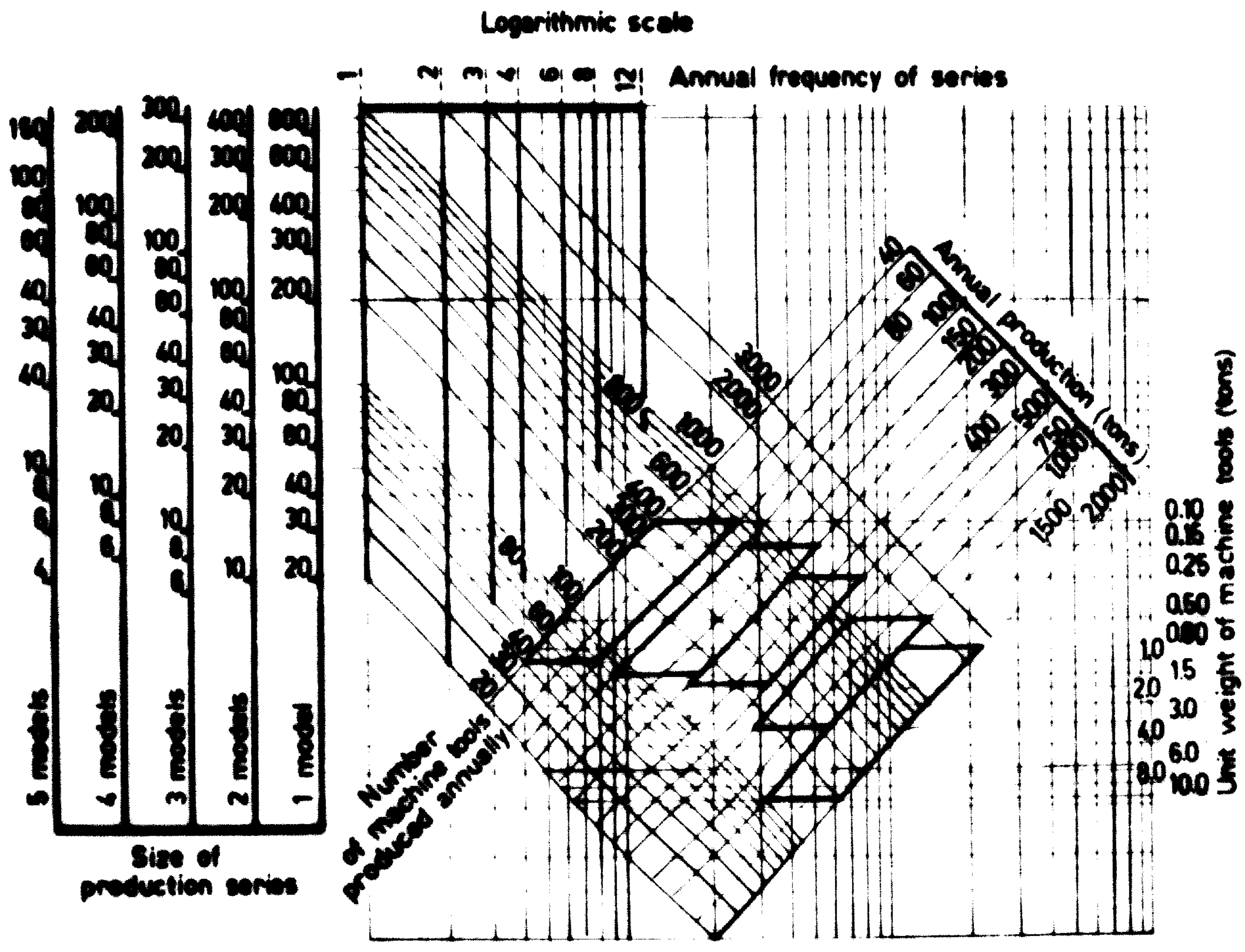


Figure 6

SIZE OF THE REPETITIVE SERIES ACCORDING TO ANNUAL PRODUCTION VOLUME, MANUFACTURING FREQUENCY AND MACHINE-TOOL WEIGHTS

The variety of the machines usually utilized in those manufactures may be appreciated in table 6, together with the distribution for the different enterprises. Here it is naturally understood that the displacement of Te_1 towards Te_5 implies an improvement of its quality with repercussions over the price.

In order to facilitate the interpretation of the table, some comments are added in connexion with each type of enterprise.

Machines for Te_1 enterprise

The list of the machines required by this enterprise is extremely simple and offers few variants. As in this size there are no specialized sections, machines are used for direct as well as for indirect services. There are no machines to carry out special services: this is a workshop where labour is exclusively artisanal and where it is normal that the same worker executes different functions, passing from one to the other with relative facility.

Machines for Te_2 enterprise

This size is also characterized by the employment of a reduced number of indirect personnel. Its inventory of machinery is of some importance and allows it to construct machines with *Ic* and *Q* features which favourably meet the demands of the industrial inventories of such countries which are just starting to develop mechanical industries. As a rule, the technical and commercial guarantees which this type of enterprise may provide are not in sufficient demand to subscribe fabrication agreements through licences from foreign firms. For them it is more common to subcontract some project services. The equipment itself as well as methods of utilization still reflect elementary technical levels.

Machines for Te_3 enterprise

The evolution of enterprises from Te_1 to Te_4 and Te_5 is accompanied by increasing technical and organizational capacities, starting from the artisanal system for Te_1 and progressing to a complete structure, already possible for Te_4 and consolidated for Te_5, Te_3 offering diverse interpretations of machines, equipment and organization. This means that Te_3 may represent as much of an enterprise of Te_2 type, though somewhat larger, as an enterprise which is trying to develop its general structure taking as a point of reference the organization and the techno-productive results that may be achieved in superior sizes. In the present case, the selection is made with a view to the latter hypothesis which implies that beginning by Te_3 it is interesting and feasible to work with licences from specialized firms.

Machines for Te_4 enterprise

When a machine-tool enterprise reaches Te_4 size, the structure of almost all its sections is well delineated and the firm is in a position to elaborate products of a certain complexity and of its own design. Such an enterprise may therefore contribute in some measure to the technological evolution of the sector.

Machines for Te_5 enterprise

In this size of enterprise, the preferential selection of equipment for the manufacture of metal-cutting machines is more evident. It may also be observed that in Te_5 enterprises indirect machines can attain almost 9 per cent of the total, which allows internal construction of complex auxiliary production equipment. Under these conditions, rational employment of installed machinery, together with efficient administration and organization of the different sections, make possible productions with low Hs 100 values although *Ic* and *Q* might be high.

Other investments

This denomination covers mainly the following items:

(*a*) Indirect and complementary production equipment;
(*b*) Internal mechanized means of transport;
(*c*) Trucks and vehicles;
(*d*) Furniture and office machines;
(*e*) Equipment for laboratories;
(*f*) Industrial installations;
(*g*) Terrain;
(*h*) Buildings.

Before evaluating the probable amount of investment, the position of every enterprise with regard to these points should be defined. This is summarized in table 7.

This scheme expedites the discrimination on capital density among the different *Te*. On the basis of available information and taking average conditions within those normally registered in practice, it has been possible to estimate total investment by types of enterprise, as indicated in table 8.

In practice, within the same size of enterprise varied situations coexist especially as to terrain, buildings and installation values. Moreover, these values differ between one zone and another within the same country, as well as in the different countries. It is estimated, however, that the values adopted for total investment in table 8 are sufficiently indicative of the structural differences that separate the several enterprises.

Cost of direct man-hour

One of the more accepted methods for calculating hourly costs consists of relating all fixed expenses registered in one year with direct or productive man-hours actually available. Given its simple structure, in the smaller enterprises it is enough to assume for the direct hour an average value equal for all sectors of the factory. For Te_4 and Te_5, it is preferable to establish average values for the direct hour for each group of similar machines and for the different production sections, as in these cases the hourly cost is diverse either owing to the stronger or weaker incidence of labour or to the degree of intensity of the applied capital.

According to the purpose of this outline, it is enough to present the average cost of direct hour for each enterprise so as to reduce the number of variables, already high. In this respect, the following should be kept in mind:

Table 6

INVENTORY OF MACHINERY REQUIRED BY THE DIFFERENT TYPES OF ENTERPRISES

Denomination	T_{e1}	T_{e2}	T_{e3}	T_{e4}	T_{e5}
Production machines					
Parallel lathes of various dimensions	6	9	13	18	24
Screw-cutting lathe				1	2
Vertical lathe					1
Turret lathe		—	1	6	9
Copying lathe		—	—		1
Universal milling	1	1	3	5	5
Vertical milling	—	1	2	3	4
Special milling		—	1	2	3
Horizontal milling	—	—			1
Screw-cutting milling			—		1
Planning	1	2	3	4	4
Planemilling	—	—	—	—	1
Slotting	—	—	1	1	2
Shaping	3	3	3	5	3
Horizontal boring	—	1	2	3	3
Vertical boring	—	—	—	—	2
Pillar and bench drilling	3	6	8	12	14
Column drilling	—	—	—	—	6
Radial drilling	1	1	2	4	6
Universal cylindrical grinding	—	2	2	4	7
Internal cylindrical grinding	—	—	—	2	3
Plain grinding	—	1	2	2	4
Plain grinding for slides and large surfaces	—	—	—	1	1
Grinding for splined profiles	—	—	—	—	1
Gear cutting, Fellows type	—	—	1	2	3
Gear cutting, Maag type	—	—	—	—	1
Gear cutting, Pfauter type	—	—	1	1	2
Gear cutting, Barber-Colman type	—	—	—	—	1
Conical gear cutting	—	—	—	—	1
Grinding for gears	—	—	—	1	2
Bevelling gears	—	—	—	1	2
Broaching	—	—	—	1	1
Threading, CRI-DAN type	—	—	—	1	2
Straightening for shafts	—	—	—	—	1
Saws	1	3	4	6	7
Machine for sheets	1	1	2 *	3	4
Welding		1	1	2	2
Hydraulic press	—	—	—	—	2
Honing and lapping	—	—	—	—	1
Dynamic balancing	—	—	—	—	1
Centre hole grinding	—	—	—	—	1
Centring shafts	—	—	—	—	1
Dividing and engraving	—	—	—	1	2
Special[a]	—	—	—	4	7
Others	—	—	—	2	8
Total direct machines	17	32	52	98	160
Machines for tool manufacture, maintenance and construction of jigs and special production equipment					
Jig boring	—	—	—	1	2
Precision milling	—	—	—	—	1
Universal milling	—	—	1	1	1
Universal grinding	—	—	—	1	1
Precision parallel lathe	—	1	1	2	3
Tool grinding	1	1	2	3	4
Shaping	—	—	1	1	1
Drilling	—	1	1	1	2
Welding	1	—	—	—	
Total indirect machines	2	3	6	10	15
Total inventory	19	35	58	108	175
			(United States dollars)		
Total value of machines[b]	36,000	105,000	244,000	663,000	1,356,000
Average value of machines[c]	1,900	3,000	4,200	6,140	7,750

[a] Constructed or adapted in the same industry.
[b] For simple machines, the types and prices prevailing on the Argentine and Brazilian markets have been considered.
[c] For machines of non-Latin American origin, an overcharge of 10 per cent over the f.o.b. value for transport and insurance, and another of 20 per cent for internment expenditures and others have been considered.

(*a*) Accounting of all direct man-hours already determined, that is those considered as productive; this is done by means of the cards enclosed with the work during its execution. The sum of all direct hours accumulated in the course of a year should coincide with the theoretical hours available, which are deduced in accord with the number of direct persons working in an enterprise. It is understood that passive times of work preparation as well as of the operational cycle proper should also be accounted for, charging them to the respective piece or machine;

Evidently each *Te* will be characterized by a different *Ch* value that will increase as long as *Te* augments.

Table 9 presents relevant data that should be kept in mind when calculating the cost of direct man-hour on the basis of average situations occurring in the Latin American countries, with special reference to Argentina and Brazil. Once *Ch* has been determined, it is easy to arrive at the fixed cost per 100 kilogrammes of finished product Co/100, which if other conditions are maintained equal will be different and variable according to its productivity in each size of enterprise. In agreement

Table 7

SCHEMATIC DISTRIBUTION OF INVESTMENT, EXCLUDING MACHINE TOOLS

Item	Te_1	Te_2	Te_3	Te_4	Te_5
(*a*)	almost nil	scarce	medium	complete	complete
(*b*)	—	tackles	tackles	bridge crane and lifting tackles	complete
(*c*)	—	—	—	yes	yes
(*d*)	negligible	scarce	medium	complete	complete
(*e*)	—	—	—	—	medium
(*f*)	almost nil	primary	scarce	medium	complete
(*g*)	yes	yes	yes	yes	yes
(*h*)	yes	yes	yes	yes	yes

Table 8

ESTIMATE OF TOTAL INVESTMENT BY TYPES OF ENTERPRISE

(*Values in thousand dollars*)

Denomination	Te_1	Te_2	Te_3	Te_4	Te_5
1. Direct and indirect machines (see table 6)	36.0	105.0	244.0	663.0	1,356.0
2. Other investment (see table 7)	5.4	23.0	69.0	387.0	984.0
3. Total investment	41.4	128.0	313.0	1,050.0	2,340.0
4. Relationship of 1 over 3	87%	82%	78%	63%	58%
5. Investment per occupied person	2.07	2.56	3.13	4.20	4.68
6. Investment per direct person	2.18	3.12	4.35	6.78	8.50

(*b*) Accounting of all expenses during the year in connexion with wages and salaries, social taxes, general expenses of operation and indirect material for consumption by the office and the workshop, as well as other expenses except raw materials, sales and banking expenditures;

(*c*) Amortization of all investments. In the following estimates an annual amortization of 10 per cent over the total value of investment has been considered. In fact, part of the amortization, that of indirect manufacturing equipment relative to a determined model, measurement calibres, cast iron models and others, should refer to inferior times, while the other, that of buildings and installations, allows for longer periods.

It derives that the cost of direct man-hour (*Ch*) will be:

$$Ch = \frac{b + c}{a}$$

with the average figures adopted, it may be pointed out that Co/100 values fluctuate between $45 and $150. Owing to the method followed to estimate Co/100, this represents only part of the cost, the rest being constituted by:

(*a*) Raw materials (cast iron, steel bars, sheet, etc.);

(*b*) Eventual machining subcontracted to third parties;

(*c*) Parts and pieces bought in the market and used directly on the assembly line;

(*d*) Propaganda and sales expenditures;

(*e*) Banking expenditures.

The sales value is obtained through the addition of gross profit to these expenses and to those indicated in table 7.

If Co/100 cost is related to the sales value of 100 kilogrammes of product (Vv/100), it follows that although an optimum unique value cannot be attributed to this rela-

Table 9

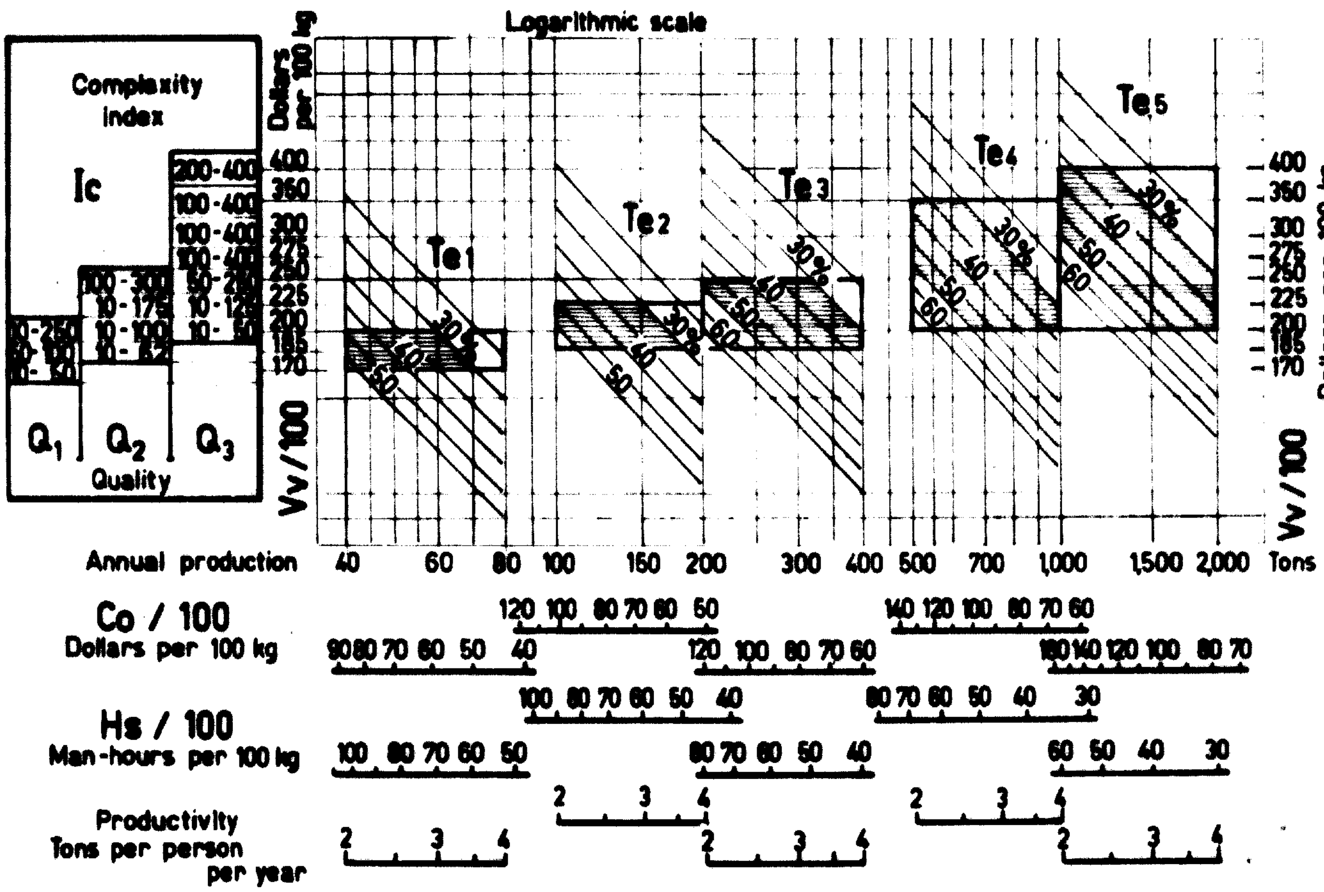
BACKGROUND DATA FOR CALCULATING DIRECT MAN-HOURS

(Values in dollars)

Denomination	Te_1	Te_2	Te_3	Te_4	Te_5
1. Persons occupied in the enterprise ..	20	50	100	250	500
2. Directs (with and without machines) .	19	41	72	155	275
3. Indirects	1	9	28	95	225
4. Annual hours per direct person	2,220	2,200	2,200	2,200	2,200
5. Total direct man-hours per year	41,800	90,200	158,400	341,000	605,000
6. Annual wages of direct labour	10,500	27,000	55,400	126,000	242,000
7. Annual wages of indirect labour	2,400	9,000	28,000	114,000	315,000
8. Total wages (6 + 7)	12,900	36,000	83,400	240,000	557,000
9. Social taxes and insurance (percentage of 8)	60	60	60	60	60
10. Total annual expenditure on personnel	20,640	57,600	133,440	384,000	891,200
11. Annual amortization (see table 8, 10 per cent)	4,140	12,800	31,400	105,000	234,000
12. Fixed general expenses per year......	6,000	20,000	45,000	100,000	250,000
13. Consumption material per year	5,000	12,000	30,000	70,000	140,000
14. Total fixed expenditure per year (10 + 11 + 12 + 13)	35,780	102,400	239,840	659,000	1,525,200
15. Cost of direct man-hour (14:5)	0.86	1.14	1.51	1.93	2.52

tionship, given the general terms under which the problem is framed, it is true that such a relationship keeps within practical limits of further operative feasibility of the order of 30 to 50 per cent. These are applied in figure 7 to each *Te*, together with the already defined data on total annual production in tons, Hs/100, *Ic* and *Q*. Thus, starting from favourable and/or possible factors, the field of action of the five enterprises is clearly delimited.

As regards the correlations among quality, complexity of the product and sales value of the same, it is evident as illustrated in figure 7 that this is an empirical accommodation whose objective is to gather into a single panorama the free play of the several techno-economic variables characteristic of the sector. Furthermore, it may easily be seen that the right lines which define the percentual relationship between Co/100 and Vv/100 are



· *Figure 7*

TECHNICO-ECONOMIC FEASIBILITY OF ENTERPRISE OPERATIONS lines of "equi-invoicing", that is, of equal economic effect for different technical conditions of operation.

An observation here is that Te_1 and Te_2 enterprises would find obstacles to productivities of the order of four tons a year per person, and this in practice is confirmed by the Argentine and Brazilian cases. In return, the other sizes of enterprise offer possibilities in this field, which is in agreement with the structures assigned to them.

Relationship between machine-tool manufacturing enterprises and the infrastructure of the rest of the mechanical industry

It is usually admitted as a general rule that the producer depends to a greater or lesser extent upon auxiliary industries that provide him with services, specialized parts and pieces for the manufacture of his products, whose existence has been transformed into an indispensable infrastructure for the development of the sector. It is obvious that the magnitude of such a structure as a supporting element for machine-tool construction is enlarged, complemented and complicated in the measure that quality, complexity and sometimes even the weight of the machines increase; in other words, on direct account of the installation of firms of growing size.

Thus, the presence of factories of type Te_1 and Te_2 does not necessarily imply the existence of an important auxiliary industry as they produce quite simple machines. But for the products attributed as feasible by the rest of the enterprises, the assistance of other specialized enterprises is imperative.

It is understood that the comparison among different Hs 100 will be valid as long as the manufacture is integrated in the same manner. It must be pointed out that in practice the integration variables are not many, as the producers usually buy the cast iron material, machine it, purchase in the market the parts and pieces indicated on table 10, and machine the remaining pieces.

The group of raw materials and services mentioned in that table constitutes a point of reference about that which has been defined as infrastructure and which should consequently be considered as a domestic activity. In accordance with the qualitative hypotheses connected with the size of the constructor, the quality demands of cast iron material go together with the increase of *Te*. Hence, the importance of an iron foundry, as cast iron is the basic raw material for the manufacture of machines (from 50 to 80 per cent in gross weight with regard to the weight of the finished machine). The second group of parts and pieces presented in table 10 and its respective qualitative appreciations in relation to the enterprises, deserve further comment.

In the first place, it is not indispensable that the availability in the market of all the items is conditioned by their being nationally manufactured. On the contrary, it is admissible that some of them—bearings, complex

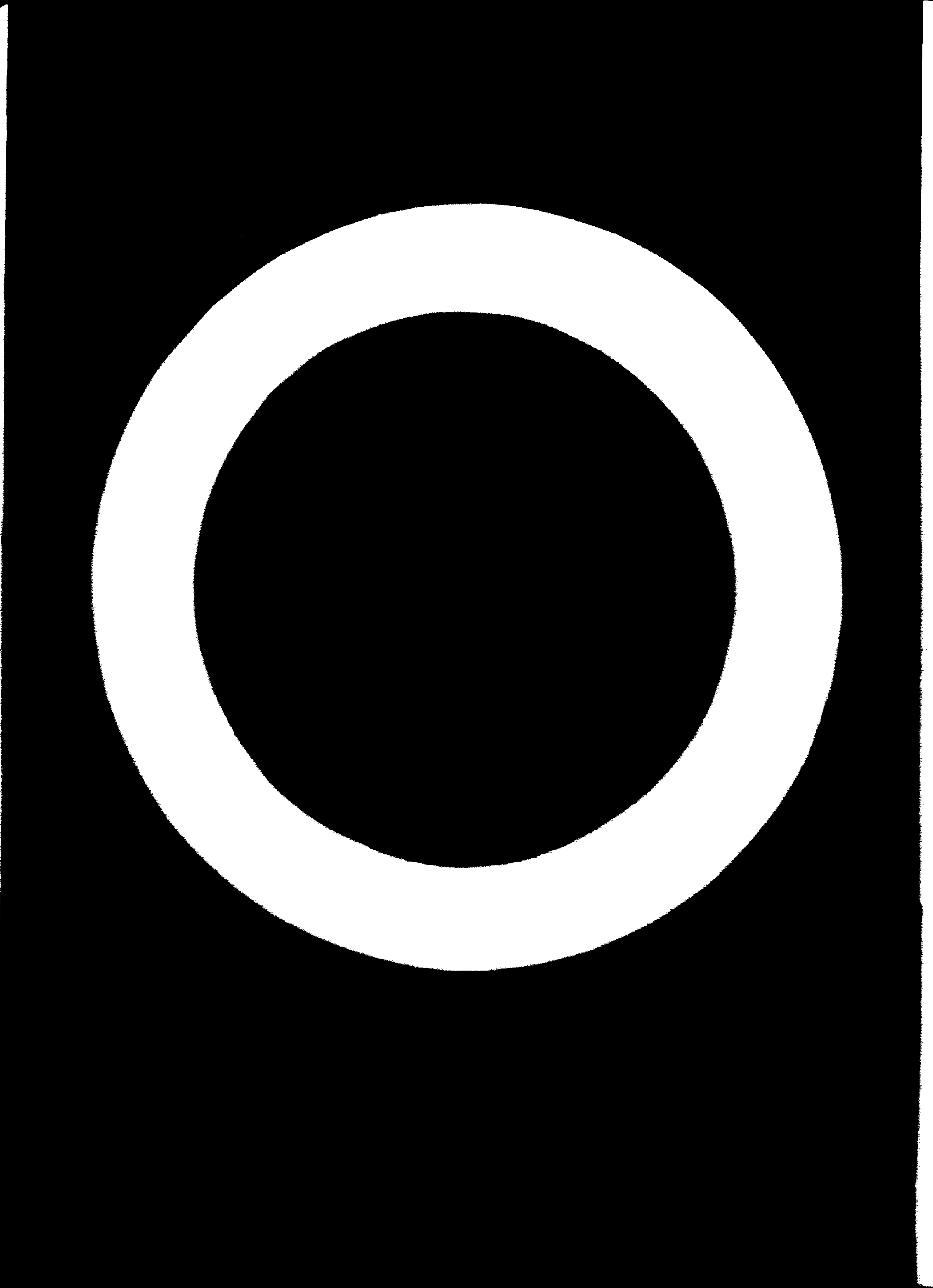
Table 10

LIST OF MAIN INTERCONNEXIONS BETWEEN MACHINE-TOOL MANUFACTURING AND AUXILIARY INDUSTRIES

Denomination	Te_1	Te_2	Te_3	Te_4	Te_5
Raw materials and services					
Cast iron (quality)	medium	regular	good	perfect	perfect
Relief of stresses	no	sometimes	sometimes	always	always
Variety of cast irons	scarce	scarce	sometimes	high	high
Hardness demand of cast iron	scarce	scarce	sometimes	rigorous	rigorous
Foundry of non-ferrous (quality)	medium	regular	good	perfect	perfect
Use of common steels	scarce	scarce	regular	normal	normal
Use of special steels	different	reduced	reduced	normal	normal
Heat treatments	very scarce	scarce	insufficient	normal	normal
Commercial parts and pieces					
Electric motors	common	common	common	special	special
Simple elements for electric circuits	medium	almost regular	regular	good	good
Complex elements for electric circuits			sometimes	normal	frequent
Elements for hydraulic circuits			sometimes	correct	good
Elements for pneumatic circuits			sometimes	correct	good
Elements for circuits of lubrication	elementary	elementary	almost normal	good	complete
Elements for circuits of refrigeration	elementary	almost regular	normal	good	good
Clutches, brakes, torsional, couplings, etc.	-	elementary	scarce	sufficient	complete
Screws, screw nuts, washers and similar items	elementary	almost regular	normal	good	good
Use of precision bearings	no	no	irregular	normal	normal
Springs of every type (quality and variety)	scarce	scarce	almost regular	complete	complete
Non-metallic accessories (use)	scarce	scarce	regular	complete	complete
Non-electric accessories of machines (quality)	medium	elementary	almost normal	normal	complete
Electric accessories such as magnetic plates, etc.			sometimes	normal	complete
Simple non-metallic elements (use)	scarce	almost regular	regular	complete	complete

elements for electric and hydraulic circuits, clutches and others highly specialized, for example depend upon importation. In this group, several less complicated products may also be included which are bought from local industries. Nevertheless, it is interesting that the exaggerated dependency of domestic industry upon the incorporation of certain accessories for machines would affect the elasticity of the productive process up to the point that it would be more convenient for the producers to take charge of the manufacture of parts of such elements until finding someone who could elaborate them. Similar situations have occurred in Argentina and Brazil where, only recently, firms capable of designing and constructing accessories under strict specifications are starting to emerge from the mechanical industry.

Owing to the limited equipment available to Te_1, Te_2 and Te_3, it is a normal practice for these enterprises to subcontract services for specialized machining such as gears, splined shafts and machining of heavy pieces. Within the flexibility with which it has been intended to define the most probable field of action of the different *Te*, minor cases of subcontracting of services other than usually considered would be contemplated. In general, elementary and simple machines do not need the addition of highly specialized and technically advanced elements, and that their respective unit values of sale are not too influenced by the pieces bought in the market. However, as long as the machine becomes complicated in its diverse aspects, the producer will certainly begin adding to it, in growing quantities, complements from other specialized machines, thus substantially altering the relationship between his work and the value of pieces and equipment purchased from third parties: in some very complex machines, the correspondingly high values of Vs 100 are achieved through the important contribution by other provider industries of parts and pieces.



MINIMUM NOMENCLATURE OF METAL-CUTTING EQUIPMENT RECOMMENDED FOR PRODUCTION IN DEVELOPING COUNTRIES

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Technical revolutions are characteristic features of the present epoch. Countries which are technically developed achieve new success by continuously developing productive forces and improving the means of production. New means of mechanization and automation of work processes have been widely adopted by all branches of industry. During the past fifteen to twenty years, industrial production has acquired a new form and new contents. Advances also have been made by some countries which until recently were considered to be lagging in industrial development. Humanity has not known any other period in its thousand-year history during which productive forces, means of production and techniques developed so rapidly, widely and comprehensively. This is why we call the occurring industrial development a real technical revolution.

Science and technology occupy special places in this development of industry. Science practically becomes the motivating power of the technical progress which would be impossible without the latest and newest discoveries. Rapid development would be impossible if countries were isolated from the experience and achievements of others. This is especially clear in industrially backward countries with small populations. Rapid technical progress is possible only on the basis of mutually beneficial scientific and technical collaboration and production co-operation among individual countries.

The machine-tool industry is most important in the development of machine construction because it produces machines for the manufacturing of machines. As the decisive factor, machine-tool equipment determines the technical culture of machine construction and dictates the rate of its technical development.

On this basis, it is possible to say that the development of any national industry leads to the creation of national machine and machine repair industries. The latter cannot exist without a national machine-tool industry. The development of a machine-tool industry is an objective necessity for every developing country. This has been proved to us by history and current practice. It is explained by the fact that the availability of a machine-tool industry allows a nation to realize its potentialities with new machines and construction and to modernize existing equipment. This is the most reliable guarantee of continuous technical progress. It is considered correct that the rate of growth of the machine-tool construction sector should be greater than the rate of growth of the machine construction sector.

MAIN KINDS OF METALWORKING MACHINES REQUIRED BY INDIVIDUAL BRANCHES OF INDUSTRY IN DEVELOPING COUNTRIES

It is typical in the economies of most developing countries that there exist simultaneously both small and handicraft production of a wide assortment of machines and industrial production of machines for industry. The necessity to repair and maintain machines (which as a rule are supplied by different manufacturing firms) leads to the use in various branches of industry of a wide assortment of metalworking machines.

It is expected that till 1980 individual and handicraft machine production will continue to furnish a considerable part of the total production of the developing countries. As a rule, the sector needs the so-called standard types or universal machine tools and metalworking machinery, such as: universal lathes; drilling and radial drilling machines; plain cutting-off machines; hack-sawing machines; shapers and planers; universal surface and cylindrical grinding machines; gear-cutting and gear-finishing machines; eccentric and friction presses; and spring and pneumatic hammers of small and medium sizes.

In the machine branch, the most important factor for the selection of machines is the kind of article (refrigerators or television sets, wireless sets, tractors and other agricultural machines) and yearly production. However general purpose machines of the so-called standard types are required at the initial stages of production in all cases. Special and specialized machine tools with programmed controls should be used only after additional calculations of their efficiency in each specific case.

Despite the diverse nomenclature of machines manufactured in the sphere of individual and small production, the quantity of machine tools (by types and sizes) used in machine construction of the developing countries may be reduced to a certain minimum with the help of rational planning.

As for the other branches of the economy which need machine tools, the situation becomes more complicated because of their unequal development in different countries. Most of the countries have one-sided economies and partially developed textile industries.

In the developing countries, machine tools are used in all branches except machine production (including the electrical industry) mainly for the repair and maintenance of basic equipment and rarely for the manufacture of complete equipment. This makes it difficult to recommend the necessary machine tools to different branches.

For example, such branches of the textile industry as those dealing with processing flax, cotton, hemp, etc., and knitting enterprises need mainly light, general purpose, standard machine tools.

On the contrary, mining, power, metallurgical and paper industries need large machine tools of low efficiency but notable for a wide technological range (chucking machines and turning-and-boring mills, machines for regrinding rolls for metallurgical works).

As a rule, the repair workshops of these branches need both universal standard type machines of medium weight and some special and large size machines, recommended by specialists.

Main groups of machine tools recommended for production in developing countries

Among the most important factors determining the main groups of machine tools to be recommended to developing countries are:

(a) Requirements of the country must determine the profitability of production. The lower limit of profitable production of universal standard type machines may be considered fifty to sixty pieces per year.

(b) Availability of native raw materials and finished and half-finished products (such as: electric motors, electrical equipment, hydraulic elements, castings, etc.). It follows that from the economic point of view the most expedient method is mastering universal machines of the main standard types shown in table 1.

Table 1

Nos	Name and basic parameters
1.	Universal lathes with the maximum machining diameter up to 630 mm
2.	Drilling (column type and bench type) machines with the maximum drill diameter up to 5 mm
3.	Milling machines with the maximum width of table from 200 to 300 mm
4.	Shapers with the maximum length of stroke up to 630 mm
5.	Main types of hacksawing machines for cutting off material having diameters of 160, 250 and 400 mm
6.	Universal and plain cutter and tool-grinding machines
7.	Boring machines for repair of engines
8.	Universal cylindrical grinding and surface grinding machines
9.	Horizontal boring machines

The mastering of these main groups of machines is a natural road to development in the field of machine-tool construction. Besides, all this is bound up with the following:

(a) These machines are necessary for machine construction and machine repair in different branches of industry of the developing countries. They can make up about 65–75 per cent of all required machines. Therefore, it is expedient to manufacture them within the country;

(b) Accumulation of experience in manufacturing these machines makes it possible to pass in the future to the production of machine tools having higher performance.

Basis for choosing main parameters

The designing of new machine tools of any kind (except unique ones) should be preceded by the typification of these machines. The typification is accomplished on the basis of a general analysis of existing machines of a similar type which have been manufactured during the last three to five years. Typification is necessary because the practical operational range of a kind should be covered by a minimum number of sizes. Among the aspects of typification are construction, technological, operational and repair likenesses and the possibilities of vertical and horizontal unification of some constructional elements and eventual use of the assembly principle for general purpose machines; nomenclature limitations of production programme; and organization of serial production with all ensuing economic advantages.

It is necessary to determine the limits of the whole scope of machine-tool series with respect to basic parameter and eventually with respect to parameters following it, to classify the necessary sizes within the whole scope, to determine basic technological data, e.g., geometrical dimensions of an article manufactured with the help of the given machine, connecting or fastening surfaces).

Parameters and sizes are selected in conformity with a series of recommended numbers according to the standard used in the country (e.g., TOCT 8032–60). The recommended numbers form the basis of a series of linear dimensions (e.g., TOCT 6636–60) which are decimal series of geometrical progressions with the following exponents:

For series R5 $\sqrt[5]{10}$ 1.60

For series R10 $\sqrt[10]{10}$ 1.25

For series R20 $\sqrt[20]{10}$ 1.12

For series R40 $\sqrt[40]{10}$ 1.60

Parametric series and dimensional series are determined for each kind of new machine tool. The parametric series is a series of numerical values of one or several parameters of a machine. The dimensional series is a series of basic parameters of machines of the same type.

The problem of the density of series of basic parameters for machine tools of the same type is important. A series too dense results in a large nomenclature of machines similar by parameters. A greatly rarefied series deteriorates the technical and economic indices of machine operation since it is necessary to use larger machines instead of the excluded small ones. Determination of the optimum series of basic parameters is an important task which demands a detailed technical and economic grounding. The optimum series is a series of machine dimensions which always ensures that losses are minimized during the manufacture of machines and during their operation.

When creating a new series of machines of the given type, it is profitable to begin with a rarefied series which may become more dense when necessary. Thus, the common shortcomings of the series are eliminated by a small number of sizes, and improvements connected with experiments are also performed with the help of a small number of machines.

In grounding the selection of series, it is necessary to consider in succession the following factors: overhead expenses change, annual programme in pieces, material expenditures, machine cost price, annual programme cost price, annual amortization assignments, additional expenditures during operation and total annual expenditures.

Countries belonging to CMEA have agreed to adopt common basic parameters and series of numerical values of parameters of machine tools. For instance, adopted as the basic parameter of universal lathes is the maximum machining diameter, numerical values series being according to R10 with exponent ϕ = 1.25. The range from 100 to 630 mm is covered by nineteen machines.

The basic parameter chosen for drilling machines is the maximum drill diameter in steel with σ_b = 50 – 60 kg/mm^2. Numerical values series are:

Bench-type drilling machines: 1.5, 3, 6, 10, 12, 16, 20, 25;

Vertical drilling machines: 12, 16, 20, 25, 32, 40, 50, 63, 75–85, 100.

The series of bench-type drilling machines from 1.5 to 6 inclusive is rarefied after two numerical values and corresponds to series R10; from 10 to 25, series R10 is complete. The series of vertical drilling machines is in conformity with the complete series R10.

Universal lathes manufactured in the People's Republic of Bulgaria have the following numerical values of the basic parameter: 200, 320, 400, 500 and 630 mm. This corresponds to series R10. (Lathe with basic parameter of 250 mm is not mastered.)

In order to ascertain the mastering of series it is necessary to compare the basic parameters of mastered lathes and then to compare basic parameters of lathes which are being mastered at present.

There are two parallel series of mastered machines differing in their completeness and additional parameters.

Models of lathes

Basic parameter	200	320	400	500	630
Basic series	CY201	CY321	C11M	C10M	C13M
Additional series	—	C8	C5	—	—

Lathes of the basic series are more powerful. They are intended for heavy duty operation in main workshops with a high degree of organization. Lathes of the additional series are intended for auxiliary use.

The basic series was mastered after the additional one on the basis of experience.

Methods of mastering minimum nomenclature of machine tools

There are mainly four ways of creating and developing machine tools:

(*a*) By individual scientific and technical research, design and technological work;

(*b*) By joint scientific research, design and technological work;

(*c*) By documentation or samples of existing machines;

(*d*) By buying licences.

The first method is typical of all countries, but mainly for those which in addition to many years of experience and with traditions in production, laboratory and operation research, possess great engineering technical and economic potential.

The second method of development is used almost by all countries regardless of technical level in the given branch. However, it is characteristic that this method of solving scientific research and design problems is selected by those countries which have equal or similar achievements in the given sphere and common technical and economic interests.

The third way of gaining results in this field is typical of countries which are backward qualitatively or quantitatively when they design and manufacture machine tools. This method also is characteristic of some socialist and developing countries.

The fourth method of development is used almost by all countries wishing to miss some stages which are necessary for making articles at a high technical level but would entail considerable losses in time and means. For many countries with the material and technical bases for the timely and effective mastering of a new article in full compliance with the licence bought, this is the only way of quick achieving a high standard of manufactured produce which would meet all competition in domestic and world markets.

The third and fourth methods are most important for developing countries. Therefore, they will be discussed in more detail.

Documentation or samples are given by countries advanced in the branch. They are chiefly used by those countries which are backward in the sphere of development and mastering of machines.

The use of documentation bought at low prices represents great advantages for the developing countries. Making documentation which is sold at seller's prices also has advantages for the developing countries, but documentation can be made at a high level only by organizations which have great experience. Such organizations are not available in the developing countries. When using documentation, the specialists of a new plant use specific experience and quickly raise their qualification. Machine flow sheets help to organize production better, more easily and in conformity with existing conditions and to use the available equipment, experience and traditions to a greater extent. There is considerable reduction of the total time required for the mastering of the machine, because no time is spent on designing, making and testing the pilot model and it is possible to start the adoption of the zero series immediately.

In Yugoslavia, the production of machine tools was mastered in a comparatively short time using documentation supplied by the Soviet Union. In that way, such machines as horizontal boring machines, models 2620A, and 2630, planer type milling machine, model 6642, vertical boring mills and lathes with basic parameters of 1,000 and 3,000 mm, were mastered.

In the United Arab Republic, on the basis of documentation received from the Soviet Union, the production of a universal lathe, model 1A62, and a surface grinding machine, model 3 Б722 with a basic parameter of 320 mm, was mastered. Considerable assistance in the rational designing of cylindrical grinding machines, surface grinding machines and planer type milling machines was rendered to the People's Republic of Bulgaria which received corresponding technical documentation from the Soviet Union and Czechoslovakia.

France occupies first place among countries which sell licences, followed by Switzerland, the United States, West Germany, the United Kingdom, and Italy. Japan is first among countries buying licences. India, Yugoslavia, Hungary and Spain come next in that order.

The purchase of licences is especially profitable for the developing countries. Usually, when drawing a licence purchase contract, they stipulate conditions ensuring that the technical level of the buyer will be raised by the firm selling the licence. This is done by means of supplying the necessary equipment and machinery, by training personnel and by passing on production experience or know-how. The buyer gets the right of know-how. This allows a new enterprise to quickly gain that which takes tens of years in other countries. Machines manufactured by licence sell better in domestic and world markets because the firms possessing rich experience and traditions enjoy confidence.

On the basis of studying the mastering of new machine tools, it is possible to draw the following conclusions:

(*a*) Most developed countries make progress in designing and developing machine tools mainly through their own scientific and technical research and designs. Joint scientific-research works and designs come second, mainly used by partners equally developed in the given sphere, whose joint activity is caused by common economic interests. Although the buying of licences is not a principal method of development for these countries it is used for the sake of maintaining continuously high technical levels in the branch.

(*b*) Countries which are backward in the production of machine tools more often use the third way of development, i.e., documentation or samples. The purchase of licences is also very important to these countries.

(*c*) The majority of countries which buy licences do so because of the absence or shortage of engineering staff (e.g. India, Yugoslavia, Hungary and Spain). If the engineering staff and material and technical basis are adequate, licences are bought for the sake of quickly and efficiently mastering new articles. Other countries buy licences mainly to ensure the highest technical level in all fields of the branch so as to secure domination in home and world markets. A typical example in this respect is Japan. The developing countries buy licences which ensure the delivery of required equipment and machinery and assistance in training personnel. This is the shortest and most reliable way of quickly mastering machine production.

Regardless of the method selected, it is possible to master a minimum nomenclature of machine tools only in case there is available an industrial enterprise with necessary machines and equipment. The minimum set of equipment depends to a great extent on the possibilities of co-operation inside the country and abroad. The machines mentioned below are necessary in case the enterprise operates in the conditions of limited possibilities of co-operation. Usually the developing countries have such conditions.

When selecting an initial set of machines, it is necessary to select those most suitable for every purpose. This should be done on the bases of the scale of production, possibility of delivery and successful use of new and high-efficiency machines.

For the machining of frame works it is necessary to use milling machines with a table width of 350 mm, planer-type milling machines and planing machines. But depending on the scale of production it is possible to have only some of these machines. In a larger series, the group of machines for processing frame works must include special grinding machines for guides.

Horizontal boring machines are necessary for processing openings and faces of frame works. At small enterprises, it is possible to use radial drilling machines fitted with suitable conductors. It is expedient to use such machines at large enterprises as well in addition to horizontal boring machines.

For machining such articles as axles, shafts, gears and rings it is necessary to have universal lathes and also turret and copying machines.

For the machining of drive screws it is possible to use high-accuracy screw cutting lathes. But in most cases it is necessary to have special lathes or milling machines.

For the manufacturing of main spindles use is made of precision cylindrical grinding machines for external and internal grinding. It is advisable that grinding machines used for machining main spindles should not be used for grinding other articles.

Machine-tool production needs a great number of gears, most of which are ground. Therefore, it is expedient to master the technology of grinding gears. For processing gears, it is necessary to have basic gear hobbing, gear tooth rounding and gear grinding machines.

Depending on the scale of production and kind of mastered machines, a number of additional machines is added to the basic set of machines to increase the efficiency and accuracy of machining.

For the processing of precise openings, it is recommended to have a precision boring machine. Keyways and splined openings of gears are machined with the help of broaching machines.

Auxiliary departments are of great importance for the development of an enterprise. They include tool, forge, foundry, thermal, maintenance and other shops. It is necessary to have them in the plant or constant and stable co-operation with other plants or shops.

The machines and equipment recommended for a complete small machine-tool plant cannot have equal production loads, especially when the scale of production is minimal. In view of this, some machines are to be used with reduced efficiency and for unusual operations. In order to keep special machines running at full capacity, it is practical to accept orders from other enterprises, especially those dealing with machine-tool repair.

Structure of machine-tool production in developing countries

The analysis of machine-tool application in developing countries shows that besides the machine industry, these machines are used in light and extractive industries and motor transport mainly for repair work. The requirements of these branches, which are key ones in developing countries, determine the necessary composition of the stock of machine tools in operation.

Proceeding from the experience of Bulgaria pertaining to the same stage of development at which at present are some developing countries, we can accept an approximate structure of the stock of machine tools which will be in operation in the developing countries by 1970. This structure is shown in table 2.

Table 2

Approximate structure of machine-tool stock in developing countries, 1970 1975

	(per cent)
Lathes 44%	
Copying	2.0
Turning-and-boding	1.5
Universal	95.5
Chucking	1.0
Milling machines 8%	
Knee type, universal, horizontal and vertical	96.7
Planer type	0.3
Copying and engraving	2.5
Special purpose	0.5
Drilling and boring machines 25%	
Vertical drilling	95.5
Radial drilling	2.5
Horizontal boring	1.5
Jig boring	0.5
Grinding machines 4%	
Universal cylindrical	43.0
Internal	15.0
Cylindrical internal	7.0
Surface	35.0
Honing, lapping and tool and cutter grinding machines 1.5%	
Honing	60.0
Lapping	5.0
Tool and cutter grinding	35.0
Shaping, slotting and broaching machines 9%	
Planing	30.0
Shaping	50.0
Slotting	20.0
Gear-cutting and thread-cutting machines 3%	
Gear cutting and gear shaping	24.0
Gear milling and spline milling	76.0
Cutting-off machines 5%	
Other machines 0.5%	

At the first stage of development, the production of machine tools should be organized on the basis of internal needs of the country. It is also necessary to take into consideration the fact that it is most economically effective to master those machine tools which are in the greatest demand in the domestic market.

It should not be forgotten that at the initial stage some countries will not have enough skilled personnel and experience. Consequently, these countries must begin with mastering those machines which are comparatively simple.

We consider it to be most expedient and profitable for the developing countries to have by 1970 1975 the approximate structure of machine-tool production as found in table 3.

Table 3

Structure of machine-tool production in developing countries by 1970 1975

	(per cent)
Lathes 40%	
Universal	100.0
Milling machines 7%	
Knee type, universal and vertical	100.0
Drilling and boring machines 40%	
Vertical drilling	95.0
Precision boring	5.0
Grinding machines 4%	
Universal cylindrical	85.0
External	15.0
Honing, lapping and tool and cutter grinding machines 2%	
Tool and cutter grinding	100.0
Shaping and slotting machines 3%	
Shaping	80.0
Slotting	20.0
Cutting-off machines 4%	

THE POSITION OF METALWORKING INDUSTRIES IN THE STRUCTURE OF AN INDUSTRIALIZING ECONOMY

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In this report are described the relationships, to each other and to all other sectors of an industrial economy, of industries in the metalworking complex. Systematic quantitative information should facilitate translation of the preliminary aggregative outlines of a national development plan into specific industrial programmes which, in turn, should provide a firm basis for detailed design and assessment of individual investment projects.

The emphasis in this intermediate stage of developmental planning is on interindustrial balance: on the provision, for each newly established branch of production, of an appropriate supply of raw and semi-finished materials, of power, and of other kinds of inputs on the one hand, and of a properly assured outlet for its output on the other. The analytical procedures and the factual information are intended to facilitate planning the expansion of metalworking industries within a framework assuring balanced growth of all sectors in a developing economy.

In an industrial economy, metalworking industries function as the chief suppliers of durable capital goods to all sectors. Indeed, metalworking and construction sectors are the only major suppliers of durable capital goods. In 1958, United States metalworkers contributed 31 per cent of all gross private capital formation, the bulk of the remainder coming from the construction industry. In contrast, their contribution of current account inputs, that is, materials, parts and components, and services to other industries in the economy, was relatively small. Because of the special interest here in capital-producing sectors, particular attention must be given to problems of capital accumulation, of growth and replacement, if the economic functions of the metalworking industries are to be understood.

Current account input-output tables

The presentation will be organized around a series of tables, each designed to illustrate a particular aspect of industrial interdependence. Table 1 is an input-output table for the United States in 1958. It shows the dollar value of sales by establishments in each of the eighty-one industries of the economy in relation to each other and to final consumers, households, Government, exports and imports, net change in inventories and gross capital formation. Imports are shown as negative entries, i.e., as an offset to other final demand items. Each row describes the industrial destinations of an industry's products; each column details an industry's purchases from the other sectors. If we divide the purchases by each industry (in a given column) by that industry's output, we obtain a set of input-output coefficients. These are shown in table 2. The coefficients in each column are essentially a recipe for a unit of its output. They show, for example, how much coal, ore and scrap are purchased by the steel industry per unit of steel output.

Throughout the world, input-output tables have been made for more than fifty countries varying in stages of industrial development and types of economic organization. Economies differ quite a bit, and so, naturally, do the input-output tables which describe them. Look, for example, at the input-output tables for India and Japan, tables 3 and 4. While it is not easy to compare them (the transactions are in different currencies, and prices and the sectoring plans are not the same), important resemblances and differences are apparent. Sales and purchases by manufacturing and particularly by metalworking sectors have much greater relative importance in Japan than in India. In both countries, however, primary metals producers and other metalworking sectors supply the bulk of metalworkers' inputs.

A country which is formulating its development plan will want, naturally, to base its analysis on its own input-output table in so far as possible. In the discussion which follows, we shall refer most often to the most recent material for the United States economy, since this is the material most readily available to us. Because the United States already has a highly developed metalworking complex, we can use it to provide examples of the interrelationships among metalworking and other sectors. Later, imports are introduced as an alternative source of metalworking products. The analytical procedures which are presented can, and indeed should, be applied to data for other economies as well.

In tables 1 and 2, sectors have been arranged roughly in "triangular order", i.e., the industries producing primarily final goods (machinery, clothing, processed foods) are placed at the top of the chart, followed by the producers of intermediate products (engines and turbines, electronic components, machine shop products), and still below that by producers of raw materials, energy, etc. If production were always a "one-way street", the arrangement would be perfectly triangular: there would be no transactions in the upper triangle of the input-output table. But this is not the case. Chemicals are used to make paper, but paper is used to package chemicals.

Steel is used to make blast furnaces, but blast furnaces are used to make steel. Nuts, bolts, and screws go into machines, but are also made by machines, etc. These circular or backfeeding aspects are very important in a complex industrialized economy. It is important to insure balance, among these interdependent processes, in planning or forecasting economic development.

A standard input-output computation permits us to trace the impact of any given change in deliveries to final demand on all inter-industry flows on current account, and hence on all industries' outputs. If more automobiles are to be produced for consumers or for export, then the economy will have to deliver more steel, metal products, textiles, and power to the automobile industry. To supply these additional inputs to automobiles, the steel industry will have to consume more coal, ore, and scrap, the metal products industry still more steel, the textile industry more chemicals and natural fibres. To supply this second round of additional inputs, still more ore, coal and scrap, more chemicals, more coal, and so on, are needed. To compute all the direct and indirect requirements of a given change in final demand, we compute the so-called "inverse coefficient matrix."[1] Table 5 is such an inverse matrix. Each element tells how much of the products of the industry on the left are required per unit increase in final demand for the product listed at the top. The inverse coefficient for steel into automobiles tells how much the total production of steel in the economy must increase per dollar increase in deliveries of automobiles to final demand. Inverse coefficients will always be equal to or larger than direct input-output coefficients (table 2) because they include indirect, in addition to direct, production requirements.

Foreign trade and import substitution

In tracing the direct and indirect effects of changes in the bill of final demand on domestic outputs, exports must be added to the other items included in the final demand, while imports have to be entered in it as a column of negative figures. If, for example, a country were to increase its export of electric motors, the output of the electric motors industry and of its various direct and indirect suppliers would have to increase by the same amount by which they would have to be raised if the additional motors were produced for domestic use. Increased imports of electric motors would have just the opposite effect.

Import substitution is nothing but a combination of a cut in imports and an equal rise in domestic output (with the level of domestic final demand remaining the same as it was before). The combined direct and indirect impact of the two shifts on every sector of the economy can be estimated through simple summation of the separate effects of each of them. In general, given a complete export programme and a corresponding import programme of a country, their total effect on the level of output in each branch of domestic industry can be estimated through subtraction of the direct and indirect effects of all types of imports from the combined (positive) effects of all the different kinds of exports.

Using the table of technical input coefficients, it is even simpler to compute the import requirements for raw material, semi-finished and finished goods—or the export surpluses—corresponding to any combination of projected output levels of domestic industries with given quantities of their respective products allocated to exports and absorbed in final domestic use. The inputs required by each industry to attain the projected level of output can be determined on the basis of the appropriate input coefficients. These inputs combined with projected deliveries to final use will yield estimates of total domestic demand for each type of goods. Comparing these with the projected total domestic outputs, we arrive at the figures of required imports or exportable surpluses.

Labour and capital coefficients; aggregation to a 38-sector classification

Large coefficients in the United States coefficient table and in the inverse coefficients table are shaded. They represent relatively important direct or indirect linkages between a given selling industry (identified on the left) and purchasing industry (identified at the top). Sectors 9–35 (sector 15 can be excluded) in tables 1, 2, and 5 are metalworking sectors.

With large capacity high-speed computing equipment, it is not difficult to deal with eighty-odd sector input-output tables, or even much larger ones. On the other hand, it is still very clumsy to print and reproduce large matrices on a single page of paper. To facilitate presentation here, we have chosen to consolidate, or aggregate, the United States input-output materials to a thirty-eight-order classification. The consolidated flow and coefficient tables are given as tables 6 and 7. Since we are concentrating on the metalworking sectors, we have kept full detail in the twenty-five metalworking industries, but aggregated the non-metalworking sectors into only thirteen sectors. Metalworking sectors are renumbered 1–25. The last five rows in the coefficient table, 7, show total fixed capital requirements (dollars per dollar of output), labour requirements in man-years per thousand dollars of output, for three different types of labour skills, and total labour requirements. Multiplying the output levels for each of the thirty-eight industries by these labour coefficients, we can obtain estimates of each of the three types of labour required in each producing sector. Comparison of these estimates of labour requirements with projections of skilled labour supply or manpower training plans will tell whether a given set of output levels is feasible.

Supplies of other factors of production which may introduce bottlenecks can be treated analogously. If an economy has only a limited supply of, for instance, an

[1] $(I-A)^{-1}$, where A is the matrix of flow coefficients

$$\text{coefficients: } \begin{matrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & \cdot & & \cdot \\ \cdot & \cdot & & \cdot \\ \cdot & & \cdot & \cdot \\ a_{n1} & & & a_{nn} \end{matrix}$$

as exemplified in table 5

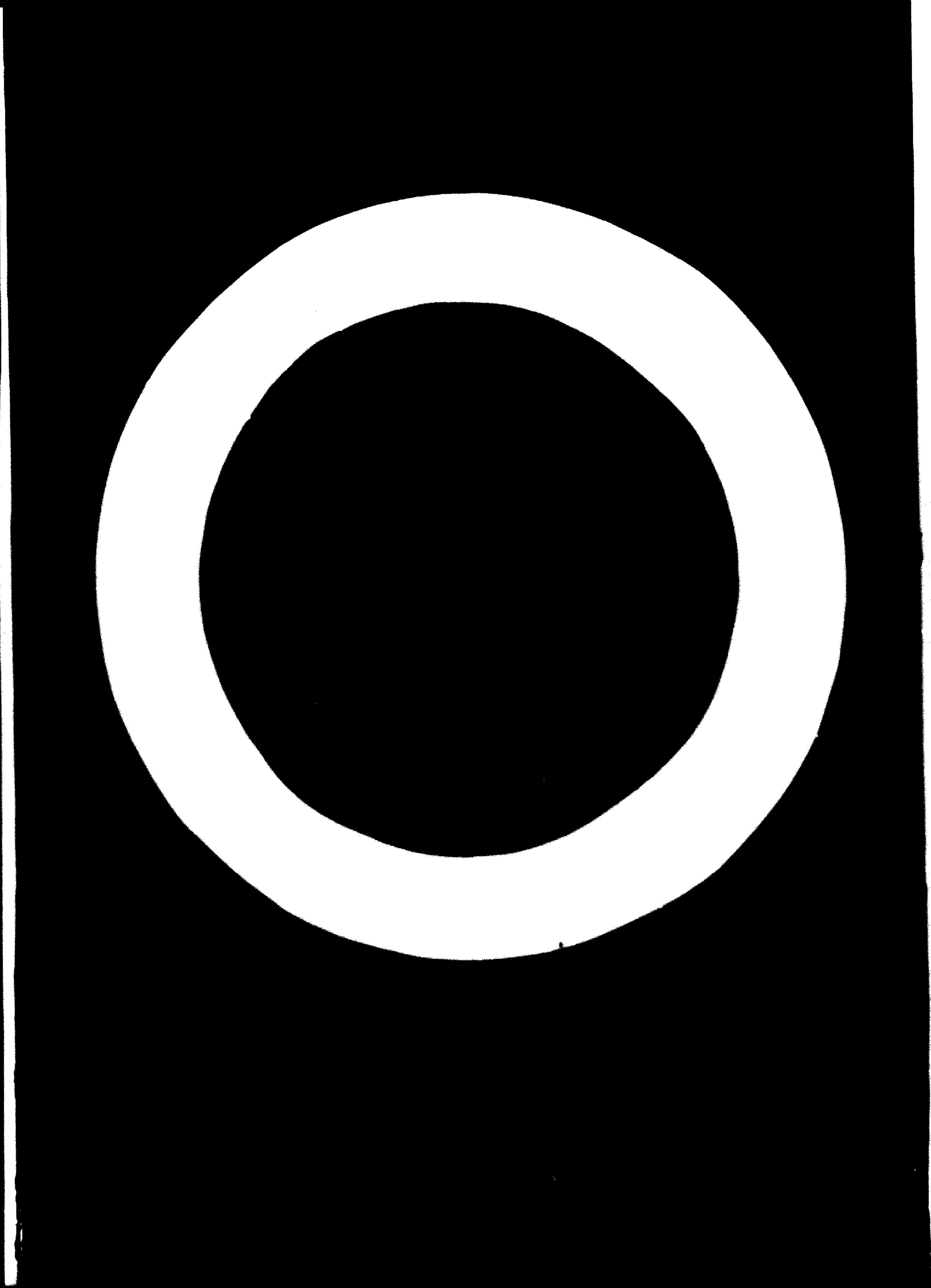

Table … OUTPUT

Table … FINAL DEMAND ON INDUSTRY

10.7.74

4 OF 11

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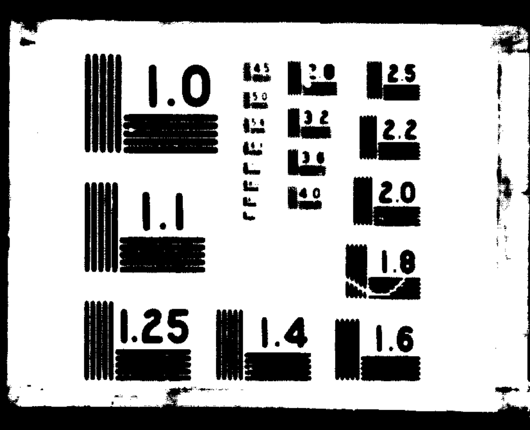
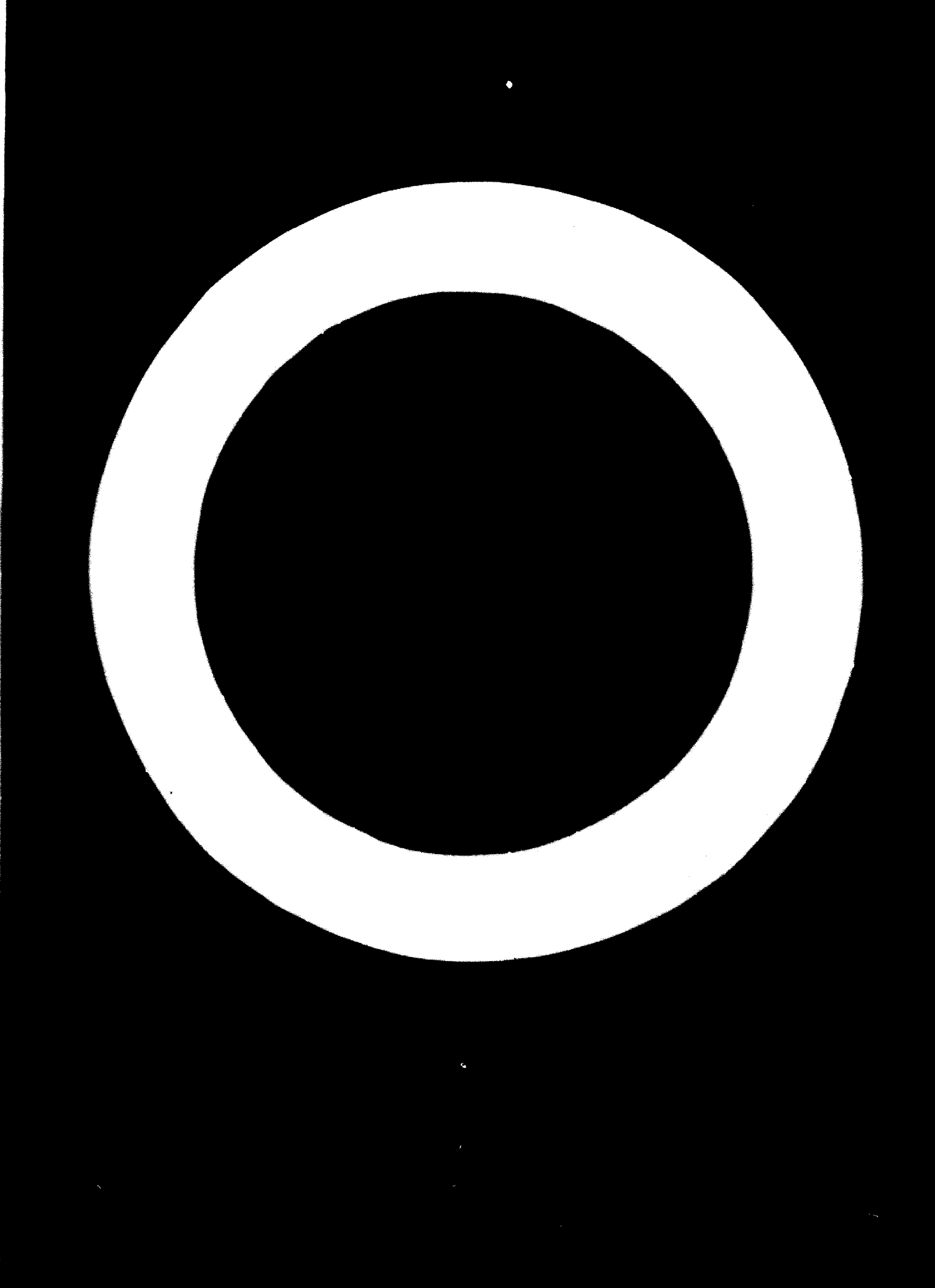


Table 2. COEFFICIENTS[a]

Column groups: FINAL NONMETAL (1–8), FINAL METAL (9–30), BASIC METAL (31–39), BASIC NONMETAL (40–59), ENERGY (60–63), SERVICES (64–77), 78–81.

Group	Sector	No.	1	2	3–81
Final nonmetal	Footwear and other leather products	1	[illegible]	0.01	[illegible]
	Miscellaneous furniture and fixtures	2	0.01	[illegible]	[illegible]
	Household furniture	3	0.32	[illegible]	[illegible]
	Tobacco manufactures	4			[illegible]
	Apparel	5	5.62	1.07	[illegible]
	Miscellaneous fabricated textile products	6	0.45	0.46	[illegible]
	Drugs, cleaning and toilet preparations	7	0.33	0.04	[illegible]
	Food and kindred products	8	0.25	0.07	[illegible]
Final metal	Special industry machinery and equipment	9	0.01	[illegible]	[illegible]
	Ordnance and accessories	10			[illegible]
	Aircraft and parts	11	[illegible]	1.08	[illegible]
	Miscellaneous transportation equipment	12	0.03	0.87	[illegible]
	Radio, television and communication equipment	13		[illegible]	[illegible]
	Materials handling machinery and equipment	14	0.07	[illegible]	[illegible]
	Miscellaneous manufacturing	15	3.79	[illegible]	[illegible]
	Optical, ophthalmic and photographic equipment	16	[illegible]	0.01	[illegible]
	Service industry machines	17		0.37	[illegible]
	Household appliances	18		0.61	[illegible]
	Scientific and controlling instruments	19	1.77	[illegible]	[illegible]
	Office, computing and accounting machines	20		7.03	[illegible]
	Farm machinery and equipment	21	0.07	0.01	[illegible]
	Engines and turbines	22			[illegible]
	Construction, mining and oil field machinery	23		0.33	[illegible]
	Miscellaneous electrical machinery, equipment and supplies	24	[illegible]	[illegible]	[illegible]
	Metalworking machinery and equipment	25	[illegible]	[illegible]	[illegible]
	Motor vehicles and equipment	26	[illegible]	[illegible]	[illegible]
	General industrial machinery and equipment	27	0.11	1.87	[illegible]
	Electric lighting and wiring equipment	28	0.73	[illegible]	[illegible]
	Electric industrial equipment and apparatus	29	0.03	0.12	[illegible]
	Electronic components and accessories	30	0.01	0.11	[illegible]
Basic metal	Heating, plumbing and structural metal products	31	0.12	[illegible]	[illegible]
	Machine shop products	32	0.09	[illegible]	[illegible]
	Metal containers	33			[illegible]
	Stampings, screw machine products and bolts	34	[illegible]	7.27	[illegible]
	Other fabricated metal products	35	[illegible]	[illegible]	[illegible]
	Primary nonferrous metal manufacturing	36	[illegible]	[illegible]	[illegible]
	Nonferrous metal ores mining	37			[illegible]
	Primary iron and steel manufacturing	38		[illegible]	[illegible]
	Iron and ferroalloy ores mining	39			[illegible]
Basic nonmetal	Stone and clay products	40	2.33	1.72	[illegible]
	Stone and clay mining and quarrying	41			[illegible]
	Printing and publishing	42	[illegible]	[illegible]	[illegible]
	Glass and glass products	43	[illegible]	[illegible]	[illegible]
	Paperboard containers and boxes	44	[illegible]	[illegible]	[illegible]
	Paper and allied products except containers	45	0.50	[illegible]	[illegible]
	Wooden containers	46	[illegible]	[illegible]	[illegible]
	Lumber and wood products except containers	47	0.76	[illegible]	[illegible]
	Forestry and fishery products	48			[illegible]
	Miscellaneous textile goods and floor coverings	49	[illegible]	[illegible]	[illegible]
	Rubber and miscellaneous plastics products	50	[illegible]	[illegible]	[illegible]
	Broad and narrow fabrics, yarn and thread mills	51	[illegible]	[illegible]	[illegible]
	Paints and allied products	52	[illegible]	[illegible]	[illegible]
	Leather tanning and industrial leather products	53	[illegible]	[illegible]	[illegible]
	Livestock and livestock products	54			[illegible]
	Miscellaneous agricultural products	55			[illegible]
	Agricultural, forestry and fishery services	56			[illegible]
	Plastics and synthetic materials	57	[illegible]	1.11	[illegible]
	Chemicals and selected chemical products	58	0.32	[illegible]	[illegible]
	Chemical and fertilizer mineral mining	59			[illegible]
Energy	Petroleum refining and related industries	60	0.11	2.01	[illegible]
	Electricity, gas and water	61	3.34	[illegible]	[illegible]
	Coal mining	62			[illegible]
	Crude petroleum and natural gas	63			[illegible]
Services	Federal government enterprises	64	2.25	[illegible]	[illegible]
	Transportation and warehousing	65	[illegible]	[illegible]	[illegible]
	State and local government enterprises	66	0.09	0.19	[illegible]
	Hotels, personal and repair services except automobile	67	[illegible]	[illegible]	[illegible]
	Automobile repair and services	68	0.11	[illegible]	[illegible]
	Radio and television broadcasting	69			[illegible]
	Amusements	70	[illegible]	0.04	[illegible]
	Medical and educational services, nonprofit organizations	71	[illegible]	[illegible]	[illegible]
	Wholesale and retail trade	72	[illegible]	[illegible]	[illegible]
	Finance and insurance	73	[illegible]	[illegible]	[illegible]
	Communications except radio and television broadcasting	74	[illegible]	[illegible]	[illegible]
	Business services	75	[illegible]	[illegible]	[illegible]
	Real estate and rental	76	[illegible]	[illegible]	[illegible]
	Maintenance and repair construction	77	[illegible]	[illegible]	[illegible]
	Research and development	78			[illegible]
	Office supplies	79	[illegible]	[illegible]	[illegible]
	Business travel, entertainment and gifts	80	[illegible]	[illegible]	[illegible]
	Scrap, used and secondhand goods	81			[illegible]
	Noncomparable imports				[illegible]
	Value added		[illegible]	[illegible]	[illegible]

[a] This coefficient table is one way to present transactions among the eighty-one sectors of the 1958 United States economy. Sectors are listed vertically and are repeated horizontally. Reading horizontally across one sector, the coefficients in each cell govern outputs, or sales, to other sectors. Reading vertically down one sector, they govern inputs, or purchases. The coefficients are ratios of the input in a given cell to the total output of sector in whose vertical column the cell appears. Cells are shaded where the ratio exceeds 1/81.



ore, or petroleum, which cannot be increased in the short run, then their requirements can be computed as in the case of skilled labour, and the feasibility of a given programme evaluated. Imports can sometimes fill the gap.

Capital requirements should be treated in exactly the same way in the short run. Given sufficient time, of course, skilled labour can be "produced" through education and industrial training programmes and capital goods can be manufactured. The role of metalworking industries in the investment process is considered in detail later on.

A line is drawn around the industries in the metalworking bloc in tables 6 and 7. Note that there are very few sizeable entries beyond 26 (construction) in the 1–25 band of metalworking suppliers. Within the bloc, however, there are strong elements of interdependence. Before going further into the relation of metalworking to other sectors, let us survey the internal structure of metalworking more carefully.

Internal structure of the metalworking complex

Summing the transactions within the box (table 6), we observe that the total value of transactions among the metalworkers themselves is 28 per cent of their combined total output. Thus, a fair proportion of metalworking activity is "taking in each other's wash". Makers of, for instance, engines and turbines, purchase bolts and nuts and stampings from other metalworkers and, in turn, furnish marine engines to boat builders. Intra-industry transactions along the "diagonal" may often consist of sales of specialized parts made in one establishment to assembling plants included in the same industry. Thus, for example, the very large volume of sales among automobile establishments reflects the United States practice of decentralizing automobile assembly plants throughout the country.

Table 8 presents direct input-output coefficients for the metalworking sectors alone for the United States in 1958.[2] Metalworking industries are specially arranged in that table to highlight their internal organization: industries which specialize in components for other metalworking industries are placed near the bottom of the table, and producers who specialize primarily in final metal products are located near the top.

Final metal products are divided into three major groups: transportation equipment (automobiles, aircraft, railroad equipment, cycles, etc.), electrical equipment (electrical transmission equipment, radio and television sets, household appliances, office and computing machines) and non-electrical equipment (industrial processing equipment, farm machinery, materials-handling equipment, metalworking machinery, etc.). Industries listed near the top of each final product group or "bloc", such as office, computing and accounting machinery, and materials-handling machinery, sell little or nothing to other metalworking sectors on current account. Below them are listed sectors such as electronic components and electric lighting and wiring equipment, which provide current inputs to electrical machinery producers at later stages, or engines and turbines, which produce components for industrial and transportation equipment manufacturers. The bottom rows of the table consist of industries which perform more general metalworking functions not specialized to a particular final metal product: stampers, makers of ball and roller bearings, etc. These provide components for all the later stages of metalworking production.

Note the bloc character of the electrical and non-electrical machinery sectors. These blocs buy relatively little from each other, although both groups purchase from the "general intermediate" metalworkers detailed at the bottom of the table. Transportation equipment manufacturers do not form a self-contained bloc. They purchase from both the electrical and the nonelectrical blocs as well as from each other.[3]

One should not, of course, expect metalworking complexes to be fully developed in all economies. Relatively few metalworking activities will be represented in the input-output table for a developing economy, and within each input-output category the mix of such activities will be very different. The expansion, proliferation, and balancing of these activities is an essential part of economic development. Even among highly industrialized countries, specialization patterns vary to some extent.

Some variations in the division of labour within the metalworking bloc appear from a comparison of tables 8, 9, and 10. Table 8 shows the interdependence of metalworking sectors for the United States in 1958. Table 9 shows the same kind of picture for the United States in 1947. Although we know that there were many dramatic changes in metalworking techniques used during the period 1947–1958, the over-all pictures are similar: the relative dependence of each of the sub-blocs on the others does not change substantially, and the importance of general intermediate metalworkers in the over-all picture remains about the same. This paradox of input-output coefficient stability in the face of known instances of changing techniques should not be surprising. New cutting techniques, for example, are introduced gradually, affecting only a very small portion of actual operation at first. Some qualitative changes in the design of components may not be discernible in terms of the present industry classification.

Table 9 describes the Japanese metalworking complex for 1960. While the basic industrial classification is different from that of the United States, it was possible

[2] Coefficients in tables 8 and 9 exclude some fictitious "secondary product" transfers included in tables 2 and 7.

[3] The specialization pattern observed in the United States input-output table for metalworking must be interpreted in the light of the conventions of the input-output accounting. The statistics are compiled for establishment units and classified in terms of the principal activity of each establishment. Common metalworking processes such as stamping, sheet-metal work, die making, wire work, etc., are actually performed within many product-specialized metalworking establishments, but are "transferred" fictitiously to the special processing sectors in the input-output accounts. Furthermore, where several processing stages are integrated within an establishment, they may never appear as transactions at all. Thus, table 6 and the derived coefficients in table 7 do not tell us exactly how much stamping activity was actually performed in the United States economy, but only what stamping products were purchased or sold

Table

INPUT-OUTPUT FOR

Current account inter-industry

(Ten million

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Construction, urban and industrial	1																
Construction, rural	2																
Electrical equipment	3			2	1	2	2										
Transport equipment	4				7												
Non-electrical equipment	5	23	3	6	1	6	3	0			1				7		
Iron and steel	6	214	26	4	22	71	43										
Iron ore	7						5										
Cement	8	44	5														
Other metals	9			10	3	44	12			8							
Other minerals	10			0			7		6	5							
Plantations	11																
Leather and leather products	12			0							0		46				4
Animal husbandry	13												42		16		10
Food industries	14												2	55	48		6
Food grains	15													97	23	421	
Cotton and other textiles	16			0													18
Jute textiles	17			1	0		1		8			1	0		6	3	4
Other agriculture	18														772	3	300
Chemical fertilizers	19											6				15	
Glass, wooden, and non-metallic mineral products	20	280	35	2	1	1		0			0	3			1		6
Forestry products	21	61	8	1	11					0			9				
Motor transport	22																
Petroleum products[i]	23	14		1	2	1	2		0	0		0	1		5	12	7
Crude oil	24																
Rubber products	25			0	8	0											
Rubber	26																
Chemicals	27	.		3	4	5	[illegible]			0		2	12	19	7	4	34
Railways	28																
Electricity	29			2	3	4	6	0	3	1	1	0	1		6	6	22
Coal	30			0	0	3	11		6	0		1	0		3	0	6
Others	31			40	27	28	14	0	4	0	2	11	6		90	9	72
Intermediate sum	32	636	77	72	90	165	112	1	27	14	4	24	119	171	984	473	409
Value added	33	314	309	45	91	130	111	7	20	13	41	168	47	932	271	3409	277
Margin	34	251	30	9	20	50	47	0	7	4	1	3	23	27	67	13	34
Value of output	35	1201	416	126	201	344	269	8	53	32	45	196	189	1130	1323	3974	800

Note: Flows under 5 million rupees are represented by zero.
[a] Represents adjustment for exaggerated industrial consumption shown in table.
[b] Inclusive of margin.
[c] Inclusive of "others".
[d] No interindustry transactions shown for rows 22 and 28. Subtotal for row 32 is therefore less than subtotal for column 31 by 443.0.
[e] Gross value added.
[f] Includes RS. 98.1 crores of taxes on petroleum products.
[g] Includes RS. 33.6 crores of taxes on petroleum products.
[h] 1090.5 -- C.I.F. value of imports, excluding RS. 33.6 crores of taxes on petroleum products.
[i] Petroleum products measured at market prices.

3

INDIAN ECONOMY, 1960–1961

transactions (1959–60 prices)

rupees)

17	18	19	20	21	22	23	24	25	26	27	28	29	30	Intermediate sum (cols. 1–30) 31	Others 32	Household consumption 33	Government consumption 34	Exports 35	Imports 36	Gross fixed capital formation 37	Stocks 38	Output 39
															133		104			344		1201
																				416		416
														6		33	17	1	57	124	2	126
														7		39	46	1	69	173	5	201
1			1			8		0		2			4	65		113	31	3	−229	345	16	344
														380	−4			10	−121		4	269
														5				2			0	8
			3											53				0	0		0	53
										3				80	−1			0	49		2	32
			6							8				32	−1			24	10			45
								16						16		74		110	−9		6	196
														51	18	96		24	−0		1	189
										3				71		1057		21	−19			1130
										11				122		979	94	36	−10		102	1323
														541		3520			−195		58	3974
0			0					7		0				26		703	11	55	−4		9	800
3		1								2				30	5			94	−0		2	130
61	84									0				1220	172	761		49	−125		19	2097
	9													30	−0				−11		1	21
			8							7				345		63		2	−11		2	398
			59							13				161	12			12	−5			180
														165	63	97						325
0	6	0	10		104	0		0		3	23	3	0	195	12	81	27	4	−83[g]			237
						44								44					−40			3
					17			1						26	4	40		1	−3		0	68
								1						1					−2		1	0
3	2	4	26			1		4		63				200		179		10	−111		6	234
														278	87	89						454
4	2	0	7			2		1		6	3		3	83	6	11	5				−2[a]	103
1		1	6					0		3	32	14	7	95	4	6		2	−1		2	109
6		3	39	9	29	26	0	5		14	18	13	5	468			185[b]	7	−11			15716
78	104	10	16[c]	9	150	81	0	35		137	75	29	19	4353[d]	530	7942	520	468	−1091[h]	2002	231	15598
49	1992	9	198	171	173	56	3	25		122	378	66	89	9594	3224		860					13678[e]
3	1	2	33		2	3		8		25	0	8	1	671		4663[d]		165		276		
130	2097	21	398	180	375	237[f]	3	68		284	454	103	109	14715	530	12605	1380	633	−1091	2278	231	

Table

INPUT-OUTPUT FOR

Current account inter-

(Billions

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Agriculture, Forestry and Fisheries	1	490	10	2	1541	339	332	46	0	1	50	58	5	2	2	1
Coal, Petroleum and Natural Gas	2	0	3	2	5	6	1	11		0	2	25	255	22	5	1
Metal and Other Mining	3	1		1	8		0	3	0		0	33	0	46	176	
Food Products and Tobacco	4	125			527	6	0	1	0	18		20		0		0
Textiles and Apparel	5	35	2	0	2	892	5	4	2	4	38	7	1	2	5	16
Wood Products and Furniture	6	7	2	0	15	5	90	16	1	0	0	21	2	2	6	23
Pulp, Paper, etc.	7	4	1	1	28	8	3	280	120	0	0	70	2	16	5	12
Printing and Publishing	8	1	2	1	4	7	1	20	6	0	0	5	1	2	10	13
Leather Products	9	0			1	18	0	0	0	8		0			0	2
Rubber Products	10	2		0	0	7	1	0	0	0	5	1		0	4	26
Chemicals	11	149	4	3	85	248	21	19	15	2	26	468	7	11	26	36
Petroleum and Coal Products	12	41	1	3	19	10	3	7	0	0	5	55	19	24	125	20
Ceramic, Stone, and Clay Products	13	4	0	0	38	0	1	1	0	0	2	8	0	44	27	29
Primary Metals	14	8	5	2	25	11	32	2	2	2	1	22	5	15	2186	680
Machinery, except Transportation Equip.	15	21	6	3	3	13	3	3	4	0 *	2	13	5	3	40	818
Transportation Equipment	16	14	1	0	1	0	1					0	0	1	2	12
Precision Instruments	17	0	0	0	0	1	0	0	1	0	0	0	0	0	1	23
Miscellaneous Manufacturing	18	7	0	0	8	4	3	0	1	2	3	1	1	0	1	39
Construction	19	16	2	5	12	5	3	1	1	1	1	8	2	5	10	8
Electricity and Gas	20	6	17	6	17	24	6	33	2	0	3	53	3	23	66	25
Trade	21	34	4	3	145	88	30	20	11	3	11	57	8	27	71	68
Real Estate	22	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1
Transportation and Communication	23	26	5	5	64	31	19	21	20	1	4	48	15	34	67	66
Services	24	28	6	3	48	31	11	9	12	1	3	52	5	12	31	59
Undistributed	25	21	6	12	114	41	11	10	19	1	6	54	34	1[illegible]	90	118
Intermediate Total	26	1036	80	52	2710	1795	577	507	216	45	162	1080	368	309	2953	2096
Business Consumption	27	7	7	6	33	20	13	5	15	0	3	22	6	7	29	52
Wages and Salaries	28	224	107	56	182	251	100	67	88	6	35	149	16	91	318	399
Profit	29	1615	10	32	176	184	56	59	59	4	36	139	100	91	385	401
Depreciation	30	210	21	13	47	47	11	24	8	1	5	91	21	22	100	69
Indirect Taxes	31	48	6	4	510	12	7	4	2	0	1	20	123	7	13	50
Subsidies	32	1	0	0	29							0				
Value Added	33	2103	150	111	919	515	188	159	173	12	80	451	266	219	845	972
Total Production	34	3138	230	163	3629	2310	764	666	389	56	242	1531	634	523	3798	3067

Note: Flows under 500 million yen are represented by zero.

to subdivide the complex into roughly the same general bloc categories used in tables 8 and 9. Note the resemblances between the specialization patterns of the two countries: the relative paucity of above diagonal entries, the relative self-sufficiency of blocs and the prominence of general intermediate metalworking sectors. These latter seem to be less important in Japan than in the United States, while transactions among establishments within each sector seem to be relatively large. It is not clear whether this difference represents real differences in specialization patterns of Japanese and United States establishments or differences in accounting conventions. (Perhaps the Japanese count plants making wire products for household machines in the household machinery rather than the wire products industry.)

General intermediate metalworkers sell the bulk of their output as current inputs. They furnish parts and components to other metalworking sectors. Products of the later stages of metalworking, the so-called "final metalworking" products, are delivered to both metalworking and non-metalworking sectors on capital account: they become part of the stocks of durable goods essential for modern industrial technology. Referring back to the national imput-output table, table 1 or table 6, we note that transactions between metalworkers and other industrial sectors are really very small. Metal-

4

JAPANESE ECONOMY, 1960

industry transactions

of yen)

16	17	18	19	20	21	22	23	24	25	Intermediate total 26	Non-household consump. expend. 27	Private consump. expend. 28	Gov't expend. on current account 29	Domestic fixed capital form'tion 30	Net inventory increase 31	Exports 32	Subtotal (cols. 27–32) 33	Imports 34	Tariffs 35	Total outputs 36
−1	5	13	26	0	−1	0	0	7	24	2949	29	556	1	14	100	61	761	567	5	3138
1	0	0	0	88			15	7	2	450		10	2		6	0	6	218	7	230
		2	51	−1					3	324		3			5	1	8	169	0	163
	0	2			2			2	24	725	372	2556		86	61	3075	61	118	53	3629
6	5	3	33	1	21	0	12	17	101	1212	24	647	5	3	67	364	1109	10	1	2310
15	1	15	380	1	22	0	2	18	3	645	6	50	2	20	8	37	123	4	0	764
3	4	15	12	0	31	0	3	15	18	650	2	8	3		14	17	28	12	0	666
1	0	1	6	1	31	0	11	128	0	235	2	113	15		5	3	138	4	0	389
1	3	3	0					0	1	37		15	0		2	4	21	1	0	56
95	1	0	4	0	0		1	6	11	163	1	35	1		13	31	80	1	0	242
16	·5	92	25	0	1		2	93	41	1394	41	122	7		37	61	269	−119	13	1531
5	2	4	53	13	50	0	122	21	26	629	0	33	18		22	13	85	−77	3	634
10	2	1	293	1	−1	0	0	5	11	477	2	−10	0		14	46	52	−5	0	523
168	23	20	524	4	13		2	8	57	3816	4	15	2	−78	51	189	183	195	6	3798
256	9	1	244	32	1	0	7	12	46	1541	10	178	11	1143	149	155	1645	−109	10	3067
203			45	0	33	0	123	3	25	466		71	43	597	36	178	924	−26	2	1362
4	32	0	8	1	3	0	1	35	4	113	0	47	1	28	12	31	119	−14	2	217
8	2	5	30	0	3	0	1	20	25	165	3	87	1	5	12	81	188	3	1	349
5	1	1	3	25	31	79	16	56	0	293			6	2877		6	2889	0		3182
13	1	3	6	5	23	1	24	57	6	422		157	7		0	4	169	1		590
36	6	16	155	9	39	0	29	78	23	971	102	1099	13	158	23	136	1532	14		2489
0	0	0	1	0	7	0	2	8		23		596					596			619
24	5	8	132	23	104	0	76	114	99	1010	10	486	51	13	7	145	713	81		1804
26	9	12	49	4	166	8	32	283	107	1007	277	1600	1471			5	3353	5	1	4354
47	10	15	99	12		5	100	83	0	918		1	−11		22	90	102	55	6	959
940	126	230	2177	220	577	93	580	1073	659	20654	885	8456	1649	4780	678	1719	18166	1696	110	37064
15	5	6	40	12	200	1	45	191	146	885										
207	40	43	455	92	689	3	627	1766		6010										
125	30	55	477	62	793	294	242	960	71	6457										
42	5	5	56	125	149	161	283	277		1793										
32	11	9	7	80	82	68	26	88	87	1299										
							−0		−3	34										
422	91	118	!005	370	1912	526	1224	3281	300	16910										
1362	217	349	3182	590	2489	619	1804	4354	959	37069										

workers supply important inputs only to other metalworkers, and changes in final demand for sectors other than metalworking have very little direct or indirect impact on metalworking sectors. The characteristic dependence of all sectors on the metalworking complex becomes apparent only when the capital account is considered.

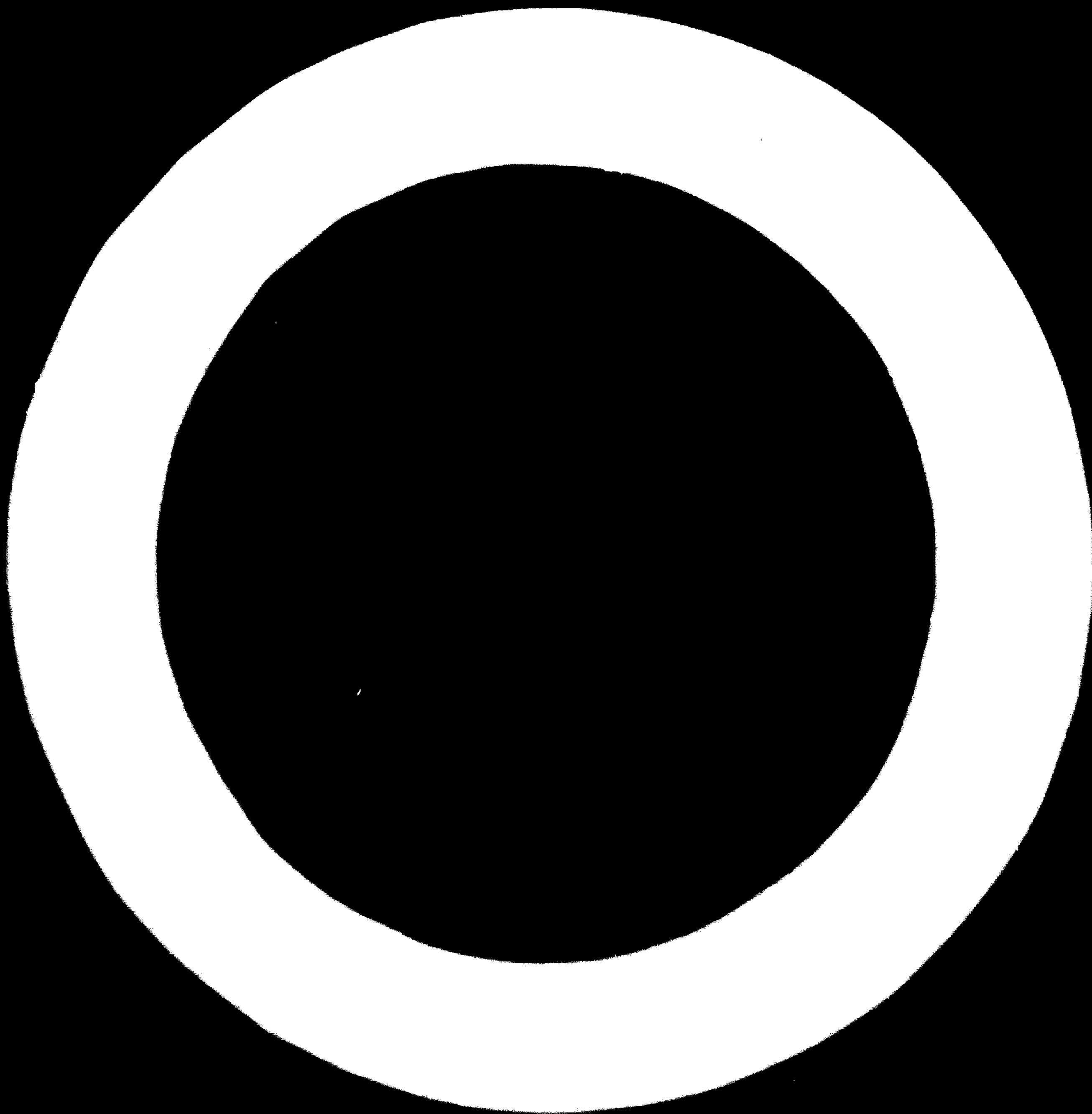
REDUCED INPUT-OUTPUT TABLES

Being interested primarily in metal products, we should like to ignore all the other sectors of the economy except in so far as they contribute to, and in turn depend upon the growth of the metalworking complex in the framework of an over-all developmental plan. We shall now introduce an analytical device that will permit us to centre all attention on a selected group of industries, in this case, the metalworking complex, with the assurance that the requirements of all the other sectors of the economy are automatically taken into account. In order to explain the practical meaning of the analytical transformation that leads to the construction of what we call the reduced input-output matrix of a national economy, we will ask you to visualize a situation in which, for trading purposes, all industries of a country have been divided in two groups. The industries belonging to

Table 5. INVERSE COEFFICIENTS[1]

FINAL NONMETAL · FINAL METAL · BASIC METAL · BASIC NONMETAL · ENERGY · SERVICES

[1] Inverse coefficient table shows indirect relations between the eighty-one sectors of the 1958 United States economy. Each sector delivers a certain amount of its output to what is called "final demand." (The final demand totals appear in table IX.) The coefficient in any cell of this table gives, per dollar of delivery to final demand made by sector listed at top, the total input directly and indirectly required from industry listed at left. Cells … its total output.



group I are "contracting" industries; those in group II are identified as "subcontracting" industries.

Each contracting industry covers its direct input needs for the products of other group I industries by direct purchases and each group II industry makes direct purchases from other group II industries. However, the products of group II industries delivered to group I industries are manufactured on the basis of special work contracts. Under such a contract, the group I industry placing an order with a group II industry provides the latter with its own products and also the products of all other group I industries, in amounts required to fill the particular order. To be able to do so, it must, of course, first purchase all these goods, from group I industries that manufacture them, on its own account. The relationship between a contracting, group I, and a subcontracting, group II, industry is thus analogous to the relationship between a tailor and his customer who buys the cloth himself and then brings it to the tailor to be made into a suit.

In planning its purchases from other sectors, each group I industry has, under these conditions, to take into account not only its own immediate input requirements but also the input requirements of the group II industries to which it will have to deliver correct amounts of the products of various group I industries (including, frequently, its own) to be processed under contract. For planning purposes, a group I industry might as well account for the amounts of the product of group I industries that it will have to supply to the group II industries working for it, as if they were elements of its own input structure. That is exactly what is being done in constructing a reduced input-output table.

The relationship of the reduced table to the original table from which it is derived is similar to the relationship of an abbreviated train timetable to the complete, detailed timetable which also lists the intermediate stations. The subdivision of all the sectors of an economy into groups I and II must, of course, depend on the specific purpose of the proposed analysis.

Using a reduced table for planning purposes, we can be sure that if the input-output flows among the group I industries shown in it are properly balanced, the balance between the outputs and inputs of all the other industries omitted from it will also be secured, at least with respect to the supply and demand for commodities and services classified in group I.

In the process of consolidation, the technical details of which we will not describe here, the labour and the capital coefficients of each of the selected principal industries can also be transformed, that is, recomputed, in such a way that these coefficients will reflect not only its own labour and capital requirements, but also the capital and labour requirements of all the group II industries which deliver their products to it. It is as if, under the imaginary contracts described above, each group I industry provided the group II industries working for it, not only with the inputs coming from all the different group I sectors, but also with all the capital and labour employed by the group II industries in filling their contractual orders. Thus, the output levels of all the primary industries as projected on the basis of reduced input-output table will, if multiplied with the appropriate consolidated capital and labour coefficients, account not only for the capital and labour requirements of these group I industries, but also for those of all the group II industries without whose support these output levels could not be attained.

Table 11 is a reduced coefficient table derived from table 7. All the metalworking industries, construction, and ferrous metals are included in group I, and all other industries are considered to be in group II. Thus, while table 7 has thirty-eight endogenous sectors, table 11 has only twenty-seven. All of the coefficients in the twenty-seven-order reduced table are equal to or greater than the corresponding coefficients in the original thirty-eight-order table. For example, the coefficient showing ferrous metal inputs into construction and mining equipment (row 27, column 13) is .15 in the original table and .16 in the reduced table. This is because the reduced table's coefficient includes both iron and steel used directly to make construction and mining equipment and iron and steel used directly and indirectly to make the products which construction machinery manufacturers purchase from group II industries: pit props for coal mines, steel sheet for metal containers used to package paint, repair parts for rubber and plastics producers' machinery used in the production of plastic parts and tyres, etc. The last five rows of both tables show labour (subdivided by skill types) and total capital requirements on the original and the reduced form basis respectively. Total capital requirements for farm equipment in table 11 include not only capital goods used directly in making farm equipment, but also capital requirements for making paints used in manufacturing farm equipment.

The reader will note that the differences between corresponding "input coefficients" in tables 11 and 7 are very small indeed. Most of the differences between corresponding entries were small enough to disappear when the coefficients were rounded to two decimal places. On the other hand, differences between corresponding labour and capital coefficients in the original and reduced tables are sizeable. This feature brings out, once again, the unique position of metalworking industries in relation to the rest of the economy. As was pointed out before, metalworkers furnish only a very small proportion of their products to non-metalworkers on current account. Thus, as members of group I, they are not required to contribute appreciable amounts of metalworking products to their subcontracting suppliers in group II. Direct purchases by metalworkers from other metalworkers account for most of all current account metalworking product requirements in the reduced table. Metalworkers do have to supply relatively large amounts to group II industries on capital account, if the latter are to be able to furnish requisite non-metalworking inputs to group I industries; but this is a quite different matter that will be taken up in the context of dynamic input-output analysis. Similarly, under this new system of accounting, metalworking sectors are called upon to supply labour not only for their own production but also for the production of all their inputs from group II

Table

THIRTY-EIGHT SECTOR INPUT-OUTPUT

Current account inter-

(Millions of

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Aircraft and parts	1	2414	17	9	15	15	1	52	1	.		2	9	2	5	22	5	.	56	6
Ships, trains, trailers, and cycles	2	3	251	20		1	7	1	.	.		4	8	15	5	20	5	1	5	26
Motor vehicles and equipment	3	81	50	6795	.	28	8	1	53	.		10	7	45	41	56	6		51	8
Office and computing machines	4	6			193	.	.	7	1		13	1	4	1			1	1	46	3
Service industry machines	5	8	9	29	.	106	104	4	.	2	.	2	12	2	1	.	1		6	2
Household appliances	6	28	19	.	.	143	39	2	4	1	2		3	1	9	.	.		3	3
Radio, television, and communication equipment	7	344	6	119	21	7	1	330	7	5	90	.	23	2	.	.	1	7	38	52
Batteries, x-ray, and engine electrical equipment	8	46	5	352	1	.	1	2	57	67	2	2	1	5	19	39	3	6	3	11
Electric lighting and wiring equipment	9	16	13	96	9	15	28	69	57	92	21	3	1	3	2	1	1	6	12	86
Electronic components and accessories	10	76	.	18	92	.	.	1088	21	8	162	.	7	1			.	.	102	140
Materials handling machinery and equipment	11	5	16	5	.	3		.		.		41	12	17	1	3	1		.	2
Special industry machinery and equipment	12	6	1	6	12	6	.	2	.	.	1	5	125	6	7	3	10	2	6	6
Construction, mining, and oil-field machinery	13	2	20	10	.	1	1	1	2	1	2	54	19	173	31	61	5	.	2	6
Farm machinery and equip.	14	2	19	24	.	1	.		1	1		5	7	54	92	30	1		1	1
Engines and turbines	15	20	114	87		4			2			15	1	80	120	202	8		.	81
Machine shop products	16	126	13	147	5	2	4	6	12	4	3	17	10	14	37	66	107	1	26	9
Optical, ophthalmic and photographic equipment	17	26	.	1	.	.	5	14	1	.	1	.	5	.	.	.	.	86	20	3
Scientific, controlling instruments and clocks	18	197	5	100	8	29	109	33	6	6	13	1	4	2	3	2	2	22	202	67
Electrical apparatus and motors	19	43	125	50	52	200	149	100	36	78	88	53	97	35	15	38	8	21	120	341
Metalworking machinery and equipment	20	246	19	257	21	7	28	28	22	13	15	17	58	52	44	37	29	7	43	59
General industrial machinery and equipment	21	138	58	130	14	35	39	8	26	3	3	73	139	176	140	71	15		20	45
Hardware, plating, valves, and wire products	22	131	79	823	13	59	119	72	7	40	36	23	42	40	17	6	33	16	57	43
Stamping, screw machine products and bolts	23	245	18	709	25	79	193	112	37	63	62	19	32	32	80	49	8	9	63	76
Heating, plumbing, and structural metal products	24	8	171	23	.	52	57	4	.	5	1	13	27	49	6	3	3		4	15
Automotive repair services	25	2	3	8	1	2	1	1	1	1	.	1	4	3	3	1	2	1	1	3
New and maintenance construction; glass, stone and clay products	26	72	51	370	8	22	37	55	16	82	105	5	14	19	16	16	34	47	24	51
Primary iron and steel mining and manufacturing	27	405	442	2005	49	154	275	56	47	155	54	117	224	975	367	224	127	9	67	299
Primary nonferrous metal mining and manufacturing	28	360	68	261	42	114	153	117	164	122	119	13	112	22	19	72	123	42	141	369
Miscellaneous manufacturing and service sectors	29	90	60	134	59	29	41	129	23	45	67	45	49	39	32	32	22	20	106	123
Chemicals, plastics, rubber, drugs, and prints	30	119	101	829	30	55	166	112	113	102	70	24	41	57	97	16	4	108	69	107
Lumber and wood products; paper and paper products	31	68	141	138	29	51	70	219	13	50	62	3	23	11	19	17	.	62	66	73
Textiles and leather goods	32	19	12	310	2	2	17	7	2	3	4	3	9	3	5	3	5	3	51	8
Food, tobacco and metal containers	33		.	.		.	.			.		.	1	.	3				24	
Coal, petroleum and utilities	34	102	43	171	11	19	27	25	12	16	24	8	28	34	26	20	29	12	18	53
Radio and television broad casting; communications	35	56	10	47	9	8	15	20	5	6	8	4	24	10	6	6	11	5	16	21
Transportation and warehousing	36	112	65	426	18	34	57	69	20	31	28	13	28	44	40	27	15	22	34	61
Wholesale and retail trade	37	229	178	688	107	122	151	211	52	144	145	46	97	109	100	59	49	55	133	155
Other business and personal services	38	177	78	774	91	73	345	209	54	67	103	37	79	87	100	65	58	124	113	131
Totals		6028	2282	15972	938	1477	2247	3167	875	1211	1300	678	1386	1719	1509	1265	733	695	1748	2544

Note: Flows less than .5 million are represented by dots; components may not add to total because of rounding.

6

FOR UNITED STATES ECONOMY, 1958

industry transactions only

dollars)

20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	Final demand	Gross domestic output
20	63	5	6	12		1	1	.	32	18	19	2	7	.		163	68	1561	1435	12693
1	19	5	1	57	10	3	18	6	15	2	9	.	23	13	5	303	13	70	2778	3723
173	24	32	98	32	1131	9	37	15	140	2	6	1	58	16		88	208	209	13318	22836
.	.	1	2	3			1		34	7	10	.		8		2	14	301	1321	2217
7	33	9	7	67		219	2	2	12	3	15	.	.			2	35	149	1401	2249
7		13	9	54		266	2	4	36	4	5		5				24	279	2630	3594
.	7	2	1	1		59	1	8	137	6	8			8	157	18	64	405	4079	6008
.	4	2	1	.	118	20	.	50	8	2	1	.	32	2	4	73	49	48	496	1534
2	4	15	15	17	33	951	10	56	16	14	30	6	26	8		7	18	83	443	2287
.	1	5	3	8		4		2	11	2	2	2		11	5	25	10	387	454	2649
9	29	7	1	8		281	2	1	4	9	6	.		11		14	13	8	575	1081
31	25	16	2	29		6	24	2	32	136	102	65		9			28	15	1784	2509
7	28	19	1	24		268	39	29	10	15	1			139			28	29	2057	3084
6	8	7	4	14		3	27	.	11	1	1	1	20	.			18	154	1745	2439
7	48	7	6	32		2	3	1	3	.			.	17		81	11	155	1094	2200
22	22	19	14	33	105	8	144	34	47	24	8	1	10	2		7	22	11	438	1587
.	1	1	2	1		1	2	1	23	18	53	3	.	.	.	.	36	930	805	1542
3	23	21	7	71	16	213	5	4	55	39	14	15	1	2	.	26	42	447	1683	3498
99	193	25	15	91	6	514	85	40	39	24	12	1	10	52	.	31	23	182	2012	5103
207	67	171	42	44	1	14	129	73	14	19	20	4	40	15	.	23	15	156	1575	3629
118	257	54	3	92		303	60	34	23	14	23	3	16	86		14	29	12	1468	3744
75	72	248	98	253	114	1021	336	109	126	187	461	59	180	411	3	41	63	54	875	6440
97	42	129	100	155		131	126	94	121	58	72	5	225	23		15	44	28	311	3686
14	69	57	29	150		6080	49	3	34	7	33	1	10	10		1	98	24	925	2035
2	3	6	3	17	133	313	7	6	8	27	101	15	395	59	17	821	826	479	4639	7913
35	48	52	35	89	245	7126	484	63	60	371	365	62	1561	716	301	1259	1005	6978	58387	80285
277	400	1262	739	1920		2562	5181	205	308	305	240	6	921	89		38	7	30	141	19900
106	106	439	241	587		1177	368	4021	328	251	88	5	64	37	23	49	16	51	170	10220
70	63	109	59	115	107	673	683	486	458	723	802	724	2256	331	185	769	2060	2793	367	13944
21	27	128	72	57	342	2433	324	294	466	7204	1329	2168	2232	775	8	345	484	1487	8041	30459
7	26	148	78	99	14	5136	123	56	1662	925	11660	462	1846	157	130	144	1222	6812	6690	38513
4	7	21	7	13	36	29	18	29	340	690	419	13168	261	11	14	45	144	658	16295	32675
1	.	5	13	3		264	7	1	2246	728	1117	18025	2254	133		138	693	2451	89750	121535
41	37	78	58	94	189	2074	1152	310	54	1398	671	267	1849	16653	81	1692	2648	2284	17176	49587
30	34	18	9	32	55	162	70	30	29	108	295	84	298	75	148	271	1012	3084	4760	10841
28	49	86	57	193	74	2618	1007	214	2725	834	1174	502	3495	1313	19	2106	396	971	19332	33290
102	170	219	108	290	671	6702	701	338	675	916	1458	1133	4912	608	67	1004	1582	2767	69498	95250
139	102	189	103	225	679	3827	538	265	1354	2048	1881	965	6460	2998	834	2279	11799	20014	130035	189549
1768	2106	3627	2047	4932	4079	45472	11768	6888	11699	17138	22961	21532	79153	24797	1993	11896	24898	56264	970327	892828

Table

THIRTY-EIGHT SECTOR INPUT-OUTPUT

(Dollars per

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Aircraft and parts	1	.19	.	.	.01	.01	.	.01	.	.		.	.	.	.
Ships, trains, trailers, and cycles	2	.	.07	.		.	.	.	.	.		.	.	.	.
Motor vehicles and equipment	3	.01	.01	.30	.	.01	.	.	.03	.		.01	.	.01	.02
Office and computing machines	4	.			.09	.	.	.	.		.	.	.	.	
Service industry machines	5	.	.	.	.	.05	.03	.	.	.	.	.	.	.	.
Household appliances	6	.	.01			.06	.01	.	.	.	.		.	.	.
Radio, television, and communication equipment	7	.03	.	.01	.01	.	.	.05	.	.	.03	.	.01	.	.
Batteries, x-ray, and engine electrical equipment	8	.	.	.02	.	.	.	.	.04	.03	.	.	.	.	.01
Electric lighting and wiring equipment	9	.	.	.	.	.01	.01	.01	.04	.04	.01	.	.	.	.
Electronic components and accessories	10	.01	.	.	.04	.	.	.18	.01	.	.06	.	.	.	
Materials handling machinery and equipment	11	.	.	.	.	.		.		.		.04	.	.01	.
Special industry machinery and equipment	12	.	.	.	.01	.	.	.	.	.	.	.	.05	.	.
Construction, mining, and oil-field machinery	13	.	.01	.	.	.	.	.	.	.	.	.05	.01	.06	.01
Farm machinery and equipment	14	.	.01	.	.	.	.		.	.		.	.	.02	.04
Engines and turbines	15	.	.03	.		.			.	.		.01	.	.03	.05
Machine shop products	16	.01	.	.01	.	.	.	.	.01	.	.	.02	.	.	.02
Optical, ophthalmic, and photographic equipment	17	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Scientific, controlling instruments, and clocks	18	.02	.	.	.	.01	.03	.01	.	.	.	.	.	.	.
Electrical apparatus and motors	19	.	.03	.	.02	.09	.04	.02	.02	.03	.03	.05	.04	.01	.01
Metalworking machinery and equipment	20	.02	.01	.01	.01	.	.01	.	.01	.01	.01	.02	.02	.02	.02
General industrial machinery and equipment	21	.01	.02	.01	.01	.02	.01	.	.02	.	.	.07	.06	.06	.06
Hardware, plating, valves, and wire products	22	.01	.02	.04	.01	.03	.03	.01	.	.02	.01	.02	.02	.01	.01
Stampings, screw machine products, and bolts	23	.02	.	.03	.01	.04	.05	.02	.02	.03	.02	.02	.01	.01	.03
Heating, plumbing, and structural metal products	24	.	.05	.	.	.02	.02	.	.	.	.	.01	.01	.02	.
Automotive repair services	25	.	.	.	.	.	.	.	.	.	.	.	.	.	.
New and maintenance construction, glass, stone, and clay products	26	.01	.01	.02	.	.01	.01	.01	.01	.04	.04	.	.01	.01	.01
Primary iron and steel mining and manufacturing	27	.03	.12	.09	.02	.07	.08	.01	.03	.07	.02	.11	.09	.15	.15
Primary nonferrous metal mining and manufacturing	28	.03	.02	.01	.02	.05	.04	.02	.11	.05	.04	.01	.04	.01	.01
Miscellaneous manufacturing and service sectors	29	.01	.02	.01	.03	.01	.01	.02	.02	.02	.03	.04	.02	.01	.01
Chemicals, plastics, rubber, drugs, and paints	30	.01	.03	.04	.01	.02	.05	.02	.07	.04	.03	.02	.02	.02	.04
Lumber and wood products; paper and paper products	31	.01	.04	.01	.01	.02	.02	.04	.01	.02	.02	.	.01	.	.01
Textiles and leather goods	32	.	.	.01	.	.	.	.	.	.	.	.	.	.	.
Food, tobacco and metal containers	33					.	.		.			.	.	.	.
Coal, petroleum and utilities	34	.01	.01	.01	.	.01	.01	.	.01	.01	.01	.01	.01	.01	.01
Radio and television broadcasting; communications	35	.	.	.	.	.	.	.	.	.	.	.	.01	.	.
Transportation and warehousing	36	.01	.02	.02	.01	.01	.02	.01	.01	.01	.01	.01	.01	.01	.02
Wholesale and retail trade	37	.02	.05	.03	.05	.05	.04	.04	.03	.06	.05	.04	.04	.04	.04
Other business and personal services	38	.01	.02	.03	.04	.03	.10	.03	.04	.03	.04	.03	.03	.03	.04
Total capital	A	0.3	0.4	0.2	0.7	0.3	0.3	0.3	0.3	0.3	0.3	0.4	0.6	0.4	0.4
Professional, technical and clinical workers,	B	21.1	13.7	5.6	17.9	11.9	12.1	20.4	19.3	15.5	20.7	16.8	19.3	14.0	14.0
Skilled workers	C	21.5	24.4	6.0	18.7	12.4	12.4	12.3	11.7	11.2	12.5	17.5	20.1	14.6	14.5
Semi-skilled and unskilled workers	D	19.2	20.0	14.9	23.4	15.7	16.7	33.9	32.2	27.0	63.4	22.0	25.2	18.4	18.3
Total labour	E	61.8	58.6	26.4	60.0	40.0	41.2	66.6	63.2	53.8	67.6	56.4	64.6	47.0	46.7

Note: Coefficients less than .005 are represented by dots; components may not add to total because of rounding. Labour rows B-E are man years per thousand dollars of output.

7

COEFFICIENTS FOR UNITED STATES ECONOMY, 1958

dollar)

15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
.01	.	.	.02	.	.01	.02	.	.	.	.	.	.	.	.	.	.	.	.	.		.	.	.01
.01	.	.	.	.01	.	.01	.	.	.01	.	.	.	.	.	.	.	.	.	.	.	.01	.	.
.03	.		.01	.	.05	.01		.03	.	.14	.	.	.	.01	.	.	.	.	.		.	.	.
	.	.	.01	.	.	.	.	.	.			.	.	.	.	.	.		.		.	.	.
.	.		.	.	.	.01	.	.	.01	.	.	.	.	.	.	.	.		.		.	.	.
.	.		.	.	.		.	.	.01		.	.	.	.	.	.		.			.	.	.
.	.	.	.01	.01	.	.	.	.	.		.	.	.	.01	.	.			.	.01	.	.	.
.02	.	.	.	.	.	.	.	.	.	.01	.	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.02	.	.	.	.	.	.	.01	.	.01	.	.	.	.	.	.		.	.	.
	.	.	.03	.03	.	.	.	.	.		.		.	.	.	.	.		.	.	.	.	.
.	.		.	.	.	.01	.	.	.		.	.	.	.	.	.	.		.		.	.	.
.	.01	.	.	.	.01	.01	.	.	.		.	.	.	.	.	.			.		.	.	.
.03	.	.	.	.	.	.01	.	.	.		.	.	.	.	.	.	.		.			.	.
.01	.		.	.	.	.	.	.	.		.	.	.	.	.	.	.	.	.			.	.
.09	.01		.	.02	.	.01	.	.	.		.	.	.	.	.	.	.	.	.			.	.
.03	.07	.	.01	.	.01	.01	.	.	.	.01	.	.01	.	.	.	.		.	.		.	.	.
.	.	.06	.01		.	.	.	.	.		.	.	.	.	.	.	.	.	.		.	.	.
.	.	.01	.06	.01	.	.01	.	.	.01	.	.	.	.	.	.	.	.	.	.		.	.	.
.02	.	.01	.03	.07	.03	.05	.	.	.01	.	.01	.	.	.	.	.	.	.	.	.	.	.	.
.02	.02	.	.01	.01	.04	.02	.03	.01	.01	.	.	.01	.01	.	.	.	.	.	.	.	.	.	.
.03	.01		.01	.01	.03	.07	.01	.	.01		.	.	.	.	.	.	.	.	.	.	.	.	.
.	.02	.01	.02	.01	.02	.02	.04	.03	.03	.01	.01	.02	.01	.01	.01	.01	.	.	.01	.	.	.	.
.02	.01	.01	.02	.01	.03	.01	.02	.03	.02		.	.01	.01	.01	.	.	.	.	.	.	.	.	.
.	.		.	.	.	.02	.01	.01	.02		.08	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.02	.	.	.	.	.	.	.	.	.	.	.02	.01	.
.01	.02	.03	.01	.01	.01	.01	.01	.01	.01	.03	.09	.02	.01	.	.01	.01	.	.01	.01	.03	.04	.01	.04
.10	.08	.01	.02	.06	.08	.11	.20	.20	.24		.03	.26	.02	.02	.01	.01	.	.01	.		.	.	.
.03	.08	.03	.04	.07	.03	.03	.07	.07	.07		.01	.02	.39	.02	.01	.	.	.	.	.	.	.	.
.01	.01	.01	.03	.02	.02	.02	.02	.02	.01	.01	.01	.03	.05	.03	.02	.02	.02	.02	.01	.02	.02	.02	.01
.01	.	.07	.02	.02	.01	.01	.02	.02	.01	.04	.03	.02	.03	.03	.24	.03	.07	.02	.02	.	.01	.01	.01
.01	.	.04	.02	.01	.	.01	.02	.02	.01	.	.06	.01	.01	.12	.03	.30	.01	.02	.	.01	.	.01	.04
.	.	.	.01	.	.	.	.	.	.	.	.	.	.	.02	.02	.01	.40	.	.	.	.	.	.
			.01		.	.	.	.	.	.	.	.	.	.16	.02	.03	.06	.43	.		.	.01	.01
.01	.02	.01	.01	.01	.01	.02	.01	.02	.01	.02	.03	.06	.03	.	.05	.02	.01	.02	.34	.01	.05	.03	.01
.	.01	.	.	.	.01	.01	.	.	.	.01	.	.	.	.	.	.01	.	.	.	.01	.01	.01	.02
.01	.01	.01	.01	.01	.01	.01	.01	.02	.02	.01	.03	.05	.02	.20	.03	.03	.02	.03	.03	.	.06		.01
.03	.03	.04	.04	.03	.03	.05	.03	.03	.04	.08	.08	.04	.03	.05	.03	.04	.03	.04	.01	.01	.03	.02	.01
.03	.04	.08	.03	.03	.04	.03	.03	.03	.03	.09	.05	.03	.03	.10	.07	.05	.03	.05	.06	.08	.07	.12	.11
0.4	0.6	0.6	0.3	0.4	0.6	0.5	0.5	0.5	0.4	1.1	0.5	0.5	0.6	0.6	0.8	0.6	0.9	0.5	2.0	1.9	0.2	0.4	0.1
12.2	27.3	20.3	19.1	18.2	19.6	16.4	14.4	17.9	14.0	21.8	1.7	8.7	8.4	8.2	14.0	19.8	11.1	7.1	7.3	57.0	25.0	105.1	49.5
12.7	28.4	12.1	11.6	11.0	20.4	19.1	13.8	16.6	13.0	70.1	1.4	13.0	8.1	4.9	5.8	14.4	5.6	8.0	6.3	16.9	15.4	8.0	3.5
16.0	35.7	34.4	32.8	30.3	25.6	21.5	24.8	33.6	26.2	15.3	5.3	22.8	19.3	14.1	18.4	30.8	59.3	57.3	9.1	2.3	39.7	21.7	6.1
40.9	91.4	66.8	63.5	59.6	65.6	55.0	52.9	68.1	53.1	107.2	8.9	44.5	35.8	27.2	38.2	65.0	76.0	67.9	27.7	76.2	80.1	135.4	59.1

Table 8

INTERNAL STRUCTURE OF METALWORKING; UNITED STATES, 1958

Input-output coefficients excluding secondary transfers

(Dollars per dollar)

Group	Industry	No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	13	19	20	21	22	23	24	25
Transportation Equipment	Aircraft and parts	1	.19																								
	Ships, trains, trailers and cycles	2		.07																							
	Motor vehicles and equipment	3		.01	.30											.04											.14
Electrical Equipment	Office and computing machines	4				.09														.01							
	Service industry machines	5					.05	.02																			
	Household appliances	6		.01				.01																			
	Radio, television and communication equipment	7	.02						.05																		
	Batteries, x-ray and engine electrical equipment	8			.01					.04	.02					.04	.02										.01
	Electric lighting and wiring equipment	9					.01	.01	.01	.02	.04										.01						
	Electronic components and accessories	10	.01			.04			.17	.01		.06								.03	.02						
Non-Electrical Equipment	Materials handling machinery and equipment	11											.04														
	Special industry machinery and equipment	12												.05													
	Construction, mining, and oil-field machinery	13													.06												
	Farm machinery and equipment	14														.04											
	Engines and turbines	15		.03									.01		.01	.05	.09										
	Machine shop products	16	.01		.01								.01			.01	.03	.07		.01							.01
Instruments	Optical, ophthalmic and photographic equipment	17																	.06								
	Scientific, controlling instruments and clocks	18	.01				.01	.03												.06						.01	
General Metalworking	Electrical apparatus and motors	19		.03		.02	.09	.04	.01	.01	.02		.05	.03	.01	.01	.01		.01	.02	.07	.02	.04			.01	
	Metalworking machinery and equipment	20	.02		.01	.01		.01		.01	.01	.01	.01	.01	.01	.02	.02	.01		.01	.01	.06	.01	.02	.01		
	General industrial machinery and equipment	21	.01	.01		.01	.01	.01		.02			.05	.04	.05	.06	.02				.01	.03	.07			.01	
	Hardware, plating, valves and wire products	22	.01	.02	.04	.01	.02	.03	.01		.02	.01	.01	.01	.01			.01	.01	.01	.01		.01	.04	.02	.03	.01
	Stampings, screw machine products and bolts	23	.02		.03	.01	.03	.05	.02	.02	.03	.02	.01	.01	.01	.03	.02		.01	.02	.01	.01	.01	.01	.03	.01	
	Heating, plumbing and structural metal products	24		.04									.01	.01	.01								.01			.02	
	Automotive repair services	25																									

Note: Coefficients less than .005 are excluded.

Table 9

INTERNAL STRUCTURE OF METALWORKING; UNITED STATES, 1947

Input-output coefficients excluding secondary transfers

(Dollars per dollar)

Group	Industry	No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Transportation Equipment	Aircraft and parts	1	.11																								
	Shop, trains, trailers and cycles	2		.08																							
	Motor vehicles and equipment	3		.01	.26																						.19
Electrical Equipment	Office and computing machines	4				.08																					
	Service industry machines	5					.06	.02																			
	Household appliances	6					.03	.03																			
	Radio, television and communication equipment	7							.13			.07															
	Batteries, x-ray and engine electrical equipment	8			.01					.02	.01		.01	.01			.02										.03
	Electric lighting and wiring equipment	9							.01		.06	.20							.01								.01
	Electronic components and accessories	10							.06			.06															
Non-Electrical Equipment	Materials handling machinery and equipment	11											.03														
	Special industry machinery and equipment	12												.03													
	Construction, mining and oil-field machinery	13													.02	.01											
	Farm machinery and equipment	14													.01	.05											
	Engines and turbines	15		.04									.02		.05	.08	.05				.01		.01				
	Machine shop products	16		.03				.01							.01		.01	.01									.02
Instruments	Optical, ophthalmic and photographic equipment	17																	.07								
	Scientific, controlling instruments and clocks	18	.01				.01	.01												.09						.01	
General Metalworking	Electrical apparatus and motors	19		.03		.01	.09	.07	.01	.01	.02	.01	.05	.03	.02		.01		.01	.01	.05	.02	.03			.02	
	Metalworking machinery and equipment	20	.01		.03	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01		.01	.01	.05	.01	.02	.01	.01	
	General industrial machinery and equipment	21	.01		.01		.01	.01		.01			.03	.03	.03	.03	.04	.01		.01	.01	.02	.04			.01	.01
	Hardware, plating, valves and wire products	22	.01	.02	.02	.02	.03	.03	.01	.01	.02	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.03	.02	.03	.02
	Stampings, screw machine products and bolts	23	.02	.01	.04	.02	.06	.08	.03	.02	.05	.03	.02	.02	.02	.04	.03	.01	.04	.03	.02	.01	.01	.03	.01	.04	
	Heating, plumbing and structural metal products	24		.02																			.01			.03	
	Automotive repair services	25																									

Note: Coefficients less than .005 are excluded.

industries. Comparison of the last rows in tables 11 and 7 shows that these amounts are far from trivial.

The transformation of the original input-output table to reduced form also requires, of course, an appropriate consolidation of the column containing the final bill of goods. These deliveries to final users are recomputed in the same way as the inputs to a group I industry: purchases from sectors classified in group II are not shown as such. Instead of that, the amount of the product of each of the group I industries absorbed by all the group II industries in the production of their deliveries to final users are added to the amounts of the same goods directly purchased by the final users. Thus, the consolidated final bill of goods will not show any purchases from the chemical sectors, when chemicals is classified as a group II industry. The figure representing the final deliveries from the ferrous metals industry will, however, be augmented by the amount of ferrous metals absorbed in the manufacture of chemicals actually purchased by the final users. Thus, in the reduced, compact input table, the balance between total supply and the total demand for the products of all the group I industries will be accounted for as fully as in the original table.

Table 12 is a reduced input-output flow table corresponding to the thirty-eight-order flow table, table 6. Note that the total output levels for the twenty-seven industries included in group I are the same in both tables. Corresponding final demand entries for each group I industry are larger in table 12 than in table 6. This is because final demand for, say, materials-handling equipment, in the reduced table, includes not only materials-handling equipment directly purchased for the expansion of industrial capacity but also repair and maintenance parts furnished by the producers of this equipment to the manufacturers of food, chemicals, textiles, and other excluded group II items in final demand.

By using a compact input-output table with the corresponding complement of appropriately enlarged technical coefficients, the planner can centre his attention on a selected group of industries without worrying that any particular decision concerning the levels of output in these industries may turn out to be abortive because of unforeseen capital or labour shortages or insufficient supplies of materials, produced by these group I industries, in any other sectors.

Capital account

Let us shift our attention, now, to the economy's capital account. Table 13 is a capital stock matrix for the United States economy in 1958. Each entry shows the value of the stock of goods, produced by the industry identified on the left, held by the industry identified at the top of the table. While input-output flow tables report actual transactions, sales and purchases among industries over a given time period (generally a year), the stock table presents the inventory of buildings, machines and all other facilities held by each industry at a given point of time. Thus, a flow table is analogous to the income account and a stock table to the physical assets in the capital account. They show different aspects of the same productive process.

Strictly speaking, all items which are reported as flows should also appear as stocks, perhaps in the form of inventories: materials, goods in process, and finished goods. So-called "fixed capital goods" are distinguished by their relative longevity: the sizes of their stocks will be large relative to their annual flows. Compared with inventories, a machine or building tends to remain in the stock for a relatively long period of time—three, five, ten, even fifty years before it is replaced. Actually, the stocks in table 13 do not include the relatively short-lived inventory items, but only stocks of durable capital goods.

Table 13 has two outstanding features. First, notice the importance of metalworking products in the stocks of durable capital.

More than 42 per cent of the economy's capital originated in metalworking industries. In contrast to the current account picture shown in table 6, metalworking stocks appear to be important across the entire table, that is, in virtually all using industries. Second, note the preponderance of stocks held outside the manufacturing sectors. While we are accustomed to thinking of steel, automobiles and cement as the prototype of capital intensive industries, much larger actual volumes of capital goods are required in our networks of communication, transportation and trade. This feature is important in newly developing countries as well. In the United States economy, these co-ordinating sectors are growing in relative importance, and so are their capital requirements. Agricultural capital is also far from negligible in the general picture.

The ratio of stock appearing in each cell to the annual rate of output of the industry which uses it is called a capital coefficient. A table, or matrix, of capital coefficients tells the value of the stocks of the various types of durable or capital goods required per unit of output. (Here the notion of capacity output is important because of the possibility of idle capital goods.) Table 14 is a matrix of (fixed or durable) capital coefficients. To make the table less cumbersome, only capital coefficients greater than .005 are cited in the table.

This simplification tends once again to emphasize the concentration of capital originating in a few metalworking sectors. Total capital required per unit of capacity is given, for each sector at the bottom of the table. These total capital coefficients vary greatly from industry to industry, particularly outside of manufacturing.[4]

Accumulation of required capital stocks

How do we relate stock requirements, described in table 13, to interindustry flow requirements pictured in table 6? It takes time to produce and accumulate stocks

[4] Complete sets of capital coefficients, such as those cited in table 14, are not yet available for many countries. A set was developed for the Indian economy on a fairly aggregated classification basis, and sets of total capital coefficients (corresponding to the column sums in table 14) are available for several years for Japan. Rough preliminary intercomparison suggests that the Japanese capital coefficients are of the same order of magnitude as those for the United States. Those for India appear to be roughly double the United States ones. The source of the differences, real or statistical, has still to be studied in some detail.

Table 10

INTERNAL STRUCTURE OF METALWORKING; JAPAN, 1960

Input-output coefficients including secondary transfers

(*Yen per yen*)

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Transportation Equipment	Shipbuilding	1																						
	Railroad equipment	2		.04																				
	Motorcycles and bicycles	3			.20																			.03
	Miscellaneous transportation equipment	4				.41																		
	Aircraft	5					.11																	
	Motor vehicles	6						.14																.29
Elect. Equip.	Household machines	7							.13															
	Household electrical appliances	8								.17												.01		
	Office machines	9									.07													
Non-elect. Equip.	Industrial machinery	10							.05			.17												
	Machinery and equipment for general use	11										.04	.14	.01		.01								
	Machine tools and metal forming machines	12									.01			.14										
	Prime movers, boiler	13	.12		.14			.15				.02	.01		.21						.01			.08
Instruments	Optical instruments	14														.13								
	Watches and clocks	15								.02							.14							
	Precision machines	16	.01				.02				.02	.01	.02	.01		.04		.13						
General Metalworking	Miscellaneous batteries and wiring devices	17	.02	.01	.07	.01	.07	.04	.01	.15					.01				.25	.04				.03
	Heavy electric machinery and apparatus	18	.01						.05	.01		.03	.03	.01					.01	.15				
	Metal products for construction	19				.01						.01	.01								.03			
	Miscellaneous metal products	20	.02		.01			.01	.01	.01		.01	.01		.02		.01		.01		.02	.01		.01
	Ball and roller bearings and other common parts	21	.02	.02	.04	.07	.02	.02	.04	.02	.16	.05	.04	.09	.03	.02	.05	.03	.01	.04			.04	.02
	Repair of automobiles	22					.01					.01	.01										.01	

Note: Coefficients less than .005 are excluded.

of capital goods. In the short run, therefore, the stock of capital invested in, that is, possessed by, various producing sectors of the economy sets an upper limit on the flow of outputs that they can produce. The capital coefficient table tells us what durable goods we must have to produce any given set of outputs. Realistically, if these capital goods (largely metalworking products) are not available, the projected levels of production cannot take place. As time goes on, a step-by-step accumulation of domestically produced, or imported, capital increases the productive capacities of an economy and, if these are properly balanced, permits it to increase its output and deliveries to final demand.

Purchases of capital goods by the various industries are not reported in a conventional input-output table as current account transactions, but are relegated to a special gross capital formation column in final demand (table 1A). This column tells the total amounts of office machinery, trucks and electrical transmission equipment supplied to the whole economy in a given year. In the absence of capital imports over the years, all additions to equipment stocks must pass through the gross capital formation account. The single gross capital formation column is a sum of additions to capital stock made by all using industries. It combines new tractors bought by agriculture with those bought by mining and construction. Given the detailed statistical information, one could elaborate this single capital formation column into a complete matrix of many columns which would tell gross additions of each kind of capital goods in each industry in a given year. Thus, we would distinguish separately the tractors bought by agriculture and by construction, the materials-handling equipment bought by food processing and chemicals and automobiles, etc.

Each element in the gross capital formation vector, or in a capital flow matrix, in turn combines two elements: capital goods to replace or renew existing stocks, and capital to expand productive capacity by net addition to previously accumulated stocks. In a highly industrialized country, a relatively large proportion (perhaps 60 per

Table

“REDU[illegible]ED” INPUT-OUTPUT COEFFICIENTS

(Dollars per

	1	2	3	4	5	6	7
1 Aircraft and parts	.19	.01	.	.01	.01	.	.01
2 Ships, trains, trailers, and cycles	.	.07	.	.	.	.	.
3 Motor vehicles and equipment	.01	.01	.30	.	.01	.	.
4 Office and computing machines	.	.	.	.09	.	.	.
5 Service industry machines	.	.	.	.	.05	.03	.
6 Household appliances	.	.01	.	.	.06	.01	.
7 Radio, television, and communication, equipment	.03	.	.01	.01	.	.	.06
8 Batteries, x-ray, and engine electrical equipment	.	.	.02	.	.	.	.
9 Electric lighting and wiring equipment.	.	.	.	.	.01	.01	.01
10 Electronic components and accessories	.01	.	.	.04	.	.	.18
11 Materials handling machinery and equipment	.	.	.	.	.	.	.
12 Special industry machinery and equipment	.	.	.	.01	.	.	.
13 Construction, mining, and oil-field machinery	.	.01	.	.	.	.	.
14 Farm machinery and equipment	.	.01	.	.	.	.	.
15 Engines and turbines	.	.03	.	.	.	.	.
16 Machine shop products	.01	.	.01	.	.	.	.
17 Optical, ophthalmic, and photographic equipment	.	.	.	.	.	.	.
18 Scientific, controlling instruments, and clocks	.02	.	.	.	.01	.03	.01
19 Electrical apparatus and motors	.	.03	.	.02	.09	.04	.02
20 Metalworking machinery and equipment	.02	.01	.01	.01	.	.01	.01
21 General industrial machinery and equipment	.01	.02	.01	.01	.02	.01	.
22 Hardware, plating, valves, and wire products	.01	.02	.04	.01	.03	.04	.01
23 Stampings, screw machine, products, and bolts	.02	.01	.03	.01	.04	.05	.02
24 Heating, plumbing, and structural metal products	.	.05	.	.	.02	.02	.
25 Automotive repair services	.	.	.	.	.	.	.
26 New and maintenance construction, glass, stone, and clay products	.01	.02	.02	.01	.02	.02	.01
27 Primary iron and steel mining and manufacturing	.03	.12	.09	.02	.07	.08	.01
A Total capital	.04	0.6	0.4	0.9	0.6	0.6	0.4
B* Professional, technical and clinical workers	26.8	26.0	15.2	29.8	25.6	28.8	31.5
C* Skilled workers	23.0	27.9	8.1	21.0	15.6	16.0	15.0
D* Semi-skilled and unskilled workers	23.1	28.2	21.6	29.7	24.1	26.4	41.2
E* Total labour	72.9	86.2	44.8	80.5	65.3	71.1	87.8

Notes: Labour rows B*–E* are man years per thousand dollars of output.
Coefficients under .005 are represented by a dot.

cent in the United States) of annual capital goods purchases is devoted to renewal or modernization, and 40 per cent to expansion. In developing countries, the percentages for expansion will be much higher.

Table 15 gives rough estimates of the split of the gross capital formation vector into a replacement and an expansion portion for the United States in 1958. To simplify the present exposition, it will be assumed that replacement requirements are fixed, say, at approximately the levels given in column two of table 15.[5] Beyond the maintenance and replacement of existing stocks, additional capital goods are required for the expansion of capacity. Let us see how this second component of gross capital formation is determined.

If we begin in a situation of full utilization of capacity in consumption goods industries, additional capital requirements will be proportional to the increase in output levels in each industry. Suppose a change in consumption demand calls for higher levels of output in consumer goods and supporting industries. Higher output levels will be possible only if necessary additional capital stocks are also forthcoming. For each industry, the amounts of the different kinds of capital goods per unit of additional output are given by a column in the capital coefficient matrix. To produce an output $2 million greater than 1958's, the food industry must

[5] One can argue that roughly the same proportion of capital stock must be renewed each year. Since capital stock requirements are, in turn, proportioned to output, one can then justify converting the replacement capital flows to coefficients and adding them to the coefficients of the original flow matrix. This procedure is obviously a gross oversimplification, particularly if applied in analysis of a highly industrialized economy. In many instances, it is difficult to distinguish replacement from expansion expenditures, and the development of new technological alternatives makes replacement a matter of economic advantage rather than pure technical necessity. In developing countries, where a large proportion of equipment is of recent origin, and new capital goods are relatively difficult to obtain, it will generally be rational to restrict replacement to a minimum level close to that required by absolute technological necessity.

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FOR UNITED STATES ECONOMY, 1958

dollar)

8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27
.	.	.	.	.	.	.	.01	.	.	.02	.	.01	.02	.	.	.	.	.	.
.	.	.	.	.	.01	.	.01	.	.	.	.01	.	.01	.	.	.01	.	.	.
.04	.	.	.01	.	.02	.02	.03	.	.	.02	.	.05	.01	.01	.03	.	.14	.	.
.	.	.01	.	.	.	.	.	.	.	.01	.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.01	.	.	.01	.	.	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.01	.	.	.
.01	.	.03	.	.01	.	.	.	.	.01	.01	.01	.	.	.	.	.	.	.	.
.04	.03	.	.	.	.	.01	.02	.	.	.	.	.	.	.	.	.	.02	.	.
.04	.04	.01	.	.	.	.	.	.	.	.	.02	.	.	.	.	.	.	.01	.
.01	.	.06	.	.	.	.	.	.	.	.03	.03	.	.	.	.	.	.	.	.
.	.	.	.04	.	.01	.	.	.	.	.	.	.	.01	.	.	.	.	.	.
.	.	.	.	.05	.	.	.	.01	.	.	.	.01	.01	.	.	.	.	.	.
.	.	.	.05	.01	.06	.01	.03	.	.	.	.	.	.01	.	.	.	.	.	.
.	.	.	.	.	.02	.04	.01	.	.	.	.	.	.	.	.	.	.	.	.
.	.	.	.01	.	.03	.05	.09	.01	.	.	.02	.	.01	.	.	.	.	.	.
.01	.	.	.02	.	.	.02	.03	.07	.	.01	.	.01	.01	.	.	.	.01	.	.01
.	.	.	.	.	.	.	.	.	.06	.01	.	.	.	.	.	.	.	.	.
.	.	.01	.	.	.	.	.	.	.01	.06	.01	.	.01	.	.	.01	.	.	.
.02	.03	.03	.05	.04	.01	.01	.02	.01	.01	.03	.07	.03	.05	.	.	.01	.	.01	.
.02	.01	.01	.02	.02	.02	.02	.02	.02	.01	.01	.01	.06	.02	.03	.01	.01	.	.	.01
.02	.	.	.07	.06	.06	.06	.03	.01	.	.01	.01	.03	.07	.01	.	.01	.	.	.
.01	.02	.02	.02	.02	.01	.01	.	.02	.01	.02	.01	.02	.02	.04	.03	.03	.02	.02	.02
.03	.03	.02	.02	.01	.01	.03	.02	.01	.01	.02	.02	.03	.01	.02	.03	.02	.	.	.01
.	.	.	.01	.01	.02	.	.	.	.	.	.	.	.02	.01	.01	.02	.	.08	.
.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.02	.01	.
.02	.04	.05	.01	.01	.01	.01	.01	.03	.04	.01	.02	.01	.02	.01	.02	.02	.04	.10	.03
.04	.07	.02	.11	.09	.16	.15	.10	.08	.01	.02	.06	.08	.11	.20	.20	.24	.	.03	.26
0.7	0.6	0.6	0.6	0.8	0.6	0.6	0.5	0.8	0.9	0.6	0.7	0.8	0.7	0.8	0.8	0.6	1.3	0.8	0.9
33.7	31.0	35.1	28.1	30.6	22.7	25.2	20.4	37.7	36.6	31.4	29.2	28.5	27.1	26.1	28.9	25.1	41.0	21.7	21.1
15.9	14.8	15.8	19.8	22.8	16.3	16.8	14.7	31.2	16.0	14.7	14.2	22.3	19.3	17.1	19.8	16.0	72.9	5.9	16.5
43.8	36.8	43.3	28.8	32.4	22.8	24.6	21.1	42.6	44.9	42.9	38.9	30.5	27.2	33.7	42.4	34.0	23.1	17.0	31.8
93.4	82.6	94.2	76.7	85.8	61.8	66.6	56.2	111.5	97.4	89.1	82.3	81.4	73.6	76.9	91.1	75.1	137.1	44.6	69.3

acquire additional capital stocks of 2 × (.117) of farm machinery, 2 × (.026) of motor vehicles, 2 × (.189) of construction, and similarly prescribed amounts from other metalworking sectors. These are the additions to capital stock which must be delivered, that is, included in the gross capital formation column, if the given expansion programme is to be possible. Thus, if we increase the consumption column in final demand, we must also add to the capital formation column. But this latter addition to final demand will itself generate further output increases, in turn, further additional capital requirements, and so on.

As an illustration, column three of table 16 shows the amounts of additional capital goods which must be supplied by the various sectors of the economy in order to support a 20 per cent increase in household consumption. It is obtained by multiplying the increase in household consumption, detailed in column one, by the inverse coefficient matrix. This gives total outputs required on current account to deliver the specified increase in consumption (column two); multiplying the increase in total output levels for each industry (column two) by the corresponding capital coefficients, given in table 14. The sum-totals of all capital requirements from each supplying sector are given in column three.

Note that direct increases in household demand (column one) and their indirect current account impact (column two) affect, primarily, non-metalworking sectors. (The only important exceptions to this occur in automobiles and other consumers' durable sectors. These elements are usually much less important during the early stages of industrial development.) The capital impact (column three), of course, is heaviest in metalworking and construction.

The current consumption and capital formation vectors in final demand are in fact interrelated through stringent technological requirements. In the absence of idle capacity, our increase in household consumption required

Table

"REDUCED" INPUT-OUTPUT TABLE FOR

Current account inter-industry

(Millions of

		1	2	3	4	5	6	7	8	9	10
Aircraft and parts	1	2419	20	25	17	16	6	56	3	2	2
Ships, trains, trailers, and cycles	2	5	253	28	1	2	9	3	1	1	1
Motor vehicles and equipment	3	86	52	6804	2	29	10	5	54	2	2
Office and computing machines	4	7	1	5	194	1	2	9	1	1	13
Service industry machines	5	9	9	31	.	106	105	5	.	2	.
Household appliances	6	29	20	3	.	144	40	3	4	1	3
Radio, television, and communication equipment	7	348	8	128	22	8	4	334	8	7	92
Batteries, x-ray, and engine electrical equipment	8	49	6	357	2	1	3	4	59	68	3
Electric lighting and wiring equipment	9	21	14	101	10	16	30	71	59	94	23
Electronic components and accessories	10	78	1	22	93	1	1	1089	21	8	162
Materials handling machinery and equipment	11	5	16	6	.	3	.	.	.	.	.
Special industry machinery and equipment	12	8	3	15	13	7	2	5	1	1	2
Construction, mining, and oil-field machinery	13	5	21	14	.	2	2	2	3	2	3
Farm machinery and equipment	14	3	19	26	.	1	1	1	1	1	
Engines and turbines	15	21	114	89	.	4	1	1	2	.	.
Machine shop products	16	129	14	151	6	3	5	7	14	5	4
Optical, ophthalmic, and photographic equipment	17	28	1	6	1	1	7	16	1	1	2
Scientific, controlling instruments and clocks	18	199	7	107	8	29	111	36	7	7	14
Electrical apparatus and motors	19	47	126	56	52	201	152	103	38	80	89
Metalworking machinery and equipment	20	252	21	264	22	8	31	30	24	15	17
General industrial machinery and equipment	21	141	59	134	15	36	40	10	27	5	4
Hardware, plating, valves, and wire products	22	145	86	850	16	64	127	83	13	96	42
Stampings, screw machine products, and bolts,	23	254	21	720	26	82	197	117	41	66	65
Heating, plumbing and structural metal products	24	9	172	26	.	53	57	5	.	6	2
Automotive repair services	25	12	10	38	4	6	7	10	3	5	5
New and maintenance construction, glass, stone, and clay products	26	110	73	486	20	36	70	88	28	98	122
Primary iron and steel mining and manufacturing	27	425	451	2039	54	161	286	69	56	163	62
Totals	T	4840	1597	12531	579	1022	1306	1620	470	686	736

Note: Flows less than 500,000 are represented by a dot; components may not add to total because of rounding.

a total volume of capital formation almost as great as the initial increase in final demand. Going one step beyond table 16, we could show that the capital formation in column three itself requires additional capacity and hence still more capital in the metalworking and construction industries.

Available capacity in the capital goods industries limits the rate at which consumer goods industries can expand. Furthermore, the production and installation of new capacity does not take place instantaneously: there are appreciable lags between the production of goods that go into the creation of new productive capacities and the utilization of those leading to an increase in current output flows.

TIMING OF INVESTMENT IN METALWORKING INDUSTRIES IN A DEVELOPING ECONOMY

An increase in the rate of output in one or several different sectors in any given year has to be preceded by a sequence of investments properly distributed over a number of preceding years.

It is the task of dynamic input-output analysis to describe direct and indirect intertemporal dependence among the levels of output, investment, and employment in all the different sectors of a growing economy. A dynamic input-output table, similar in its structure to a static one, can be constructed, in which all flows of goods and services are identified not only in terms of their sectoral origin and destination, but also in terms of the time, for example, the year, in which the particular transaction that they describe took place. The total output, the final deliveries, and the labour inputs of each sector are entered on such a time-phased input-output table separately for each year. For purposes of developmental planning, steel demanded and supplied in the year 1966 has to be distinguished from the steel demanded and supplied in 1967. In a sense, these are now different goods. A dynamic input-output table describing the development of a national economy, broken down, say, into twenty sectors, over a period of ten years, would have

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UNITED STATES ECONOMY, 1958

transactions only

dollars)

11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	FD	GDO
3	11	4	7	23	6	2	59	9	22	65	10	8	18	10	94	21	9755	12692
5	9	16	6	21	6	1	6	28	2	20	8	3	60	12	48	34	3137	3723
11	9	46	42	57	7	1	54	12	174	26	36	101	38	1136	67	54	13919	22836
1	4	2	1	.	1	1	47	4	1	1	3	3	4	4	30	7	1866	2216
2	12	2	1	.	1	.	6	2	7	33	9	7	67	1	233	4	1589	2248
.	4	1	9	.	.	.	4	4	8	1	14	10	56	2	285	7	2940	3594
1	25	3	1	1	2	8	40	55	2	9	6	3	6	6	108	17	4755	6007
3	2	5	20	40	4	6	5	15	2	5	7	3	6	119	47	8	685	1533
3	3	4	2	2	3	7	14	90	3	5	20	17	23	35	979	17	622	2286
1	7	1	.	.	.	1	102	141	1	2	6	4	10	3	26	5	862	2648
41	12	17	1	3	1	.	.	2	9	29	7	1	8	1	288	4	625	1081
5	126	6	8	3	10	3	8	8	31	26	19	3	31	4	55	31	2073	2508
54	20	173	32	62	6	1	3	8	8	28	22	3	28	2	293	47	2239	3084
5	7	54	92	30	1	.	2	2	6	8	7	4	15	1	15	29	2105	2439
15	2	80	121	202	8	.	1	82	7	49	8	6	33	1	21	8	1323	2190
17	11	14	37	67	108	2	28	12	23	23	23	16	37	106	29	151	545	1586
.	6	1	1	1	1	86	21	5	1	2	3	3	3	3	37	7	1298	1542
1	5	3	4	2	3	23	203	69	4	24	24	8	74	20	252	14	2237	3497
53	98	35	16	39	9	21	122	345	100	194	29	18	97	9	549	95	2328	5103
18	60	53	45	38	30	8	45	65	209	68	177	46	52	3	49	138	1843	3628
73	140	177	141	71	16	1	22	48	119	258	57	5	97	2	332	69	1645	3743
25	46	43	20	9	37	20	65	56	80	77	265	107	272	125	1237	380	2103	6439
20	34	33	81	51	11	11	67	85	100	45	139	105	167	4	199	144	800	3686
13	28	49	6	3	3	.	5	16	14	70	58	30	152	2	6102	54	1098	8034
2	7	6	6	3	4	4	6	10	6	8	16	9	29	148	533	58	6956	7912
11	28	32	30	26	43	61	46	82	52	66	92	57	135	313	7868	646	69565	80285
120	231	479	371	228	132	14	79	320	284	407	1286	753	1949	12	2760	5231	18421	19900
504	946	1340	1102	983	455	284	1059	1575	1277	1547	2352	1335	3968	2082	22537	7282	157334	216449

200 (20 10) rows and 200 columns. The final deliveries of each type of goods, to consumption and exports, as well as the imports (entered as negative figures), will be entered in such a table in the form of a dated bill of goods showing the deliveries from each sector separately for each year.

Investment, i.e., additions to the stock of capital goods productively employed in various sectors, can now be shifted out of the externally prescribed column of final demand into the main body of the input-output table describing interindustrial transactions. A rise in output in any given year requires creation of appropriate productive capacities, i.e., additional investment, in the preceding years. If the magnitudes of the appropriate capital coefficients are known, the direct and indirect linkages between the final deliveries of one year and the corresponding input and output changes, some of them charged to the capital account, in the preceding years, can be computed through inversion of a dynamic input-output matrix, just as the direct and indirect effects of changes in the final deliveries on current interindustrial transactions can be determined through inversion of an ordinary static input-output matrix.

Because, as we have seen before, the products of the metalworking industries are used mainly for investment purposes, a proper integration of their output into an over-all developmental plan depends to a very large extent on proper timing. To illustrate the use of dynamic input-output computations for this purpose, we have constructed and solved a dynamic input-output system.

The flow, capital and labour coefficients incorporated in that dynamic matrix, as in some of our previous examples, are those of United States industries for 1958. The product mixes in the household consumption, the export, and the import vectors used in these computations are based on Indian input-output studies. They seem to represent fairly well the structure of final demand which prevails in a developing economy. New productive capacities created from the output of one year are assumed to be put into operation in the following year.

Table

STOCKS OF CAPITAL GOODS IN

(Millions of

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Aircraft and parts	1																		
Ships, trains, trailers, and cycles	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Motor vehicles and equipment	3	11	22	91	3	9	10	13	6	4	2	8	27	30	27	4	9	9	6
Office and computing machines	4	16	9	28	5	2	6	8	2	3	4	2	6	7	4	3	4	9	9
Service industry machines	5	4	2	6	2	1	2	3	1	1	2	.	2	2	1	1	1	3	4
Household appliances	6		2	20															
Radio, television, and communication equipment	7	3	2	7	1	1	1	2	.	1	1	.	1	1	1	1	1	1	1
Batteries, x-ray, and engine electrical equipment	8	1	1	6	1	.	.	2	.	.	.	.	1	1	1	1	1	1	.
Electric lighting and wiring equipment	9	11	7	30	4	3	4	7	2	2	3	2	5	5	4	3	4	4	4
Electronic components and accessories	10																		
Materials handling machinery and equipment	11	232	88	690	95	65	90	143	51	53	58	22	56	69	48	32	53	61	42
Special industry machinery and equipment	12	14	35	30	4	3	4	176	35	32	78	2	23	7	5	18	6	126	124
Construction, mining, and oil-field mach.	13	1	1	2	.	.	.	.	1	.	.	.	.	.	.	.	.	.	.
Farm machinery and equipment	14																		
Engines and turbines	15	6	6	31	4	.	1	9	2	.	.	.	4	4	6	3	3	6	2
Machine shop products	16																		
Optical, ophthalmic, and photographic equipment	17	3	1	5	1	.	1	1	.	.	1	.	1	1	1	.	.	2	5
Scientific, controlling instruments, and clocks	18	19	12	44	6	3	6	17	2	4	8	2	6	7	6	6	4	8	24
Electrical apparatus and motors	19	98	58	280	45	21	42	166	43	22	55	12	45	44	35	18	35	28	25
Metalworking machinery and equipment	20	645	415	1582	219	162	194	53	65	88	22	114	384	350	248	171	301	50	74
General industrial machinery and equip.	21	119	83	389	57	30	51	73	25	26	35	17	53	55	40	23	30	48	52
Hardware, plating, valves, and wire products	22	25	15	62	9	4	9	17	4	5	8	3	10	11	8	5	6	9	11
Stampings, screw machine products, and bolts	23	12	7	33	5	3	4	7	2	2	3	2	6	6	4	3	4	4	4
Heating, plumbing, and structural metal products	24	84	53	269	29	13	32	45	11	21	22	8	26	32	30	20	14	22	26
Automotive repair services	25																		
New and maintenance construction; glass, stone, clay production	26	1088	615	2295	376	201	382	572	172	213	260	130	487	490	322	243	304	288	351
Primary iron and steel mining and manufacturing	27	27	12	46	7	3	6	13	3	4	6	2	7	8	6	4	4	7	9
Primary nonferrous metal mining and manufacturing	28	33	21	89	13	7	12	21	6	7	9	5	15	15	11	8	10	11	13
Miscellaneous manufacturing and service sectors	29	3	2	9	1	1	1	2	1	1	1	.	2	2	1	1	1	1	1
Chemicals, plastics, rubber, drugs, and paints	30	14	8	37	5	3	5	8	3	3	3	2	7	6	5	3	5	4	5
Lumber and wood products; paper and paper products	31	73	37	134	25	13	25	37	8	13	18	9	33	33	20	16	19	18	24
Textiles and leather goods	32																		
Food, tobacco, and metal containers	33	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Coal, petroleum, and utilities	34	7	4	16	2	1	2	4	1	1	2	1	3	3	2	2	2	2	2
Radio, television broadcasting and communications	35	1	1	3	.	.	.	1	.	.	.	.	1	1	.	.	.	.	.
Transportation and warehousing	36	48	28	116	17	10	17	26	8	10	11	6	22	22	15	11	15	13	15
Wholesale and retail trade	37																		
Other business and personal services	38	327	194	791	118	68	114	180	56	66	78	42	151	149	104	75	102	92	106
Totals	T	2915	1739	7139	1055	630	1021	1607	512	584	689	392	1385	1359	953	674	938	827	938

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THE UNITED STATES ECONOMY, 1958

dollars)

19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	Totals
																	2875			2875
.	.	.	.	.	.	.	18	171	19	.	4	29	1	222	17		33116			33600
23	27	28	44	23	111		340	57	35	73	239	375	238	2809	330	345	5807	1112	.	12307
9	10	8	14	19	14		111	162	35	28	212	127	106	306	239	65	8	447	716	2760
3	2	2	3	2	3	251	9	37	7	8	90	39	65	228	161	28	4	1264	291	2541
										5	2	35	798	5			8			874
2	2	2	3	2	2		8	18	5	3	20	20	11	20	128	8797	38	38		9144
2	2	1	2	1	2		9	23	8	2	26	22	9	16	129	69			.	340
8	10	7	11	7	10		35	77	22	12	90	89	49	85	47	1027	8		.	1700
						584					.				21	9				614
138	138	138	254	193	150		488	662	230	280	702	842	483	2148	280				.	9122
106	31	10	82	15	13	584	1899	617	291	272	2967	4664	2230	3750	929					19181
1	.	.	.	.	.		1432	183	182	.	42	5	2	1017	2331					5202
							240	1	3		.			12641	9					12895
8	7	3	8	3	9		46	130	42	11	154	184	46	84	3721					9545
1	1	1	2	1	2		9	44	7	2	59	29	12	24	43				.	261
13	11	8	14	8	15		104	198	58	15	432	233	94	192	1183	11		95	32	2989
147	52	53	45	44	88		294	603	208	104	658	540	250	491	15623	184	11			20567
209	691	502	643	488	690		136	2605	523	387	168	323	94	337	3516		38	2604	.	19171
94	108	71	113	81	112		370	1527	622	150	1340	822	460	842	848					8766
19	17	12	20	12	21		617	233	70	26	421	296	134	256	781			38	.	3193
9	11	8	13	9	11		37	77	22	13	87	92	52	88	43			219	.	982
60	41	35	57	36	60	251	253	751	189	58	1126	678	267	838	1251	11		1055	.	7774
691	786	596	955	585	946	6690	4134	6533	2499	967	6996	7317	3981	20384	50153	3258	17402	27491	9599	180750
14	12	9	14	8	15		82	192	64	19	365	248	105	206	6904				.	8420
25	28	20	32	21	31		114	254	73	36	351	301	157	280	233	6519				8779
2	3	2	4	2	3		10	21	6	4	23	24	14	23	26	9		561	90	856
10	12	9	15	10	13		53	89	27	15	107	104	58	100	49		335			797
38	62	38	63	32	61		132	286	81	60	302	452	296	420	143	1179		2556	553	7309
							.	.	.		.							209	.	209
.	.	.	.	.	.		1	.	.	.	3	2	1	8	4					21
5	5	4	7	4	6		18	41	12	7	47	49	26	45	25					359
1	1	1	1	1	1		4	8	2	1	9	10	5	9	5					71
32	38	29	46	29	43		149	289	86	46	335	345	186	664	466	121	5799	162	24	9300
220	259	195	313	199	293		858	1961	566	317	2285	2357	1272	2159	1187				2	17257
1969	2369	1792	2880	1835	2728	8360	12020	17851	5997	2923	19662	20703	11501	50695	90823	21631	65112	37819	11313	915361

Table

FIXED CAPITAL COEFFICIENTS FOR

(Dollars per dollar

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Aircraft and parts	1														
Ships, trains, trailers and cycles	2	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Motor vehicles and equipment	3	.	.	.	.	.	.	.	.	.	.	.01	.01	.01	.01
Office and computing machines	4	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Service industry machines	5	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Household appliances	6		.	.											
Radio, television, and communication equipment	7	.	.		.	.	.	.	.	.	.	.	.	.	.
Batteries, x-ray, and engine electrical equipment	8	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Electric lighting and wiring equipment	9	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Electronic components and accessories	10														
Materials handling machinery and equipment	11	.02	.02	.02	.05	.03	.02	.02	.03	.02	.02	.02	.02	.02	.02
Special industry machinery and equipment	12	.	.01	.	.	.	.	.02	.02	.01	.03	.	.01	.	.
Construction, mining, and oil-field machinery	13	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Farm machinery and equipment	14														
Engines and turbines	15	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Machine shop products	16														
Optical, ophthalmic, and photographic equipment	17	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Scientific, controlling instruments, and clocks	18	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Electrical apparatus and motors	19	.01	.01	.01	.02	.01	.01	.02	.02	.01	.02	.01	.02	.01	.01
Metalworking machinery and equipment	20	.04	.08	.04	.11	.07	.04	.01	.03	.03	.01	.10	.14	.09	.08
General industrial machinery and equipment	21	.01	.02	.01	.03	.01	.01	.01	.01	.01	.01	.01	.02	.01	.01
Hardware, plating, valves, and wire products	22	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Stampings, screw machine products and bolts	23	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Heating, plumbing, and structural metal products	24	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.01
Automotive repair services	25														
New and maintenance construction, glass, stone, and clay products	26	.07	.12	.06	.19	.08	.09	.07	.09	.08	.09	.11	.17	.13	.10
Primary iron and steel mining and manufacturing	27	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Primary nonferrous metal mining and manufacturing	28	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Miscellaneous manufacturing and service sectors	29	.	.	.	.01	.	.	.	.	.	.	.	.01	.	.
Chemicals, plastics, rubber, drugs, and paints	30	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Lumber and wood products; paper and paper products	31	.01	.01	.	.01	.01	.01	.	.	.	.01	.01	.01	.01	.01
Textiles and leather goods	32														
Food, tobacco, and metal containers	33		.	.	.	.	.	.	.	.	.	.	.	.	.
Coal, petroleum and utilities	34	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Radio, TV broadcasting and communications	35	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Transportation and warehousing	36	.	.01	.	.01	.	.	.	.	.	.	.01	.01	.01	.
Wholesale and retail trade	37														
Other business and personal services	38	.02	.04	.02	.06	.03	.03	.02	.03	.02	.03	.04	.05	.04	.03
Totals	T	.20	.33	.19	.55	.26	.24	.21	.27	.22	.24	.33	.49	.36	.30

Note: Coefficients less than .005 are represented by dots; components may not add to total because of rounding.

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UNITED STATES ECONOMY, 1958

per year)

15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
											.10										.01		
.	.	.	.	.	.	.	.	.	.		.	.	.	.	.	.	.	.	.	.	.09		
.	.	.01	.	.	.01	.01	.01	.	.01		.01	.01	.	.	.01	.01	.01	.03	.01	.03	.02	.01	
.	.	.01	.	.	.	.	.	.	.		.	.	.	.	.01	.	.	.	.01	.01	.	.	.01
.	.	.	.	.	.	.	.	.	.	.03	.	.	.	.	.	.	.	.	.	.	.	.01	.
											.03	.			.	.	.02	.			.		
.	.	.	.	.	.	.	.	.	.		.	.	.	.	.	.	.	.	.	.79	.	.	
.	.	.	.	.	.	.	.	.	.		.	.	.	.	.	.	.	.	.	.01			
.	.	.	.	.	.	.	.	.	.		.	.	.	.	.	.	.	.	.	.09	.		
										.07	.								.	.			
.01	.03	.04	.01	.02	.03	.03	.04	.04	.02		.02	.05	.02	.02	.02	.02	.02	.01	.02	.01			
.01	.	.08	.03	.02	.01	.	.01	.	.	.07	.06	.05	.01	.02	.09	.11	.06	.03	.02				
.	.	.	.	.	.	.	.	.	.		.05	.	.	.01	.	.	.	.01	.05				
											.01		.	.	.			.12	.				
.	.	.	.	.	.	.	.	.	.		.	.	.	.	.	.	.	.	.08				
.	.	.	.	.	.	.	.	.	.		.	.	.	.	.	.	.	.	.				
.	.	.	.01	.	.	.	.	.	.		.	.	.	.	.01	.01	.	.	.03	.		.	.
.01	.02	.02	.01	.02	.01	.01	.02	.01	.01		.01	.02	.01	.02	.02	.01	.01	.	.34	.02	.		
.07	.15	.03	.02	.05	.15	.12	.10	.11	.08		.	.07	.06	.04	.	.01	.	.	.08		.	.03	
.01	.02	.03	.01	.02	.02	.02	.02	.02	.01		.01	.03	.04	.05	.04	.02	.01	.01	.02				
.	.	.01	.	.	.	.	.	.	.		.02	.	.01	.01	.01	.01	.	.	.02			.	
.01	.01	.01	.01	.01	.01	.01	.01	.01	.01	.03	.01	.01	.02	.01	.03	.02	.01	.01	.03	.		.01	
.01	.15	.17	.10	.11	.17	.14	.14	.13	.11	.85	.14	.17	.15	.19	.21	.17	.11	.19	1.09	.29	.05	.29	.10
.	.	.	.	.	.	.	.	.	.		.	.	.	.	.	.	.	.	.	.		.01	.
.	.	.	.	.	.	.	.	.	.		.	.	.	.	.01	.01	.	.	.15				
.	.	.01	.	.	.01	.	.	.	.		.	.01	.01	.01	.01	.01	.	.	.01	.59			
.	.	.	.	.	.	.	.	.	.		.	.	.	.	.	.	.	.	.				
.01	.01	.01	.01	.01	.01	.01	.01	.01	.01		.	.01	.01	.01	.01	.0	.01	.	.	.11		.03	.01
											.01											.	
.	.	.	.	.	.	.	.	.	.		.	.	.	.	.	.	.	.	.				
.	.	.	.	.	.	.	.	.	.		.	.	.	.	.	.	.	.	.				
.	.	.	.	.	.	.	.	.	.		.	.	.	.	.	.	.	.	.				
.	.01	.01	.	.01	.01	.01	.01	.01	.01		.	.01	.01	.01	.01	.01	.	.01	.01	.01	.02	.	.
.03	.05	.06	.03	.04	.06	.05	.05	.04	.03		.03	.05	.05	.04	.07	.05	.03	.02	.03				.
.28	.47	.50	.25	.32	.52	.43	.43	.40	.32	1.06	.53	.42	.46	.50	.58	.48	.30	.47	1.97	1.94	.17	.32	.12

The inverse of the dynamic matrix is essentially similar to the inverse of a static input-output matrix. It describes the changes in the output of each industry required, directly and indirectly, to deliver one additional unit (for example, $1 million worth in fixed base year prices) of the output of any given industry to final demand. In a dynamic system, that change cannot, however, be described by a single figure. It consists of a whole train of successive changes in the output of the industry in question, distributed over a number of years preceding the year in which the final delivery is actually to be made. The sequence of figures shown below represents, for example, a single element of a dynamic inverse. It shows the successive changes in the output of the auto, aircraft and intermediate metalworking industries, distributed over the preceding nine-year period, that would be required, directly and indirectly, in order to enable the national economy to deliver an additional dollar's worth of products of the electrical equipment and instruments industry to final demand in the last year, i.e., the year 0.

Year	−8	−7	−6	−5	−4	−3	−2	−1	0
Change in output	0.001	0.001	0.003	0.006	0.012	0.026	0.056	0.111	−0.065

Theoretically, the chain stretches backward over an infinite number of years. Its earlier members, however, are so small that for all practical purposes they can safely be neglected.

The large negative entry in the last year, i.e., the year in which the delivery to final demand is actually made, requires explanation. It reflects an abrupt reduction in the utilization of previously accumulated productive capacities that would become idle as soon as the final delivery has been made. Actually, an increase in the final delivery of electrical equipment and instruments in year 0 is most likely to be followed by an equal, or possibly even a greater increase, projected or planned for the following year, i.e., for year +1. The effects on the industry in question of these two elements of a given dynamic, that is, time-phased, bill of goods should be superimposed. They are described, in this instance, by a summation of the two series.

Year	−8	−7	−6	−5	−4	−3	−2	−1	0	+1
Change in	0.001	0.001	0.003	0.006	0.012	0.026	0.056	0.111	−0.065	
output		0.001	0.001	0.003	0.006	0.012	0.026	0.056	0.111	0.065
Total	0.001	0.002	0.004	0.009	0.018	0.038	0.082	0.167	0.046	0.065

Table 15

EXPENDITURES ON FIXED CAPITAL EQUIPMENT (EXCLUDING CONSTRUCTION) FOR REPLACEMENT AND EXPANSION OF CAPACITY, U.S. ECONOMY, 1958

(Millions of dollars)

Capital producing sectors	*Total fixed capital expenditures*	*Expenditures for replacement and modernization*	*Expenditures for expansion of capacity*
Aircraft and parts	360	291	69
Ships, trains, trailers and cycles	1,175	966	209
Motor vehicles and equipment	3,561	3,027	534
Office and computing machines	1,017	379	638
Service industry machines	950	278	672
Household appliances	93	28	65
Radio, television and communication equipment	1,006	269	737
Batteries, x-ray, and engine electrical equipment	83	34	49
Electric lighting and wiring equipment	25	9	16
Electronic components and accessories	27	12	15
Materials handling machinery and equipment	350	197	153
Special industry machinery and equipment	1,467	819	648
Construction, mining and oilfield machinery	1,316	618	698
Farm machinery and equipment	1,670	1,386	284
Engines and turbines	576	216	360
Optical, ophthalmic and photographic equipment	161	49	112
Scientific, controlling instruments, and clocks	530	176	354
Electrical apparatus and motors	1,618	552	1,066
Metalworking machinery and equipment	1,152	673	479
General industrial machinery and equipment	1,051	536	515
Hardware, plating, valves and wire products	166	78	88
Heating, plumbing, structural metal products	706	313	393
Miscellaneous manufacturing and service sectors	1,115	469	646
Chemicals, plastics, rubber, drugs and paints	53	17	36
Lumber and wood products; paper and paper products	930	315	615
Textiles and leather goods	49	17	32
Food, tobacco and metal containers	10	5	5
Radio and television broadcasting; communications	362	72	290
Transportation and warehousing	507	233	274
Trade and services	3,744	1,736	2,008
Total	25,830	13,770	12,060

Table 16

DIRECT AND INDIRECT EFFECTS OF A HYPOTHETICAL 20 PER CENT INCREASE IN PRIVATE CONSUMPTION EXPENDITURES ON INDUSTRIAL OUTPUTS AND GROSS FIXED CAPITAL REQUIREMENTS, UNITED STATES 1958

(Millions of dollars)

Producing sectors	*Increase in consumption expenditures* (*1*)	*Additional output required on current account* (*2*)	*Additional capital required to produce (2)* (*3*)
1. Aircraft and parts	5	108	298
2. Ships, trains, trailers and cycles	145	235	425
3. Motor vehicles and equipment	1,840	3,083	1,162
4. Office and computing machines	12	110	498
5. Service appliances	49	114	446
6. Household appliances	483	546	226
7. Radio, television and communication equipment	273	401	1,344
8. Batteries, x-ray, and engine electrical equipment	52	170	48
9. Electric lighting and wiring equipment	63	159	230
10. Electronic components and accessories	30	194	107
11. Materials handling machinery and equipment	0	16	1,189
12. Special industry machinery and equipment	4	74	2,766
13. Construction, mining and oilfield machinery	0	58	766
14. Farm machinery and equipment	2	72	2,697
15. Engines and turbines	25	96	722
16. Machine shop products	0	101	0
17. Optical, ophthalmic and photographic equipment	94	193	30
18. Scientific, controlling instruments, clocks	70	232	405
19. Electrical apparatus and motors	3	175	3,176
20. Metalworking machinery and equipment	6	148	1,942
21. General industrial machinery and equipment	0	118	966
22. Hardware, plating, valves and wire products	76	582	403
23. Stampings, screw machinery products and bolts	50	365	116
24. Heating, plumbing, structural metal products	14	200	1,019
25. Automotive repair services	887	1,337	0
26. New and maintenance construction; glass, stone, clay	72	2,779	26,119
27. Primary iron and steel mining and manufacturing	4	1,403	348
28. Primary non-ferrous metal mining and manufacturing	2	724	235
29. Miscellaneous manufacturing and service sectors	1,276	3,396	141
30. Chemicals, plastics, rubber, drugs and paints	1,052	4,189	93
31. Lumber and wood production; paper and paper production	1,205	5,070	1,098
32. Textiles and leather goods	3,265	6,376	57
33. Food, tobacco and metal containers	10,966	22,768	3
34. Coal, petroleum and utilities	3,116	7,808	42
35. Radio and television broadcasting; communications	782	1,643	8
36. Transportation and warehousing	1,732	4,222	535
37. Wholesale and retail trade	12,313	15,368	0
38. Other business and personal services	17,365	26,629	2,019
Total	57,332	112,697	51,668

Note: Column components may not correspond to totals due to rounding.

The productive capacities built up for the delivery of an additional dollar's worth of electrical equipment and instruments in year 0 are not set free as they were in the previous example. Instead, they are utilized to fill additional capacity requirements serving the next year's needs. The sum-total of two superimposed trains of additional outputs of autos, aircraft and intermediate metalworkers contributed (directly and indirectly) by that industry for final delivery of one dollar's worth of electronic equipment and instruments in year 0 and another dollar's worth of electronic equipment and instruments in year +1 now turns out to be positive in year 0. True, it becomes negative in the year +1. However, the requirements generated by subsequent deliveries to final demand in years +2, +3 and so on will obviously postpone the final liquidation of idle capacities indefinitely.

The combined total effects, on the output levels of a particular industry, of any given sequence of final deliveries planned or projected over a number of years, can thus be computed by summing the properly weighted elements of the dynamic inverse year by year.

The inverse, that is, the generalized numerical solution of the dynamic system described above, is reproduced in full in table 17. Each one of its elongated rectangular cells holds nine figures, representing a sequence of nine annual changes in the output level of the industry named on the left of the row. These changes represent the required direct and indirect contributions of that industry to the delivery by the industry listed at the head of the corresponding column of one additional unit of its respective output to final demand in the last year, year 0.

As in most other input-output computations, the unit in terms of which the output of each sector is measured (unless specified otherwise) is a dollar's worth in base year prices. Base year prices are the prices in terms of which we compiled the basic sets of technical coefficients that went into the construction of the dynamic input-output system. Wherever some of the coefficients, for example, the labour coefficients or the electric energy consumption coefficients, are described in physical units such as man-years or kilowatt-hours, the corresponding output and input levels in the inverse of the dynamic matrix will be expressed in such units, too. Incidentally, there exists no objection to the simultaneous use of base year price measures in some parts of the system and direct physical measures in others.

we have to compute a properly weighted average of the corresponding elements of the dynamic inverse.

The final results of such a computation are summarized in table 18. It shows how an additional composite unit (say, an additional dollar's worth in base year prices) of household consumption, of exports, or of imports, would affect the production programmes of the three metalworking sectors, of the ferrous metals and of the construction industries over the nine-year stretch at the end of which the final deliveries are actually to be made. The product mixes ascribed to the household consumption bundle, the export bundle, and the import bundle are based on the projected composition of these three vectors for India in 1970.

All sequences of output changes can be of course translated into corresponding nine-year sequences of changes in investment and employment. These are

Table 17

DYNAMIC INVERSE

Final demand, in year 0, for products of industry

Industry 1

Year of output	8	7	6	5	4	3	2	1	0
1	0.000	0.000	0.000	0.001	0.002	0.005	0.012	-0.011	1.167
2	0.001	0.002	0.004	0.008	0.017	0.035	0.076	0.160	0.028
3	0.000	0.001	0.001	0.002	0.005	0.011	0.024	0.037	0.004
4	0.001	0.001	0.003	0.007	0.014	0.030	0.061	0.162	0.235
5	0.000	0.000	0.001	0.002	0.004	0.009	0.021	0.038	0.250

Industry 2

Year of output	8	7	6	5	4	3	2	1	0
1	0.030	0.000	0.000	0.001	0.002	0.004	0.013	0.018	0.015
2	0.001	0.002	0.003	0.007	0.015	0.032	0.071	0.109	1.137
3	0.000	0.000	0.001	0.002	0.005	0.010	0.022	0.034	0.000
4	0.001	0.001	0.003	0.006	0.013	0.027	0.052	0.181	0.245
5	0.000	0.000	0.001	0.002	0.004	0.009	0.019	0.027	0.194

Industry 3

Year of output	8	7	6	5	4	3	2	1	0
1	0.000	0.000	0.000	0.001	0.002	0.003	0.009	0.009	0.005
2	0.001	0.001	0.003	0.006	0.012	0.026	0.056	0.111	0.065
3	0.000	0.000	0.001	0.002	0.004	0.008	0.018	0.038	1.158
4	0.001	0.001	0.002	0.005	0.010	0.022	0.045	0.119	0.168
5	0.000	0.000	0.001	0.002	0.003	0.007	0.015	0.026	0.042

Industry 4

Year of output	8	7	6	5	4	3	2	1	0
1	0.000	0.000	0.001	0.001	0.002	0.005	0.007	0.069	0.071
2	0.001	0.002	0.004	0.009	0.018	0.038	0.079	0.205	0.174
3	0.000	0.001	0.001	0.003	0.006	0.012	0.029	0.063	0.055
4	0.001	0.002	0.003	0.007	0.015	0.032	0.073	0.085	0.899
5	0.000	0.001	0.001	0.002	0.005	0.010	0.021	0.058	0.015

Industry 5

Year of output	8	7	6	5	4	3	2	1	0
1	0.000	0.000	0.001	0.001	0.002	0.005	0.014	0.088	0.020
2	0.001	0.002	0.004	0.009	0.018	0.039	0.085	0.109	0.152
3	0.000	0.001	0.001	0.003	0.006	0.012	0.027	0.059	0.084
4	0.001	0.002	0.003	0.007	0.015	0.033	0.065	0.640	0.265
5	0.000	0.001	0.001	0.002	0.005	0.010	0.023	0.052	1.284

1 Railroad, farm, and construction equipment. 2 Autos, aircraft, and intermediate metalworkers. 3 Electrical equipment and instruments.
4 Construction. 5 Ferrous metals.
Each entry tells the output in a given year of the industry designated by number at the left (see key to industry, above), required per dollar increase in final deliveries in year 0 of the industry designated by number at the top.

The total annual final bill of goods projected or planned for a particular national economy is usually described in terms of several different bundles of goods destined to satisfy different kinds of final demand. For purposes of present analysis we distinguish three such bundles. One, by far the largest, consists of the combination of goods and services absorbed in private household consumption; another is destined for export, and the third represents imports. To determine the direct and indirect effects of a change in the level of household consumption or of exports and imports, in any given year, on the time-phased production programme of a particular industry, we have only to add together the separate effects of the final deliveries from each industry that make up that particular bundle of final demand. In other words,

entered in table 18, too. In interpreting these investment and employment figures, it is important to remember that the entire computation is based on a reduced input matrix in which only the five listed industries were included in group I, all others being treated as belonging to group II. Hence, the capital and the labour figures shown for each of the five selected industries satisfy not only its own requirements, but also requirements of capital and labour for group II industries supplying intermediate inputs to it.

Finally, we wish to show how the elements of the dynamic inverse are used as building blocks in the construction of a developmental plan for metalworking industries. In actual planning, we must sum all the direct and indirect requirements for metalworking outputs generated by the whole chain of annual final bills of goods specified over the entire stretch of time covered by a particular over-all projection. Because of the retroactive effects of each annual bill of goods, the given projection of the final demand must be extended for a number of years beyond the last year of the period of time covered by the detailed programme of sectoral production, investment, and employment.

Table 19 presents such a hypothetical production programme and investment programme for the three metalworking industries covering a time span of ten years.

The sequence of annual deliveries to final demand that these production programmes are intended to serve was projected for eight years beyond the last year covered by the detailed sectoral programmes. It is described in terms of levels of household consumption, of exports, and of imports given for the first year and growing at three constant, but different prescribed rates for the years that follow. For the first year, the relative magnitudes of the total levels of household consumption, of exports, and of imports are set at 20.0: 1.0: 1.5 (which implies an aggregate final demand or gross national product of 20.0 + 1.0 − 1.5 = 19.5). The excess of imports above exports implies foreign aid or private capital inflow. Consumption is assumed to expand at an annual rate of 4 per cent and exports and imports at the rate of 3 per cent.

The time-phased direct and indirect output requirements corresponding to one unit of annual final deliveries of each kind are shown in table 18. Changes in the annual levels of each one of the three components of final demand and the corresponding growth in the output level of each one of the three metalworking industries are shown in table 19. Total investment and employment in each sector is shown for each year, too. The projected growth curves of the three components of final demand extend beyond the last year for which the sectoral production programmes were actually computed. While these later

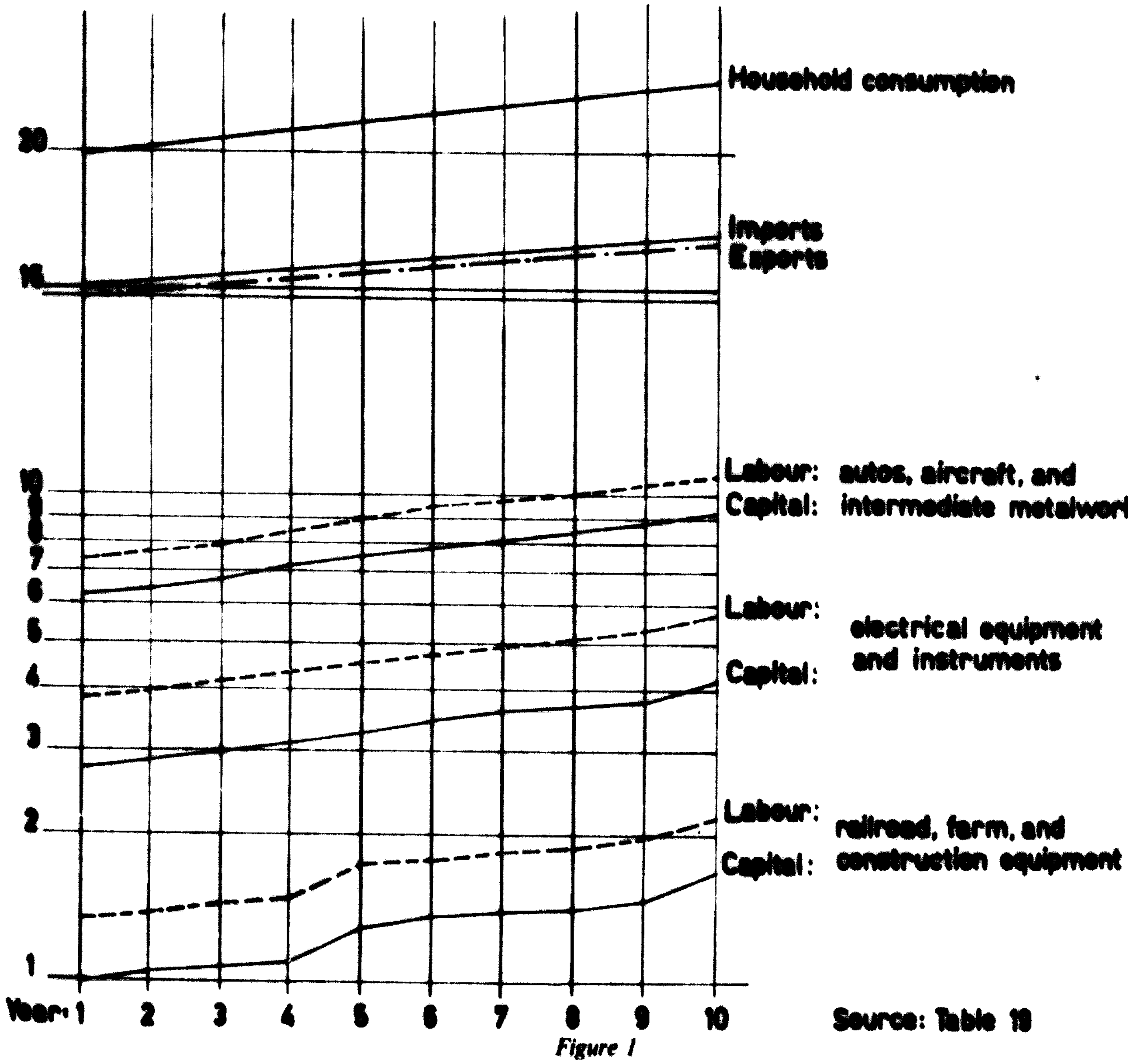


Figure 1

RELATIVE RATES OF GROWTH OF CONSUMPTION, EXPORTS, IMPORTS AND OF LABOUR AND CAPITAL IN THREE METALWORKING INDUSTRIES

Table

ANNUAL SEQUENCES OF INDUSTRIAL OUTPUT, LABOUR

IN SELECTED FINAL DEMAND

		Private consumption											
	Year of output:	8	7	6	5	4	3	2	1	0	8	7	6
Railroad, farm and con-struction equipment	Output[a]	.0001	.0002	.0005	.0010	.0023	.0041	.0144	.1010	.1102	.0001	.0003	.0006
	Labour[b]	.0096	.0201	.0429	.0910	.1977	.3569	1.2553	8.8320	9.6368	.0122	.0262	.0551
	Capital[c]	.0001	.0002	.0003	.0007	.0015	.0027	.0093	.0657	.0717	.0001	.0002	.0004
Autos, aircraft and intermed. metal-workers	Output	.0008	.0018	.0038	.0080	.0169	.0354	.0825	.0078	.0827	.0011	.0023	.0048
	Labour	.0630	.1340	.2850	.6030	1.2830	2.6830	6.2590	.5930	6.2740	.0812	.1723	.3658
	Capital	.0005	.0011	.0024	.0051	.0108	.0225	.0526	.0050	.0527	.0007	.0015	.0031
Electrical equipment and instruments	Output	.0003	.0006	.0012	.0025	.0052	.0109	.0245	.0649	.0878	.0003	.0007	.0015
	Labour	.0224	.0474	.1000	.2121	.4510	.9409	2.1137	5.5978	7.5745	.0285	.0604	.1285
	Capital	.0002	.0003	.0007	.0015	.0033	.0068	.0152	.0417	.0544	.0002	.0004	.0009
Con-struction	Output	.0007	.0015	.0031	.0067	.0141	.0308	.0548	.1898	.2635	.0009	.0019	.0040
	Labour	.0312	.0660	.1400	.2975	.6271	1.3737	2.4423	8.4642	11.7534	.0401	.0852	.1802
	Capital	.0006	.0012	.0025	.0054	.0113	.0247	.0439	.1522	.2113	.0007	.0015	.0032
Ferrous metals	Output	.0002	.0005	.0010	.0021	.0045	.0094	.0222	.0391	.0526	.0003	.0006	.0013
	Labour	.0153	.0326	.0700	.1477	.3148	.6546	1.5407	2.7119	3.6466	.0201	.0423	.0895
	Capital	.0002	.0004	.0009	.0019	.0040	.0084	.0198	.0348	.0468	.0003	.0005	.0012

[a] Dollars of output required per dollar increase in final demand. [b] Man years required per thousand dollars of final demand.
[c] Dollars of investment required per dollar of final demand.

projections were used in the computations, they are not reproduced in the table.

The total levels of consumption, exports, and imports, together with the corresponding levels of investment and employment in the three metalworking industries, are also depicted in figure 1. The vertical scale is logarithmic, so that the steeper slopes represent higher, the gentler slopes lower, rates of growth.

The metalworking outputs shown in table 19 grow more rapidly than the assumed rate for households, 4 per cent. (Unfortunately, the differences in rate of growth are too small to be apparent in figure 1.) The relatively high rates of growth of all metalworking industries are explained by the fact that both exports and imports are in this case assumed to expand less rapidly (3 per cent) than household consumption (4 per cent). Since imports contain more manufactured metal products than either exports or domestic consumption, their relatively lower growth rate has to be compensated by accelerated expansion of domestic metalworking industries called upon to cover a greater and greater proportion of the total demand for manufactured metal products. We have here a typical instance of import substitution.

The assumption of a constant rate of growth for each component bundle of final demand was used only to simplify the computation and the presentation of its details. The figures contained in the numerical inverse of a dynamic input-output system permit us to determine, through a simple process of addition and subtraction, a mutually consistent set of time-phased production programmes corresponding to any given—also, time-phased—combination of final deliveries.

The time profile of final deliveries represents a country's specific goals and projections and must be tailored to its specific needs and policies. Ideally, of course, the dynamic inverse itself should be tailored to the special features of each developing area. This requires expert judgment as to the appropriate input-output and capital coefficients to choose as a basis for planning. Practical planners already know that collection and selection of basic data is still the most difficult part of their task.

18

AND CAPITAL REQUIRED FOR AN INCREASE OF ONE DOLLAR

BUNDLES IN YEAR 0

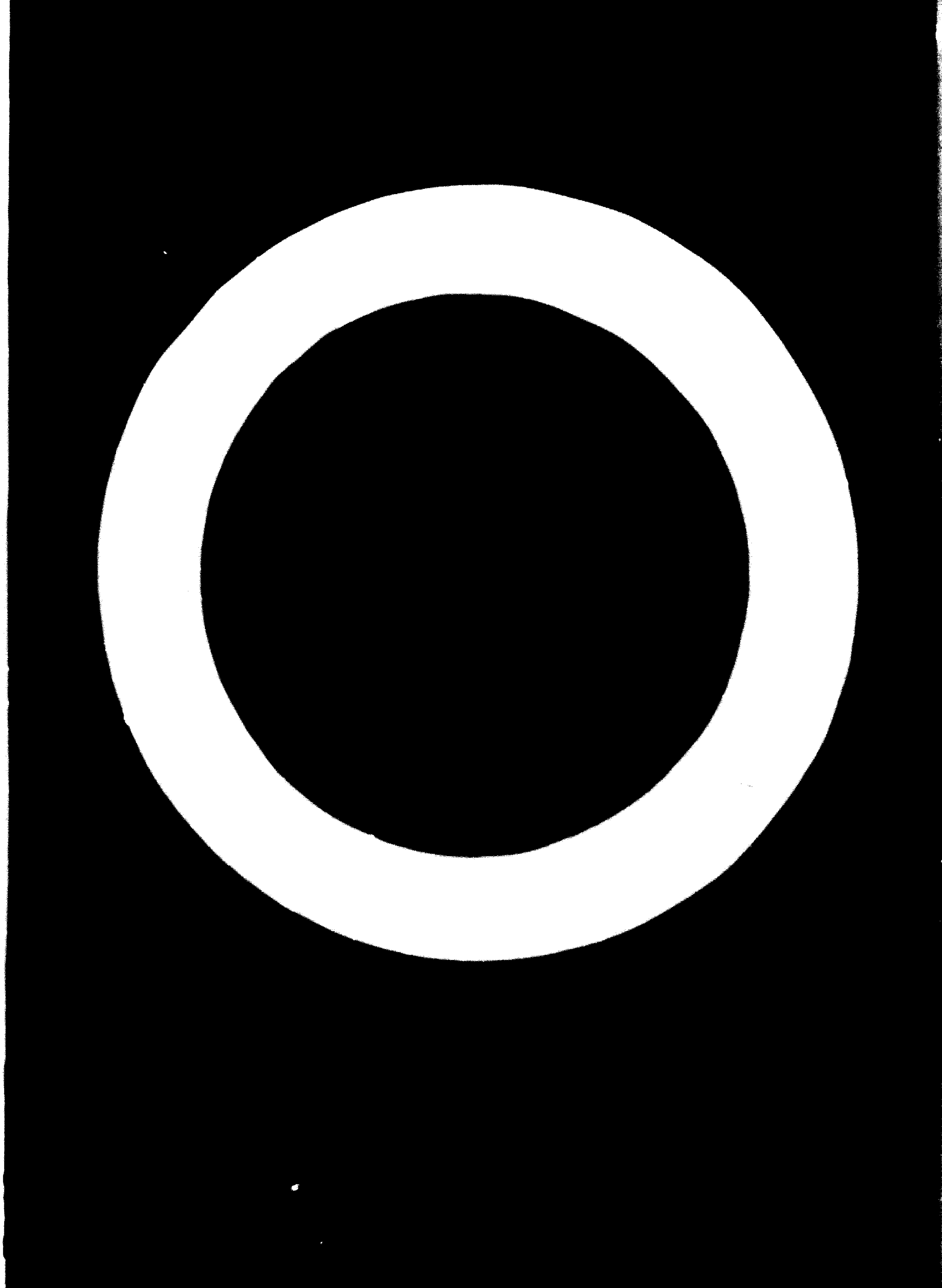
Imports						Exports								
−5	−4	3	2	−1	0	8	7	6	5	4	3	2	1	0
.0013	−.0029	−.0053	−.0197	.0285	.1181	.0001	.0002	.0005	.0010	.0022	.0041	.0147	.0688	.0712
−.1164	−.2537	.4636	1.7225	2.5142	10.3349	.0096	.0201	.0429	.0892	.1951	.3552	1.2851	6.0143	6.2277
.0009	.0019	.0035	−.0128	.0185	−.0769	.0001	.0002	.0003	.0007	.0015	.0026	.0096	.0447	.0463
.0102	.0217	−.0456	−.1032	−.0368	.1966	.0008	.0018	.0037	.0079	.0167	.0350	.0805	.0349	.0803
.7765	−1.6493	−3.4576	−7.8329	2.7901	−14.9189	.0622	.1328	.2816	.5966	1.2675	2.6550	6.1106	2.6497	6.0917
−.0065	−.0139	−.0290	−.0658	.0234	−.1253	.0005	.0011	.0024	.0050	.0107	.0223	.0513	.0223	.0512
.0032	−.0067	−.0140	−.0323	−.0800	.0105	.0003	.0005	.0012	.0024	.0052	.0108	.0242	.0298	.0324
−.2725	−.5804	−1.2108	−2.7864	6.9027	.9055	.0216	.0466	.0992	.2096	.4459	.9297	2.0853	2.5682	2.7924
−.0020	−.0042	−.0087	−.0200	−.0495	.0065	.0002	.0003	.0007	.0015	.0032	.0067	.0150	.0184	.0200
−.0086	−.0181	−.0395	−.0170	−.2599	.3617	.0007	.0015	.0031	.0066	.0139	.0304	.0545	.1977	.2741
−.3827	−.8068	−1.7613	−3.1666	−11.5929	16.1309	.0308	.0651	.1383	.2939	.6199	1.3550	2.4325	8.8183	12.2244
−.0069	−.0145	−.0317	−.0569	−.2084	.2900	.0006	.0012	.0025	.0053	.0112	.0244	.0437	.1586	.2198
−.0027	−.0058	−.0122	−.0287	−.0656	−.0797	.0002	.0005	.0010	.0021	.0045	.0093	.0219	.0387	.0119
−.1900	−.4050	−.8439	−1.9866	−4.5459	−5.5236	.0153	.0326	.0687	.1463	.3113	.6476	1.5179	2.6828	.8217
−.0024	−.0052	−.0108	−.0255	−.0583	−.0708	.0002	.0004	.0009	.0019	.0040	.0083	.0195	.0344	.0105

Table 19

ANNUAL SEQUENCES OF INDUSTRIAL OUTPUTS, LABOUR AND CAPITAL REQUIREMENTS FOR ASSUMED ANNUAL RATES OF GROWTH OF FINAL DEMAND BUNDLES[a]

Year		1	2	3	4	5	6	7	8	9	10
Household consumption		20.0000	20.8000	21.6000	22.4000	23.2000	24.2000	25.2000	26.2000	27.2000	28.2000
Exports		1.0000	1.0300	1.0600	1.0900	1.1200	1.1500	1.1800	1.2200	1.2600	1.3000
Imports		1.5000	1.5450	1.5900	1.6350	1.6800	1.7250	1.7700	1.8300	1.8900	1.9500
Railroad, farm, and construction equipment	Output	.1511	.1553	.1603	.1681	.1963	.2024	.2093	.2145	.2228	.2513
	Labour	13.2200	13.5900	14.0200	14.7100	17.1700	17.7100	18.3100	18.7600	19.4900	21.9800
	Capital	.0983	.1011	.1043	.1094	.1278	.1317	.1362	.1396	.1450	.1635
Autos, aircraft, and intermediate metalworkers	Output	.9609	.9978	1.0421	1.1031	1.1628	1.2068	1.2542	1.3058	1.3737	1.4420
	Labour	72.9300	75.7300	79.1000	83.7300	88.2600	91.6000	95.1900	99.1100	104.2600	109.4500
	Capital	.6127	.6362	.6644	.7033	.7414	.7695	.7997	.8326	.8759	.9194
Electrical equipment and instruments	Output	.4419	.4572	.4744	.4967	.5321	.5502	.5685	.5889	.6095	.6535
	Labour	38.1100	39.4300	40.9100	42.8400	45.8900	47.4500	49.0300	50.7900	52.5600	56.3600
	Capital	.2735	.2830	.2936	.3074	.3293	.3405	.3518	.3645	.3772	.4044

a Based on assumption of 4 per cent annual growth rate of household consumption and 3 per cent annual growth rate of exports and imports.



DESIGN OF MACHINE-TOOL PLANTS FOR DEVELOPING COUNTRIES

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Introduction

This report is about the design of machine-tool plants for developing countries organizing national engineering industries. Examples are given of projects and their basic characteristics and structural principles; specialization and co-operative ties; goods produced; structure of workshops and services; equipment; labour; architecture and layout.

The report utilizes materials from projects undertaken by Giprostanok in accordance with foreign orders.

Based on the practical experience in designing machine works for a number of developing countries enjoying Soviet technical aid, let us discuss some basic information and design solutions for a similar machine plant.

Machine plant

The plant is designed for a multi-purpose enterprise. It incorporates a machine assembly shop, a foundry to produce iron and steel castings, a forging-welding shop to produce forged parts and welded structures, and space for auxiliary and administrative services.

If the country plans to build a central foundry, the plant may be supplied with castings on a co-operative basis. This method also may be applied to forged articles and press work; in this case, the structure of the plant should be modified.

The plant also is expected to produce spare parts to foreign order, to make and restore welded structures and to overhaul and restore some machinery and equipment.

Power

The rated power consumption amounts to 7,000 kilowatts.

Water consumption in production processes equals fifty-five cubic metres an hour.

Figures 1 and 2 depict the plant's architectural and structural setting, and the machine assembly building plans. The buildings of the works are simple and all production buildings have the same span of 18.0 metres and only two heights, which allow extensive standardization of structural elements. Basically, the structures include ferro-concrete sectional or monolith columns and metal girders with sheet aluminium or asbestos-cement roofing.

The plans for other major buildings, as well as the administrative buildings, are represented in other figures.

Transportation inside the buildings is provided by overhead travelling cranes; motor transport and electric cars provide for intershop transportation.

The foundry has modern equipment, including that for cleaning castings (grit machines, mechanized shake-out grilles, hydro-chambers) and mechanized systems of supply and preparation of holding and core sand.

Table 1

PLANT'S YEARLY OUTPUT

Article	*Weight in tons, yearly output*	*Notes*
Spare parts from other enterprises to orders	1,500	
including:		
(*a*) Heavy parts	650	Up to five tons
(*b*) Medium and small housings and flat parts	350	
(*c*) Shafts and bushings	300	
(*d*) Gears	170	
(*e*) Standard small parts	30	
Overhaul and restoration of some machinery and equipment	700	Up to ten tons
Production and restoration of welded metal structures	1,000	Up to five tons
Castings not processed mechanically, to external orders:		
(*a*) Iron castings	900	Maximum weight three tons
(*b*) Steel castings	1,225	Maximum weight 2.5 tons
Total	5,325	

G

Machine-tool plants

While working out the nomenclature of machine tools to be produced at a designed machine-tool plant in a developing country, stress is laid primarily on meeting the need of the country for multi-purpose machine tools used in various branches of industry, agriculture and transportation and capable of becoming items of export to other developing countries.

These include the following machine tools: toolroom lathes, shapers, multi-purpose cutters and upright drilling machines.

new models. The project of machine-tool plants for developing countries envisages three types of machine-tool producing enterprises, different in volume of output and nomenclature of production, but similar structurally and in their co-operative ties and specialization:

(*a*) A plant to produce 400 machine tools of one of the four adopted models, with four possible programmes;

(*b*) A plant to produce 800 machine tools of two of the adopted models, with two possible programmes;

(*c*) A plant to produce 1,600 machine tools of the four adopted models.

Table 2

Composition, room area, equipment and personnel of the plant

Building	*Services*	*Floor area (sq.m.)*	*Equipment, pieces*		*Personne*	
			Main	*Auxiliary*	*Total*	*Workers*
Foundry building	Foundry shop: iron tons; castings, 2,400 tons; steel castings, 2,000 tons; non-ferrous castings, 50 tons ..	6,512	16	26	198	178
Forging-welding building	Forge shop: 255 tons	742	4	2	13	11
	Metal structures shop: 1,050 tons	1,500	24	5	52	47
	Blanks section of machine shop	234	4	2	4	4
	Woodworking shop	648	13	10	42	37
	Storage	1,412	—	—	4	3
Machine assembly building	Machine assembling shop: 2,200 tons	4,944	.111	14	310	281
	Heat treatment shop: 332 tons	504	10	18	18	14
	Electroplating workshop	324	30	—	13	12
	Electric equipment repair shop	432	13	5	31	26
	Tool toom	744	34	9	73	65
	Storage	756	—	—	7	5
	Total	18,752	—	—	765	683
Adminis-trative building	Managerial, services and laboratories	3,470	—	—	80	—

To work out the nomenclature of machine tools to be included in the programme of the designed plant, the list of those produced in the Soviet Union's machine-tool enterprises was studied to choose those most widely applied because of dimensional characteristics and the modern standard of technology. As a result, the following four types have been chosen: Screw-cutting lathe, model 1A616; Shaper, model 7B35; Cutter, model 6H80; Upright drilling machine, model 2H125.

Mention of these machine tools by no means restricts the range of machine tools to be produced by such plants.

When the plant is operative, other machine-tool models might be produced within the limits of rated weight and precision characteristics, which will involve some additions to the standard stock of machine-making shops and some modification in the amount of machine tools produced, depending on the labour needed for the

The plants are designed as machine assembly enterprises characterized by extensive co-operation; it is assumed that all the necessary blanks (castings, forged items, press work, welded assemblies) are supplied from other national enterprises. Such enterprises may include the above-mentioned mechanical works or other enterprises of developing mechanical engineering industries which specialize in producing semi-manufactured goods.

Prior to establishment of such enterprises in the developing country, all complete parts (electric motors, electric equipment, bearings, pumps, hydraulic units, etc.) should be supplied from the country whose models of machine tools are to be produced by the plant.

The plants incorporate: the mechanical, assembly and heat treatment shops, tools and repair rooms, necessary laboratories including a technology laboratory, painting and electroplating workshops, compressor room, trans-

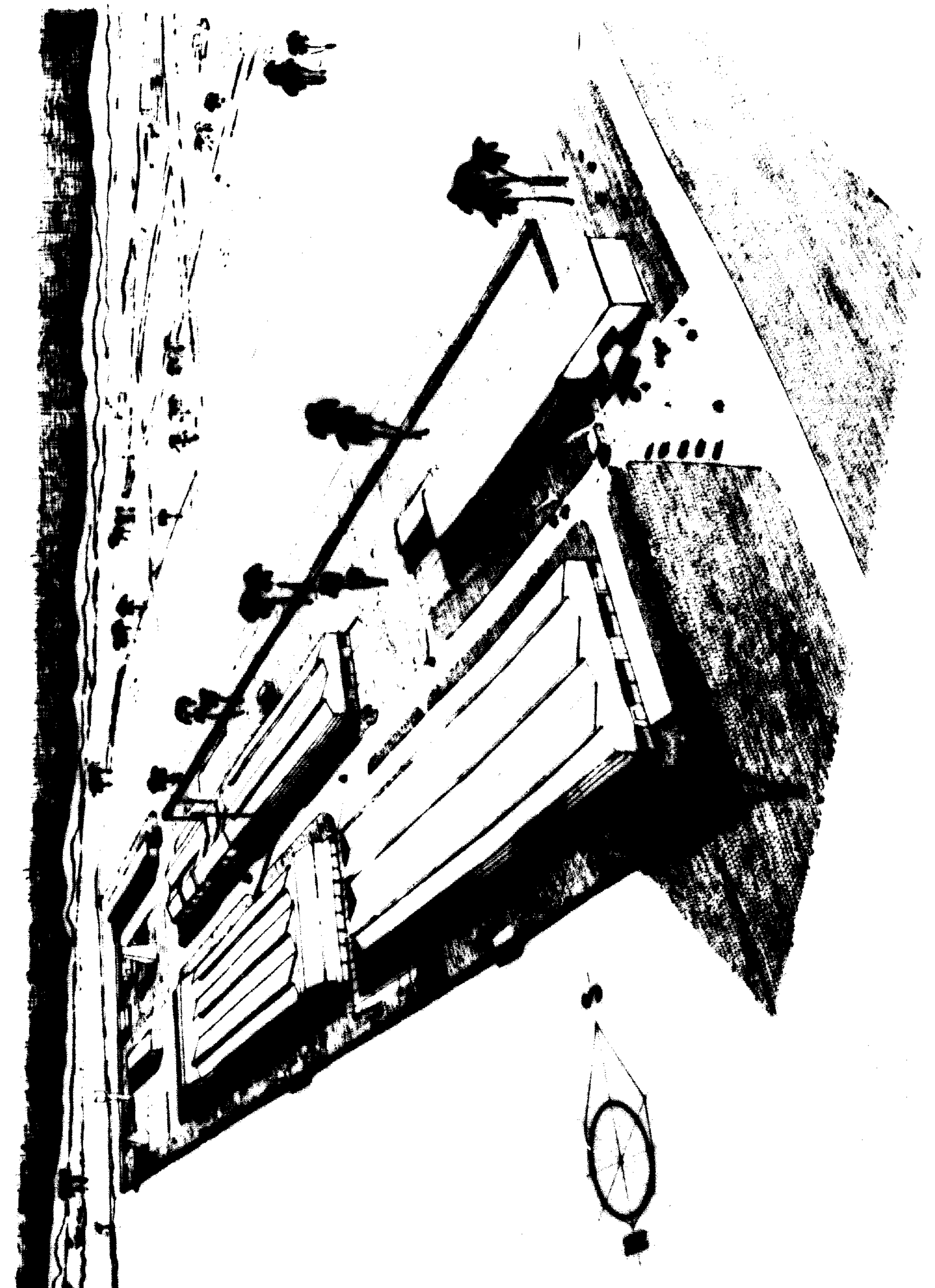
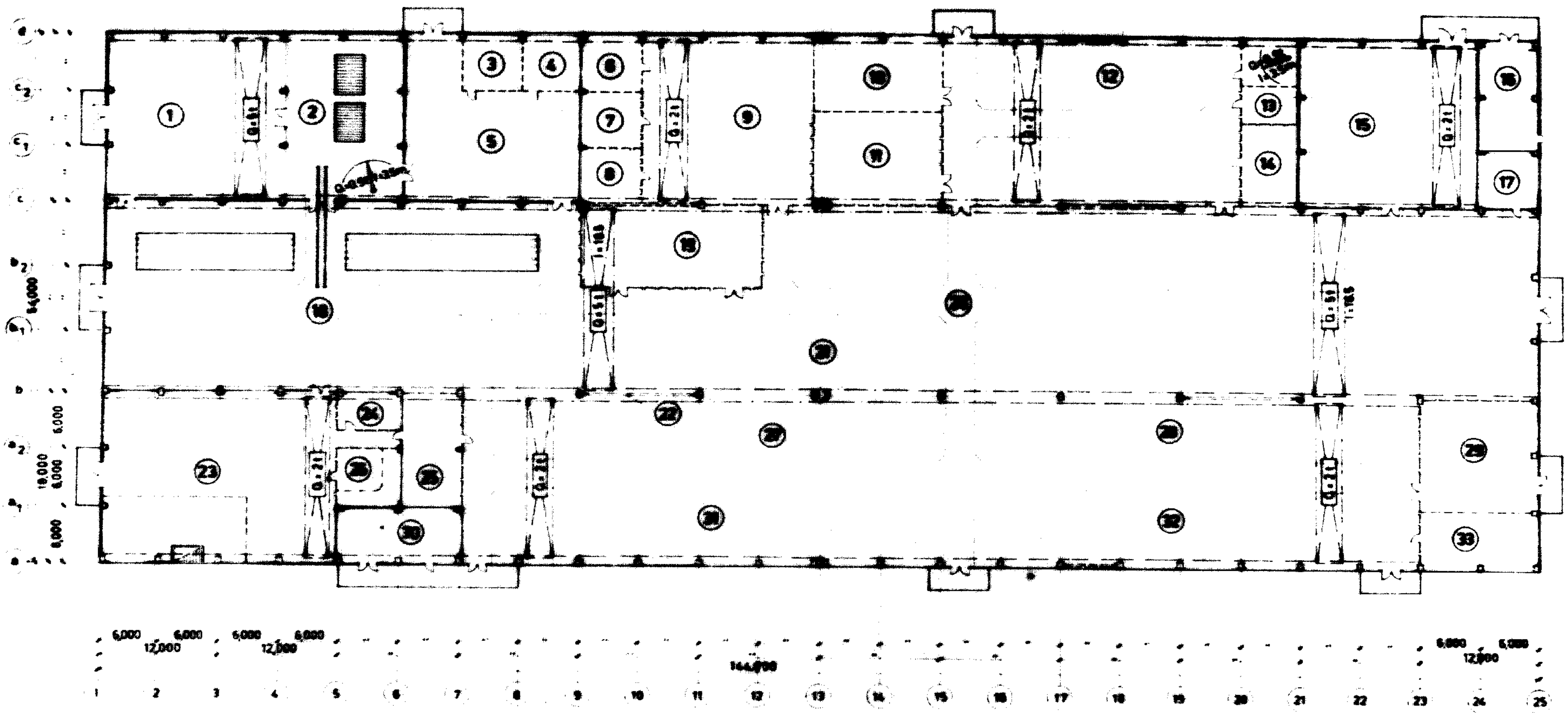


Figure 1
MECHANICAL WORKS. PERSPECTIVE



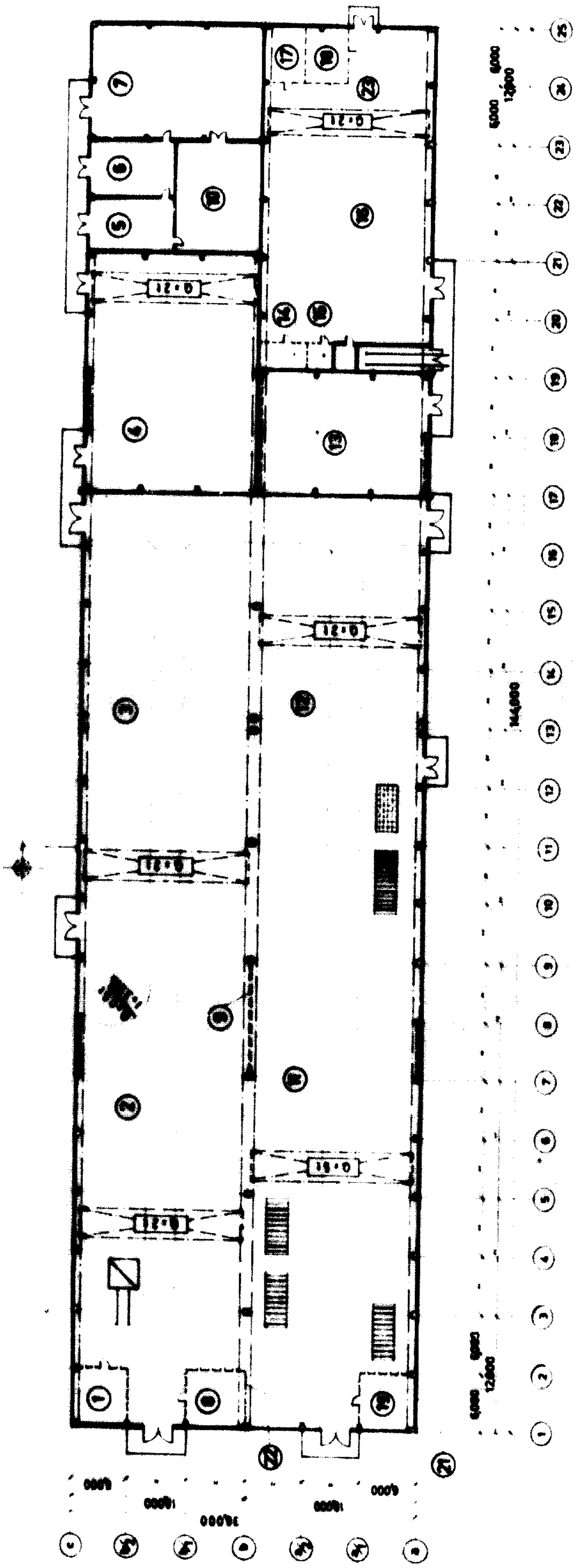
Key for symbols:
- Block walls
- Metal net partitions
- Glazed partitions

Explanation of premises

1 Packing department and finished parts storehouse
2 Painting section
3 Section of tables production
4 Grinding polishing section
5 Electroplating workshop
6 Soaking drying section
7 Testing station
8 Store room
9 Electric equipment repair shop
10 Sharpening shop
11 Tool distributing store room
12 Tool room
13 Intershop store room
14 Blanks store room
15 Control material
16 Transformer substation
17 Emulsion workshop
18 Assembly department
19 Storehouse of finished parts
20 Machine assembling shop
21 Section of large parts
22 Vertical connections
23 Heat treatment shop
24 Checking department
25 Intershop store room
26 Cleaning section
27 Gears section
28 Section of medium and small parts
29 Blanks storehouse
30 Transformer substation
31 Section of shafts and bushings
32 Section of standards
33 Offices

Figure 2

MACHINE-ASSEMBLY BUILDING



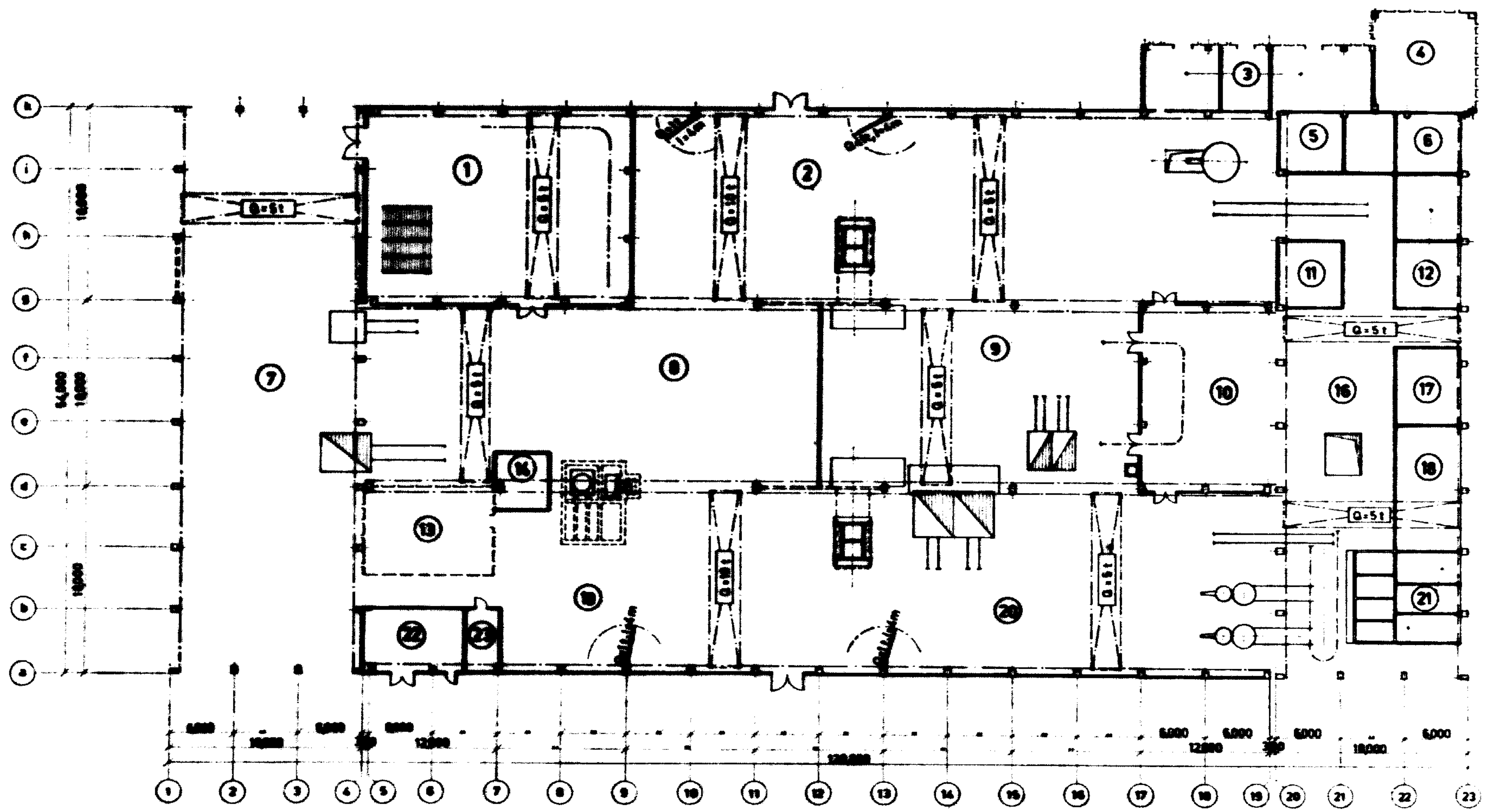
Explanation of premises

1 Ventilation area
2 Forgeshop
3 Metal storehouse
4 Patterns storehouse
5 Transformer substation
6 Assistant station mastr.
7 Compressed air station
8 Spare parts store room
9 Vertical connections
10 Distribution point
11 Metal structures shop
12 Metal storehouse
13 Boiler house
14 Store room
15 Office
16 Woodworking shop
17 Sharpening room
18 Pattern painting section
19 Auxiliary materials store room

20 Key for symbols:
21 Block walls
22 Metal net partitions
23 Glazed partitions

Figure 3

FORGING-WELDING BUILDING



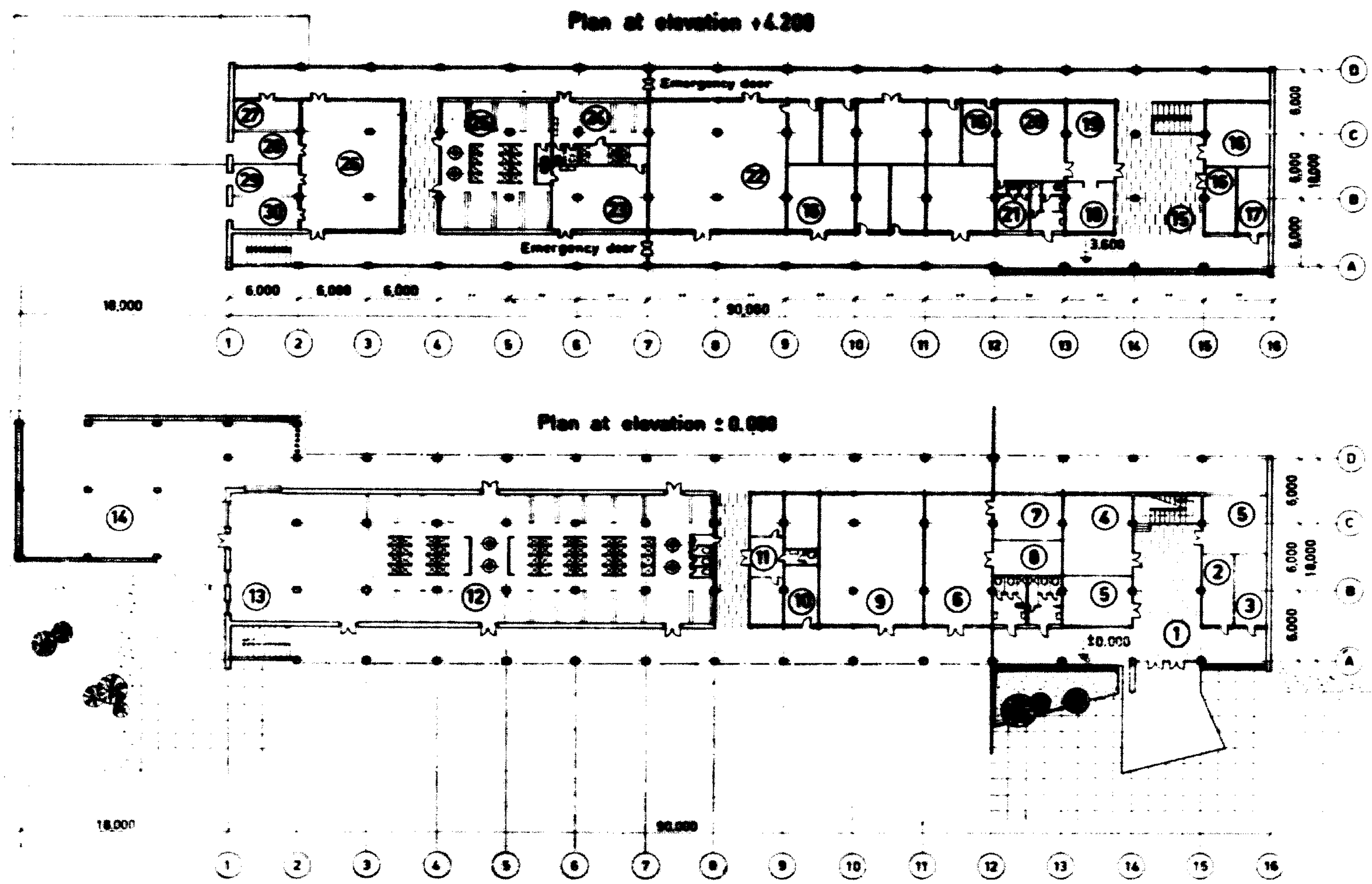
Explanation of premises

1 Castings priming department
2 Moulding department for steel castings
3 Transformer substations
4 Department of sand regeneration and water clarification
5 Bins for metal charge
6 Bin for regenerate
7 Trestle for castings and mould boxes
8 Fetling department
9 Core department
10 Sand preparation department
11 Bin for metal charge
12 Bins for sand
13 Intermediate patterns storehouse
14 Pumping station
15 Vertical connections
16 Storehouse for charge and moulding material
17 Bin for clay
18 Bin for coke
19 Non-ferrous castings section
20 Moulding department for iron castings
21 Bins for metal charge
22 Transformer substation
23 Laboratory of proximate analysis

Key for symbols:
Block walls
Metal net partitions
Glazed partitions

Figure 4

FOUNDRY BUILDING



Explanation of premises

at elevation 0.000

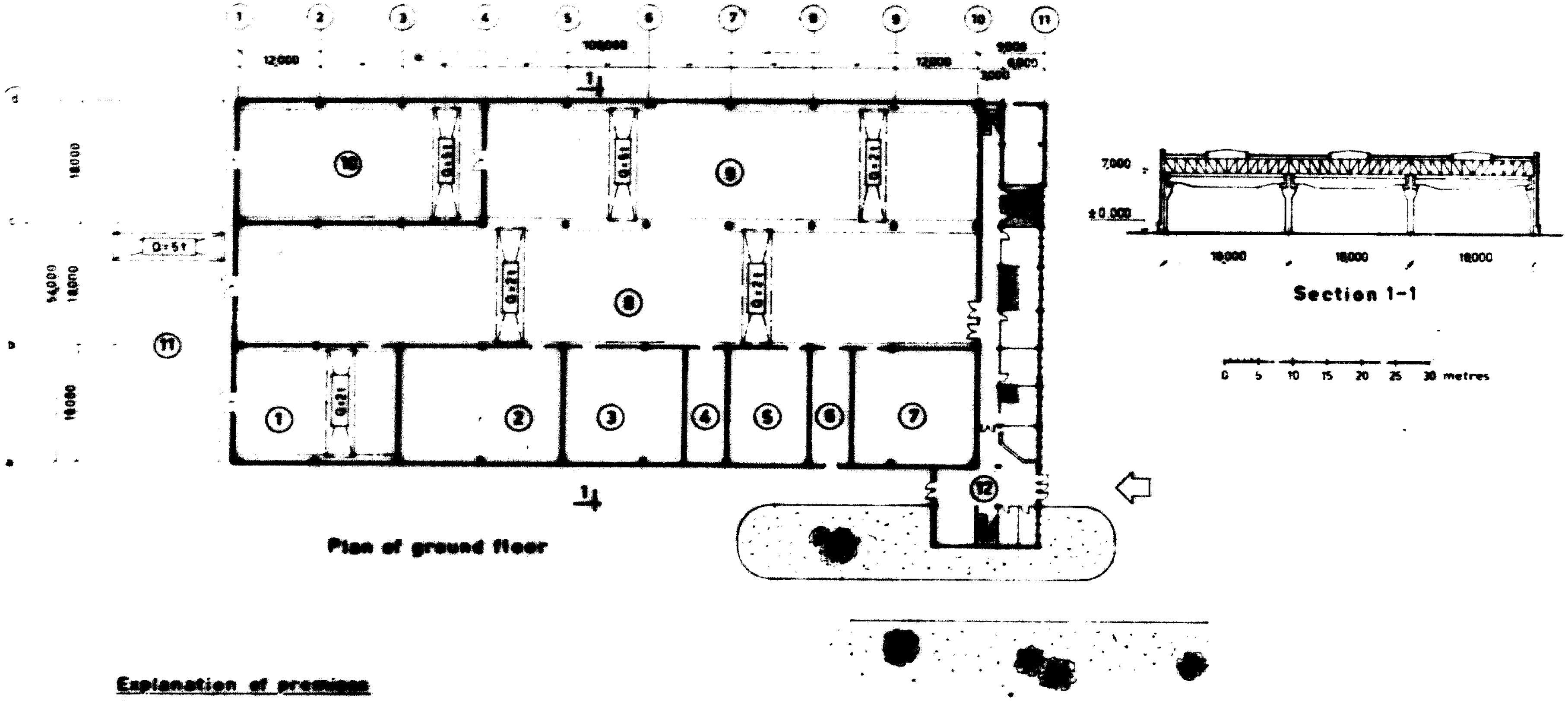
1 Lobby
2 Janitor's room
3 Fire post
4 Automatic exchange
5 Offices
6 Hall for mechanical testing
7 Grinding and polishing department
8 Photo room
9 Measuring laboratory
10 Room of measuring laboratory manager
11 Surgery
12 Men's cloak room (for 384 persons)
13 Auxiliary premises of canteen
14 Dining hall under shed

at elevation +4.200

15 Exhibition hall
16 Offices
17 Radio centre
18 Technical manager's office
19 Reception room, secretary
20 Director's office
21 Rest room and toilet
22 Designing office
23 Men's cloak room (for engineers)
24 Women's cloak room (for 50 persons)
25 Men's cloak room (for 352 persons)
26 Chemical laboratory
27 Room for determination of carbon percent
28 Weighing room
29 Washing room
30 Room of central laboratory manager

Figure 5

ADMINISTRATIVE BUILDING

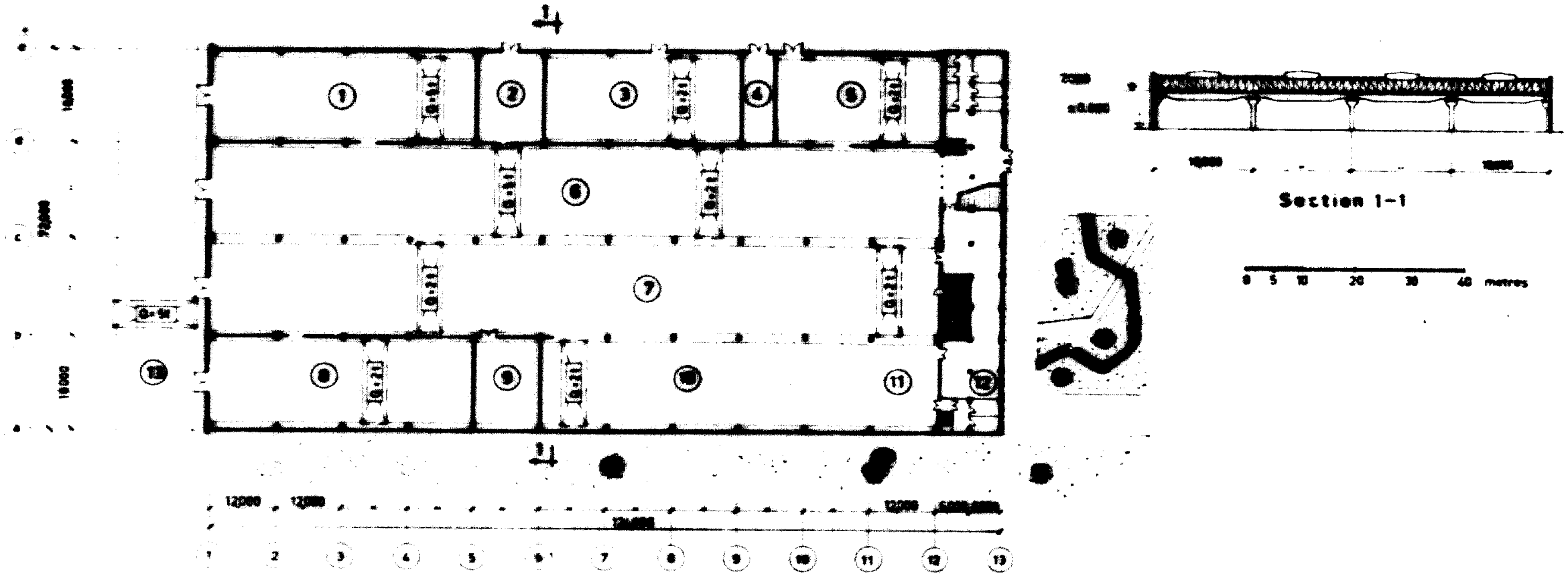


Explanation of premises

1 Store of metal
2 Tools repair room
3 Heat treatment room with electroplating section
4 Transformer substation
5 Compressor room
6 Store of chemicals and lubricants
7 General store of materials
8 Machine department
9 Assembly department
10 Painting, packing and store of finished products
11 Gantry
12 Administrative-welfare building

Figure 6

PLANT WITH YEARLY PRODUCTION OF 400 MACHINE TOOLS



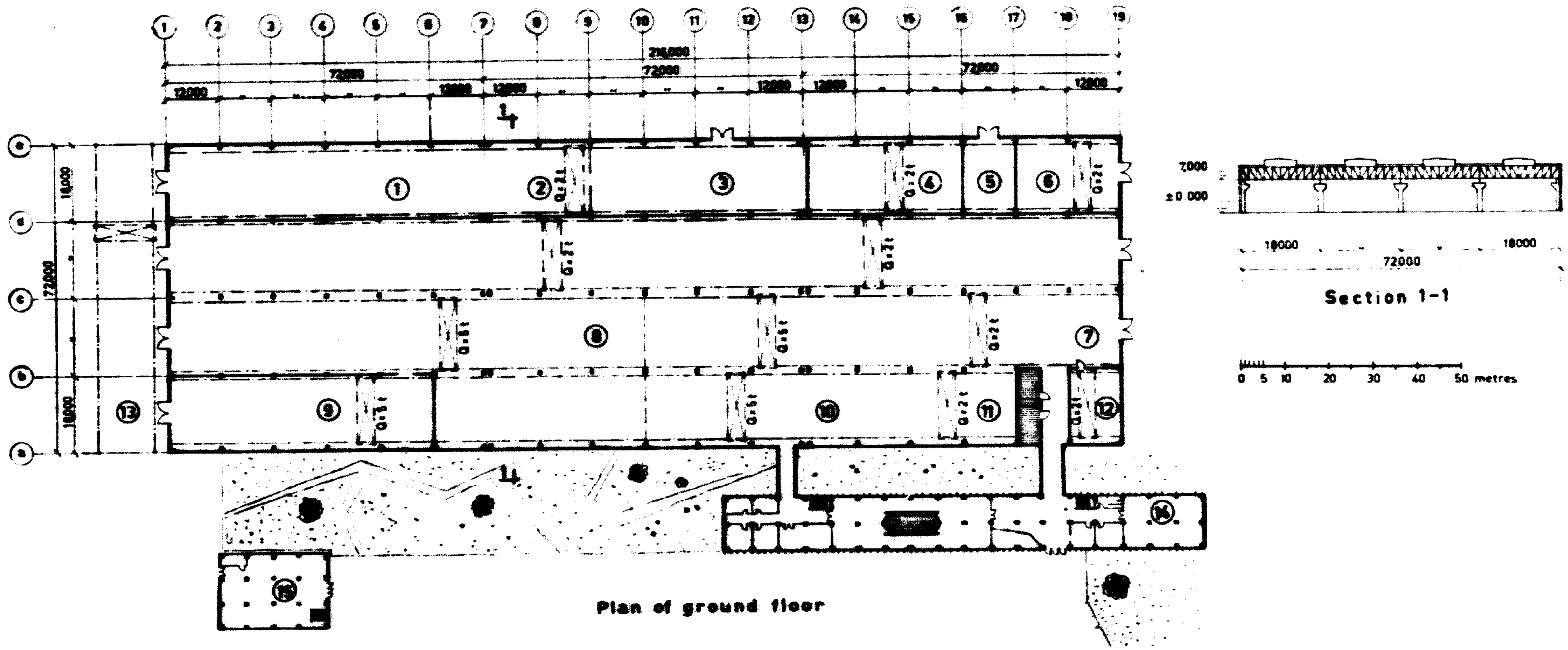
Plan of ground floor

Explanation of premises

1 Painting, packing and store of finished products
2 Compressor room
3 General store of materials
4 Transformer substation
5 Heat treatment room with electroplating substation
6 Assembly department
7 Machine department
8 Store of metal
9 Technology laboratory
10 Tools repair room
11 Machine and repair room
12 Administrative-welfare building
13 Gantry

Figure 7

PLANT WITH YEARLY PRODUCTION OF 800 MACHINE TOOLS



Explanation of premises

1 Store of metal
2 Preparation section and section of makers standard parts of machine shop
3 General store of materials
4 Heat treatment room with electroplating department
5 Transformer substation
6 Compressor room
7 Machine shop
8 Assembly shop
9 Painting, packing and store of finished products
10 Machine and repair room
11 Tool room
12 Technology laboratory
13 Gantry
14 Administrative-welfare building
15 Canteen

Figure 8

PLANT WITH YEARLY PRODUCTION OF 1,600 MACHINE TOOLS

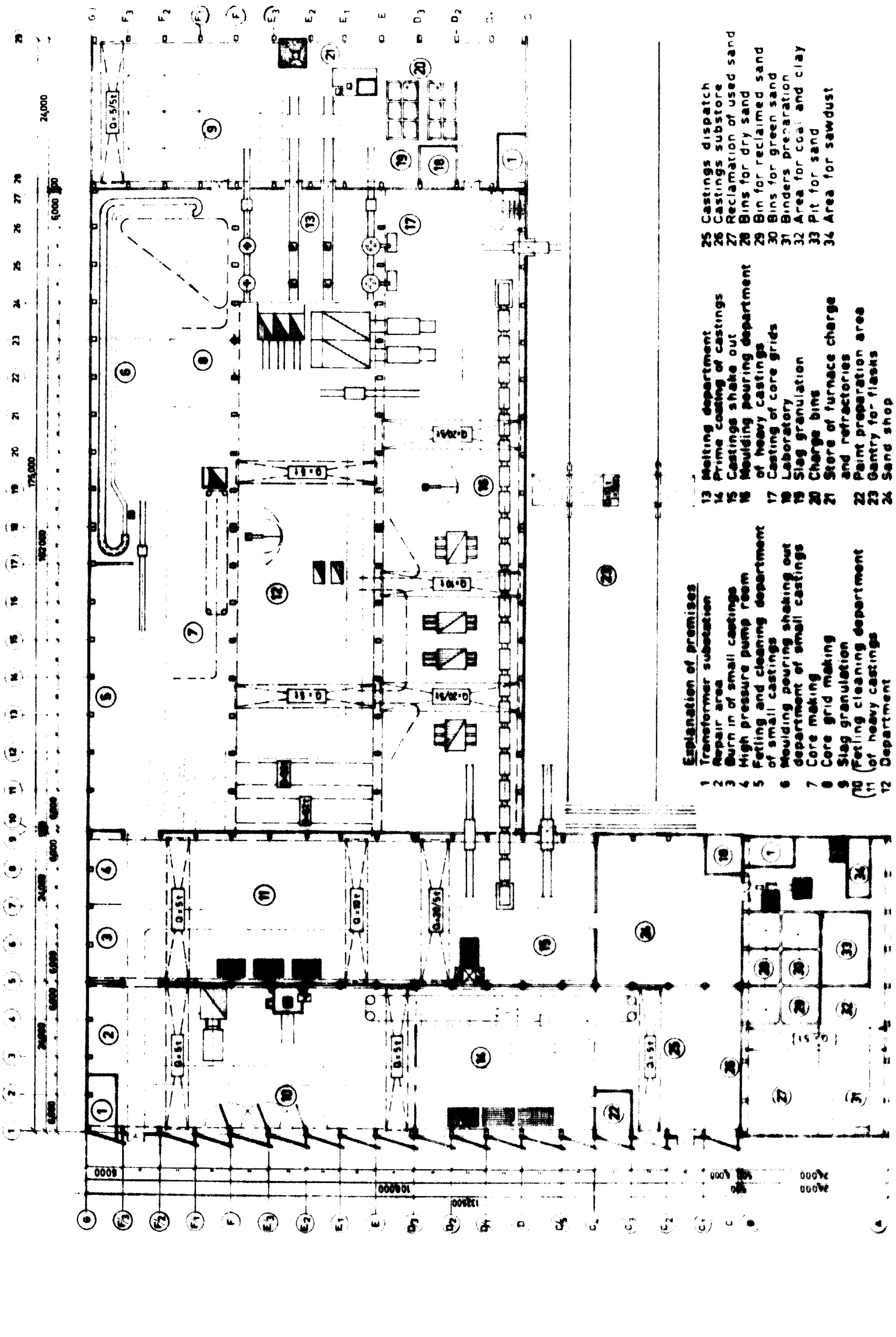
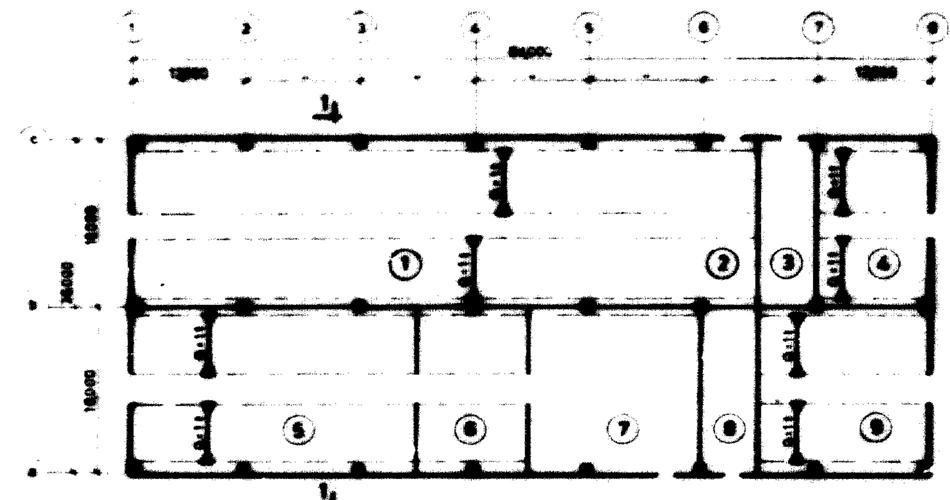
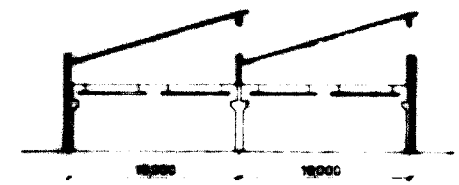


Figure 9
FOUNDRY SHOP FOR HEAVY CASTINGS



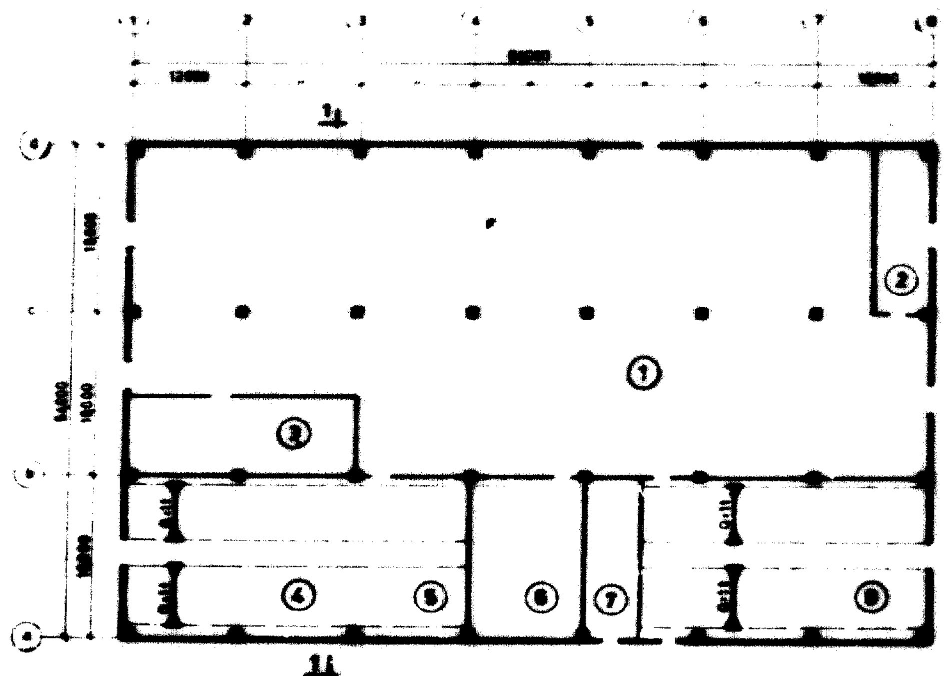
Building of auxiliary shops



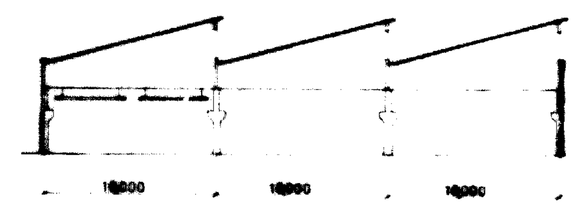
Section 1-1

Explanation of premises

1 Tool room
2 Machine repair shop with electrical equipment repair department
3 Transformer substation
4 Compressor room
5 Metal store
6 Department of cut blanks tools and hack-saw bands
7 Forge-welding shop
8 General tool store and general abrasive store
9 General materials store



Production building



Section 1-1

Explanation of premises

1 Machine shop
2 Emulsion room
3 Technological laboratory and tool testing
4 Store of finished products
5 Packing and despatch
6 Electroplating department
7 Transformer substation
8 Heat-treatment shop

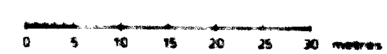


Figure 10

LAYOUT OF TOOL FACTORY

Table 3

Plant for 400 machine tools yearly

Yearly programme

Item	*Model*	*Pieces*	*Weight in tons* — *Unit*	*Weight in tons* — *Yearly programme*
Variant 1				
Screw-cutting lathe	1A616 (diameter 320 · 710mm)	400	1.5	600
Spare parts and accessories				3
Total		400		603
Variant 2				
Shaper	7B35 (length of ram stroke 500 mm)	400	1.8	720
Spare parts and accessories				3
Total		400		723
Variant 3				
Horizontal milling machine	6B80 (table 200 × 800 mm)	400	1.2	480
Spare parts and accessories				2
Total				482
Variant 4				
Upright drilling machine	2H125 (diameter 25 mm)	400	0.87	348
Spare parts and accessories				2
Total				350

Number of shifts: two

Composition, room area, equipment and personnel of plant

Shops and services	*Floor area (sq.m.)*	*Equipment, pieces* — *Basic*	*Equipment, pieces* — *Auxiliary*	*Personnel* — *Total*	*Personnel* — *Workers*
Machine department	1,940	50	11	105	92
Assembly department	1,300	—	18	70	59
Painting, packing and store of finished products	650	—	5	10	8
Heat treatment room with electroplating	330	20	25	10	8
Tool and machine repair room	430	10	8	25	20
Laboratories	250	—	—	4	1
Storage facilities	870	—	—	4	3
Compressor room	220	2	—	4	3
Transformer substation and telephone exchange	110	2	—	8	6
Total	6,100	84	67	240	200
Management, offices, canteen, welfare, etc.	1,530	—	—	25	3

Power

The rated consumer motor power amounts to 2,200 kilowatts.

Water consumption in production processes equals 7 m³/hr.

former substations, storage facilities to keep complete parts, blanks, and finished goods, and all necessary administrative, welfare and engineering service areas.

The plants are planned within one technological building to include all production and auxiliary services, and only the largest of them has administrative, welfare and engineering services areas removed to a separate block connected with the main technological building by covered passages.

As far as the architecture and setting up are concerned, the buildings of the three plants are identical, with parallel bays eighteen metres wide and eight metres high from the base of the truss. Each bay has an overhead travelling crane and crane beam capable of carrying five tons. The structural design includes sectional or monolith ferro-concrete columns and metal roof trusses.

Tables 3–5 give basic information on the varieties of machine-tool plants.

Table 4

Plant for 800 machine tools yearly

Yearly programme

Item	*Model*	*Pieces*	*Weight in tons*	
			Unit	*Yearly*
Variant 1				
Screw cutting lathe	1A616 (diameter 320 · 710 mm)	400	1.5	600
Upright drilling machine	2H125 (diameter 25 mm)	400	0.87	348
Spare parts and accessories				5
Total		[illegible]		953
Variant 2				
Shaper	7B35 (length of ram stroke 500 mm)	400	1.8	720
Horizontal milling machine	6H80 (table 200 · 800 mm)	400	1.2	480
Spare parts and accessories				5
Total		[illegible]		1,205

Number of shifts: two

Composition, room area, equipment and personnel at plant

Shops and services	*Floor area (sq.m.)*	*Equipment, pieces*		*Personnel*	
		Basic	*Auxiliary*	*Total*	*Workers*
Machine department	3,240	101	16	218	193
Assembly department	1,510	—	33	159	145
Painting, packing and store of finished products	860	—	7	16	15
Heat treatment room with electroplating	540	20	25	12	10
Toolroom	650	18	8	29	25
Machine repair room	650	15	11	34	30
Laboratories	510	—	—	7	2
Storage facilities	1,800	—	—	7	5
Compressor room	220	2	—	4	3
Transformer substation and telephone exchange	110	3	—	8	6
Total	10,090	159	100	494	434
Management, offices, canteen, welfare, etc.	2,340	—	—	38	5

Power

The rated power consumption amounts to 3,400 kilowatts.

Water consumption in production processes equals 10 m^3/hr.

Table 5

PLANT FOR 1,600 MACHINE TOOLS YEARLY

Item	*Model*	*Yearly programme, pieces*	*Weight in tons*	
			Unit	*Yearly*
Screw-cutting lathe	1A616 (diameter 320 · 710 mm)	400	1.5	600
Shaper	7B35 (length of ram stroke 500 mm)	400	1.8	720
Horizontal milling machine	6H80 (table 200 · 800 mm)	400	1.2	480
Upright drilling machine	2H125 (diameter 25 mm)	400	0.87	348
Spare parts and accessories to machines				10
Total		1,600		2,158

Number of shifts: two

Composition, room area, equipment and personnel at plant

Shops and services	*Floor area (sq.m.)*	*Equipment, pieces*		*Personnel*	
		Basic	*Auxiliary*	*Total*	*Workers*
Machine department	6,400	175	19	385	346
Assembly department	2,810	—	44	269	250
Painting, packing and store of finished products	1,000	—	10	25	23
Heat treatment room with electroplating	650	25	32	16	15
Tool room	860	25	10	35	31
Machine repair room	860	18	12	44	40
Laboratories	660	—	—	10	3
Storage facilities	2,380	—	—	9	7
Compressor room	430	2	—	5	4
Transformer substation and telephone exchange	230	4	—	8	6
Total	16,430	249	127	806	725
Management, offices, canteen, welfare, etc.	3,490	—	—	52	8

Power

The rated power consumption amounts to 5,000 kilowatts.
Water consumption in production processes equals 15 m^3/hr.

FOUNDRY

A foundry is necessary for a developing country to produce metal-processing machine tools and other products of machine-building industries.

The modern principle of specialization and co-operation of mechanical engineering enterprises, including machine-tool plants, predetermines the economic efficiency of producing blanks, and castings in particular, at specialized foundries or in founding shops designed to meet the needs of a number of machine-building enterprises. Thus, it is hardly reasonable to organize foundry production in developing countries by setting up small founding shops designed only to meet the needs of the plant on the premises, although there are exceptions to the rule.

Following are projects of a specialized founding shop for an output of 15,000 tons of iron castings a year, which can be self-supporting as a small foundry if a models shop, storage facilities for models, compressor room, transformer substation and administrative and welfare services are added. The shop is designed to supply machine-building enterprises, including machine-tool plants, with shape castings. Production is organized in large or small series with castings distributed by weight as shown in table 6.

The founding shop is an L-shaped, one-storey building with co-perpendicular spans twenty-four metres wide provided with overhead travelling cranes with a load-lifting capacity of twenty tons.

Mechanization of production and transportation is envisaged: a mechanized store of furnace load as well as mechanized supply of charge into the cupola, pre-

Table 6

Up to 5 kg.	1,250 tons
5–20 kg.	2,750 tons
100–200 kg.	1,600 tons
200–500 kg.	3,800 tons
500–1,000 kg.	2,600 tons
1,000–2,000 kg.	1,700 tons
2,000–5,000 kg.	1,300 tons

Maximum weight of casting, 5,000 kg.
Maximum size of casting: 4.7 × 1.6 × 1.0 m.
Number of shifts: two.

Composition, room area, equipment and personnel at plant

Shops and services	Floor area (sq.m.)	Equipment, pieces	Personnel Total	Personnel Workers
Founding shop	11,420	40	421	369
Repair room	80	3	16	14
Laboratories	70	—	4	—
Storage facilities	4,130	—	5	5
Total	15,700	43	446	398

Power

The rated power consumption amounts to 5,330 kilowats.
Water consumption in production processes equals 50 m^3/hr.

paration and supply of moulding and core mixtures, shaking-out, cleaning and prime coating of castings.

Pouring and assembly of small and heavy castings are to be effected on conveyor lines, and removal of cores in hydro-chambers. The mechanical shop is up to all modern standards.

The buildings are planned to be made of monolith ferroconcrete.

The establishment of such a specialized founding shop should precede building of customer enterprises: machine-tool plants and other machine-building enterprises.

Tool factory

Though the problems of designing tool factories for developing countries are in no way the theme of the present report, it seems useful to cite briefly some information on a project of a tool factory, designed for developing countries, which is to meet the needs of machine-building industries.

The factory is a complex enterprise intended to produce cutting tools.

The factory is to make the basic types of cutting tools: normal cutting tools, drills, reamers, taps, threading dies, cutters, hacksaw bands and small quantities of other tools in small series.

The main technological and auxiliary shops are located in separate buildings.

The factory buildings are simple and composed of parallel spans eighteen metres wide and seven metres high provided with suspended travelling cranes wherever necessary.

Technical and economic characteristics organization of design and production

Some of the following technical and economic characteristics are entirely tentative, as well as indices concerning machine-tool plants, since in developing countries labour costs, the costs of power, local materials and manufactured and semi-manufactured goods vary widely.

Similarly different are the norms of depreciation, overhead expenses, and the costs of storage, transportation and procurement. Plant and shop expenses are also different.

Wide variations can be observed in the cost of building and mounting a plant in these countries, as well as in the prices of purchased goods and equipment to be installed, depending on where these goods and equipment are bought.

Since the above factors making up the prime cost of produced goods and determining capital investment in plant construction vary to a great extent, these two technical and economic indices can also vary substantially, depending on the specific conditions existing in the developing country in which the plant is being built.

Therefore, to obtain objective technical and economic indices of the designed plant, the economic part of the project must be formulated in view of the specific conditions of the developing country undertaking construction of the plant.

To obtain preliminary estimates of the basic technical and economic indices and projects suggested, rough calculations were carried out on the basis of the average values of critical cost factors, in dollars, for the toolroom lathe, model 1A616, produced at a plant designed for 400 machines of this model yearly.

As a result, the prime cost of the lathe at this plant was estimated at $2,980, including 40 per cent for materials, semi-manufactured goods and purchased articles, 55 per cent in shop and over-all plant expenses and basic wages of the workers engaged in production and 5 per cent in overhead expenses outside the plant.

Rough estimates were also performed to calculate tentatively capital investment, in dollars, necessary to build the three types of machine-tool plants. This investment is:

Plant to produce 400 machines yearly, $2,900 thousand, including: equipment, $1,900 thousand, or 65 per cent;
Plant to produce 800 machines yearly, $4,800 thousand, including: equipment, $3,200 thousand, or 67 per cent;
Plant to produce 1,600 machines yearly, $7,800 thousand, including: equipment, $5,400 thousand, or 69 per cent.

Since the economic effectiveness of building powerful machine-tool plants is self-evident, two or more developing countries may co-operate in establishing a comparatively large enterprise under certain conditions.

Design of machine-tool plants for developing countries is to be first organized by formulating the basic technical and economic estimate containing an analysis of the need for the machines to be produced in view of the country's development targets and export possibilities, followed by preparation of the design programme, collection of initial data and selection of the site for the project, accompanied with the technical and economic estimates of the possible locations for the enterprise. This work is, as a rule, performed by agencies of the developing country, assisted by competent advisers from the country undertaking the general plant design.

It is desirable, when designing a plant, to attract national engineers, especially to design external com-

Table 7

FACTORY YEARLY PROGRAMME

Item	*Size in mm*	*Yearly programme, pieces*	*Weight in tons*
Cutting tools		320,000	205.7
Drills	Diameter 0.5–50	338,000	47.24
Reamers	Diameter 3–100	84,000	16.03
Counterbores	Diameter 10–100	25,000	12.94
Cutters, all types		70,000	64.85
Taps	Diameter 2–52	239,000	34.23
Threading dies	Diameter 3–52	195,000	13.6
Toothing tools		3,500	30.55
Hacksaw bands		640,000	22.4
Knives, spare		51,000 sets 552,000 knives	39.46
Other tools			33.0
Total			520.0

Composition, room area, equipment, and personnel at factory

Building	*Services*	*Floor area (sq.m.)*	*Equipment, pieces*		*Personnel*	
			Basic	*Auxiliary*	*Total*	*Workers*
Main building	Machine shop	2,630	150	13	255	220
	Heat treatment shop with electroplating	760	43	55	55	42
	Dispatch office and packing department	220	—	2	8	6
	Technology laboratory	220	7	—	5	2
	Emulsion room	110	—	5	2	2
	Store of finished products	430	—	—	2	1
	Repair department	60	4	—	9	8
	Transformer substation	110		—	3	2
	Total	4,540			339	283
Auxiliary shops building	Forge-welding shop	330	7	6	21	17
	Blanks section of machine shop	220	20	2	30	28
	Tool room	540	30	10	55	47
	Machine repair shop with workshops	640	26	14	56	48
	Metal store	540	—	3	4	4
	General materials store	330	—	5	3	3
	General tool store	110	—	—	2	1
	Compressor room	220	2	—	4	3
	Transformer substation	110	4	—	3	2
	Total	4,040			178	153
Store building	Store of oil and lubricants	430	—	4	1	1
Administrative building	Central and test laboratories, offices, canteen, welfare	—	—	—	58	8

Power

The rated power consumption amounts to 4,000 kilowatts.

Water consumption in production processes equals 12 m³/hr.

munications and facilities, water supply systems, signal communication, access roads, sewage, and power supply systems as well as for elaborating shop drawings.

This gives a strong impetus to design work, enables more adequate utilization of local resources and materials and, most essential, makes it possible to train skilled national specialists (designers) within short periods.

If a favourable situation is available, maximum use should be made of the developing country's national enterprises and shops of a mechanical specialization to produce relatively simple metal structures, some unique equipment and other articles uneconomical to import. The manufacture of the above items in accordance with the drawings of the general designer and under the supervision of his instructors will make it possible to enhance the construction of the plant, train skilled workers and save currency. Systematic supervision by specialists from the country carrying out general design work and supplying the equipment is essential in securing good quality of work and compliance with the project.

The period within which a plant becomes fully operational in a developing country depends on timely training of specialists and workers for its operation, which can be carried out either in the country of the general contractor or in the developing country with the assistance of instructors, provided adequate conditions prevail.

Of great importance also is timeliness of design work and manufacture of technological rigging (special appliances and tools) and working out of the operational technology to provide for the needs of production processes without which manufacture is impossible.

It takes considerable time to manufacture the rigging for a machine-tool plant.

As an illustration, putting the tool room, model 1A62, into production involved about 1,200 special appliances, tools and dies at a cost of $350,000.

Training of personnel and preparatory technological work necessary to start manufacture should be carried out while the plant is still being built, so that these problems may have been mainly solved by the time the plant is started.

It is desirable, during the initial period of operation of the plant, to purchase in the general contractor's country some dozen sets of machine castings, particularly basic and frame types, to use in training personnel under the guidance of skilled instructors and for assembling the first machines.

Conclusions

1. Designing of machine-tool plants for developing countries is not a problem by itself but is to be solved in co-ordination with promoting mechanical engineering in these countries.

2. It is reasonable, during the initial phases of developing machine building in developing countries, to set up a small multi-purpose complex type machine plant designed for maintenance, repair and restoration of equipment, manufacture of spare parts, simple machinery and welded metal structures to meet the needs of industry transport and agriculture. This works will serve as a training centre for personnel and the basis for further expansion of specialized mechanical engineering including machine-tool production.

3. Machine-tool plants should be designed to produce a limited number of multi-purpose tool models which can find wide application in the various branches of industry and become items of export. Projects must provide for replacing the models with new ones, within the limits of rated weight and precision characteristics.

4. Machine-tool plants should be designed as mechanical assembly enterprises with extensive co-operation in the supply of semi-manufactures, such as castings, forged pieces and stampings, parts, purchased articles, standards and normal tools.

5. Modern principles of specialization and co-operation demand that developing countries set up economically effective specialized plants or shops to manufacture castings and forged and stamped pieces to satisfy the demands of a number of machine-building enterprises.

6. Along with establishing machine-tool plants, it is desirable to promote tool production, first as a small specialized factory to manufacture cutting tools such as cutters, drills, reamers, taps, threading dies and hack-saw blades.

7. Designing of machine-tool plants for developing countries must be based on comprehensive technical and economic calculations in view of the country's development targets and with participation of national specialists, which will make possible training of national designers and enhancement of design work.

8. To bring a ready plant to its rated capacity within the shortest practical time, it is important to perform timely technological preparation of production processes, to design and make the technological rigging and special tools, to formulate operational technology and train specialists and workers. These problems must be solved through extensive co-operation of the country giving technical assistance.

METHODOLOGICAL AND OPERATIONAL ASPECTS OF MACHINE-TOOL STUDIES IN DEVELOPING COUNTRIES

Secretariat of the United Nations Economic Commission for Latin America

BACKGROUND DATA

One of the worst difficulties usually encountered in the preparation of industrial development programmes in developing countries is the lack of reliable basic data on demand and costs in manufacturing activities. The seriousness of the problem depends, of course, upon the industrial sector and whether the work is to be done on the basis of a macro-economic estimate or on the level of branches of industry or specific products.

In relation to certain types of industry, either because of the characteristics of the production process or because of the nature and homogeneity of the goods manufactured or the use to which they are put, the basic data in question are more readily accessible or are relatively easy to determine; it is even possible, in many cases, for coefficients or ratios established in the more highly industrialized countries to be adopted without much adjustment. This would apply, for instance, to activities characterized by a continuous production flow resulting in homogeneous final products, such as the cement, chemical, and petroleum refining industries.

On the other hand, in those sectors of industry which display great flexibility in respect to the machinery they use and the products manufactured, satisfactory basic data and production coefficients are in very short supply and difficult to establish. Outstanding cases in point are the metal-transforming industries. With a few exceptions, the machines used in this branch of activity, i.e., machine tools, are not designed for the specific purpose of manufacturing a given product, but are intended to perform a particular operation (turning, milling, drilling, etc.) which, moreover, can be carried out by different machines. Thus, the capacity of a plant and the technical coefficient for the manufacture of any one product are highly relative concepts that are very difficult to quantify.

The factors conditioning production capacity, for example, will include, *inter alia*, the product manufactured and the machinery used, and the latter, in turn, is not determined by the product to be obtained because of the possibilities of interchanging machines for a large number of operations. One thing which may cause marked variations in technical production ratios in such industries is the standard of quality for the final product. Furthermore, the "universality" of the machines enables enterprises to run several widely differing lines of production simultaneously, which enormously complicates the establishment of technical coefficients and may make them useless in practice unless their precise significance and the possible limits to their applicability are clearly specified.

In developing countries where the degree of specialization is very low, and it frequently happens that the great majority of enterprises manufacture a very wide and varied range of products, this severely restricts the use of coefficients established for more highly industrialized regions, irrespective of the limitations deriving from the differences in capital-labour ratios, in standards of quality, in external economies and so forth. This last factor also has a noteworthy influence on technical production coefficients since, in the countries under discussion, the situation usually existing in the more developed regions is reversed and interindustrial relationships are slight owing to the lack of manufacturing activities specializing in services for third parties, with the result that enterprises show a marked degree of vertical integration, undertaking the manufacture of parts and accessories that in the developed countries are normally purchased from the subsidiary industry.

Little of the literature available on this subject bears on the metal-transforming industries, and the various studies that have been carried out were not exactly planned with a view to establishing production ratios or coefficients for application in other countries or under conditions different from those in relation to which they were determined. The methodologies have varied widely and so have the ways in which data have been presented but, generally, the feature common to all these studies is the rigidity of their findings, in the sense that they cannot be adjusted or amended so as to adapt them to different conditions in respect to volumes of production, technical processes, lengths of series, degrees of integration, standards of quality, composition and characteristics of lines of manufacture.

In carrying out its studies on the metal-transforming industries, ECLA was hampered by the lack of information of this type and consequently each survey had to be preceded by intensive field work to fill some of the gap. Data thus collected, in relation to the specific situation under analysis, might also be open to a good many criticisms of the same sort as those levelled above, with respect to their validity under other conditions. But since they were established in developing countries and correspond to the average conditions, they perhaps need less adjustment and can be more freely adopted for direct application in other countries at similar stages of development, as experience has shown in several instances.

The purpose of this report is to expound the methodology followed in the studies carried out by ECLA in the Latin American countries, as well as some aspects of its application, and a few of the conclusions to be drawn from a preliminary review of the various data assembled. The sole aim is that of offering other developing regions a share in the experience acquired in Latin America, and thus helping to facilitate the execution of any studies that may be undertaken with respect to the metal-transforming industries.

The information presented here relates particularly to the determination of demand for machine tools.

Remarks on the determination of demand for machine tools

It will be as well to state clearly what is understood in the present study by the terms of metal-transforming industries and machine tools. Both are frequently used in the literature of the subject, and what they are meant to cover apparently differs in different places.

In ECLA studies, metal-transforming or metalworking industries include all those activities which in the United Nations International Standard Industrial Classification of All Economic Activities (ISIC) are comprised in the following major groups: 35 Manufacture of Metal Products, except Machinery and Transport Equipment; 36 Manufacture of Machinery, except Electrical Machinery; 37 Manufacture of Electrical Machinery, Apparatus, Appliances and Supplies; and 38 Manufacture of Transport Equipment. The term machine tools is applied only to machinery used for metalworking purposes (whether cutting or forming) and therefore excludes machines for working wood or other materials.

In the case of machine tools, as in that of other capital goods, demand is conditioned by so many factors of such different kinds that to analyse them is a distinctly complex task. To the usual considerations bearing on demand for capital goods, such as, *inter alia*, their durability and its relation to depreciation, degrees of mechanization and the effects of production processes for which greater or lesser volumes of manpower are required, the existence of idle installed capacity or the possibility of making more intensive use of capacity through a system of two or three shifts, which enables production to be expanded without affecting demand for machinery, and the rate of replacement of capital goods whose useful life has come to an end, on account of either wear and tear or economic obsolescence, three others must be added which stem from machine-tool characteristics that cannot be overlooked in a study of demand.

The first is the interchangeability of many machine tools for the fulfilment of one and the same function, although this does not necessarily imply any change in the extent to which operations are mechanized; the second is the dependence of demand on specifications as to the quality and precision of the products to be manufactured, which means that machine performance must be evaluated; and the third consists of the extreme frequency with which technical innovations are introduced in machine tools and the emergence of new machining and metal-forming processes based on such as electroerosion, supersonics, electron beams, explosives and magnetic impulses. Strictly, therefore, demand should be studied in the light of a separate analysis for each of the many activities in which it has its origin. Obvious requisites for such research are, on the one hand, highly complete and detailed statistical information and, on the other, a series of basic data on operational conditions at the level of each activity, which are not easy to obtain or to reconstitute in developing countries.

Another point to be stressed is that inasmuch as the significance and incidence of the various determinants of demand for machine tools are not the same in developing countries as in those at more advanced stages of industrialization, the methodology applied must be adjusted to the needs of these two cases. For example, replacement on account of wear and tear or obsolescence will carry less weight in developing than in developed countries because, as a rule, inventories in the former are relatively new and rapidly expanding. Conversely, the characteristic of interchangeability will be of more importance in small national inventories where machine tools carry out very similar operations and the products manufactured are of a primary nature.

Another factor whose incidence is relatively heavier in developing countries is the qualitative aspect of demand. It often happens that in such countries the metal-transforming industries show high growth rates attributable not only to the manufacture of larger quantities of their products but also, and perhaps in greater measure, to the establishment of new lines of manufacture that are becoming imperatively necessary in view of import substitution requirements.

Consequently, changes are almost constantly introduced in the structure of production and in manufacturing techniques and this affects the characteristics of the machines in demand. This consideration is important also in connexion with the evaluation of installed capacity and the more intensive utilization of existing machine tools. It may well happen that the machine-hours which for some reason may be available in inventories in developing countries cannot really be turned to account for the purposes of expanding production, if the increases in the volume of output are largely to derive from the manufacture of new products calling for more advanced techniques.

From these brief remarks it can be seen that the developing countries need to adopt a methodology slightly different from that habitually applied in the more highly industrialized areas in the study of demand for machine tools. The modifications introduced will be conceptual rather than procedural, and in this sense certain stages of the process of analysis will have to be approached or covered by means of an *ad hoc* interpretation of the facts. Comparison with present or past situations in the industrialized countries may be useful in many cases, provided that the phenomenon under analysis can be adequately interpreted.

But this is not always possible, because the available data are so unsatisfactory both in quantity, homogeneity and explicitness. It would seem that in the field of machine tools no laws or criteria operate that can be universally applied or extended from one region to another without prior analysis of the situation or phenomena involved, and in practice this means dealing with factors that vary widely in character and are often difficult to quantify.

Despite these complications, such studies are in one sense easier to carry out in the developing than in the highly industrialized countries, as the field of operations is more limited in its extent and less complex as regards range of products and technological alternatives. What is more, their very aims are less ambitious with respect to the degree of detail of their findings; their purpose is rather to arrive at an over-all and approximate assessment of the volume of demand to be expected in the future, and thus provide the general groundwork for evaluating the possibilities of starting domestic manufacture of certain machine tools, usually the simplest, and those that make the least technical demands, or for demarcating the areas of production in which the country's machine-tool industry should develop.

These were the objectives of the relevant studies carried out by ECLA in the Latin American countries and in order to attain them research was conducted at the level of three major groups which strikingly differ from one another in both the nature of the factors determining demand and the characteristics of the machinery required, and which comprise machine tools for production, for maintenance operations and for replacement purposes.

By definition, machine tools for production are all those installed in the metal-transforming industry, even though some of them may be used for making tools and for maintenance and repair work. Thus, demand for such machines is closely linked to the evolution of the metal-transforming industry during the period under study.

All machine tools used in activities other than those comprised in the metal-transforming sector are classified in the maintenance group, although in some instances they may be fulfilling functions that can be described as definitely productive. Demand for these machines is somewhat difficult to analyse, inasmuch as it is contingent not only upon the possible expansion of the sectors using them but also on other and perhaps more important factors which can hardly be expressed in quantitative terms.

Maintenance, in the sense ascribed to it here, if undertaken by workshops proper, is an auxiliary and not indispensable service in manufacturing, mining and other activities, so that the decision for or against its inclusion is influenced by a number of considerations peculiar to each individual enterprise, such as, *inter alia*, the size of the plant, its location with respect to metal-transforming centres where this service could be provided, and the degree of urgency with which maintenance requirements must be met (as determined by the nature of the production process), whose evaluation must be based on careful research. The incidence of this group of machines on aggregate demand may be considerable in countries where the metal-transforming industries are of little significance.

The term replacement is used with reference to cases where a machine tool is finally eliminated from the inventory on the grounds of its unfitness to carry out any operation, and requirements thus represent the net amount of machinery that should be replaced. Consequently, this group does not include machines that ought to be replaced in a specific sector or activity on account of technical obsolescence, loss of precision or other similar causes, if they are still usable for other and perhaps less demanding operations and continue to form part of the plant installed.

This definition, linked as it is to the end of the useful life of the machine, implies that the decision to replace a machine tool is dictated by widely varying criteria, and can only be adopted at the level of each individual unit in relation to the work it is doing. Thus, machine-tool requirements under this head can be estimated solely on the basis of specific and highly detailed research. Since in developing countries the machine-tool inventories have been only recently set up and manufacturing requirements are not very exigent, the incidence of the replacement group on aggregate demand is of minor importance. Accordingly, for the studies undertaken it was thought best to make a very rough over-all assessment of replacement needs, based on a general survey of the situation and on interpretation of the evidence collected elsewhere.

Clearly, then, data on the size and composition of the inventory of machine tools currently in use in the industrial sector, and on the characteristics of the units comprising it, are essential for an analysis of demand, inasmuch as they represent background material for the determination of the machines needed not only to keep pace with the expansion of production in the metal-transforming industries, but for the purposes of maintenance operations in other industrial sectors and replacement of machine tools that have reached the end of their useful life.

Information of this type is not as a rule directly available in developing countries, and has to be procured by means of intensive field work. In such countries, the selection of simpler and more direct alternative procedures which might yield equally useful information or might at least provide guidelines for demand studies is generally ruled out by statistical deficiencies. For example, the national inventory might be approximately quantified on the basis of the records of the machinery imported over a reasonable number of years, from which some knowledge of the age distribution of the machines might also be obtained. But this is virtually impossible in a developing country for want of statistical data on imports, even at the highest level of aggregation, and on domestic production, if any. Separate records of imports of machine tools are seldom kept and, where they are, they include spare parts, accessories and tool kits, besides which, the definition of machine tools applied is not always the same as that adopted in the studies under discussion.

As regards future demand trends, an analysis of the evolution of machine-tool consumption in the past, supposing this can be reconstituted, is not of much value for projection purposes in developing countries for the reasons indicated above. But it should be carried out

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because it is useful from other standpoints, as will be seen later.

Hence it appears that the most feasible method of determining future machine-tool requirements is to ascertain the number of units installed in the main consumer sectors and to estimate the expansion of production that is likely to take place in each of these sectors during the period under study.

DETERMINATION OF THE MACHINE-TOOL INVENTORY AND PROJECTION OF DEMAND

Determination of the inventory

It has already been pointed out that data on the number and characteristics of machine tools installed in a given country are not as a rule directly available in developing regions and therefore have to be obtained by means of a survey of the consumer sectors. For this purpose, sampling procedures are adopted, according to the size of the sector concerned, in order to save time and resources. Here the first problem arises: deciding on the right size of sample.

Although this is a matter of mathematical statistics, some observations may usefully be proffered on the requisites with which the sample should comply, and on its representativeness. In the first place, the extent to which the sample is representative of the universe cannot be measured in terms of its percentage share in the number of workers employed or in the value of output, since the direct proportional relation of machine tools to these magnitudes cannot be established until certain considerations relating to the average size of the plants covered by the survey and of those constituting the universe have been taken into account. The studies carried out have shown that the ratios represented by the number of machine tools per employed person and per unit of value of production vary with the size of the plants (measured in terms of the manpower employed), but that in this respect the behaviour pattern of the former is more clearly defined: the ratio is high for small plants and low in those of larger size. Accordingly, it is easier to use the coefficient of machine tools per employed person than the ratio between machine tools and the value of production, and the resulting estimate is more likely to be reliable. Clearly, therefore, a sample that is strongly influenced by the bigger plants, which may account for a percentage of the manpower employed in the universe, precludes the possibility of ascertaining the total number of machine tools installed by extrapolation based directly on the proportion of the personnel employed in the universe which the sample represents because, in the case of workers not covered by the survey, most of whom would probably be employed in smaller plants, the number of machine tools per worker would exceed the ratio indicated by the sample. Extrapolation by this method would result in under-estimation of the inventory. Conversely, a sample including too many small plants would lead to over-estimation of the existing number of machine tools.

If plant size is an important factor in establishing the total number of machine tools in the inventory, it is of no less significance in relation to the latter's composition. In the bigger plants, the types and characteristics of the machine tools installed are much more varied than in those of more modest size, where the predominant items in the inventory are usually lathes, shapers, drilling and sawing machines, and a few machine tools for the simpler sorts of forming operations.

Consequently, a sample with a high proportion of large establishments will be conducive to under-estimation of the machine-tool inventory as a whole and over-estimation in respect to certain types of machine tools that are used only in the bigger plants; the position will be reversed if the incidence of small enterprises on the sample is heavy. In this sense, the large plants may be said to exert a marked influence as regards the variety, and the small ones in relation to the number of the machine tools inventoried.

Hence, the extent to which a sample is representative of the universe cannot be measured in over-all terms, but must be evaluated in relation to the composition of the universe by plant sizes, and if the composition of the sample differs greatly from that of the universe, extrapolation must be based on size categories. A direct proportional relationship between the machine tools installed and the manpower employed in the sample and in the universe is possible only when the average plant size is the same in the former as in the latter.

The distinction drawn between machine tools for production and machine tools for maintenance operations indicates that two inventories must be made: one in the metal-transforming industry and another in the other pertinent activities, including the extractive industries, construction, manufacturing (excluding metal transforming), provision of public utilities, government dependencies, and so forth. The foregoing comments on the quality of the same apply particularly to the first inventory, production machinery, which is really the more important.

Owing to the nature and characteristics of maintenance services, the conditions that the sample should fulfil in this case and the way in which it should be dealt with in order to obtain information on the universe have not been established in such concrete terms. The ECLA studies carried out in the field in question, which is far more extensive than that of the metal-transforming industries, and in which machine tools do not represent productive resources, have been mainly exploratory, and designed to seek out some data on the stock of machine tools in sectors other than the metal-transforming industry.

In the relevant studies undertaken in Latin America, the size of the sample could not be mathematically established for want of appropriate statistical information on the universe concerned, and other methods had to be adopted as circumstances decreed. The number of plants to be visited was tentatively established, according to the size of the industry under survey, with a view to covering all the activities involved and the range of plant sizes in each.

At this selective stage, every effort was made to work at the lowest possible levels of aggregation with respect to activities, to ensure homogeneity of products, production systems, etc. In other words, the survey was not conducted at the level of the ISIC breakdown, which is carried only as far as the three-digit group, but at that of a four-digit subdivision established *ad hoc* or by adapting extant national classifications to this system.

In the course of the survey, the initial list was gradually amended and supplemented until in every size category in each activity a measure of constancy was observable in the number of machine tools per worker and in the composition of the machine-tool inventory. It proved possible to fulfil this condition with a sample comprising no more than 10 per cent of the establishments constituting the universe. An important decision that must be taken before a survey relates to whether it is to be nationwide or confined to major centres. Generally speaking, in developing countries a high proportion of the metal-transforming activities is concentrated in two or three such centres.

The next stage in the preparation of the inventory is the extension of the sample findings to the universe in order to estimate the total number of machine tools installed. Although the sampling procedure itself can be carried out in considerable detail, the same does not apply to the extension of the sample, since data on the labour force employed are not usually available at such a low level of aggregation. Industrial censuses do not as a rule go into so much detail, and the extension can be effected only at the level of the ISIC major groups 35, 36, 37 and 38. For this purpose it was decided to group activities by size categories and make the appropriate extrapolation for each of these in respect to both the number of machine tools and the composition of the inventory.

In developing countries, however, an important preliminary step is to find out what proportion of total employment is represented by personnel in establishments that do not need to use machine tools, such as workshops undertaking different types of simple machine repairs, or the installation of electrical fittings and the maintenance of electrical and electronic appliances and accessories, or electroplating and nickelplating, and so on. Evidence of the existence of this situation and of the significance attaching to it, especially in the smaller size categories, was gathered in the course of the surveys.

With regard to the age of the machines, the criteria governing the validity of the sample in relation to the number of machine tools installed and the composition of the inventory are no longer adequate and other factors must be taken into account. But, as previously remarked, in developing countries the inventories have been more or less recently built up, and replacement is not a major component of demand, so there is no need for such accuracy. The information on age requested in the survey is wanted mainly as a general guide and, in addition, for the purpose of checking certain aspects of the calculation, particularly with respect to the size of the inventory. From this point of view, it is decidedly useful to compare the age distribution of the sample with the composition by age groups that can be worked out from the estimated total for the machine-tool inventory and data on imports or apparent consumption of machine tools in previous years. From such a comparison, valuable conclusions can be drawn as to the estimate formulated and the quality of the data used.

The procedure followed for determining the inventory of machine tools used in maintenance operations resembles, in broad outline, the method described above, although the coverage of the sample is extensive rather than intensive, and its extrapolation to the universe is effected at higher levels of aggregation, by more direct and consequently less exact methods. In the case of this inventory, the field of action can be circumscribed and the survey confined to plants whose size exceeds a specific minimum, which can be fixed in the light of a preliminary review of the situation.

In the Argentina study, for example, it was established that maintenance services, as defined here, were found mainly in enterprises employing more than thirty persons, which meant that the field of operation could be restricted to approximately 4 per cent of the existing plants. As regards extrapolation of the results of the studies carried out, it was thought advisable, in view of the wide dispersion of the sample, to deal with the sample data in the aggregate, omitting the stage of inventorying the machine tools in each of the activities covered by the survey; moreover, this procedure may well be adequate for the aims and scope of such studies. It was ascertained that when the inventory in the metal-transforming industries exceeds 20,000 machine tools, the size of the maintenance group ranges from 15 to 25 per cent of this total.

With respect to the composition of the maintenance inventory and the age of the machines, the same observations hold true as were formulated in relation to the metal-transforming industries. Very little diversification is usually found, lathes, drilling machines, shapers, shears, folding machines and others with simple characteristics being by far the commonest items, while the average age in this group is much higher than in the inventory of machine tools for production.

The purpose of the foregoing description is to indicate the most salient aspects of the task of inventorying machine tools. In practice, according to the circumstances and to the availability of basic statistics, operational problems may arise which entail some modification of the procedure, thus making the research either easier or more complicated.

Projection of demand

The problems raised by the projection of demand are also many and varied, and derive from the many factors that affect demand for machine tools. Although in theory many of these factors are relatively easy to identify, their incidence and implications are difficult to assess in quantitative terms and, in practice, therefore, their accurate evaluation is attended by serious difficulties. For the problems thus created, tentative solutions must be sought whereby over-all effects can be analysed in the light of personal experience, information on the situation under study and interpretation of what has happened in other countries.

In these circumstances, obviously, various devices, methods or criteria may be applicable for the purposes of projecting demand. The object of this paper is not to examine all the methods of determining future machine-tool requirements, but to give an account of the method followed in the ECLA studies, thus providing a rough estimate of the prospective volume of demand and a general idea of the direction of its probable trends.

In line with the classification established above, demand was analysed separately for each of the three groups of machine tools: those for production, those for maintenance, and those for replacement.

For production machinery, the procedure comprised three stages. The first consisted of determining the value of production and the volume of employment in the metal-transforming industries at the end of the period covered by the projection; in the second, the aggregate number of machine tools likely to be in use was estimated; and in the third, the composition of this inventory by types of machine was established. Thus, the difference between the inventories computed for the base and for the final year of the projection gave the number of machine tools that would be needed.

The influence of the determinants of demand enumerated in earlier paragraphs will be reflected mainly in the total number of machine tools and the composition of the inventory. In the first connexion, their effect can be interpreted and evaluated through the behaviour pattern of certain indicators such as productivity (measured in terms of value added per worker), value added per machine and the number of machines per person. For the purposes of the studies under consideration, it was thought sufficient to subject these magnitudes to a series of adjustments in order to make them, by means of successive approximations, more or less consistent with one another in respect to both the total projection and the additions to the base-year inventory. A further consideration that was also taken into account for checking purposes was the maintenance of the total amount of investment entailed in the expansion of the inventory at a level which would represent a reasonable proportion of the increased product that should be generated in the projection period.

Assumptions as to the percentage composition of this new machine-tool inventory were deduced from the following points of reference: the structure of the inventory in the base year; changes in the composition of apparent consumption of machine tools; specific manufacturing projects and development programmes, particularly in certain branches of the metal-transforming industry; and breakdowns of inventories in other countries at different stages of economic development.

In view of the difficulties of estimating demand in qualitative terms, and specifying the models, types and characteristics of the machine tools that would be required, so as to define this other important aspect of future demand, it was decided that in the ECLA studies an over-all evaluation from the qualitative standpoint should be based on the average weight of the machines and their average price per kilogramme.

Thus, machine-tool requirements in the production group were established in terms of numbers of units and types of machine, with the indication of quality provided by weight and average price.

As regards machine tools for maintenance, neither local statistical data nor reference material bearing on the situation in other countries were available on a scale that would permit the establishment of the most suitable criterion for determining requirements. In a few instances, however, it was possible to ascertain that the maintenance inventory is equivalent to a relatively small proportion of the production inventory when the latter exceeds 20,000 units. Moreover, the composition of the former is more stable, and the factors primarily influencing the demand generated in the maintenance sector differ from those discussed in the context of production activities, and are usually less dynamic.

Accordingly, it was decided to assume as a first approximation that during the period covered by the projection the inventory of machine tools for maintenance would continue to bear the same proportional relation to that of machine tools for production as in the base year and that its composition would remain constant. Obviously, the validity of this assumption will have to be more carefully tested in the future in the light of such data as may be collected on the subject.

Mention has already been made of the low incidence of replacement on total demand in developing countries, attributable to the fairly recent formation of the inventories. In this connexion, however, some distinctions must be drawn in relation to the ways in which the inventories have been built up. The shortage of capital which is all too well-known a feature of such economies often means that, in decisions to purchase machinery, price carries more weight than quality, with the result that units are imported whose useful life will necessarily be very short.

This noteworthy fact, evidence of which has been found on various occasions, acquires still greater significance in countries possessing a domestic machine-tool industry which, while not very highly developed as regards the variety and quality of its products, is sizable in quantitative terms. Upon the extent to which such a process has taken place will depend the potential incidence of replacement at any given moment; it may attain appreciable proportions even in the case of relatively new inventories.

Thus, given the definition of replacement adopted here, not even a rough over-all estimate of machine-tool requirements for this purpose can be formulated unless data on age distribution are supplemented by an evaluation of the quality of the inventory and of the way in which it has been formed. Numbers are not enough in themselves; qualitative data must also be collected, to which end extremely useful information can be obtained from first-hand inspection of inventories from machine-tool distributors and from other sources.

Machine-tool inventories in Latin America, especially in Argentina and Brazil, showed no signs, at the date when the surveys were carried out, that replacement requirements were likely to be of much significance in the ten-year period selected for the study of demand. They contained, however, a large proportion of domestically manufactured machines whose standard of quality was not very high, especially in the under ten-years age group, which suggests that in these countries the incidence of replacement on demand may be heavier in the future. The estimates formulated in the case studies were highly tentative over all computations in respect to both the total number of machine tools and the composition of the inventory by types.

It was assumed that neither machines added to the base-year stock nor those that were less than ten years old in the base year would be replaced during the projection period or, in other words, that the machines over ten years old in the base year would constitute the group in which replacement requirements would be mainly concentrated. A further postulate was that 20 per cent of such machine tools would be replaced in the ten-year period under consideration which would be tantamount to assuming that the average age of the machines in this section of the inventory was about 25 years. In the case studies, replacement represented between 8 and 9 per cent of the total number of machine tools installed in the base year.

Data required and methods of obtainment

In the preparation of machine-tool studies on the lines described above, the supply of data available plays an important role. The degree of detail in which the conclusions deriving from the analysis can be presented, the evaluation of specific situations and the alternative methods of dealing with them that can be adopted, the accuracy of the findings, in short, the methodological process itself, are largely contingent upon the quantity, quality and level of aggregation of the data to hand. Furthermore, the time and resources expendable also exert a marked influence on the findings of the research and the method pursued, particularly if it is the first time that such studies have been undertaken in the country concerned. This was precisely the position in respect to the studies carried out by ECLA in Latin America.

Much of the information in question, as has already been pointed out, is not directly available in the developing countries, and a considerable amount of time and resources has to be spent on assembling it. The field is extensive, and action has to be taken in various directions, so that special attention must be devoted to this stage of the work.

It is particularly important, in this connexion, to establish beforehand what level of aggregation will be adequate for the purposes of the study, or will be feasible in view of local conditions, and to plan the collection of data on that basis: the more detailed the breakdown by activities and types of machines required for the final results, the lower the level of aggregation of the requisite data will have to be. It should be borne in mind that generally little headway can be made in this direction in developing countries, since in the first place the subdivision of activities is limited by the low degree of specialization, and the classification of enterprises at very low levels of aggregation is virtually impossible, while, in the second place, not many subdivisions by types and models of machinery can be established owing to the lack of diversification of the inventories, especially as regards highly specialized machine tools or those whose characteristics are suited to long manufacturing series.

Before embarking on this stage of the collection of data, it is useful to prepare a list of what will be required and adapt the investigation to the aims and objectives of the research. A mistake frequently made is to ask for excessively detailed information, on the supposition that the study will thereby be facilitated or that its findings will be more accurate. While this may be true of specific aspects of the analysis, it is not generally so for the work as a whole since, as has been shown, in many phases a number of assumptions and hypotheses have to be postulated which entail a higher level of aggregation.

To facilitate the listing of the information needed, the main items will be summed up briefly with some indication, where appropriate, of their importance and their repercussions in the various stages of the work. The data in question can be grouped in three major categories, according to whether they are required for the inventorying of the machine tools installed, for the determination of apparent consumption or for the projection of demand.

For inventorying the machine tools installed

Two surveys have to be made to determine the inventories of machine tools for production in the metal-transforming industries, and of machine tools used for maintenance operations in other activities. The information required is much the same in both cases and to save time and space the account given here will be related primarily to the former.

In order to prepare the sample and select the enterprises to be covered by the survey, the size of the universe must first be ascertained in terms of the number of establishments and the personnel employed in each activity and of the geographical distribution of the plants. This information generally can be obtained from industrial censuses or similar sources. However, it may not be sufficiently detailed as regards the subdivision of activities and the breakdown of establishments by plant size which, as has been shown, is an important factor.

In such circumstances, recourse must be taken to the actual source of the data and the original census or sample survey figures must be sought out so that the universe can be reconstructed at the desired level of aggregation. In addition, this procedure will provide a list of enterprises, with the location of each, from which the sample can be selected.

Two points are worth noting here, one bearing on the size of the plants covered by the survey and the other on the datedness of the figures, which may give rise, where expedient, to adjustments of two kinds. In some instances, statistical data may relate only to establishments above a given size (defined in terms of employment levels). This may, according to the size chosen, involve extra work for the purpose of incorporating the smaller plants in the sample, or making an adjustment at the time of extension to the universe, or may entail nothing other than the adaptation of the whole research to the limitations imposed by the basic statistics. Similarly, if the statistical data do not apply to the year of the survey, information on the universe will have to be brought up to date or the enterprises will have to be asked to supply the relevant figures in respect to the nearest year for which statistics are available, with due regard, of course, to the length of time that has elapsed and the significance of whatever changes may have taken place.

It must once again be stressed that the extension of the sample can only be effected at the level of aggregation for which data on the universe are to hand. If no census data are available for the year of the survey or for one close to it, it will not be possible to carry the breakdown beyond the three-digit ISIC group.

To ensure that the survey can be successfully and speedily completed, it is important to cut the inquiries to a minimum and to prepare the simplest possible questionnaire which will be easy to answer in the environment under study. In the ECLA case studies it was thought sufficient to confine the general question to the following items: (*a*) name and location of the enterprise; (*b*) number of actual working days in the year and average number of hours worked per day; (*c*) number of persons employed (operatives and employees); (*d*) annual sales; (*e*) main activity of the enterprise, and its incidence on sales; (*f*) secondary activities; (*g*) estimated percentage of production capacity utilized. Good results have been obtained with the breakdown of machine tools by types indicated in table 1. In the case of each of these types of machine, the number installed and their ages are ascertained. But for the sake of simplicity, since information on the age of the inventories is mainly for guidance, all that is requested in this connexion is an estimate of average age for each of the two major categories of machine tools (cutting machines and forming machines), with a breakdown by the following age groups: under 10 years old, 10 to 20 years old and over 20 years old. If such figures were requested for each individual machine tool it would make the questionnaires lengthy and the replies and their subsequent tabulation unduly complicated, while little would be gained towards the purpose for which the information was intended.

Table 1

BREAKDOWN OF MACHINE TOOLS BY TYPE

Group A: Metal-cutting machines	
Lathes	Broaching machines
Bench	Threading machines
Engine	Chip-production type
Copying	Forming type
Plateau	
Vertical	Gear-cutting machines
Turret (manual and semi-automatic)	Gear cutters
Other semi-automatic (i.e., multi-tool lathes)	Grinders, shavers, etc.
	Chamfering
Automatic (single multi-spindle)	
Other (spinning, oval-chuck and other specials)	Sawing machines
	Hack-saws
Milling machines	Bandsaws
Universal	Circular
Vertical	Grinding machines
Others	Universal cylindrical
Pantographs	Surface grinding
Drilling machines	Centreless
Bench	Others (internal, contour grinders, thread grinders, etc.)
Pillar	
Radial	
Multi-spindle	Tool-grinding machines
Boring machines	Universal
Universal by co-ordinates	Special
Jig	Honing and lapping machines
Production	Honing
Planers, shapers and slotting machines	Lapping
Shapers	Special multi-station machines
Planers	Machining units, transfer machines, etc.
Milling and planing	
Others (slotters, etc.)	
Group B: Metal-forming machines	
Presses	Machines for sheet
Hydraulic	Shears, hand drive
Eccentric	Shears, power drive
Friction	Folding, hand drive
Others	Folding, power drive (including press brakes)
Forging presses	Bending rolls, hand drive
Upsetters (hot and cold)	Bending rolls, power drive
Others	Others
Forging hammers	
Mechanical	
Steam or air:	
free forging	
die forging	

The survey itself can be conducted either by mail or by direct interviewing; the relevant decision will have to be taken in individual cases in the light of such considerations as the volume of the sample, the resources available and so forth. It need only be pointed out here that in developing countries direct interviewing has obvious advantages over sending the questionnaires by post, although the latter procedure is less burdensome. The following are the main arguments in favour of the former method: the certainty of obtaining replies is greater, especially where small- and medium-sized establishments are concerned; there is a better chance that information will be given correctly; the homogeneity of the replies is safeguarded as errors deriving from wrong classification of the machines, or from terminological or conceptual causes will be minimized; and, lastly, the inventories can be inspected and evaluated at first hand.

For the determination of apparent consumption

As already explained, apparent consumption data are not of fundamental importance for demand projections and serve mainly as a supplementary guide to the elucidation of certain aspects of the research relating particularly to the qualitative evaluation of the machine tools installed, to replacement requirements and to the possible structure and characteristics of future demand. Information on imports, domestic production and exports during a given number of years is therefore needed. Statistics of this kind are seldom directly available and field work must be done.

For import and export figures, it is often necessary to have direct recourse to customs records, and even to carry investigation to the extreme of going through the bills of lading in order to obtain the data at the requisite level of aggregation, severely handicapping the preparation of a long apparent consumption series. If this information is to be of use for the purposes mentioned, the data should be collected as far as possible in terms of units, weight and value; accessories and tool kits should be excluded; and the machine tools should be classified in accordance with the breakdown adopted for the inventory.

With regard to domestic production, the survey that has to be carried out is usually on a scale small enough for all the existing establishments to be covered. Moreover, this is desirable when the research is extended to future development prospects. The same data should be asked as in the case of imports and in that of the actual breakdown of the machine inventory.

Clearly, the analysis of apparent consumption must relate to the total number of machine tools consumed, whether they are for production or for maintenance, as it is very difficult to ascertain the final use to which either domestic production or imports are to be put. The inferences to be drawn will concern chiefly the average weight and the price per kilogramme of the machine tools that have fed the inventory, the respective percentage contributions of domestic production and imports, and trends in the composition of consumption by types of machine. The possibility of deducing more or less final conclusions from these relationships will depend upon how long a time series can be constructed and on how evenly consumption is distributed throughout the period. In any event, the effort is worth making for the sake of the guidance such information can provide.

For the projection of demand

A country's machine-tool requirements are closely linked to its economic development process in general and, in particular, to the evolution of its metal-transforming industries. In this connexion, all available information must be procured on the growth prospects of the gross domestic product, the manufacturing sector and the metal-transforming industries in the period under study. It is also important to collect data on the establishment of new metal-transforming activities which may affect the composition and characteristics of demand for machine tools as, for instance, the motor vehicle industry, shipbuilding, manufacture of machinery, etc. Information of this type can often be obtained directly from national development programmes and from planning agencies, which obviates the need to spend much time on research. Otherwise, this task too will have to be tackled, but a detailed account of it would be out of place here.

Of great importance for this stage of the study is the information derived from the preceding phases, i.e., from the determination of the inventory and of apparent consumption. Equally useful are any data that may be available on what has happened in other countries, provided they can be satisfactorily interpreted.

Various studies carried out in other regions and touching upon the problem of estimating future machine-tool requirements have noted other methods of criteria applied for this purpose, two of which are worth special mention. One is based on the ratio between the value of the machines purchased and that of the products manufactured by the metal-transforming sector, and the other on the relation between the machine-tool inventory and steel consumption. For various reasons, it was impossible to apply these criteria in the Latin American case studies for the projection of demand itself, but they were considered of interest as a means of cross-checking, although not in very conclusive terms, the order of magnitude of the final figures.

RESEARCH UNDERTAKEN IN CONNEXION WITH MACHINE-TOOL STUDIES

A preliminary review of the data collected in Latin American countries where specific studies on machine tools or on the metal-transforming industries in general have already been carried out revealed a measure of uniformity in the evolution of certain coefficients. This suggested the possibility of establishing a set of these proportional relations such that, while making no claim to take the place of an inventory, it might provide a basis for appraising a given situation rapidly and with some degree of accuracy, and even afford background material for machine-tool studies.

To this end, a start was made on systematic analysis of the data with a view to defining, in an initial phase, the general behaviour pattern of the coefficients in question, the factors that may modify them and the effect of these on their magnitude, so as to be able to demarcate the margin of variation to which they were likely to be subject and determine the conditions in which they could be reasonably safely applied. To begin with, research was concentrated on two factors, one relating to the coefficient of machine tools per worker and the other to the composition of the inventories by types of machine.

As regards the former, it is a common practice in studies carried out in the industrialized countries to adopt a fixed ratio between the number of machines installed and the number of workers employed, i.e., around 50 machines per 100 workers. Since not enough data are available for the possibility of applying this figure indiscriminately in the developing countries to be evaluated, it was considered worth while to undertake preliminary research on the subject. The second factor, so far as is known, has not been the object of special analysis.

The metal-transforming industry as defined in the present study, covering four of the ISIC major groups, is an immense body of activities whose production characteristics are heterogeneous in the extreme. Moreover, its structure differs from one country to another and is liable to change as the development process makes headway, particularly in the developing countries. Thus it seems hardly likely that coefficients or ratios could be established for the metal-transforming industries as a whole which at the same time would be applicable throughout the region. Accordingly, the analysis was begun at the lowest level of aggregation consistent with the available data, i.e., that of the four major groups, with the idea that this would permit of greater flexibility in the application of the coefficients, since the over-all position would be calculated by weighting the sum of the results for each group.

The first steps in the analysis were directed towards determining the behaviour of the coefficients of machine tools per worker and of the composition of the inventories in relation to plant size. It was demonstrated that the magnitude of the former was very closely linked to the latter variable and that, at the same time, the behaviour pattern was different in each of the major groups. By comparison of the findings of the country studies, the extent to which this divergence was attributable to factors other than plant size was also assessed.

If anything like final conclusions are to be reached in an analysis of this kind, it is necessary to handle and have access to much data. Those so far assembled are not sufficient to provide a basis for specific findings, but they do give a fairly clear idea of the behaviour pattern of the coefficients in question.

For illustrative purposes, figure 1 shows how the coefficient of machine tools per person varies in relation to plant size. The curves thus plotted for the four groups are all hyperbolic, only the magnitudes altering, and the variations are as indicated in the figure.

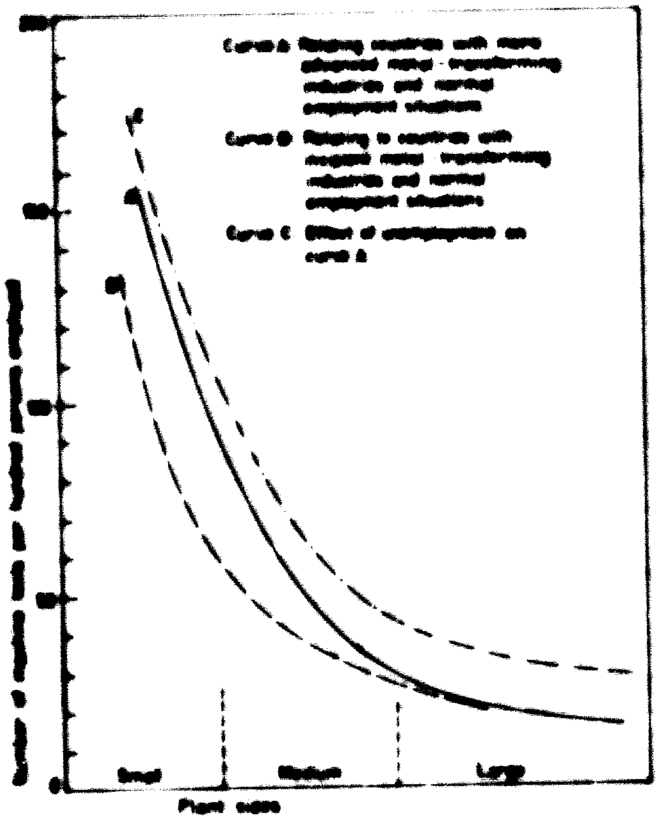

Figure 1

RELATION BETWEEN NUMBER OF MACHINE TOOLS PER HUNDRED PERSONS EMPLOYED AND PLANT SIZE

In the first place, an important determinant of the changes in the magnitude of this coefficient, irrespective of all other considerations, is the level of employment in the industry. Where unemployment is rife, the number of machines per hundred workers is of course larger, but the shifted curve, instead of remaining parallel to that plotted for a normal employment situation, indicates relatively higher figures for the bigger establishments than for plants of small or medium size. This discrepancy can be noted between curves A and C in the figure; the explanation probably lies in the fact that as a general rule the effect of unemployment is proportionally more significant in large than in small establishments. Thus, in dealing with the coefficient under discussion, it is important to bear the influence of this factor in mind and, in the case of comparative studies, relate it to normal employment conditions.

Furthermore, the coefficient of machines per hundred workers alters from one country to another in accordance with the stages of development reached by the metal-transforming industries concerned; it is lower where they are in the initial phases of development and higher where they are more advanced. Curves A and B in figure 1 represent the variations in this coefficient as between countries at different levels of development or, in other words, where metal-transforming industries differ in size. Curve A relates to countries with a total machine-tool inventory of more than 100,000 units, and curve B to those whose inventory is less than 30,000 machines. It is worth noting that in both cases similar curves result, from which a curve representing the average position can be safely derived. This suggests that it might be possible to plot a set of curves representing different levels of development and thereby enormously reduce the field of variation of the coefficient, especially in respect of small- and medium-sized enterprises, where the greatest discrepancies occur.

From a comparison of curves A and B it can be seen that the effect of different stages of development on the size of the coefficient is marked in the case of medium- and small-scale enterprises, but not in very large or very small plants where the coefficients draw close to one another. For all practical purposes, the problem reduces itself to defining the position in respect to plants employing from 10 to 300 workers, which is precisely the range within which most metal-transforming establishments in developing countries fall.

The explanations that can be adduced to account for the greater influence exerted by the stage of development in small- and medium-sized enterprises are many and varied. Two, however, deserve special mention. In countries where the metal-transforming industry is of limited dimensions and in the early stages of development, a high proportion of the small- and medium-scale enterprises concentrate their attention on maintenance services or assembly work, or the manufacture of a few simple products, all of which activities are characterized by low ratios between the machines and the number of workers, so that the plants in question naturally show very low coefficients of machine tools per hundred workers. In somewhat more advanced countries, on the other hand, where the industry is on a larger scale, such enterprises also play an important productive role, either as direct suppliers of the market or by providing inter-machine products for the larger firms, and this is of course reflected in a higher coefficient of machines per hundred persons.

Secondly, it is important to note that in the latter group of countries the domestic machine-tool industry is beginning to play a more outstanding part in the satisfaction of internal consumer demand, especially with respect to simple and not very high-quality machines. This more plentiful supply of precisely those machines which are in most demand in small and medium establishments naturally helps to explain why such enterprises are better equipped in the larger countries than in those with narrower markets, where domestic production is negligible or non-existent.

The asymptotic nature of the curves as manifested in the very slight variations in the coefficients of machines per hundred workers in the case of large enterprises may account for the fact that in the industrialized countries it is possible to adopt a fixed coefficient, as was pointed out above, without incurring the risk of any significant error, since in the countries in question the proportion of big establishments is higher than in developing countries. The *a priori* inference is that the coefficient commonly used in the industrialized countries is unlikely to be applicable in countries in process of development.

Nevertheless, the behaviour of these curves in the industrialized countries would need to be investigated a little further in this connexion. Such research would shed useful light not only on this aspect of the problem, but also on the behaviour pattern of this coefficient and its magnitude at stages of development that the Latin American countries have not yet reached but towards which they will be heading in the future.

The composition of the inventories by types of machine tools, which is the other proportional relationship studied, is likewise largely conditional upon plant size, while here too the effect of the stages of development reached by the different countries is discernible. Figures 2 and 3 give an outline indication of the trends that it has been possible to trace so far. As in the case of the coefficient of machines per hundred workers, a more specific pronouncement will be possible only when more data have been analysed. Here, the variations depending on plant size tend to follow a straight curve, and the incidence of the stage of development is revealed by the slope of the curve. Moreover, considerable differences are observable from one group to another.

The effect of plant size on the relative importance of the various types of machines in the composition of the inventories can clearly be seen in these figures. For the

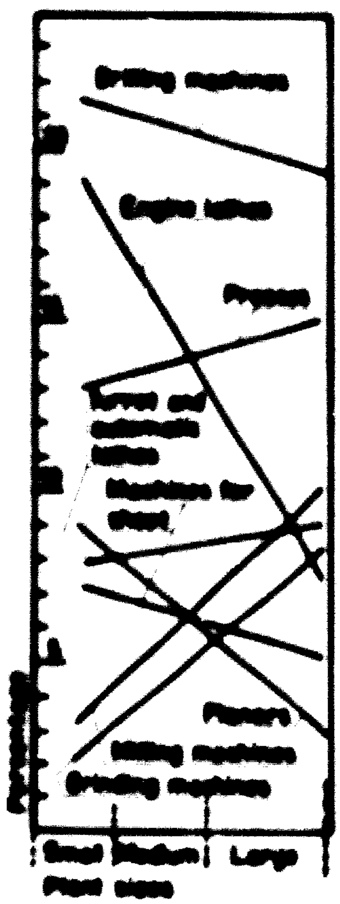

Figure 2

VARIATIONS IN COMPOSITION OF INVENTORIES BY TYPES OF MACHINES IN RELATION TO PLANT SIZES

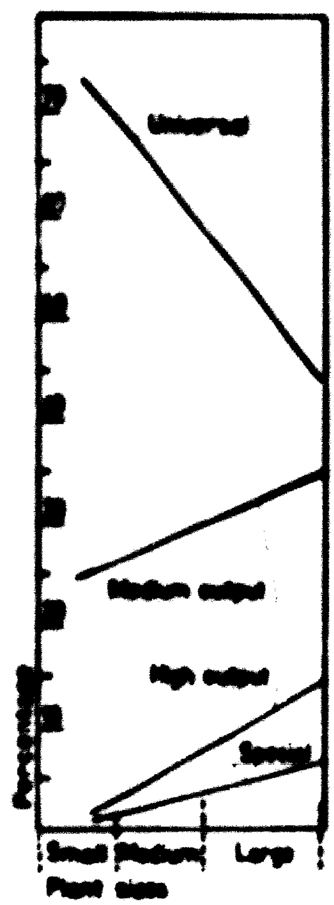

Figure 3

PROPORTIONS OF INVENTORIES REPRESENTED BY UNIVERSAL, MEDIUM AND HIGH OUTPUT AND SPECIAL MACHINES IN RELATION TO PLANT SIZES sake of simplicity, only those machines that represent major proportions of the inventories are shown in figure 2. Particularly sensitive to plant size, and inversely proportional to it, are the shares corresponding to engine lathes, planers, drills and machines for sheet (shears, folding machines, bending rolls, etc.).

The relative importance of all the other machine tools in the composition of the inventories increases with the size of the plants. This is a logical and unremarkable phenomenon in itself, but some interest attaches to the regularity of the variations. The same may be noted in figure 3, where the machine tools are classified by their characteristics (universal, medium- and high-output, and special).

Although the findings of the research on these proportional relationships are not yet concrete enough for their practical applicability to be guaranteed, it was thought worth while to give some idea, in this brief paper, of the work that is being done in this field and the conclusions reached, so that they may at least afford some general guidance for any studies that may be carried out in other regions.

ESTIMATION OF MANAGERIAL AND TECHNICAL PERSONNEL REQUIREMENTS IN METAL-PROCESSING INDUSTRIES

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TERMINOLOGY

Manpower

In order to avoid confusion and possible misinterpretations, certain terms as used in this report will mean:

A "manager" exercises authority and provides leadership in a working situation. He must plan the activities of his organization (which may be a division of a larger enterprise), setting goals and objectives. He must organize the enterprise so as to attain these objectives and must lead, direct and motivate his subordinates toward accomplishing the goals. He must exercise control over their activities to assure that objectives are met on time and within predetermined limits of cost, quality, etc.

For convenience and clarity here, the over-all group of managerial personnel has been divided into two subgroups: managers and foremen.

A "foreman" directly supervises a group of manual workers in the performance of productive or service work. He is concerned with applying procedures, methods and techniques developed by others and for seeing that his men maintain quality and quantity production standards. His job is at the first level in the managerial hierarchy. Also in this subgroup are supervisors, one step above the lowest level, whose principal responsibility is to oversee the work of two or more first-line foremen but who, nevertheless, are primarily responsible for direct production operations.

All personnel above the foremen are classified as managers, on the assumption that they are concerned with procedures, policies and the ultimate goals of the enterprise. The extent of this latter responsibility tends to vary, depending on the size of the concern. The smaller the company, the more heterogeneous will be the responsibilities of lower level managers and the more diverse the abilities they must possess.

The title "engineer" refers to a graduate of a college or university who has earned a degree in applied technology; in industry, he is primarily concerned with design and development. He may be assisted by others designated as "technicians". The latter have less formal education in technological work and are not fully qualified to carry out design and development work independently. They assist and work under the direction and supervision of engineers.

Functions

The term "organizing" generally includes managerial decisions and reviews involved with the structural design of the relationships and responsibilities among functional, personal, financial and physical factors required to accomplish the established policy.

It is beyond the scope of this paper to deal with decisions as to physical and financial considerations[1] or, for that matter, to consider at length other than managerial and technical people. In these areas, however, every enterprise must be so organized that maximum effectiveness will be imparted to the effort to achieve a firm's objectives. Competent managerial and technical manpower is scarce enough in every country that it must be husbanded in quantity, improved in quality and replenished as fully and rapidly as possible.

The words "line", "staff" and "service", when applied to functions within an organization, refer to day-to-day relationships. The line jobs are those which are directly associated with the production of goods and services, while the other two assist and contribute to line efficiency.

Staff personnel are specialists in various fields who advise on how to produce goods and services, how many units to produce, at what cost, with what materials, etc. They do not issue orders.

Service activities are those which provide light, power, water, housekeeping, maintenance, etc., without which the production activities of the line would be seriously hampered, if not completely halted.

"Responsibility" may be defined as an individual's obligation to perform his duties in accordance with established practices and instructions as received. The responsibilities assigned to lower level managers and supervisors generally consist of fairly homogeneous functions but, as the organizational level rises, heterogeneity increases.

"Authority" is the power to decide what should be done and how to do it, as well as to issue orders for their execution. A manager, at any organizational level, must be delegated sufficient authority by his superiors to discharge the responsibilities which have been assigned to him. If responsibility for making appropriate decisions has been delegated as far down in the organization as possible, the authority must be concurrent; to do less would automatically prevent subordinate managers from making decisions and a vast number of trivial problems

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[1] A study by the United Nations in 1963 describes the analysis of engineering and financial problems in connexion with the establishment of factories for various types of equipment for making producers' goods. See *The Manufacture of Industrial Machinery and Equipment in Latin America: I. Basic Equipment in Brazil*, 1963. United Nations publication, Sales No.: 63. II. G.2

(which lower level supervisors could handle) would be referred to the top of the organization for resolution. Whenever this has occurred, it has always and inevitably overloaded top management and caused intolerable delays in attaining organizational objectives.

"Accountability" means that no manager or supervisor can shirk the consequences of the decisions and actions of his subordinates. Even though he has delegated his own responsibilities far down in the organization he is, nevertheless, held to account for the way in which those responsibilities were discharged. Ultimately, the chief executive of the enterprise is accountable for everything which goes on in the ranks, just as each intermediate level manager is accountable for his own segment of the operation.

"Delegation" of responsibility and authority places the making and execution of decisions at the lowest organizational level at which personnel are competent to so act. It enables those who are closest to an operation to handle problems quickly and simply. Furthermore, every decision made at a lower level relieves higher echelon managers of details and allows them to concentrate on broader and more important problems. It should be borne in mind, however, that delegation of responsibility and authority presupposes competence in subordinates and does not relieve the superior of accountability for the acts of everyone under this jurisdiction.

Metalworking plants and their products

A number of countries have found that industrial enterprises engaged in relatively uncomplicated operations are the most likely to succeed. On the other hand, highly sophisticated products with a large engineering and technological component have, in several instances, imposed an insupportable strain on managerial and technical manpower resources. Also, the plants making this type of products have not done well financially because of limited markets, both domestic and foreign.

The pattern which has proven most satisfactory is the establishment of maintenance job shops to repair and produce simple replacement parts for rail and highway transportation equipment, agricultural and mining machinery and similar devices. From these operations have grown plants making builders' hardware, home utensils, heating systems and other products for local consumption. All these products are usually characterized by light metal-transforming operations with a large labour content. Fairly inexpensive raw materials go into them and, even though such materials must often be imported, the use of local labour in fabrication tends to reduce the required amount of foreign exchange to appreciably below that which would be needed to purchase the finished goods abroad. Additionally, local manufacture provides industrial experience for local labour and, perhaps even more important, managerial experience for local entrepreneurs. A considerable time may elapse before it becomes necessary or desirable to embark on the more complex activities of heavy industry. Managerial and technical problems, as well as the lack of need for more sophisticated products, are limiting factors.

Manpower utilization

Whether the initial metalworking activities in a developing nation operate under state ownership or private auspices or function in both sectors, it is essential that they be so organized as to make maximum use of the country's existing and potential resources in managerial and technical manpower. This can be done effectively only if two conditions are met:

(*a*) Manpower requirements must be known with a fair degree of accuracy;[2]

(*b*) an inventory of available manpower resources must be at hand.

The first of these prerequisites can be satisfied through careful advance planning and organization of enterprises in this area of activity. The second prerequisite depends for its solution on the degree to which responsible authorities, in the nation, the industry and the enterprise, have catalogued the qualifications and availability of actual and potential managerial and technical personnel.

Managerial and technical manpower allocation

Before specialized manpower can be allocated, requirements for it must be determined and it must be identified and inventoried. Requirements can be ascertained through well-considered organizational studies. Analysis of the characteristics of jobs at various levels should be the first step.[3] The associated "man-descriptions" indicate the physical, educational and experiential qualifications required of the incumbents (a range in some of these qualifications usually extends from absolute minima to those which are desirable but not essential).

The next step involves a determination of the number of each type of job to be filled.[4] These figures depend on the number and size of the metalworking plants which it is desired to establish. The third step is, perhaps, the most uncertain of all: cataloguing available manpower. Ideally, every person who has immediate or potential ability in managing an activity or in making significant technological contributions to its success should be listed in a central file and be available for assignment when, where and as needed.

Sharing manpower in an industrial park

In view of the critical shortage of competent and qualified manpower in almost all countries, it is essential that the available supply be used to the maximum. One way is to develop a plan for sharing managers, engineers and staff people among industrial users. Obviously, the

[2] See Debeauvais, Michel, "Manpower Planning in Developing Countries", *International Labour Review*, vol. LXXXIX, No. 4, April 1964, pp. [illegible]. Also, Paukert, F., "The Interdependence of High-Level Manpower Planning and Economic Planning", *International Labour Review*, vol. LXXXIX, No. 4, April 1964, pp. [illegible].

[3] A section on job descriptions is included towards the end of this report. See also *International Standard Classification of Occupations* (International Labour Office, Geneva, 1958).

[4] For the experience of one country in estimating requirements see [illegible], "The Future Manpower Situation in India", *International Labour Review*, vol. LXXXVII, No. 5, May 1963, pp. [illegible].

particular enterprises cannot be engaged in competition, but it should not be difficult to avoid conflicts of interest by grouping non-competitive organizations.[5] Unless operating units are large, specialized managerial and staff personnel could be shared; the primary consideration is to strip every managerial and engineering job of all activities which are not essential or which can be delegated to subordinates, staff assistants or clerks. This will leave only those decisions and activities which genuinely require the attention of a trained and experienced manager or engineer and the person discharging the responsibilities of the job will be free to devote all his time and energy to it.

The concept of the industrial park, or industrial estate, has been widely adopted in a number of countries.[6] It permits manufacturing enterprises, both large and small, to utilize jointly the specialized buildings, utility services and maintenance facilities of the complex, thereby giving each much more efficient and satisfactory services than they could afford on an individual basis. There is no reason why essential but scarce managerial talent could not also be provided on a shared or consulting basis. This practice would be most satisfactory if the plants in which the manager worked were physically adjacent, but such proximity is not absolutely essential. The matter which is essential is that no problems be referred to the manager which can possibly be solved at a lower level.

The provision of staff advice and service functions to a number of enterprises can also be carried out ideally in an industrial park or estate. Engineering and design activities are minimal in many metalworking enterprises, especially those doing job-shop maintenance work or manufacturing relatively simple products. These, like other staff and service activities, can be provided quite satisfactorily to a number of enterprises in the park, reducing costs to the individual concerns, enhancing quality and, above all, conserving scarce technical manpower resources.

The industrial park concept can facilitate the development of prototype industries under the aegis of established enterprises. Production difficulties and managerial problems can usually be smoothed out during the early experimental operations in the prototype shop of the park. Machinery can be shared if neither shop requires it full time. And, when the time is ripe and facilities are available, the offshoot plant can move out of the prototype shop and become a distinct operation.

MANPOWER ALLOCATION IN DEVELOPED COUNTRIES

In Canada, the United Kingdom, the United States and other industrialized countries, the allocation of managerial and technical manpower is on a voluntary basis. In practice, in a highly industrialized country where private enterprise predominates, a catalogue such as that mentioned earlier in this paper is extremely difficult to compile and almost impossible to keep up to date. The United States attempted to do this some years ago and dropped the idea as a failure shortly afterward. At present, about the only satisfactory rosters of managerial and technical manpower are maintained by individual companies for their own employees. The great advantage of such a catalogue to an enterprise is that gaps in the manpower pool show up clearly and steps can be taken to remedy the deficiencies through hiring, training and development before the need becomes acute. The same might be said for a national roster of qualified personnel if it could be kept current and accurate.

Companies in need of managerial and technical people who cannot be found within the ranks of present employees recruit through various channels. Or, they may select promising individuals from the ranks for special, intensive training. In any case, the acceptance of an appointment is at the option of the individual; in all but the most serious of national emergencies, no pressure is exerted. There are, however, certain limiting factors on the assignment of manpower which affect the staffing of enterprises.

Span of control

In organizing and staffing an industrial operation, it must be recognized that the span of control limits the number of people any supervisor can oversee and direct effectively. The size of this group of subordinates varies with a number of factors, such as geographical distribution; homogeneity, type and complexity of work; and ability of both the supervisor and the supervised. Experience has shown that, in some metalworking enterprises, competent operatives using similar machines and working in close proximity to each other can be directed effectively in groups as large as thirty.[7] This presupposes, of course, that the supervisor is both a competent craftsman in the fields he directs and is familiar, also, with the managerial duties associated with his job. If these conditions, competence, proximity and homogeneity of function, are not met, the number of operators per supervisor must be decreased or inefficiency must be accepted as the price.

In the case of executives, who are responsible for directing several dissimilar functions, the supportable span of control is much less, generally between four and seven subordinate managers. When the number of subordinates or dissimilarity of functions decreases the efficiency of a manager, it becomes desirable to relieve him of a part of the load. This may be done either by subdividing his job into two or more major units, each under the direction of a subordinate manager, or by providing him with staff assistants to advise him on the problems he encounters. In most cases, the executives of metalworking companies have preferred the first alternative, as the provision of staff advisors does not narrow the span of control exercised by the manager; rather, it tends to expand it by adding still more sub-

[5] For an example of this type of sharing, see "The Tenney Company", *Forbes*, vol. 97, No. 4, 15 February 1966, p. 27.

[6] See Percival [illegible], "Industrial Estates in Wales", *International Labour Review*, vol. XC, No. 2, August 1964, pp. 130-140.

[7] A 1965 study showed that in 404 plants in the United States the small units (under 250 employees) averaged 16.7 production employees per foreman and 9 maintenance workers per foreman. In large plants (1,000 or more employees), these figures were 22 and 12, respectively. The over-all averages for the entire group of plants were 20 and 11.3. See "Manpower Ratios in Manufacturing", *Factory*, vol. 123, No. 3, March 1965, pp. 84-91.

ordinates. The principal disadvantage of increasing the number of supervisory levels is that communications from top to bottom and vice versa become more difficult and uncertain as the messages must pass through more people. Adding an intermediate managerial level, however, may not be easy, unless competent personnel are available.

In United States metalworking plants, the range of span of control has resulted in two extremes in the shape of the organization chart. One type has narrow spans of control and many operating levels (figure 1). At the other extreme, where conditions and the qualifications of personnel permit (or where short supplies of manpower require), there is a much wider span of control and fewer levels in the managerial hierarchy (figure 2). It should be emphasized that local conditions within any given company or area will dictate the exact shape of an enterprise's organization chart and that the types of organizational structures shown in figures 1 and 2 could exist in companies of the same size.

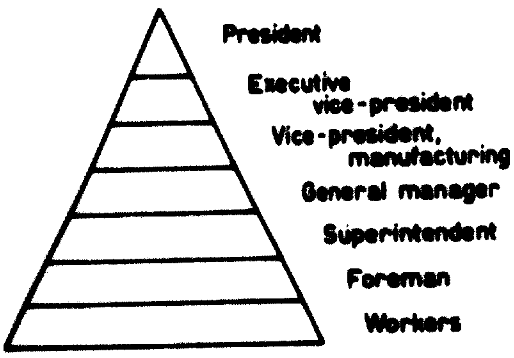


Figure 1

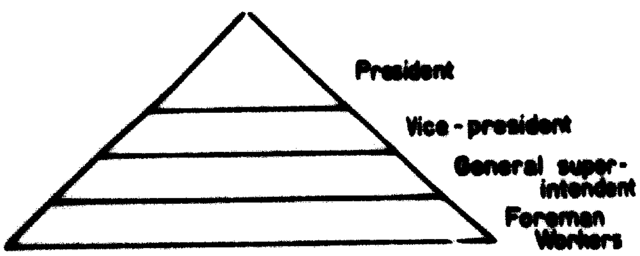


Figure 2

Staffing: averages

Studies on the allocation of managerial and technical manpower in various industries suggest patterns based on type of product and size of operation. These studies covered a considerable number of plants and it must be borne in mind that differences in the details of manpower allocation would make direct, literal translation of average figures to a specific situation somewhat hazardous. Nevertheless, they may be used as a guide to conditions in the United States.

Two tables illustrate the influence which product sophistication and size of enterprise exert on organizational structure. In table 1, it will be noted that the more complex the product (rising from primary metals to instruments and controls) the higher the ratio of indirect and specialized personnel, including a dramatic rise in engineers and staff specialists. Conversely, the downward trend on the percentage of direct, producing operators is steady and sharp.

Table 2 illustrates the fact that the ratio of management to workers decreases as the size of the operation increases: every enterprise, regardless of size, has but one chief executive and his subordinate managers tend to become somewhat more efficient as their jobs become more specialized. Also, as size increases, it becomes feasible to add engineers and staff specialists to replace the jacks-of-trades in the small plants.

Table 1

PERCENTAGE OF TOTAL FORCE IN EACH CATEGORY

	404 plants	*Primary metals 45 plants*	*Machinery-general 199 plants*	*Instruments and controls 18 plants*
Executives, managers and department heads	3.0	2.8	3.2	3.8
Foremen and first line supervisors ..	5.6	5.7	5.4	5.5
Engineers and staff specialists	6.2	3.0	7.2	11.0
Clerical workers....	3.7	3.2	4.1	6.5
Manual workers (operators)	81.5	85.3	80.1	73.2
Total	100.0	100.0	100.0	100.0

Table 2

PERCENTAGE OF TOTAL FORCE IN EACH CATEGORY

	404 plants	*116 small plants (100 to 249 workers)*	*209 medium plants (250 to 999)*	*79 large plants (1,000 or more)*
Executives, managers and department heads	3.0	6.3	3.3	2.2
Foremen and first line supervisors	5.6	6.4	5.6	5.0
Engineers and staff specialists	6.2	4.1	6.9	6.5
Clerical workers....	3.7	3.3	3.9	3.3
Manual workers (operators)	81.5	79.9	80.3	83.0
Total	100.0	100.0	100.0	100.0

Staffing: individual companies

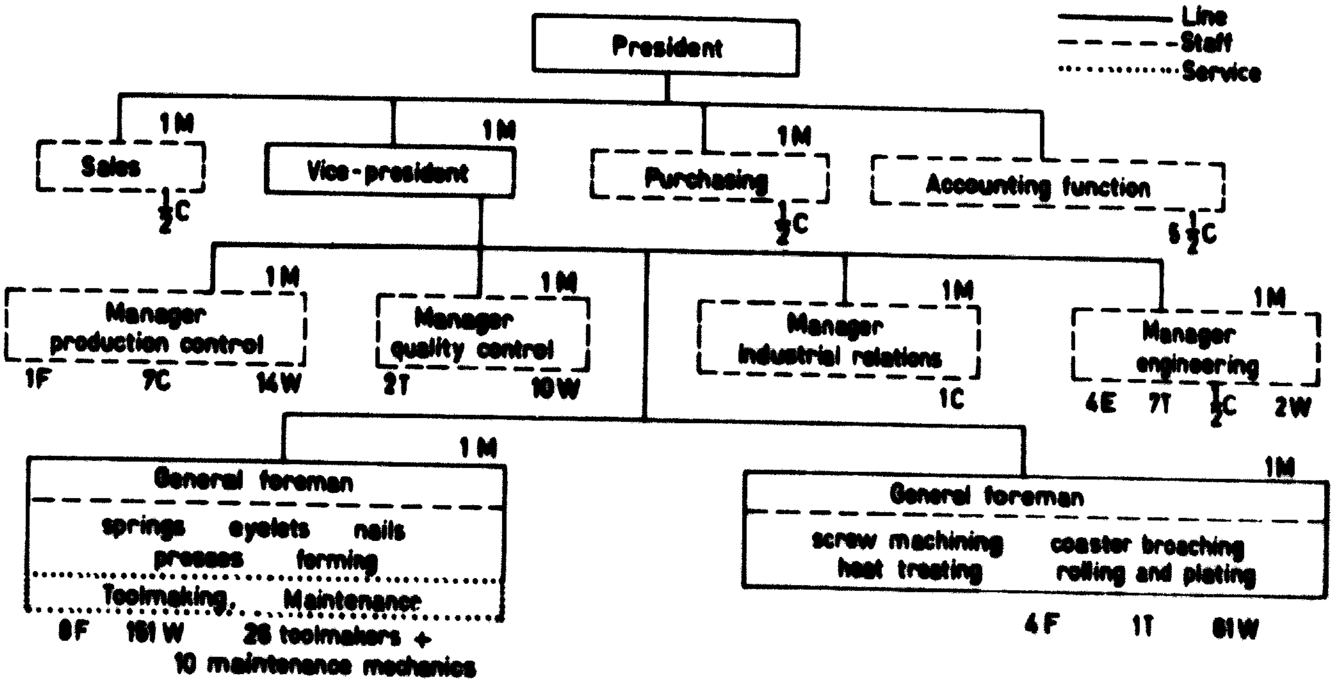
Following are several examples of staffing in United States plants engaged in a variety of industrial operations and covering different aspects of the metalworking trades.[8] These concerns illustrate, in their organizational structures, some of the points just made.

[8] The organizations have not been identified by name, as their executives requested anonymity. The same policy of anonymity has been extended to the organization charts of metalworking enterprises in other countries subsequent in this report.

(a) Job-shop manufacture of small metal parts

Figure 3 shows the organization of a company with fewer than 300 employees. It manufactures a vast array of small metal parts (approximately 1,500 separate items) for other companies. A few of the products might qualify as components because they are assembled from two or more pieces, but most are single bits of metal formed from sheet, strip, tube or wire stock. The concern makes one semi-consumer item, coaster brakes (750,000 parts a year) for bicycles, which can be identified as its product, although this, too, ends up as part of a larger unit.

The orders, as received, are for lots of widely varying



Totals

Managers	10	3·4%
Engineers	4	1·3%
Technicians	10	3·4%
Foremen	13	4·6%
Clerks	15	5·1%
Manual workers	238	82·2%
	290	100·0%

Figure 3

sizes. On some items, the shop can set up for almost continuous machine runs of 40 to 50 million pieces. On others, the quantities are far smaller, scaling down to 100,000. On a very few items, the company will accept orders for as few as 15 or 20 units.

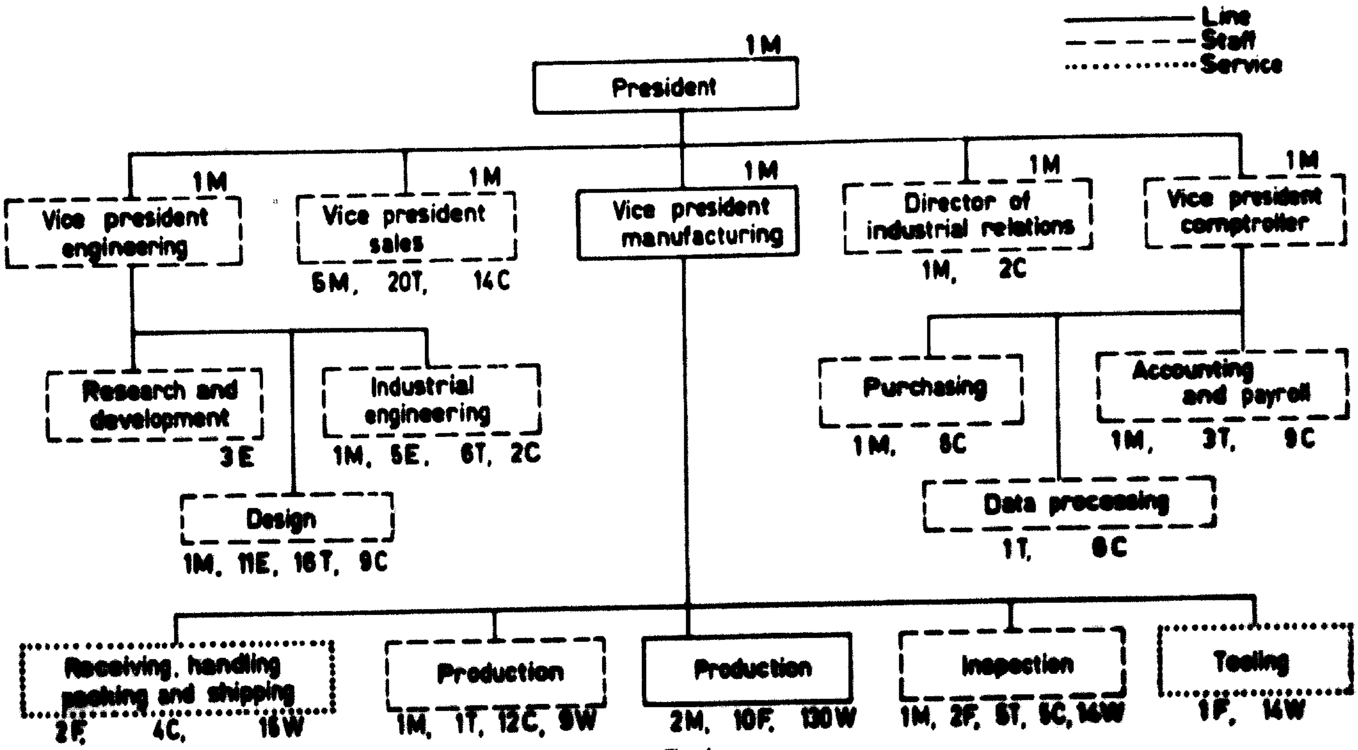
The annual value of products is in the neighbourhood of $3–$3.5 million. The value added by manufacture is high, as the concern uses only about 1,500 tons of steel stock a year.

The customer specifies tolerances and quality standards to which the company must conform. The customer also supplies the designs and specifications of the pieces in the order. This relieves management of the necessity for maintaining a sizeable force of design engineers but puts a premium on the ability to devise better and more efficient ways and means of manufacturing. Hence, the technical staff is concerned primarily with methods engineering. The president and vice-president of the concern are both graduate engineers who have had long experience in the management of metalworking operations in other plants. The general foremen and first-line supervisors are long-term employees and in most cases, were journeymen mechanics before promotion. The ratio of workers to supervisors in production (18.5 to 1) is supportable because the work force is both competent and concentrated. There are ten maintenance mechanics to one foreman in this phase.

(b) Manufacture of complex products

In figure 4, in contrast to the job-shop just described, the organization is slightly larger. It manufactures a line of highly sophisticated small valves and precision control devices, worth about $200 each. These products have an abnormally high engineering and design content. They have been developed to meet what the company has found to be the up-coming needs of other industrial concerns. New items in the product line are designed and prototypes are tested under exacting and rigorous service conditions before they are offered to customers on the basis that they will do the job better than anything available. The result is a minimum of customer specifications. The company produces 35,000–40,000 units a year.

The company's engineering and technical force comprises about 20 per cent of employees, the manual workers, most of them skilled, are just over 50 per cent and the ratio of production workers to foremen is 12 to 1



Totals

Managers	20	=	5·6%
Engineers	19	=	5·3%
Technicians	52	=	14·6%
Foremen	15	=	4·2%
Clerks	69	=	19·0%
Manual workers	182	=	51·3%
	357	=	100·0%

Figure 4

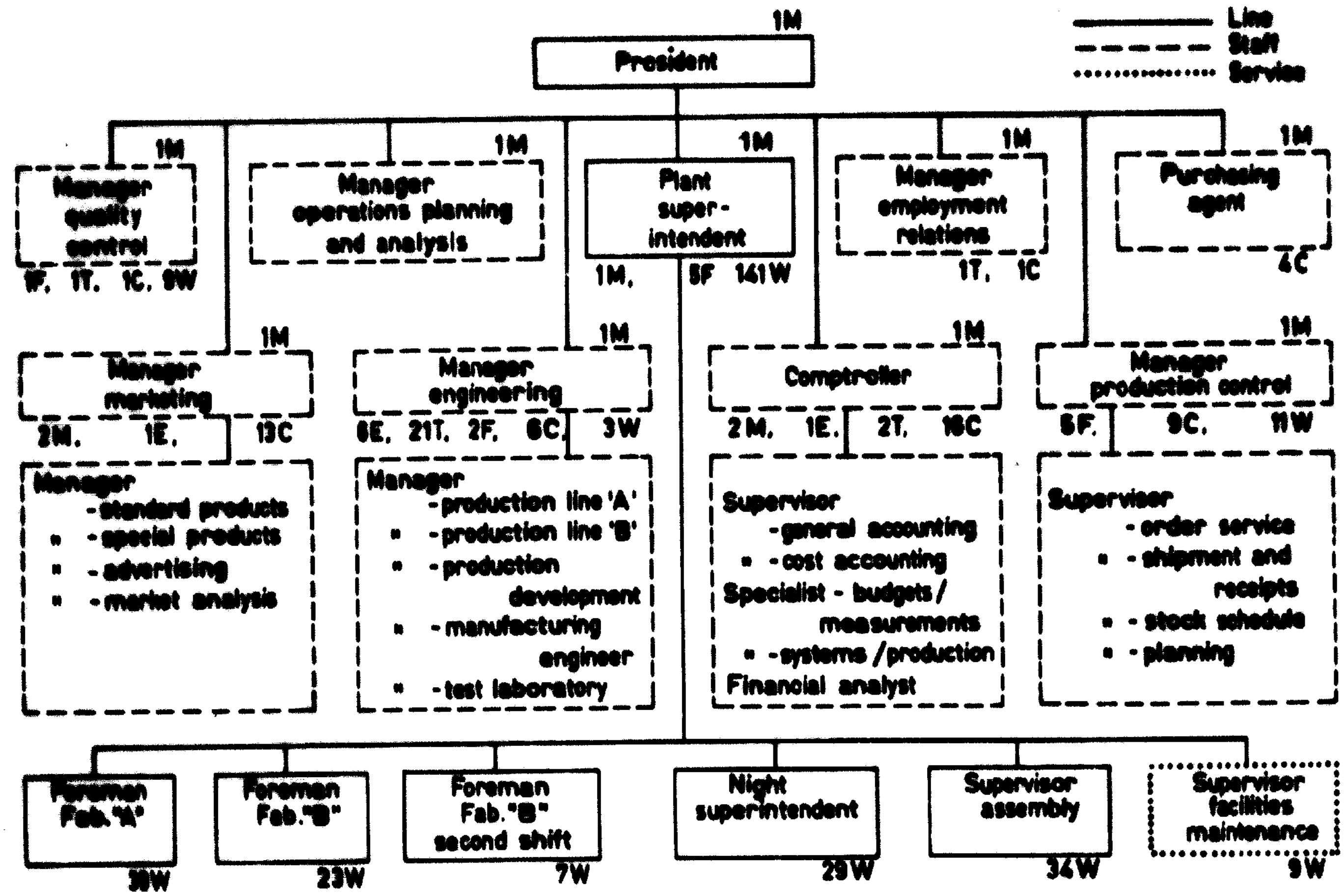


Figure 5

All these data are sharply different from the corresponding items in figure 3. Management personnel are skilled specialists, as are the engineers. This company is typical of those in the United States which cater to other manufacturers' needs for highly sophisticated, precision components to incorporate in their own products and which they find it more economical to buy than to make for themselves.

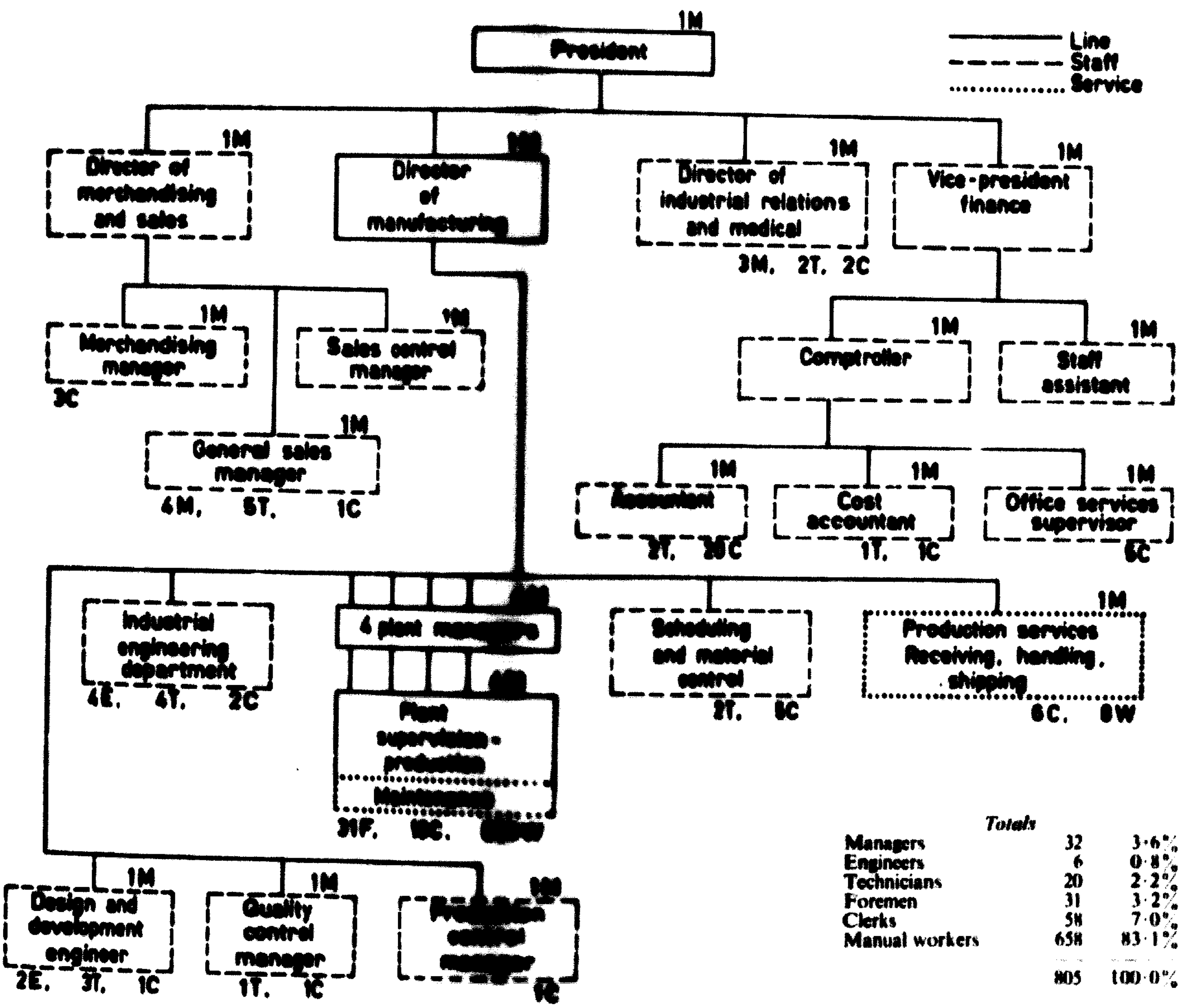
(c) *Heavy fluid-control equipment manufacture*

Figure 5 illustrates the organization chart of a company approximately the same size as the one in figure 3. The two charts reveal some interesting contrasts. This company makes valves, regulators and flow tubes in very large sizes; the units weigh from 100 pounds to 2 tons, with most of them in the 100–300 pound range. Some 7,500 units are produced each year; sales gross a little over $6 million.

The products must meet the exacting standards of the United States Government and, therefore, much more design and technical manpower is required than for the wide variety of metal parts turned out by the job-shop. Even so, it has been found possible and desirable to extend the span of control for the president to nine department heads. It will be noted, also, that there is one less level of management in the hierarchy:

Figure 3	*Figure 4*
President	President
Vice-president	Plant superintendent
General foreman	Foreman
Foreman	Workers
Workers	

This illustrates the principles shown in Figures 1 and 2, as two companies of almost identical size have different organizational profiles. Furthermore, in this company, the span of control assigned to the first line supervisors follows the same pattern and averages 26.4 workers in production, as against the figure of 18.5 for the job-shop which was itself slightly above the average. The figures for maintenance mechanics per foreman are comparable



Totals		
Managers	32	3·6%
Engineers	6	0·8%
Technicians	20	2·2%
Foremen	31	3·2%
Clerks	58	7·0%
Manual workers	658	83·1%
	805	100·0%

Figure 6

for the two plants. As has been mentioned, such a situation facilitates communication but places a heavier burden on each manager and supervisor in the line organization. Managerial personnel are assigned to handle a wider variety of tasks and on a more intensive basis than in the job-shop; hence, there is a higher proportion of personnel classed as managers in the total work force.

(d) Consumer goods (metal) manufacture

Many enterprises in the United States are engaged in the production of metal goods which go directly to the ultimate users under the brand name of the manufacturer.

Table 3

Managers	15	or	5.3%
Engineers	14	or	5.0%
Technicians	25	or	8.7%
Foremen	13	or	4.6%
Clerical workers	51	or	18.1%
Manual workers	164	or	58.3%
Total	282	or	100.0%

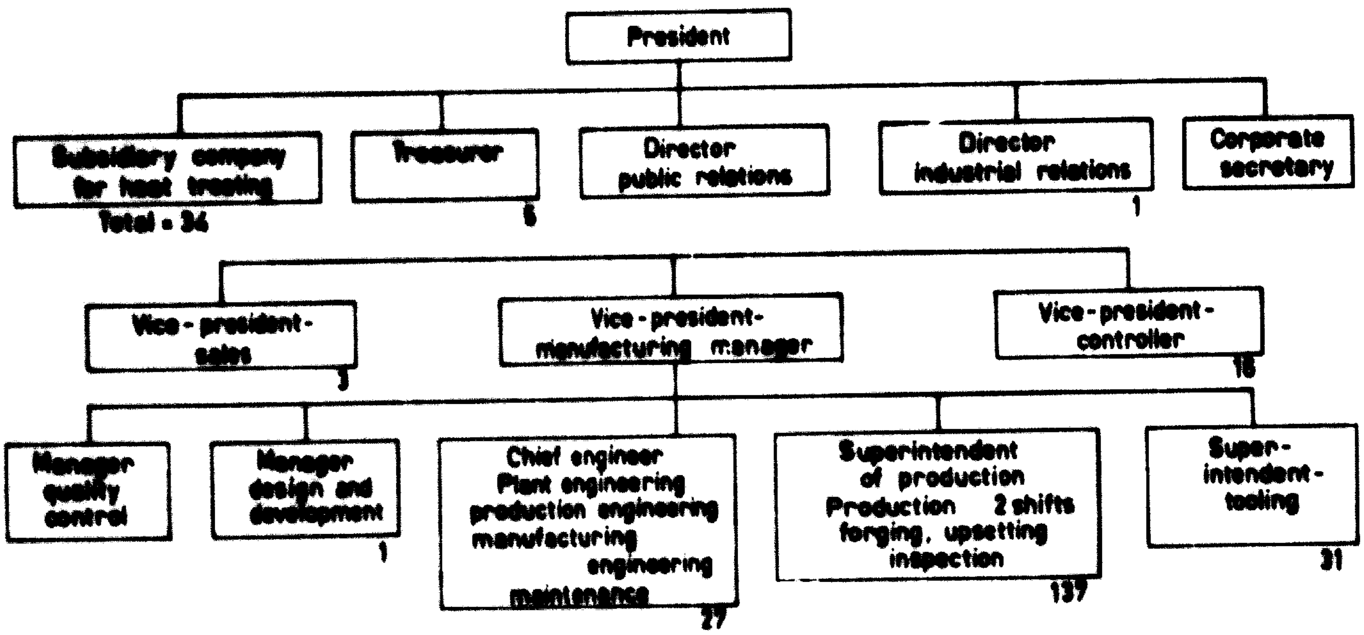
workers to supervisors are high, reflecting similarity of work and physical proximity of workers to each other. Annual sales run at about $14.5 million.

(e) Manufacture of precision forgings

Figure 7 illustrates the organization of a company which produces small forged parts to exacting tolerances. In contrast to many forge plants, this concern uses no hammers but relies entirely on presses to form its products. The management includes several engineers who, in cooperation with employees classed as technicians, perform such engineering work as is required. However, as most of the parts the company turns out have been designed in detail by the purchasers, there is a minimum of real design work to be done and the engineering consists principally of devising methods to reach the required tolerances in final dimensions. The number of workers per foreman is unusually low (12 or so) for a plant of this size, but the percentage of workers in the total force is about average.

(f) Several small metalworking plants

Figures 8, 9 and 10 are typical of the ways in which



Totals

Managers	13	4·7%
Technicians	11	4·0%
Foremen	19	6·8%
Clerks	15	5·4%
Workers	220	79·1%
	278	100·0%

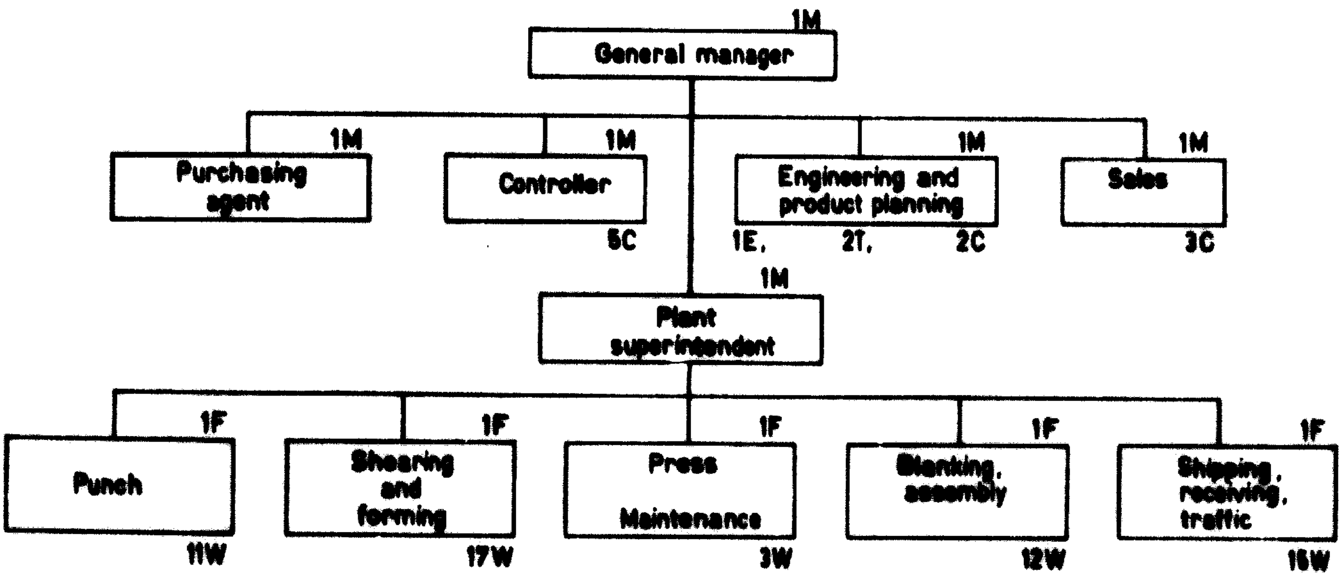
Figure 7

Among these is the sporting-goods company whose organization chart is illustrated in figure 6. This concern is a subsidiary of a larger company and can, if necessary, draw upon the staff advice of the parent, although this is not always done. The product lines are well established and require little yearly upgrading; hence, the principal engineering effort is directed to methods. Ratios of small foundries and forge shops are frequently organized. They are job-shops, rather than long-run production operations (design changes in the products are frequent and customers come and go). It should be noted that the heater plant (figure 8) is top-heavy with clerks. Management is aware of this and knows that it detracts from profitability; efforts are being made to reduce the number of clerks by employing more efficient people and eliminating paper work. When these changes are effected, it is expected that the percentages of clerical and vocational employees will be more in line with those of the other two companies. The concern turns out somewhat less than 100,000 space heaters a year and grosses about $2,550,000.

Of interest, also, is the unusually high percentage of vocational people in the foundry (figure 9); this is because nearly all the patterns for the castings are sent in by customers and the company can put all its effort into the casting of products. This plant casts valve bodies for plumbing installations in sizes up to about 20 pounds, as well as valve stems, small pipe fittings and junction fittings for thin-wall electric conduit. Production totals about 1,500 tons of fittings a year.

The drop forge plant (figure 10) produces camshaft and crankshaft blanks for small gasoline engines, as well as forged parts for aircraft. The products are designed by the purchasers and this plant need only make the dies to proper dimensions. Annual production runs to about 600,000 camshafts and crankshafts, plus an unstated number of smaller miscellaneous parts, with a value of $2.8 million in 1965. The distribution of the total work force of 10,000 demonstrates certain points which it is important to note:

	(per cent)
Managers	3.0
First-line supervisors	8.8
Engineers and technicians	6.5
Clerical workers	2.2
Manual workers	79.5



Totals

Managers	6	6%
Engineers	1	1%
Technicians	2	2%
Foremen	5	5%
Clerks	10	11%
Workers	73	74%
	97	100%

Figure 8

A SHEET-METAL PLANT (HEATERS)

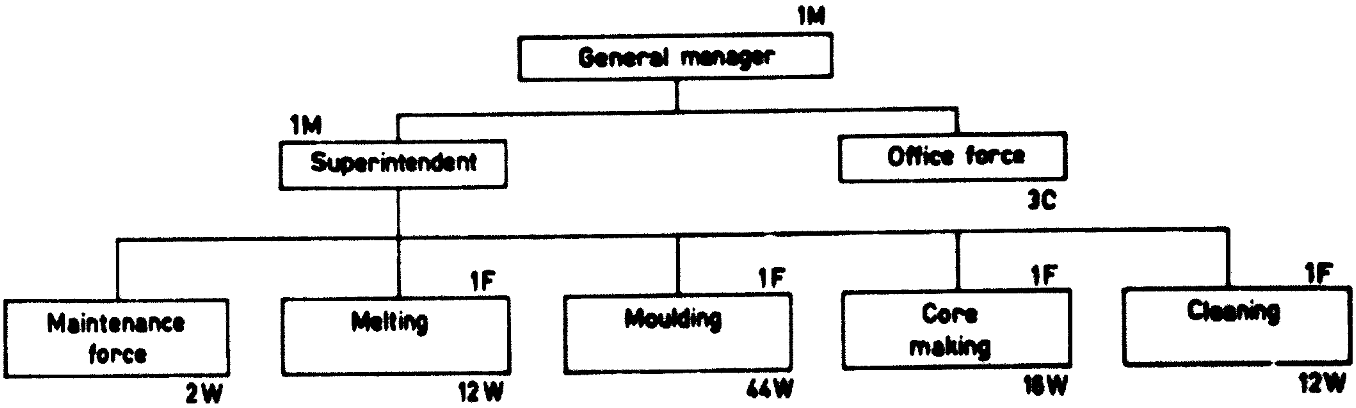
The job-shop character of the work is reflected in an unusually high percentage of skilled mechanics to semi-skilled and unskilled workmen and helpers; there are 63.2 per cent of the former and only 16.3 per cent of the latter.

It should be noted, also, that the ratio of manual workers to supervisors is only slightly higher than 9 to 1, well below the corresponding figure for all metalworking plants.

Manpower allocation in countries with intermediate-term industrial traditions

A number of countries began to develop local industries to balance their formerly agricultural economies after the First World War; others joined this movement following the 1939–45 conflict. Still others expanded their industries from long-established operations concentrated in certain localities to cover much larger areas within their borders. In all these cases, it has generally been necessary for the state to organize and finance the expansion and also to allocate managerial and technical manpower. Such people have frequently been the beneficiaries of government-financed education and training outside their country and have obligated themselves to extended periods of service in government-controlled industry following their return home.

Among the countries which fall in this general category are Israel, Turkey and Yugoslavia. These three nations share certain background factors; their geographic



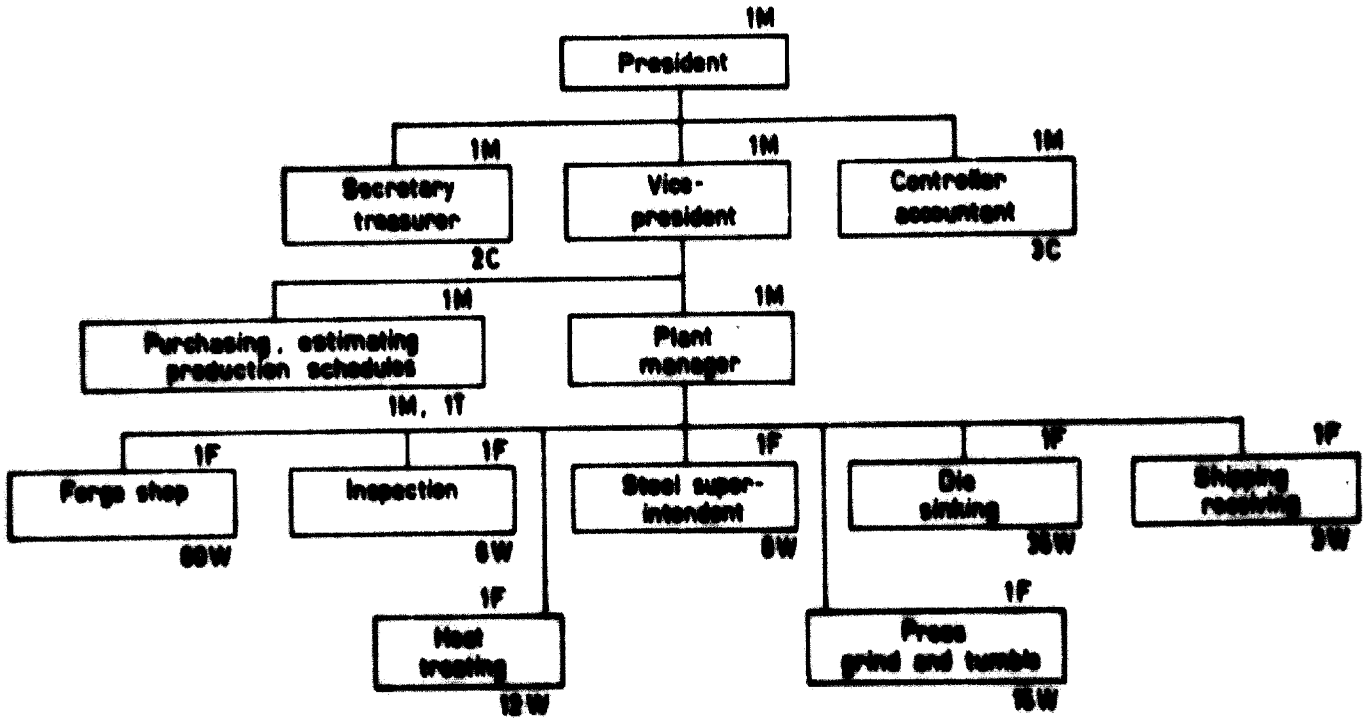
Totals

Managers	2	3%
Foremen	4	4%
Clerks	3	3%
Workers	86	91%
	95	100%

Figure 9

IRON FOUNDRY

boundaries and ethnic composition were the results of either the First or Second World Wars, or both, and they have been the recipients of large amounts of foreign capital through various channels. There are, also, certain significant differences, largely in political systems and the roles played by labour organizations in government and social activities. Their industrial development is, however, typical of the group of countries which have progressed a considerable distance in this field in a relatively short time.



Totals

Managers	7	5%
Technicians	1	less than 1%
Foremen	7	5%
Clerks	5	3%
Workers	139	87%
	159	100%

Figure 10

DROP FORGE JOB-SHOP

Managerial and Technical Manpower Allocation in Developing Countries

The countries which have no substantial manufacturing tradition are finding it necessary to follow one of two courses with respect to industrialization. They must either allow industry to grow up in a haphazard fashion, with citizens embarking on whatever operations they choose and with little regard for any considerations other than the profits they foresee, or there must be some sort of governmental control. Because private capital is usually non-existent or strictly limited in amount, the government must aid in the establishment of even a moderate operation requiring any sizeable investment; and, for practical purposes, the government has had to take some action in almost every case. The net result is that government controls either direct assignment of managerial and technical personnel to selected government-owned enterprises or much of the private sector of industry.

Government supervision of operations

In the former situation, the government not only controls man-power but also controls the allocation of financial and material resources. This is most likely to occur when planning officials consider that the establishment of metalworking plants turning out specific products not currently being made is in the national interest.

In such cases, it is advantageous if a reservoir of civil servants trained in managerial and technological work is available. Unfortunately, such pools are scarce.

In some countries, the technical education and vocational training facilities are under governmental control or persons who have been educated abroad are obliged to enter public service in return for their education. Often, an industry is so far down the priority list that it receives none of this personnel.

Inasmuch as indigenous managerial personnel in most developing countries is likely to be drawn from the former trading and export-import groups, there is a likelihood of strong orientation to the marketing side of industrial operations. Under conditions of short supply of managerial and technical personnel, it is often necessary for people to assume multiple responsibilities (e.g., line manager and staff specialist, technologist and manager, engineer and staff specialist). Such people may not possess the education and/or experience to perform their dual assignments satisfactorily but, as the only ones even approximately qualified, they will have to do their best on the job while, at the same time, attempting to improve their own work and to develop subordinates to take over part of the load. The alternative is to draw on outside experts in the manufacturing area until local personnel can be trained and have gained the experience to carry on effectively.

Meanwhile, if markets exist and money and materials are available, these managers can generally make a profit, providing they receive what amounts to a government subsidy in the form of a limited import policy on competing foreign goods. Perhaps some managers of local enterprises may be able to enter into licensing agreements with foreign manufacturers. If this can be done, it will provide a channel through which foreign technological advice and services can flow into the developing country.

It is extremely important in industrializing countries to attempt to develop a technological middle class. It is essential for full industrial activity that there be available design, industrial, standards, process and tool engineers and planners, and tool makers, the specialists who make up the service personnel of successful industrial enterprises. At first they can be imported but local people must take over eventually.

Metalworking

In most developing countries, the principal objectives in establishing industrial operations, especially in metalworking, are (*a*) to build up local production in order to become independent of imported goods; (*b*) to provide for local citizens jobs which are not directly dependent on the agricultural economy, and (*c*) to raise the standards of living of the inhabitants of the conntry by making more goods available. These objectives can be attained by various means, in varying degrees and with varying amounts of governmental control. Much will depend on the amount of private and official capital available to the metalworking industry, on the availability of suitable labour, the conditions of the market and the quantity and quality of managerial and technical manpower which can be marshalled to direct operations.

Unless a government adopts a completely *laissez faire* attitude, some controls and/or assistance will be necessary in order to facilitate the establishment and initial operation of a metalworking industry. Exemption from import duties on necessary machinery and tools; assistance with the purchase of raw materials from foreign sources or allocation of domestic supplies; import restrictions on competing products from abroad: all these and other actions will be required to nourish infant industries. If such encouragement does not persuade entrepreneurs to enter the metalworking industry, the government may decide to enter it directly, with operations under the management of public employees.

Whichever course is elected in a given country, the programme which experience has shown is likely to be most successful is one of step-by-step expansion, beginning with the least complex products. Initially, items produced under this type of programme have been those with a high content of labour possessing minimal skills, for local consumption, at moderate prices.

Conservation of foreign exchange has then gone hand in hand with the development of markets, raising the standard of living and the absorption of available manpower. In nearly all cases, the goods turned out by these plants have been modelled after foreign items which were not necessarily of the best or most up-to-date lines; they have thus been unexportable.

To command interest and attention in foreign markets, manufactured items must incorporate both good design and quality workmanship. Until local factories can incorporate both of these ingredients in their products, they can hope to serve only local markets. It is essential, therefore, to develop design and production engineers if a country desires to sell abroad.

In any developing country, the industrial park concept might be given serious consideration for a nascent metal-working industry. Geographical proximity of factories turning out different types of goods and services has generally facilitated the operations of all. The structures housing the activities can be specially designed and built for efficient operation; machinery can be more fully utilized; maintenance services can be shared; and planning, organizing, scheduling, quality control, marketing and other managerial functions can be offered to enterprises which, because of their size, could not afford such on an individual basis.

Estimation of requirements

As markets and product demand grow, additional facilities can be set up and dispersed throughout the country. It has been estimated that, for each million in population, initial industrialization will require approximately 10,000 to 12,000 persons for making metal products, machinery and tools and for the repair and maintenance of transport, agricultural, mining and industrial equipment.

These people would typically be classified as managers (± 5 per cent), first-line supervisors (± 5 per cent) and workers (± 90 per cent). The value of output which may be expected for each person in the industry will vary widely, depending on wages, labour productivity, cost of materials, money and services, the tax situation and protection from import competition.

A very rough guide would be that, for each person on the pay-roll, the industry should produce at least two and a half times the average annual wage. This takes into consideration the facts that machinery will probably not be particularly sophisticated or costly and the labour content of the product will approximate a third or more of the input.

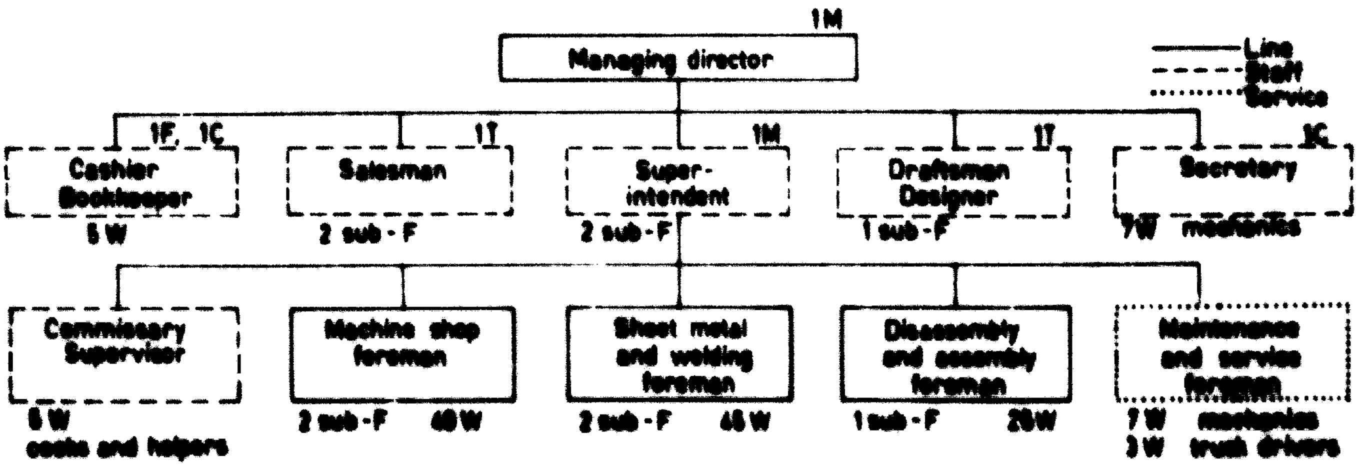
As the industry progresses in its ability to compete with foreign goods and, perhaps, to begin exporting, the number of employees will rise. It has been estimated that, when metal product exports reach 5 per cent of total production, the industry work force will amount to 25,000 to 30,000 per million in population.

The ratios of the different labour categories also will change significantly. Managers, engineers and technicians will rise to 8-9 per cent (primarily because of increased numbers of technical people), first-line supervisors will remain at about 5 per cent, a few clerks (say 1 to 2 per cent) will be required and the non-supervisory, manual workers will drop to about 85 per cent. Of the last group, the proportion which must possess a fair degree of skill will increase sharply, probably to more than half of the total. As a greater degree of mechanization and automation is achieved, the need for skilled people will rise.

The job-shop

A job-shop type of maintenance plant is often the precursor of other small industrial enterprises; growth in the scope of such operations often follows naturally, as markets expand and quality and quantity of goods produced increase. Such job-shops have satisfied important needs in countries where electricity is being used more, where expanding rail and road communication networks are used by an increasing volume of traffic, where agriculture is being mechanized at an accelerating pace, and where more and more sophisticated equipment of all kinds is breaking down or wearing out.

The old handicraft skills which may have sufficed to fix simpler devices fail to meet modern demands. Precision tools operated by competent mechanics have been found essential if countries changing from craftwork and farming to mechanized economies are to develop as rapidly as they hope. It has been found, also, that for these maintenance shops to operate successfully and



Totals

Managers	2 =	1·4%
Foremen	11 =	7·6%
Technicians	2 =	1·4%
Clerks	2 =	1·4%
Workers	126 =	87·2%
	143 =	100·0%

Figure 11

profitably, they must be staffed by well-trained mechanics and, above all, directed by competent managers.

Staffing

Studies by the United Nations and the Agency for International Development describe the physical equipment of such shops in detail. Suffice it to note here that minimum requirements include a few of general purpose lathes, a milling machine, drill press, power grinders and saws, a metal shear and break for forming sheet metal, acetylene welding and cutting and electric welding sets and a full complement of hand tools and gauges for machine and bench work.

The direct labour to operate such a shop would include about five to eight skilled men and half as many unskilled labourers and helpers, supervised by a foreman to get the jobs out and a manager to exercise over-all direction, bring in new business and handle finances. The manager is the key person in an operation of this type, as he must be competent in both technical and business matters. He is in a position to initiate, when the time is ripe, the expansion of the shop, to train subordinate and replacement managers and technicians as needed, to diversify the product line and, generally, to be alert to opportunities.

Such a shop can be expanded, both in equipment and manpower, as demand dictates. With more of the tools already mentioned, together with more sophisticated tools such as a planer, shapers and boring mills, it would be possible to handle a wider variety of agricultural and factory machinery repairs; it has been possible, in certain situations, to make new machines for industry.

Personnel requirements increase somewhat in proportion to the physical property of the plant. A typical operation of this type is staffed by some 125 men, with approximately 20 per cent skilled mechanics, 12 per cent semi-skilled production or maintenance people, and the balance helpers, apprentices and labourers. Management is more numerous but more specialized than in the smaller shop. An organization chart showing the set-up of a plant in Central America is given in figure 11.

Expansion of operations

In the event that it appears desirable to produce, for example, nails or screws for the local building trades, it would be feasible to install a nail heading machine and tumbler and/or a screw header and thread roller in either the small or the enlarged maintenance machine shop just described. One additional semi-skilled operator for each heading machine and a labourer to move material have been found to be all the extra labour necessary. Die maintenance and machine repair have been handled by personnel of the larger shop. Management and the few incidental technical services have been provided by people from the parent shop without undue extra effort. When demand for the products of the prototype shop increased sufficiently, operations were moved out of the parent plant and the business placed on a self-containing basis. It is estimated that one nail machine can turn out approximately 250 tons of nails and tacks a year and that each machine can supply the annual requirements of 100,000 to 150,000 persons in a developing country.

Development of managerial and technical manpower

Managers and technicians in all kinds of activity are in heavy demand the world over. The supply never seems to equal the demand and constant efforts are being made to increase the number and improve the quality. Progress can be made in a number of ways.

Formal training procedures

Regular instruction has been offered in technical subjects and business administration for a long time. Courses in these fields have been established in institutions of higher learning in all the industrialized nations and in many of those which are in the process of industrialization. This is a good method for giving potential managers theoretical knowledge, but it is slow and limited in the number of graduates annually. It makes use of the knowledge and experience of experts who spend most of their time teaching and are, therefore, somewhat removed from the field. Even in those countries which have a long tradition of manufacturing activities and specialized education for management, this produces too little talent too late, and means have had to be found to supplement it.

Managerial development at the work place

Another method is on-the-job development by superiors. This is the most widely used system and produces the largest number of candidates for higher level assignments in industry. The principle on which it rests is that every managerial employee or entrepreneur is accountable for helping his subordinates prepare themselves for more exacting and more responsible jobs, by precept, instruction and encouragement. The understudy system, rotation among jobs, out-of-hours study and coaching are all used effectively. The extent to which this type of programme can be applied in any country will depend on a number of considerations including the number and competence of existing managers and the extent to which they accept responsibility for their subordinates.

Managerial training in developing countries

The shortage of managerial, entrepreneurial and technical skills in a country which sets out to establish a metalworking industry *de novo* can seldom be solved quickly through the use of indigenous personnel. However, steps can be taken in that direction. An essential ingredient in any increase in the number of qualified managers is an upgrading of formal, basic education. As education is traditionally a function of government, a country which aspires to industrialization must be prepared to devote a considerable percentage of its public expenditures to this purpose. It may be worth while to consider such expenditures as an investment in the future, an improvement in the productive potential of the nation. While local educational facilities are being established or expanded, foreign facilities may be considered.

Training abroad

Students from developing countries have been studying in other countries for years. They have brought back with them the latest and best techniques of the industrial societies they have visited. But they have also encountered difficulties.

The problems faced by the managers and technicians in metalworking plants in the developing countries are different from those found in similar operations in highly industrialized countries and for which the students have been prepared by their studies. To name but a few, there is likely to be a shortage of workers with any experience in the manufacture of metal products, or even training in any kind of industrial work; there probably will be a dearth of the staff personnel and the mechanical and electronics aids on which managers often rely for data on which to base their decisions; domestic markets will be limited and the operating efficiencies of the plants will be correspondingly lowered; the entrepreneurial environment will probably be considerably restricted, e.g. import quotas on materials, power shortages and transportation deficiencies.

The prevalence of these problems in the developing countries strongly suggests the desirability of tailoring the training of managers and technicians destined to direct operations so that it would be different from German, Italian, American or Japanese training, for example. Many of the techniques which are applied widely in the industrial nations, such as in administration, quality assurance, production scheduling and inventory control are not applicable in a setting of short supplies, partially obsolescent machinery, unskilled labour and non-discriminating customers such as is found in many countries just emerging from an almost totally agricultural economy.

It is frustrating to the new manager and wasteful of the time and money spent on his education abroad to expect him to utilize the latest techniques developed by a highly industrialized society in a situation which is by no means ready for them. It would, perhaps, be better to train at least a part of the managerial cadre in techniques which are more realistic in terms of immediate application (e.g., inspection of products by employees rather than by statistical quality control; manual instead of mechanized handling of goods and materials; installation of multi-purpose machine tools instead of automatic equipment). However, it is questionable whether standard courses in management offered in universities and schools of business in the industrial nations could be modified readily to incorporate such ideas, so the students are likely to continue to receive the same training as their hosts.

There is another problem which has been encountered by some of the developing countries which have sent many of their brightest young men abroad to learn management techniques. Upon completing training, the students have been reluctant to return to their own countries. They have become accustomed to the higher standards of living in the host country and look with distaste on the less comfortable lives they would lead in their own lands. Furthermore, they realize that they could earn a great deal more abroad than at home.

Training at home

Managerial and technical instruction by local institutions has been moderately successful in some of the less developed nations. This has served as an alternative to sending students out of the country. Because of the difficulty of obtaining enough local citizens competent to conduct such courses, it has been found necessary to invite faculty members from institutions in the industrial nations to bring their expertise to the developing countries. This reduces drastically the travel costs involved and precludes the loss of students who decide not to return home.

However, care must be taken in selecting instructors to make sure that they are able and willing to adapt their courses to the conditions which exist in the developing countries; they must stress managerial practices which can be used effectively under local conditions. It may require some time for the guest instructor to acquire a good enough working knowledge of the local situation to teach a really satisfactory course, but this will be time well spent if it results in better managerial development.

Another method of developing indigenous managerial and technical personnel is to encourage foreign capital products manufacturers to set up plants in developing countries. The greatest benefits will be obtained if the products assigned to each of these plants are specialized for local markets and fit the capabilities of the local labour force. The more labour-intensive the product line, the better. Such operations, if under government licence, might well be required as part of the contract to employ an increasing proportion of local managerial and technical personnel, with eventual phasing out of foreign nationals from the supervisory and specialist staffs.

It has been noted elsewhere in this report that some countries have been successful in developing both technicians and managers through the medium of licensing. The foreign managers have been charged with the responsibility of developing competent local replacements for themselves as quickly as possible. This process has automatically advanced the training of local candidates.

Another training device successful in a number of places, including [illegible], is the correspondence school. There are many standard textbooks on management [illegible] correspondence instruction [illegible]. Correspondence schools in a number of countries [illegible] courses in many aspects of technology. The use of home-study material is extremely widespread. But its successful prosecution depends almost entirely on the will of the individual student; unless highly motivated he will derive little benefit from the study. In those cases where correspondence courses have been successful, [illegible] because of high interest and application, [illegible] by some sort of [illegible] through which the students can obtain aid and understanding answers to questions they raise about the material.

For information and help in manager development the developing countries can turn to a variety of foreign aid programmes. Such help can be obtained through [illegible] from the United Nations, from the International [illegible]

[illegible] Office, the United States Agency for International Development and from the Soviet Union through the Council of Mutual Economic Assistance. Japan has an International Co-operation Division of its Vocational Training College; Austria has an Institute for Development Aid and Technical Co-operation. Israel's programme is carried out through the Department for International Co-operation in the Ministry of Foreign Affairs. Other countries which have provided assistance in developing managerial and technical ability outside their own borders include Yugoslavia, New Zealand, Canada, the United Kingdom and Australia. There is no lack of advice on the ways in which managers can be trained.

CONCLUSIONS

The establishing of metalworking industries in developing countries will be beset by certain problems. Looming large among these will be shortages of skilled and competent managerial and technical manpower. [illegible]

(a) Advance planning, both as to industrial [illegible] and as to the requirements for managerial and technical manpower.

(b) Preparation of job descriptions for managerial and technical personnel [illegible]

(c) [illegible]

(d) [illegible]

(e) [illegible]

[illegible]

and market conditions [illegible]

(f) Establishment of pilot operations in the metal-working field devoted initially to maintenance of transport, agricultural, mining and other machinery and equipment.

(g) Establishment, with the maintenance shops of (f), of prototype manufacturing facilities where managers and technicians can gain experience before breaking away to form independent industrial units.

(h) Establishment of curricula in managerial and technical studies in local colleges, universities and technical schools.

(i) Establishment of out-of-hours study programmes in management and technology at productivity centres and institutes, where working personnel can prepare themselves for better and more responsible positions.

(j) [illegible]

(k) [illegible]

(l) [illegible]

(m) [illegible]

(n) [illegible]

(o) [illegible]

[illegible]

[illegible]

[illegible]

Review and approve procedures developed by subordinates for implementing board policies.

Review and approve labour agreements made with duly selected representatives of employees.

Maintain necessary contacts between the enterprise and government officials, community representatives and other industries.

Oversee the work of four deputy directors.

Deputy director, production

Basic function

To direct the use of manufacturing facilities so as to assure most efficient production of goods consistent with the objectives of the enterprise.

Duties

Propose manufacturing policies, objectives and programmes to the general director.

Determine design and specifications of products and services.

Determine and establish the most efficient and economical methods of meeting production demands.

Provide for procuring and using most effectively the requisite materials, facilities and manpower to meet the demand for products and/or services.

Interpret manufacturing policies to subordinates and control their execution in accordance with established criteria.

Oversee the work of three shop superintendents and staff personnel.

Form of questionnaire

(a) What is the enterprise's principal product line(s)?

(b) What is the annual production volume of the plant (in units of product or tons of output)?

(c) What is the annual value of product in local currency or United States dollars?

(d) (i) What is the organization of the enterprise, from the principal executive down to, and including the first-line supervisors? Please show on a separate sheet.

(ii) How many subordinates report to each individual shown on the chart?

(e) Indicate the total employees in the enterprise broken down among the following classifications:

(i) Managers. Persons who set policies, exercise over-all responsibility for execution of these policies and direct individual departments or special phases of operations.

(ii) Engineers. Persons who hold college or university degrees in engineering and scientific fields and who are engaged in design or scientific laboratory work.

(iii) Technicians. Persons who do not hold degrees but who carry out minor design work under the supervision of engineering or managerial personnel.

(iv) First-line supervisors (or foremen). Persons who direct manual or clerical workers in the actual performance of productive or service operations. The next higher level of supervision may be included here if their principal responsibility is production rather than policy making.

(v) Clerical employees. Persons who perform clerical type work, regardless of difficulty level; their work is primarily mental instead of manual.

(vi) Workers (or operators). Persons who perform manual operations in production, transportation, maintenance or service. Include all levels of skill.

(f) What is the principal source of managerial personnel for the enterprise?

(i) Internal (promotions from lower ranks in the enterprise)?

(ii) External (newly hired and with no previous connexion with the enterprise)?

(g) What is the educational level of the present managerial personnel of the enterprise?

(i) Per cent college or university graduates.

(ii) Per cent college or university non-graduates.

(iii) Per cent with no college or university training.

(iv) For enterprises in non-industrialized or partially industrialized countries:

a. Per cent of university trained managers educated at home.

b. Per cent of university trained managers educated abroad.

(h) Projected requirements of managerial personnel (stage and directions).

(i) Any additional information which can be supplied on managerial and technical manpower: salaries, training and development, available supply, etc.

BASIC PRINCIPLES OF TRAINING ENGINEERING AND TECHNICAL SPECIALISTS FOR THE METALWORKING INDUSTRY

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Progress in any branch of science and technology as well as efficient use of scientific discoveries for the benefit of society depends mostly on the availability of engineering, technical and scientific specialists. The higher the quality of training of the specialists and the greater the number of high-rated personnel working in the industry and in the research and scientific agencies, the larger the output of products required for the welfare and further progress of society.

Metalworking is essentially the most important technological process as, for today and evidently for the next decades, metals are and will be the main materials used for manufacturing a large variety of machines oriented to the human being. That is why considerable attention is being paid to training engineering and technical specialists for the metalworking industry.

Metalworking, i.e. manufacturing of various components of machines, is accomplished mostly by casting, forging, stamping, welding and cutting as well as by electrophysical and electrochemical methods. This report deals mostly with the training of engineering and technical specialists for metal cutting.

The process of metal cutting is effected on the metal-cutting machines with the aid of metal-cutting tools. Metal cutting is a complicated process. It is accompanied by large strains and high friction, heat liberation, work hardening and wear of the cutting tools. The engineer engaged in this process should be well trained for designing metal-cutting machines and tools, for manufacturing these machines and tools, and for their rational use for production of the elements required in making some other machines. The ever-growing requirements for efficiency and accuracy of the metal-cutting machines face the engineer with the necessity of having a thorough knowledge of many other branches of science and technology.

The problems of training engineering and technical specialists should be seriously treated in the developing countries as well, since experience proves that only that country may become actually independent which has a well-developed heavy industry and particularly a machine-building industry.

Training by the developing countries is effected mostly in two ways:

(a) By sending their citizens on a training mission to other countries with well-developed industries and with experience in training specialists;

(b) By organizing the training of engineering and technical specialists in their own country.

Training missions to other countries is a necessity, particularly during the first stage of independent development.

Domestic training of specialists will be successful if there is participation and assistance by some other countries.

The Soviet Union has wide experience in organizing and developing an educational system for training specialists. The well-known successes of the Soviet Union in science and technology and in space ventures were possible only due to the availability of a large number of its own national specialists and scientists. This experience will surely be useful to other countries which take the path of independent development.

In tsarist Russia (before 1917), three-quarters of the population were illiterate. There were only a few high and secondary special schools. This huge country had only 105 high schools including seven technical schools with 12,000 students.

The high schools were located mostly in Petersburg (Leningrad) and Moscow. The schools were attended only by representatives of the rich strata of society since the educational fee was too high. There were several groups of workers and peasants who had the luck to be admitted into the schools. The representatives of other nations were not allowed to study at all.

The people's power has changed the tsarist educational system for the better. Now all forms of education are free. All the citizens of the Soviet Union have the rights to an education irrespective of race, nationality, sex, religion, property and social status.

The schools may be attended also by foreigners living on the territory of the Soviet Union in accordance with the Convention on the Struggle against Discrimination in Education adopted by the General Conference of UNESCO.

In the Soviet Union there is a unified state system of education. This system ensures coordination and continuity of training at all stages of study.

The first stage is obligatory eight-year schools of general education; the second stage is secondary schools of general secondary education, secondary schools of special secondary education (technical schools); the third stage is higher education.

In addition, the educational system in the Soviet Union includes professional technical training of workers on the basis of obligatory eight-year education.

[illegible]

Higher schools (universities and institutes) may be attended by persons who have secondary school certificates and who have passed the entrance tests. The entrance tests may be taken by any person (for the day departments there exists a thirty-five-year age limit while for the evening and correspondence departments there are no limitations at all).

When entering the engineering and technical faculties, the following tests should be passed: mathematics (oral and written tests) and physics (oral test), which are the main subjects, and chemistry (oral test) and Russian language and literature (written test) which are auxiliary subjects.

Those who enter higher schools in the Soviet socialist republics where education is carried out in the national language should pass a written test in the national language and literature instead of the Russian language and literature.

Students in the higher schools may include all the studies and use of laboratory equipment, textbooks and training appliances and sports equipment free. Medical service for the students is also free. When necessary, a hostel is provided for a small fee. Food is served in a refectory (located both in school and hostel) at prices considerably lower than in restaurants.

The majority of students get state scholarships (fixed money allowances to undergraduates).[2]

The number of higher schools and students in the Soviet Union is continuously growing.

In the 1963/64 academic year there were 742 higher schools in the Soviet Union with 3,261,000 students[3] including 43 per cent of women. The technical faculties of the higher schools (with the exception of agricultural engineers and technicians) were attended by 1,425,400 students. Special secondary schools were attended by 1,509,100 students. Twenty-nine per cent of the students in technical high schools were women.

In 1963, there were 331,700 post-graduates including 120,000 engineers.

In 1965, there were 403,900 higher school post-graduates.

In the 1965/66 academic year in the Soviet Union there were 756 higher schools with 3,861,000 students.

In 1966, the day departments of the higher schools only were to be entered by 404,000 students. The total number of students was to reach 868,000.

In the course of 1966–70, there will be trained about seven million specialists (post-graduates of the higher and secondary schools) which is 65 per cent more than during 1961–1965. By 1980, the number of students in the Soviet higher schools will reach eight million.

The number of specialists to be trained in the various branches of industry is determined by the general state plans on development of the economy. Therefore, all the postgraduates in the Soviet countries get jobs according to their specialities.

[2] Persons sent to an institute by an enterprise get the scholarship from the enterprise. This scholarship is 15 per cent larger than a general one. After graduation, these students go back to their enterprise.

[3] Including 1,383,000 in day departments; 439,000 in evening departments and 1,439,000 in correspondence departments.

Higher schools are located throughout the huge area of the Soviet Union. Each Soviet socialist republic has its own higher schools. More than 80 per cent of the students are studying where the lectures are in their mother tongue.

During the first stages of development of the Soviet higher schools, considerable difficulties were encountered owing to the young people lacking secondary school certificates. Of great importance during this period were working faculties organized by the Soviet Government to reduce the terms of training of the workers and peasants for entering high schools. In the course of further development of a general secondary educational system and in the course of setting up the conditions for getting the secondary education by anyone who wishes, the need for the working faculties was eliminated.

General conceptions for training engineers and mechanics on metal cutting in the Soviet Union

The main problem faced by the Soviet's higher schools is training highly educated, active members of society, capable of independent and efficient labour in a selected branch of industry. The education of specialists is based on a combination of theoretical and practical training.

The mechanical engineer should be capable of designing, manufacturing and servicing machines. After graduation from an institute he should have a good knowledge of the fundamentals of scientific and technical achievements. He should be capable of using modern techniques and be ready for designing techniques of the future. Being a specialist in production means the mechanical engineer should be a good economist as well.

Engineering and technical specialists are trained both by the polytechnical institutes (technical universities) and by the higher schools of the branches of industry.

By way of exception, technical specialists are trained by some universities which commonly train specialists in humanitarian, physical, mathematical, chemical and other natural sciences. This is the case in some universities of the republics where there is a limited requirement for the engineers of some specific branch of industry. Mechanical engineers trained in metal cutting are turned out by eighty-five higher schools of the Soviet Union.

Training of highly educated specialists is effected both with work being discontinued (the so-called stationary or day high schools and their departments) and without discontinuing work (evening and correspondence high schools and their departments, technical high schools in the producing plants).

Studying with discontinuation of work

According to this system, the term of training the mechanical engineer equals four years ten months.

With due account for high rates of technical progress, high degree of automation of modern production, ever-growing requirements for the quality of the products, for the reliability and long life of the machines used in production of new materials, wide implementation of electronics, optics and computers, the mechanical engineer should have a profound knowledge of a given branch of technology.

This means that he should be well trained in physics, mathematics and general techniques, should know the scientific and technical foundations of a given branch of industry, and be a specialist in some narrow branch. Good knowledge of physics, mathematics and general techniques will enable the young specialist to settle independently most of the problems which will be encountered in his work, enabling him to improve the machines and to carry out scientific research. Specialization in some narrow branch of industry will enable the young specialist to work fruitfully in the economy immediately after graduation. Additionally, the mechanical engineer should be a good technologist and a good designer which will enable him to solve successfully specific production problems.

Let us consider in more detail the curriculum[4] for training the mechanical engineer on metal cutting (speciality: machine-building technology, metal-cutting machines, and metal-cutting tools).

The curriculum is divided into five years, each year divided into two terms. The duration of terms is: first term—18 weeks, second term—17 weeks, third term—18 weeks, fourth term—17 weeks, fifth term—18 weeks, sixth term—17 weeks, seventh term—18 weeks, eighth term—10 weeks, ninth term—10 weeks, tenth term—15 weeks.

About a third of the total time (4,[illegible] hours) allotted in the curriculum for all types of education (including educational and productional practical work) is allocated for general scientific subjects which make up the theoretical fundamentals of the engineer. These subjects include social sciences (350 hours), higher mathematics (456 hours), physics (278 hours), chemistry ([illegible] hours), and foreign language (210 hours). Higher mathematics is studied during the first, second, third and fourth terms; physics during the second, third and fourth terms; chemistry during the first and second terms; foreign languages during the first, second, third and fourth terms (English, French or German).

Physics as a natural science has become an active force in technical progress. Study of scientific knowledge of the natural laws, good knowledge of the basic sections of physics such as mechanics, electricity, optics, acoustics, thermodynamics, molecular physics and atomic physics—all this is of great value for the future theoretical and practical activity of the engineer.

The processes and laws of nature are recorded in the form of mathematical expressions. Therefore, the engineer should have a good command of mathematics, otherwise he will be unable to develop new machines and to elaborate new technological processes. The engineer should be knowledgeable in such branches of mathematics as differential equations, theory of probability, mathematic statistics, linear programming, theory of information, theory of errors and the like.

About 1,500 hours are allotted for the study of general engineering subjects including: machine-building drawing—159 hours during the first, second, third, fourth and fifth terms; descriptive geometry—72 hours during the first term; theoretical mechanics—190 hours during the second, third and fourth terms; technology of metals and of other structural materials—142 hours during the third, fourth and fifth terms; structure of materials—88 hours during the fifth and sixth terms; resistance of materials—174 hours during the third and fourth terms; theory of gears and machines—87 hours during the fourth and fifth terms; machine components and handling and transportation facilities—142 hours during the fifth and sixth terms; fundamentals of interchangeability and technical measurements—72 hours during the fourth term; general electrotechnique—141 hours during the fifth and sixth terms; hydraulics—87 hours during the fifth and sixth terms; thermodynamics and heat transfer—51 hours during the sixth term; fundamentals of safety measures and fire prevention regulations—55 hours during the ninth and tenth terms; fundamentals of artistic design—36 hours during the seventh term; and computers in engineering and economical calculations—40 hours during the eighth term.

Since the metal-cutting mechanical engineer should be not only a technologist but also a designer of machines and tools used for metal cutting, the special subjects (with the total time of 900 hours) include theory of metal cutting—68 hours during the sixth term; metal-cutting machines—193 hours during the sixth and seventh terms; design and production of metal-cutting tools—112 hours during the seventh and eighth terms; machine-building technology—218 hours during the seventh, eighth, ninth, and tenth terms; machine electrical equipment—36 hours during the seventh term; fundamentals of machine appliance design—50 hours during the eighth term; fundamentals of machine-building plant design—50 hours during the ninth term; fundamentals of automation and productional process automatics—95 hours during the eighth, ninth, and tenth terms; and industrial electronics—51 hours during the sixth term.

The programmes for special subjects and the respective educational tasks for the students include calculations of the machines, their elements and units for strength, static rigidity, resistance to vibration, resistance to wear, long life, and the economical calculations as well.

In addition to the specified subjects, the curriculum provides allocation of 110 hours for study of obligatory subjects as determined by the council of the institute. These hours are allotted for study of additional sections of some subjects specified in the curriculum (e.g., for study of some chapters of higher mathematics, physics) and for study of some new special subjects relating to the branch of machinery selected by the metal-cutting mechanical engineer.

In the Moscow Machine-Tool Construction Institute which turns out the specialists for the machine-tool construction industry, mechanical engineers are trained in four more "narrow" specialities: metal-cutting machines, tool production, machine-building technology and electrophysical and electrochemical methods of material

[4] All curricula are approved by the Ministry of Higher and Secondary Special Education of the Soviet Union and are obligatory for all the schools training specialists of the same [illegible].

dimensional machining. About 420 hours are allotted in each speciality for studying special subjects.

These subjects are:

On the faculty of metal-cutting machines: machine-building technology—70 hours during the eighth term (complete with the course project); design and construction of metal-cutting machines—70 hours with the course project during the ninth term; fundamentals of designing automatic machines, shops, and plants—11 hours; hydro- and pneumoautomatics and equipment—84 hours; machine electrical equipment—84 hours.

On the faculty of tool production: tool-production machines—36 hours; measuring tools and gauges—40 hours; technology of tool production and design of appliances—90 hours with the course project to be made during the eighth term; heat treatment of cutting tools and equipment of heat treatment shops—54 hours; design and construction of cutting tools—80 hours; dies—30 hours; design of tool production shops—30 hours; electrical equipment of tool production plants—40 hours.

On the faculty of machine-building technology: machine-building technology—80 hours for special sections, with the course project to be made during the ninth term; metal-cutting machines—112 hours for special sections, with the course project to be made during the eighth term; technology of production of cast, forged and stamped parts—60 hours; fundamentals of machine building shop design—60 hours; fundamentals of appliance design—54 hours; machine electrical equipment—54 hours.

The mechanical engineer who controls complicated technological processes in the machine-building industry should have a good economics education. He should be capable of comparing the technical and economic parameters of several versions of a machine and independently selecting the optimal version of the machine, process, shop plan, and the like. To this end, such subjects are studied as industrial economy—54 hours during the seventh term; organization and planning of enterprises—105 hours during the eighth, ninth and tenth terms. Economics are considered also when studying some special subjects.

For the benefit of the physical development of the students, the curriculum provides 140 hours (during the first, second, third and fourth terms) for gymnastics which is obligatory for all.

The study of subjects specified in the curriculum is carried out in lectures (2,285 hours), laboratory work (638 hours) and practical work (1,100 hours).

Laboratory studies are an important element of the educational process. They contribute to mastering the required material and are essentially the beginning of scientific research. Carrying out the obligatory minimum laboratory work, the student obtains good habits for independent performance of experiments.

The practical laboratory work will become effective provided that:

(*a*) The laboratories of the institute are equipped with modern instruments and apparatus;

(*b*) The practical laboratory work on each subject is in close connexion (wherever and whenever it is possible) with the tasks and problems that are faced by science and production.

(*c*) The student (who has been preliminarily instructed) is entrusted with performance of an experiment, with processing the results, and with making conclusions.

All the laboratories of the higher school should be educational centres and scientific centres as well.

The higher school as well as any other school cannot function without textbooks and training appliances. The textbooks and training appliances which are needed in each subject should be as brief as possible and should comply with the respective approved programmes. The contents of the textbook are based on the latest achievements of the science and technique and therefore it is important to revise and republish textbooks. During revision of the textbooks, some of the material should be omitted, some of the material should be revised, and some of the material should be new.

In 1965 in the Soviet Union there were published 768 textbooks and training appliances for the higher schools.

The textbooks and training appliances, though being very important for training highly educated specialists, cannot often give answers to numerous questions arising during study of new material, during various home tasks, laboratory work, course (year) projects and projects presented for diploma. Hence each higher school has a library fully equipped with the required sources of information: reference books, encyclopedias, monographs and periodicals on all the subjects specified in the curriculum. The value of the library to the future engineer lies in the fact that in the course of his work there he acquires habits for self-controlled searches for scientific information.

Physical education and sport are considered as a continuous educational process consisting of a set of exercises and games and intended to add to the health of the students, to ensure their good physical development, education, sport improvement and to prepare the students for highly efficient labour and for defence of their motherland. The most widespread are such sports as gymnastics, basketball, volleyball, football, heavy and light athletics, rowing, skiing, skating, boxing and swimming. A large number of students has a passion for tourist and mountain trips.

The maximum load of the students by all types of studies including optional studies is thirty-six hours a week during the first through fourth years of education and thirty hours a week during the fifth year.

Much attention in training mechanical engineers is paid to acquiring the practical habits for work and studying up-to-date methods directly in the plant.

With this purpose in view, seventy hours are allotted during the first year of education for work in the studying shops of the institute and one month is allotted for practical (technological) work by the students in the best plants of the country. The studying shops of the institute have five sections (shops): casting shop, forging shop, welding shop, locksmith shop and mechanical (machine building) shop.

In each shop, the student independently (under the supervision of his teacher and foreman) works at the bench station and performs all the necessary operations on production of some part, acquiring practical habits in manual and machine treatment of metals and non-metallic materials, basic technological methods of part production, becomes acquainted with the construction and operation of the equipment, cutting and measuring tools and appliances, becomes familiar with safety precautions and the arrangement of the work station.

Production (technological) work is carried out within twelve weeks, during the eighth term. During this practical work, the students acquire experience in solving practical problems in the machine-building plant. They should master the products manufactured by the plant, requirements for the products and basic technological processes. Special attention should be paid to studying the most economical and efficient technological processes in parts production (beginning with production of blanks and finishing with machine assembly and finishing operations), to the problems of mechanization and automation of the productional processes, organization of production, and safety precautions.

The practical work is carried out under the supervision of the professor and plant engineer.

The final production-practical work (designing-technological work) is carried out during the tenth term. During this fifteen weeks' practical work the student accumulates the material for the project presented for his diploma and therefore it is often termed pre-diploma practical work. This work also is carried out in the best machine-building plants, preference being granted to the plants in which the student is going to work after graduation (distribution of the students to the plants is effected one year before graduation from the institute).

To ensure that the future mechanical engineer will have the 'know-how' for designing and computation, the student in the institute undertakes two-course (year) tasks devoted to the fundamentals of automatics and automation of productional processes and to organization and planning of the enterprises and six-course (year) projects devoted to the theory of gears and machines, machine components, transportation and handling facilities, metal-cutting machines, metal-cutting tools, and machine-building technology.

For better appreciation of the material, homework is planned in some of the subjects including mathematics, theoretical mechanics, resistance to materials and theory of metal cutting.

There are exams and tests after each term. Grading is by the four-mark system: excellent (5), good (4), satisfactory (3) and unsatisfactory (2).

The final stage of training is performance and defence of the project (design) presented for diploma. The students are allowed to work on the diploma project provided that they have passed the whole of the training course in the institute. The time allotted for preparation of the diploma project is sixteen weeks.

The topic of the diploma project is selected by the student before the pre-diploma practical work, based on specific problems faced by the industry or on future problems.

By way of example let us mention some of the topics of diploma projects: "Technological process for manufacturing engine cylinder block for specified truck", "Technological process for manufacturing change-over gearbox for boring machine 2A450", "Gear grinding machine for wheels of up to 500 mm in diameter", "Drilling machine with timed control system", "Tools for automated production of turboengines", "Tools for ball-bearing automatic production line".

One of the elements of the diploma project should be worked out by the student quite thoroughly with reference to experimental research.

The diploma project, consisting of ten to twelve sheets of drawings and 100–120 pages of notes is defended at an open meeting of the State Examination Committee whose staff is approved by the Ministry of High and Secondary Special Education.

After successful defence of the diploma project, the young specialist who has graduated from the institute with discontinuation of work receives a temporary certificate and a badge. The diploma is handed over after the expiration of one year during which he should prove that he is a good engineer. The engineer with 75 per cent "excellent" marks and 25 per cent "good" marks and who has defended the diploma with the "excellent" mark receives an excellent student diploma.

The five-year training of the metal-cutting mechanical engineer consists of 251 weeks which are allotted as follows: 143 weeks theoretical training with discontinuation of work, four weeks studying practical work, twenty-seven weeks production work, sixteen weeks preparation of the diploma project, twenty-nine weeks exams, and thirty-two weeks vacation.

Recently, technical training means such as cinema films, computer (programmed) training, tape recorders, radio sets, television sets and the like have found extensive application.

Production and application of training films devoted to some subjects makes it possible to explain graphically difficult material.

Most of the institutes are equipped with cinematic and photographic laboratories. This work is also participated in by the cinema studios of our country. Control over the production of the cinema training films is exercised by the Ministry of High and Secondary Special Education. The circulation of the training films is directed by the Central Cinema Laboratory of the Ministry.

Short scientific and technical films are also produced for student use by the cinema studios.

Programmed training, which involves use of training and testing machines, makes it possible to increase appreciation of the material owing to participation also by the teacher and the possibility of simultaneous active participation of all the students in the study process (individual training). The programmed training makes it impossible for the student to neglect studies occasionally and adds to his self-control.

During programmed training, all material to be studied (from a special textbook or training appliances) is divided into sections arranged in logical sequence. Only after mastering the previous section may the student go to the next one. Some material is introduced into the machines which enables the student to appreciate more what he has learned already. In this event the machine does not act as a teacher. The machine does not teach the students but fulfils the programme prepared and introduced into it by the teacher.

Recorders find extensive application in learning foreign languages.

In our century of rapid development of science and technology, when science becomes an active productional force, the higher school will be unable to train a good specialist if the teaching staff does not carry out scientific research. Hence, all the chairs as a rule carry out scientific research which contributes to the increase of the level of the educational and training work with the students and promotes the raising of the scientific and pedagogical rating of the teaching staff.

This work is continuously and actively participated in by the students who take part in the theoretical and production work of the students' scientific circles headed by the professors and teachers of the institute. In these scientific circles, the students acquire the habits of scientific research.

Students also work in special students' designing and technological offices, thus giving practical assistance to production agencies. Some of the work carried out by the students in these offices may be considered as course projects.

It is not enough for the student to be a good specialist. He should be an educated, life-loving person interested in literature, music, art and theatre. Therefore, an extensive cultural and educational programme is being carried out in all higher schools. Along with going to literary parties, exhibitions, theatres and sports events, the students are active in drama circles, photographic, cinematographic and drawing.

Very popular now is the "Club of Funny and Sharp-Minded Youth". At the meetings of this club the students' groups [illegible] of the whole institutes compete in various kinds of amateur art, in knowledge and sharp-mindedness on various problems. Competition between institutes is shown on television. Judges are prominent scientists, writers, actors and artists.

Training without discontinuing work

Training of specialists for all branches of the national economy without discontinuing work is the basic method for increasing the cultural and technical level of the people as this system makes it possible to study after the work day. More than half of all the students in the higher and secondary special schools of the Soviet Union study without discontinuing their work.

There are three types of training engineering and technical specialists in the Soviet Union without discontinuing work: evening education, correspondence education and productional education (high schools at the producing plants).

The evening and correspondence educational systems involve the whole institutes and evening and correspondence faculties (departments) available in nearly all stationary (day) institutes.

All the citizens who passed the entrance tests may be enlisted in the evening or correspondence department of the engineering high school, but preference will be given to the persons who work in the same speciality (or close to it) as that which will be acquired by them in the high school. To ensure better preparation for the entrance tests and to recollect material studied in secondary school, the preparatory courses are organized by the institutes and production enterprises for those who desire to study in the institute without discontinuing their work. The studies in these preparatory courses which function for ten months are carried out in spare time (after the work is over).

The persons enlisted into the institute and successfully studying there in the evening or correspondence departments receive certain benefits established by the Government. Thus, when carrying out practical laboratory work or taking exams and tests, students are given additional leave with preservation of average monthly pay. This additional leave equals twenty days for students in the evening departments and thirty days for the students in the correspondence departments (during the first and second years of study). The students of the third, fourth and fifth years are given thirty days in the evening departments and forty days in the correspondence departments.

When preparing and defending the diploma project, additional leave with preservation of average monthly pay is extended to four months. One month before preparation of the diploma project, the student may be given an additional month's leave for practical production work and preparation of materials. During this leave, the student receives the state scholarship in compliance with the common procedure.

Additionally, during a ten-month period before preparation of the diploma project, the students of the evening and correspondence departments have one free day a week for preparation. On such days, the students get 50 per cent of their pay. Besides, the student may have one or two days a week (at the student's option) without pay.

All those who work and who are allowed to take the entrance exams have the right to additional leave for fifteen days (plus the time for travelling) without pay.

In the evening system, the terms of training of the mechanical engineer in metal cutting (i.e. machine-building technology, metal-cutting machines and tools) is equal to six years and nine months. The total number of hours allotted for obligatory studies with the teacher is [illegible]. There are [illegible] terms of study, each being divided into two [illegible] (the duration of the first term, [illegible] weeks; duration of the second term, [illegible] weeks; third term, [illegible] weeks; fourth term, [illegible] weeks; fifth term, [illegible] weeks; sixth term, [illegible] weeks; seventh term, [illegible] weeks; eighth term, [illegible] weeks; ninth term, [illegible] weeks; tenth term, [illegible] weeks; eleventh term, [illegible] weeks; twelfth term, [illegible] weeks; [illegible] for preparation and defence of the diploma project).

Thus, the number of weeks is [illegible] including [illegible] weeks for theoretical studies without discontinuation of work, four weeks for practical production pre-diploma work [illegible]teen weeks for preparation of the diploma project, seventy five weeks for exam session and fifty weeks for vacation.

The number of subjects and their nomenclature are the same as in the school plan for the mechanical engineer to be trained with discontinuation of work but the number of hours allotted to each subject for obligatory studies with the teacher is less. This is explained first by the fact that the students of the evening courses commonly have certain experience in their specialty and secondly by the fact that the time allotted for study is limited. As a rule evening students study in the institute four days a week four hours a day (when free from work).

The volume of each subject is determined by the curriculum. This curriculum is commonly identical for all kinds of training. Hence, in the system of evening education a lot of attention is paid to elaboration and publication of proper textbooks and training appliances which may facilitate mastering of the material by the student of the evening course.

In the correspondence system, the term of training the mechanical engineer in metal cutting is equal to five years and nine months.

According to the correspondence system, the student is supposed to master independently all the subjects mentioned in the curriculum. The nomenclature and number of subjects are identical to those specified in the curriculum for studying with discontinuation of work. There are compiled several test tasks on each subject which should be fulfilled by the student with the aid of the textbooks and training appliances. The test tasks are delivered by the student to the institute.

In accordance with the correspondence system, the whole studying process is divided into years but not into terms as is the case with the day and evening systems. Once a year the student should pass a test on each subject. To take exams, the student goes to the institute once a year. The exam and laboratory session takes from four to six weeks. During this session, the student also carries out practical laboratory work and listens to [illegible] and lectures.

The higher schools engaged in training the mechanical engineers in accordance with the correspondence system have an extensive network of training and consulting stations located in other towns and at the plants in which there are many students. These stations make a record of studies of the students who take the correspondence courses [illegible], organize review lectures for these students delivered both by the local teachers and by the teaching staff of the basic high schools and give consultations and tests.

Since 1962 there have been two stages of correspondence training. The first stage involves general technical faculties for the first three years. The general technical preparation includes mechanical, [illegible] and [illegible] courses, enabling those who wish it to get higher education without discontinuation of work by studying for the first three years in the general institute at training and consultation stations.

The second stage involves studying in the same courses in the higher schools which prepare specialists for the branches of economy close to the branch in which the student is working.

The schools carrying out correspondence preparation of the technical specialists commonly organize day studies devoted to the most difficult topics of the subjects.

On the general technical faculty these studies are planned to be conducted within thirty five weeks, twelve hours a week, the total not over 450 hours a year. Correspondence course students who regularly attend day studies may be permitted to omit the test tasks.

For the students of the correspondence courses who may not attend the day studies such studies are conducted during the exam and laboratory session.

The total time allotted by the curriculum for three years of the general technical faculty is equal to [illegible] weeks including 116 weeks for studying the subjects, thirteen weeks for carrying out laboratory work and taking the exams, and eighteen weeks for vacations.

The total time allotted for the next three years is [illegible] weeks including ninety-one weeks for studying the main subjects, eighteen weeks for carrying out laboratory work and taking the exams, four weeks for carrying out practical production pre-diploma work, sixteen weeks for preparation of the diploma project, and eighteen weeks for vacations.

To give assistance to the students of the correspondence courses and to enable them to study successfully all the subjects mentioned in the curriculum, special training lessons are conducted by radio and television.

Similar to the evening system of training, the studies in the correspondence system end in defence of the diploma project in the presence of the State Examination Commission after which the young engineer is awarded a diploma and a badge. All the diplomas are identical irrespective of the training system.

The term of training the mechanical engineer in metal cutting in the plant-technical higher school system is equal to five years and ten months.

Plant-technical higher schools are [illegible] developed in the Soviet Union since 1960. They are distinguished from all other higher schools by a distinctive organization of the training process which combines theoretical studies with practical work at the plant for the whole of the training term.

These schools are organized at the largest and most progressive enterprises and function either as independent higher schools or as [illegible] of the [illegible] higher schools. Such plant-technical schools exist at the Moscow automobile plant named after I. A. Likhachev, at the Leningrad metal-working plant and at the [illegible] metallurgical plant, among others.

The students of the schools are the employees of the given plant and the workers of the other plants belonging to the same branch of the economy who have graduated from secondary school, passed the entrance [illegible] competition, and worked for at least one year at the plant.

[illegible]

The theoretical studies which are not obligatory for the students are conducted in succession (by weeks or by terms): studies with discontinuation of work (as in the day system) are followed by work in the plant (studies being conducted similar to the evening system). When the student studies with discontinuation of work, he gets a scholarship from the plant. This scholarship is 15 per cent more than the common state scholarship for students of stationary day higher schools. The term of study with discontinuation of work is included in the whole length of service of the worker. The scholarship is also paid to the worker student during an additional six to twelve-day leave annually.

Some portion of the material is mastered directly on the working stations. The stations of the workers are changed in the course of their studies so that production work will contribute to a better understanding of the problems discussed in school. Additionally, the worker students get special production assignments.

For instance, the following working positions changes [illegible] adopted for the students involved in "Machine-Building Technology": during the first year the worker students are employed as machine operators; during the second year as [illegible]; during the third year as [illegible]; during the fourth year as technologists; during the fifth year as designers; and during the sixth year as [illegible].

Such an organization of the training process makes it possible to reduce (as compared to the stationary day schools) the time period allotted for lectures, laboratory work and design work by [illegible] per cent and to increase by the same amount the time period allotted for general theoretical subjects, performance of research and scientific work and [illegible] studies.

[illegible]

young countries, one of the most important aid components being preparation of national technical specialists.

The assistance is given in two ways: (a) training of specialists in the Soviet higher schools; (b) assistance in organization of the schools directly in the developing countries.

The number of highly rated foreign specialists trained in the Soviet Union is increasing every year.

The schools of the Soviet Union turn out for the developing countries mechanical engineers, heat energy engineers, electrical engineers, radio engineers, metallurgical engineers, building engineers, hydrotechnical engineers, economic engineers and others.

The foreigners are accepted into the schools irrespective of their nationality, race, sex and religion provided that they have a secondary school certificate.

Foreigners who do not know the Russian language are enlisted first on the preparatory faculties for one year. Besides the Russian language the preparatory faculties deal with mathematics, physics, chemistry, drawing and some other subjects with due regard to the speciality of the foreign student. These subjects are studied in order to acquaint the foreign student with Russian language terminology and to bring the level of his knowledge close to the school entrance level.

All the students from the developing countries study in the higher schools free. They have the right to use laboratories, libraries and sports equipment. All the foreign students get a scholarship of [illegible] a month [illegible] on the preparatory faculties, are given a place in the hostel and get free medical service.

[illegible]

diploma projects are commonly taken back to their country.

After successful defence of the diploma project the State Examination Committee confers on the foreign student the rating of a mechanical engineer in accordance with the obtained speciality and gives him a standard diploma filled in two languages (in Russian and in foreign language selected by the student). The diploma is supplemented by a list which specifies the subjects and the grades. The best students receive the excellent diploma. All the postgraduates also get the badges.

The higher school diploma of the Soviet Union is equivalent to the master of science degree in the United States.

Apart from many higher and secondary schools which may be attended by foreigners, there is the University of Friendship of Peoples, named after Patrice Lumumba. The basic task of the university is giving assistance to the countries of Asia, Africa and Latin America in training national specialists and enabling the youth of these countries (especially the representatives of poor layers of society) to get high education.

The University of Friendship of Peoples was set up by the Soviet Government on 5 February 1960 in Moscow.

The assistance rendered by the Soviet Union to the developing countries in setting up their own high schools includes designing, constructing and equipping the schools, by elaborating and delivering textbooks and training appliances and by sending Soviet professors and teachers to work in the high schools of the developing countries.

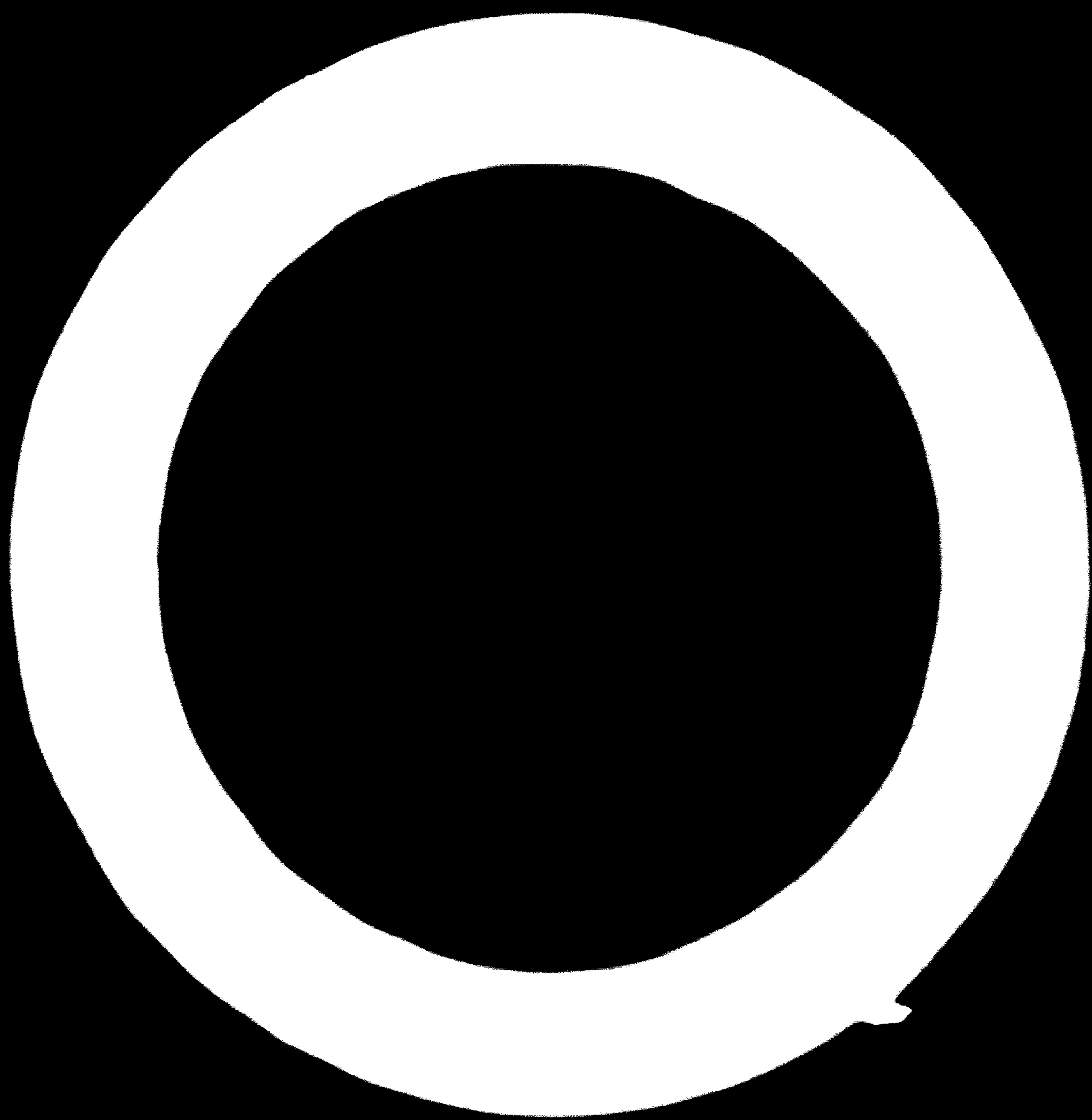
About ninety schools (institutes, colleges, technical and secondary schools) were or are being constructed in the developing countries with the aid of the Soviet Union. They include the Technological Institute in Bombay (India) rated for 2,000 students and postgraduates (1958), Technological Institute in Rangoon (Burma) for 1,100 students and 100 postgraduates (1961), Polytechnical Institute in Conakry (Guinea) for 1,100 students and 100 postgraduates (1963), High Technical School in Pnom Penh (Cambodia) for 1,000 students, Oil and Gas Institute in Boumerdes (Algeria), and the Polytechnical Institute in Kabul (Afghanistan).

Specialization of the schools in developing countries is determined by the specific features of the historical, social-economic, economical and cultural development of each country. Considerable effect comes from the natural resources available in the country.

On the basis of the problems and perspectives of development of its country, the Polytechnical Institute in Conakry, for instance, turns out specialists in industrial and civilian construction, agriculture, prospecting and development of natural resources.

At the first stages of development of the national machine-building industry in the developing countries it is difficult to have specialized plants for production of the metal-cutting machines and tools. Therefore, the mechanical engineer on metal cutting should be rather universal, i.e. working on the machine building plant he should be able to fulfil the functions of a designing engineer, technological engineer and mechanical engineer. In all these capacities he should be a good organizer capable of highly efficient and economical labour.

The progress of the higher educational system in the developing countries is also contributed to by the scientific and cultural relations between young institutes in these countries and higher schools of the Soviet Union. Mutual exchange of scientists delivering lectures, of publications, textbooks and training appliances, establishment of personal relations between the scientists and between the students' organizations — all this promotes mutual enrichment of experiences gained in organization of the training processes and of scientific research.



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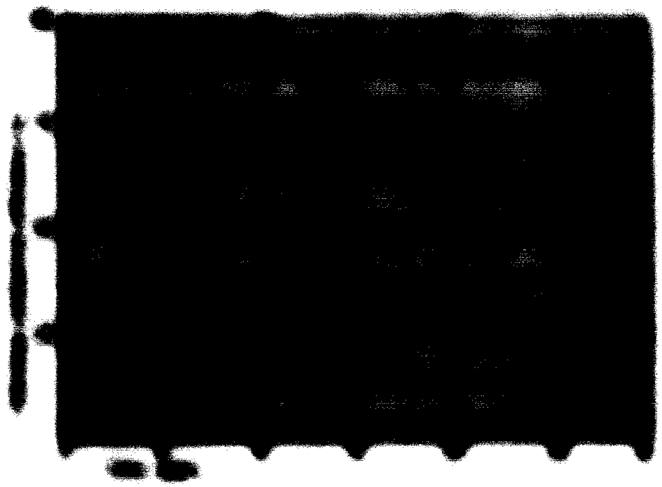
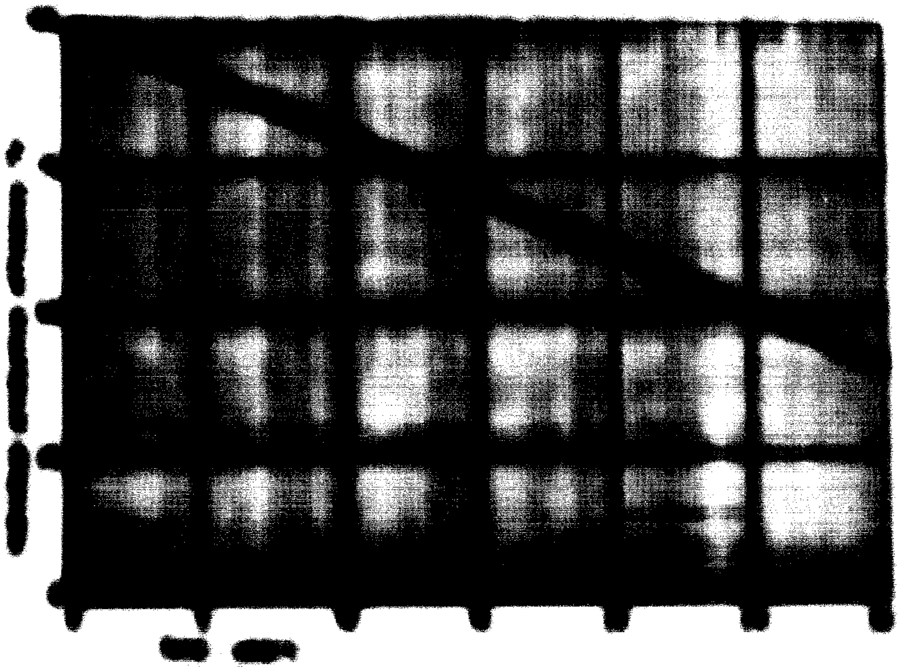
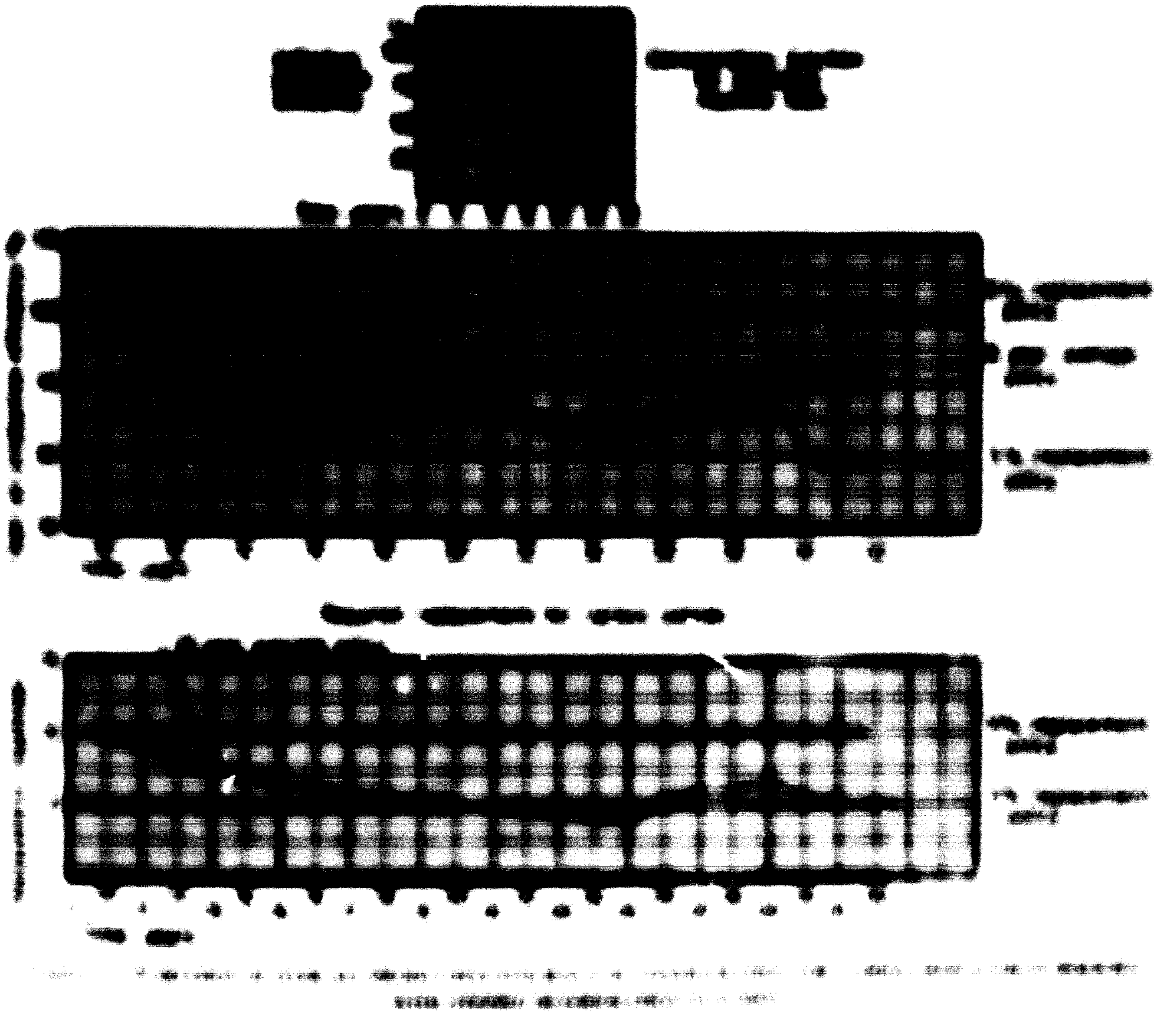






would take several years. In the case of the constant linear deterioration, the decrease in efficiency is much greater but the pattern of recovery is similar.

It is apparent that for any orderly replacement policy there will be a transient condition where over-all productive efficiency varies with time. Subsequent to this, a steady state condition is realized where the over-all productive efficiency remains constant. The length of this transient stage and the ultimate level of the stable over-all productive efficiency depends on:

(a) The condition of the machine-tool configuration before the replacement policy is begun, i.e., age and wear of the machines.

(b) The quantitative level of the replacement policy.

(c) The type of replacement policy.

unchanged and machine tools of a similar nature replace those thrown out by use; it can be shown that to restore efficiency completely under these conditions one would have to replace some 49 per cent of them over a year or so.

For given conditions of deterioration, the quantitative level of replacement must be governed by the estimated savings from restoration of productive efficiency offset against the depreciation and capital cost of new equipment.

As overhauling may not completely restore a machine tool to its former efficiency, it may nevertheless affect the deterioration in efficiency, and if one assumes the linear deterioration effect together with an overhaul restorative effect as in figure 5, one can get the comparative over-all factory efficiency curves as in figure 6.

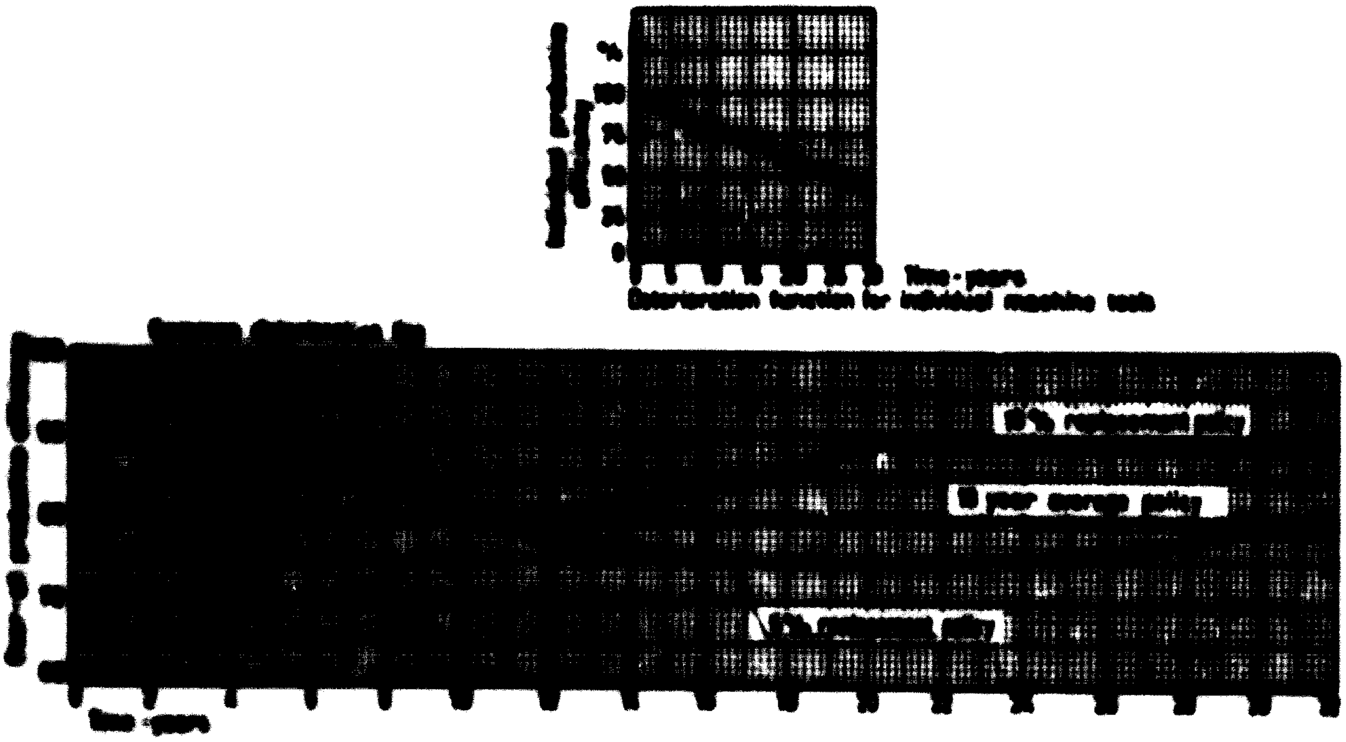


Figure 4

VARIATION OF OVER-ALL PRODUCTIVE EFFICIENCY OF CONFIGURATION FOR VARIOUS REPLACEMENT POLICIES FOR STRAIGHT-LINE DETERIORATION FUNCTION

In the case of most factories, the imponderables are:

(a) What is, or was, the state of the original configuration?

(b) If an orderly replacement policy is in being, where are they along the transient curve, or have they reached stability?

Having reached stability and realizing the loss of over-all efficiency, what corrective measures can be employed to bring the system back to its former competitive position?

FACTORS DETERMINING THE REPLACEMENT POLICY

The hypothetical conditions just indicated assume that the basic technology on which the factory works remains

One would expect that the results of overhaul would not necessarily restore a machine completely to its former efficiency, also that the frequency with which overhauling becomes necessary would increase with age.

The cost of overhaul and just what is required has to be assessed against the type of work to be carried out on the machines. In fine-finish accurate work, one would need to spend more money on remachining the slide ways as well as replacing the gears and lead screws than for work of a rough nature. In the latter case, time between overhauls would be much longer. More often than not, however, machines are expected to perform both rough and finish machining, in which case the latter conditions determine the extent and cost of the overhaul.

Policy will obviously be determined by the nature of

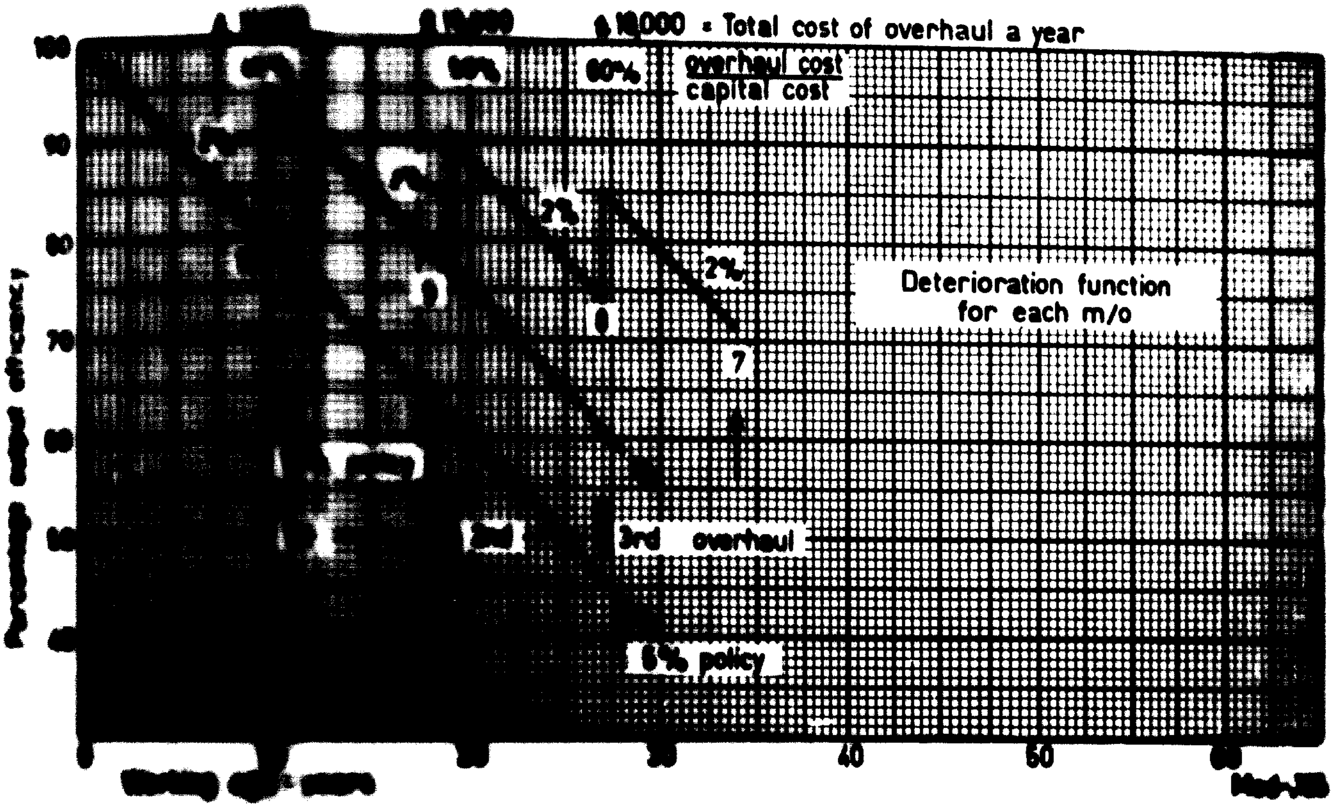


Figure 5

MACHINE-TOOL REPLACEMENT POLICY

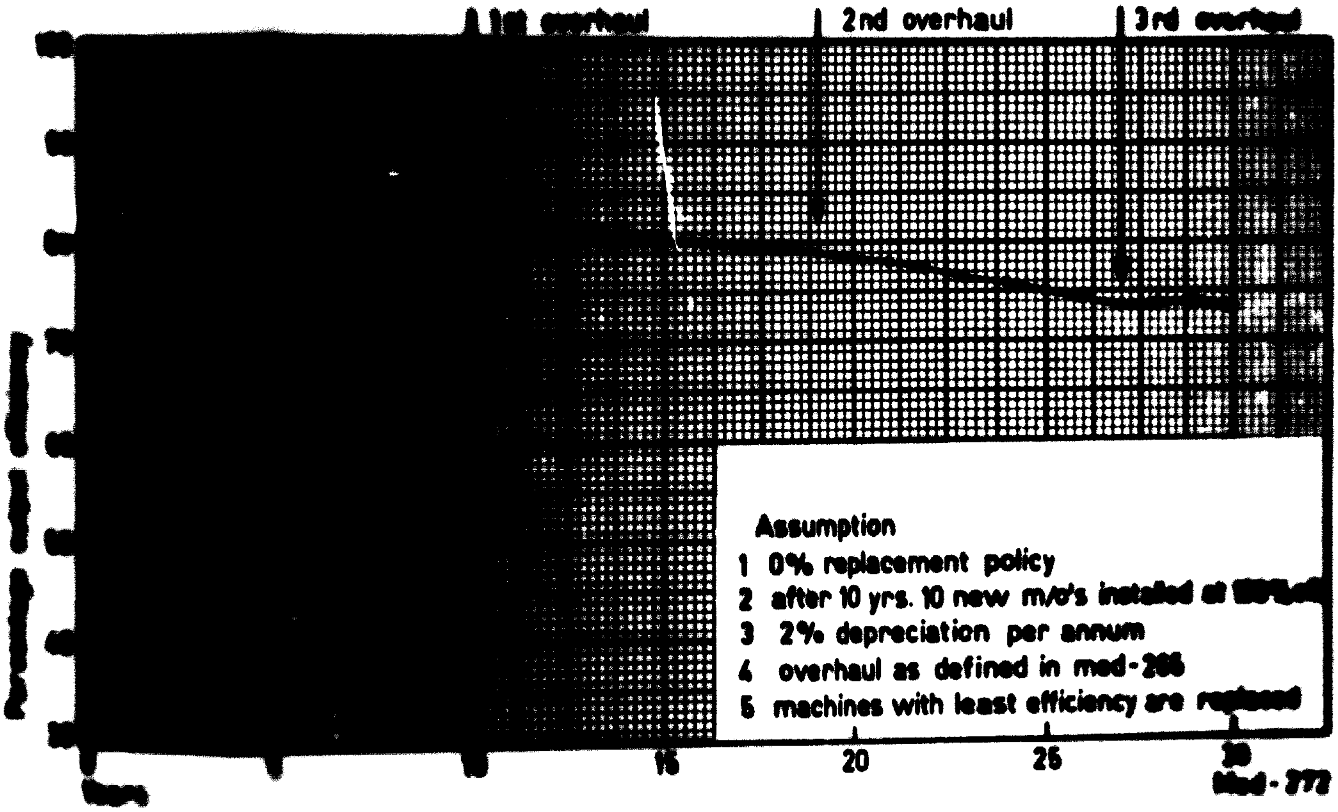


Figure 6

MACHINE REPLACEMENT POLICY

the work in a factory, and this may well change radically over a period of some twenty years.

The transition from small quantity, small-batch work in great variety to large volume production will give rise to the transition to full automation as an economic necessity, but where batches are to remain small without any concession in terms of reduction in variety or increase in quantity, then the changes will mainly be in techniques or in the individual design of the machines. The over-all policy will be implemented as a judicious mixture of replacement by new machines of improved design and efficiency, new techniques applied to old machines to improve their productivity and accuracy, and the renovation of old machines.

Figure 7 shows the effect on factory efficiency if the average efficiency of the combination of new machines, renovations and new techniques exceeds that of the productivity brought about by the replacements should give rise to improved profitability. The capital cost of the new machinery must be amortized without an increase in the cost of manufacture of the components.

Figure 8 shows the curve for the 2 per cent deterioration and the effect of injecting new machinery at the ten-year stage of 120 per cent average efficiency on a 10 per cent replacement basis. Figure 9 shows a similar set of conditions but with the replacement machinery assessed at 180 per cent.

The cost of parts produced over the period is represented by the bar chart. This cost can be graphed under three main headings: Direct cost of labour, standard overhead charges such as rent rates, heating, lighting supervision, maintenance and administration charges, and the amortization of the capital equipment. Over the first period, the productivity diminishes, increasing labour

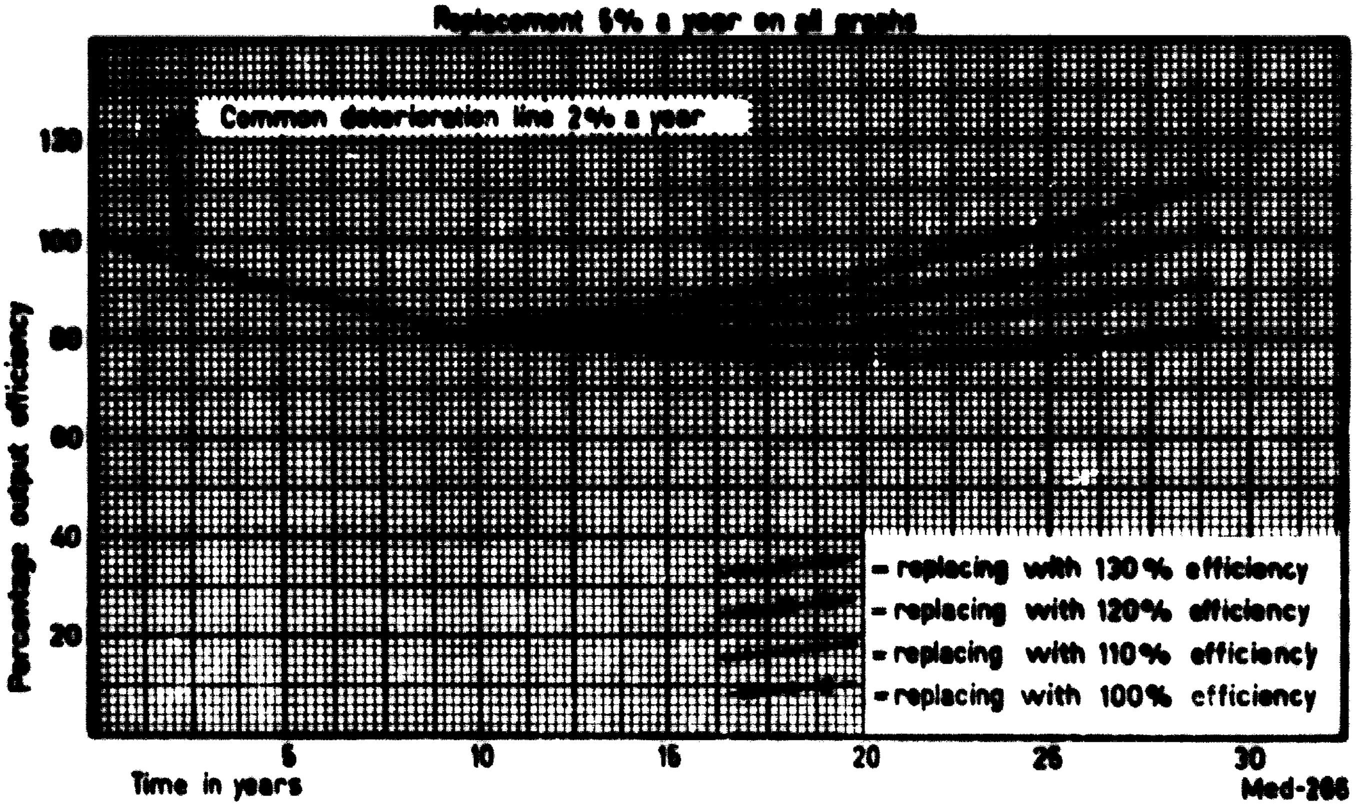


Figure 7

MACHINE-TOOL REPLACEMENT POLICY

original machines when they were first installed. From this it can be seen that to make any rapid effect the required average improvement in efficiency must be quite high on the basis of 5 per cent replacement if the condition of the original machines has been allowed to deteriorate to the 80 per cent efficiency level. In all probability, however, the changes in technique could be applied to a large number of the older machines without too great an increase in capital cost. At the same time, however, it will be necessary to replace the older worn-out machines on a basis consistent with the money available and the best efficiency.

The most important consideration is that the improved costs. The greater production time means that an additional overhead must be carried by the part, that is to say, time on the shop floor proportionally increases the amount of rent, light, heating and supervision. In the same way, the amortization rate for capital equipment must fluctuate as repayments can come only through sale of the produced articles. As manufacturing time lengthens there will be fewer of these and hence the amount of money which must be levied against each article will have to change.

At the end of ten years, the first machine will be paid for, theoretically reducing the cost of manufacture but from this point, the cost of the new machine must b

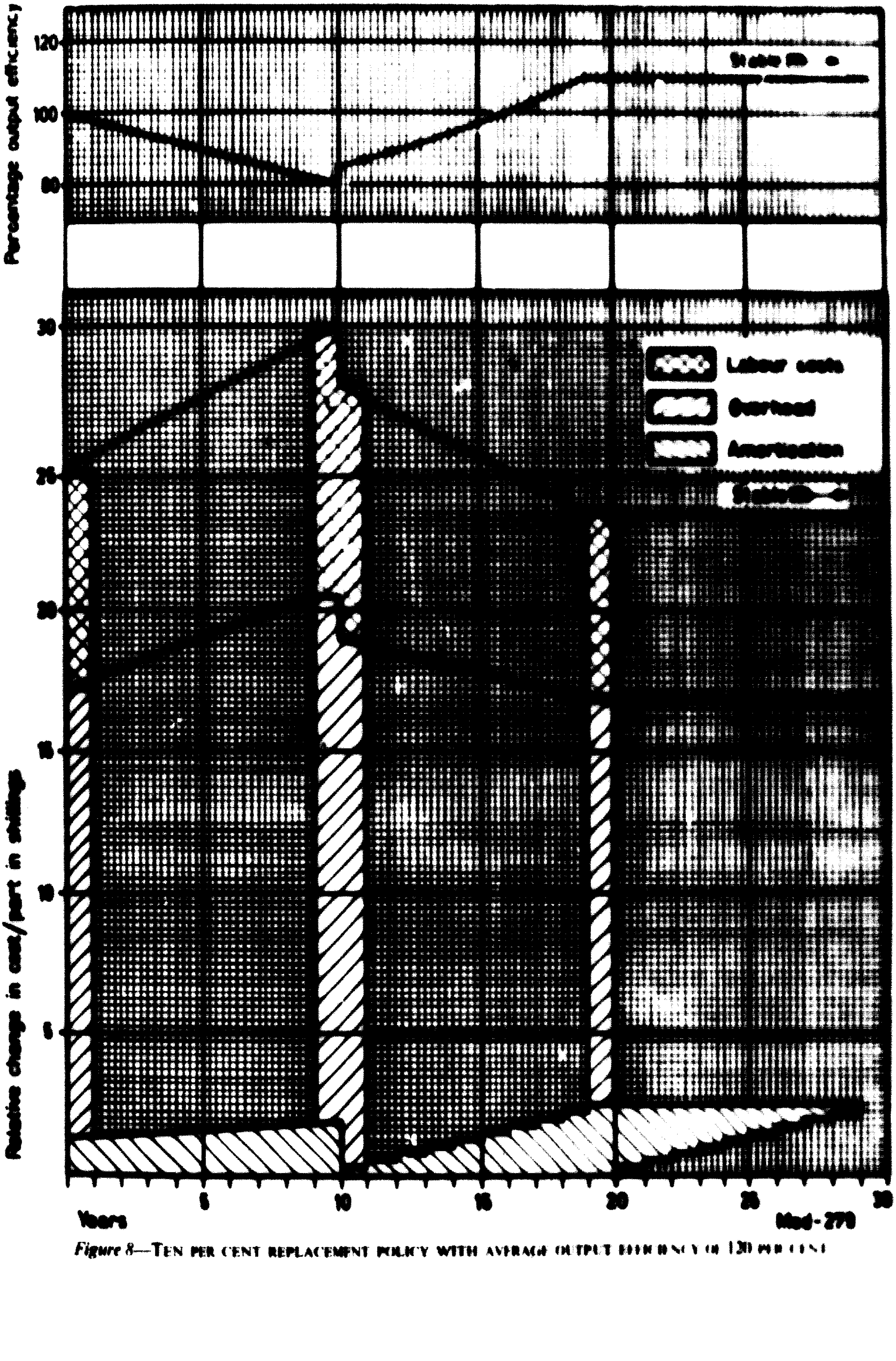
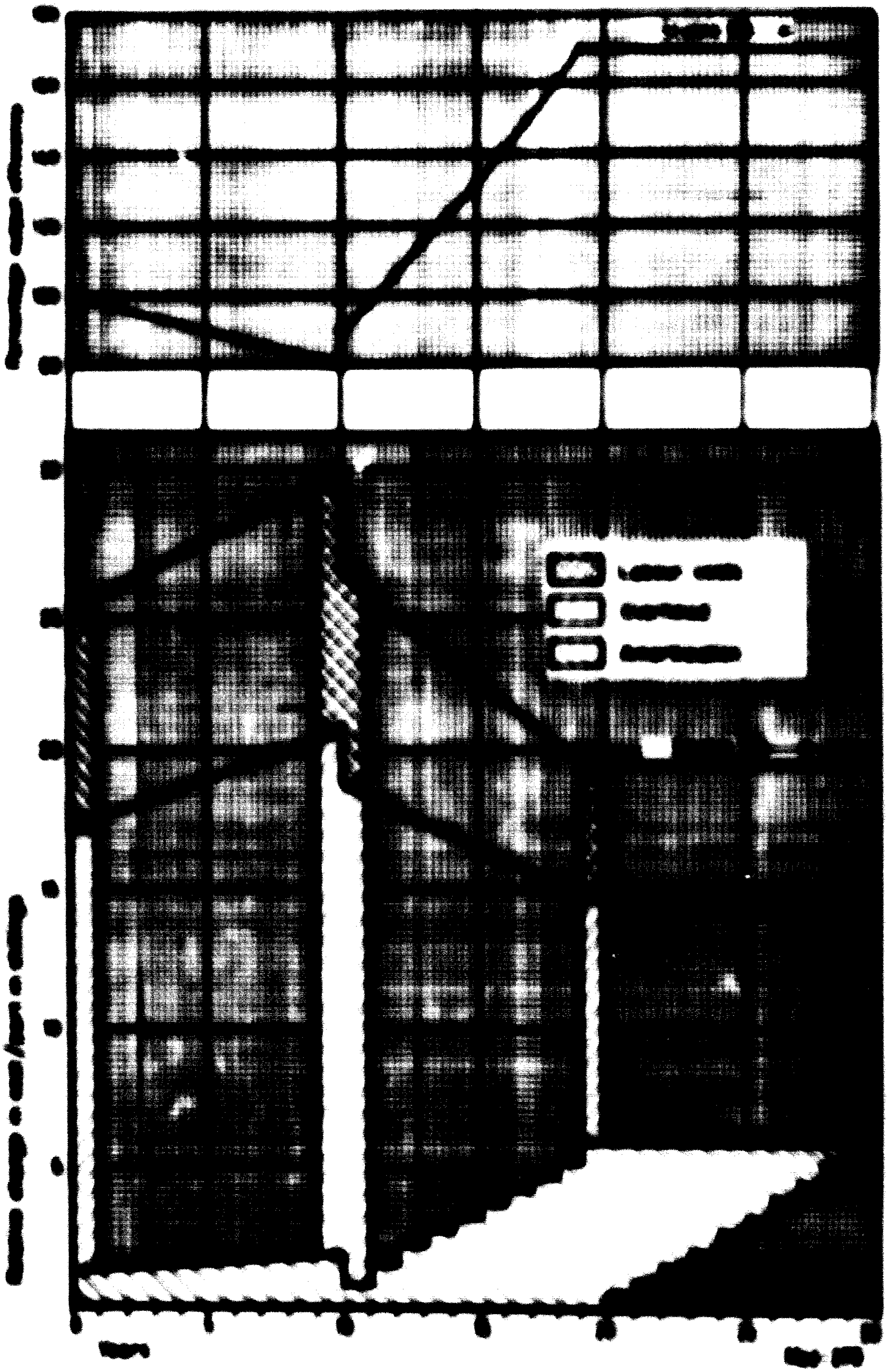
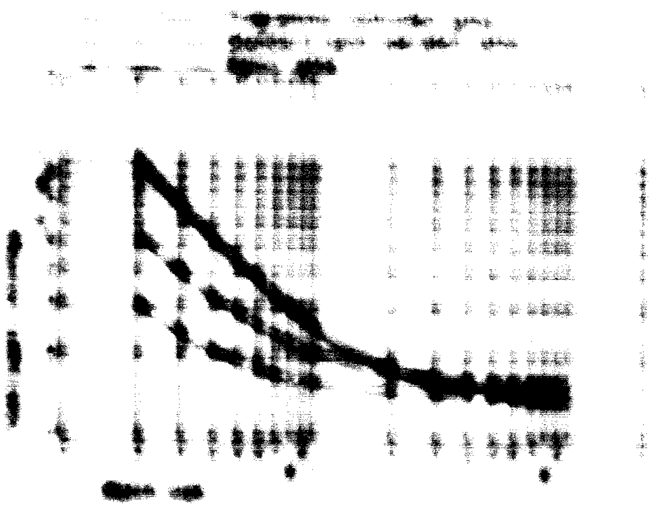
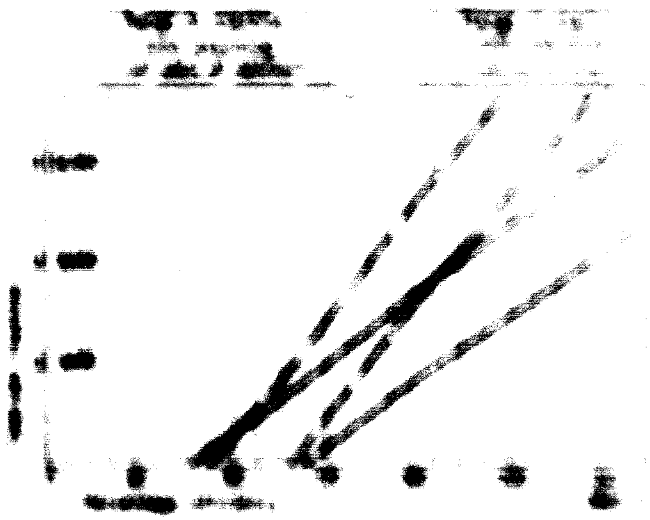
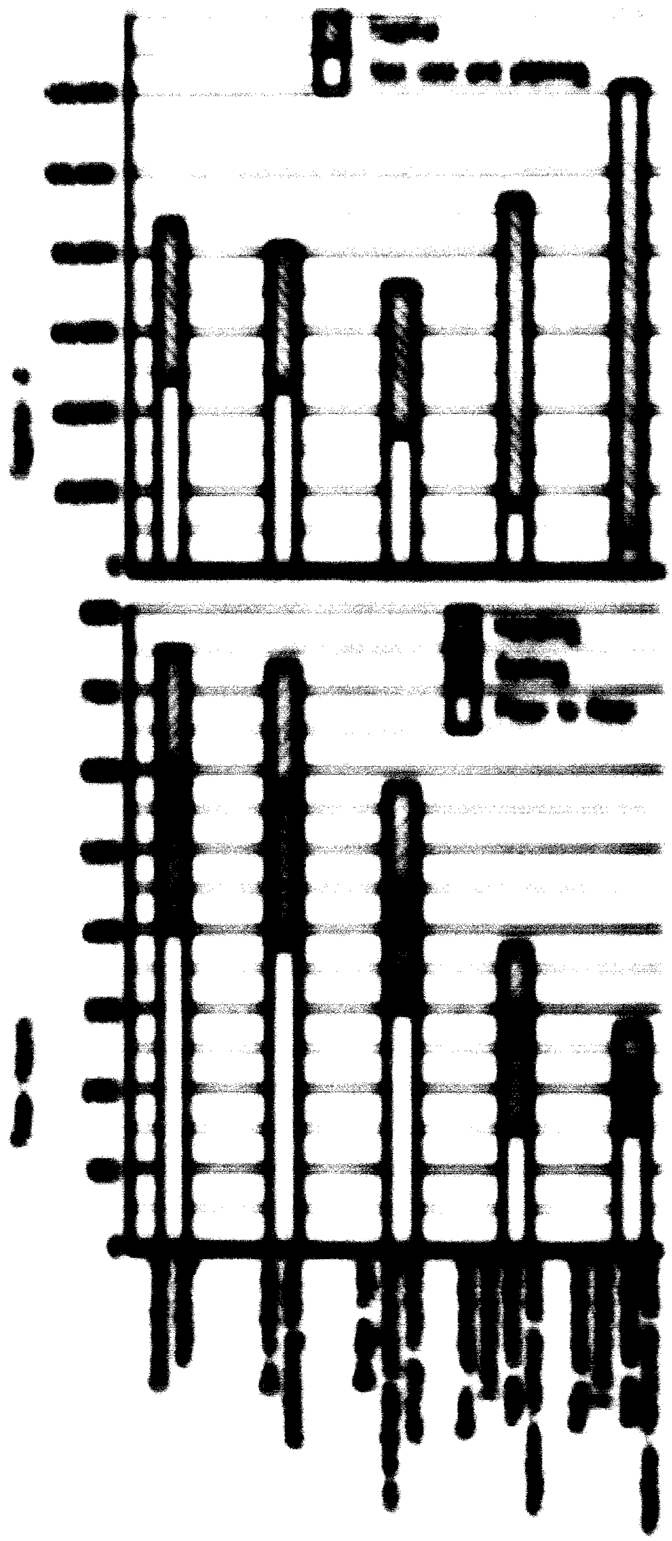


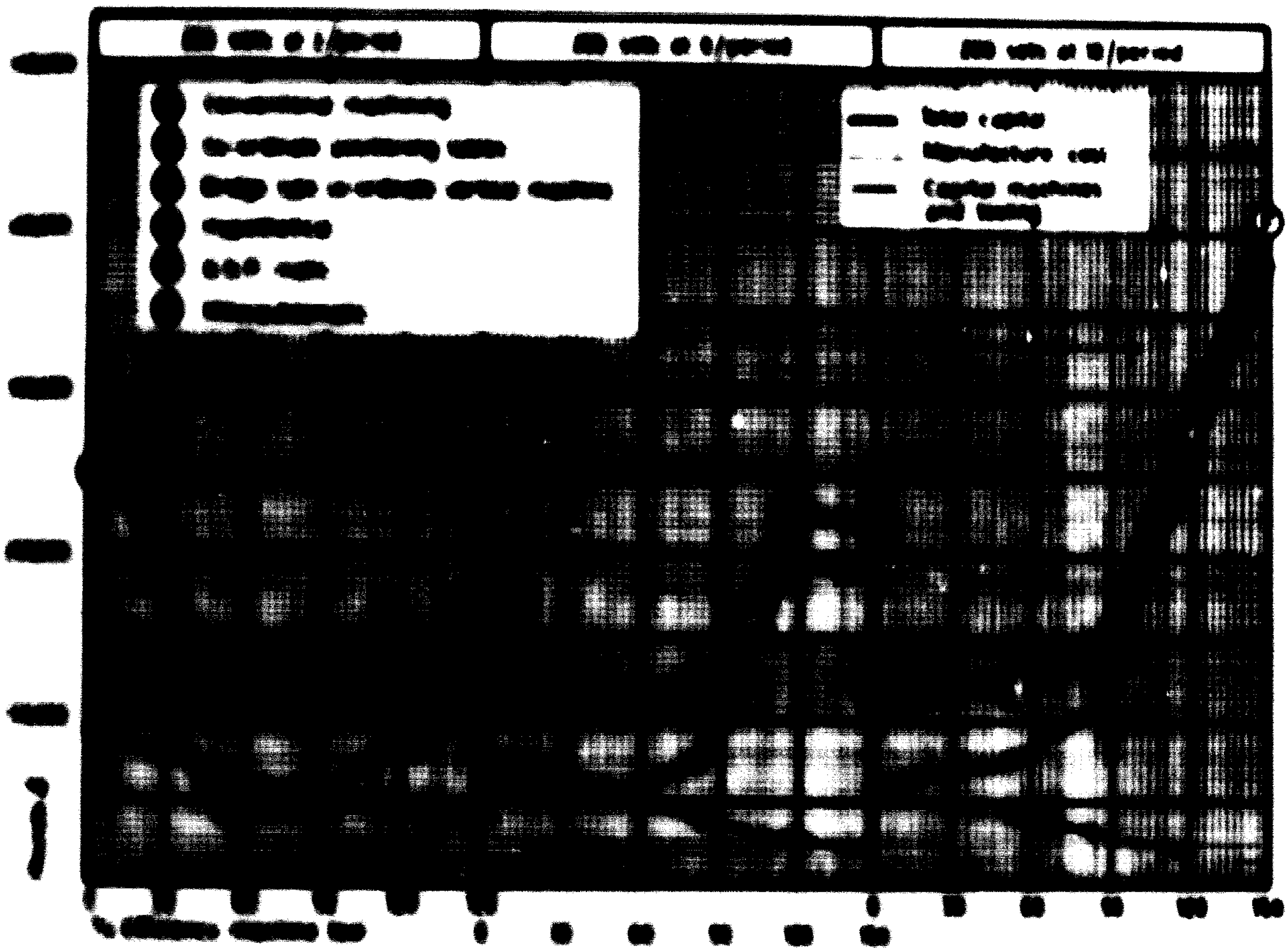
Figure 8—Ten per cent replacement policy with average output efficiency of 120 per cent











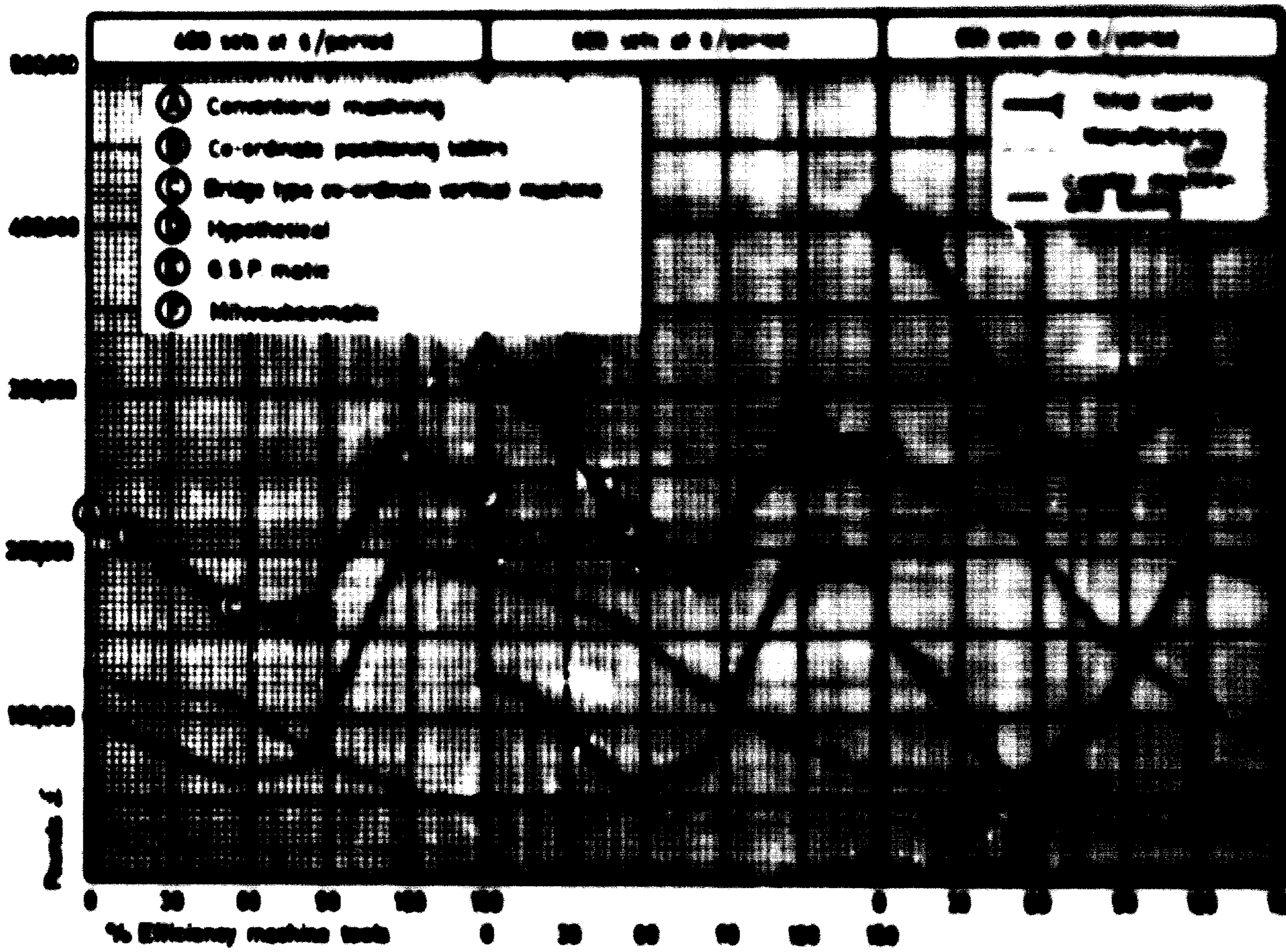


Figure 14

inspectors will be required together with the reduction in work for a given output.

When choosing the particular type or types of machine as replacements from this category one must again give careful consideration to the exact nature of the work in hand and the possible future trends from the point of view of quantity, variety and rates of production. Such machines would initially be used to augment existing equipment, tackling the short-run or prototype work, but ultimately their scope would widen.

Observations derived from conventional practice

The figures and examples form only a very limited outline of the problem. They provide a basis for study in order that the problems can be delineated with greater accuracy.

The true effects of machine wear on the productivity of a factory are not easy to determine. Ostensibly, time studies result in rates of manufacture which do not change and theoretically the cost of a particular part should not alter, but with machine wear must inevitably come increasing difficulty in maintaining standards of accuracy and quality. This difficulty is bound to be assessed by the operator and taken into account when the time for subsequent new parts is being considered.

This deterioration in efficiency may be masked by the introduction of new materials about which there is insufficient data as to their machinability. It will be a very gradual effect very much related to the nature of the work and output demands. Its effect, when translated into terms of profitability, will be magnified since, as a direct result, the sale of a reduced number of articles must carry the overhead burden.

From these observations stem the problems of assessing machine wear and measuring the over-all efficiency of a factory system. Much work has been done in the field of planned maintenance to overcome the productive loss caused by machine breakdown, but there is the need to be able to measure more accurately just how the machine behaves in relation to the work it has to perform. The accuracy with which the parts can be produced can be checked with relative ease, but the effect of wear which results in the increased tendency towards vibration and a deleterious effect upon cutting-tool life and surface finish needs further study. Tests need to be devised which will demonstrate the condition of the machine in this respect and records of this nature should determine the programme for planned maintenance. To this knowledge must be added that of the better understanding of the machining characteristics of the materials from which the parts are to be made. Tool wear and horsepower measurements enable an accurate assessment to be made as to whether a particular machine is performing at th

[illegible]

[illegible]

[illegible]

This state of affairs develops as the company grows. In small companies the owner or entrepreneur wears several hats. Very often he is engineer, salesman and production engineer and can decide on the basis of his knowledge of all three departments the best course of action. As the company grows, these functions reach magnitudes which are beyond the control of any one man and the firm splits into departments. The continued growth of the company sees the strengthening of the boundaries between the departments and a general lack of understanding of each other's problems. The production team has no time to get out and observe at first hand the type of work which is being carried out by its customers or the various ways in which profitable help could be given. The salesmen on the other hand are not always chosen for their technical ability. They often miss opportunities and make unreasonable demands with regard to time in solving production problems.

Both sides must have a wider knowledge of the complete set of problems facing a firm if the correct policies on replacement of company machinery are to be adopted. Communication techniques must be evolved which are understood by both sides. A language which is comprehensible to both must be formulated. This language must obviously be an improvement upon that which has been used up to the present, that is, standard accounting procedures.

Accounting procedures

The accountant attempts to satisfy the requirements of management, production and sales for control information by collecting all data relating to expenditure and then presenting it in a form which purports to show the profit or loss situation at the time of data collection. The departments then measure their performance against this information. This is obviously a vignette, a cross-section [illegible]

[illegible]

If we consider the curve showing man's ability to travel at speed against time and [illegible] progress at this stage was slow and almost linear. It would have been possible in the early years of Elizabeth's reign to predict what England would have been like at the end of the century. The same was almost possible in the late seventeenth and early eighteenth centuries, but now we are on that part of the curve where change is becoming rapid. We tend to project our experience in the past along the tangent to the curve and inevitably are surprised when we find that the advances are much greater than expected. This state of affairs will inevitably get worse and we will find ourselves underestimating our targets by greater margins unless we can develop better methods of prediction and be able to assess rates of change with greater facility.

The present accounting methods will not fulfil these needs and a more scientific approach will have to be devised.

As a first step, it will be necessary to rethink many of our ideas. The salesman, the production engineer and the accountant have very different ideas of what a company may be trying to do. The salesman feels that he is selling a service—this may be in the form of a special product, but he regards as paramount the needs of his customers and the servicing of their requirements as the first duty of his firm.

The production engineer has to make pieces of intricate shapes and high quality. He has to keep his machines running at minimum cost, or so he thinks.

The accountant is obsessed with return on capital and regards people and materials as items which can be reduced to purely money values and juggled accordingly. Fifty people are fifty times their weekly wage as far as he is concerned, but the production engineer will see in each a different potential for productive effort. The salesman views them as remote beings who never produce enough and are always the root cause of difficulties with his customers.

[illegible]

The accountant should be able to provide figures which show just what action should be taken by the sales force to change the product mix in such a way that the production engineer can operate at maximum efficiency while, at the same time, obtaining the optimum added value for the labour force.

It should be possible to predict the changes required in production techniques to meet alternatives in product mix and to show just where and how the introduction of new machinery would affect the trading position of the company as a whole.

PRINCIPLES OF ENGINEERING ECONOMICS

The advent of the computer has enabled a much more sophisticated approach to these problems, but not all production engineers and not all salesmen are familiar with the latest scientific techniques or how they can be used.

There is a simple approach which in a large number of cases could be applied to the problems of small firms and which would lead to an understanding of just what could be done at a later stage when the problems are bigger. A. W. Rucker in 1932 formulated the concept of added value.

[illegible]

For convenience, the accounting procedures are usually brought into action each month and sets of figures are produced to compare performance over previous intervals.

If the total estimated labour costs and added values for each product sold during the monthly period are plotted graphically, a pattern of points will emerge. The pattern delineates the product mix. A simple statistical assessment of the mean value will give a line shown as S in figure 15A. The slope of this line is the theoretical production ratio that could be obtained by the mix of products.

Those above the line constitute good products from the point of view of their contribution to the trading surplus; those below would require more labour than their total returns warrant. Product 1 is good, as well as product 3, but product 4 should not really have been accepted. The difference between the added value and that which would have been obtained for a job with the same labour cost but whose added value was at the intersection of the vertical for the labour cost and line S m[illegible]

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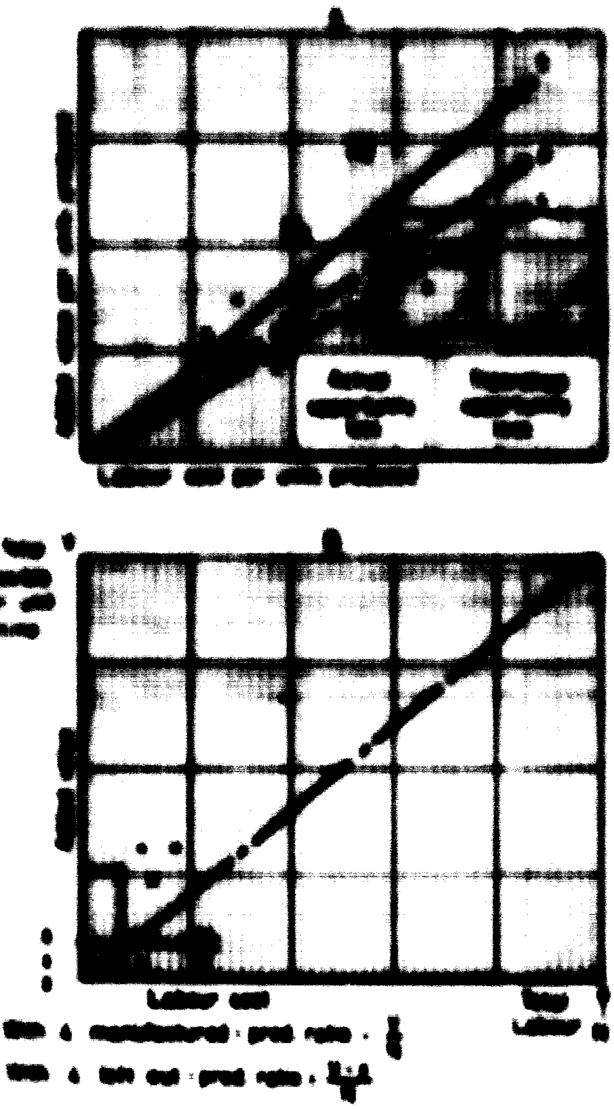

Figure 15

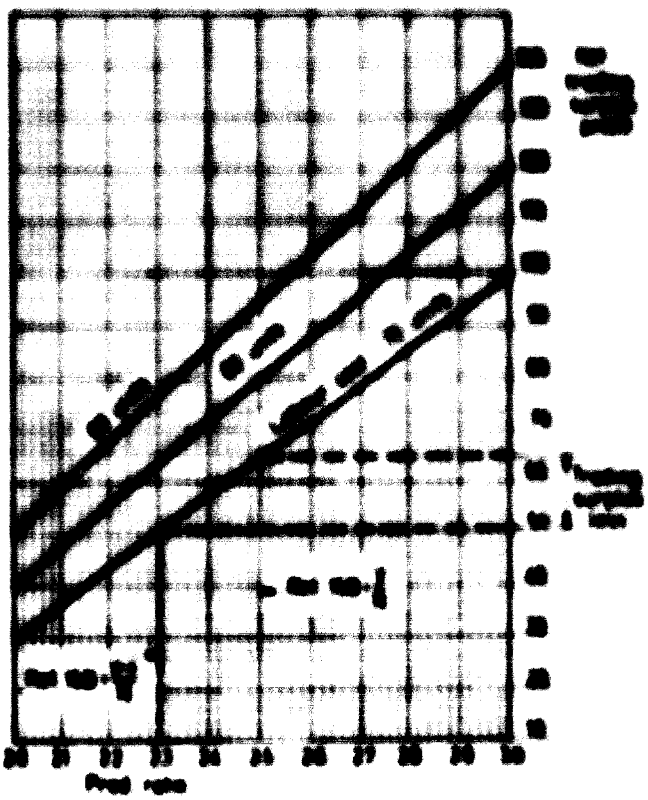

Figure 16

The graph can be extended to embrace the total labour cost which can be attained, that is, defining the total labour force and the total added value that can be obtained. When the labour force is virtually fixed, a small total added value even though theoretically favourable would result in a poor production ratio, *P*, and indicate the amount of surplus labour.

It is also possible by these methods to examine the manufacturing processes of individual products and

This simple approach does not take into account the effect of constraints in the production system. It may be that certain equipment constitutes a bottleneck. Again turning to figure 15A, the production of item 4 may occupy a certain piece of machinery which has also to be used for items 1 and 3. The net result of this might be that less of 1 and 3 can be produced if all of 4 has to be made. This would compound the ill effect of manufacturing item 4 or if the amounts of I and I could be increased, the possible production ratio S would be much greater. Where there are a number of constraints affecting many of the items produced, then the problem becomes complex. In these circumstances a study relating all the items to be produced, their production rates, costs and the constraints in terms of a matrix of linear equations can be made for which a computer will provide answers similar to those derived in the simple way.

Projected estimates of product sales can be divided into product types and detailed requirements. From this can be derived optimum methods of manufacture and specifications of possible machinery for production. Theoretical assessments along these lines will enable determination of where the maximum returns can be obtained for a given capital investment. For example, in a factory manufacturing a number of items, a section dealing with grinding is overloaded in the manufacture of certain products which are in themselves very profitable and whose total volume is fairly large. A good case could be made out for more machinery to alleviate this problem. The toolroom, however, needs a similar grinding machine to deal with the increased load in servicing the tools for other machines needed to produce a much larger and equally profitable line of products. The returns from installing the grinding machine in the toolroom, by normal accounting assessment procedure very difficult to justify, could, in fact, yield returns many times greater than from putting it in the production line.

In terms of replacement policy, it is therefore necessary to consider the system as a whole and plan the introduction of new or replacement machinery in a pattern which will fit the short-term as well as the long-term requirements.

In what has been called the conventional approach, the production engineer has (by reason of his remoteness from the over-all picture) tended to think purely in terms of the increased efficiency of the individual units under his control. He isolates the returns to that particular section, with the real issues blanketed or fogged by the arbitrary assessment of overhead costs, materials often used being lumped together with fringe benefits and depreciation costs in such a way as to confuse the issue and prevent a true assessment of how he is using his labour.

By the suggested approach, much of this misunderstanding can be removed and the production engineer and the sales engineer can look quite dispassionately at the basic effects of their actions upon the company's trading position.

Cost of Replacement and New Machinery

The principle of setting money aside to allow for the dilapidation and general wear and tear of machinery is sound. However, the rates at which this has been set in the past have been purely arbitrary and unrelated either to obsolescence, from the point of view of production techniques, or to the true condition of the machinery. There has been an ingrained belief that one should conserve capital equipment and by doing so minimize costs.

Fortunately or unfortunately, the limiting factor in the past has been the cutting tool itself. The time lost in replacing a worn cutting tool has determined the optimum rate at which metal should be removed.

Consider the equation given for determining cutting conditions

$$TMC = TR \cdot \frac{CRT}{CO}\left(\frac{1}{a} - 1\right)$$

Where

TMC = tool life for minimum cost
TR = tool replacement time when worn
CRT = cost of the tool cutting edge
CO = overhead rate
a = tool-life exponent in the metal-cutting equation $ST^a d^b f^c = G$
d = depth of cut
f = feed per revolution
G = the machinability constant for the group of materials being considered
S = surface cutting speed
T = time for the tool to wear out or to reach a given condition of wear
c = exponent for the feed factor

Where the overhead rate is high, the expression CRT/CO becomes small. Overhead in the equation is comparable to the total labour costs, that is, costs incurred by both direct labour and support labour plus contributions to sales and administration and depreciation. In big firms this will be large and, as can be seen in the graph in figure 16, the larger the total labour cost the higher must be the production ratio for a given trading surplus to satisfy a given capital outlay.

In the small companies where the costs are low, the minimum cost is obtained by taking this low overhead into consideration and where a very expensive cutting tool has to be employed it would appear to pay better to conserve this by operating at lower speeds.

The fallacy in this argument is that the cost has no relationship with the selling price and that the added value of the article should determine the rate of production. It is obviously better to produce as fast as possible in order that time saved can be employed on other profitable work. The graphs in figure 17 illustrate this point.

From this it can be derived that in almost all cases it is probably the best policy to drive machinery to its maximum, bearing in mind that finishing operations and accuracy must not be impaired. The type of business will obviously determine the pattern of machinery to be used and the nature of the market it serves will also influence the decisions in what type of equipment would be needed. The jobbing shop will tend to try and remain as flexible in its array of operations as possible while the specialist product firm will in the future tend to employ more and more specialized machinery. The growth in sales of special machine tools over the past few years has been considerable. The automotive industry is a typical example but the trend has been set, particularly in the [illegible] costs are high, to move away [illegible] to highly specialized, fully [illegible] Market growth has been suf- [illegible] approach. Even in these cases [illegible] driving the machinery to the [illegible] advantage of the market situation [illegible] to obtain the best pos- [illegible] research is now being carried out in [illegible] wear and incorporation of [illegible] hydrostatic bearings will probably [illegible] high production machine tools in the [illegible]

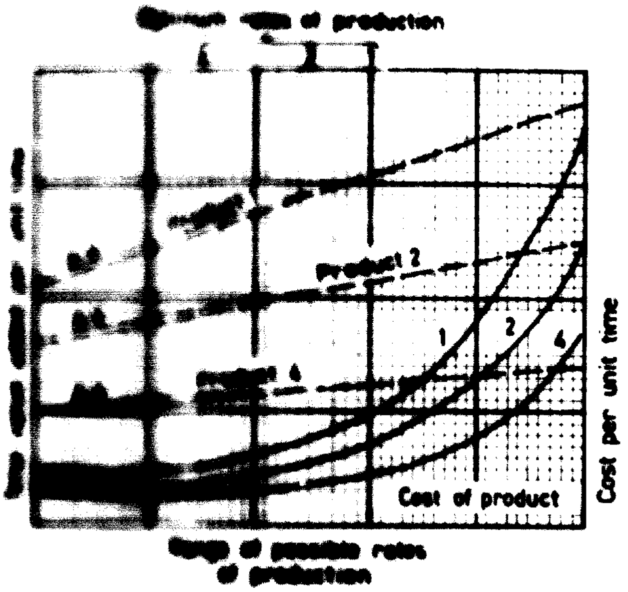

Figure 17

[illegible] saved by the use of fully automated [illegible] control with feed-back controls [illegible] will help to offset the high [illegible] innovations, but additional [illegible] to make these complicated [illegible] systems more reliable. Down [illegible] minimum for servicing and the [illegible] sophisticated machinery is to [illegible] principle of redundancy [illegible] possible. This principle in- [illegible] of a number of control circuits, [illegible] of performing the operation. [illegible] take over. In this way, the circuit [illegible] dependent upon the reliability of the [illegible] and its reliability as a whole [illegible] of times. The cost of the extra [illegible] small compared to costs if the [illegible]

[illegible] amount of capital that can be [illegible] to exploit a given market situation. [illegible] the equation $TS = AV - LC - SA - D$ [illegible] TS = trading surplus; AV = [illegible] the total labour costs, both direct [illegible] sales and administrative expenses; [illegible] depreciation figure, then we can see that [illegible] where the added value is more or less [illegible] LC and D determine the value for TS.

There is a limit to which the value of LC can be reduced, as this involves both those actually operating machines and those who keep them running, both the equipment and refurnishing the cutting tools, i.e., electronics experts and toolroom personnel. The cost of the support labour will rise with increased automation since a high degree of specialized training will be needed to ensure satisfactory performance by these people.

If we consider a certain product and the effect of mechanizing or automating the operations, one can express this in graph form, as in figure 18. The degree of assistance to the actual labour forms the base and the cost of direct labour; support together with the cost related to the capital expenpiture (as on predetermined rate of return) forms the vertical axis.

The summation of these factors yields an optimum expenditure and determines the degree of mechanization or automation that should be employed.

It is possible to express the same situation in another way and relate the expenditure to the improvement in the production ratio. In figure 19, it can be seen that when the cost of automation rises rapidly, surplus will fall off indicating that in each case there will be a point beyond which it is not worth pursuing full automation. The cost of automation is seen as a depreciation or capital recovery charge and this is obviously related directly

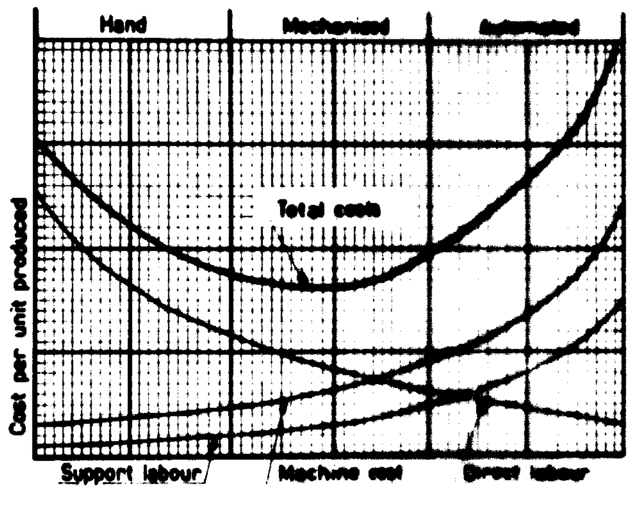

Figure 18

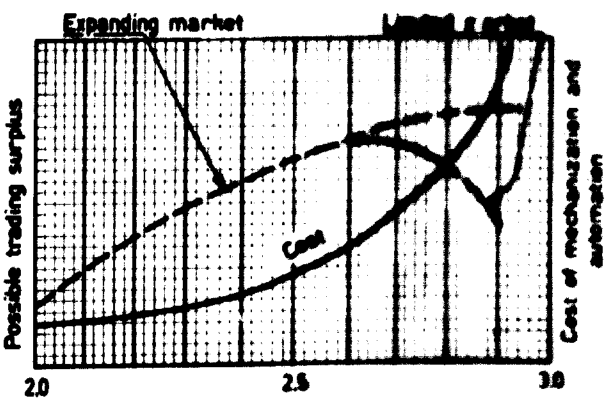

Figure 19

to volume produced. The greater the volume the less will be the value of D in the equations and the further to the right will be the trading surplus optimum in figure 19.

With the move to more and more specialized machinery, it can be seen that the longevity of the production equip- must be related more and more to the duration of the project. It will have to last and perform satisfactorily until a new product in concept of manufacture renders it obsolete. With standard machinery working in conjunction with specialized equipment, the same rules will apply and the tendency will be for such to be designed to give the maximum output over shorter durations of time.

Budgeting for capital expenditure

From the foregoing, it can be seen that even in small firms it will no longer be wise to budget for capital expenditure by purely off-the-cuff guesses. Quantified relationship between the sales projections, with their attendant market constraints, can be made with the degree of production expenditure and with its calculated effect upon the efficiency of the organization as a whole. The mathematical equations for the various relationships can be obtained and by a process of iteration the optimum expenditure commensurate with returns calculated. The services provided by the computer are now well within the reach of all sizes of firms, either by renting time or by actual purchase. These equations when formulated constitute what is termed "soft ware" as opposed to the physical entity of the actual computer installation categorized as "hard ware".

The group of equations as soft ware constitute a mathematical model of the organization upon which experiments can be tried out. These experiments would take the form of considering various possible market situations and then determining the optimum degree of capital expenditure. That is, how much mechanization or automation would produce just how much trading surplus. By making the model more complex and relating the operations of the various departments within the firm, the interactions of restraints or production bottlenecks can be assessed and the returns in terms of the organization's trading calculated.

In this way, many of the possible future developments in terms of market changes and the attendant effects upon the company can be analysed and from these a policy laid down which will be as near the optimum as possible.

Summary and conclusion

An assessment is given of the effect of rough-and-ready policies on ultimate factory efficiency when considering the replacement of standard machine tools by tools of a similar technological standing. In the light of this the effect of merely replacing the tool or introducing new or better techniques can be determined, but in all these approaches the link between the machine tools, the constraints that each group of machines places upon the other in relation to the factory output as a whole, is missing.

A simple approach to engineering economics enables an understanding of the sophisticated methods that are now available.

By studying the interaction of all the machine tools and processes and constructing a model which relates their operations mathematically, either by techniques such as linear programming or simulation, to their outside or sales environment, their requirements can be matched to predicted future requirements. The company may decide to diversify its operations or embrace new markets with products not previously manufactured. It may introduce new technologies in a field it already exploited or increase the production of the goods it already makes.

In all this, a forward prediction or marketing plan is the first requirement and this must be matched to the model of the company in its present form. The deficiencies in production capabilities can be determined for optimal profitability. These specifications may, in the first instance, be impracticable, but they may indicate profitable lines of development. The type of machine tool which can be made will have a performance which can again be assessed as to what its effect will be on the factory as a whole. This may be shown to exceed by many orders of magnitude the returns related to its individual productivity.

The capital outlay needed to finance these new tools can be assessed in terms of the productivity of the factory and a much more accurate calculation made of the ultimate returns. It is now possible to hand large investments covering many factories and business in a large corporate body, timing the introduction of new equipment and installations to maximum profitability. It is interesting to note that the conclusions from such a study indicate that the solutions are robust from the point of view of the actual expenditures, even though the markets may not develop precisely as predicted. All that happens is that the timing of the capital expenditures may either be delayed or advanced to meet the situation.

Part Three

TECHNOLOGICAL DEVELOPMENTS IN THE METALWORKING INDUSTRIES

TRENDS IN THE DESIGN OF METALWORKING MACHINERY AND IN PRODUCTION METHODS

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INTRODUCTION

For every nation, the world of tomorrow depends upon the metalworking machinery of today and the development of such machinery in the years ahead. Nations with highly developed metalworking industries enjoy the highest standards of living. The industrially developing countries are striving to follow this pattern.

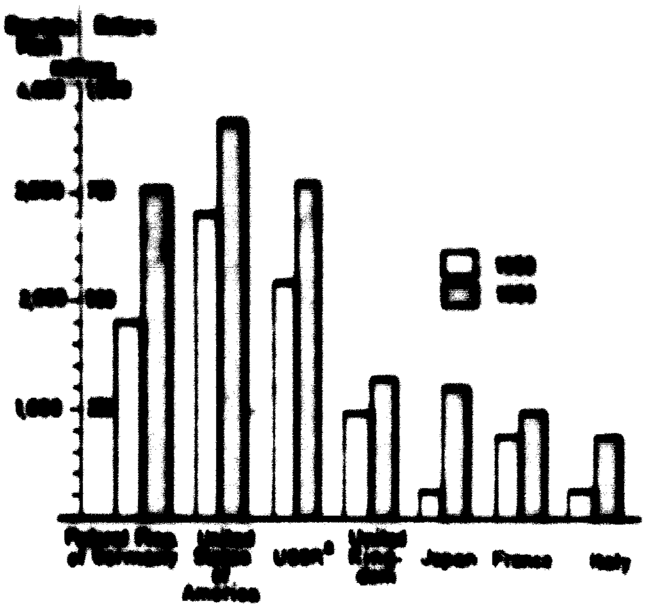
All modern products, whether large or small, are manufactured on machine tools or on machinery that has been produced on them. Machine tools are power-driven machines, not portable by hand, which are used to shape or form metal, primarily by cutting, but also by impact, pressure or electrical techniques, or by a combination of these processes.

Estimates of the magnitude of chip-producing operations illustrate the significance of machine tools for the general economy. In the first edition (1927) of a book by the present author, it was estimated that approximately 1.5 million machine tools of all types were in operation in German machine shops (1). About 1 million of these tools could be classified as metal-cutting machines. On the basis of one eight-hour shift per day and 300 days per annum, there was a total of 2,400 million working hours on machine tools per annum. Thus, at a charge of $2 per hour (in 1927), it was estimated that $4,800 million was spent annually in Germany for metal-removing operations. This author subsequently estimated that about $10,000 million was spent in the United States of America for these purposes (2). In a similar estimate of metal-cutting operations in that country, H. Ernst arrived at the same figure (3).

In an estimate prepared for the United States Air Force, Metcut Research Associates came to the conclusion that $3,000 million was spent in chip-making on machine tools for aircraft parts alone and $34,000 million for all the metalworking industries in the United States of America.

According to shipment data for 1963 (see figure 1), collected by the machine-tool industry in the Federal Republic of Germany, the industry in the United States of America was leading with $925 million, followed by the Union of Soviet Socialist Republics (estimate of $770 million) and the Federal Republic ($750 million). Other countries of significance in machine-tool production include the United Kingdom of Great Britain and Northern Ireland ($325 million), Japan ($300 million), France ($225 million) and Italy ($190 million). No data are available for Austria, Eastern Germany and Switzerland.

With regard to technological developments in the industry, there has been much progress. In the past forty years, the horsepower available in machine tools has increased tenfold and the accuracy fiftyfold. It is therefore possible to remove ten times as much metal per minute (in cubic inches) at the current time as it was in the 1920s. High-precision workpieces for the aircraft and spacecraft industries can now be produced. Forty years ago there was neither the need for nor the ability to produce such workpieces.



Source: Amtliche Statistiken der Länder.
a Estimated.

Figure 1

DATA ON SHIPMENTS BY MACHINE-TOOL INDUSTRY, SELECTED COUNTRIES, 1958 AND 1963

Technological developments also have an important bearing on the human side of production. The strenuous physical effort formerly associated with operating a machine tool, such as cranking a lathe carriage or milling-machine table, has been reduced to pushing buttons or loading the machine with stock, or to supervising a numerically controlled (NC) machine tool. The workers are, therefore, less fatigued. Furthermore, less scrap is produced.

It should be noted, however, that there is no indication that metalworking plants will become so completely automated that workers will not be needed. On the

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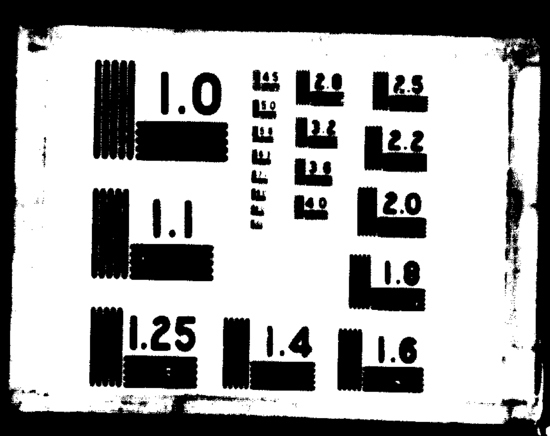


contrary, in its report to the National Commission on Technology, Automation and Economic Progress, the National Nachine Tool Builders Association stated that by 1975 the number of workers in metalworking industries could be expected to increase by 15 per cent (1). Numerical control will create many new jobs requiring high skills and technical training—for example, programmers, electronic-maintenance men, systems analysts and machine-tool control service technicians.

The programmer for numerically controlled machine tools must be familiar with the relationships between cutting speed, cutting force, tool life, horsepower, depth of cut, feed, geometry of the cutting edge, vibration, production time, etc., in order to obtain optimum results. Numerically controlled machine tools may be doing up to 80 per cent of the work handled by general-purpose machines in modern small- and medium-sized machine shops, when their owners can realize corresponding profits.

With technological progress, there is an increased need for research. Forty years ago, the number of engineers engaged in machine-tool research and metal-cutting science was very small; today, thousands of engineers are working in this area of ever-increasing significance to industrial production. This increase has been greatly fostered by the progress in NC machine tools and by the new metals coming into application.

The increase in metal-removing capacity—as indicated by the increase in horsepower—and the great improvements in accuracy require the elimination or reduction of the vibration and deflection of machine tools. This depends, in turn, upon the reduction of cutting forces, an increase in the rigidity and related problems which are discussed in this paper. The need for research in regard to vibration was expressed in 1927 by the present author:

> "The development in machine tools will correspond to that of other branches of engineering, particularly aircraft development, namely, building for high speeds, low forces, increased rigidity—which is not identical with increased weight—and absence of vibration.
> "More research should be devoted to vibration problems in machine tools, because high speeds to be expected will come into resonance with the neutral frequencies of the structural design of machine tools" (1).

The trend towards high speeds has increased, due to the advent of carbide and ceramic tools, and vibration research is being conducted at many places.

As noted above, the new metals, among them the high-temperature alloys and the refractory metals, are another reason for the increase in metal-cutting research. These metals are often difficult to machine; and, in some instances, the cutting speeds have had to be reduced so much—in comparison with the machining of conventional materials—as to require more machine tools, more floor space and higher investment in order to produce the same number of units.

Therefore, alternative machining methods have been and are being developed. Many of these methods are still in the experimental stage and may develop slowly, while others may be expected to influence production methods in the near future. Among the latter group are the electrical machining methods, hot machining, laser cutting and measuring, and high-energy forming. These methods, as well as others, are discussed in the present paper.

I. Numerical control

Metalworking by numerical control will grow rapidly in application and will have a great influence on trends in the design and production of machine tools. This is not an evolutionary development, but a complete change in the operation of a factory and of the machine tools in it. At the current time, numerical control is still limited to a relatively small number of machine tools which are in operation in the industrialized countries. In the United States of America, for example, of a total of 2.1 million machine tools currently installed in industry, 7,000 are numerically controlled. It is anticipated, however, that by 1975 the production of NC machine tools may well amount to 40 per cent, in monetary terms, of the machine-tool industry in the United States of America.

With numerical control, operation of the machine tools in the shop is the responsibility of the methods department and the control engineer rather than of the operator. Time studies in the shop will gradually become superfluous, as the tape will control both the handling and the cutting time. The operator is thus elevated to being a supervisor of the machines, requiring greater skill in that he must be able to service the machines should trouble develop.

In early 1963, about 150,000 tool and die makers were employed in the United States of America (4,5) in addition to 360,000 machinists, layout men and instrument makers, and 40,000 set-up men. During the 1960s 35,000 workers will be needed to replace those who die or retire. An adequate labour supply is not expected to qualify unless company training programmes are established to teach workers in a brief time to do new jobs; such upgrading then opens vacancies further down the line.

There is no place for NC machine tools in mass-production industries, where automated transfer lines and similar large-scale production equipment, e.g., automatic machine tools, will continue to prevail. Rather, NC machine tools are intended for the shop in which the usual lot size is one to ten or twenty pieces of a kind.

The skilled operator of conventional general-purpose machines manually arranges such elements as speed levers and feed-changing levers, and dials the depth of cut, etc., according to instructions he receives from reading blue prints or from consulting routing cards delivered to him with the workpieces to be machined. In the case of the automatic machine, however, instructions on tool travel, positioning etc. are built into the machine by the operator himself, who manually adjusts cams, bars, cycle times and other mechanical and electrical devices. In automatic screw machines, automatic single- or multiple-spindle bar machines and others, the operator's activity is thus limited to the set-up of the machines.

With NC machines, the set-up time is considerably reduced, due to the elimination of cams and levers. Such machines do not even have hand-wheels, levers, dials and similar elements for operating them. The ratio of machining (i.e., productive) time to set-up and handling time is substantially increased by numerical control. A punched tape is virtually free of inertia, in comparison with a heavy drum for cams, and thus permits a more rapid travel and the shortening of idle time. Electronic controls work more accurately and also more rapidly than mechanical devices, which need often complex linkages. The tape takes over the set-up procedure, which is expensive in time and quality of labour because it must be repeated each time an operation is changed. In the case of NC machine tools, it is only necessary to replace one tape with another.

Research on numerical control began in 1947 and was accelerated by the needs of the aircraft industry for new techniques that could produce intricate parts more rapidly and more accurately than conventional manufacturing methods.

In 1952, this writer had the opportunity of observing the performance of the first NC machine tool at the research laboratory of the Massachusetts Institute of Technology (United States of America). At that time, numerical control was, in many quarters, considered impractical, and relatively few engineers expected a development of such magnitude as that which has occurred during the past decade. Numerical control became practical as a result of advances in machining research and electronics used in other fields of engineering, such as radar, teletype and communications.

A. *Economy of numerical control*

The first question that arises when considering the application of NC machine tools is that of economy. In general, the initial investment is higher than that for manually controlled machine tools. It is, therefore, advisable to quote a few case histories which show the actual savings obtained (and also sometimes not obtained) when installing NC machinery.

Brown & Sharpe, who operate NC boring mills made by Giddings & Lewis, realized the following savings several years ago: 40 per cent in the machining of turret heads for boring machines; 28 per cent in the machining of columns; 42 per cent in machining milling-machine tables, mostly owing to reducing down-time; and 50 per cent in the milling, fine boring and thread cutting of milling-machine housings. A total of $47,000 was saved during one year; 80 per cent of this sum was due to the elimination of jigs and fixtures, and the reduction of set-up and handling times. The NC machine paid for itself in four years. The deciding factor was the elimination of fixtures that would have had to be built for the production of a new line of machinery. Furthermore, they gained additional freedom in the design of machine parts because changes in some dimensions only required changing the tape, rather than rebuilding a fixture.

In an aircraft factory, it was found that the set-up time for an average operation was 2 hours on a manually operated machine tool and only 15 minutes on one which was numerically controlled. The number of pieces that could be machined during one shift rose from two or three on the manual machine tool to ten and more on the NC machine. In this case also, the elimination of fixtures and jigs played a major role in reducing costs and increasing production.

At the Miehle-Goss-Dexter plant, presses for the graphic industries are manufactured on many horizontal boring mills of the Giddings & Lewis type. Several years ago, management decided that it would be best to begin with one machine in order to get experience with NC boring mills. The intention was to reduce the number of machines so as to save space in the shops and to cut the cost of fixtures, which often required considerable investment, particularly when only one machine was on order, as is frequently the case in this type of manufacturing. Formerly, it was necessary to design and build new fixtures for almost every customer because the presses had to be adapted to the special requirements of each order. Through the introduction of NC machine tools, it was possible to eliminate 750 fixtures and to save large areas of floor space which had been required for storing the fixtures. More productive space thus became available. The company is currently storing more than 15,000 punched tapes in a small space. Many of them can only be used for a special part, but such tape is economical, particularly when high accuracy is required. A punched tape is always made when six to eight holes are to be drilled in a workpiece. It is up to the programmer to decide whether to manufacture on a numerically controlled or a manually operated machine tool when less than six holes occur.

The preparation of punched tapes is a new field for many plant divisions where NC machine tools are being introduced for the first time. The designer will learn without difficulty to enter dimensions in co-ordinates from a reference point on the drawing. Recently, method has been developed which even permits programming directly from a dimensionless drawing.

Operation scheduling begins with the drawings and entails the use of standard form sheets containing columns for the position of work and tool, their size, cutting speed, spindle rpm, type of tool, feed, depth of bore etc. These data, retyped on a special typewriter, are deposited in duplicate in a fireproof box. Simultaneously with the retyping, the punched tape is produced on the typewriter. It is often possible to save tape preparation time when different workpieces have, in part, the same dimensions. One tape can be used for them, with additions to or removal of a part of the tape. Scribing of heavy workpieces can often be entirely eliminated when punched tapes are used. After about three months' training, an engineer will even be able to programme complicated processes.

The cases discussed so far refer only to positioning operations by numerical control. Economic considerations will be different in cases where fixtures do not exist and, hence the cost in this regard cannot be saved,

Table 1

TRACER CONTROL VERSUS NUMERICAL CONTROL: LOT SIZE, SIX PIECES[a]

Operation	Operating time (minutes) Tracer lathe Total	Tracer lathe Per piece	Numerically controlled lathe Total	Numerically controlled lathe Per piece
Drawing of template	90.0	15.0	—	—
Programming	—	—	496.00	82.60
Production of template	1,500.0	250.0	—	—
Punching of tape	—	—	124.00	20.60
Set-up time	90.0	15.0	15.00	2.50
Floor-to-floor time	112.8	18.8	125.52	20.92
Total time per lot	1,763.70	—	759.60	—
Total time per piece	—	298.80	—	126.60

Savings in time: 57.7 %

[a] See figure 2 for illustration of workpieces.

as, for instance, in turning operations. The R. K. Le-Blond Machine Tool Co. has given attention to this fact and has run comparative turning operations on tape-controlled and numerically controlled lathes. The latter produce workpieces with cylindrical as well as sloped and curved portions in continuous operation. Figure 2 shows a workpiece, and comparative data are given in table 1.

It will be seen from table 1 that the floor-to-floor time was slightly less on the tracer lathe (18.3 minutes) than on the NC lathe (20.92 minutes). In spite of this, the total time per piece was 57.7 per cent less on the NC lathe than on the tracer lathe. This result is mainly due to the fact that the production time per piece for the manufacturing of the template is as high as 250 minutes, while the corresponding time for the NC machine, namely, the tape-punching time, is only 20.6 minutes. If the lot size had been considerably larger than six pieces, say, 600 pieces, the floor-to-floor time per piece would have been the same as indicated in table 1, while the handling and preparation times would have been reduced to one-hundredth of the indicated time per piece.

The break-even point, that is, the lot size for which the

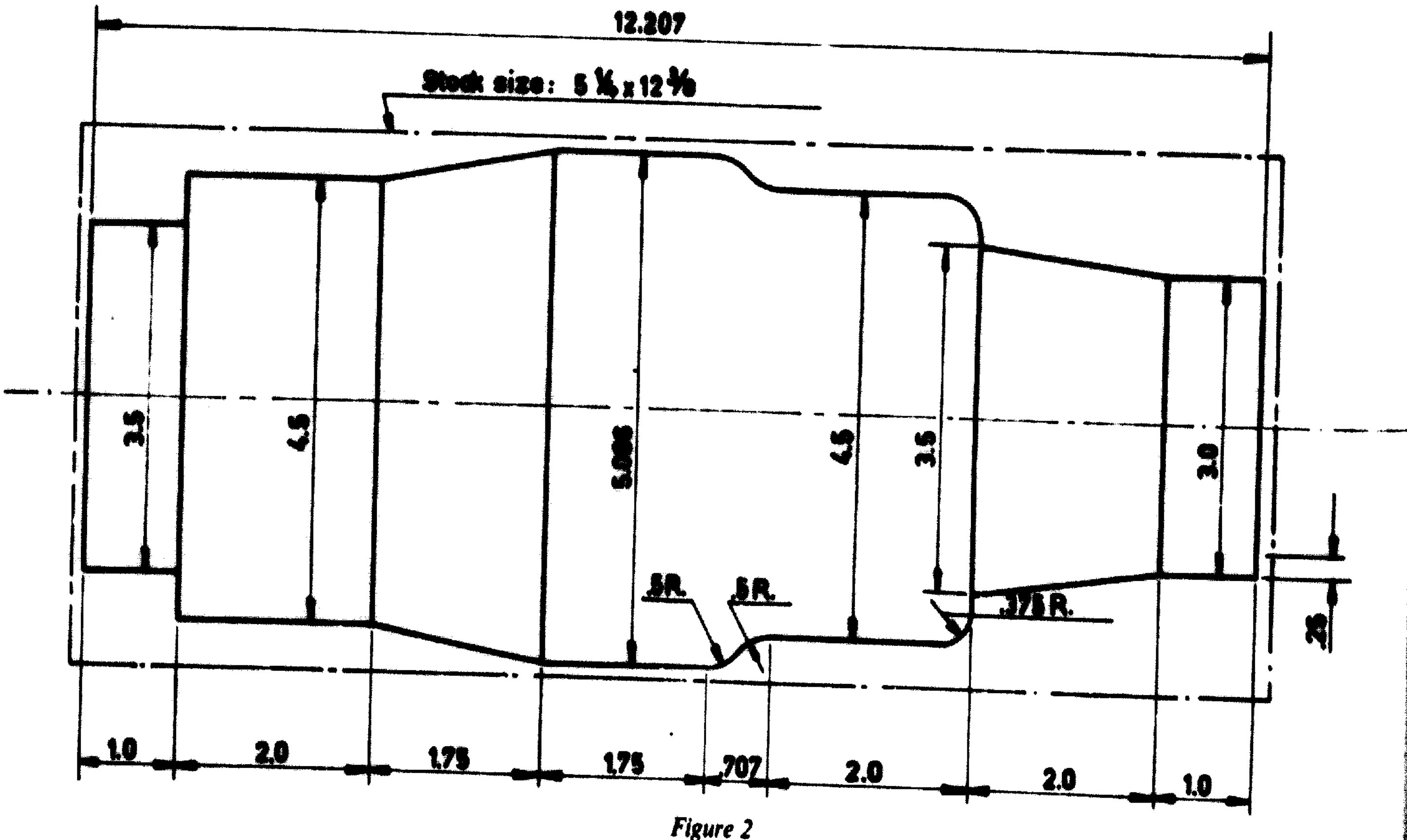


Figure 2

WORKPIECE USED FOR COMPARATIVE TESTS ON TRACER LATHE AND NUMERICALLY CONTROLLED LATHE tal time per piece is the same for NC and tracer-controlled machine tools, can be computed in the following way for the workpiece illustrated above in figure 2. Let:

H_t handling + preparation time for tracer lathe
H_n same for NC lathe
F_t floor-to-floor time for tracer lathe
F_n same for NC lathe

The total time would be the same for the two types of machines when:

$$H_t + F_t = H_n + F_n = \text{total time per piece}$$
(Equation I-1)

Assuming that the floor-to-floor times would remain unaffected when increasing the lot size, one finds from table 1 that the difference between them, namely, $F_n - F_t$, is 2.12 minutes. Hence, from equation 1:

$$F_n - F_t = H_t - H_n = 2.12 \text{ minutes}$$
(Equation I-2)

The lot size (L) times 2.12 minutes must equal the known lot size (six pieces) times the difference between the sum of the handling times; hence:

$$2.12\,L = 6\,(280 - 105.7) = 1{,}045.8$$
(Equation I-3)

Thus the "break-even" lot size:

$$L = 1{,}045.8/2.12 = 495 \text{ pieces.}$$
(Equation I-4)

Details of this analysis are given in table 2.

denied. Their problem is the cost of initial investment. The trend in the prices for NC machine tools supports the general trend towards the increasing application of numerically controlled machines. Although the prices for a number of NC machine tools has gone up during the past five years, the prices have been reduced in many more cases, resulting in an over-all reduction of about 15 per cent during the period from 1960 to 1964. This figure applies, as an average, to all types of machine tools. The picture is different when the price changes are itemized for various types of machines and types of controls.

In 1964, about four times as many NC machine tools were shipped as in 1960. Positioning controls increased somewhat more than four times and contouring-path controls about five times, while the straight-cut systems increased only twofold. Technological differences between the various numerical controls are discussed in the following section.

Eight times as many NC drilling machines were delivered in 1964 as in 1960 and 60 per cent more NC horizontal boring mills.

The price of machine tools equipped with positioning-control systems dropped about 31 per cent from 1960 to 1964 and that of the positioning systems themselves, by 45 per cent. The same percentages apply approximately to the straight-cut systems, that is, to systems where the cutting tool stays in the cut during the tape-control travel. In the case of point-to-point control, the tool is not in engagement during travel. Contouring-control systems have been considerably improved and their prices have risen about 21 per cent, causing a price increase of 40 per cent for the machine tools equipped with this type of numerical control. The difference reflects the cost of changes in the design of these machines.

Table 2

TRACER CONTROL VERSUS NUMERICAL CONTROL, LOT SIZES, SIX PIECES AND 495 PIECES[a]

	Operating time (minutes)			
	Tracer lathe		Numerically controlled lathe	
Operation — *Lot size*	6	495	6	495
Preparation and handling time per piece	280.0	3.39	105.70	1.27
Floor-to-floor time per piece	18.8	18.80	20.92	20.92
Total time per piece......................	298.8	22.19	126.62	22.19
Savings in time (percentage)..............			57.7	0

[a] See figure 2 for illustration of workpiece.

It is evident from these figures that the NC machine tool has a considerable advantage over the tracer-controlled machine tool as long as the lot size does not approach mass-production quantities. The advantage of the NC machine is particularly great in the case of the small lot sizes. This confirms the claim that NC machine tools are intended for the job shop and other plants in which the production of a few pieces is predominant.

3. *Reduction of prices for numerically controlled machine tools*

The technological advantages of NC machine tools for the small and medium-sized machine shops cannot be

Comparing the prices by types of NC machine tool yields significant information. In the case of horizontal boring mills, the price rose about 8 per cent from 1960 to 1964. This applies to both the control systems themselves and the machine tools equipped with them, indicating that no substantial price changes were necessary, due to improvements in the design of horizontal boring mills.

The prices for drilling machines equipped with numerical control dropped about 60 per cent, which is the same percentage as the price drop in the control systems alone. Hence, the price reduction in the NC systems was passed on to the user of these machines. On the other hand, from 1960 to 1964, the price for lathes with numerical control was reduced by 43 per cent, although the price for the control systems dropped 64 per cent. The difference reflects again the cost increase caused by substantial changes in the design of the machines themselves. Data for milling machines with numerical control do not permit a clear analysis and conclusions.

The cost of the NC equipment averages about 30 per cent of the total cost of a machine tool. This figure has not changed substantially during the period 1960–1964, even within the different categories considered above, as is shown in table 3.

Table 3

PROPORTION OF COST OF NUMERICAL CONTROL IN TOTAL MACHINE PRICE

(*Percentage*)

Category	*1960*	*1964*
Point-to-point control	37	29
Straight-cut positioning	?	30
Contouring control	37	32
Boring mills	31[a]	31
Drilling machines	30	34
Milling machines	34	?
Lathes	41	25
Over-all average (approx.)	30	30

[a] 1961.

C. *Types of numerical control*

Three types of numerical control are usually considered. First, there is the so-called "positioning control", also known as point-to-point control, where the tool is not in engagement with the workpiece during positioning. Either the tool or the workpiece is moved by NC in order to position a drill or milling-cutter over several holes. The second is the straight-cut control, where the tool performs a machining operation, such as cutting a groove in a workpiece, while travelling under numerical control. These two types of NC are often combined, for instance, when drilling holes. The positioning is effected by NC when the tool is not cutting, while the straight cut—in this case, drilling the hole—is carried out under NC after positioning. In the third type, contouring control, the cutter follows a predetermined path consisting of straight lines, tapers, and simple or complex curves, as required by the contour of the workpiece to be machined.

In 1960, only 15 per cent of NC machine tools were designed for contouring and 85 per cent for positioning and straight-cut control. Since then, the trend has changed considerably. The application of contouring control has risen to 30 per cent, and that of the two other types has fallen to 70 per cent of all NC machine tools built in the United States of America. The trend in other countries is similar.

In contouring control, two subgroups can be differentiated, namely, point-to-point and continuous-path control. The latter system makes use of the fact that most contours of workpieces are composed of simple slopes, circular curves and ellipses. When the lengths and slopes of the straight lines and the arc lengths are known, the continuous-path contouring system converts the data into continuous movements of the machine. Control sheets are developed directly from the engineering drawings and the punched tapes on a typewriter.

Figure 3 shows the difference between the two subgroups of contouring control. At the left are shown three cases for the point-to-point contouring method, also called "step contouring", while the corresponding continuous-path method is shown at the right. In the top row, slopes are considered. In the case of step contouring, the steps represent the actual path of the tool, requiring many separate commands to approximate the straight line of the slope.

Circular arcs are compared in row "B". Again, the steps at the left represent the actual path of the tool for producing an arc of radius "R". At the right, it is shown that the arc can be produced by one command. In the case of ellipses, many commands are required for contouring them by the step method, while with the continuous-path method, only two commands (marked c_1 and c_2) and two repeat commands (marked d_1 and d_2) are necessary. The numerous computations required for the steps are reduced to a few in the case of continuous-path contouring systems.

D. *Co-ordinate systems: machine axis designations*

The designation of the axes of NC machine tools began with the drilling machine, where the customary co-ordinate system applies, namely, that $+x$ is the axis to the right in a horizontal plane, $+y$ is the axis going north to the x axis and z is the axis vertical to the $x-y$ plane. Although this principle is still used, it was found necessary to adapt the co-ordinates to the requirements of programming for numerical control.

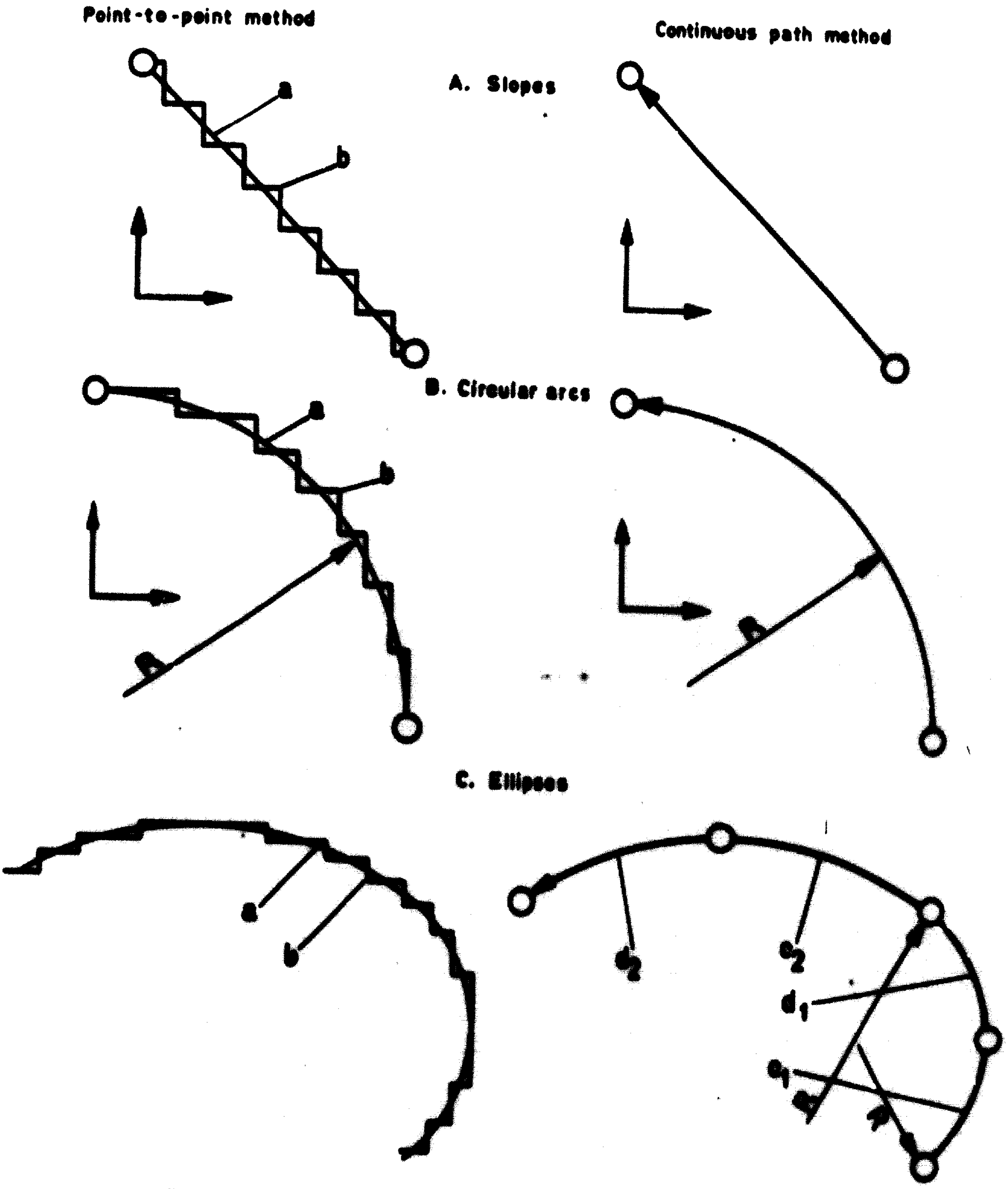
Numerical control can be simplified if the z axis is not always vertical (as is customary and in use for drilling and other machines), but if z is taken either as the axis of rotation of the tool (fig. 4) or as the axis of rotation of the workpiece (fig. 5).

As is shown in figure 4, z is vertical in the case of the single-spindle drilling machine, but horizontal for the knee type of milling machine and for horizontal boring mills. In the case of a skin mill, the z axis may even be inclined.

Correspondingly, the z axis is horizontal for workpieces with horizontal work rotation, as on lathes, grinding machines or turret lathes, as is shown in figure 5.

When more complex machine tools are considered, e.g., milling machines for profiling and contouring (see fig. 6), the z axis, taken in the traditional way, is vertical when the cross-rail movement is tape-controlled, but it becomes the sloped axis of tool rotation if the vertical movement is not tape-controlled. In the case of shaping machines and planers, z is again the vertical co-ordinate.

These axis designations have not been universally



a = line to be produced; b = actual path of tool; R = radius of arc; c_1, c_2 = commands; d_1, d_2 = repeat commands.

Figure 3

COMPARISON OF POINT-TO-POINT AND CONTINUOUS-PATH METHODS OF CONTOURING

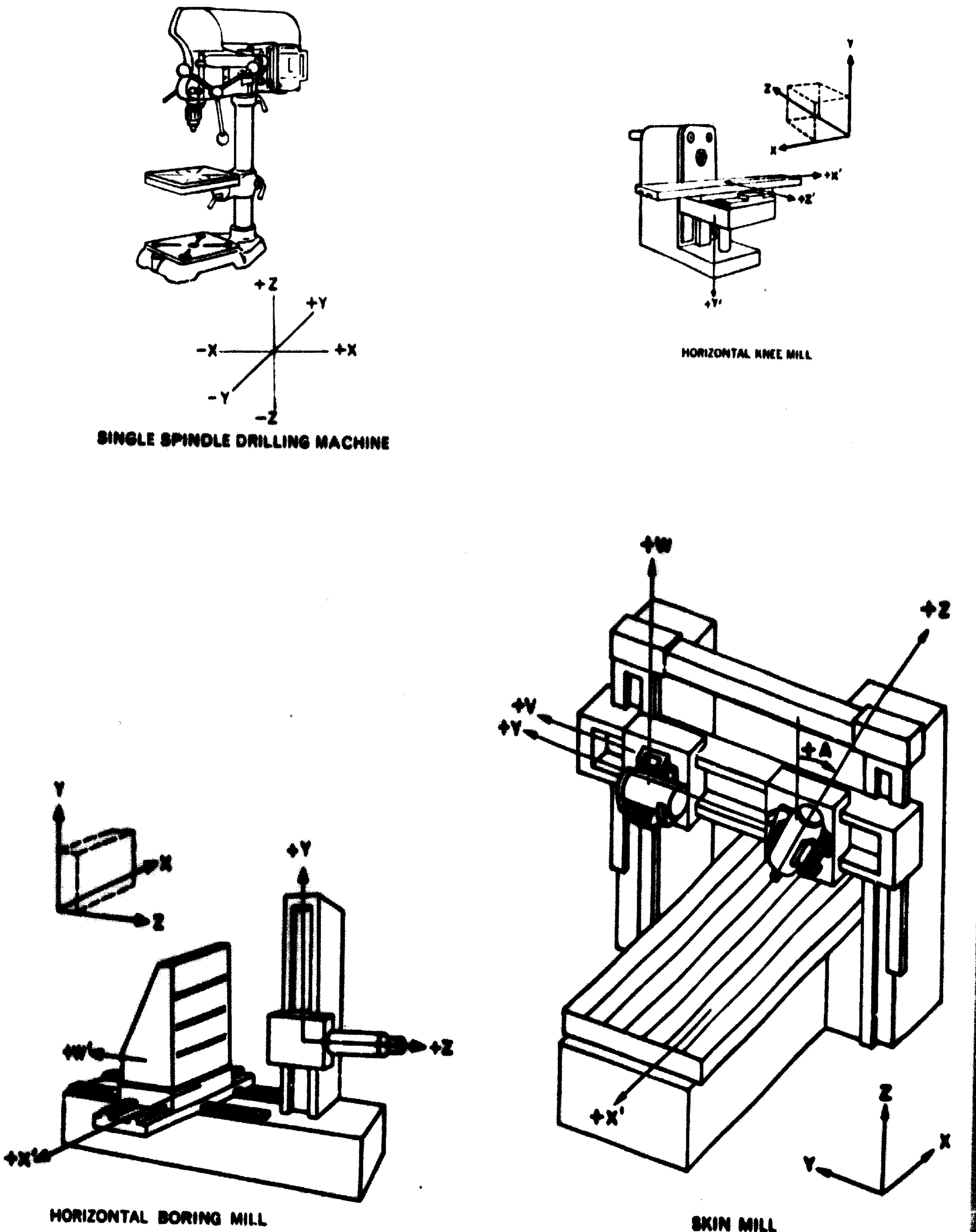


Figure 4

CO-ORDINATE SYSTEMS WITH Z TAKEN AS AXIS OF ROTATION OF THE TOOL

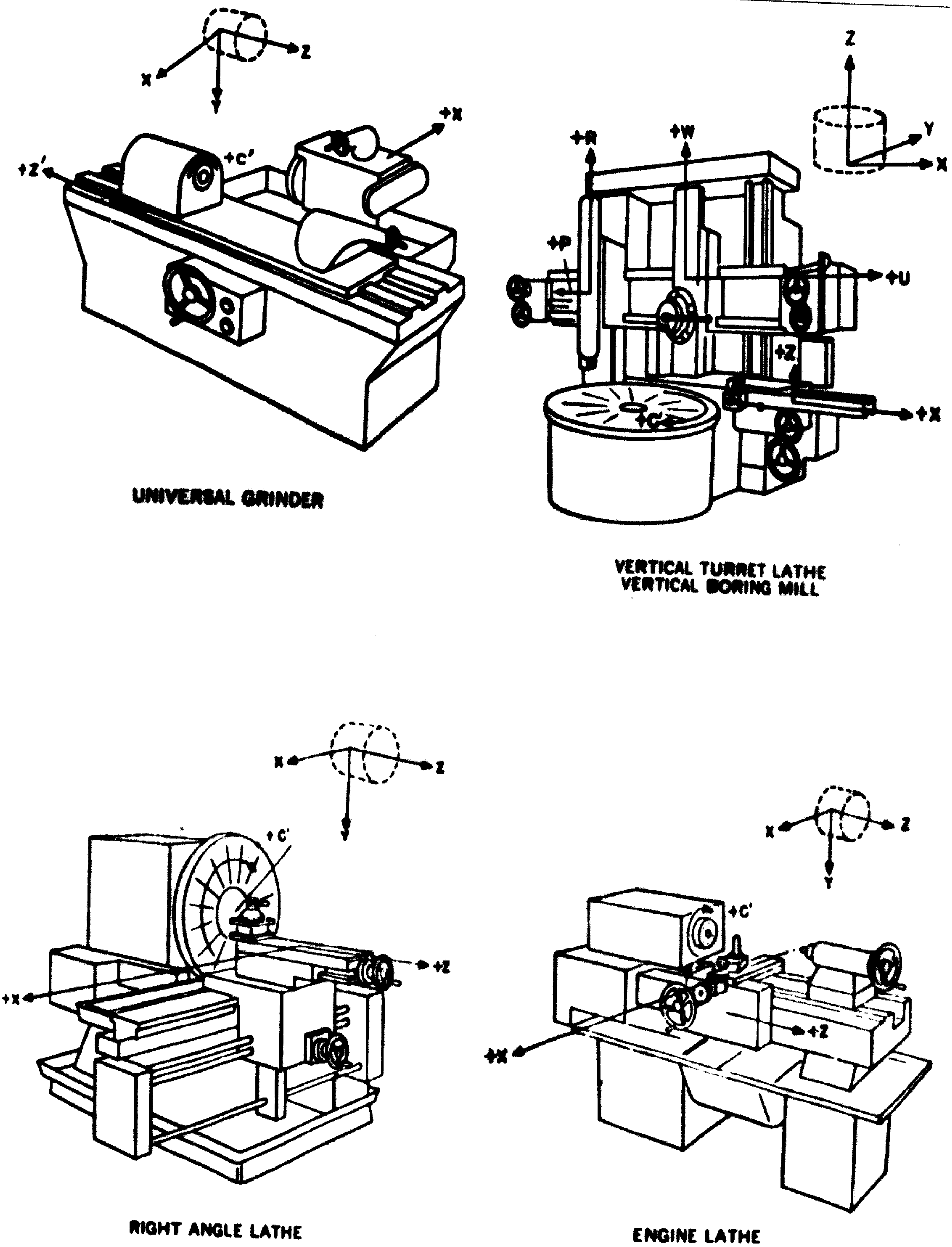


Figure 5

CO-ORDINATE SYSTEMS WITH Z TAKEN AS AXIS OF ROTATION OF THE WORKPIECE

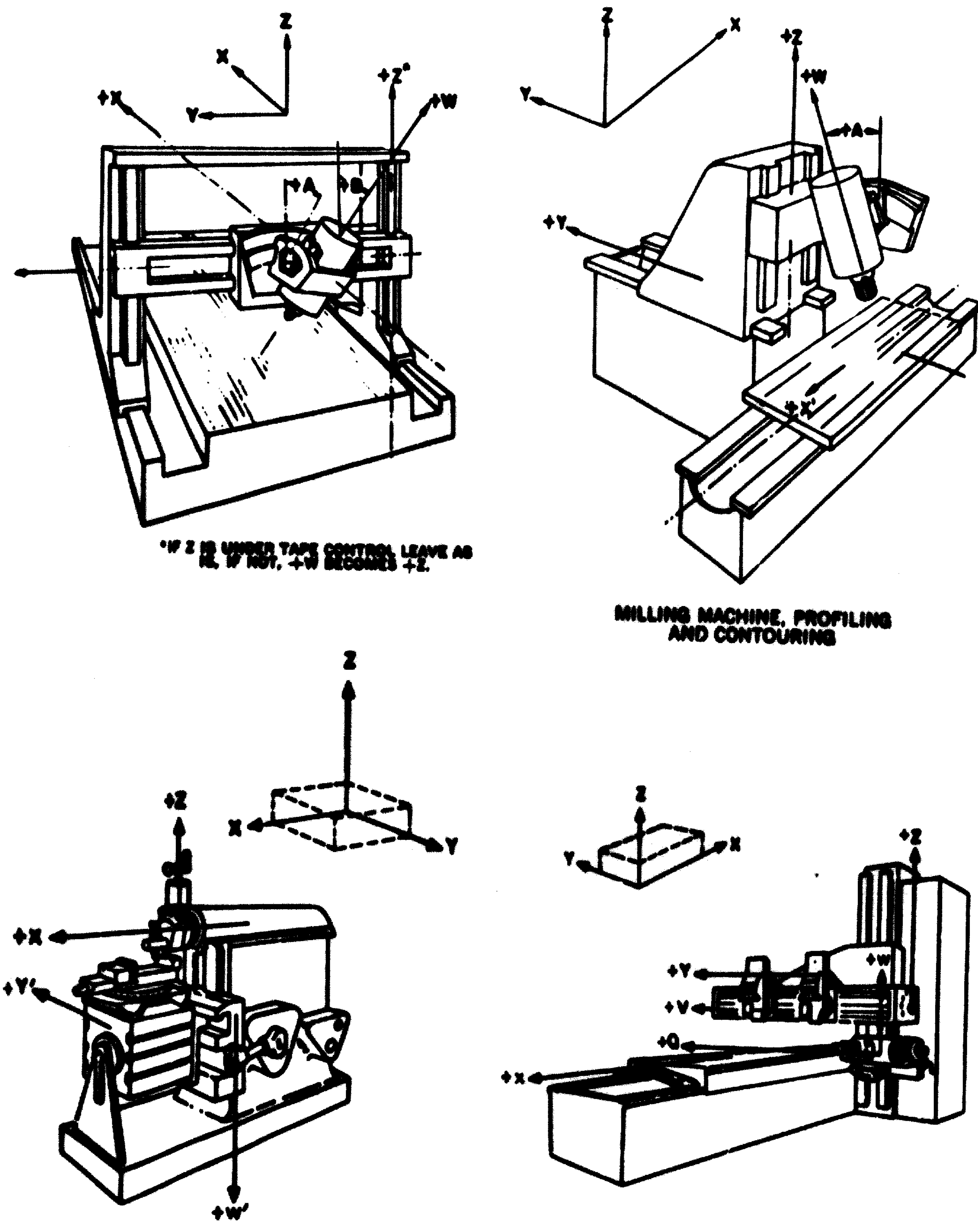


Figure 6

Co-ordinate systems for milling machines used for profiling and contouring, and for shaping machines and planers

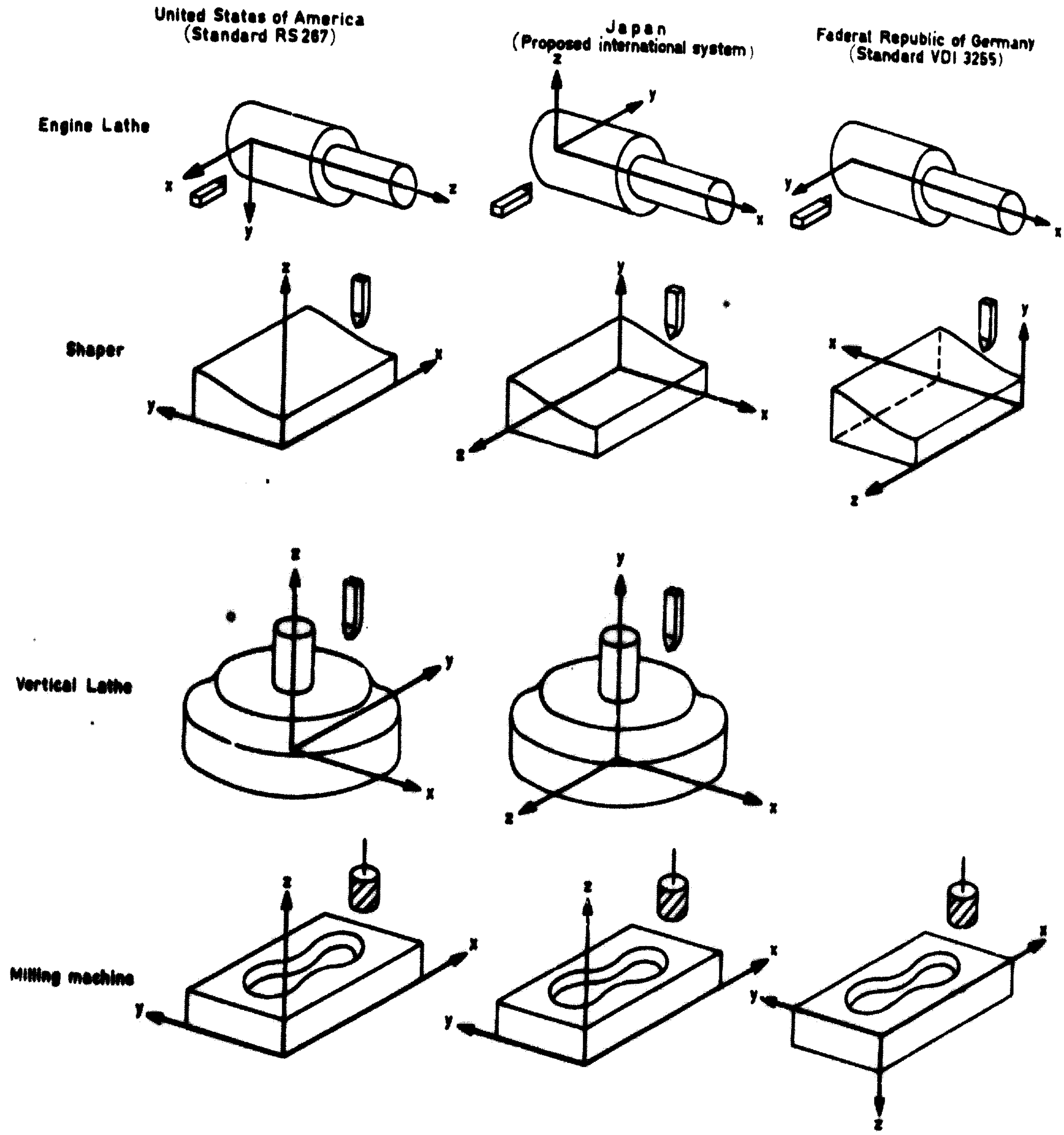


Figure 7

COMPARISON OF TWO STANDARD CO-ORDINATE SYSTEMS FOR NUMERICALLY CONTROLLED MACHINE TOOLS AND INTERNATIONAL SYSTEM PROPOSED BY THE PROGRAMMING COMMITTEE OF THE JAPANESE ELECTRONICS INDUSTRY

adopted, however, and this situation prompted the Programming Committee of the Japanese Electronics Industry to prepare suggestions for an international standardization of co-ordinate systems for NC machine tools. Figure 7 shows a comparison of Standard RS 267 of the United States of America with Standard VDI 3255 of the Federal Republic of Germany and with the Japanese compromise solution. The standard used in the United States of America is based on a right-hand co-ordinate system and that of the Federal Republic on a left-hand system.

This is particularly evident from the sketch of the vertical milling machine shown in figure 7. Looking at the workpiece in the direction of the z axes shown there, it will be realized that the x axis turns the workpiece to the right in the co-ordinate system used in the United States of America and to the left in the system used in the Federal Republic of Germany. In the case of the vertical milling machine, the Japanese Committee has suggested the adoption of the method used in the United States, while in other cases, new designations have been submitted. The following definitions for the z axis have been suggested by the Committee:

(*a*) For machine tools with rotating tools (milling machines, horizontal boring mills, drilling machines), the z axis is that which is parallel to the axis of tool rotation;

(*b*) for machine tools with rotating workpieces (lathes, turret lathes) and for machine tools with rotating tools and workpieces (grinding machines), the z axis is that which is parallel to the direction of the main cutting force;

(*c*) For machine tools with straight-line motion of non-rotating tools or workpieces (shaping machines, planers), the z axis is that which is parallel to the direction of the stroke of tool or workpiece.

In a number of cases, definitions used in the United States of America agree with the Japanese suggestions, while in others, they do not. In the United States, Standard RS 273 lists fourteen different motions and designations for NC machine tools. Obviously, no one machine tool will have all fourteen; in fact, only the more complex machines have four or, occasionally, five or six axes. The additional axes are the axes of swing (designated by a, b, c) around the basic x, y and z axes.

In the United States of America, the trend in NC machine tools is towards the utilization of simultaneous multiple movements. Such a method will permit simultaneous machining in various directions, as is desirable for the machining of complex contours. This will free the designer from the limitations imposed by production problems, so that he will be able to use special contours on vehicles and machine parts, such as helicopter rotor blades or impellers, which give optimum performance.

Although industries in the United States of America are the most advanced in the development and application of NC machine tools, other industrialized countries have also entered the field.

In the Federal Republic of Germany, numerous machine-tool companies are beginning to produce NC machine tools. The Automation Committee has, among its eighteen subcommittees, a group concerned with numerical control. Items handled by this subcommittee include electrical control, hydraulic control, tools, machine-tool standards and training.

A few years ago, programming work in the United Kingdom was at a relatively low level. The machine-tool manufacturers had been taken by surprise, but they changed their policy upon realizing that NC machine tools would be used in factories everywhere. Research facilities were established to investigate such design problems as deflections, vibration and thermal expansion. At the current time, sixteen companies in the United Kingdom are building NC machine tools.

In the USSR, numerical control began with a milling machine and a turret lathe with punch-card control. The machining cycle included speed and feed change, work stroke adjustment, rapid traverse, positioning, dwelling, spindle reverse for tapping etc. Seventy-seven horizontal and twenty-two vertical columns were punched. The punched cards were mounted on a silver-plated brass drum. The Soviet Union is currently producing several types of NC machine tools, and programming involving the machining of three-dimensional workpieces with curved surfaces is also being developed.

Other countries in which NC machine tools are being produced include Austria, Czechoslovakia, Eastern Germany, France, Italy, Japan, Sweden and Switzerland.

E. *Standardization of punched tapes*

Punch cards are no longer so significant, having been replaced by the eight-channel punched tape, which is 1 inch in width. The binary system is mainly used because it requires only "On" and "Off" positions. In practice, however, it is often difficult to read binary numbers, which are, of course, based on the numerical 2. Table 4 provides useful data for conversion from the binary to the decimal system.

Table 4

BINARY/DECIMAL CONVERSION

(Read from right to left)

Place in binary figure..........	6	5	4	3	2	1
Exponential value............	2^5	2^4	2^3	2^2	2^1	2^0
Decimal value................	32	16	8	4	2	1

In order to convert the binary number 1100 into decimals, one must read "1100" from right to left, remembering that "0" means "off" and "1" means "On". The two zeros at the right end of 1100 indicate "Off" and do not appear in the decimal equivalent. Numerical "1" in the third place from the right in 1100 has a value of 4, according to table 4; the next "1" taking the fourth place from the right in 1100 has, correspondingly, a decimal value of 8. The sum of the valid numbers is therefore: $4 + 8 = 12$. Hence, the binary number 1100 is represented by 12 in the decimal system. After some practice, it will be found that the conversion offers no great difficulties. Table 4 can be extended to the seventh place, which has a decimal value of $2^6 = 64$ etc.

The disadvantage of binary numbers is their length. For example, fourteen digits are required to represent the decimal number 10.256. On the punched tape, therefore, a combination of horizontal and vertical binary numbers is used. Most of the standard tapes have channels 2^0, 2^1, 2^2 and 2^3. Each of these numbers (1, 2, 4, 8) thus has one channel, resulting in the following arrangement for 10.256:

First channel: $2^0 = 1$ 10.010 (each 1 means 1)
Second channel: $2^1 = 2$ 00.101 (each 1 means 2)
Third channel: $2^2 = 4$ 00.011 (each 1 means 4)
Fourth channel: $2^3 = 8$ 00.000 (each 1 means 8)

Sum 10.256

Although the figure 10.256 is now represented by twenty digits, the optical reader can process five short numbers faster when they are arranged in four channels than it can handle one long figure in one channel. The oles, representing the "1" and the blank spaces, representing the "0", are compressed into a shorter length.

In RS 244, which is the *de facto* standard used in the United States of America for the eight-channel, 1-inch wide tape, the code requirements are spelled out for designating numbers, letters and symbols to be placed on the tape. Other standards include the following: RS 227, which specifies the tolerances of the medium and the holes punched therein for the 1-inch perforated paper tape, RS 267, which applies to interchangeable perforated tape for positioning and straight-cut NC machine tools, and RS 274, which deals with the interchangeable perforated tape for contouring and contouring positioning NC machine tools.

The rise of the computer and, with it, the increase in codes, created an economic problem, due to the cost of the computers. As a result, a new code, known as ASC-II, was developed. This trend in the development of NC machine tools, however, has resulted in a controversy, which is going on at the current time. Opposing the new code are many engineering organizations, including among others, the American Society of Mechanical Engineers, the American Society of Tool and Manufacturing Engineers, the Society of Automotive Engineers, and the National Machine Tool Builders Association.

An argument presented by the proponents of the new code—which has, thus far, been suggested only—is that information will, in increasing volume, be sent *via* teletype to programming centres from a machine shop many hundreds of miles away and that this can be done faster with the proposed code. Those opposed to the new code claim that this is also possible with the existing codes, although at somewhat reduced speed. The main objection centres about the increased cost for the conversion of existing tapes into tapes adapted to the proposed code. It is, furthermore, pointed out that the proposed code requires twice as many holes as the codes currently used and that the punching errors will, therefore, considerably increase. Figure 8 shows a comparison of the two codes. At the right is the standard code, which is used to a proportion of 98 per cent in the United States of America; at the left is the proposed code, ASC-II. The short horizontal lines in the figure refer to the right-hand (standard) code; they separate commands as indicated by the hole punched in the eighth channel, counting the channels, as always, from right to left. In the new code, shown at the left in figure 8 four holes are required for the same purpose.

In the Federal Republic of Germany, the preliminary standards for numerical control (series VDI 3250) cover nomenclature, programming and tapes. Programming should be based on fourteen letters, ten numerals and the plus and minus signs. Most of the standards refer to the five-channel tape, which is more widely used in Europe than in the United States of America, where the eight-channel tape is nearly 100 per cent in use. The European five-channel tape was developed in conjunction with the teletypes used abroad to a considerable extent. Repair parts available for teletype machines can thus be utilized in the devices for numerical control.

The eight-channel system, however, permits 255 punch combinations, while the European five-channel tapes allow only 31 combinations. There are tapes that can be used for both five- and eight-channel programming. Companies in the United States of America have developed typewriters that are mainly used for eight channels; but there are adapters which translate automatically from the eight-channel system to the five-channel system used in Europe, thus making it possible to convert methods used in the United States into European methods of programming and coding. It should be noted that in Czechoslovakia, 35-mm film is used in NC machine tools.

F. *Recent trends in programming*

During the past few years, newer systems have been developed in the United States of America, primarily for programming contours, namely, the so-called "ADAPT", "APT" and "APT III" systems. ADAPT and APT III can also be used for positioning purposes. With the ADAPT system, the complete NC processing of a workpiece can be described by "English-like" sentences, which represent the information on the drawing and the

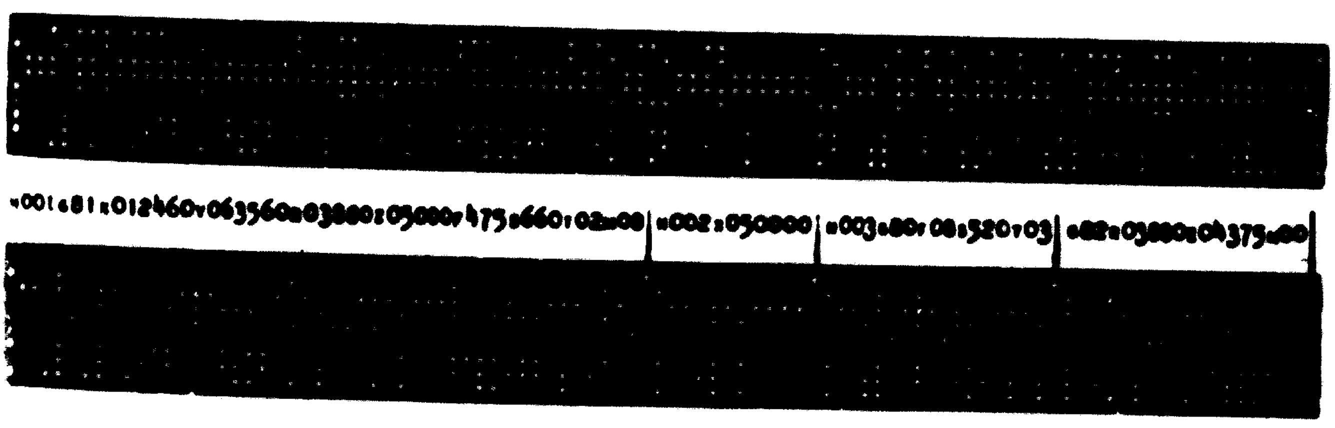


Figure 8

COMPARISON OF NEW ASC-II CODE WITH STANDARD EIGHT-CHANNEL CODE USED IN UNITED STATES OF AMERICA actions necessary to manufacture the part. It consists of the main processor, which translates the part programme to computer "language", and the post processor, which converts the output of the main processor into a control tape. With these systems, the user can employ any computer or have his programme prepared outside. APT III is available at outside data-processing centres for participating companies. ADAPT is simpler, but it can handle 75 per cent of the requirements of the average shop. These systems can also detect punching errors, such as punching I instead of 1. The computer cannot handle a dimension, such as 5.125 instead of 5.125.

Another step in the direction of saving time in the preparation of the tape is the development by the General Electric Company (United States of America) of the "Autoprogrammer". This machine makes it possible to prepare a punched tape from a drawing without dimensions on it. It eliminates the typing of programme manuscripts and the dimensioning of drawings. A stylus is placed over the drawing on the layout table and scans the dimensionless drawing, automatically punching the x and y co-ordinates into the tape. As soon as all information from the drawing has been entered, the tape is ready for use. The operator can give auxiliary commands, such as spindle speed, feed etc., by depressing the appropriate letters on the console.

G. *Design features of numerically controlled machine tools*

The advent of NC machine tools has influenced the design of not only this important portion of machine tools, but also all or many other types of conventionally controlled machine tools, as is discussed in detail in a subsequent section of this report.

As far as NC machine tools are concerned, some companies deemed it necessary to make such machine tools heavier than the corresponding manually controlled machine tools. The guideways were widened and anti-friction bearings and rollers were incorporated. These changes were necessary because of the so-called "stick-slip" effect of slowly moving tables, carriages and saddles before coming to an accurate stop at a predetermined position. Motors must be dimensioned to avoid overheating, and the lubricating systems must be well designed. Lead screws must have a good fit, and carriages must be able to travel to within fractions of a thousandth of an inch. The design of the machines not only requires good machine-tool practice, but also good theoretical knowledge of the deflections, thermal expansion and vibration of machine tools and of their elements. Research into the structure and the distribution of the masses for minimizing or eliminating these disturbances is playing an increasing role in the design of all machine tools.

Engineers in the Soviet Union challenge the theory that friction, reduced by increasing speed or increased by reducing speed, is mainly responsible for the phenomenon of stick-slip. They claim that the design of guideways and drives has a major effect on friction and that it is not sufficient to consider only the lubrication and the material of the gliding surfaces. They consider also the surface finish, the guideway design and the inertias of the travelling machine-elements.

At least two degrees of freedom of vibration must be considered, one in the direction of motion and the other perpendicular thereto. Adding weight to a machine tool does not necessarily reduce vibration. This conclusion was reached by machine tool experts in both the Soviet Union and the United States of America. The floating of a table depends upon the oil film, tilting the table at stroke reversal in various ways, depending upon the velocity. The leading edge of a table rises at slow speed but drops at higher speeds. Between these speeds, the table remains stable.

Similar investigations carried out in the Federal Republic of Germany, where lead screw drives were tested at various speeds and with different masses, resulted in the following formula for the optimum table speed to minimize over- or undershooting of the positioning location:

$$v = \left(\frac{v_o \cdot s_e}{1.6\,c}\right) 3.8 \qquad \text{(Equation I–5)}$$

where v_o = coasting velocity while approaching the desired position, s_e = distance travelled and c = constant involving mass and friction. It will be noted that the effect of these quantities is very large, due to the exponent 3.8.

In the United Kingdom, NC machines with conventional cast-iron beds and slides were compared with combinations of cast-iron beds with bronze-impregnated bearings and hydrostatic bearings, as well as with other combinations. In the case of cast-iron on cast-iron, it is necessary to take the microasperities into account, in addition to the surface shape and flatness. The combination of cast-iron *versus* impregnated bronze seems to have a substantial advantage because the coefficient of friction remains constant as the slide approaches its final position, while the coefficient of friction increases in the case of the conventional combination of cast-iron on cast-iron. Hydrostatic bearings can be adapted to maintaining a thin oil film, as is desirable for continuous-path contouring.

In Switzerland, the effects of NC requirements on machine-tool design are likewise closely examined. Good results have been obtained with regard to the stick-slip problem by coating the guideways with a molybdenum compound.

In the present paper it is possible to describe only a few of the many NC machine tools which have recently been designed. The trend is towards the so-called "machining centre". Machines of this type are multiple-purpose NC machine tools permitting milling, drilling, boring, tapping etc. in one or a few set-ups. The workpieces may have several surfaces. Considerable savings are realized, particularly in handling and set-up time. On a workpiece with four sides, one top and one bottom surface, only three changes in the set-up are required when using a machining centre, as against thirty-two set-up changes in the case of conventional methods. Hence $\frac{3}{32}$ = 0.94, or 94 per cent of the set-up time is saved, which may amount to $100 per workpiece, assuming a cost of $20 per hour and 10 minutes per change.

Numerically controlled machine tools usually do not ave hand-wheels or levers, as is made evident in figure 9, hich shows lathe model 1025 of the American Tool Works. This machine is equipped with the Mark Century 02 C numerical control made by the General Electric Company. The tool can stay in the cut when the spindle peed is changed by numerical control.

to-point straight-line system that handles milling, drilling, reaming, tapping and boring in a single set-up. It changes the tools automatically, selecting the proper one from an indexed rotary magazine which is capable of storing fifteen tools and which can be seen at the top of figure 11. The tool changes are co-ordinated with the positioning of the workpiece for the next operation. The four-position indexing table permits the machining of four sides of a workpiece in a single set-up. The machine can also be equipped with two-axis contouring control.

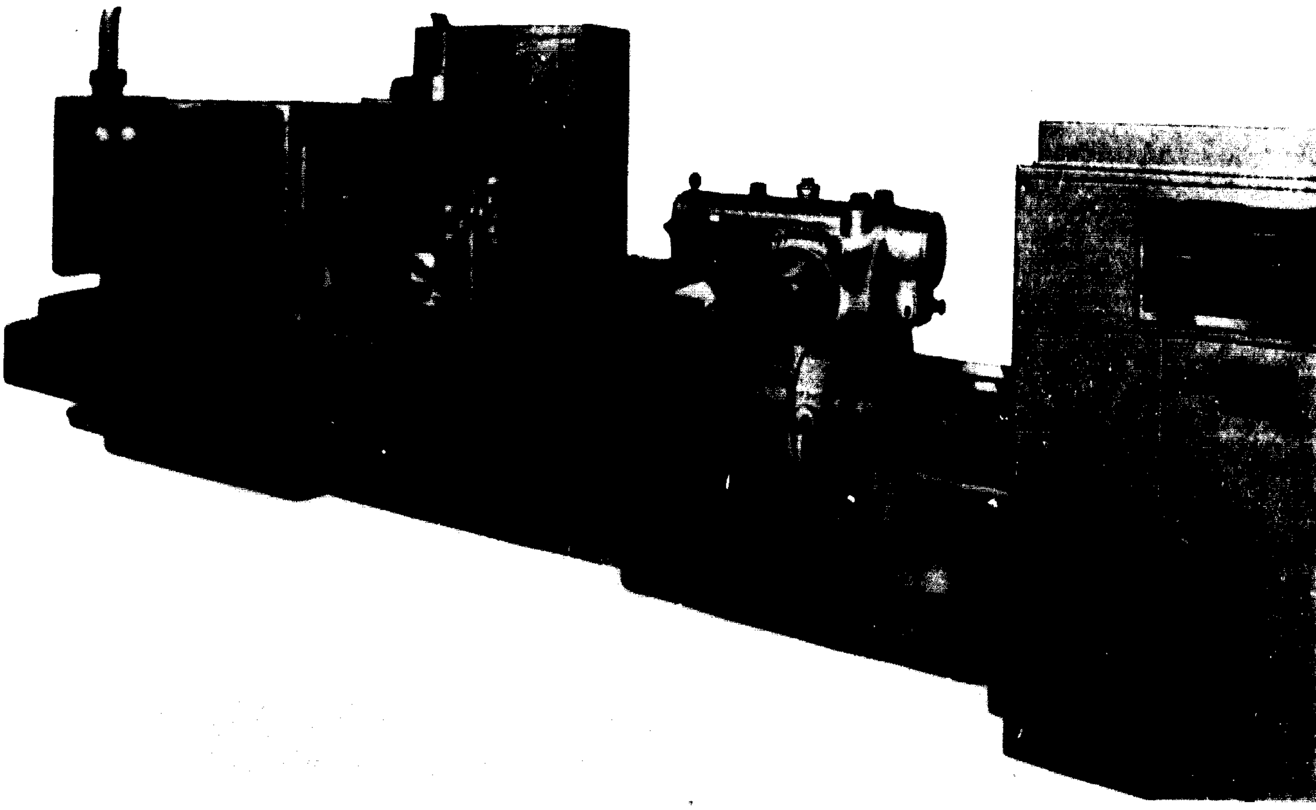


Figure 9

NUMERICALLY CONTROLLED LATHE, MODEL 1025, AMERICAN TOOL WORKS

Figure 10 shows a new model of the turret lathe with inclined bed, which is being built by Warner & Swasey (United States of America). This machine, in the design of which the present author participated, offers several innovations. The bed is slanted at 20° to the vertical. Research had shown that the cutting forces could be well distributed over the guideways and other elements of the machine. The width of the ways with regard to least wear and minimum cost was also investigated. The machine is equipped with the Mark Century No. 100 NC model. The sequence of operations can be programmed by the operator himself. If a change in feed, cutting speed or depth of cut should be necessary during the automatic cycle, the operator can override the tape commands without affecting the remaining commands. In this way, optimum metal-removal rates and accuracy can be obtained. The operator can also correct the command when the tools begin to wear or when the stock of material on the rough workpieces varies. The slides are moved by ball screw feed shafts.

The new Milwaukee-matic (see fig. 11), which is built by Kearney & Trecker (United States of America) is designed for multiple machining operations. It is a point-

II. PRODUCTIVITY

The increase in metal-removal rates required by modern manufacturing methods is well reflected by the increase in the horsepower currently available at the cutting edge and in the motors of machine tools, in comparison with those in use only ten years ago. The metal-removal rate, measured in cubic inches per minute, depends upon the hp of the machine tool, according to the following equation:

$$\text{cu. in./min.} = \frac{396{,}000 \,.\, \text{hp}}{k_s} \qquad \text{(Equation II-1)}$$

where k_s = unit cutting force (lb/sq. in.) of the material being cut. It follows from equation II-1 that more metal can be removed per minute when the horsepower of the machine is increased. Limits for this general equation for the metal-removal rate are discussed below; they are due to tool wear, feed, speed and other qualities.

Figure 10

NUMERICALLY CONTROLLED TURRET LATHE WITH INCLINED BED, PRODUCED BY WARNER & SWASEY

Dividing both sides of equation II–1 by the horsepower results in:

$$\frac{\text{cu. in./min.}}{\text{hp}} = \frac{396{,}000}{k_s} \qquad \text{(Equation II–2)}$$

Equation II–2 indicates that the metal removal rate per horsepower of the machine is nothing but the reciprocal of the unit cutting force, multiplied by 396,000. Hence, trying to establish a trend based on cu. in./min./hp cannot give the desired information. Such information pertains only to the unit cutting force required for machining the respective materials. This is often not realized by many engineers and salesmen for machine tools.

It is, rather, the horsepower of the machine tools that may serve, within its limits, as a fair criterion for the trend in productivity and in the metal-removal rates.

Productivity, as expressed by the metal-removal rates and the horsepower of the machine tools, has increased more than 100 per cent during the period from 1953 to 1963. A few typical examples of this trend are listed in table 5.

These increases in productivity, together with the increased demand for higher accuracy, have been made

Table 5

SURVEY OF INCREASE IN PRODUCTIVITY AS EXPRESSED BY INCREASE IN HORSEPOWER OF MACHINE TOOLS

Machine-tool group	*Horsepower* 1953	*Horsepower* 1963	*Increase* (*percentage*)	*Spindle speed (maximum rpm)* 1953	*Spindle speed (maximum rpm)* 1963	*Make*
Lathes (engine)	10	20	100	700	1,750	Monarch
Lathes (tool room)	1	2	100	1,200	2,500	Monarch
Lathes (turret)	10	25	150	730	2,000	Gisholt
Horizontal boring mill	25	60	140	—	—	Giddings & Lewis
Grinders (small)	15	30	100	—	—	Mattison
Grinders (large)	30	70	133	—	—	Mattison
Grinders (rotary)	150	250	67	—	—	Mattison
				Feed (inches per minute)		
Milling machine (knee)	10	18	80	40	90	Cinti Mill.
Milling machine (bed)	15	55	268	30	150	Cinti Mill.
		Over-all average 125				

…ssible by changes in the design of the machine tools, …en based on scientific and applied research into …idity, deflection, thermal expansion and vibration.

A. *Productivity charts*

The utilization of the horsepower available at the cutting edge of the tool has been made possible by metal-cutting research and application of results to practice. The man in the shop used to rely upon data collected from observed experience; these data often had such wide tolerances that it was nearly impossible to determine optimum values for a specific job with sufficient accuracy. In an effort to improve this situation, the significant metal-cutting data collected in the United States of America and in numerous European countries have been investigated and brought into a logical system.[1] Numerous tests have been conducted, and many of the formulae and data discovered in this way have proved useful in practice.

To get the message through to those who need it, these data and findings should be presented in ways best suited to the eventual user, i.e., the tool engineers, time-study men, supervisors, managers and operators. The means may be charts, tabulations or instruction sheets. Charts give a survey and permit realization of the effect of change from one quantity to another. Intermediate values are more readily found from charts than from

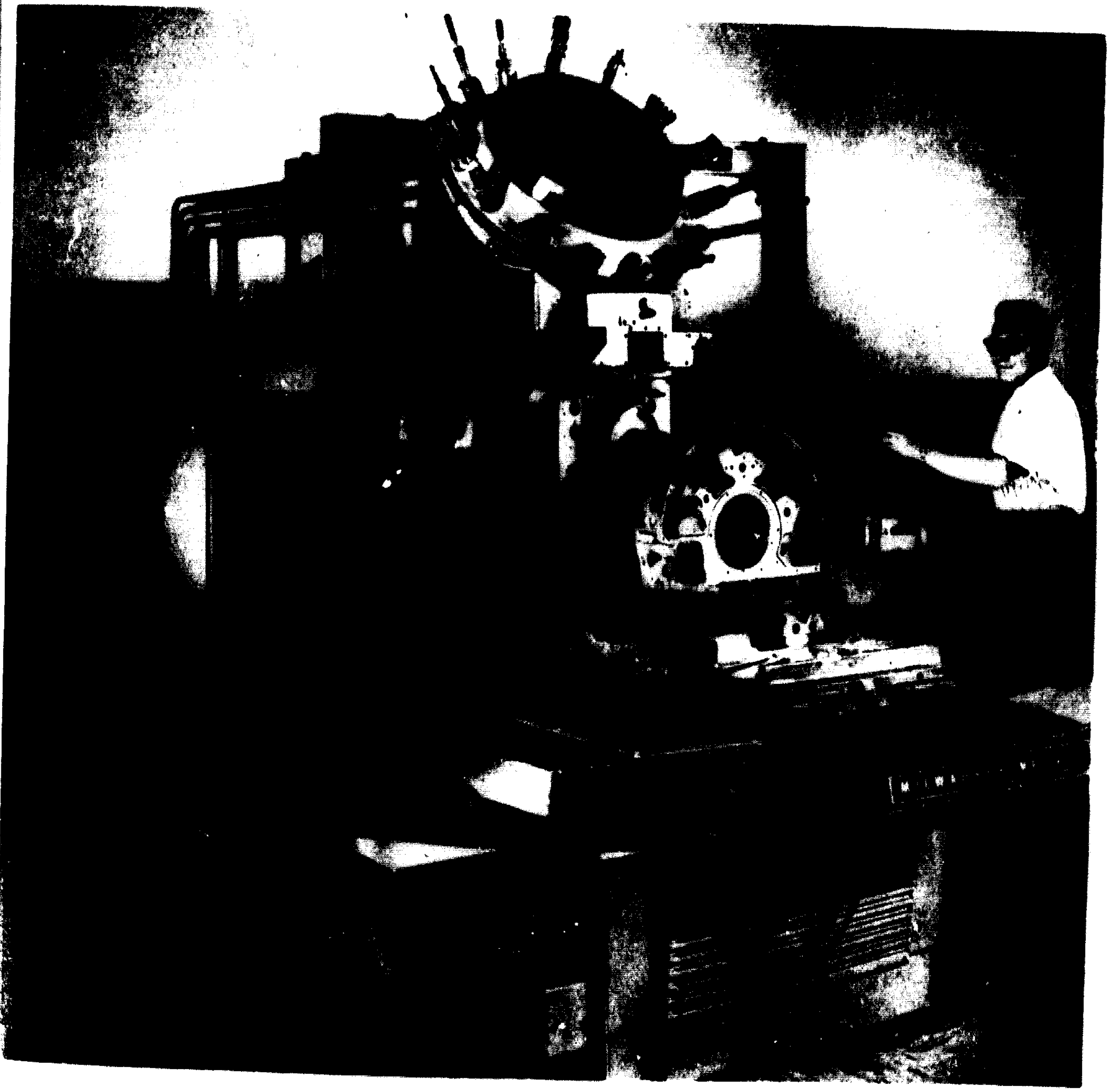


Figure 11

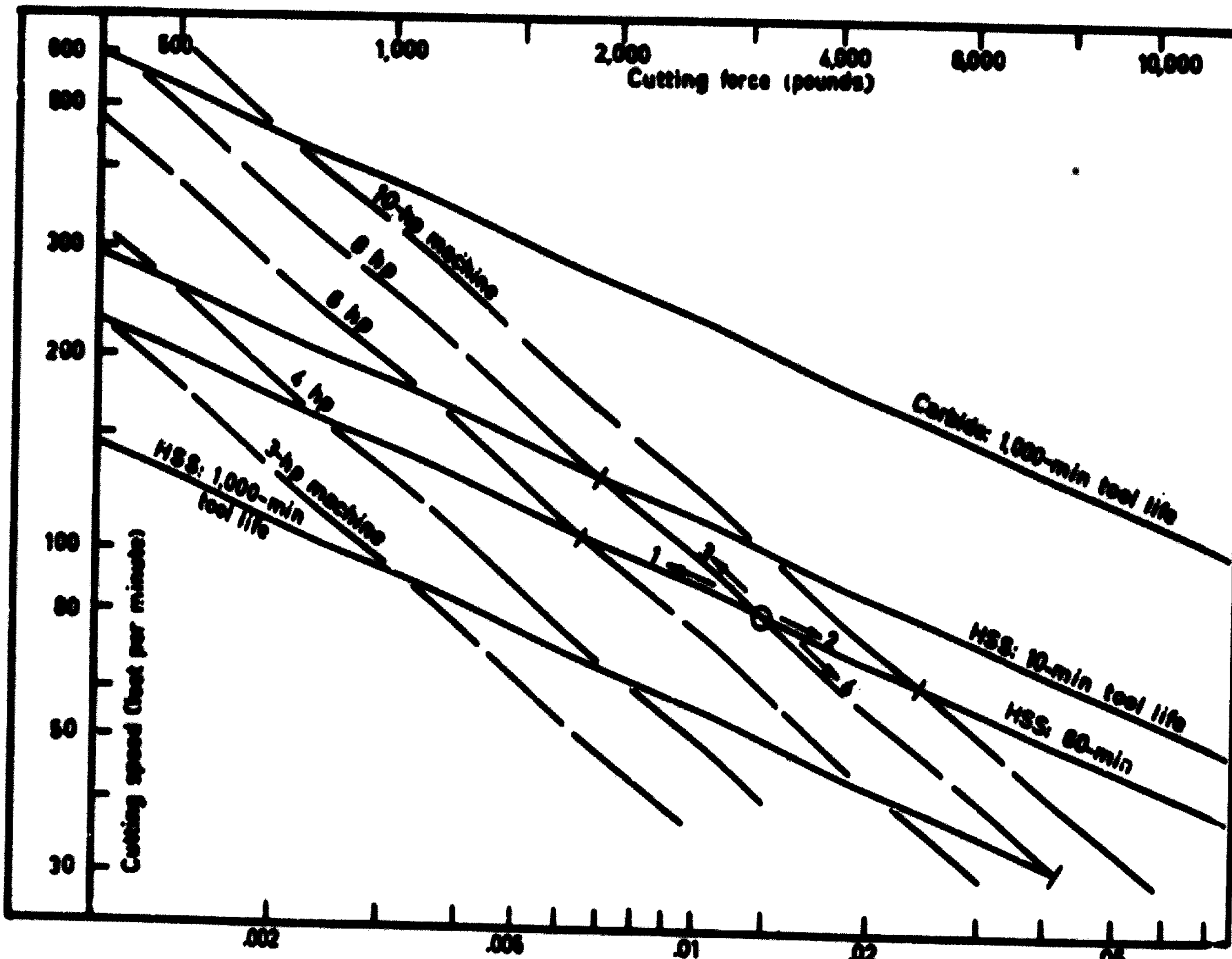
MILWAUKEE-MATIC MULTIPLE-PURPOSE MACHINE TOOL, PRODUCED BY KEARNEY & TRECKER tables. On the other hand, tables are more useful than charts when the user is not sufficiently familiar with the reading of charts (as may be the case in the industries of developing countries) or when a reading must be duplicated exactly.

Productivity charts convey basic information to the eventual users, including programmers for NC machines. In making up the productivity chart shown in figure 12 (in this case, for SAE 1035), the lower horizontal axis is plotted in terms of chip areas (feed × depth of cut) in values of 0.002 to 0.050 square inches. The cutting speed is plotted on the vertical axis for a range from 30 to 600 ft/min. At the top of the chart, a scale for cutting forces ranging from 500 to 10,000 pounds is plotted. Cutting force is a very important quantity in metal cutting and is required for determining deflections and whether the machine or the workpiece is rigid enough with respect to the accuracy desired.

In the centre field of figure 12, two series of lines descend from left to right at different slopes. The lines with the smaller slope (those going to points 1 and 2) are the result of tool-life investigations, while those with the larger slope (those going to points 3 and 4) are derived from horsepower and cutting-force investigations. The limits qualifying the application of the general formula for the metal-removal rate (equation II–1) are incorporated in the productivity chart, as will become evident hereafter. For example, assume an 8-hp machine, a high-speed steel tool and a tool life of 60 minutes for the removal of a chip of 0.013 sq. in. (¼-inch depth of cut by 0.050-inch feed/rev). The circle at the intersection of these quantities shows that these conditions will be satisfied when the cutting speed is set to 80 ft/min.

It is now desired to investigate the changes that occur in the metal-removal rates if speed, feed, horsepower or tool life are changed.

Following the 60-minute tool-life line in direction of the arrow leading to point 1 results in an increase in cutting speed and a reduction in feed. In this way, the 6-hp line is approached. Hence, an 8-hp machine cannot be fully utilized if the feed is reduced and the speed is increased in such a manner that the tool life of 60 minutes is maintained. The metal-removal rate, or, in other words, the productivity, would be reduced, as can be determined



Note: HSS high speed steel.

Figure 12

PRODUCTIVITY CHART FOR SAE 1035 (20° TRUE RAKE ANGLE)

…m the chart. At the circle, the metal-removal rate is …13 · 80 · 12 = 12.5 cu. in./min. At point 1, with a …ting speed of 105 ft/min and a chip cross-section of …065 sq. in., the metal-removal rate has dropped to …065 · 105 · 12 = 8.2 cu. in./min. This is a loss of … per cent.

Following the 60-minute tool-life line in the opposite direction, namely, along the arrow leading to point 2, results in an increase in feed and a decrease in cutting speed. Here, the 10-hp line is approached, indicating that the 8-hp machine would be overloaded.

A third possibility is indicated by the arrow leading to point 3. Again, the speed is increased, but even more so, and the feed is reduced. In this case, one leaves the 60-minute tool-life line and approaches the 10-minute line. Because such a short tool life will often be undesirable, one changes from high-speed steel to carbide tools and thereby increases the tool life to more than 1,000 minutes, as indicated by the fact that one is below the carbide line for 1,000 minutes. The metal-removal rate at point 3 is somewhat less than at the circle, namely, 0.0065 · 144 · 12 = 11.2 cu. in./min. This is a loss of only 10 per cent, as against the loss of 35 per cent when maintaining a tool life of 60 minutes for high-speed steel. The loss in the metal-removal rate is compensated by the gain in tool life and, hence, by a reduction in down-time for tool changes, as well as by improvement in the surface finish, due to the disappearance of the built-up edge at higher speeds. The accuracy will also be improved, as indicated by the reduction in the cutting force which drops from 3,200 lb at the circle to 1,800 lb at point 3. (The same drop applies also to point 1, without, however, the benefits in tool life, surface finish etc.)

In spite of the loss in the metal-removal rate, which is always the result of feed reduction and speed increase, it is often desirable to reduce the feed and increase the speed according to the line to point 3, that is, by fully utilizing the horsepower of the machine. This procedure is recommended whenever the workpiece is unstable and/or when a high surface finish is required. The trend in production methods follows this combination of speed and feed, and will do so in the future to an increasing extent when the metal-cutting relationships disclosed by research are more fully understood in the shops.

Another possibility remains, as indicated by arrow leading to point 4. Here, the feed is increased, the speed is reduced and the horsepower is again kept constant. Tool life of high-speed steel is improved, and the metal-removal rate increases to 15.3 cu. in./min. at point 4. This is a gain of … per cent. However, the cutting force increases considerably; namely, from 3,200 lb at the circle to 8,000 lb at point 4. The workpiece and machine would, therefore, … considerably more deflected than they are at the circle, resulting in a poorer finish and reduced accuracy. This type of change is therefore recommended only in the case of roughing heavy workpieces on powerful and rigid machines.

B. *Time-studies of production methods*

Although numerical control is going to reduce the significance of time-studies—because handling time depends upon the commands given the machine by the tape—such studies will be required for many years to come in a great number of machine shops.

Productivity charts are also useful for time-studies, as in the case of mass production on a 2.5-hp automatic screw machine (see fig. 13), turning 1-inch brass bar stock. By following the 2.5-hp line from right to left, one obtains, for each point, a different combination of feed, speed, cutting time etc. The cutting speed increases, while the chip area (and therefore the feed) decreases, as is indicated in table 6.

Table 6

MACHINING DATA FROM PRODUCTIVITY CHART FOR MACHINING BRASS: SCREW MACHINE[a]

Point on chart	*Chip area (square inches)*	*Cutting speed (feet per minute)*	*Tool life (minutes)*	*Tool*
a	0.0040	225	60	High-speed steel
b	0.0020	375	2,000	Carbide
c	0.00064	900	1,000	Carbide

[a] See figure 13.

Which combination of feed and speed will be the most favourable in practice? Note point "c" and the two arrows shown. One arrow is placed horizontally on the 900 ft/min cutting-speed line, the other one vertically on the 0.0064 chip-area line.

The time-study engineer usually assumes a feed rate that he thinks will produce a satisfactory surface finish. The assumption is 0.0051 in./rev and ⅛-inch depth of cut, giving a chip area of 0.00064. Point "c" in figure 13 shows that a tool life of 1,000 minutes would be obtained, which is not sufficient, in view of the considerable down-time involved in changing tools, particularly, as here, in the case of mass production and short runs per piece.

The time-study engineer decides that 3,000 minutes of tool life are desirable for optimum manufacturing conditions. He consults the chart and sees that at least two answers exist for obtaining 3,000 minutes of tool life. By following the horizontal arrow at point "c", he finds that the desired tool life of 3,000 minutes can be obtained by reducing the chip area to 0.00047 square inches, which corresponds to a feed of 0.0038 in./rev and a depth of cut of ⅛ inch. The cutting time for a 1-inch length of cut would be 4.6 seconds, as against 3.42 seconds, for point "c" and 1,000 minutes of tool life.

By following the vertical arrow from point "c" down to the 3,000-minute tool-life line, the time-study engineer finds that the desired tool life can also be obtained by reducing the speed to 740 ft/min. This value is adopted because the cutting time is 4.15 seconds per 1-inch length; hence, it is less than the 4.6 seconds for 3,000 minutes of tool life, although more than the 3.42 seconds for 1,000 minutes of tool life. The cutting times are computed from:

$$t = \frac{L \cdot t \cdot D \cdot \pi \cdot 60}{12 \cdot A \cdot v} \text{ sec} \qquad \text{(Equation II 3)}$$

where L = length of cut (1 inch); t = depth of cut (= ⅛ inch); D = diameter (= 1 inch); A = chip area (variable); and v = cutting speed (variable).

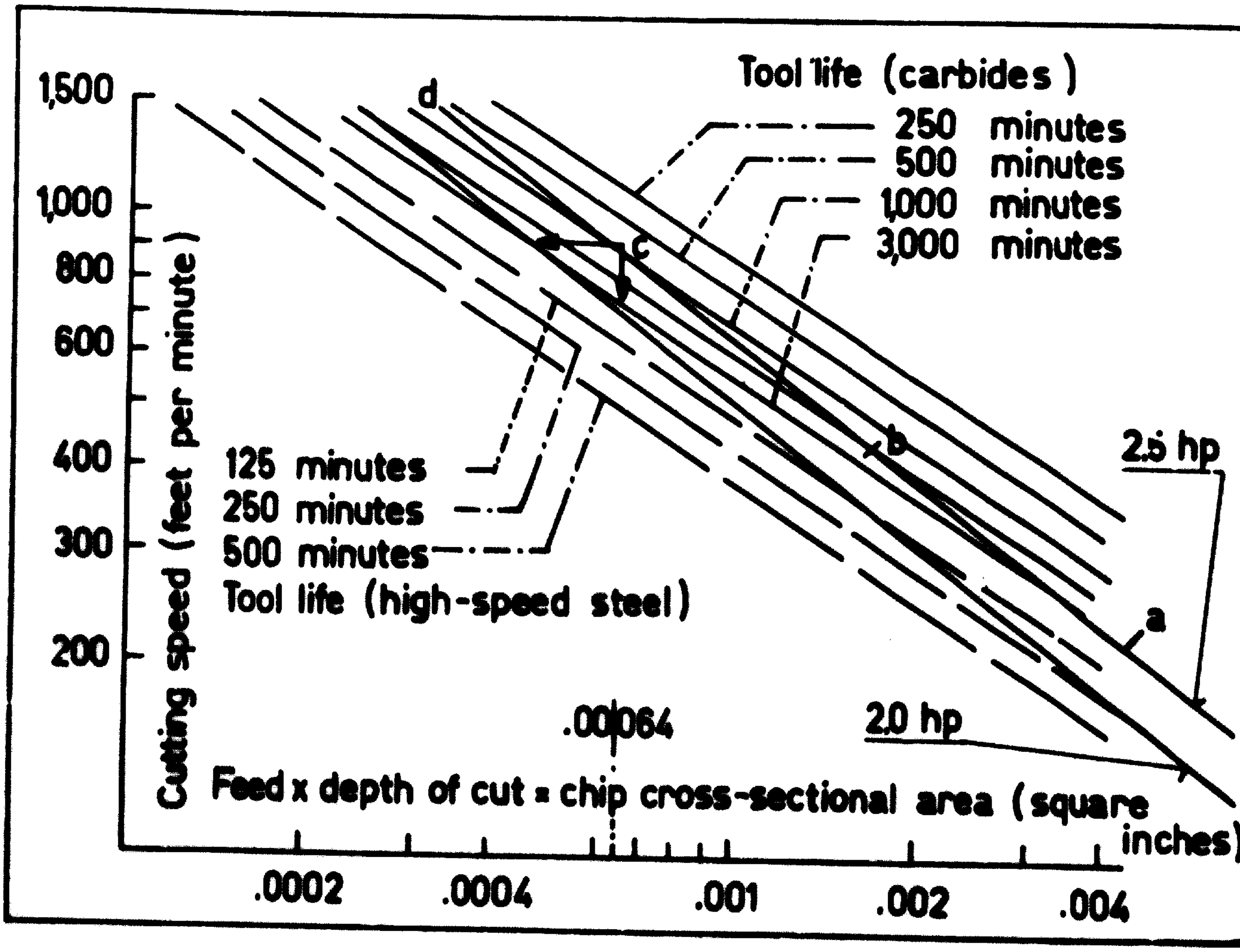


Figure 13

PRODUCTIVITY CHART FOR MACHINING BRASS: SCREW MACHINE

Charts like those discussed above can also be used by a skilled machine operator. If the operator is not able to read a technical chart, he can be furnished with tables prepared from the charts.

C. *Service life*

The design trend in machine tools is not only affected by the increase in productivity, horsepower and metal-removal rates, but also by the service life of new machines in comparison with older designs.

The service life often influences management decisions as to whether to buy a new machine or to replace an older one. Service life is, on the one hand, tied to such design features as rigidity, wear resistance and absence of vibration; and, on the other, to financial considerations. For many years, industry has been using the MAPI formulae for determining whether a new design of machine tool would improve production. The following somewhat simplified equation shows the adverse minimum (d), acquisition cost of a new machine (c) and interest rate (i) in relation to the service life of a new machine (n). The adverse minimum is the time-adjusted annual average of operating inferiority and capital cost obtainable from the equipment in question:

$$d = c\left(\frac{i}{1.4} + \frac{2n-1}{n^2}\right) \qquad \text{(Equation II-4)}$$

It will be seen that the service life (n) is a dominant factor for comparing two machine tools with regard to their economical productivity and profitability.

Assuming the same acquisition cost of $33,000 for two new machines and service lives of fifteen years and nine years, respectively, the cost of running the machines, when the interest rate is 5 per cent, would be:

Fifteen years' service life: $d_1 = 33{,}000\ (0.05/1.4 + 29/225) = \$5{,}478$

Nine years' service life: $d_2 = 33{,}000\ (0.05/1.4 + 17/81) = \$8{,}118$

Hence, purely as a result of the difference in service life of six years, the annual savings would be $8,118–$5,478 = $2,640, when the machine with the better service life is purchased. Over a period of nine years, the savings would be nearly $23,000. The better quality machine could even cost more and still be more profitable than the one with the shorter service life. At a cost of $40,000 for the machine with the long service life, the savings would amount to $13,250 over a period of nine years. The trend wards improving the quality is thus not only justified engineering considerations of increased production, also by economics.

D. *Deflection under load*

Deflection of a machine tool under load is a measure the rigidity of the machine. This deflection, however, much more complex than the deflection of a bar on a st stand. Deflection in a machine tool is complex because an assembled machine is composed of many parts with different fits. It is the deflection between the workpiece and the tool that is of prime importance because of its effect on the geometrical accuracy and on the surface finish of the workpiece, as well as on vibration and thus on service life and tool wear.

On a lathe, this deflection is a composite of the deflections of bed, headstock, carriage etc. With radial drills, lifting of the arm is caused by the cutting force and may lead to broken drills, inaccurate holes and uneconomical down-time.

On a horizontal milling machine, the most important deflection occurs between table and arbor. As a result of numerous tests to determine the relationship between load and deflection, it has been found that a hysteresis curve applies, as is shown in figure 14.

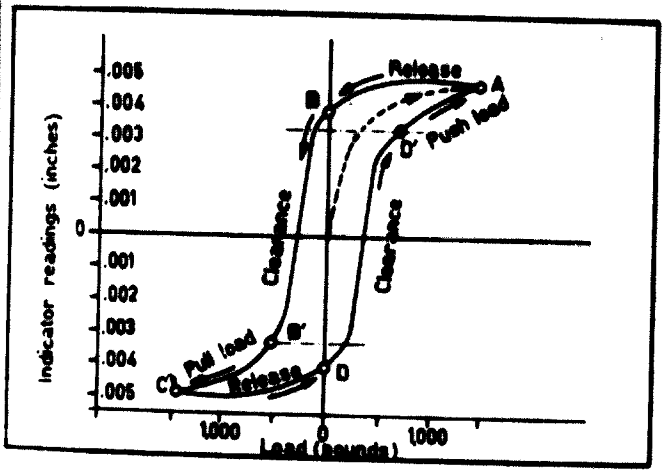


Figure 14

"PUSH-PULL" DEFLECTION OF AN ASSEMBLED MACHINE

The dotted line from the centre to point A is obtained when applying a load gradually pushing apart the tool and the work. Upon release of the load, the test indicator hand does not return to zero; it stops at point B. Reversing the direction of the load by pulling together the work and the tool results in a motion from B to C. When this load is released, the indicator hand does not go back to no deflection, but stops at point D. If the tool and workpiece are again pushed apart with the same amount of applied load, the load-deflection curve will go again to point A, but it will travel by the D-D'-A path. This cycle can be repeated many times.

In the hysteresis loop, the straight portions B-B' and D-D' are of particular interest. They indicate the motion of assembled parts, not deflection. A load of only a few pounds is sufficient to impart a sizeable motion to the parts of the machine. This load need only be large enough to overcome friction between the assembled parts. This friction must be overcome by a load in the reverse direction so that the displacement of the parts becomes zero and the indicator hand thus stops at zero deflection. Backlash in gearings accounts for a large part of the motion between assembled parts as the load direction changes, indicated by the straight portions, B-B' and D-D'.

In the case of true deflection, energy is stored in the deflected part. This energy returns a deflected part to its original state upon release of the load, without any additional outside load, except an insignificant loss caused by internal friction. It is sometimes difficult to determine which portion of a loop is due to deflection and which to motion, since the straight portions of the loop, which are not always as distinct as those shown on figure 14, may be slightly curved.

The hysteresis loop is also a measure of damping in the assembled machine parts. In the case of vibration, such load cycles occur, but at rates that cannot be simulated by push-pull tests.

E. *Rigidity*

Rigidity of a machine tool may be defined as the ratio of load to deflection. It is easiest to use 1/1,000 of an inch as the reference deflection in determining rigidity. Hence, the load in pounds that deflects a machine part 1/1,000 of an inch represents its rigidity.

On a broaching machine, the rigidity between the column face and the broach tool was found to be 1,000 lb per 0.025 inch of deflection, which is equivalent to a rigidity factor of 1,000/2.5 400 lb/0.001 in. The load was applied parallel to the column face in order to simulate the vertical cutting-force component on a broaching tool with a shear. The rigidity of the work-table in relation to the tool was substantially less, namely, 212 lb/0.001 in. The desirable rigidity depends, of course, upon the type of work being broached. When broaching a complex contour, such as those on some vending-machine parts, a higher rigidity is required than is the case when broaching flat surfaces.

The effect of milling-machine gib tightness on rigidity can also be seen from test data. With tight gibs the hysteresis loop does not have any straight portions and the branches curved to the right and the left join each other. Deflection under load was 0.0003 inches per 1,000-lb load, corresponding to a rigidity factor of about 3,300 lb/0.001 in. Turning the set screws loose by two turns, as recommended by the manufacturer, reduced the rigidity to about one-fourth, namely, to 835 lb/0.001 in. Loosening another turn reduced the rigidity to 330 lb/0.001 in.

On a horizontal milling machine, the knee deflection was 0.0037 inch when a load of 1,000 lb was applied. The rigidity was thus 270 lb/0.001 in. when feeding to the left. When feeding to the right, however, the rigidity was only 90 lb/0.001 in. Inspection of the machine showed that when feeding to the left the load was directed against a solid dovetail. When feeding to the right, it acted against an inserted dovetail. By replacing the screws of the inserted dovetail with tightly fitted dowel pins, the rigidity was increased to about 200 lb/0.001 in.

Figure 15 shows the increase in rigidity of vertical boring mills. By changing the moments of inertia and, hence, the mass distribution (see figs. 16 and 17) of the cross-rail and of other members of the machines, it was possible to strengthen the new design considerably.

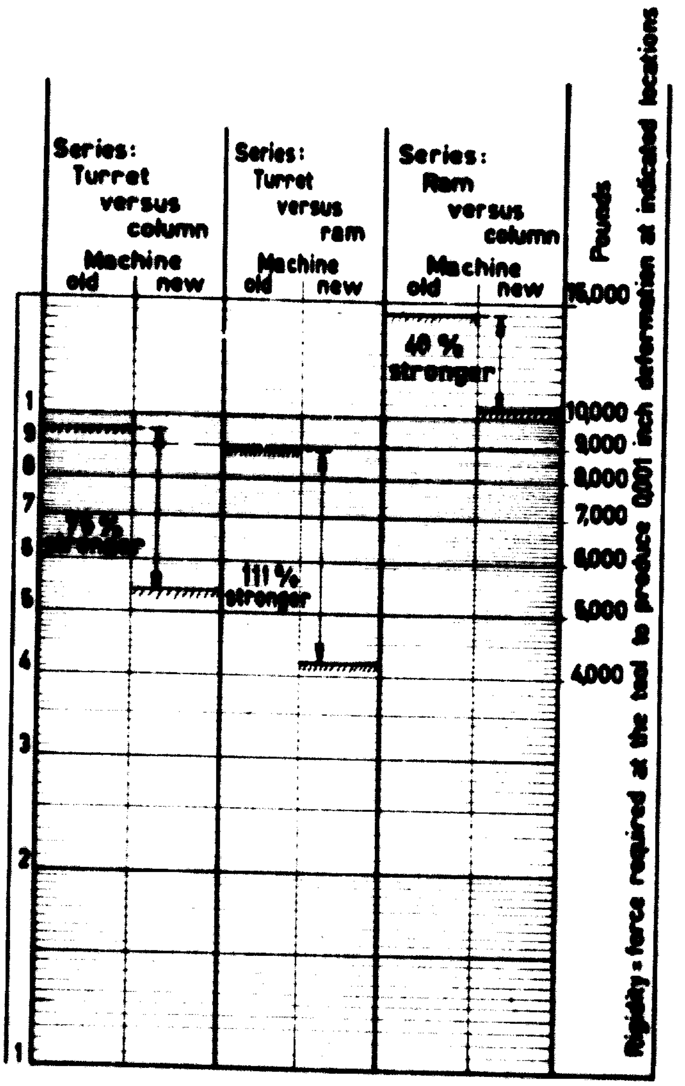


Figure 15

PRELIMINARY RESULTS OF COMPARATIVE RIGIDITY TESTS: NEW *versus* OLD 36-INCH VERTICAL BORING MILLS

Measuring the rigidity of the turret *versus* the column showed that the new machine was 75 per cent stronger. The rigidity of the turret *versus* the ram increased 111 per cent and that of the ram *versus* the column, 40 per cent.

Recently, in a similar investigation in France, the rigidity of a vertical boring mill was increased by changing the design and using a J-shaped arm, rather than modifying the mass distribution.

In precision lathes for the aircraft and space industries, very close tolerances must be met for the crosswise slope of the carriage when travelling on the bed. This requires great care in the design and production of such lathes. A

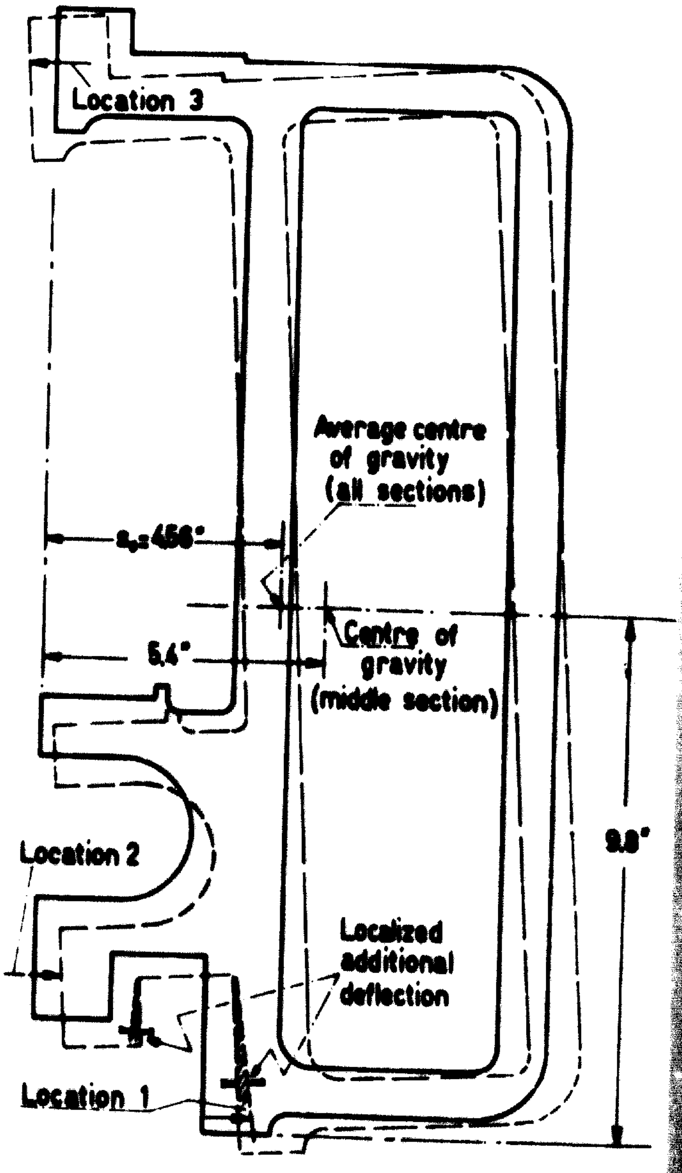


Figure 16

DEFLECTION OF OLD TYPE OF CROSS-RAIL: 36-INCH VTL

combination of a cast-iron bed and a welded-steel base brought satisfactory results after several modifications of the original concept were made. These modifications were based on the results of a series of tests. Figure 18 shows this combination of bed and base, and the instruments which were used in the initial stage of investigation of the torsional rigidity. More elaborate equipment was subsequently used, after the range of measurements had been determined from the preliminary data obtained with the inexpensive set-up shown. The torque was simulated by placing varying weights on the long arms, and it considerably exceeded the torque actually expected.

Angular displacement of bed and tool causes oversized workpieces like those illustrated by the sketches in figure 19. Horizontal displacement is considerably more severe than vertical displacement, as is indicated by the two formulae shown in figure 19. Their ratio follows:

$$\frac{u_1}{u_2} = \frac{2h \cdot 2d}{h^2} = \frac{4d}{h} \qquad \text{(Equation II-5)}$$

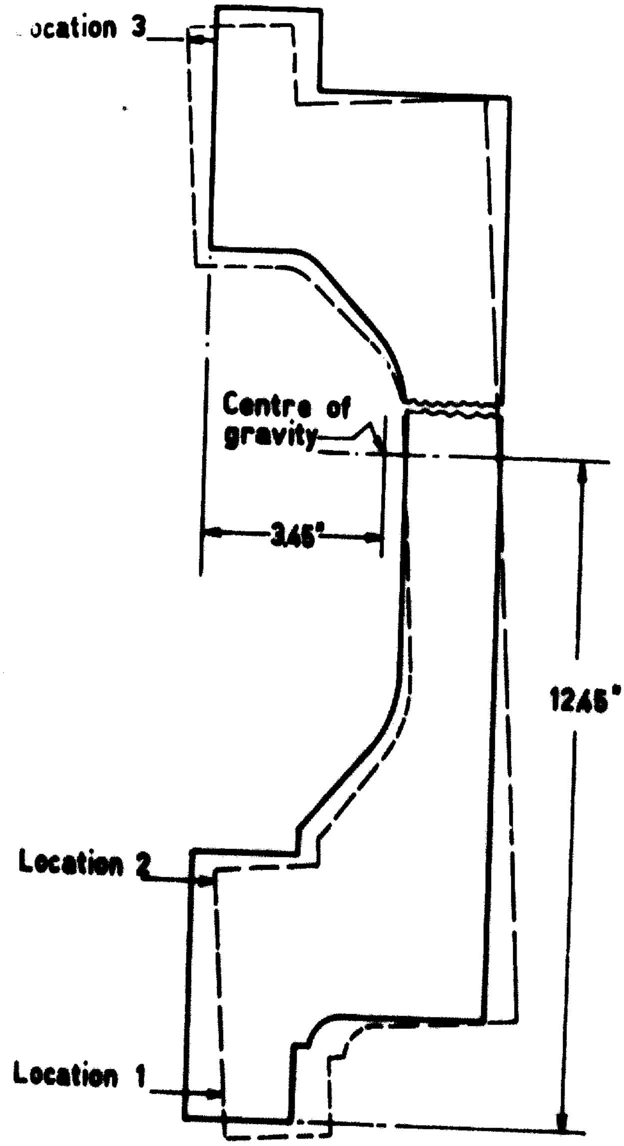


Figure 17

DEFLECTION OF NEW TYPE OF CROSS-RAIL: 36-INCH VTL

Hence, for a work diameter of 1 inch and a permissible displacement of $h = 0.0001$ inch:

$$u_1/u_2 = 10{,}000 : 1 \qquad \text{(Equation II–6)}$$

That is, a horizontal displacement between tool and work has 10,000 times more effect on the oversize of the workpiece than does a vertical displacement of the same amount. This ratio increases with increasing diameter and decreasing displacement (h).

The example indicates, furthermore, that a vertical bow in the bed is less significant in its effect on the oversize of the workpiece than is a horizontal bow. Hence, straightness of a lathe bed in the horizontal plane is important.

Measurements of angular deflections of the bed and base, and of the bed bolted to the base, are listed in table 7. The results are expressed in the degree of twist per 10-inch length and for a torque of 10,000 in.-lb. The torsional rigidity ratio in column 3 of table 7 is obtained by assigning a value of unity (1.0) to the bed and base combination and dividing the corresponding angular deflections.

Table 7

COMPARISON OF ANGULAR RIGIDITY

Structure	*Degree of twist per 10-inch length for 10,000 inch-pounds*	*Relative rigidity*
Bed + base	0.00253	1.00
Base only	0.00600	0.42
Bed only	0.02180	0.116

It will be seen from table 7 that the steel base is torsionally more than 3.5 times as strong as the cast-iron bed (0.42/0.116 = 3.6). The base strengthens the bed considerably, increasing the torsional rigidity by a ratio of 1.0/0.116 = 8.6. The bed, on the other hand, strengthens the base also, although to a lesser degree, namely, at a ratio of 1.0/0.42 = 2.4.

The great strengthening effect of the steel base is due to the fact that the material could be so distributed as to give a high moment of inertia. This is not as easily achieved with cast-iron designs, due to the core openings which reduce torsional rigidity considerably, while welded designs permit closed-box sections. The trend is, therefore, in the direction of increasing application of welded designs, often combined with cast-iron parts where desirable.

Figure 20 shows the deflection of heavy lathes when under axial loads, and figure 21 shows the deflection for radial loads. Axial deflections occur on lathes when the centres, holding the workpiece, are too tight and also when the heat causes elongation of the workpiece. In tropical countries, such deformation may also occur when a lathe is too much exposed to the sun. The beds warp upwards, and headstock and tailstock get out of alignment. The beds return to the original alignment upon release of the centre load and upon cooling. They may even take the shape shown in the lower part of figure 20 (pull load) when the workpieces or the cutting forces are too large and the rigidity is too low.

The radial cutting force may deform a weak bed, as is shown on figure 21. This is particularly undesirable because this type of deflection and the corresponding vibration causes oversize of the workpiece and undulated surfaces.

Another example of the trend towards finding the weak spots in machine tools and improving their rigidity is given in figure 22. Applying a vertical load at point "a" over the front wings of a lathe carriage or at point "b", outside the guideway of the front wings, it was found that the rear wings bulged upwards, as sketched in the lower part of figure 22. The design was subsequently changed, strengthening the cross-section of the wings at the centre line of the bridge.

In another series of tests, strain gauges were attached at the four radii marked a, b, c, and d on figure 22 and also shown at "A" on figure 23. Moving the carriage to the left (i.e., towards the tailstock) showed that the rear wings were trailing the front wings, deflecting the bridge, as sketched, and hence the tool also. Under oscillating cutting forces, the bridge would swing in this way and would produce the well-known vibration patterns on the workpieces. This type of vibration has received little attention so far.

The rigidity of machine-tool spindles has been investigated in the Federal Republic of Germany, where attention is being given to the behaviour of spindles supported in two bearings. Upon converting these rigidity data from the metric system, it may be seen that rigidities as high as 4,000 lb per 0.001 inch can be obtained on a test stand, i.e., when the spindle is tested outside the lathe and is supported on wedges. In view of the fact that bearings do not act like wedges, the rigidity of spindles built into the machine is less than those outside. Satisfactory rigidity values lie between 1,500 and 2,500 lb per 0.001 inch for a lathe of 10-inch swing.

In the United States of America, machine-tool spindles are often supported in three bearings, and the trend is in this direction in order to increase the spindle rigidity. Three-bearing support requires, of course, a careful alignment in order to avoid permanent deformation of the spindle. The alignment depends upon the bores in the headstock; they must be machined with care on a precision lathe or horizontal boring mill. Details of the present author's investigations of the rigidity of spindles with three supports have been published previously (6). The rigidity of jog borers and other precision machine tools depends upon the number and location of the points of support. In the USSR, the angle of deflection of a jog borer supported at three points was taken as reference (7). Through the addition of four support points, the rigidity of the machine could be increased by 67 per cent. Best results, however, were obtained when a jig borer was supported at two points at the front of the base and at one point at the rear. With this set-up, the rigidity increased 180 per cent. More than three points make a rigid system statically indeterminate.

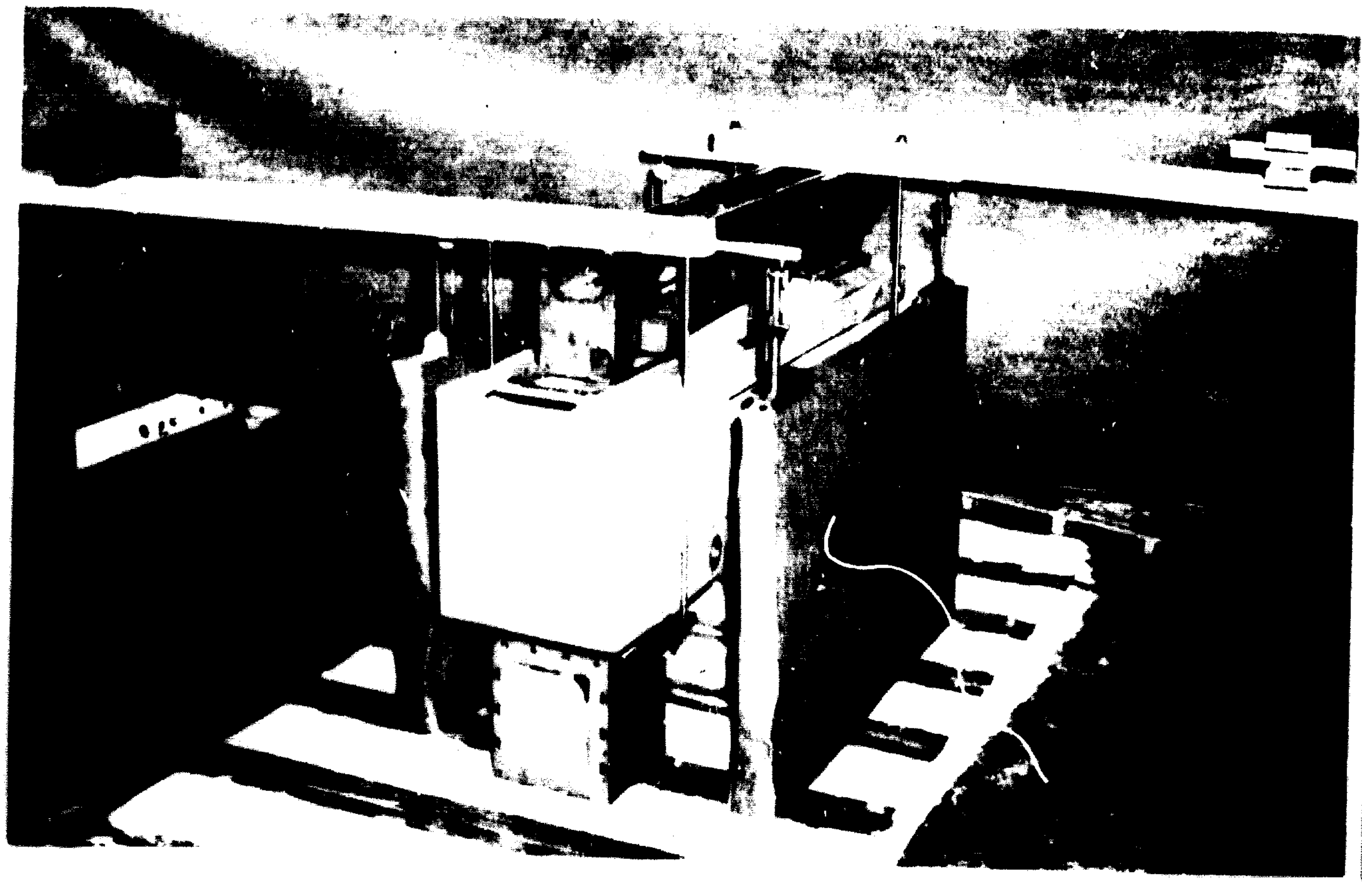


Figure 18

CAST-IRON BED AND WELDED-STEEL BASE, AND INSTRUMENTS USED IN INITIAL TESTS OF TORSIONAL RIGIDITY OF PRECISION LATHES

As an example of a method for obtaining high rigidity of the frame of multiple-spindle automatics, figure 24 shows a unit built by the New Britain Machine Tool Company. Headstock, base and pan are cast integrally.

The trend towards increasing the rigidity of machine tools is further indicated by the advent of hydrostatic and hydrodynamic bearings, by duplex walls, by mounts and by similar advances in the design.

F. *Vibration*

Attempts to combat vibration are closely linked to the efforts to increase the rigidity of machine tools. In the case of vibration, however, consideration must be given

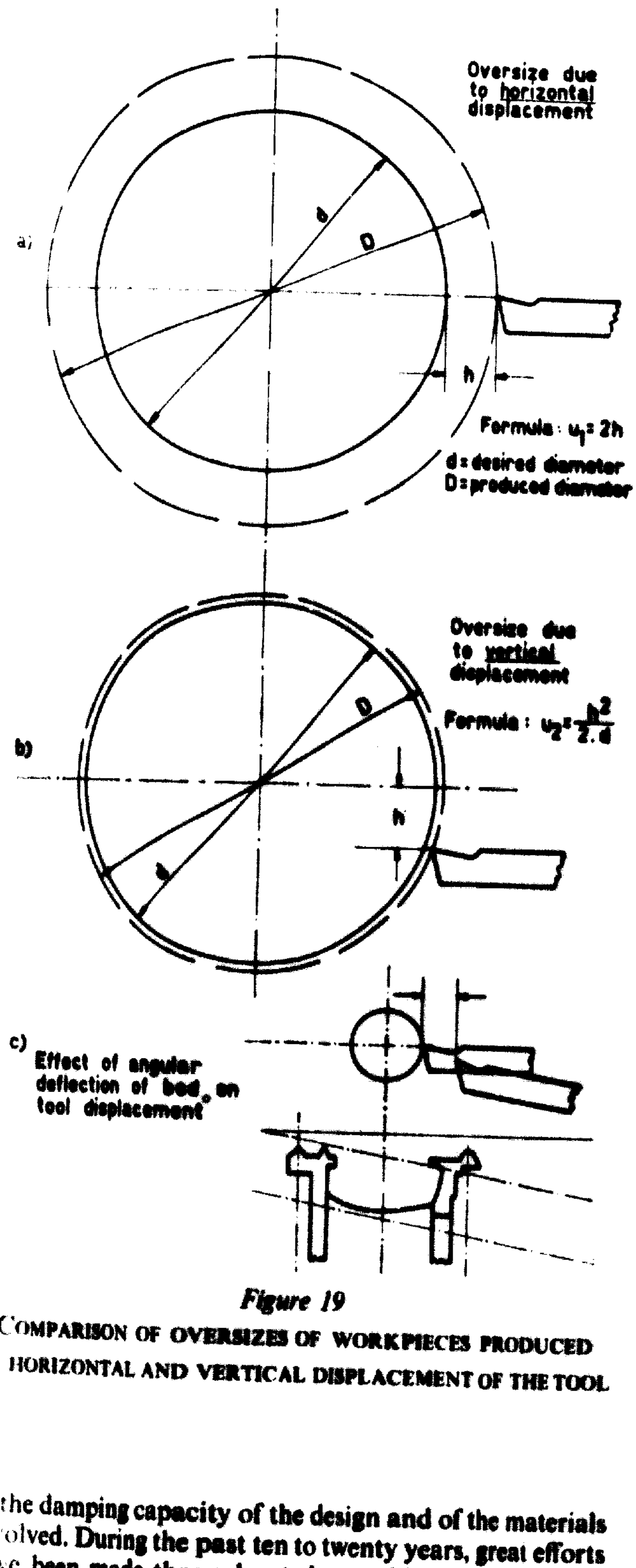
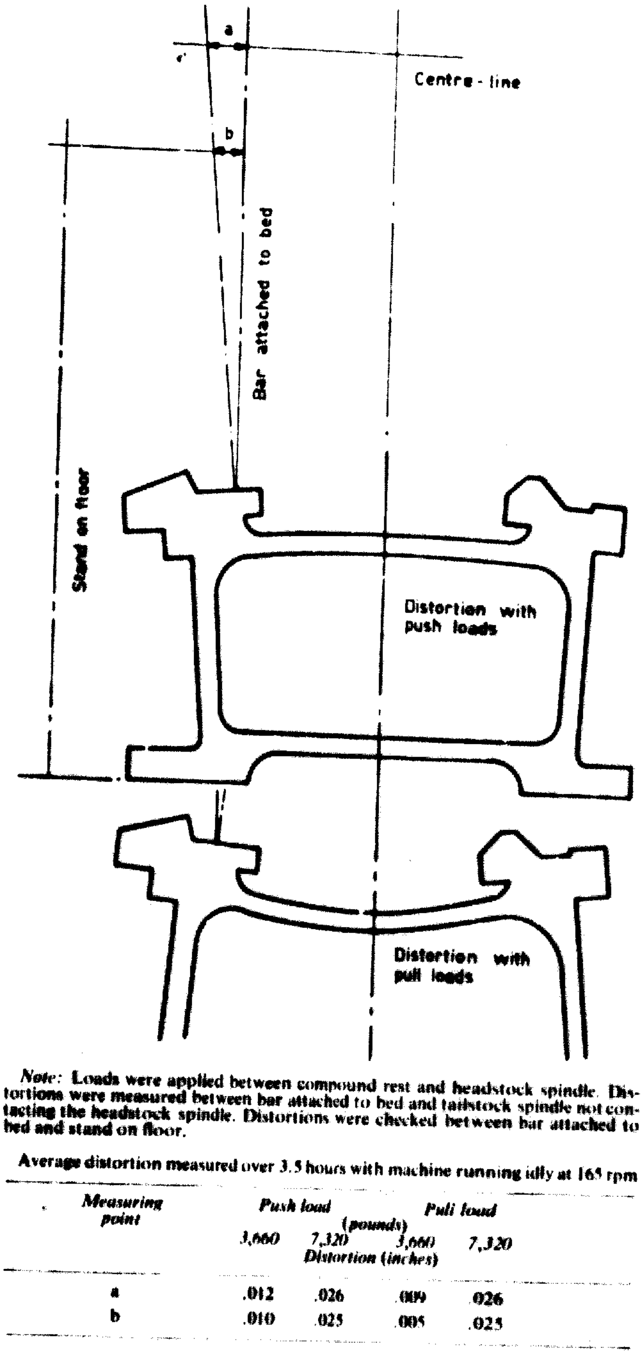


Figure 19

COMPARISON OF OVERSIZES OF WORKPIECES PRODUCED BY HORIZONTAL AND VERTICAL DISPLACEMENT OF THE TOOL



Note: Loads were applied between compound rest and headstock spindle. Distortions were measured between bar attached to bed and tailstock spindle not contacting the headstock spindle. Distortions were checked between bar attached to bed and stand on floor.

Average distortion measured over 3.5 hours with machine running idly at 165 rpm

Measuring point	*Push load* (*pounds*) 3,660	7,320	*Pull load* 3,660	7,320
	Distortion (inches)			
a	.012	.026	.009	.026
b	.010	.025	.005	.025

Figure 21

DISTORTION OF BED SECTION UNDER RADIAL LOADS: 50-INCH HEAVY-DUTY LATHE

... the damping capacity of the design and of the materials ...volved. During the past ten to twenty years, great efforts ...ve been made throughout the world to find the rela- ...nships between the numerous factors that affect vibra- ...n in machine tools, although the significance of the ...blems had been recognized for many more years (6). ...rder to reduce the number of factors, a serrated bar ... used as a vibration exciter, thus eliminating the ...ts of dulling of the tools, chip formation, hard spots ...he material and the like, which are difficult to control ... to evaluate in the case of exciting vibration under ...al cutting conditions. Subsequently, other exciters, such as electric and magnetic fields, were used. In the case of the serrated bar, the direction of the exciting force could be so directed as to simulate the direction of the main cutting force.

In this way, the effect of mounting a carriage on two different designs of lathe beds could be studied, and improvements in vibration performance could be obtained. Figure 25 shows the results. The shaded areas indicate the improvement obtained by the new design. It will be seen that the intensity of vibration, measured with strain gauges, exceeded the admissible value of 40-• millionth of an inch per inch for almost all spindle

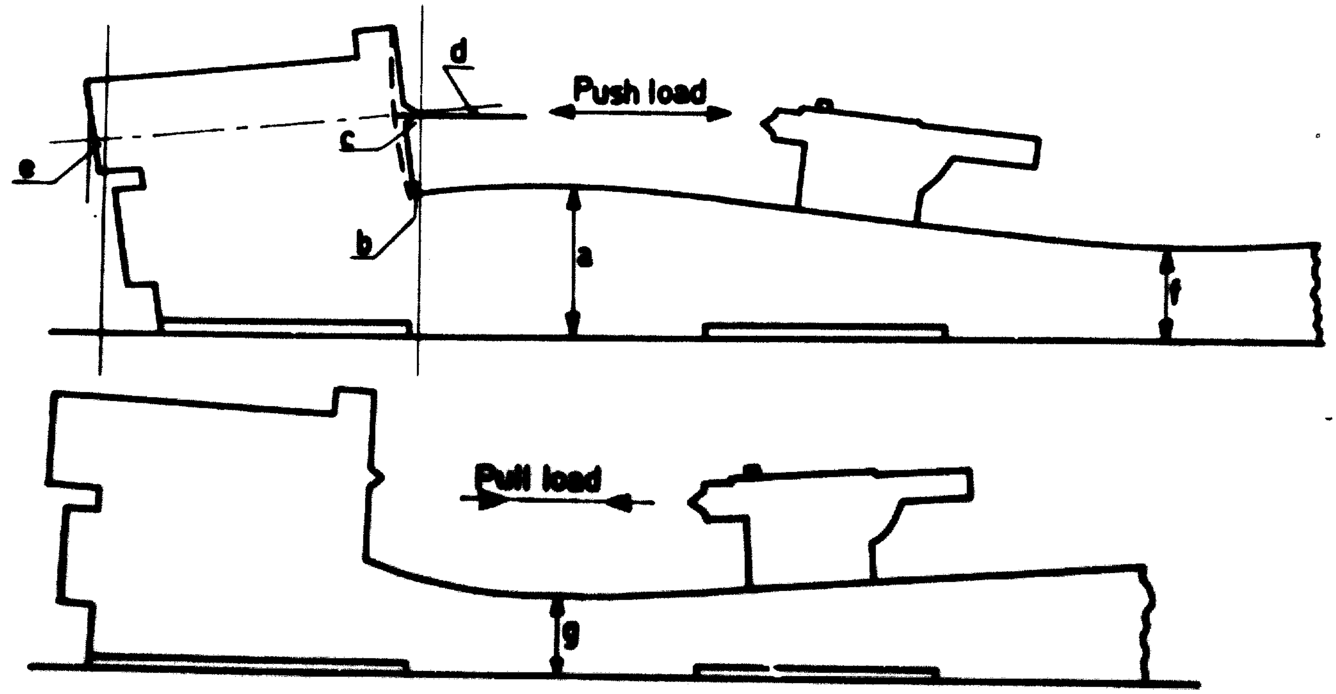


Figure 20

DISTORTION OF 50-INCH HEAVY-DUTY LATHE UNDER AXIAL LOADS

Measuring point	*Load (pounds)*	*Deflection at Guideway (inches)* Front	Rear	*Centre-line*	*Direction of deflection*
a	27,000	.0030	.0065		Vertical (increase)
	7,300	n.m.*	.0014		Vertical (increase)
b	27,000			.0013	Horizontal
c	27,000			.0075	Horizontal
d	27,000			.0025	Vertical (increase, 10 inches from spindle end)
e	27,000			.0065	Horizontal
f	27,000	—.0010	0		Vertical (decrease)
g	7,300		—.0014		Vertical (decrease, pull load)

*n.m. = not measured.

speeds except the lowest ones of less than 180 rpm. In the new design, the intensity of vibration is well below this value, except in the area between 300 and 380 rpm.

Figure 26 shows the enlarged surface with vibration marks of a workpiece rotating in the vertical direction of the paper. The change in the pattern from an inverted "v" at the right side to slightly slanted vertical lines at the left is owing to the stiffening effect of the chuck which the tool approached when travelling towards it. In this case, long slender bars had to be machined without the help of steady rests. Vibration was generated by the resilience in the compound rest for the tool, which was, however, reduced by the resistance offered by the chuck and by the shorter distance between tool and drive gears. After changing the design of the compound rest, vibration was reduced, although not entirely eliminated.

The vertical bending vibration is considerably less when the machine is supported by wedges than when it is mounted on rubber. The bending vibration in the horizontal plane, which is, in this writer's opinion, often more important than vertical vibration, follows the same trend. That is, it is better reduced by wedges than by rubber. These findings will be useful in the design of mounts and other support means.

While it has been customary to improve the design of machine tools on the basis of practical experience and customers' reactions to existing models, the trend is now shifting towards a more scientific approach based on thoroughly conducted research. The results are finding their way into the engineering offices more readily now than ever before.

The change in the bed design may serve as an example. The so-called "zig-zag" or "Peter" system of ribbing lathe bed has been used in Europe for many years, but it is being increasingly discarded, due to new findings in the Federal Republic of Germany (8). This bed design was never popular in the United States of America. The zig-zag girth has great torsional rigidity (see Fig. 27), but it is lacking in horizontal rigidity in comparison with other ribbing designs. It may thus tend to produce over-size workpieces. Also, it does not permit a free chip disposal; rather, they accumulate on the top of the ribs l heat up the bed, which is undesirable from the ndpoint of accuracy. The new German design has 50 r cent more chip space and a built-in vibration damper. e built-in damper consists of the core sand, which is liberately left in the cavities of the bed and is covered th metal plates to retain the sand at the desired places.

The three-bearing spindle design has already been entioned in conjunction with the rigidity considerations. It is now being used in European machine tools also, due to findings that the tail bearing acts as a vibration damper. The pre-loaded front and middle bearings take the load, while the tail bearing provides, in addition to damping, support for the belt drive. The tailstock spindles of European machine tools are made more rigid and the overhang of the headstock centres is reduced.

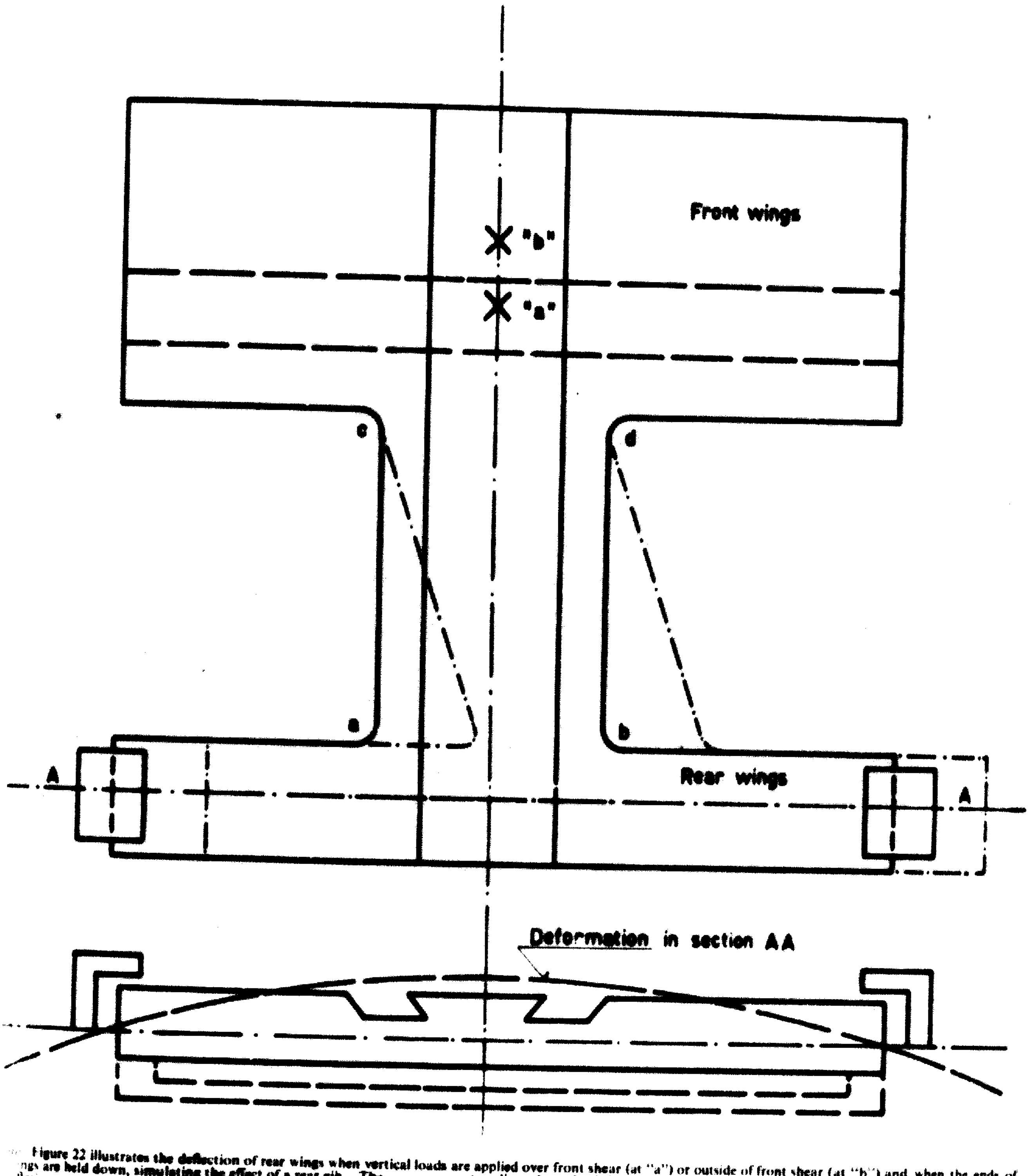


Figure 22 illustrates the deflection of rear wings when vertical loads are applied over front shear (at "a") or outside of front shear (at "b") and when the ends of ngs are held down, simulating the effect of a rear gib. The —·—·— contour lines show the deformation of the bridge under dynamic testing (grossly exaggerated), ffering an approach for exploring some types of machine-tool vibration.

Figure 22—CARRIAGE DEFLECTION TESTS

Figure 23

TESTING OF RIGIDITY WITH STRAIN GAUGES

Due to the fact that various types of vibrations—forced vibrations, self-induced vibrations etc.—occur in metal cutting, it is essential to find out, in every case of vibrational trouble, which type is predominant. In the author's experience with vibration in machine tools, it was found that many lathes, grinding machines, milling machines etc. have natural frequencies in the area of approximately 20 cps ± 20 per cent. It is thus essential to avoid motors and gear drives that may come into resonance with the natural frequencies mentioned. Often, it is advisable to separate motor and machine; in other cases, it is sufficient to balance the motor, while in still other cases, it is necessary to eliminate shaft speeds in the gearing running in the indicated area of natural frequencies.

It is considerably more difficult to reduce or eliminate self-induced vibration than forced vibrations because their origin often cannot be located. Sometimes it is advisable to modify the cutting conditions, that is, in cases where the rigidity and the damping capacity of a

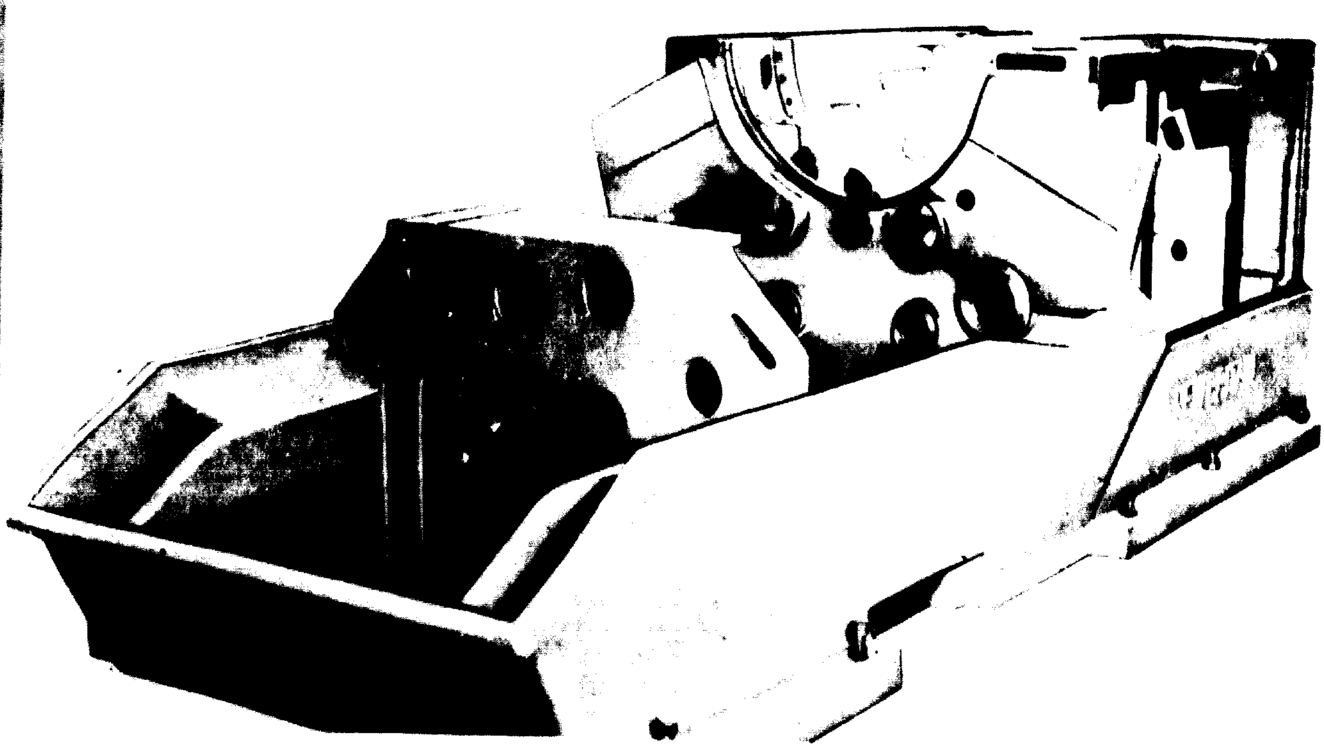


Figure 24

RIGID BED DESIGN

given machine cannot readily be changed. Such modifications include changes in speed, feed, tool geometry, coolants etc.

Reversing the direction of work rotation on a lathe has often eliminated or reduced vibration and thus improved production techniques. Figure 28 illustrates these

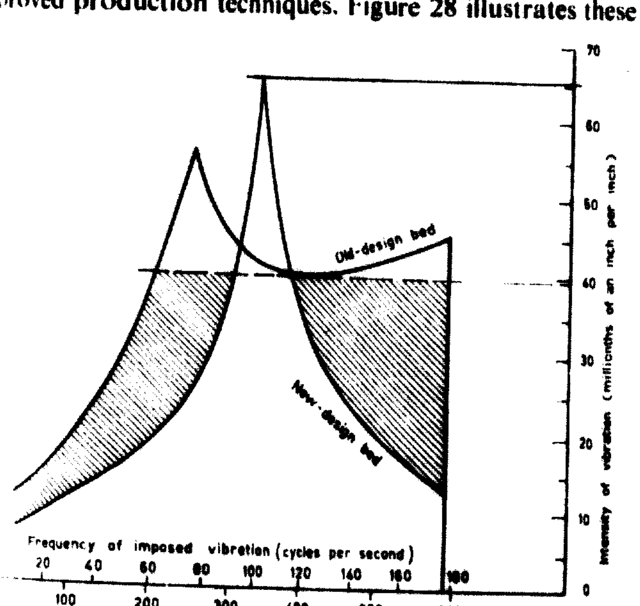


Figure 25

CARRIAGE VIBRATION

…provements, expressed in reduction in amplitude of …ration. They are very substantial in both the horizontal and the vertical planes. As an example, consider … case of 97 rpm, where vibration amplitudes at the front bearing were measured. They were 0.000,030 inch when the machine was rotating in the normal direction, but dropped to 0.000,010 inch upon reversal of the spindle rotation and placing the tool at the rear side of the carriage. This is a reduction of 95 per cent. Similar improvements were realized in almost all cases, except when running at 97 rpm and measuring the amplitude at the rear bearing in a horizontal plane. A number of overlapping conditions contribute to these results, among them a change in the damping due to the reversal of the direction of the main cutting force. The reversed rotation does not tend to lift the workpiece, but pushes it down; similar considerations apply to the forces at the drive gears and at the tool-holder and to the mass distribution in the carriage and other machine parts.

The damping capacity of cast iron is generally assumed to be greater than that of steel. This holds true in many cases, namely, when the same stress is applied to these materials. As an example, if the damping capacity for cast iron is 0.28 in.-lb/cu. in./cycle at a stress of ± 6,000 psi, it would only be 0.08 for steel at a vibratory stress of the same magnitude. However, by increasing the stress in steel to 9,000 psi the damping capacity would be raised to the same level as that of cast-iron at 6,000 psi. Hence, in order to obtain satisfactory damping in steel designs, it is necessary to increase the stress. This means using thinner walls in a steel structure than are used in a cast-iron structure. Duplication of cast-iron dimensions in steel must be avoided in machine tools, where it is not the rupture strength of the material that counts, but the deflection or rigidity. Reduced wall thickness means also less weight, which is often desirable because of the increase in natural frequency of a structure.

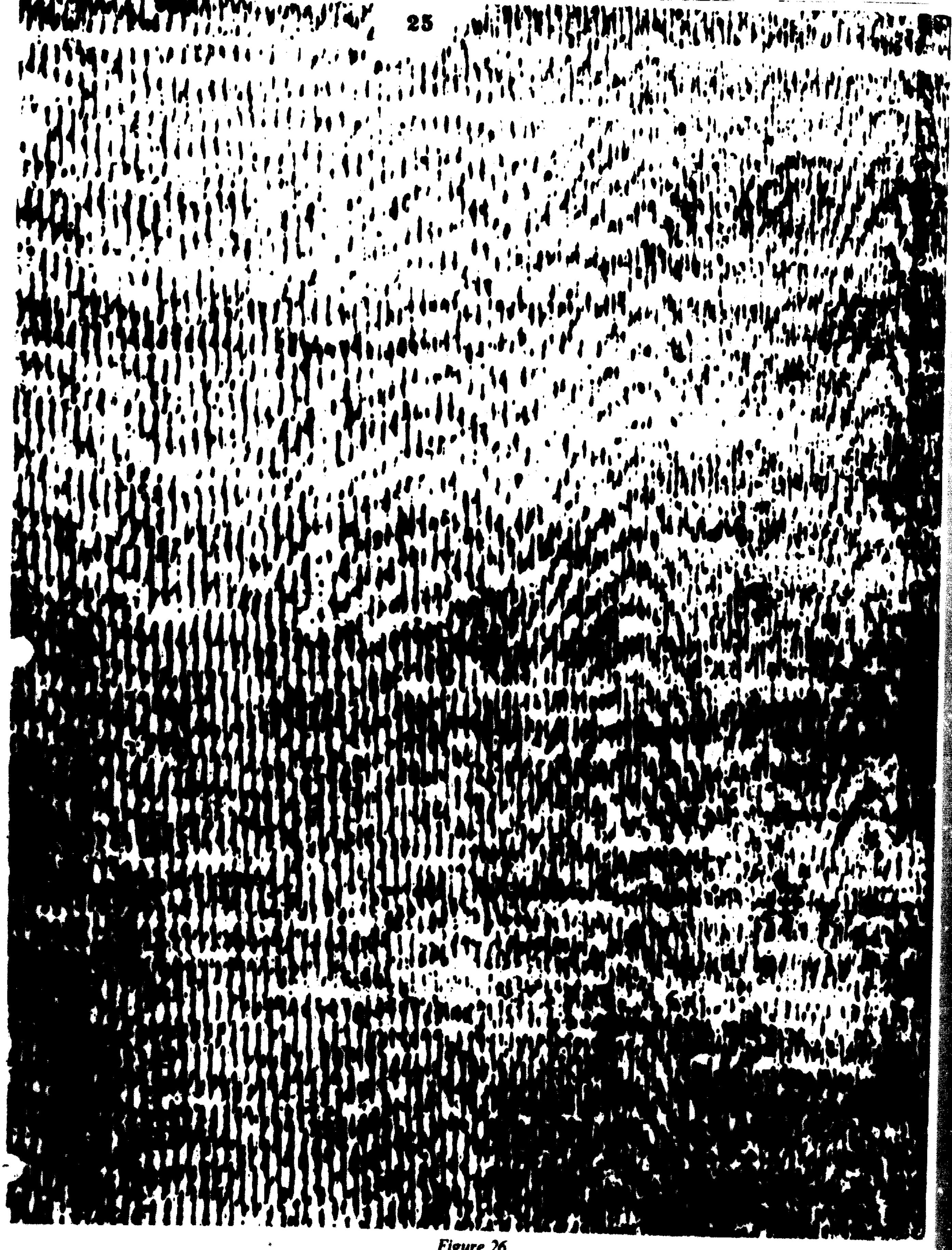


Figure 26

ENLARGED SURFACE WITH VIBRATION MARKS OF A WORK PIECE SHOWN ROTATING VERTICALLY

The following practical rules for vibration control in machine-tool design are recommended: (*a*) design for rigidity; (*b*) develop high damping capacity; and (*c*) design for light weight and high natural frequency (9). These rules have been effectively applied in the design of bases for internal grinding machines (see fig. 29). The

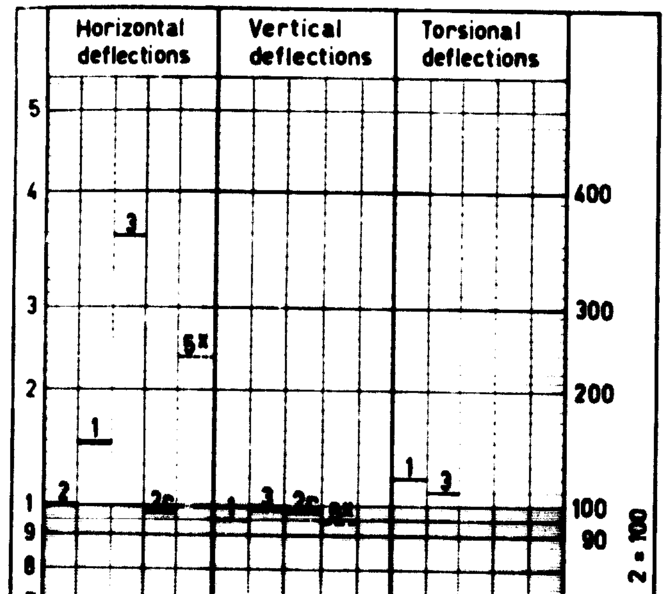
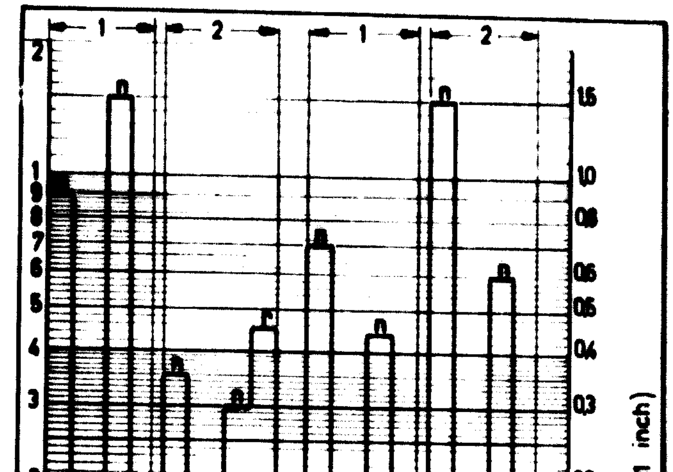


Figure 27—COMPARISON OF HORIZONTAL, VERTICAL AND TORSIONAL DEFLECTIONS (DEFLECTION OF BED 2 = 100)

centre portion, comprising plates "a", "b" and "c", and bottom "d", was designed as a closed-box section—the same as the rest of the base—for high torsional rigidity and also to establish a node of vibration at the centre. Cross-walls and internal walls were made of 3/16-inch sheet steel and the outside walls of ¼-inch gauge. The entire base has no openings except for a tube connexion, a feature which contributes to high rigidity.

In internal grinders, vertical rigidity is more important than rigidity in other planes because misalignment in the vertical planes has the greatest effect on workpiece accuracy. For this reason, walls "e" were placed vertically and were designed in a V-shape. The open ends of the V's contribute also to horizontal rigidity. Cross-walls "f" and "g" were run to the V-shaped walls in order to eliminate local "drum" effects and to increase the damping capacity by increasing the stress. The sequence of welding is shown on figure 29 by circled numbers.

Vibrations in vertical boring mills are largely influenced by the rigidity of the ram and cross-rail. This was confirmed by investigations in the Soviet Union (10). The ram and the tool with it vibrate in two directions, namely, perpendicular and parallel to the cross-rail. The



Note: n = normal spindle rotation, tool on front side of carriage; r = reversed spindle rotation, tool on rear side of carriage; 1 = measured at front bearing; 2 = measured at rear bearing.

Figure 28—DUAL-DRIVE LATHE, 15-INCH: AMPLITUDES OF VIBRATION UNDER FACE PLUNGING CUTS, EFFECT OF REVERSING SPINDLE ROTATION

ram itself contributes 80 per cent of this type of vibration, with the balance coming from the rail. In other cases—particularly when the rigidity of the cross-rail is low—the vibration of the tool is controlled by the oscillations of the cross-rail.

In the United Kingdom, vibration investigations on milling machines confirmed findings in the United States of America (11) on the initial impact of cutter and work, and the significance of placing the face mill, in relation to the workpiece, in such a position that the tip of the cutting edge does not enter first. In this way, production increases can be obtained because of reduced breakdown of the cutting edge. Supplementing these findings, investigations were also undertaken in the Federal Republic of Germany (12), as illustrated in figure 30. In the case of a long time (0.2 milliseconds) of engagement of cutter and work (see fig. 30A), the vibration due to impact is small. In the case of a short time (0.027 milliseconds) of engagement (see fig. 30B), the amplitudes of vibration are considerably heavier, causing rapid breakdown and production delay. These production troubles can be avoided by the proper positioning of work and tool, which is particularly important when machining aircraft materials with carbide or ceramic inserts in face milling-cutters.

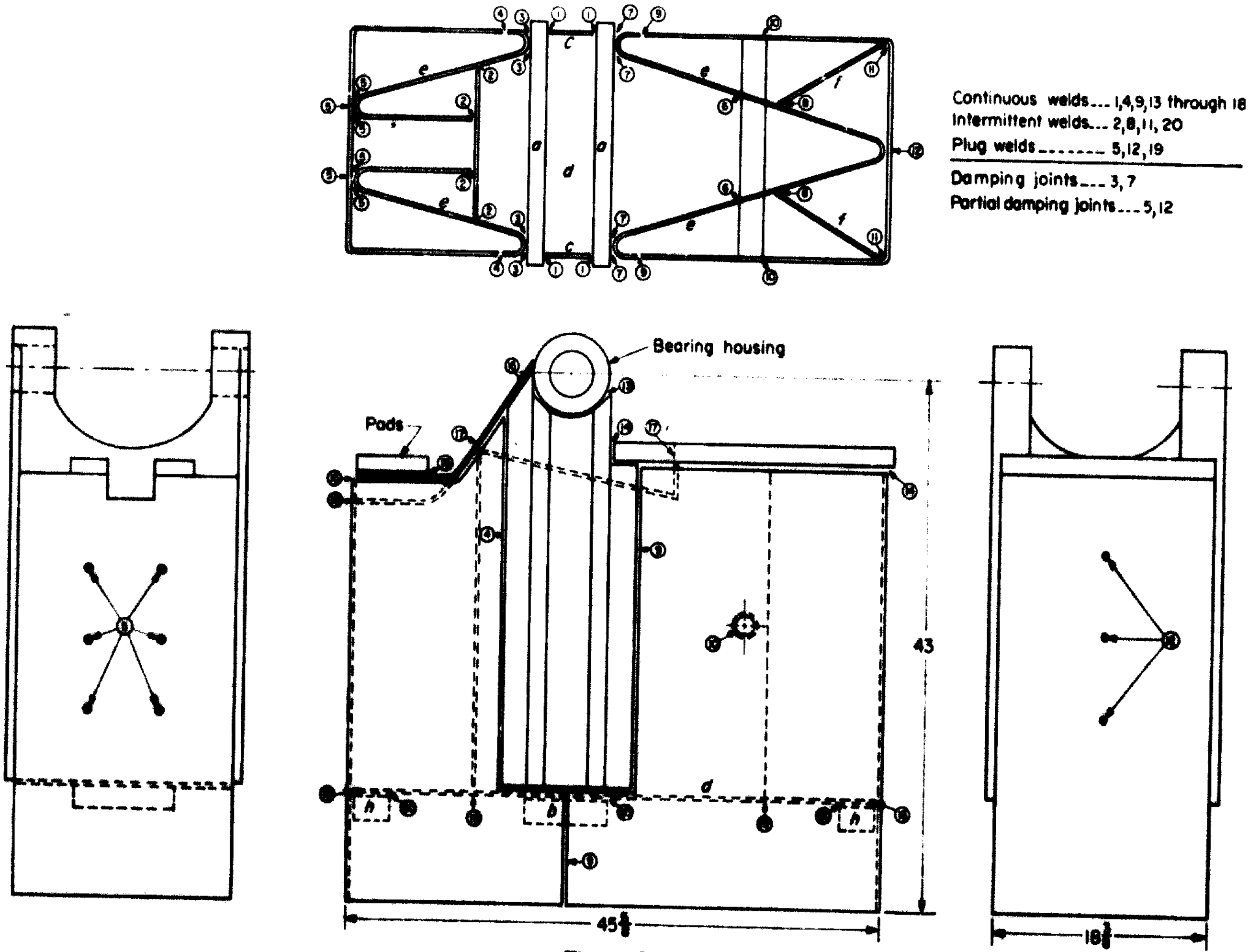


Figure 29

DETAILS OF WELDED GRINDING-MACHINE BED

G. *Accuracy, surface finish and thermal distortion*

Every skilled machine-tool operator is well aware of the fact that his machine performs differently in the morning and in the afternoon, rendering it necessary to reset the tools and adjust gibs often, and to watch the dimensions of his workpieces carefully.

His experiences are due to thermal expansion, which affects production particularly in so far as accuracy and surface finish are concerned. Scrap is often the consequence of neglecting the effects of thermal distortion. This applies to those countries in which high accuracy is required in the aircraft and spacecraft industries and also to developing countries located in climates where considerable temperature variations may take place during a short time period without the benefit of air-conditioned workshops.

The largest temperature differentials and distortions usually occur during the first two hours of warm-up. Thermal expansion is going to have increasing significance with the increase in spindle speeds. Although automatic inspection processes or control of workpieces may minimize the scrap due to thermal expansion, it is most important to know how a production machine reacts to changes in temperature.

In tests for thermal distortion, temperature rise should be measured with regard to ambient temperature. Test procedures vary in accordance with the requirements: they can be adapted to the conditions of idle-running machines or to machines running under load, and can even be so set up that a temperature rise inside a machine tool is produced by employing electric or other types of heaters.

Thermal expansion between the spindle and table of a vertical milling machine takes place in three major directions (see fig. 31, top). Heat developed in the column causes an upward movement of the head and spindle carrier. Heat generated in the spindle carrier itself causes the spindle to move down. These movements balance each other to some extent, but they do not necessarily occur at the same time. The spindle may rise slowly and then drop again until a condition is reached where only the spindle rises. This irregular rise usually occurs during the first two hours of operation of a vertical milling machine. In addition, there is an outward movement of the spindle carrier.

With horizontal milling machines, the spindle-table movement is more uniform; in most cases, it only rises.

Figure 31 gives an example of the temperature rise (upper portion of lower section) and the corresponding vertical expansion between table and spindle (lower portion of lower section) of a vertical milling machine running at 450 rpm. The curves indicate the conditions before and after improvement of the machine design, and of servicing it.

The temperature increased 30° F during a seven-hour period, resulting in an ultimate vertical expansion of 0.004 inch. The bearing design was changed, as was the supply system for the lubricant, reducing the amount of oil flowing to the bearings. It was found that too generous a supply of lubricant caused the bearing to heat because the oil was churning at high spindle speeds and lost its effectiveness. After these improvements were made, the temperature rise after seven hours was only 6° F, with an ultimate expansion of 0.0006 inch. The dip in the vertical expansion during the first two hours was even more pronounced after the improvements than before they were made. This is clearly indicated by the two lower curves. The reductions in temperature rise and in expansion were about 80 per cent.

In horizontal boring mills, even more complex conditions prevail. The machines bore more accurate holes when they are cold. To avoid vibration, however, a warm-up period is desirable. The main reason for these contradictory performances was found to be in the spindle-carrier assembly. The lubrication of the cold machine was insufficient, resulting in metal-to-metal contact in the anti-friction bearings. This condition resulted in self-induced vibration. After warm-up, no substantial metal-to-metal contact existed and the self-induced vibrations vanished. However, the hole accuracy was then poor. This could be traced to the spindle rise and the thermal expansion of the housing. In order to remedy this situation, the oil inlet system was redesigned to permit oiling

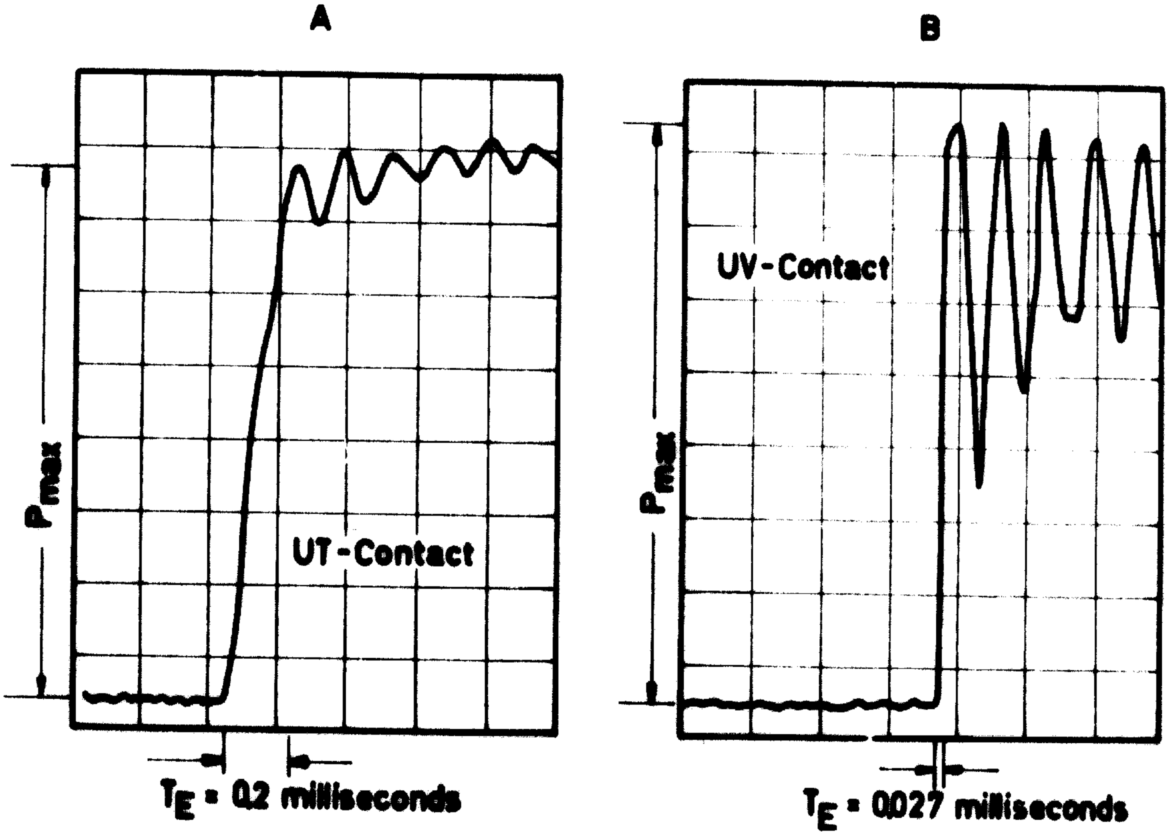


Figure 30

COMPARISON OF AMPLITUDES OF VIBRATION ACCORDING TO TIME OF ENGAGEMENT OF CUTTER AND WORK of the rollers during the warm-up period, eliminating vibration. The oil supply was simultaneously decreased to reduce the thermal expansion and thus to improve the working accuracy of the respective types of horizontal boring mills.

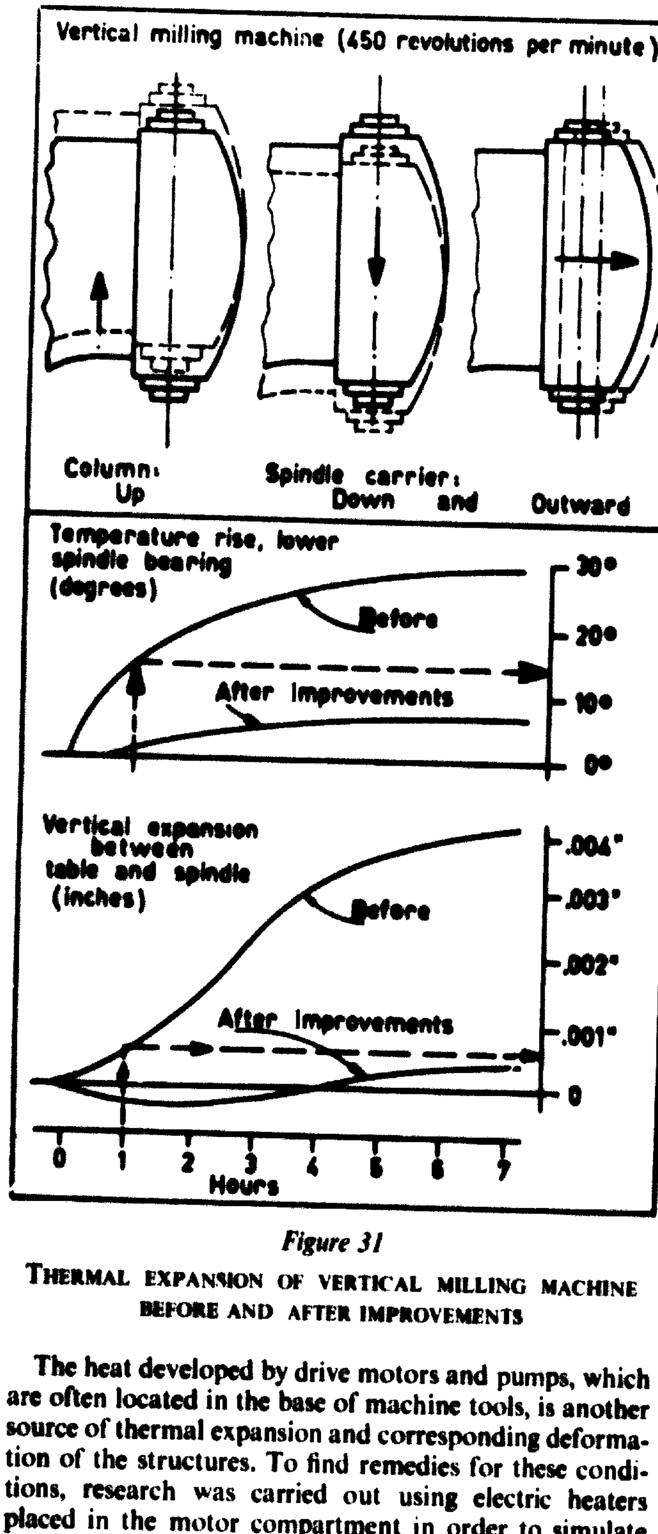


Figure 31

THERMAL EXPANSION OF VERTICAL MILLING MACHINE BEFORE AND AFTER IMPROVEMENTS

The heat developed by drive motors and pumps, which are often located in the base of machine tools, is another source of thermal expansion and corresponding deformation of the structures. To find remedies for these conditions, research was carried out using electric heaters placed in the motor compartment in order to simulate heating of the base under temperature-controlled circumstances. Figure 32 shows an example of the results. The front wall of the machine rose, while the rear wall dropped. This effect indicates that the heat generated in the drive compartment is equivalent to a torque applied in the opposite direction to the torque caused by the cutting force. Thus, in this case, the heat had an acceptable effect of compensating the cutting torque. It depends upon the wall thickness of the base, the location of louvers and the cut-outs whether the front or the rear rises more and in what direction. In the discussed case, the front rose more than the rear dropped. This could be improved and equalized by making the wall thickness at front and rear somewhat different.

On planers, the room-temperature variations affect the table temperature more than the bed temperature. Thus, the table expands more than the bed, a situation which is aggravated by the fact that the hot chips pile up on the table, heating it still more. When the width of the table increases as a result of thermal expansion, the table tends to climb out of the guideways, pushing against the outer walls of the V's. This tilts the table sideways and, with it, the workpiece changes its position in relation to the tool, causing inaccurate machining. Although the oil film tends to compensate for the table tilt, the stability of the table decreases with increasing temperature. Research is still under way in order to find out whether planers with a single V or with duplex V guideways will permit greater accuracy. The increase in table speeds for planers will have a considerable effect on the problems and the trend of future designs.

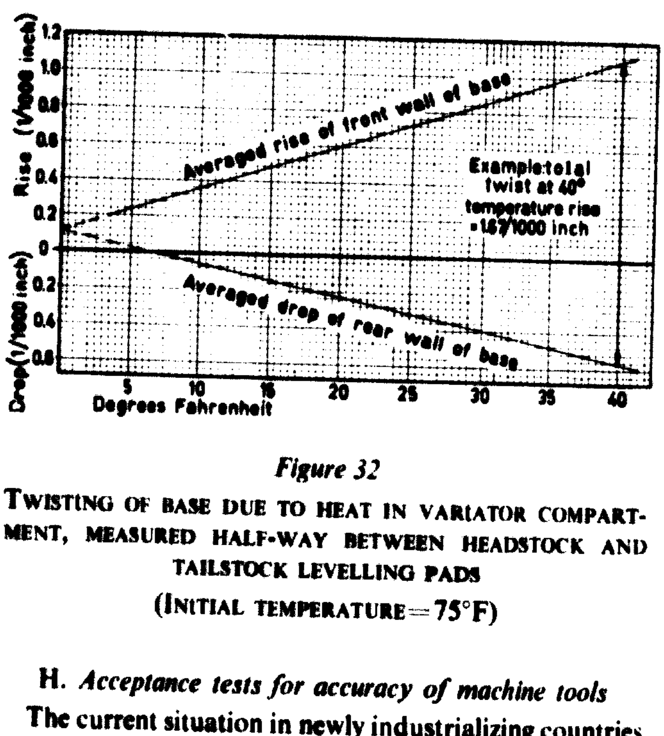


Figure 32

TWISTING OF BASE DUE TO HEAT IN VARIATOR COMPARTMENT, MEASURED HALF-WAY BETWEEN HEADSTOCK AND TAILSTOCK LEVELLING PADS

(INITIAL TEMPERATURE = 75°F)

H. *Acceptance tests for accuracy of machine tools*

The current situation in newly industrializing countries is reminiscent of the situation which prevailed nearly forty-five years ago, when the build-up of the industry in the USSR was initiated by purchasing machine tools from several industrialized countries. At that time, in conjunction with the need for examining numerous machine tools, the Schlesinger Acceptance Tests were developed, with the participation of the author.

Much can be learned from past experience and from an analysis of a few examples of the original Schlesinger data and a comparison of them with later modifications.

The requirements of countries which are currently developing may have a similar bearing on future trends in a significant sector of machine-tool development and design.

From the numerous accuracy data which comprise the Schlesinger tests, seven requirements have been selected for preliminary analysis and comparison. These requirements are listed in table 8, which covers data of the Schlesinger tests and of acceptance tests used in the United States of America, and data used by the Government of India.

1. *Surface finish*

While it may not be necessary to measure to one-millionth of an inch in many cases, the trend towards measuring to 50 Angström units is gaining momentum in the spacecraft industries. This dimension is approximately one-fifth of a millionth of an inch.

Similarly, the demand for better methods of producing and measuring a surface finish of high accuracy is increasing. The difficulties involved are related to the fact that surface-finish designations in micro-inches may signify different dimensional deviations in Europe and

Table 8

COMPARISON OF SEVEN ACCURACY REQUIREMENTS FOR ENGINE LATHES ABOVE 32-INCH SWING

(MAXIMUM PERMISSIBLE DEVIATION IN 1/1000 INCH)

Source	*1*	*2*	*3*	*4*	*5*	*6*	*7*
Schlesinger	0.36	0.60	0.60	1.20	0.4	0.8	0.8
National Machine Tool Builders Association	1.00	0.60	0.75	1.00	0.5	0.8	1.0
India	0.40	0.80	0.80	0.96	0.8	0.8	0.8

1 = bed level, longitudinal; 2 = run out of spindle; 3 = cam action of spindle; 4 = vertical headstock alignment; 5 horizontal tailstock alignment; 6 = lathe must turn round, workpiece chucked; 7 cross-slide alignment.

The few examples given in table 8 show that the standards for accuracy do not agree entirely. In some cases, the Indian standards are less demanding; in other cases, the reverse is true. All three standards are in agreement, however, on the requirement that a lathe must turn round within 0.0008 inch when the workpiece is chucked.

All these data are based on idly running machines, i.e., without load. A trend which is gaining strength is to include tests for accuracy under load. The obstacles, however, are great. On numerous occasions, suggestions have been made to include load tests, for instance, as early as 1933, by Salmon in France (13). Thus far, however, such methods have not been adopted. Possibly an international organization could handle this situation, taking into consideration the requirements of the newly industrializing nations and the development in measuring instruments, some of which were not available when the first Schlesinger standards were prepared.

Among these instruments there are autocollimation telescopes for determining the waviness of machine-tool beds, the parallelism of spindles, the tilting of clamping devices etc. Fundamentally, such telescopes are reversed alignment telescopes in which the ocular is replaced by an illumination attachment. They are accurate within [illegible]-millionths of an inch over a distance of 10 feet, which [is a]bout ten times better than the accuracy of conventional telescopes. While these instruments were developed in the Federal Republic of Germany, a device [wa]s designed in the United Kingdom for continuous [me]asurement of alignment errors with feed-back compensation. Photocells measure the deviation of a light [be]am travelling through an optical micrometer.

in the United States of America. As an example, in the Federal Republic of Germany, the *Rauhtiefe* (roughness valley) is taken to indicate surface finish; it is the value of the greatest depth of the surface in relation to the greatest peak. Such a system, it is claimed, represents values closely associated with the feed and depth of cut taken on a machine tool and can readily be realized by the man in the shop. Another dimension used in the Federal Republic is *Glaettungstiefe* (smoothness depth), the distance of a reworked surface from the initial peaks. A good surface is indicated by a small value for this dimension.

The wear resistance and strength of a surface are determined in the Federal Republic of Germany by the portion of the profile which supports the load in the longitudinal direction of the ups and downs. In the United Kingdom and in the United States of America, the arithmetical mean of the roughness valleys is used. It involves a mathematical concept which is difficult to understand in the shop. Formerly, the root mean square was used, and it still is in many instances, in the United States of America. The arithmetical mean has the advantage of a reduced scattering of data and permits the use of relatively simple measuring instruments.

There is also a trend towards the adoption of a later European suggestion (14) for surface-finish standards, based on the so-called "envelope profile" (E-profile) instead of the older mean line (M-profile). Roughness and dimensional deviation, which are often confused in the M-system, are clearer in the E-profile. This system has been incorporated into standards DIN 4760 and 4762 of the Federal Republic of Germany; it has also been adopted in Denmark, Hungary, Italy and Switzerland. It is claimed that production of accurate surfaces is simplified by the E-system because the mean line can be determined nine times faster than with the M-system.

Various methods have been developed for producing highly accurate surfaces; for example, the so-called "superfinish" method employing high-frequency oscillation of the grinding stones. Originally conceived by the automotive industry in the United States of America, this production method has been further advanced in the Federal Republic of Germany and in the Soviet Union. Coating of metals, honing and lapping with automatic transport of the workpieces indicate the trend in this area of manufacturing.

Quality control has been advanced considerably by utilizing the so-called "laser principle" for accurate positioning and dimensioning of workpieces on horizontal boring mills. Figure 33 shows the set-up on a machine built by Giddings & Lewis. It consists of three parts and utilizes light waves radiated from a sender ("a" on fig. 33) for measuring movements of millionths of an inch of the table to which a reflector is attached (b). It reflects the light waves back into the sender. They are converted into decimal dimensions by a computer (c) equipped with a read-out used by the operator to control the dimensioning.

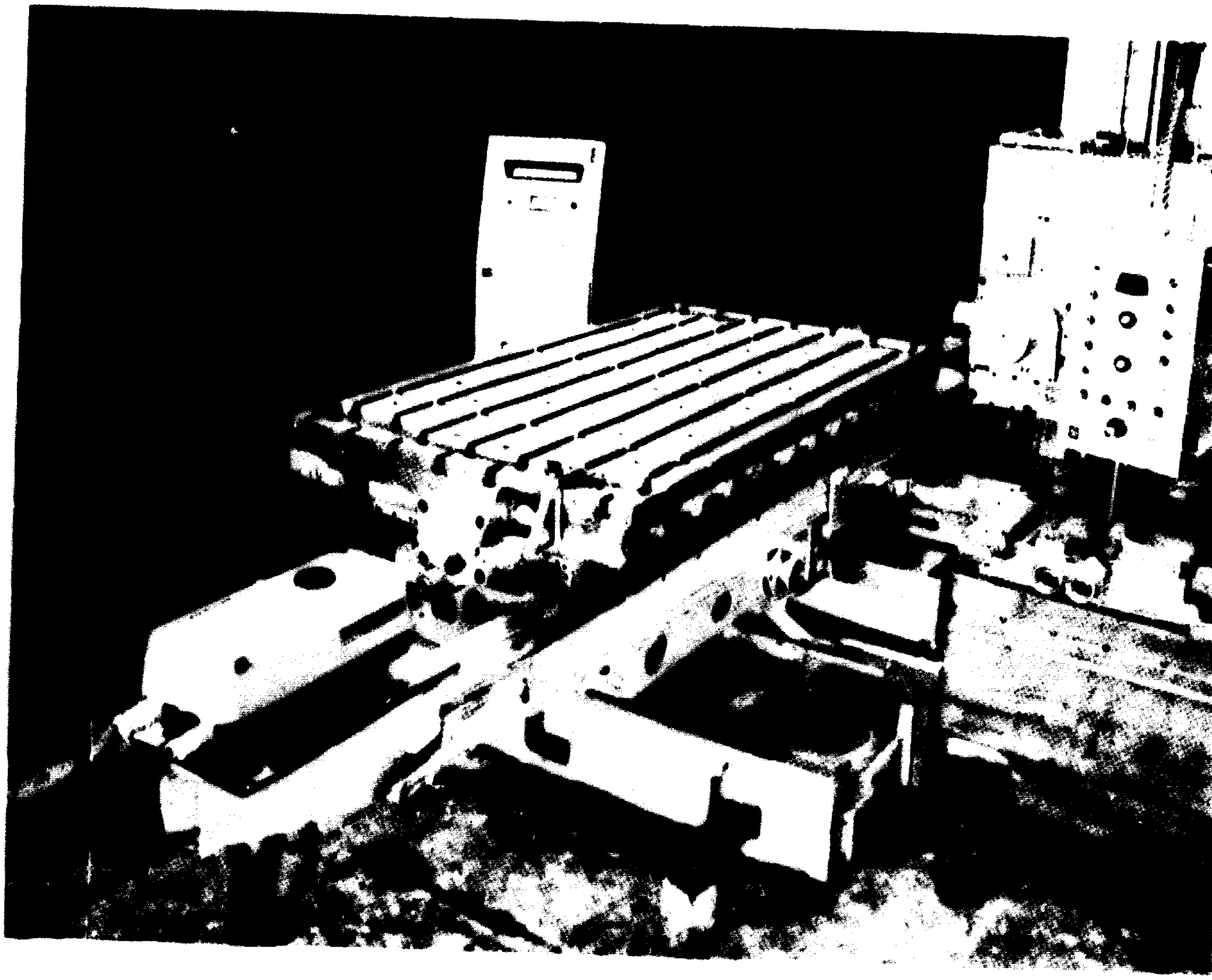


Figure 33

ACCURATE POSITIONING WITH A LASER INTERFEROMETER

J. *Alternative production methods*

The advent of high-temperature alloys and of refractory metals currently used in industry has led and is still leading to alternative production methods which were unknown a number of years ago. These metals and alloys include beryllium, titanium, zirconium, hafnium, vanadium, niobium (often called columbium in the United States of America), tantalum, chromium, tungsten and rhenium, among others. These metals are difficult to machine with conventional production methods, as was previously mentioned in this paper.

It was found that hot machining of steels and alloys could be used to advantage and that substantial increases in cutting speeds and productivity were obtained by a proper co-ordination of heat, depth of cut, tool geometry etc. (15). The cutting forces drop as much as 50 per cent

Table 9

SURVEY OF ELECTRICAL METAL-REMOVAL TECHNIQUES

Symbol	*Name*	*Tool*	*Tool movements*	*Fluid*	*Note*
EDM	Electro-discharge machining	Electrode	Non-rotating	Non-conductive	Oldest method, producing cavities by spark
ECM 1	Electrochemical machining	Grinding wheel	Rotating	Conductive (electrolyte)	90% chemical, 10% mechanical surfacing
ECM 2	Electrochemical machining	Electrode	Non-rotating	Conductive (electrolyte)	Producing holes
EUS	Ultrasonic	Electrode	Oscillating	Non-conductive with grit	High-frequency

in some cases and vibration subsides. Mirror-like surfaces are obtained. Some danger is involved in that the hot chips often escape from the machine in long stringy bands. It can, however, be expected that future developments will eliminate this drawback and will also reduce the relatively high cost involved in heating the workpieces. The technological advantages justify the trend.

Ultra-high-speed cutting is another method—although one still in its infancy—for machining the newer metals. These metals are new only with regard to their use in industry, as many of them were discovered in the nineteenth century. Using cutting speeds of up to 120,000 ft min gave the best results as far as tool life was concerned. The design of machinery capable of delivering speeds of this magnitude for any length of time is likewise an object of future development. The research results are satisfactory and need adaptation to workshop conditions.

The most rapid development in recent years—in addition to the trend in numerical control of machine tools—has occurred in the area of electrical machining. Various systems have been developed since the original tests were made in the Soviet Union. Electrical machining has expanded so rapidly that some confusion exists as to the differences between the various methods. Table 9 gives some indication of the trend and the differences in this area of manufacturing.

In addition to the above-listed electrical machining methods, which are the most important ones, several other electrical production techniques are coming up. Although the metal-removal capacity of electrical machining procedures is still very small in comparison with conventional machining, the advances already made are indicative of the trend. Among them there is electron-beam machining, used for producing tiny holes; the laser technique for the cutting and welding of sheet metal; electrochemical honing for the honing of holes, and electro-contact machining for turning, with a metal disc replacing the lathe tool.

Other alternative production techniques include explosive forming, magnetic forming, plasma machining and hydroforming. A number of these alternative manufacturing methods are still in the research stage, awaiting development into production equipment for a rapidly expanding technology.

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SPECIAL CONSIDERATIONS OF MACHINERY DESIGN FOR INDUSTRIALLY DEVELOPING COUNTRIES

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INTRODUCTION

The selection of suitable machine tools for an industrially developing country deserves more attention at the current time than ever before. The desire of such countries to share in the technological progress of the industrialized countries makes it imperative to review this particular subject. Before treating this question, however, it might be advantageous to consider briefly the special problems facing an industrially developing nation.

I. PROBLEMS OF INDUSTRIALLY DEVELOPING COUNTRIES

An essentia difference between an industrialized country and an industrially developing country is that the industrialized nation began its development under conditions which differed greatly from those facing the countries which are currently developing. In the industrialized countries, the beginning of industrialization was characterized by the existence of handicrafts and small manufactures. Contrary to the situation in the developing countries, there already existed an established system of professional training based on the principle of the division of labour. This implies that, for the evaluation of a country in respect to its stage of development, the existing training methods play a decisive role. Here, developing countries are at a disadvantage. From the viewpoint of an economy with highly divided labour, one may state that a well-balanced education is widely lacking in developing countries. This is especially true with regard to a professionally trained middle class. Therefore, it would be absolutely wrong to consider current economic aids for development in the same way as those used in the successful Marshall Plan twenty years ago. Many mistakes made during recent years are due to the fact that beginning conditions for currently developing countries have been assumed to be like those which were then existing in urope and Japan.

It must be kept in mind that the current situation is ntirely different and also that the political, cultural, imatic and economic backgrounds vary greatly from e country to another.

Another important point concerning the suitability machine tool or machine group must be considered en supporting manufacturing industries. In most cases, istries of developing countries do not export their ducts; these are destined to satisfy domestic demand y. Therefore, a generous development of manufacturindustries is not always desirable. Such countries have to satisfy their own demands by imports from abroad; imports in the absence of appropriate exports will lead to a deficiency of foreign currency. Then, in order to protect domestic industries, protective duties are set up and will keep the newly created industry from rationalization; the ability to compete on the world market will be significantly restricted. In selecting the machine tool, this peculiarity must also be taken into account. In addition to being easy to operate, it should be efficient and be designed in such a way that attachments for higher rationalization can be added later without difficulty. This, however, creates serious problems for the designer of the machine since, in developing countries, it cannot always be clearly foreseen which way will be taken towards rationalization. While costs in a developing country can possibly be decreased by a further division of labour combined with employment of an increased number of workers, cost reduction programmes in industrialized nations are primarily aimed at a decrease of the labour force. In developing countries, however, one generally finds a high surplus of labour which should be employed for economic reasons; in industrialized countries, on the other hand, the current shortage of labour leads to serious pressure.

The urge to employ the existing labour force is contrary to the frequently expressed opinion that, in industrially developing countries, fully automated machines should be used from the very beginning. Apart from the fact that even an automatic machine does not work without proper supervision, there are two points to be stressed:

(*a*) Automation decreases the number of required workers, but calls for higher skills of the remaining workers;

(*b*) Automation necessitates higher investments and higher energy consumption, and decreases the rate of employment.

However, the fundamental economic conditions in industrially developing countries are exactly opposite. Therefore, labour-oriented machines and techniques will be welcomed almost anywhere. This, no doubt, is important for judging the suitability of a specific machine tool.

This brief outline leads to the conclusion that the question of selecting suitable machine tools for industrially developing countries cannot be answered in a general way because the particular conditions will be decisive in each case. Therefore, by discussing the evolution of machine tools in industrialized countries, one may examine what the machines representing the various stages of development will demand in regard to the labour force and to the plant location. A decision can be taken in consideration of the following statements for each individual case.

II. Development of the machine tool in industrialized countries

Generally speaking, the following stages of machine-tool development can be observed in industrialized nations:

(*a*) Universal machines;
(*b*) Machines for batch production;
(*c*) Sequence-controlled machines;
(*d*) Automatic machines;
(*e*) Transfer lines;
(*f*) Numerically controlled machines.

In regard to the present subject, the following properties of the various machine-tool types are of interest.

A. *Universal machines*

Universal machines are most frequently used in factories. They combine precision, versatility, relatively low price and rather reliable operation. Since the universal machine is well suited for a large variety of jobs, it is used for a multitude of routine jobs in industrialized countries.

The value of a universal machine is determined not only by its efficiency and operating life, but also by the fact that it makes every possible concession to the operator. These concessions consist in easy maintenance and operation, and complete safety for each person that may possibly come into contact with the machine. In most cases, the universal machine is used in production as a multiple-purpose machine. Its versatility calls for well-designed gear-boxes and attachments.

The most popular example of a universal machine is the regular type of engine lathe (see fig. 1). It permits almost any turning operation, e.g., outer and inner diameter turning, facing, boring, thread-cutting and copying. The workpieces for such a machine are long or drum-shaped for turning between centres, or disc-shaped and flat to be clamped in rotating shucks. The machines are operated by hand. The tool setting and the control of the operations call for highly qualified operators whose

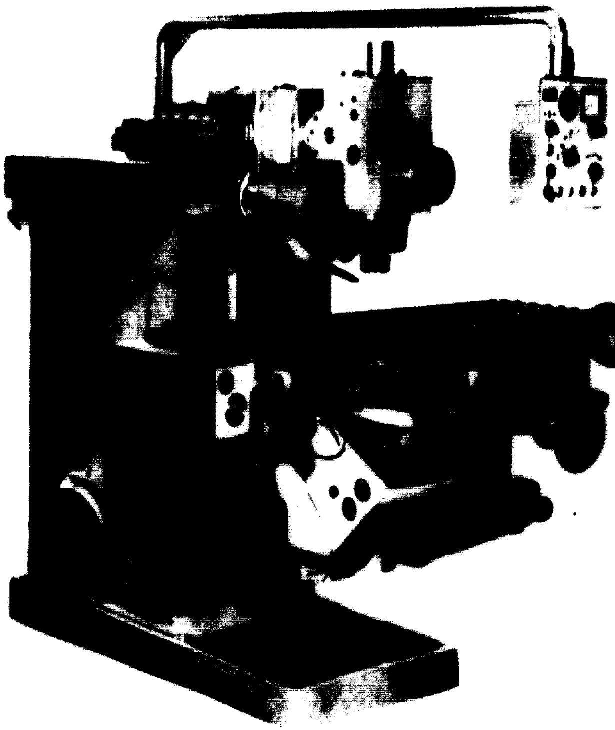


Figure 2

Knee and column type of universal milling machine

Figure 1

Engine lathe

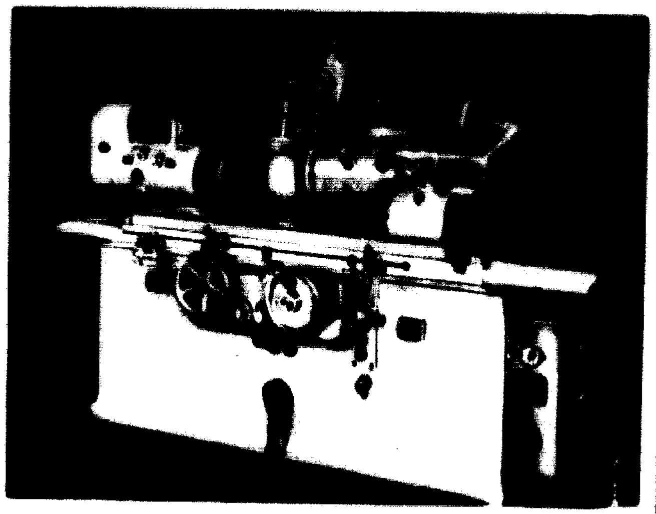


Figure 3

Universal grinding machine

[sk]ill and ability determine the accuracy of the workpieces, as well as the life and precision of the machine. Relief of [the] operator through the use of semi-automatic or fully [au]tomatic accessories is not provided. The regular type [of] engine lathe is primarily designed for frequently [ch]anging production of single pieces or small batches. Due to its flexibility, the operating personnel must be thoroughly acquainted with the theoretical principles involved and must also be highly skilled in the machining of intricately shaped workpieces.

Another widely known standard universal machine is the universal milling machine. The most important feature of milling, compared with turning, shaping or drilling, is the rotating tool: several cutting edges work simultaneously on a short cutting length. In order to make the milling machine versatile, hydraulic, electric or hydro-electric designs can be incorporated with purely mechanical gear-boxes. Due to the often very short cycle time, the operating handles and switches are carefully designed. Narrow gradations of the rpm and feed provide for a broad range of applicability of universal milling machines. An example of a universal milling machine destined primarily for single-piece production is the bed type of milling machine shown in figure 2. The requirements for operating personnel and machine flexibility are identical to those mentioned for the regular type of engine lathe.

The grinder shown in figure 3 is another example for a universal machine; it is especially designed for the tool and die shop, and for single-piece production. Occasionally, it is used for small-batch production also. If an experienced operator is employed, the operating range and accuracy of this machine are practically unlimited. It must be kept in mind, however, that it has been developed for precision work and not for efficiency in terms of pieces per hour. Therefore, accessories for a high production rate, e.g. special feed gear-boxes and automatic cycle attachments, are not provided. If existent, such accessories would often only hamper the flexibility and easy chucking of the workpiece.

Universal grinders are suitable for internal and external grinding, as well as for face grinding. However, satisfactory results can be achieved on such jobs only if the operator is highly skilled.

Universal machines are manually controlled. Because of their maximum flexibility with regard to machinable products, they are obviously well suited for developing countries. However, they must be operated and main[tai]ned by well-qualified workers, and such a skilled [la]bour force will be available in only a few developing [cou]ntries.

B. *Machines for batch production*

In industrialized nations, the type of machine tool [sel]ected for the production of a certain workpiece will [pri]marily depend upon the number and shape of the [part]s to be produced. Certain types of machines have [bee]n developed for the production of similar small [bat]ches. Such machines can be used for continuous [pro]duction and, thereafter, can be set up for a new batch [in] relatively short time. These machines are also [man]ually operated; however, automatic workpiece transport and loading can greatly accelerate the production flow. Since operators must be employed for setting up and running such machines, a determination should be made of the knowledge and skills which are available among the labour force of the developing country concerned. In regard to the development of the practical abilities of the worker and his adaptation to the working methods in a factory, it must be ascertained which type of machine will best help the worker in familiarizing himself with the machine and with industrial production in general.

The extent to which the production type of machine meets these requirements is discussed below. The basic conception of such machines is relatively simple. Compared with universal machines, they have a fairly limited range of speeds and feeds, corresponding to their destined use for a certain type of workpiece. As an example, the production lathe shown in figure 4 is

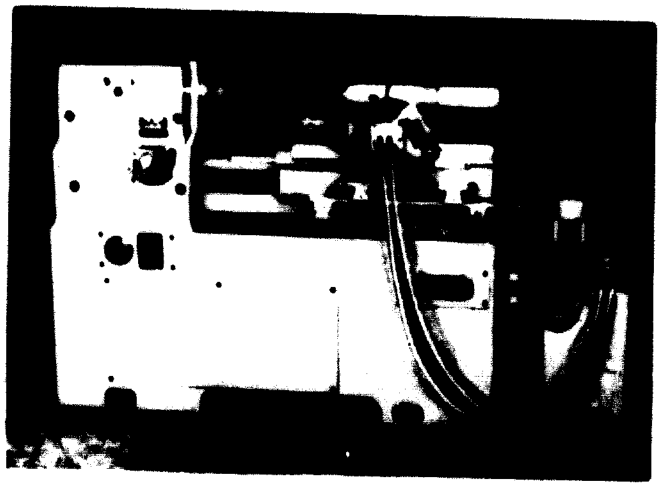


Figure 4

LATHE USED FOR BATCH PRODUCTION, WITH COPYING ATTACHMENT

equipped with an optional copying attachment. This attachment facilitates considerably the generation of complicated workpiece contours. Lathes used for batch production can produce shaft-type parts from bar stock, as well as disc-shaped parts. For each individual operation, the operator must select only the spindle rpm and the feed rate from a small group of feeds and speeds. Workpiece chucking is not difficult after proper machine set-up. Therefore, the requirements as to the skill of the operator are rather low. Since, in small-batch production,' he will repeat the limited number of interactions over and over again, he can quickly familiarize himself with this type of machine. Another advantage for the operator of such a machine is the comparatively short time required for adaptation to a new series of workpieces, which enables him to apply his initial experiences to new objects. Therefore, this type of machine may well be operated by a semi-skilled worker; the machine set-up, however, must be done by a skilled worker.

Apart from its comparatively quick adaptability to a similar batch of workpieces, the flexibility of this type of production machine is considerably increased if the machine is composed of prefabricated units, as is often the case. In this way, a factory with a relatively small number of machines can adapt itself to the production of a new series of parts in a rather short time.

Another example of the machines used for batch production is the bed type of milling machine featuring a horizontal milling spindle in a box frame (see fig. 5). The work-table, which is supported by a console at the column, can be moved in two co-ordinates. A special feature for the production of small batches is the possibility of clamping several workpieces side by side. Thus, the faces of these workpieces can be machined in one operation and with one machine setting.

If the parts cannot be clamped together, so-called "reciprocal milling" can be applied. A workpiece is clamped on one side of the machine-table. While this part is being machined, the operator clamps another workpiece on the other side of the table and brings it in working position by moving the table just after the first part is finished. After the machine is properly set up for

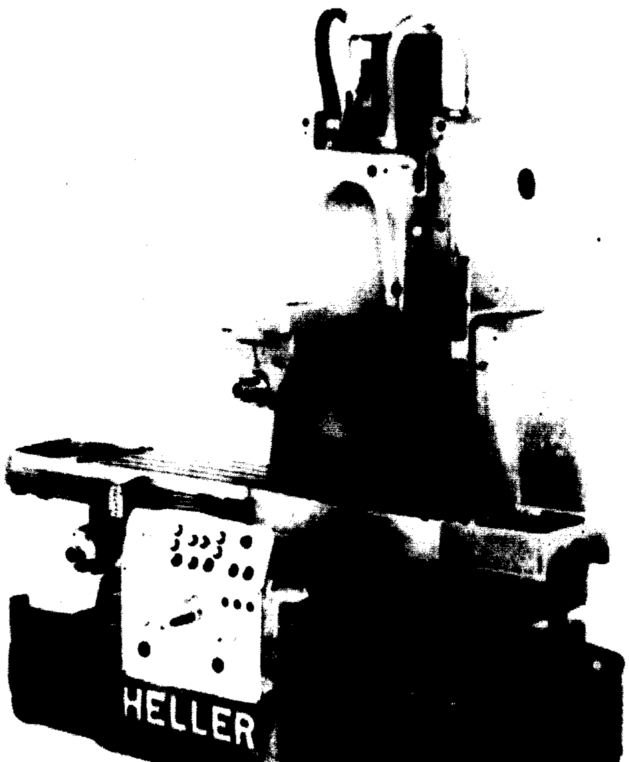


Figure 5

KNEE AND COLUMN TYPE OF MILLING MACHINE USED FOR BATCH PRODUCTION

a certain job, the operation of a production type of milling machine does not require any special skills, which permits the employment of semi-skilled workers in this case also. Furthermore, this type of milling machine is very flexible in regard to the machinable workpieces.

If a workpiece must undergo operations on several machines, these can be linked to a production line in order to make the parts in batch production pass through automatically. For such machine interlinkage, numerous loading and transportation devices have been developed.

The device shown on the left-hand side of figure 6 serves for loading a lathe. The workpiece is taken up by a grab-clamp (as seen in the right-hand side of the picture), hoisted and carried to the working point on a small carriage running on an overhead track. After completion of the part in the machine, it is grasped by the lowered empty grab-clamp and is then taken out after opening the chuck. Thereafter, the other clamp holding a new part will be lowered; the part is inserted between the chuck jaws and is clamped. Machine operation can begin as soon as the second clamp has come back to its upper position.

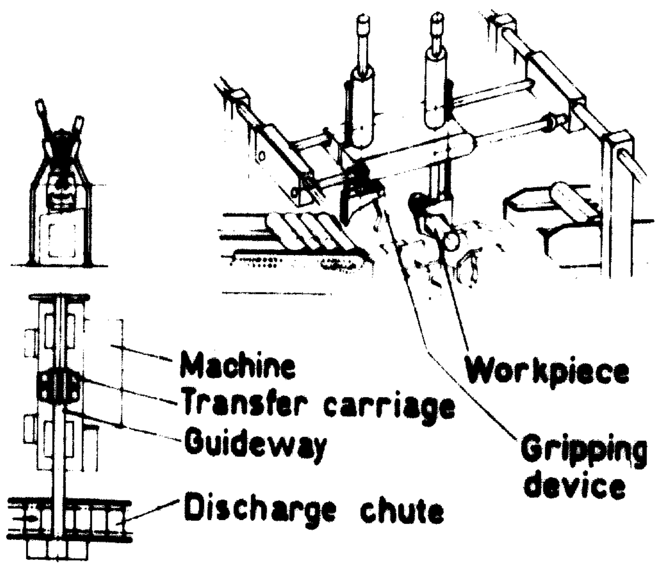


Figure 6

FEED MECHANISM

Machines destined for small-batch production are principally commanded by hand. In the production of larger batches, however, very few interactions are required. This allows the operator to focus his attention on the machine function and operation. Compared with fully automated machines, which call only for supervisory operator functions, machines used for batch production have the essential advantage that the shifting functions must be accomplished by the operator. Such machines have another advantage which is especially valuable for developing countries, i.e., their good adaptability to job peculiarities. The necessity of selecting automatic machines rather than machines for batch production, due to a labour shortage, will most certainly not arise in industrially developing countries in the near future.

C. *Sequence-controlled machines*

A sequence-controlled machine tool operates according to a predetermined work sequence, which is repeated for every workpiece. The individual operations are not fully automated. For example, tool change is accomplished by hand-indexing a tool magazine, which is fe-

...ntly designed as a turret. The technological sequence, ...luding feeds, spindle rpm and depth of cut, can be ...-selected by means of cams, discs, curves or elec-...al contacts, to the effect that the operator no longer ...kes these decisions.

Due to its simple operation, quick adaptability to a ...w work programe and high, continuous accuracy, this type of machine tool may eventually be tailored to the needs of developing countries.

Since there is a sufficient supply of non-specialized workers in such countries, there are no obstacles to single-machine operation. Thus, a machine and its semi-skilled operator represent a highly valuable and flexible production unit for both simple and complicated parts. Such production units can often be used profitably for a batch size of about ten pieces or more.

The relationship between the degree of automation and the output of different types of machines is shown in figure 7. While simple lathes will be utilized for the production of single pieces and batches of up to five pieces, large batches of over 100 pieces must be produced on automatic machines. The working range of the electrically and mechanically controlled turret lathe shown in figure 7 is approximately right between these limits; its

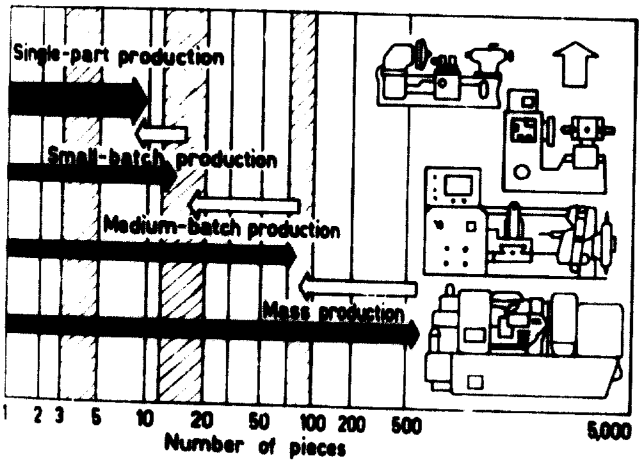


Figure 7

TURRET LATHES: STAGES OF AUTOMATION AND NUMBER OF WORKPIECES PRODUCED

degree of automation increases with the number of pieces per batch. In the figure, two different models, B and C, are shown schematically.

Figure 8 shows the design of a drum turret lathe. The headstock housing with the spindle gears, the turret ...riage with the cam selection of speeds and feeds ...ording to the tool position and the wheel for hand ...and for engaging the automatic feed can be seen. ...t to the turret pilot wheel is the board for the selec-...n of the rpm commands. For large-batch production, ...h a machine can be equipped with a plug-board ...uence control. By means of such an extended sequence ...rol, this type of machine can become even more ...ble, and the operator will be the more relieved of ...plicated interactions. However, special training of personnel in charge of the set-up and maintenance of such machines will be necessary. A sequence control for semi-skilled personnel is indeed a very valuable advantage, considering the fact that correct speeds and feeds, and the exact change of spindle rotation in relation to the actual position of the turret carriage, are always guaranteed.

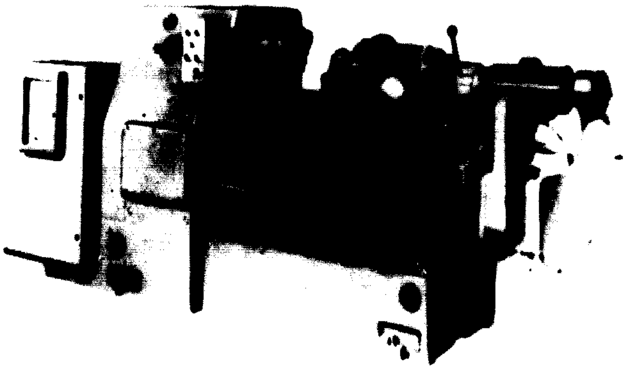


Figure 8

CONSTRUCTION OF A TURRET LATHE

Figure 9 demonstrates the simplicity of the operator's functions. The hand-wheel serves for hand feed as well as for quick engagement of the automatic feed. With another lever, the turret indexing bolt is engaged or retracted. A switch serves for the selection of the turret's direction of rotation. As previously mentioned, all other functions can be automated.

Two different turret designs may serve as tool-holders. Designs A and B, shown in figure 10, are hexagonal turrets; design C represents a drum turret. An advantage of the drum turret is the ample room around the working point, since tools are revolved horizontally. However, an additional facing carriage must be provided for longitudinal turning. As an advantage of the drum turret, it

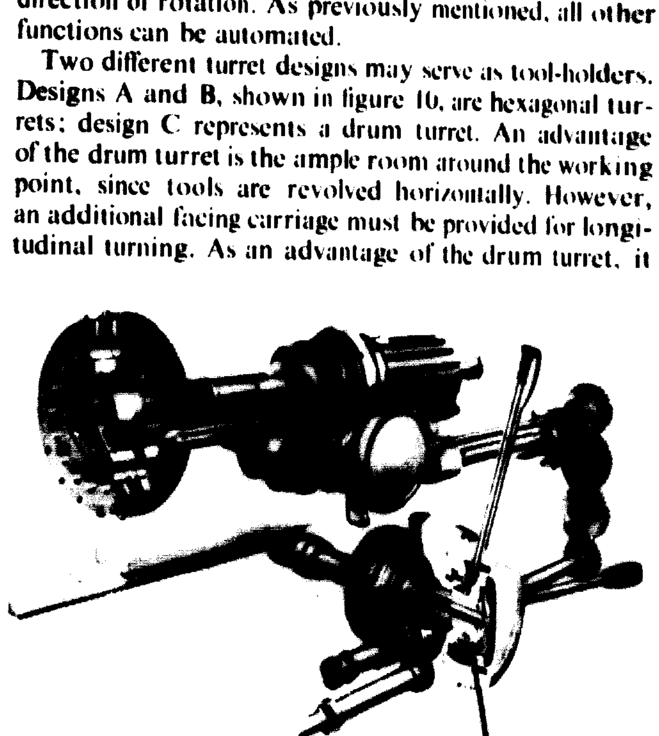


Figure 9

TURRET HEAD, TURRET SPINDLE AND FEED DRIVE

can execute longitudinal and transversal movements without an additional carriage. Another advantage is the possibility of a stiffer bearing design for the turret axis since the bearing length is not limited.

If one does not consider the technical advantages and short-comings of these two turret designs, one finds that, for a semi-skilled worker, the drum type of turret lathe affords better control and is easier to operate than the hexagonal turret lathe since all eventual tool movements can be executed by means of one tool-holder. This point should be kept in mind when selecting machine tools for a developing country.

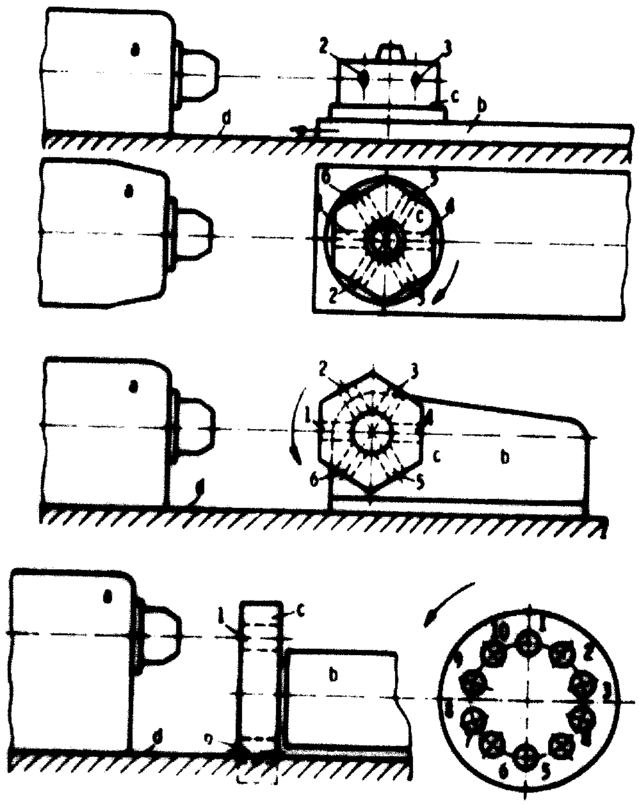


Figure 10

SEVERAL TYPES OF TURRET HEADS

In making such a selection, one would take into consideration those machine tools which, in the first place, permit good adaptation to certain production processes. In order to ensure such adaptation in regard to a universal machine like a turret lathe, there must be an exact knowledge of the actual jobs in production. Figure 11 shows schematically the production processes that can be carried out on turret lathes. These types of work suggest that, by using optional attachments, the working range of turret lathes can be considerably widened. The cutting speed to be selected depends largely upon the individual production processes and, furthermore, upon the tool type, tool material and required accuracy. Hence, modern turret lathes fulfil the requirements as to better adaptability to the job by appropriate design of the transmission-gear ratios.

The type of material to be machined has an essential influence on the cutting speed. Figure 12 represents the distribution of various materials to be machined on drum turret lathes of various sizes, as found in sixteen factories of the machinery, vehicle, instrument and tool industry. The material types were classified into four groups, representing steel, grey cast-iron, non-ferrous metals and unidentified metals. As a result of this inquiry, it was found that steel machining amounts to approximately 80 per cent for medium-size machines; non-ferrous metal jobs drop with increasing machine size from approximately 50 per cent to about 5 per cent and the machining of grey cast-iron increases with machine size from approximately 10 per cent to approximately 50 per cent. This statistic is representative for several factories in the Federal Republic of Germany. It may also be considered valid for developing countries if their industrial structure is planned to be raised to the standard of industrialized nations.

Another advantage of the turret lathe is the possibility of combining it with other machine tools in order to form a production line for batch production. Figure 13 shows the difference between a machine line consisting of turret lathes and other machine tools, including the operating

turning	turning	facing	recessing	taper-turning	copying
	ball-turning	eccentric-turning	oval turning	polygon turning	internal turning
drilling	centering	longitudinal drilling	cross drilling	reaming	counter-sinking
screw-cutting operation	thread cutting	thread chasing	thread rolling		
shaping	polygon shaping				
others	burnishing	knurling	embossing	bordering	

Figure 11

PRODUCTION METHODS FOR TURRET LATHES

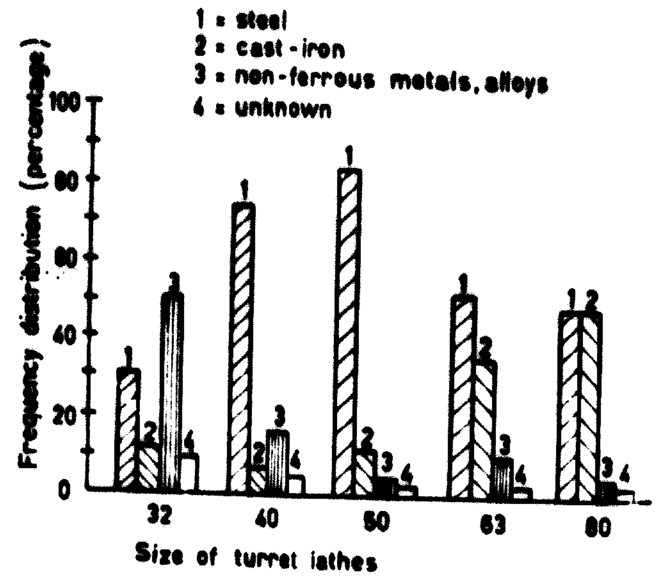


Figure 12

FREQUENCY DISTRIBUTION OF THE MACHINED MATERIALS FOR TURRET LATHES

...sonnel and workpiece feeders, compared with an ...erlinked line (shown in the lower part of the picture), ...sisting of automatic machines and only one super...or. While the machine line can produce a buffer ...rage and is very flexible in regard to its adaptation to a ...ew production programme because of the loose arrange...ent of the individual machines, the transfer line oper...ates in a fixed pace. Its adaptation to a new programme ...can be difficult.

As stated above, there are, in many developing coun...tries, numerous non-skilled workers for whom jobs must be created. Thus, the alternative shown in the upper half of figure 13 can be a first solution for a country which is just beginning its technolgical development, despite the fact that the higher degree of automation shown in the lower half of the figure would be justified in terms of the piece rate per hour.

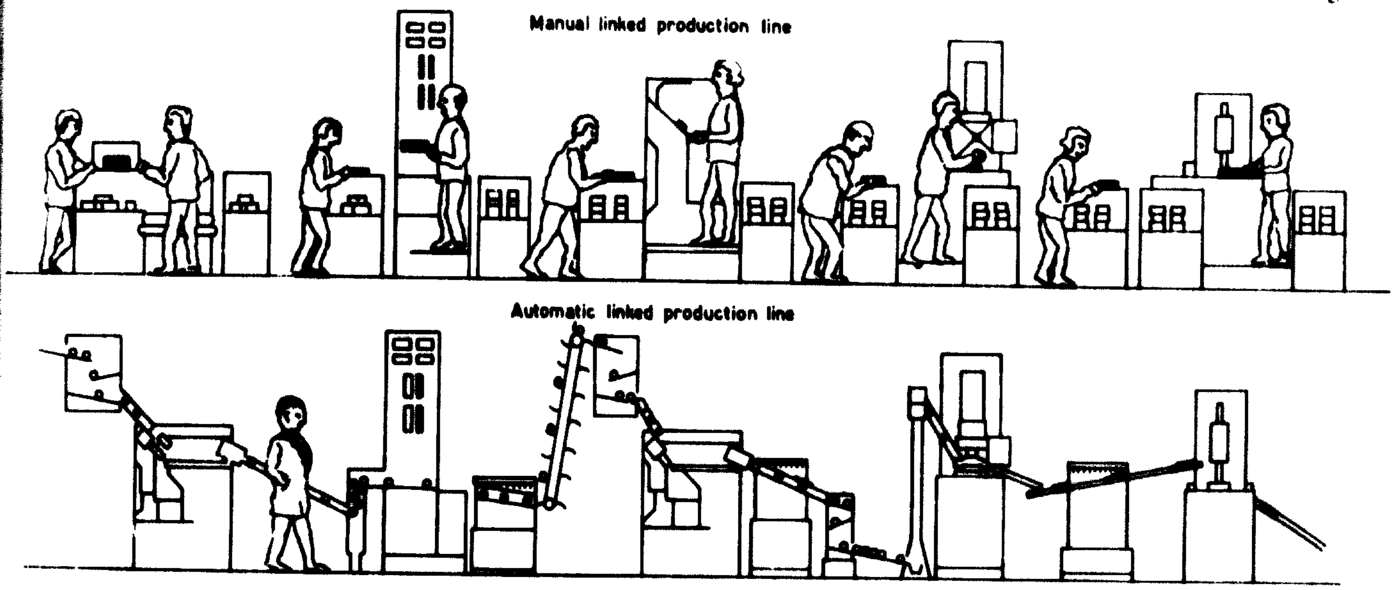


Figure 13

MANUAL AND AUTOMATIC WORK TRANSFER

Summing up, one may state that a sequence-controlled machine tool can be operated by semi-skilled workers. For this reason, as well as the fact that single-machine operation is desirable, this type of machine seems to be suited for batch production in developing countries.

D. *Automatic machines*

Turret lathes have a number of pre-set tools which can be retracted from the working point after an operation and then be brought back into working position when needed. An operation is initiated by the command of a switch actuated by an operator. Hence, an operator must always stay with the machine. He must supervise its individual operations and, furthermore, execute certain ...eractions. As batch sizes increased more and more, ...achine development tended towards liberating the work ...uence from the presence of an operator and mechan...ing it fully. The development of automatic machines ...an in the United States of America. The first machines ...this type were built in 1871 by Porkhorts, and in 1880 ... Pelzer.

The work process on automated machines necessitates automatic material feeding. One method of accomplishing this is to use long bar stock (between 5 and 6 metres in length), from which the individual workpieces are machined and, finally, are cut off. The bar feed is obtained by means of a feed collet which can be moved mechanically by means of a lever and a sleeve. During machining, the bar stock is firmly held by a collet chuck on the rear side of the spindle. This system of bar feed can be found in screw machines. The operating tools are mounted on several slides which can move longitudinally and transversally. By means of optional attachments, such operations as boring, transversal drilling, saw-cutting, thread chasing and gear generation can be carried out.

1. *Single-spindle automatic machines*

Automatic machines can be classified into single-spindle automatics, multiple-spindle automatics and index-drum automatics Single-spindle automatics have been built and applied in production for decades. As mechanical drive, they feature curved discs and cams on a main drive shaft. This main drive shaft rotates just once during a work cycle, i.e., during the production of one part, including bar feed, chucking, machining with the various tools and workpiece cut-off. Figures 14, 15 and 16 show different types of single-spindle automatic machines. As a tool-holder, single-spindle automatics normally feature a turret. In addition to the slowly rotating drive shaft, there is a rapidly rotating auxiliary drive shaft on which a number of quick-action clutches are mounted. They are actuated by the curves on the drive shaft and initiate one quick revolution of the drive curves for turret position, bar-stock feed, chucking, spindle-speed change and reversion of rotation.

A Geneva type of motion is used for turret indexing. The turret carriage is cushioned against a bracket by a resilient spring. Its feed movement is generated by a roller arm riding on the curve; a pinion on the other end of the roller arm drives a rack.

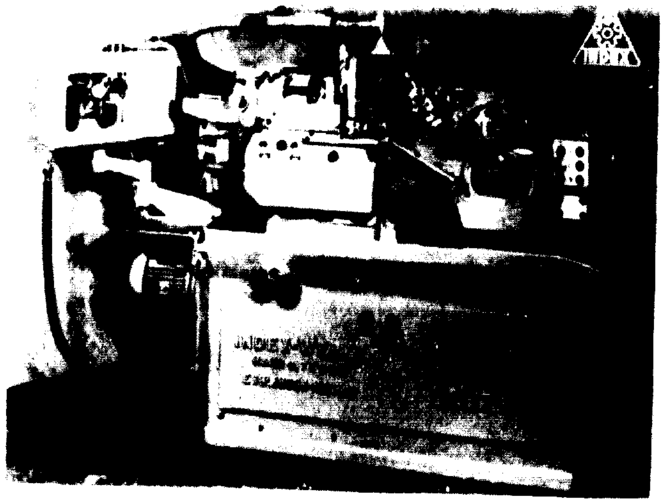


Figure 14

SINGLE-SPINDLE AUTOMATIC MACHINE, INDEX C 29 (F), WITH NEW PNEUMATIC HOLLOW CLAMPING-CHUCK

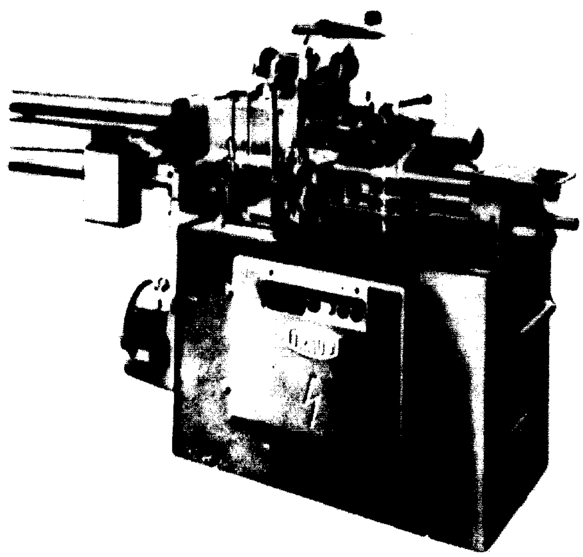


Figure 15

SINGLE-SPINDLE AUTOMATIC MACHINE

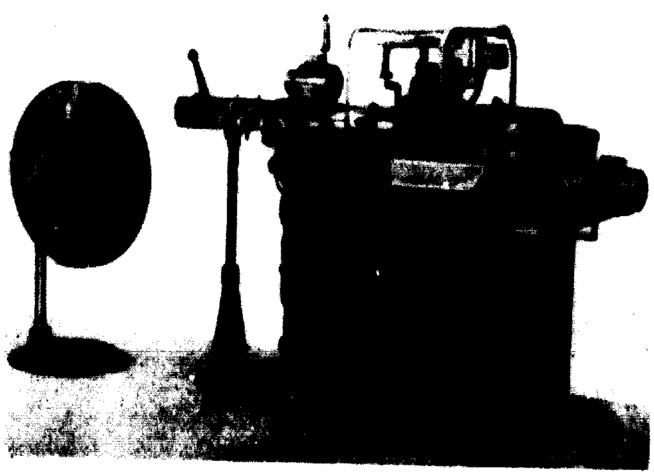


Figure 16

SWISS BUSH TYPE OF AUTOMATIC SCREW MACHINE

2. *Multiple-spindle automatic machines*

In contrast to the procedure on single-spindle automatic machines, where the individual operational steps for a workpiece follow each other, the steps are simultaneously executed in a multiple-spindle automatic machine by several work-spindles. From four to eight work-spindles are placed on a revolving drum. In case of bar automatics, the bar stock is held by chuck collets in the hollow spindles. In one of the spindle positions, there is generally no machining, but only the workpiece cut-off and bar feed against a stop. In the case of chucking automatics, an analogous spindle position is reserved for unloading the completed part and loading a new one. In all other positions, the various machining operations are carried out by tool groups. Tools for longitudinal machining are mounted on a polygonal slide which cannot be revolved but which moves along the drum axis. In addition, transversal tool slides at each work-station, held at the machine frame, can be applied. After each drum rotation to its next index stop, a completed part is ejected. The machining time for one part can be reduced by four-spindle automatics to one-third and, on a six-spindle automatic, to one-fifth of the time required by a single-spindle automatic machine. For the six-spindle automatic shown in figure 17, the drive shaft bearing the

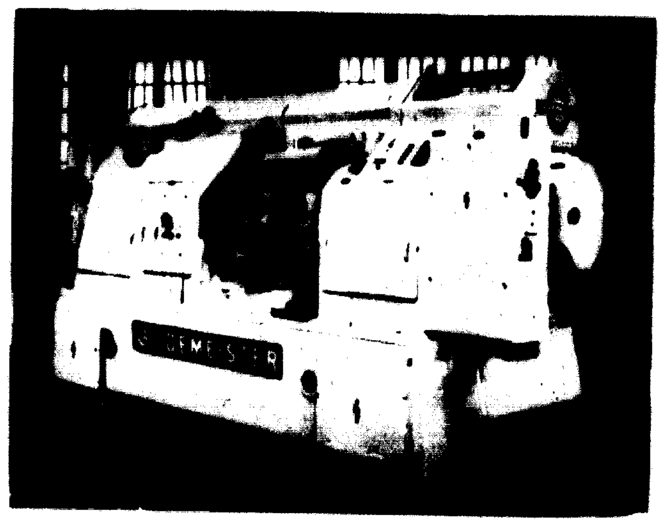


Figure 17

SIX-SPINDLE CHUCKING AUTOMATIC LATHE

curve drums and drive discs is mounted above the tool carriage and the spindle drum. This provides for unhindered chip collection. The work spindles are driven by an electric motor over change gears and a central main drive shaft inside of the hollow drum shaft. The spindle drum is indexed by a Geneva motion. For multiple-spindle automatics, many optional attachments for loading, slitting, thread chasing, long turning and the like are available.

3. *Index drum automatic machines*

The index drum automatic machine shown in figure 18 serves for machining several faces of a workpiece simu-

...eously. It is used for the production of mass-type ...ts, such as cast or die-forged parts, bar sections or ...d-formed parts. Machining from bar stock is not ...ssible. Rotating tool spindles bear the tools, which are ...equently combined into tool groups. In case of bulky shape, the parts must be clamped very close to each other. Rotation and feed movements are executed by the tools on the tool spindles; the index movement from one tool group to the next is accomplished by the parts themselves. Thus, the index drum, as known from the multiple-spindle automatics, holds only the chucking fixtures and executes the index movements in the case of this machine. By passing five work-stations with a total of ten spindles, two workpiece faces can be machined simultaneously. The machine can be enlarged by attaching radial spindle units in such a way that three faces of the parts can be machined at the same time.

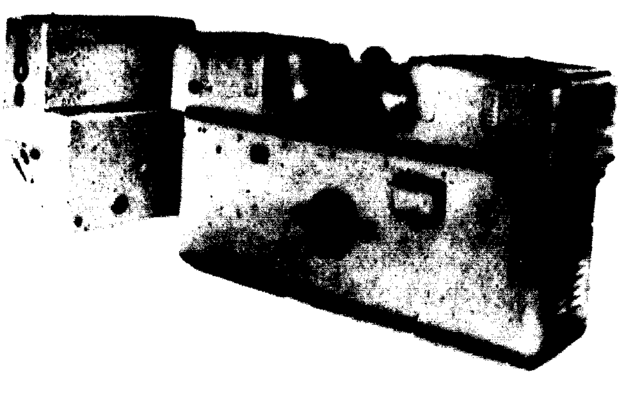


Figure 18

TWO-WAY DRUM TYPE OF AUTOMATIC INDEXING MACHINE

4. *Production planning requirements for automatic machines*

In order to ensure economic production, the use of automatic lathes calls for careful production planning and well-trained and experienced specialists for the set-up and maintenance of the machines. For servicing these machines, a non-skilled operator will suffice; he can supervise several machines simultaneously. The shortest possible set-up and production time and, hence, economic production certainly cannot be obtained by empirical and improvised design, successive corrections and trial ...ns of the drive curves. The man at the machine cannot ...expected to utilize the full potential of modern turning ...chines according to the knowledge of modern production technology. Furthermore, special experiences and ...igns for a specific production problem can be co-...inated by a central department only. For example, ...prehensive data about chip-forming operations for numerous available materials will be collected in this ...artment. In handbooks, one often finds only approxi-... values with wide tolerance ranges. The required ...al experience must include such fields as fixture ...gn, chucking and clamping problems, special tool-...ers, magazines, workpiece loading and unloading, machine interlinkage, chip collection and coolants. Highly detailed and thorough production planning is a prerequisite for a high degree of utilization of automatic machines by elimination of down-times. Furthermore, the production planning department is in charge of setting the time allowances for machine set-up and operation, depending upon the job difficulty. The parts to be machined on a lathe should be designed accordingly and should be machinable in one chucking only. Therefore, the ability of the planning engineers to adapt blue prints to the needs of efficient production is of essential advantage. Finally, the sequence of the individual operation steps must be chosen; superfluous operations must be eliminated.

The flexibility of automatic machines in regard to the producible parts is good. The possibility of machine operation by non-skilled workers would favour their use in industrially developing countries. However, since a multiple-machine operation is possible and the expenditure for a good production planning department is economically justified only if an adequate number of machines exists, this machine type will be suited for utilization in developing countries only under certain conditions, especially since the economic use of only one automatic machine can lead to a large product quantity, which would, in many cases, exceed the domestic demand of the developing country.

E. *Transfer lines*

A transfer line is a fully automated production line designed for one specific production task only. A transfer line cannot be purchased from a catalogue as can a universal lathe. When purchasing a transfer line, the customer usually presents his production problem to the manufacturer; the manufacturer will then combine a transfer line out of standard units according to his own experience. For the dimension of the transfer line, the number of pieces to be fabricated plays a decisive role since a too largely dimensioned production unit will prevent economic utilization of the line; and it is difficult to enlarge too small a unit.

If standardized units are used, adaptation to another product is possible. Due to the technological characteristics, however, adaptation to a new workpiece is generally much more complicated than it is for a single automatic machine tool.

1. *Design of a transfer line*

A transfer line is a rigidly interlinked machine line. The individual stations for machining, inspection and part positioning are interconnected by slideways or chutes, or belt conveyors for workpiece transportation. Hence, for each station, a special loading operation is necessary. The transport motion itself may be relatively inaccurate. Once it is inside the station, however, the part must be accurately positioned. It can be transported either directly, i.e., without a pilot fixture, or indirectly, by means of a pilot fixture. The method of transportation to be applied depends upon the possibilities of clamping the workpiece. The ideal production flow is achieved by direct workpiece transportation because, otherwise, there is the problem of returning the empty pilot fixtures. Furthermore, the purchase of the pilot fixtures and their return facilities entails a considerable expenditure. The return ways will usually be found behind or above the transfer line and only rarely under the main section.

If a transport step is accomplished, the workpiece or the pilot fixture will, generally, be accurately positioned in the work-station by means of two indexing bolts and will then be clamped hydraulically, pneumatically or mechanically. This is followed by a signal to begin the cycle for the machining units. The work cycles of the units mainly consist of rapid traverse, feed and rapid return. After the last unit has come back into its starting position, the conveyor is signalled to progress. If an operation has been executed incompletely or omitted, the whole line will stop. The motion signals and the motions themselves can be produced electrically, hydraulically, pneumatically or mechanically.

If more than three workpiece faces must be machined, a turn-table or revolving station can be incorporated in the transfer line to bring the workpiece into the necessary machining position. These motions are part of the feed motions and must be executed in the same cycle time as the main feeding motion.

In order to detect faulty production, an inspection station is incorporated in a transfer line. For example, an inspection station is generally placed before a thread-cutting station. It checks all threads with a feeler pin so that no part will reach the thread-cutting station without a proper drill hole. Frequently, one feeler pin is provided for each drill hole and can eventually generate an impulse to stop the whole line. The inspection stations serve not only for location detection but also for dimensional control. If an error is detected by the inspection station, it will be displayed optically or acoustically and the line will automatically be stopped.

Quite often, transfer lines are equipped with loading and unloading stations. Hence, the supervising operator does not have to ready the raw parts for machining within the cycle time and is liberated for other types of work. Loading stations are of special advantage if the workpieces are transported without pilot fixtures.

Theoretically, the length of a transfer line is unlimited. However, it was found that there is an economic limit since the larger the transfer line, the longer the down-times. Unexpected breakdowns cannot be avoided; therefore, a buffer storage is frequently provided between individual transfer lines. In this way, at least the following transfer lines can continue operation in case of breakdown. It is advantageous to fill the buffer storage to 50 per cent in order to decrease the effective down-times also during a planned tool change. Some existing transfer lines are briefly described below.

Figure 19 shows a transfer line for machining cylinder heads. The transfer line consists of eight standard units for milling, drilling, chamfering and thread-cutting operations (see fig. 20) and has a total length of 10 metres. The parts are machined from five different directions. The line is controlled from a central desk where the controls for the individual units are also housed. Two workpieces are automatically clamped together on a pilot fixture in a loading (or, respectively, unloading) station. Transport across the line is accomplished by two hydraulic pushers featuring transport bars at the sides of the pilot fixtures and retractable drive dogs. Cycle time is 23 seconds. Altogether, about 3,500 operations are executed per hour.

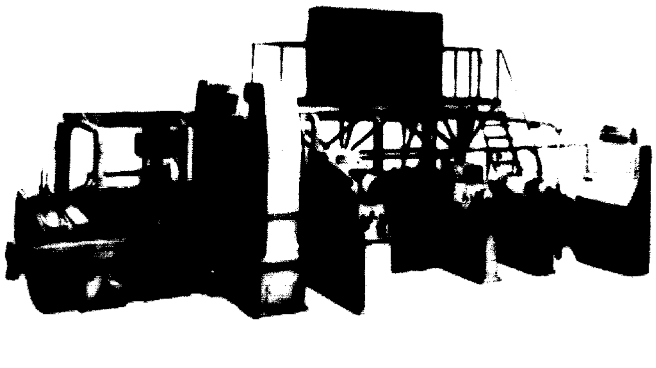


Figure 19

TRANSFER LINE FOR MACHINING CYLINDER BLOCKS

Figure 21 shows a transfer line for machining steering swivel bushes. This workpiece is shown in figure 22. The transfer line consists of twenty standardized units and measures 16 metres in length. It executes milling, drilling, chamfering, countersinking, facing, taper reaming, taper drilling, taper finish drilling and thread-cutting operations (see fig. 23). Five sides of the workpiece are machined. The parts are clamped electro-mechanically on a pilot fixture. Each pilot fixture accommodates four parts.

Figure 20

UNITS OF A TYPICAL TRANSFER LINE

Complete machining requires two passes. The guideways for returning the pilot fixtures are located behind and above the machine. The pilot fixtures are lifted and lowered by means of an inclined hoist. Transport across the transfer line is done by a hydraulically actuated transport bar with retractable drive dogs. Cycle time for two workpieces is 85 seconds. In one hour, approximately 1,300 operations are carried out.

...gure 24 represents the model of a transfer line com-...d of gear shapers. Here, the purpose is to generate ...matically the helical teeth and the clutch gear ring

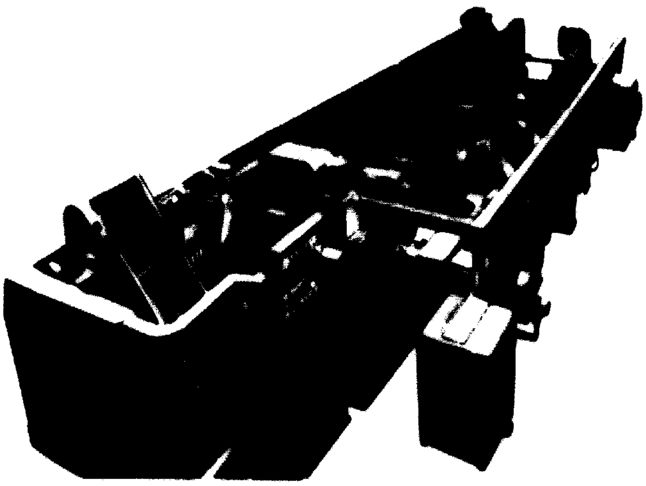


Figure 21

TRANSFER LINE FOR MACHINING OF STEERING SWIVEL BUSHES

at the main shaft of an automobile transmission and, at the same time, to eliminate the shaping burrs. The transfer line shown in figure 25 was designed for this job.

The production line consists of three gear shapers for the generation of the helical teeth and of one more gear shaper to generate the clutch ring. The cycle time is 6 minutes for three parts; i.e., the gear shapers of group A generate the teeth on one part each and the gear shaper of group B generates the clutch rings of three parts

Figure 22

STEERING SWIVEL BUSH

...n the same time. In this way, one part is completely ...ed every 2 minutes by this transfer line (see fig. 24). ...raw parts are fed by means of a conveyor. It should ...oted that there is a separate conveyor for machine groups A and B, respectively. The conveyor for group A feeds three parts every 6 minutes; the conveyor for group B feeds one part every 2 minutes. The helically geared parts are passed on by an ejector feeding three parts simultaneously every 6 minutes into the conveyor of machine group B.

2. *Conditions for the application of transfer lines*

A prerequisite for the economic application of transfer lines is a large number of pieces to be produced. In order to obtain the number of pieces justifying the use of such a line, the products should be standardized. Technical unification and model restriction contribute essentially to such a standardization. The technical unification imposes some restrictions to the engineer but, nevertheless, leaves him enough freedom for the design of the products. When working on such a unification, it

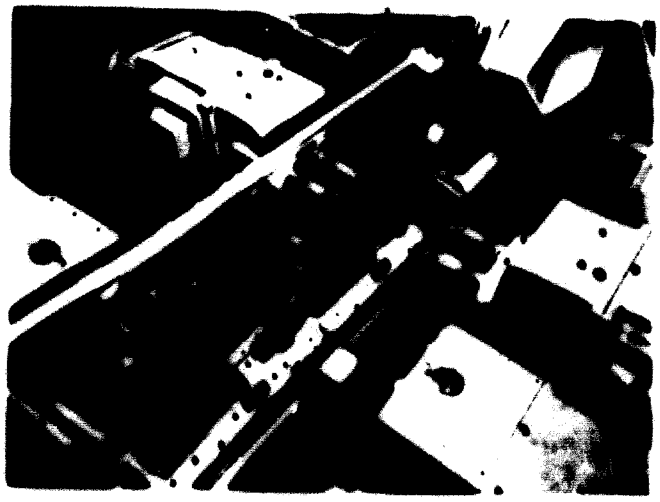


Figure 23

MACHINING STATIONS OF A TRANSFER LINE

must always be kept in mind that the standards, in spite of the natural progress of technology, must keep their validity over a long period of time.

Model restriction is also essential if a large output is to be obtained. This is an analytical, commercially oriented process of selection and is planned for the adaptation of the production programme to the actual market requirements.

Another important point for the judgement of transfer-line utilization is the labour situation in the developing country where the machine is to be set up. A transfer line not only makes it possible to produce the parts faster and at lower costs, but also spares workers, even if the total output is increased by introduction of the line. One may deduct the premise that the labour force must be fully employed; temporary unemployment can be a consequence of utilization of a transfer line. Professional and social problems will always arise as a result of the replacement of physical labour by mechanical operations, to the effect that the demands and strains of the worker will be partially changed.

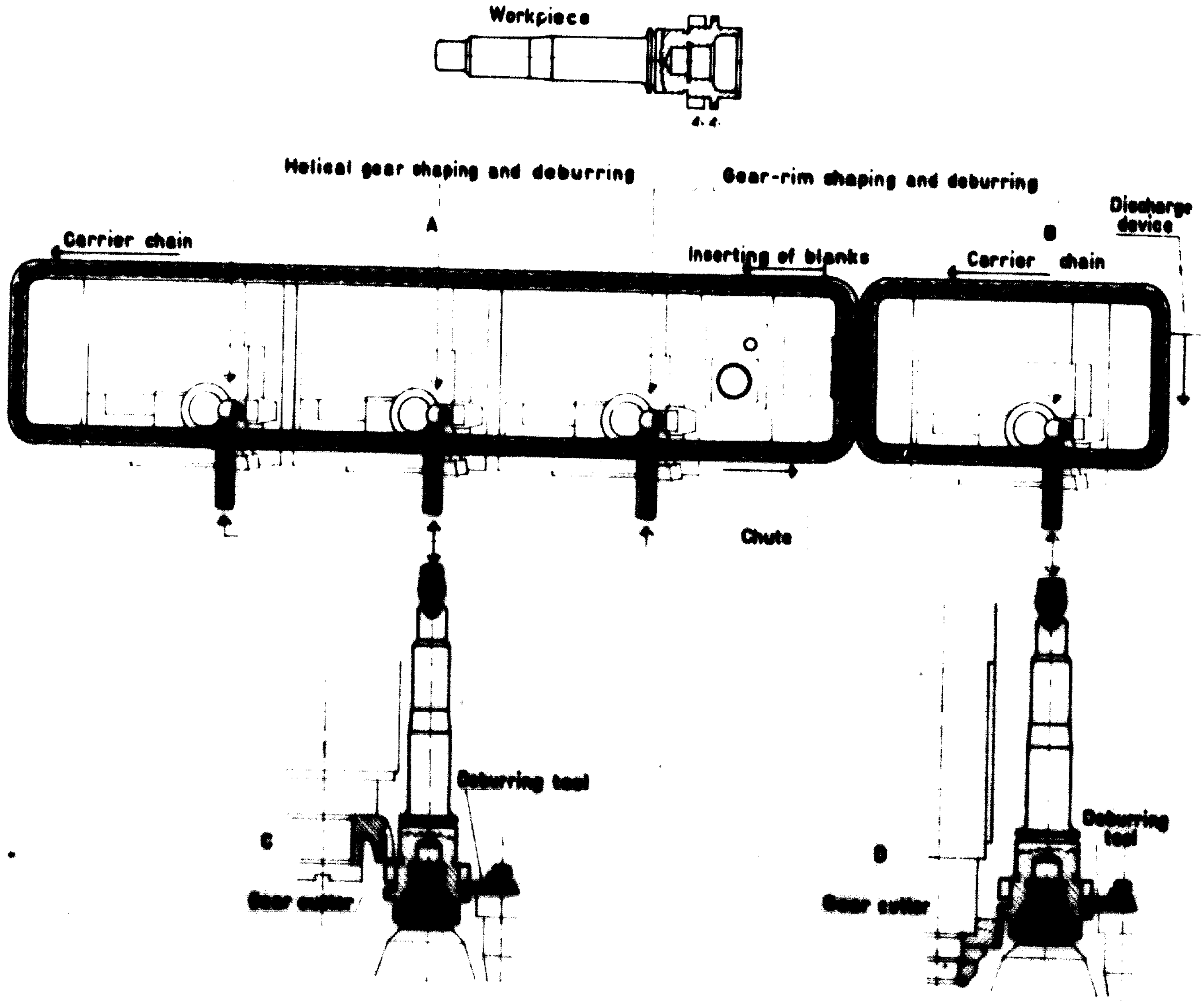


Figure 24

SCHEMATIC DRAWING OF A TRANSFER LINE

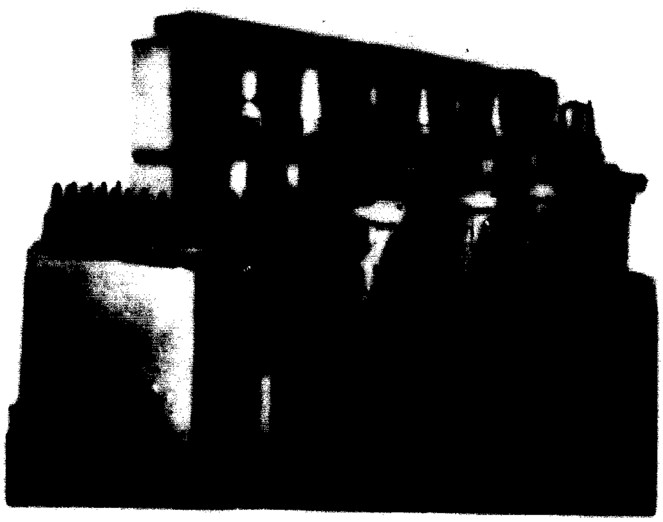


Figure 25

TRANSFER LINE CONSISTING OF GEAR SHAPERS

3. *Personnel required for transfer-line system*

For the operation of a transfer line, service, set-up, maintenance and supervisory personnel are required. The fields of activity and the connected requirements for these types of personnel are quite different from each other. Their main characteristics are outlined below.

(a) *Service personnel.* The task of a transfer line's service personnel is to start the automatic work process, to observe the entire line and to react according to optical or acoustic signals. Service personnel are not expected to take action in case of breakdowns, for example, a broken drill or a stalled unit. In such a case, the appropriate maintenance personnel must be called. Thus, the function of the service personnel has been transformed from an executing to a controlling action. It requires neither special skill nor basic professional knowledge. Hence, the operator does not need complete professional training or the equivalent education. A short period of instruction suffice. Nevertheless, not every person is suited for service of transfer lines. The selection, in regard to operator's personal qualities, must be very careful ...e a transfer line represents a very considerable in...ment value. The operator must be absolutely reliable ...d alert over long periods of time without manual acti...v. This leads to high requirements in respect of the ...erator's ability to concentrate and his willingness to ...ssume responsibility. In addition, the operator must be ...ble to communicate his observations and perceptions ...early and distinctly. He must possess most of these ...apabilities from the very beginning since they can be ...aught only to a certain degree.

(b) *Set-up personnel.* The function of a transfer-line set-up man is similar to the one of setting up automatic machines. Since a transfer line is only a line-up of automatic production machinery, the activities are often identical. The set up man must have excellent manual skill and fundamental technical knowledge. This necessitates complete professional training or a similar thorough education. Compared with multiple-spindle automatic machines, a transfer-line set-up is facilitated since the individual stations can be separately actuated, and large and strong tools are frequently used. Furthermore, tools are generally set outside of the machine by means of gauges in such a way that they can be chucked in the machine by a quick-change attachment. Detailed knowledge is necessary for the set-up of the inspection and dimensional-control stations. These stations serve for controlling the production process; they are supposed to signal production errors and tool breakdown, either acoustically or optically. Since the costs per machine-hour are very high and, hence, down-times should be restricted to the absolute minimum, it is essential that a set-up man have a good knowledge of tools and, especially, of tool life.

(c) *Maintenance personnel.* The task of the maintenance personnel is to maintain, to repair and, if necessary, to completely overhaul the transfer line. Since the breakdown of a single machine stops the whole production flow, numerous well-trained maintenance personnel must be employed for the elimination of such breakdowns in the shortest possible time. Generally, the theoretical knowledge and practical skill required for proper main...ance cannot be met by professional training of the ...sonnel as either mechanics or electricians because the ...ge of activities is much wider. A good maintenance ...n can only be formed by a further thorough training ...he skilled workers in adjacent fields. For instance, a ...y trained machine mechanic must also have basic ...wledge of hydraulics, pneumatics, control engineering, ...rical science etc. in order to detect faults quickly. ...rdingly, an electrician must have a certain command ...lds adjacent to his own profession. Then, in case of ...eakdown, the man with the best knowledge and ...ence in the concerned field will be called upon to ...nate it. The many-sided maintenance problems of ...nsfer line can be solved only if the appropriate main...nce personnel are available.

(d) *Supervisory personnel.* As supervisory personnel, it is possible to consider only those professional engineers who, on the basis of their education, have gained a sufficiently broad view of the problems connected with the use of a transfer line. The engineer should not only have theoretical knowledge of the various fields, but also satisfactory practical experience.

In regard to the suitability of a transfer line for an industrially developing country, one may conclude that, for the economic use of such a line, a large number of pieces of a product must be fabricated over a long period of time. In many developing countries, the ability to reach the minimum output for economic utilization is quite problematical. Furthermore, the installation of a transfer line entails high capital investments. For this reason and because of their low flexibility in regard to the product, transfer lines will only scarcely be suitable. In particular, the saving of personnel could cause resistance. Application of transfer lines, however, is furthered by the fact that briefly instructed, non-skilled workers without any training can be employed as service personnel. If only one transfer line is installed, a large number of highly qualified specialists, in relation to the servicing personnel, are needed for clerical and planning tasks. This proportion, however, improves if several transfer lines are installed in a developing country.

F. *Numerically controlled machine tools*

Numerically controlled (NC) machine tools can read information fed digitally by means of punched tape or magnetic tape and can translate these data into machine functions. Due to the separation of the measuring device and information storage, they show a very high degree of flexibility with regard to the production of different parts. The means of feeding the information — the most frequently used is punched tape — are prepared in the production planning department according to the blue prints. The various parts to be machined call for three different types of numerical control (see fig. 26):

(a) *Point-to-point control.* This type of control is generally used for boring mills and drills. Machining is done at predetermined points of the workpiece; during numerically controlled machine positioning, the tool does not cut;

(b) *Straight-cut control.* This control is most frequently applied to milling machines and lathes. The tool progresses along straight lines parallel (or oblique) to the machine-table's co-ordinates;

(c) *Continuous-path control.* This type of control permits the machining of irregularly shaped and, eventually, curved surfaces. An electronic computer is needed to calculate the often very complicated tracks of the tool. Controls with either an inner interpolator (i.e., a computer within the control unit) or an outer interpolator (a computer outside of the control unit) can be distinguished. The costs for an interpolator of a continuous-path control amount to a considerable percentage of the total price.

Economic considerations impose a restriction in regard to the required control types. Investigations in industrialized countries have shown that 85 per cent of all parts destined for numerically controlled machines can be produced by means of point-to-point or straight-cut control, as shown in figure 27. This percentage will probably be true for developing countries also.

In regard to the technical conception of the numerical control and the measuring system, two groups may be classified according to their functions: the digital system; and the analogue system. While the digital system will almost exclusively be found in the information-feed part of the control, due primarily to its resistance to temperature, metal ageing and other environmental influences,

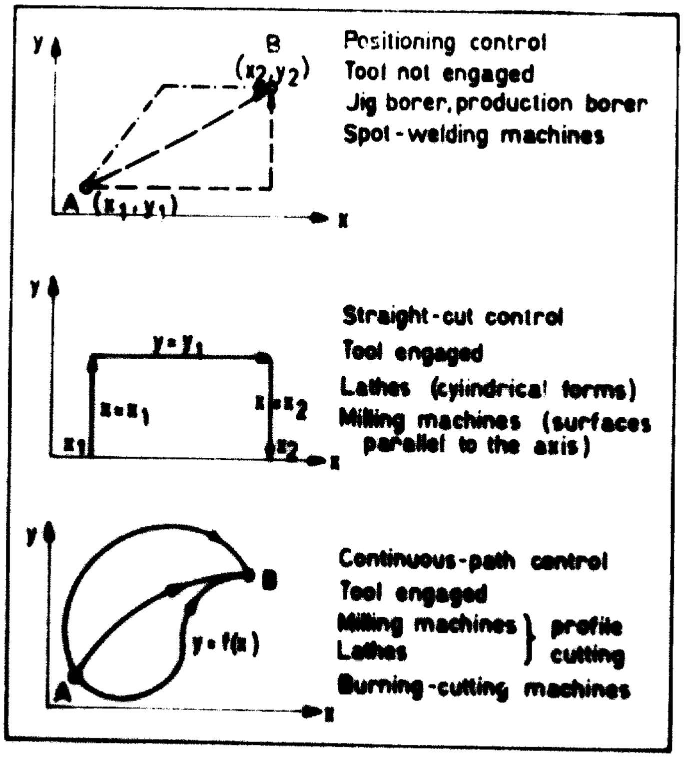


Figure 26

SEVERAL CONTROL SYSTEMS FOR NUMERICALLY CONTROLLED MACHINE TOOLS

one finds both digital and analogue designs for the (table) feed-measuring systems. Since the accuracy and reliability of the feed-measuring system determine the properties of the entire control, the various alternatives for such measurement are briefly described below.

Basically, digital feed measurement can be divided into the incremental system which is based on the principle of counting elementary non-distinguishable feed elements, and the absolute coded system, where a defined and, over the whole measurable feed range, a non-repeated combination of signals is attributed to each feed increment.

In order to be able to decipher the required feed length as a part of the whole feed range of the machine, the measuring system in analogue measurement is divided into three subsystems: the coarse system; the medium system; and the precision system. Only the precision system determines the obtainable accuracy.

The choice of the measurement principle influences greatly the expenditure for the control and some characteristic properties also. The simplest control system consists of incremental feed measurement without a fixed co-ordinate origin in relation to the machine-table. After an eventual failure of the electric current, a co-ordinate origin is freely selected by hitting a button. In absolute digital and analogue measurement, the co-ordinate origin is fixed; its relocation necessitates computer action in the control system.

Each type of feed measurement principally permits direct or indirect measurement (see fig. 28). The principle of direct measurement allows the highest possible measuring accuracy independent of the type of material. As short-comings, one must mention the frequently higher sensitivity to dirt in the case of optical systems, the narrow assembly tolerances and the higher price. Therefore, measurement by means of the sturdier indirect system is always recommendable except for machines with the highest accuracy. Through the application of ball-bearing spindles, a simple and advantageous drive of spindle and a measuring system with good precision are achievable. Besides, it should be noted that the recent development of efficient electrical step motors has opened the possibility of designing very reliable and inexpensive control systems without any measuring system.

A prerequisite for the use of numerically controlled machines is the availability of a programmer to prepare the tapes. This must be done by specially trained personnel, who bear most of the responsibility for the part to be produced. In the highest stage of development of numerically controlled production, there is a trend towards tape preparation by machines, i.e., computer-assisted programming, particularly in the case of the extremely time-consuming calculations required in connexion with gear generation. In the near future, however, such computer-assisted programming will not come into the reach of developing countries, especially for the following reasons: capital investment for the computer is high; the effect of rationalization is greatly reduced by the fact that there is a sufficient supply of labour at a relatively low wage index. Furthermore, only a fraction of the capacity of a computer installation would be utilized even if there were several numerically controlled machines. The assumption of full computer utilization by work for other fields, e.g., business administration, is certainly premature for developing countries. Therefore, the question of computer-aided programming is not dealt with further in this paper.

The considerations that must be taken into account for the judgement of the suitability of numerical control for developing countries are different from those which would be applied to industrialized nations. While there is generally a sufficient supply of labour, there is a clear lack of skilled specialists. Here, the application of numerical control can help to bridge the gap. The machine programmes are prepared in the production planning department by a small number of specialists. The machine operation itself, then, requires only non-skilled workers, who scarcely influence product quality and operational time. If several machines are served by one programmer, these advantages will be even greater.

Another point is the fact that the production of rea-

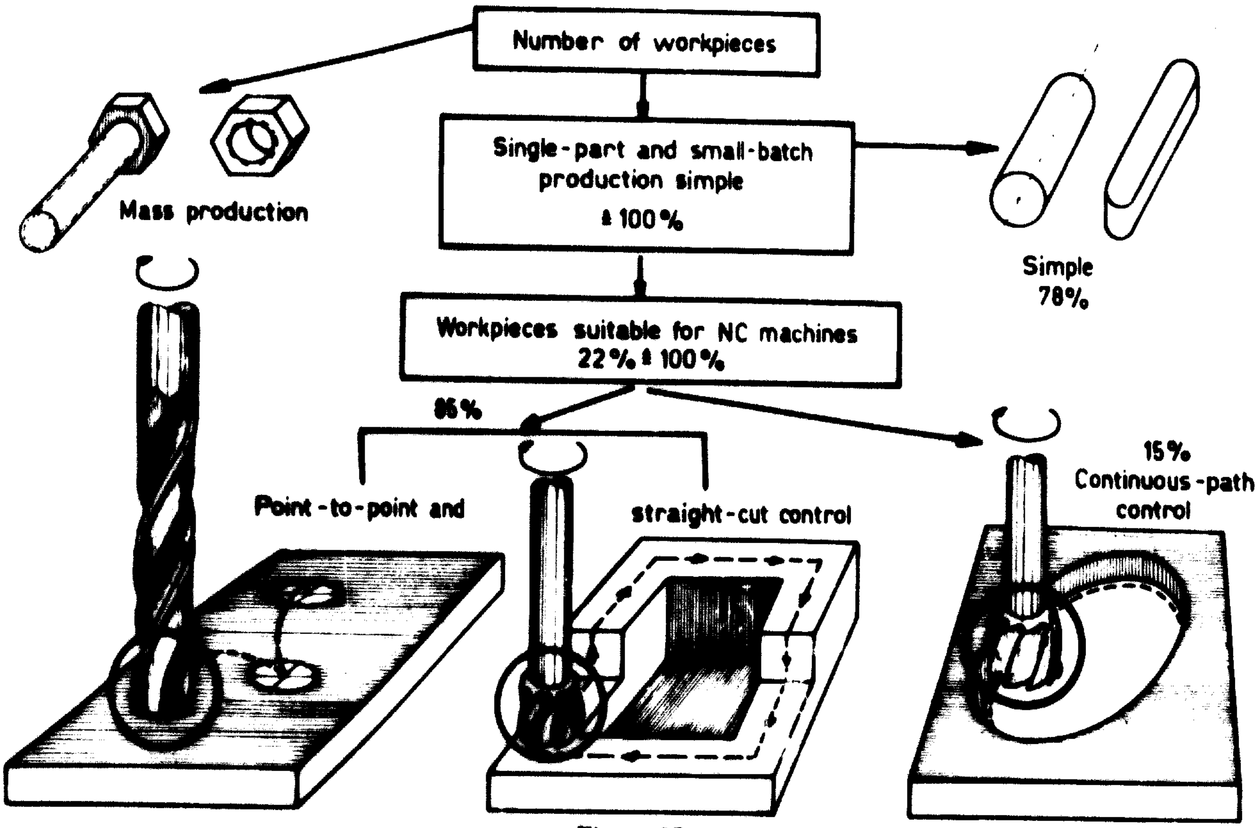


Figure 27

SCOPE OF APPLICATION FOR NUMERICALLY CONTROLLED MACHINE TOOLS AND PERCENTAGE DISTRIBUTION OF POINT-TO-POINT, STRAIGHT-CUT AND CONTINUOUS-PATH CONTROLS

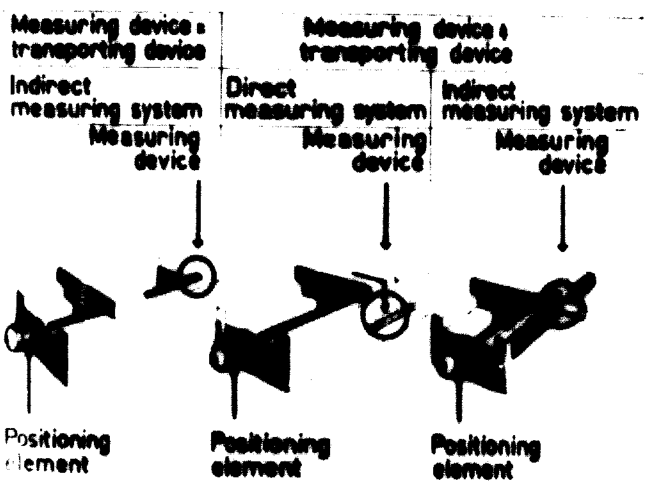


Figure 28

POSITION AND DISPLACEMENT MEASURING DEVICES

..ly small batches will be predominant in developing ..ntries. This is, indeed, the economic operational ..e of numerically controlled machines. For the selec-.. of a suitable numerically controlled machine, the ..tion of sturdiness, operational simplicity, reliability ..easy maintenance must be thoroughly investigated.

.. numerical control is introduced at all, point-to-point ..o-dimensional control will be of the greatest interest ..everal reasons. As previously mentioned, a large ..entage of the parts do not call for three-dimensional control, the purchasing costs of which are two or three times higher than those for other control types, without considering the costs for an eventually needed computer programming unit. The requirements of the maintenance and repair personnel, in respect of their special knowledge, are high.

While operational simplicity can be obtained by measures which do not call for large additional expenses, the reliability of the control system is closely connected with the reliability of the measuring system. Here, accuracy requirements should not be exaggerated since this would only increase the machine's delicacy. As mentioned earlier, the application of indirect spindle-driven and enclosed measuring elements is recommendable.

In view of maintenance and the elimination of minor breakdowns, it must be kept in mind that, frequently, there is no service centre in the nearer surroundings. By maintenance-oriented design and the use of readily available error detection and control equipment designed for the particular type of control, routine maintenance and minor repairs could possibly be undertaken by workers who had not been given special instruction in regard to the type of control.

In summary, it may be said that numerically controlled machines generally do not require specially trained operators, but they do present the maintenance and supervisory personnel with very demanding tasks. A centrally co-ordinated service for all machines would be of great advantage in a developing country. The excellent machine flexibility in regard to the product,

VARIOUS TYPES OF MACHINE TOOLS: INVESTMENT, PERSONNEL REQUIREMENTS AND PRODUCTION CHARACTERISTICS

	Capital investment (Deutsche Mark)	*Operator quality*	*Grade of supervision for maintenance*	*Grade of supervision*	*Production flexibility*	*Number of workpieces*	*Control*	*Work transfer*
Universal machines (engine lathe)	25,000	Skilled operator[a]	Skilled operator	Foreman	Excellent	Small-batch production	Manual	Manual
Machines for batch production (regular type of engine lathe)	18,000	Semi-skilled worker	Skilled operator	Foreman	Good	Medium-batch production	Manual	Manually linked production line
Sequence-controlled machines (cams, i.e., turret lathe)	45,000	Unskilled worker, single machine supervision	Skilled operator	Foreman	Good	Medium-batch production	Cams, curves (purely mechanical), fixed interlinkage of the machine functions	Linked production line
Automatic machines (single-spindle automatic)	35,000	Unskilled worker multiple machine supervision	Skilled operator (tool setter)	Foreman	Good	Mass production	Cams, curves (purely mechanical), fixed interlinkage of the machine functions	Linked production line
Transfer lines	200,000	Unskilled worker	Skilled operator (machine setter)	Engineer	Limited	Mass production	Different, fixed interlinkage of the machine functions	Linked production line
Numerically controlled machines	100,000		Electrical engineer	Engineer	Very good	Small- (medium-) batch production	Electronic	Manual (linked production line)

[a] A skilled worker should have practical knowledge of the manufacture of tolerance threads, tapers, formed parts (tools and materials); and theoretical knowledge of machine construction, calculations for the change of gears, tapers, machine time.

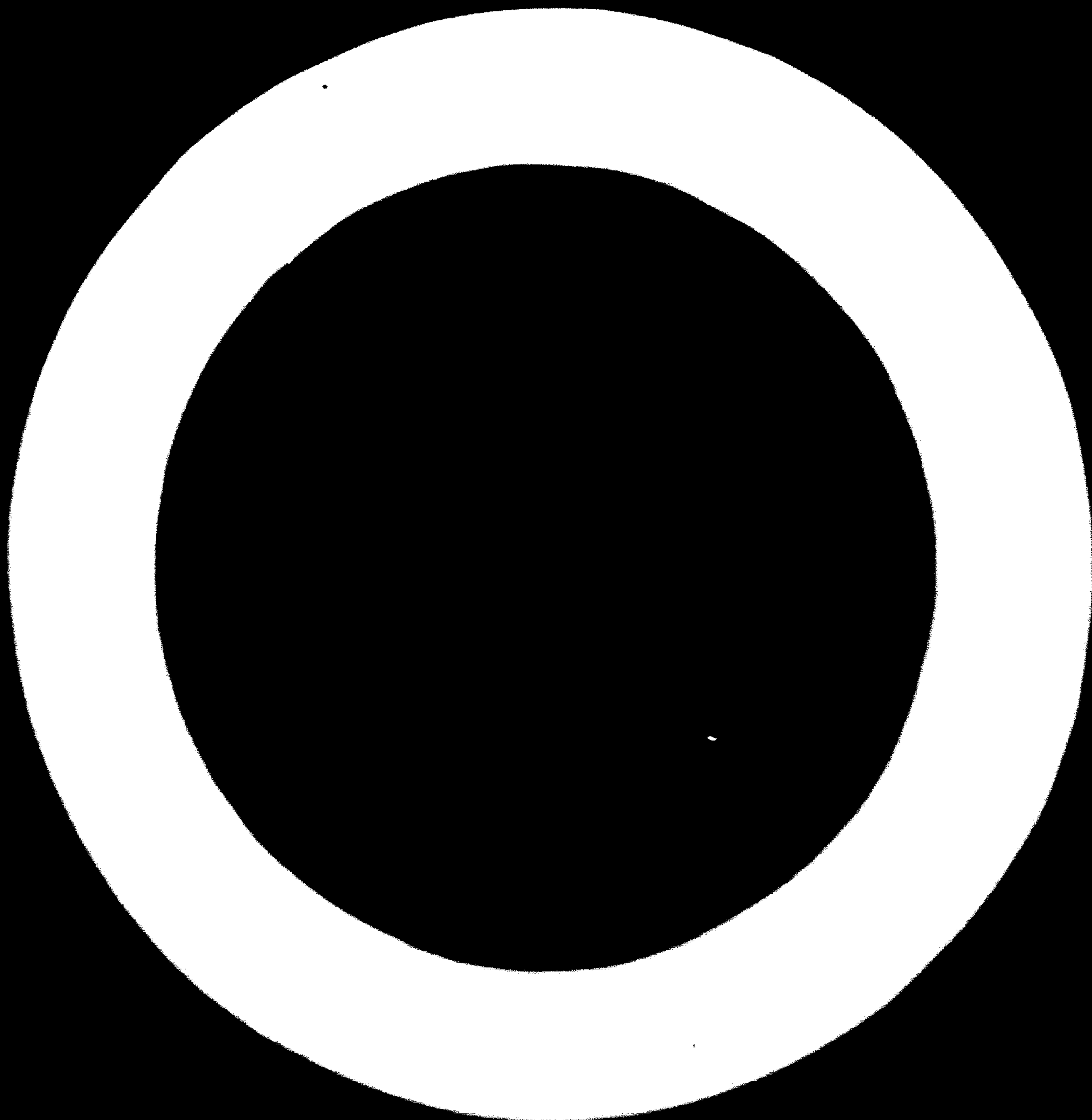
profitable use even in small-batch production and possibility of integrating it into a manually oriented work flow can be of advantage for an industrially developing country if the related requirements are fulfilled.

III. Conclusion

In this paper, the problem of designing and selecting machine tools for developing countries has been outlined and discussed on the basis of the principal considerations. The following points have been made:

1. There is a remarkable difference between the conditions which prevailed at the beginning of industrialization in the industrialized countries and the conditions which obtain for countries which are now developing industrially. This difference is that, in industrialized countries, professional training and the principle of the division of labour were already in existence before industrialization. Hence, there was already a certain level of education in those countries which can be met in only a few developing countries of today;
2. The industry of currently developing countries is pimarily supposed to satisfy the domestic demand. In order to protect sales of the domestic products, protective duties are often set up, leading to a situation where real rationalization is not introduced;
3. The excessive supply of workers, the frequent unemployment and the rather low level of education in developing countries make it appear advisable to select machine tools which are simple to operate and which can be integrated into the work flow in such a way that the rate of employment does not decrease.

The question of suitable machine tools for an industrially developing country must be answered individually for each case, taking into consideration the above-mentioned points. In order to facilitate such decisions, the requirements of the various machine types, in regard to personnel and products, have been outlined by describing the development of the machine tool in industrialized countries. The following table illustrates this development in a general survey deliberately based on machine models which are readily available in all parts of the world. In regard to operational reliability and price, the industrially developing countries should prefer these models to brand-new designs. Finally, the experiences of industrialized countries should also be significant for developing countries.



PROBLEMS IN THE DEVELOPMENT OF METAL-CUTTING TECHNIQUES

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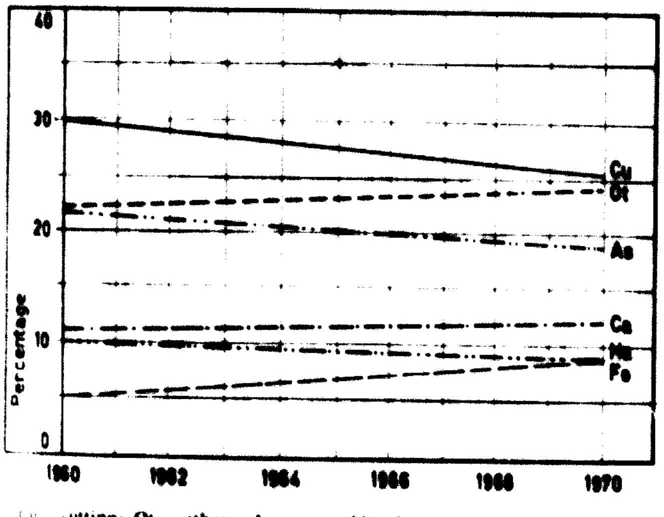
I. SIGNIFICANCE AND ASPECTS OF CUTTING DEVELOPMENT

Cutting technology is predominant in the production of machine components and metal parts. In mechanical engineering in Poland, for instance, in which it is possible to see symptoms of the changes typical of all the countries experiencing rapid industrial development, the participation of cutting machining in 1965 was about 28 per cent; casting, 12 per cent; handiwork (i.e., fitting and welding), 10 per cent; and plastic working, 7 per cent of total work-time (see fig. 1).

In 1970, according to development plans, there will be some changes in these proportions. Nevertheless, cutting will always be the method used for the greatest share of the whole work-time and value of production, and will constitute about 26 per cent of the total work-time, almost three times more than plastic working and about two times more than casting.



Cu cutting; Ot others; As assembly; Ca casting; Ha handwork; Fo forming.

Figure 1—SHARE OF VARIOUS PRODUCTION TECHNOLOGIES IN METALWORKING INDUSTRIES OF POLAND, 1960–1970

(Percentage of work-time)

The significance of cutting is even more evident if one ...nts as a criterion of estimation, instead of the work- ... share in the whole production, the share of compo- ...s which are ready to assemble in the production pro-

...e situation in this field may be illustrated by the ...ple of the Federal Republic of Germany, one of the ... industrialized countries of the world. In 1960, the ...ral Republic had one of the highest indexes of share ...achine tools for plastic working. In spite of this, the ...ber of parts produced by the plastic mean and in finished condition, ready to be assembled, was said to be only 5–15 per cent, independent of the industrial branch concerned (1).

In other countries, the share of finished components produced without use of the cutting process is far smaller.

Therefore, the reduction of cutting work-time (see fig. 1) derives, in fact, not from its elimination by other machining processes, but rather from the increase of cutting efficiency and the reduction of the share of roughing. It is characteristic that no real changes have been noted in recent years in the percentage share of cutting in the production of finished components.

This results from the fact that cutting has the best possibilities from the point of view of accuracy and universality. In addition to being one of the most economic and universal methods, cutting is the most technically advanced and the most rapidly developing method.

A. *"Peaks" and "pits" of technology*

The first of these aspects is the relative proportion of the "peaks" and "pits" of technology. From day to day one may observe the creation of peak technological realizations, which obviously influence the over-all level of technology, as well as the material conditions in existence. Nevertheless, they do not constitute a sufficient index of the actual production-engineering level.

Only the elimination and "raising" of technological "pits" can end the process of introduction and propagation of new achievements. For this reason, too, the real level of production engineering is represented by the percentage of the newest installations and production methods, and by the percentage of backward methods.

The rate at which the "pits" of technology are being raised has increased in comparison with that of the last ten years. In spite of this, however, the distance between "pits" and "peaks" is still important. That is why, when speaking of problems related to development, one must draw attention to not only the technological absolute novelties, but also the liquidation of technical backwardness and the propagation of achievements which are already known, but which are insufficiently used. These remarks concern all production engineering methods and, principally, cutting technology.

B. *Size of production run*

The second important problem of technical and economic character is that of the size of the production run. Every conclusion concerning directions and tasks

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related to the development of the cutting method must be adapted to the size of the production run and to changes in this field.

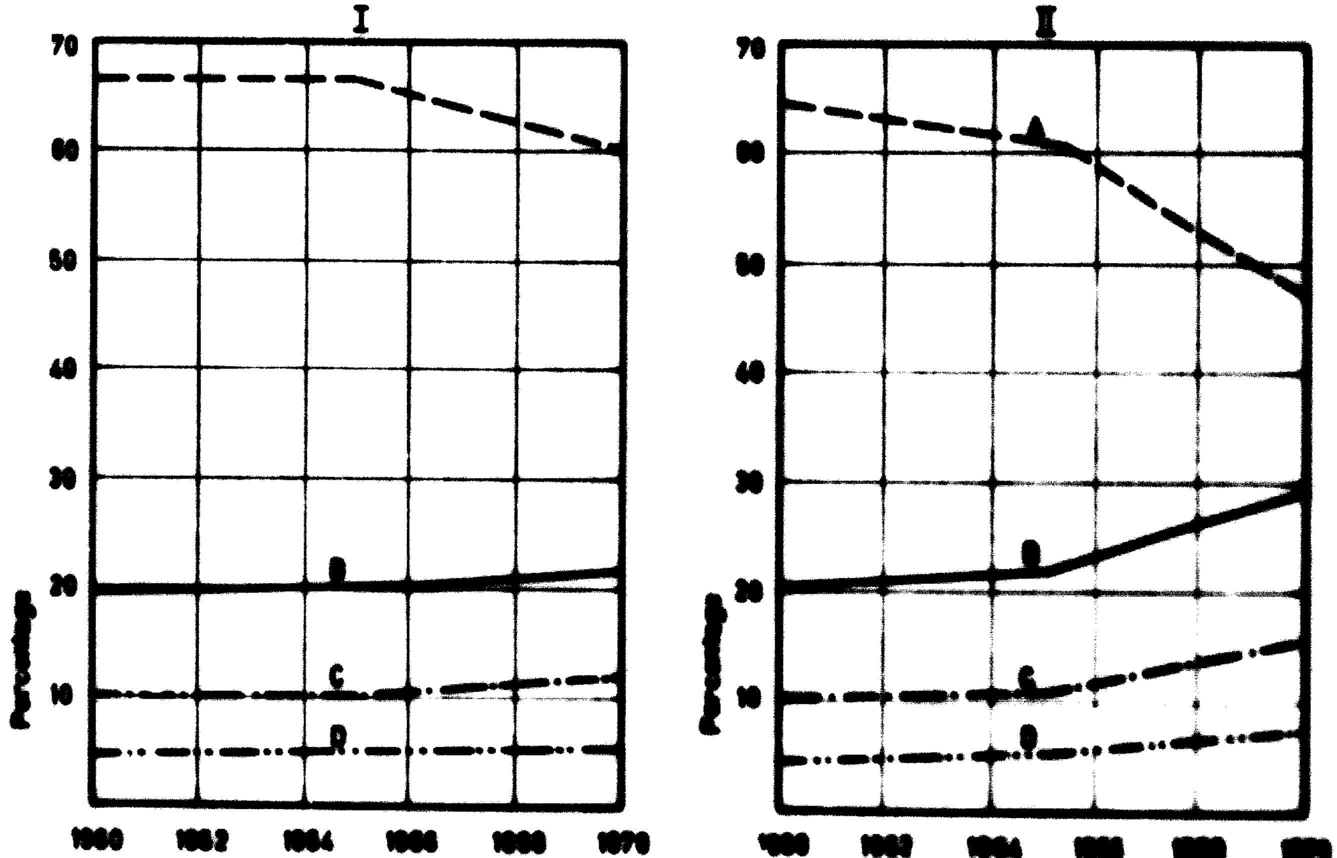
Figure 2 shows the changes achieved and foreseen in Poland in the field of so-called "final" run size (i.e., of machines and installations) and machine components. From the figure, one may see that up to 1970 small-batch production (A) will be dominant, but its share will decrease more rapidly in machine components production (II) than in the case of finished products (I). Batch production (B), large-batch production (C) and mass production (D) will also increase at a higher rate for machine components than for finished products.

C. *Share of various processes in total cutting work-time*

The third important aspect of the cutting technology development is the structure and participation in percentage of the different processes in the total work-time of cutting.

An example of the percentage share of the different processes in the total work-time of cutting in Poland during the period 1961–1970 is given in figure 3. Although this example concerns only one country, it gives, nevertheless, an idea of the trends and structure of times for the different processes in the world.

From the curve shown in figure 3, one may see that the greatest percentage is allowed for turning and, in order



I = production of finished machines; II = production of machine components; A = piece and small-batch production; B = batch production; C = large-batch production; D = mass production

Figure 2. SHARE IN PRODUCTION OF FINISHED MACHINES AND OF MACHINE COMPONENTS OF PIECE AND SMALL-BATCH PRODUCTION, BATCH PRODUCTION, LARGE-BATCH PRODUCTION AND MASS PRODUCTION, 1960–1970

(Percentage)

Source: A. Prochowski, J. Sikora and S. [illegible], *Stan obecny, kierunki i warunki rozwoju technologii obróbki skrawaniem w latach 1961–1970 w przemyśle maszynowym PRL* (Actual state, trends and conditions of cutting processing development in 1960–1970 in mechanical engineering of Poland), Series [illegible], No. [illegible] (Kraków, Institute of Metal Cutting, [illegible]), p. [illegible]

This, of course, may be an illustration of the over-all trend towards decreasing small-batch production in favour of production in larger batches. One may yet see in the field of machine components production an increase in batch size even for components which are used in products manufactured in small lots. This results from the development of designs by type classification as well as from various forms of production concentration.

of importance from the point of view of work time: drilling and boring, milling and grinding (each more than 10 per cent). Planing and parting, gear working, [illegible] working, broaching and others each use less than 10 per cent of the work time.

For turning, one may observe a trend towards an increase, mainly owing to the increase of [illegible] operations, multiple-spindle drilling and [illegible] drilling. Some percentage increase may be seen in milling, [illegible]

…ly results from the overly slow increase in efficiency.

The relatively greatest increase of work-time is to be …d in grinding, which takes place in connexion with the increase of the accuracy requirements related to machine components and products.

The reduction of the share of planing and cutting off is mainly due to the reduction of use of less efficient planing machines.

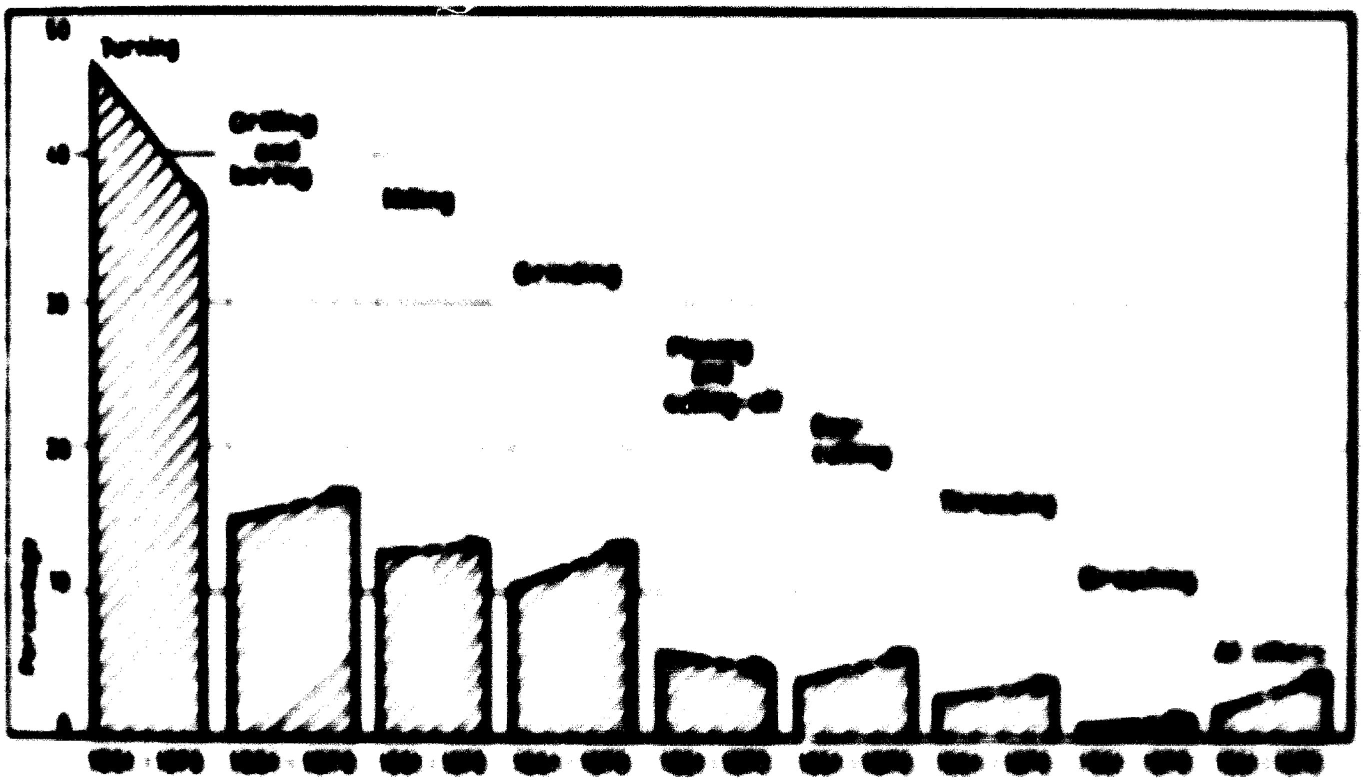
An evident increase may be noted in gear working, which is a proof that regardless of the various means which are introduced for motion transmission, gear trains are still the most used. The same trend, but with less intensity, is to be observed in winding working.

many a disparity and their importance depends upon the economic situation of the industry and its organization, as well as upon the nature of the cutting process concerned.

Nevertheless, the problems of development may be reduced to common denominators, in other words they may be generalized according to the circumstances. Thus, the generalized tendencies of development in the theory and technology of cutting are the following:

(a) Increase of savings and purposefulness of material use.

(b) Improvement of accuracy and quality of machined pieces.



[illegible]

[illegible]

materials is becoming the fundamental necessity for the designer, production engineer and user. By the same token, these questions must have their reflection in scientific research works.

Losses of materials in the cutting process involve: (a) losses of machined materials, (b) wear of tool materials and (c) losses of auxiliary materials.

The losses of auxiliary and tool materials cannot be considered without taking into account the optimal rate of the cutting process and the production efficiency, as well as the quality of machining. This is why the auxiliary or proper losses of these materials are discussed together with the problems of efficiency.

As to the losses of stock, this is a separate problem and is discussed below.

B. Stock saving

The loss of stock may be characterized by the yield ratio:

$$\eta = \frac{G_1}{G_0} \cdot 100 \text{ per cent} \qquad \text{(Equation II.1)}$$

where G_1 = weight of the workpiece after a given operation, G_0 = weight of the workpiece before the given operation.

One may also use the notion of ratio of loss or coefficient of loss, which may be expressed as:

$$\varphi = 1 - \eta = \frac{G_0 - G_1}{G_0} \qquad \text{(Equation II.2)}$$

The coefficient of loss shows what percentage of the used raw material will be lost.

[illegible] losses of material in the cutting process may be classified as follows:

(a) Losses for ends and discards,
(b) Losses for parting,
(c) Losses for [illegible], technical machining allowances,
(d) Losses for machining over-allowances due to the bad workmanship of semi-products,
(e) Losses in chips due to machining errors or other causes.

Losses for ends and discards, as well as for parting, are important in the case of production from rolled and drawn semi-products and from large castings and forgings. The value of these losses is difficult to generalize theoretically. [illegible]

[illegible]

[illegible]

of material. One must distinguish between indispensable machining allowances, which are theoretically and technically justified, and real machining allowances, which are higher than the theoretical values because of the inaccuracy of the semi-finished products.

The technically justified machining allowances for one cut are the result of the algebraic stack-up of the following factors:

- T — the dimensional allowance of the former cut,
- H — the mean value of surface roughness after the former cut,
- D — depth of the damaged layer in the former cut,
- ε — coordinate geometric error resulting from errors in setting up the workpiece in relation to the tool in the operation concerned.

Therefore, the total machining allowance of a given cut is:

$$g_i = T_{i-1} + H_{i-1} + D_{i-1} + \varepsilon_i \qquad \text{(Equation II.3)}$$

and in case of multiple-cut operation, the total machining allowance will be:

$$g = \sum g_i$$

where i = number of cuts.

The yield ratio and the coefficient of loss, taking into account only technically justified machining allowances, generally decrease when the dimensions of the workpiece decrease.

This is illustrated in the example given in figure 4. The diagram represents the dependence between the yield ratio and the necessary losses of material and machining allowances [illegible] as the function of the material diameter. [illegible]

In this example, the losses of material are about [illegible] per cent for very small dimensions [illegible]

Statistical data show that the real losses of material can be more important than they would appear to be from theoretical calculations. [illegible]

[illegible]

[illegible]

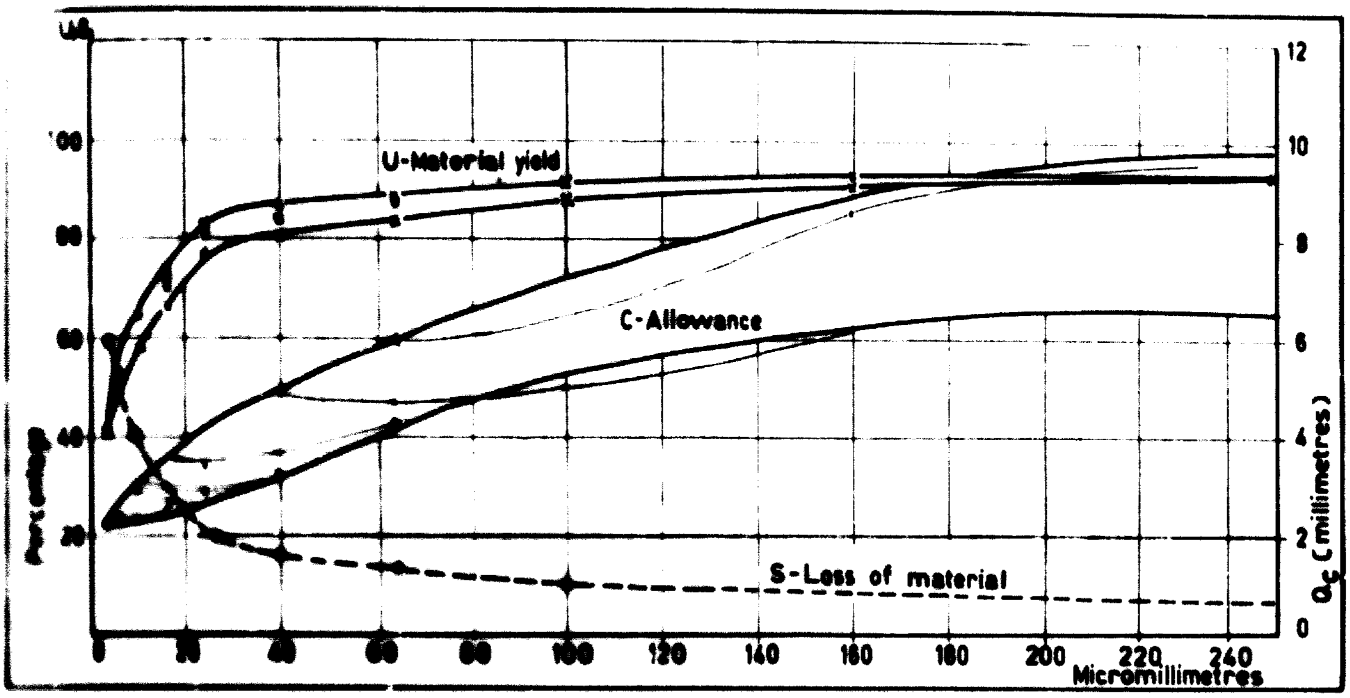


Figure 4

[illegible] OF MATERIAL YIELD, PERMISSIBLE LOSSES OF MATERIAL AND TECHNICALLY JUSTIFIED MACHINING ALLOWANCES IN TURNING OF MULTIPLE-STAGE SHAFTS IN ROLLED STEEL

[illegible] with suitable accuracy and quality requirements are fundamental prerequisites to the reduction of machining allowances.

Nevertheless, the task of reduction of stock losses must be distributed equally between the manufacture of semi-products and the cutting processing itself.

With regard to the influence of the allowance on the [illegible] of material, it is important to admit, as a principle, that semi-products ought to be manufactured at the [illegible] dimension of tolerance, rather than as they [illegible] are manufactured, at the highest dimensions of [illegible]. As for workpieces produced by cutting, they [illegible] to be manufactured at the highest dimensions of [illegible].

[illegible] recommended also that in determining the value [illegible] tolerance, designers should take into account [illegible] of material on the value of the tolerance.

[illegible] greatest amount of work remains to be done in the [illegible] the influence of the shape and dimension of the [illegible] product on the losses of material. In the [illegible] place it is necessary to make investigations and [illegible] in order to know if the admitted dimensional [illegible] and the compensation of these dimensions correspond [illegible] the real needs in mechanical engineering. This [illegible] in the first order, the rolled bars. However, it [illegible] necessary to increase the proportion of more [illegible] methods of production in casting, forging, [illegible] etc.

[illegible] field of the influence of surface microroughness [illegible] depth of the damaged surface layer, further thorough [illegible] are necessary to elaborate instructions for the [illegible] of the product. These instructions must [illegible] account the needs of the smallest surface roughness and the depth of damaged layer, as well as the most economic course of production.

Particular attention should be paid to often repeated errors of decarbonization of the upper layer in some hot-machining operations, as well as to the appearance of micro-cracks, cold shut etc., all of which lead to the increase of allowances.

The following facts—based on the example of Poland — may give an idea of the material savings it is possible to achieve by rationalization and reduction of allowances. One statistical machine tool in Poland gives 2 tons of chips. Simultaneously, it is known that the average machining allowances are 50 per cent to 100 per cent higher than those which are technically justified. This means that the introduction of technically justified allowances may result in savings of about 1 ton of chips *per annum* for each statistical machine tool. These savings, multiplied by the number of machine tools, amount to a very important quantity of material for every country.

For this reason, some countries have elaborated and are introducing new principles for the technical standardization of losses of materials.

III. Improvements of technological quality of machine components

A. *Quality of a product and quality of a component*

In popular conception, the quality of a product is basically characterized by:

(*a*) Reliability in operation and accomplishment of its functions;

(*b*) Endurance or durability, in other words, the unchangeability of its features during its use;

(*c*) External aspect of the product in its totality and of its parts, particularly its surface, in other words, the surface "finish";

(*d*) Application of those materials whose properties are particularly suitable for this use.

One may see, therefore, that the quality of a product is dependent, in the first place, upon the manufacturer, i.e., upon the production engineering. However, the designer also exerts a great influence on the quality, because he decides on the choice of material, as well as the external appearance of the different components and of the whole product.

Analysing more precisely the popular conception of quality, it is necessary to remark that the usual features of a product, which are the mean basis of estimation, depend also upon the conditions and method of use of the product.

At the moment when a given product has just been manufactured, it is impossible to know exactly if it will be used properly or not, i.e., to what degree the conditions of use may influence the opinion concerning its quality. Nevertheless, at this moment, the quality must be estimated.

The quality of a product composed of many parts depends upon their proper assembly and connexion, i.e., on the assembling process and on the quality of units or parts composing this product.

In this respect, attention must be limited to the influence of engineering technologies and methods on the quality of the components. It is obvious that the better the quality of the components, the better guarantee one may have of the complex quality of the final product. The problem, therefore, may be reduced to an estimation of the quality of the components.

Such an estimation is possible on the basis of the relationship existing between the features of the components at the end of the manufacturing process—i.e., at the end of definite technological processes—and the properties of the components when they are put to use.

With regard to the production of machines, the following technological qualities (J) of the machine components are important by reason of their functions in the final product:

(*a*) Accuracy of shape and dimension (D);
(*b*) Accuracy of surface, or surface roughness (P);
(*c*) Physical properties of the upper layer (W).

These three complex quality features of machine components influence the properties of the component in use (U), of which the most important—and most frequently required—are the following:

(*a*) Abrasion resistance, which is defined by what may be called the abrasion ratio (S);

(*b*) Friction resistance, i.e., resistance offered when working with another part (C);

(*c*) Fatigue resistance, of both the surface of the component and its shape (Z);

(*d*) Corrosion resistance (K);

(*e*) Power of reflection (R).

Apart from the above-mentioned features, there are many others which, in some cases, may play an important role.

In more precise considerations, it is necessary to introduce for the estimation the quality of machine components:

(*a*) The technological quality (J), defined by the properties D, P and W, and then: $J = f_1$ (D, P, W);

(*b*) The quality at work (U), defined by the properties S, C, E and K and then: $U = f_2$ (S, C, Z, K . . .).

In condensed expression, the technological quality will be named "quality" and the quality at work, "workability".

The relationships between some technological processes, quality (J) and workability (U) are discussed in a subsequent section of this report.

B. *Increase of accuracy required and improvement of measurement possibilities*

1. *Requirements of accuracy*

In a design office of the railway industry, an interesting analysis concerning the increase of accuracy requirements in the machining of locomotive rotary pieces (rollers and holes) has been achieved. Figure 5 shows the percentage of pieces, with various accuracies expressed in values of the International Organization for Standardization (ISO) for 1930 and 1950, and the values planned for 1970.

As may be seen from this diagram, the accuracies are increasing relatively quickly. As a result, one may really foresee that in 1970 a higher percentage of this production will correspond to rollers and holes of the No. 6 grade, and the sum of pieces of classes below and up to 6 will reach about 43 per cent, in comparison with 34 per cent for the same group in 1950 and only 24 per cent in 1930.

This example shows that the increase of accuracy requirements in machine-element manufacture is typical for every kind of product. A particularly rapid increase may be noted in mass and quantity production, for instance, in the automotive industry.

It is not an easy task to reduce the machining errors, which are influenced by elastic strains of the machine tool, chucks and tools under the cutting forces, thermal deformation, geometric and kinematic inaccuracy and tool wear. In spite of this, there are reasons, from the technical and economic points of view, for trying to improve machining accuracy.

Machining errors have a great influence on the accuracy of the joints of machine elements, both at rest and in motion, as well as on a great number of important properties at work on the product as a whole.

2. *Possibility of measurement*

In order to achieve a high machining accuracy, the improvement of machining capacities must advance simultaneously with and even precede the increase of accuracy requirements concerning shape and dimension.

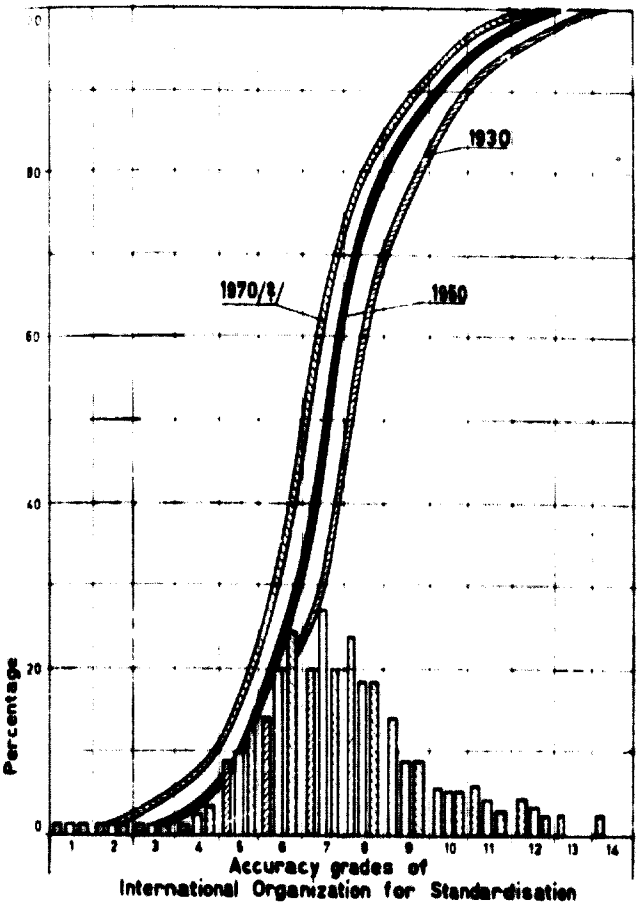


Figure 5

INCREASE OF REQUIREMENTS FOR MACHINING ACCURACY, BASED ON THE EXAMPLE OF ROTATIONAL PIECES OF LOCOMOTIVES IN THE UNITED STATES OF AMERICA

The basic condition in creating the desired machining capacities is to acquire measuring means whose accuracy would be suitably higher than the required machining accuracy. Analysis of the progress of the technical development of measuring means and machining capacities proves that the appearance of new, more accurate measuring means and methods has resulted in an improvement of machining accuracy.

Figure 6 shows, in an objective manner, the relationship between the possibilities of decreasing machining errors and the discovery of new measuring methods in the future.

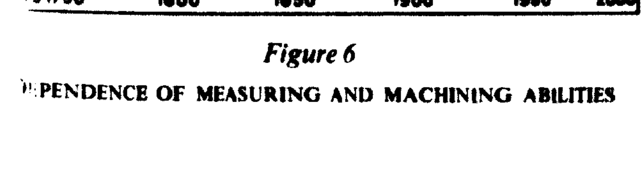


Figure 6

DEPENDENCE OF MEASURING AND MACHINING ABILITIES

In the period from 1750 to 1800, the accessible machining accuracy was characterized by errors ranging from one-tenth of 1 mm to more than 1 mm. This obviously resulted from the primitive machining methods in use, which are illustrated in figure 7.

Figure 7

METALWORKING IN THE EIGHTEENTH CENTURY

At first, however, the errors of machining were caused by the lack of sufficiently accurate measuring means. For example, at that time, the linear measure used in Great Britain was the mean foot, i.e., the arithmetical mean value of the lengths of the 2 feet of twelve persons chosen at random.

The invention of the vernier scale (see fig. 6), after the introduction of the metric scale, followed by the beginning of the manufacture of gauge calipers (about 1850), caused the improvement of the machining accuracy within the limits of 0.1 mm. Further improvements of measuring means and the expanded use of micrometric devices and gauge blocks permitted the improvement of machining accuracy within the limits of 0.01 mm.

Actually, in this period, when there are various optical and electronic devices which permit measurements with errors below 1 micron, measuring devices may be sufficient to control the machining accuracy within the limits of 0.001 mm.

From the analysis of the development rhythm of measuring means and range of accessible machining accuracy, one may conclude that:

(*a*) The development of measuring means has taken place sufficiently rapidly and does not constitute any restraint on the development of machining accuracy;

(*b*) On the basis of historical extrapolation, one may foresee that about the year 2000, the feasible range of industrial machining accuracy will be within the limits of 1 micron.

As a confirmation and guarantee of achievement of this prediction, mechanized and automatic measuring and controlling devices, which prevent subjective errors by the operator, are being used more and more frequently. For example, figure 8 shows an automatic device which meets the requirements of mass production. This device, which was designed and executed at the Institute of Metal Cutting, can select pits which do not fulfil the necessary dimensional conditions within the limits of 10 microns of accuracy.

Figure 5

[illegible] CONTROLLING AND SELECTING DEVICE

[illegible] measuring and controlling automatic [illegible] with a far higher accuracy were known and [illegible] at the bearing works in Moscow or [illegible] controlling automatic devices which [illegible] the balls with an accuracy of ± 1 or [illegible] are being used in industrial conditions.

[illegible] possibilities for measuring and [illegible] are obtained by the application of [illegible] feature of this measuring [illegible] very high accuracy, independent of the [illegible] of the part. All the methods known up to [illegible] characterized by the fact that the absolute [illegible] of the measuring error increased simultaneously with the dimensions of the machined part.

[illegible] of laser as a measuring [illegible] particularly great significance from the [illegible] of the construction of larger machines and [illegible].

[illegible] and surface working

[illegible] of machining allowances and the [illegible] of machining accuracy and quality [illegible] convenient increase of the [illegible] of grinding operations, superfinish, lapping [illegible] of surface working.

[illegible] of the range of application of various [illegible] surface-working processes (for example, [illegible] superfinish by means of abrasive belts, blast lapping, shaving, burnishing, [illegible] and roller burnishing—shows that it would be [illegible] to increase their use from two to eight times.

The reasons for the insufficient use of surface [illegible] processes as finishing methods may be listed in the following order:

(*a*) Lack of machine tools and equipment for [illegible] working;

(*b*) Difficulties in supplying with tools and [illegible] surface working;

(*c*) Designers' frequent limitation of the [illegible] of the upper-layer quality to surface finish only;

(*d*) The scarcity of production engineers and [illegible] who are trained for surface working.

It is apparent, therefore, that management [illegible] machine-tool and the tool industries must [illegible] surface-working equipment must be taken into [illegible] when considering their production plans.

It is important to emphasize that the [illegible] permitting the stabilization of the quality of [illegible] media and tools is the modernization of this [illegible].

In order to improve abrasive quality, [illegible] analyse and study the role of percentages of [illegible] each abrasive powder, as this seems to be the proper [illegible] at which to begin the definition and study of the [illegible] of the abrasive. Investigations must be performed [illegible] taneously on the assortment of abrasive tools, in order to establish their rational working parameters [illegible] functions.

In connexion with this, the following [illegible] suggested:

(*a*) The percentage of machine tools and [illegible] for abrasive and surface working in the whole [illegible] ought to be increased;

(*b*) The abrasive materials and tools industry [illegible] systematically modernized and developed;

(*c*) The abrasive and surface-working processes [illegible] be well known and widely popularized on the [illegible] theoretical considerations and the results of [illegible].

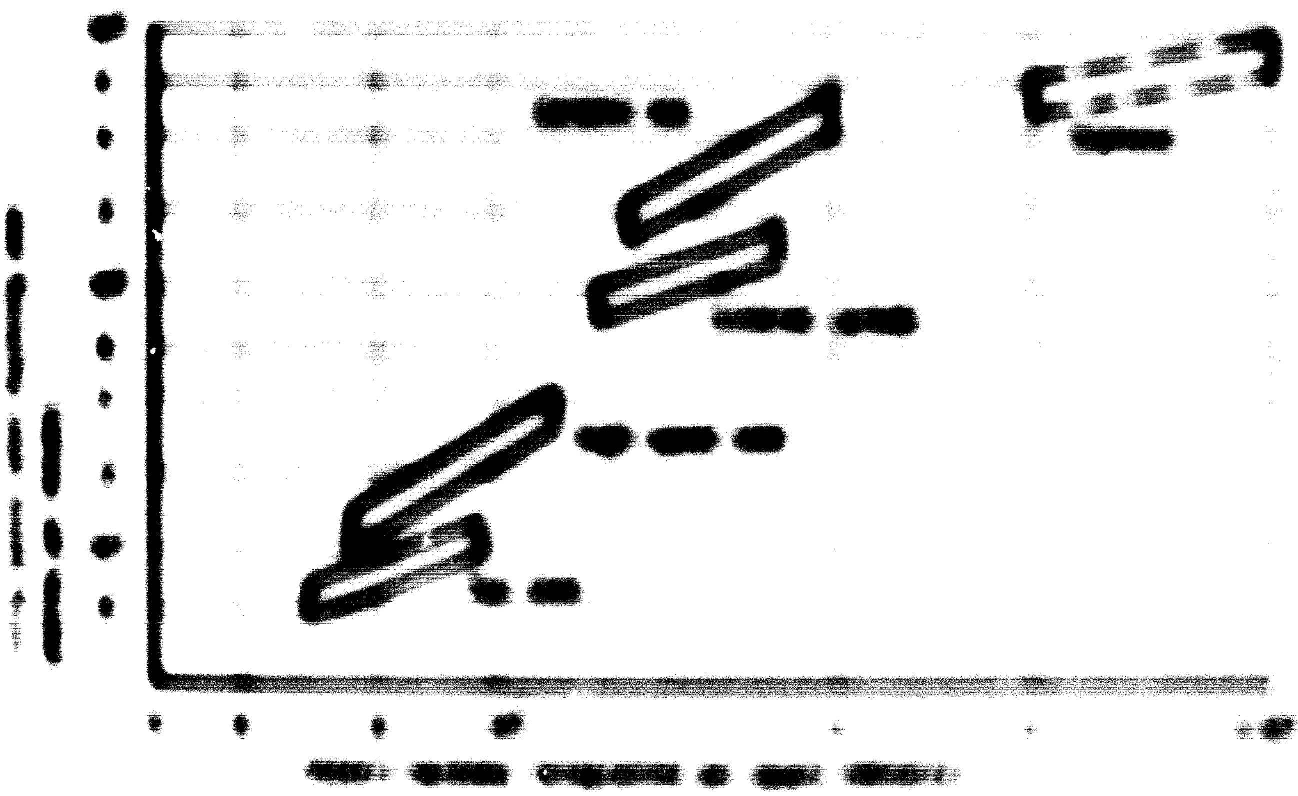
The utilization of self-sharpening grinding wheels [illegible] accurate and very accurate working is an [illegible] experimental and technical problem. Grinding [illegible] ditions of self-sharpening permits a stabilized [illegible] rate, operating independently from time, and [illegible] taneously, a good surface finish.

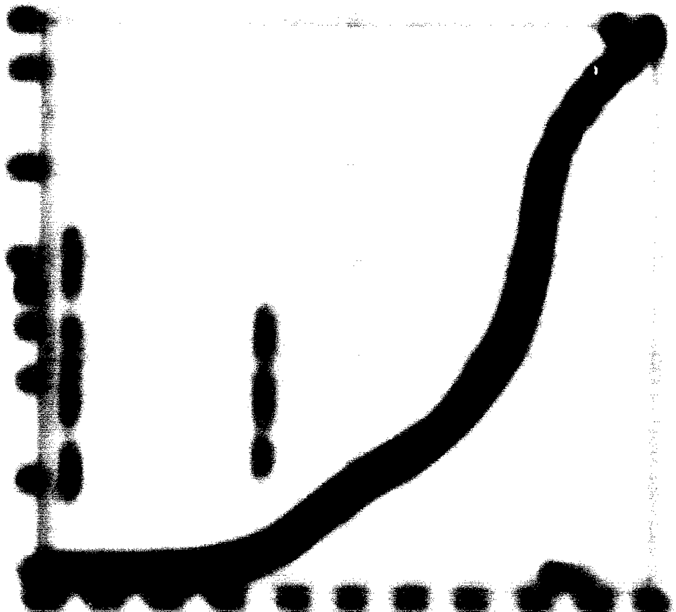
The choice of the proper machining fluids and [illegible] filtration during the process are important [illegible] development of precision working and, particularly, [illegible] abrasive working.

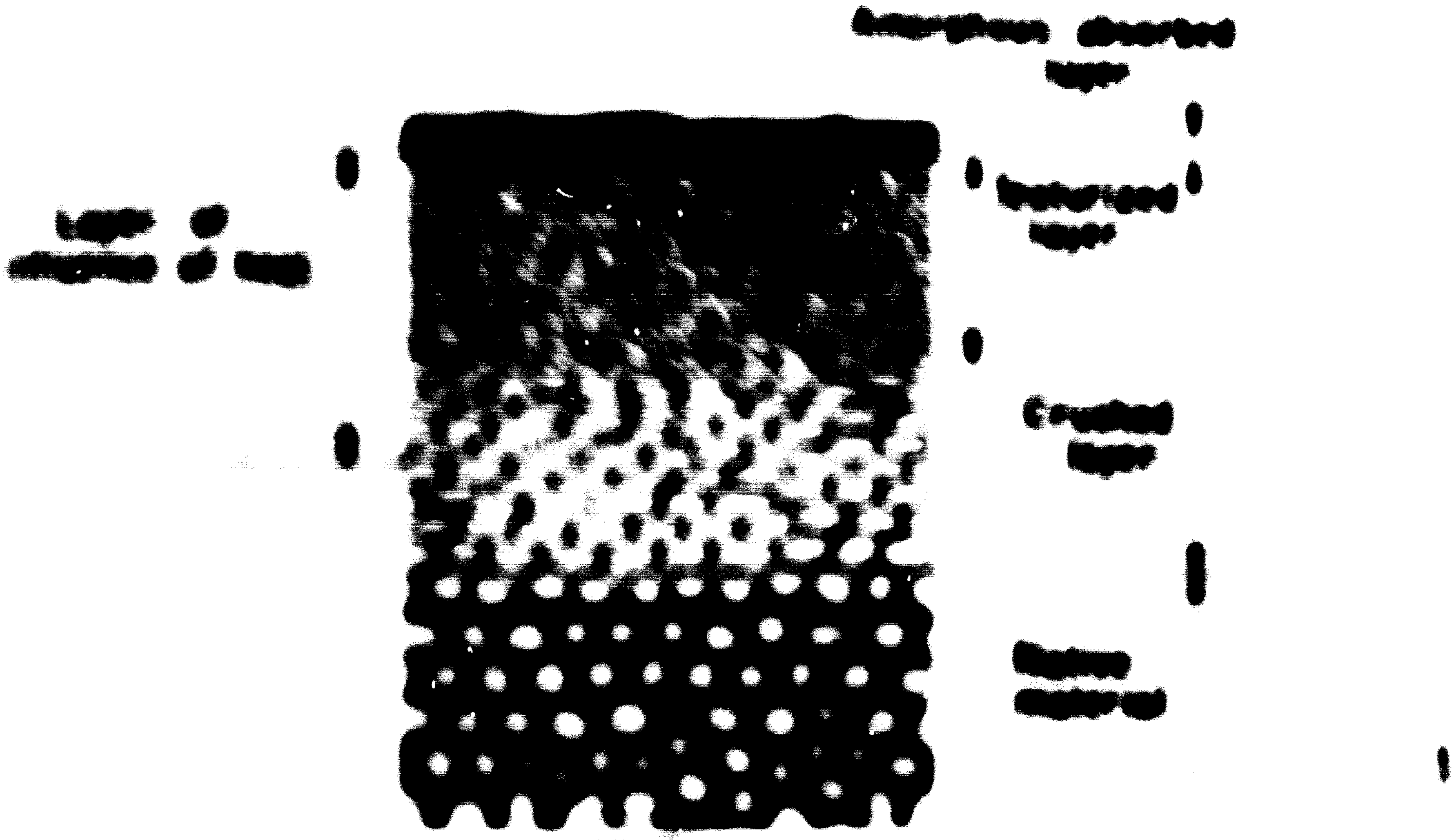
From the investigations conducted, it may be [illegible] filtration permits an improvement of the surface [illegible] one class at least. The improvement of the [illegible] and output of filtration and the durability of [illegible] to reduce the over-all dimensions of filters, [illegible] most urgent task in the near future.

D. *The role of the machine tool-workpiece* [illegible]

Machining performance of high accuracy and [illegible] is dependent upon the machine tool, the [illegible]







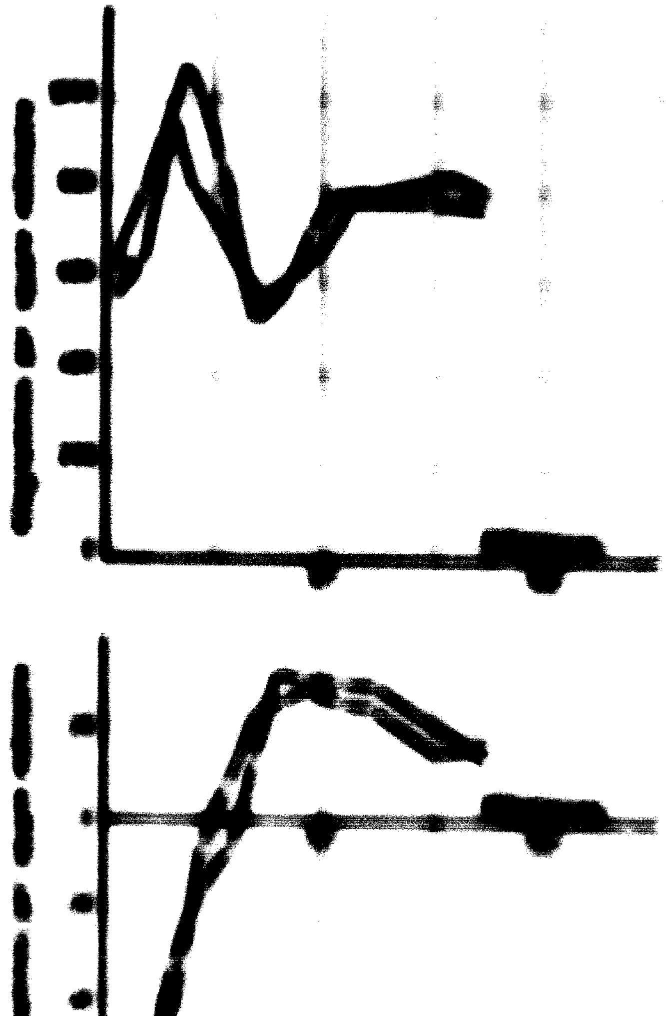


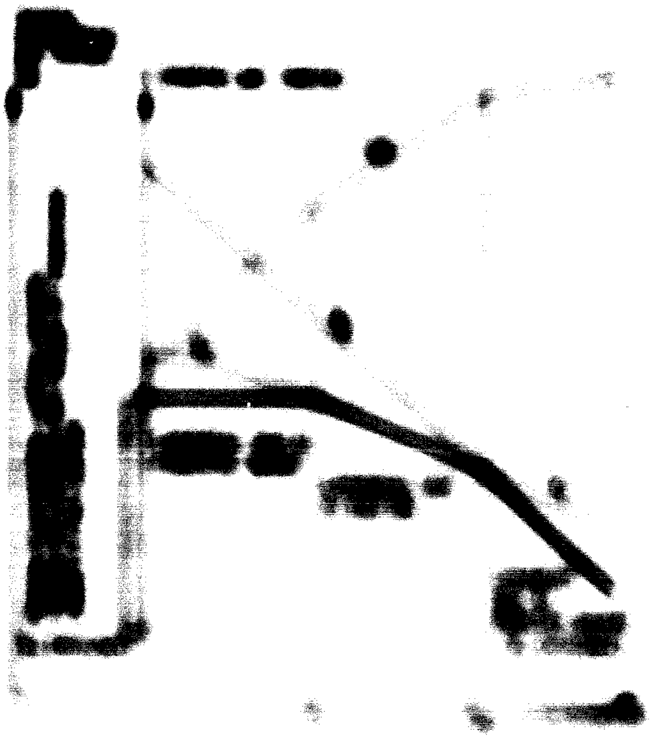
Table [illegible]

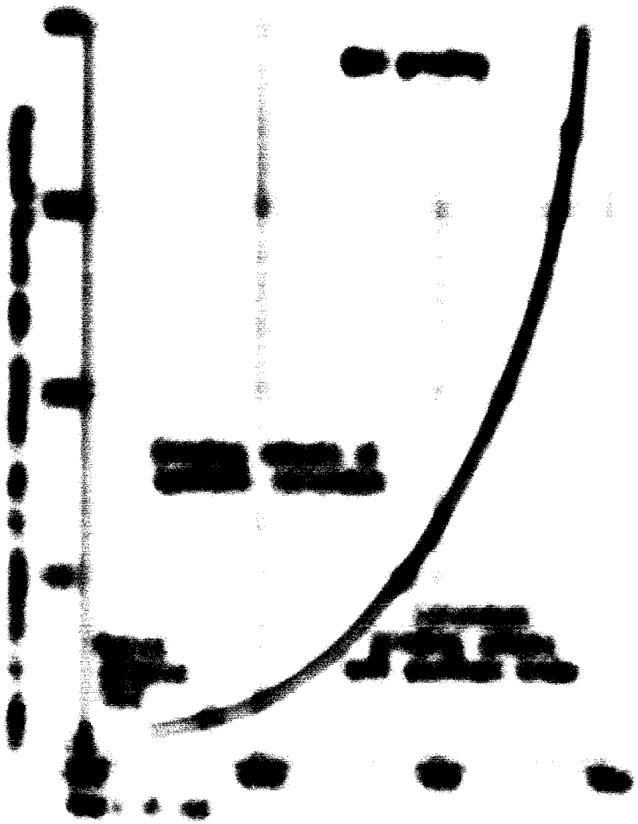
[illegible]

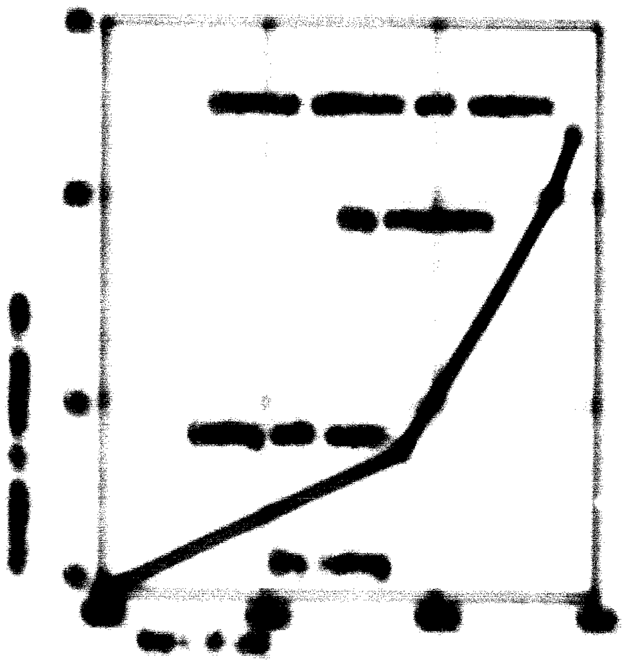
[illegible]

[illegible]

[illegible]







[illegible]

Improvement of the cutting properties is frequently achieved by means of a change of the tool-point shape. As proof of this, one may mention the numerous improvements announced and popularized in technical papers. Almost all of these works are of an entirely empirical character and may have only a very narrow range of use. This is a result of the lack of engineering methods for calculation of the tool-point's strength. Works in this field are just beginning and are progressing very slowly. Investigators and theorists dealing with material strength must work on this urgent question.

However, advances in the field of cutting properties are important, they are insufficient in regard to the needs in machining of new "difficult-to-work" alloys. Therefore, more and more tests are being undertaken with a view to ameliorating the machinability. This may be achieved by one or both of the following methods:

(a) Changes in the chemical constitution or structural composition of the material in such a manner as to avoid reducing the properties at work, simultaneously improving the machinability.

(b) Changes of the state of the material during the cutting process, i.e., the change-over to a state of momentary brittleness or momentary high plasticity, which results in a decrease of the specific cutting work.

The improvement of machinability by change of chemical constitution and momentary or constant change of structure is difficult to do and not many results have been achieved, because such changes are possible only in some peculiar cases. Not without significance in this field is the insufficient attention paid to this question by metal physicists and metallurgists, and the lack of collaboration between them and production engineers.

Much attention is being paid to the machining methods, which aim to produce profitable changes in the state of the machined material. Such changes may be reached through preliminary heating of the workpiece, which leads to a plastic state and reduces the limits of strength; by artificial cooling, which leads the material to a state of increased brittleness; and by a considerable increase of cutting speed and change of the tool geometry. The tool geometry may be changed in the process to make the material pass in the state of increased brittleness, or to have a more advantageous distribution of heat and temperature in the workpiece, chip and tool point, or to produce both effects at once.

The reduction of metal alloys which have been heated to a high temperature, the so-called "hot cutting", has been practised for several decades. From a theoretical point of view this method is based on the phenomenon of decrease of the cutting resistance in heated metal alloys. Thus, an increase of the temperature of carbon steel to about 600°C causes, for instance, a decrease of 40 to 60 per cent of the cutting resistance.

The hot-cutting method is, however, difficult to perform in practice. There are difficulties in operating with a hot workpiece, possibilities of structural changes, adverse influence on the tool life and the machine-tool durability, difficulties in obtaining good accuracy and surface finish, difficulties related to the heating of the workpiece and so on. These difficulties, together with the insufficient knowledge of the hot-cutting process, lead to the opinion that this method may be used in machining conventional metal alloys only in the case of discontinuous fine machining, for instance, in machining hot ingots, hot forging and so on.

The introduction of highly resistant alloy steels, which are very difficult to machine, and the progress in theoretical knowledge of the cutting process lead to the opinion that hot cutting may be in a defined range of a purposeful and economic process.

From investigations, it appears that the basic factor for a successful performance in hot cutting is the temperature of preliminary heating. This is illustrated in figure 16, representing the dependence of the tool-point and machined-material hardness upon the temperature.

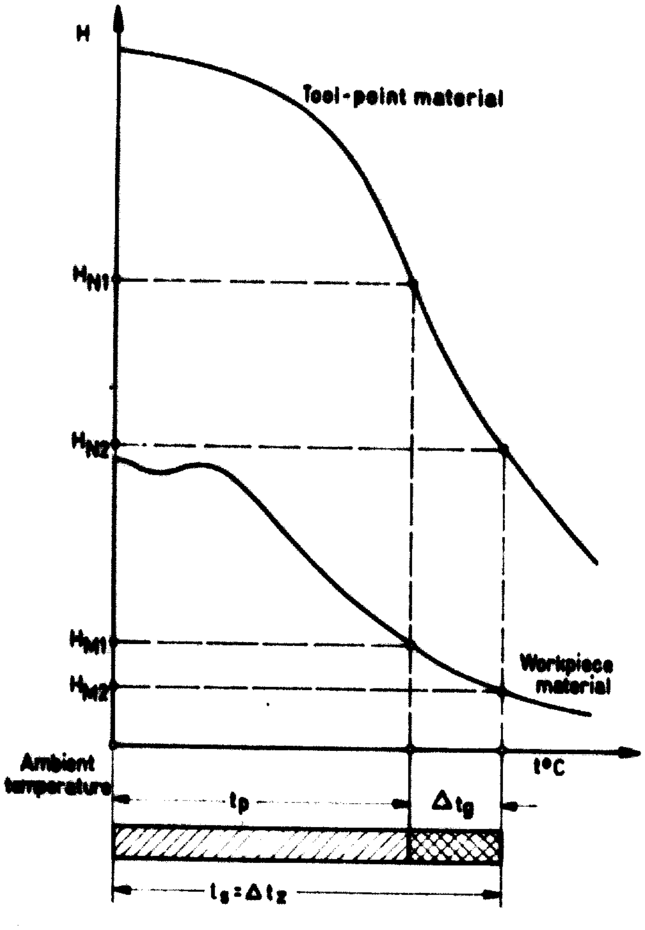


Figure 16

SCHEME OF THE DEPENDENCE OF THE TOOL-POINT MATERIAL AND THE WORKPIECE MATERIAL HARDNESS UPON TEMPERATURE

In the case of normal cutting, the highest temperature on the friction surface, called the cutting temperature, reaches t_s. This temperature results from the transformation of the cutting work into heat.

However, if the workpiece—particularly, the upper layer—is heated to temperature t_p before the beginning of the cutting process, the cutting resistance is much smaller and the cutting work performed by the tool-point is far smaller also. It follows, therefore, that the mechanical load acting on the tool-point will be far smaller, which creates a protection against the possible denting of the tool-edge and a reduction of its abrasion resistance.

The increase of temperature, Δt_g, which is created by the transformation of the cutting work into heat, is generally so small that the sum is $t_p + \Delta t_g < t_s$. This signifies, especially in discontinuous cutting, that the heating of the tool-point is lower in machining a hot workpiece than in cold machining. Therefore, if other difficulties of this method are overcome, it may become profitable.

At the current time, the hot-cutting method is used with good results in the iron and steel industry and in some plants of the aircraft industry when machining materials which are difficult to work.

On a smaller scale, investigations have been made on cutting through freezing of the cutting zone and the tool. Freezing is frequently performed by means of compressed or liquid carbon dioxide. By decreasing the temperature to some tens of degrees under 0°C, the ductility of some "difficult-to-work" and ductile steels, such as austenitic steel, decreases,and the machinability of these steels increases. The handicap of this method is the cost. Nevertheless, it is worth while submitting it to tests with a view to putting it into use in some cases.

The tests undertaken on cutting with very high speeds are interesting. Reports on these tests refer to "gun-fire speeds", i.e., about 30–60 km/min. However, this speed is not considered the final point of possibility; in the near future, a speed of 110 km/min., i.e., about one-third of the sonic velocity in steel, will be achieved.

Efforts to develop high speeds are due to increased efficiency requirements, but the primary need is for machinability of steels which are very difficult to work. This is based on some fundamental principles, resulting from the extrapolation of properties already known for the cutting process in the range being used. It has been ascertained that with the increase of cutting speed there will be a decrease of the specific cutting resistance, which is due to the decrease of the friction and plastic deformation work, and the increase in temperature will be slower in proportion to the increase in cutting speed.

One can foresee that a very important increase in cutting speed—and in the plastic-deformation velocity—must bring about a state of brittleness in the machined layer and produce a decrease of friction work and cutting resistances.

This theory was put forward in 1929 by C. Salomon and was analysed and developed by W. D. Kúzniecow. The most recent tests performed in the United States of America only partially corroborate the expectancies related to very high cutting speeds.

It would be hazardous to advance any practical conclusions from the actual investigations, mainly because the cutting time in these tests is very short. Such cutting speeds are performed by shooting the workpiece in a barrel. At the muzzle, the workpiece meets the cutting tool. There is a need for designing equipment to permit a longer cutting time, even with smaller than "shooting" cutting speeds, but allowing some comparisons and evaluation of its possible practical use.

2. Other development trends in chip removal and abrasion machining

The development of many branches in heavy industry—the power industry, iron and steel industry, chemical industry—requires machines and equipment of very large dimensions. These industries are presenting the greatest indexes of increase. For this reason, the need for machine tools designed for machining large pieces is important. There is not only a need to develop the production basis of heavy machine tools, but also a need to overcome many technological difficulties related to the dimensions and accuracy of the workpiece Research and technical works related to the fine machining of heavy, huge workpieces will be one of the most important areas of study for the expansion and improvement of chip-removing machining processes.

In the field of abrasion machining, an important improvement of machining possibilities is in the development of curvilinear-surface grinding by means of abrasive belts and liquid honing.

The abrasive-blast treatment is especially suitable for honing and, particularly, for the cleaning of free surfaces or curvilinear or nearly inaccessible surfaces, for grinding surfaces to be covered by electroplating or lacquer and so on. The applications of the abrasive-blast treatment are numerous, but the limits and rate of increase of their use depend upon the degree of production of cheap, efficient equipment.

An important improvement in the machining of exceptionally hard and brittle materials, such as semi-conductors, by means of loose abrasive grains, has been achieved by utilization of the tool energy due to its longitudinal vibrations at a supersonic frequency of about 16–18 kHz. This abrasive and erosive means, called ultrasonic machining, only appeared during the last few decades. Nevertheless, in many countries, the first abrasive and erosive machine tools, although not exactly known as "ultrasonic", have already been designed.

All of these abrasive machining methods are already at an initial state of popularization. They promise to become useful improvements and extensions of the classical abrasive means, and investigations in this field must be considered most urgent.

(Improvement of machining possibilities by means of other removal methods

Mechanical energy is not the only form of energy which may be used in removal shaping of pieces. Twenty years ago, development of the erosion treatment of metal alloys commenced by means of electrical and chemical energy. More recently, investigations and tests have been undertaken for the purpose of putting into practical use various other forms of energy, namely:

(a) Ionic machining, called plasma machining, by means of energy provided by a plasma stream, the machining process taking place by fusion and partial vaporization;

(b) Electron machining, by means of energy provided by a stream of electrons (in vacuum);

(c) Photonic machining, by means of energy provided by a strongly condensed stream of photons. This method is called laser machining.

The above-mentioned methods are currently in the research stage and will not play an important role in the production of machine elements in the immediate future. Rather, they will constitute an improvement of the cutting method.

Among the different methods of electrical erosion, the most popular at the current time are the electro-erosion and electro-impulse methods. In spite of their specific features, both of the above-mentioned methods may be compared to a chip-forming method of a discontinuous character. The removal rates of these processes depend upon the energy of each discharge and upon the frequency of these discharges. They are analogous to the removal rate in milling, which depends upon the volume of the removed layer by one tool-point and upon the frequency with which the tool-points dive into the material. The greater the energy of each discharge and the smaller the frequency, the worse is the surface finish. This phenomenon may be compared to the influence of the feed and of the dimensions of the removed layer. The tool wear in electrical machining, as in chip-forming machining, plays an important role. The dependence of accuracy and surface finish upon the removal rate is analogous also.

The most important difference between electro-erosion machining and chip-forming machining consists in the technological indexes; in the first place, the removal-rate indexes of the former are dependent upon the machined-material properties only to a low degree. The specific removal rate in the electro-erosion machining of "easy-to-work" metal alloys is far smaller than the cutting removal rate.

This situation is reversed for "difficult-to-work" cutting materials. Therefore, electro-erosion is currently (and in the near future, will be) most suited for machining materials which would be difficult to work or which would be unmachinable by the cutting method.

The application of electrochemical erosion in machining processes is very encouraging. Compared with electro-erosion machining, the advantages of this method are:

(*a*) It is an almost "cold" process, ensuring eventual changes in the upper layer;

(*b*) The tool is practically unwearable;

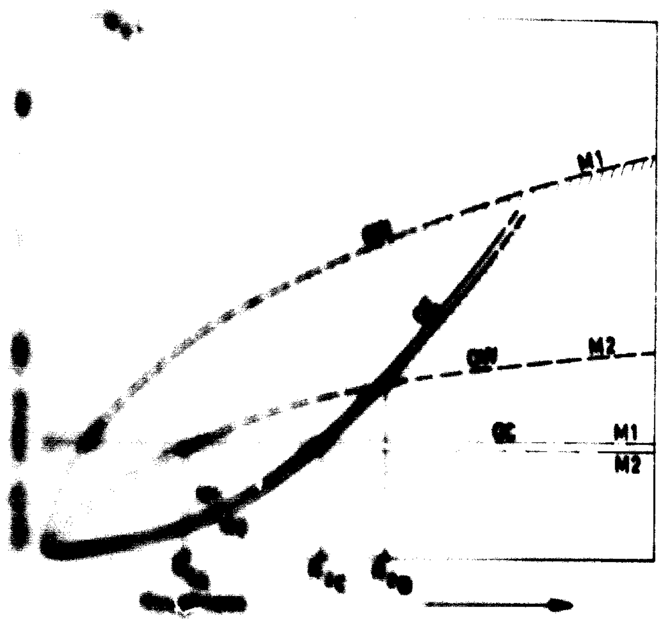
(*c*) The surface finish is dependent upon the removal rate.

The specific removal rate in electrochemical erosion has an upper limitation, but, theoretically, the possibilities of increase of its surface-removal rate are unlimited. Electrochemical erosion is, therefore, particularly suitable for machining large areas.

In figure 17, one may see the curves for the chip-forming removal rate (OW), the electro-erosion removal rate (OE) and the electrochemical removal rate (OC) for two materials, M1 and M2. M2 is very difficult to work in comparison with M1, as regards the surface roughness.

In the case of an "easy-to-work" material and surface finish ($R_z < R_{zl}$), the electrochemical method gives a [illegible] This method may, therefore, replace [illegible] means. On the other hand, [illegible] the chip-forming machining [illegible] higher [illegible] removal rate. The value of the [illegible] in this case, about 20–30 mm³/ [illegible]

[illegible] machinability of the M2 [illegible] the cutting removal rate either rapidly decreases, [illegible] the material is not machinable



[illegible] removal rate; OC [illegible]

Figure 17

[illegible] REMOVAL PRO- [illegible] NEEDED FOR THE [illegible]

[illegible] given in figure 17, within [illegible] R_z < R_{zA}, the more [illegible] machining; and [illegible] the most profitable [illegible] Above $R_z > R_{zB}$, the [illegible] machining. In [illegible] by cutting, the [illegible] the application of electro- [illegible] machining would [illegible]

[illegible] figure 17, it may be [illegible] occur in the relationship between the removal rate and [illegible] two methods mentioned may be [illegible] the different limits of their use.

None of these methods competes [illegible] whole range of its use. Further [illegible] machining must depend upon collateral [illegible] chip-forming and abrasive machining, [illegible] electro-erosion and electrochemical [illegible] with methods using other sources of [illegible]

The history of the development of [illegible] shows that it has progressed over the years. [illegible] of progress be maintained? It is [illegible] qualitative predictions, but it may [illegible] more investigations are developed, [illegible] important catalytic influence on [illegible]

The final result of development in the [illegible] machining depends—as in other [illegible] gress—upon the organization of work [illegible] of investigation results in production. [illegible] bond of science and practice", [illegible] does not only create needs for [illegible] leads to progress in economic [illegible] tivity, as a result of new inventions [illegible] cal and research work.

Finally, one must remark that [illegible] result from the activities of the [illegible] depend, to a certain degree, upon the [illegible] economy of industry and production. [illegible] tions of improvements in the economy, [illegible] direction of industry constitute an [illegible] production development.

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Table 1

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[illegible]	[illegible]

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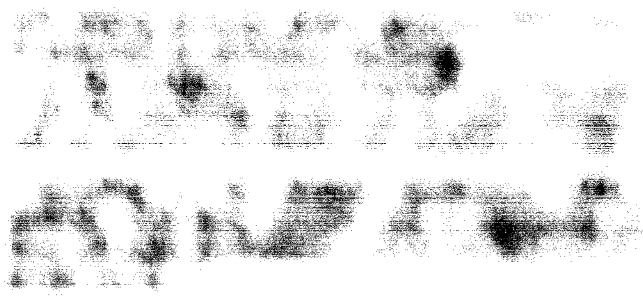

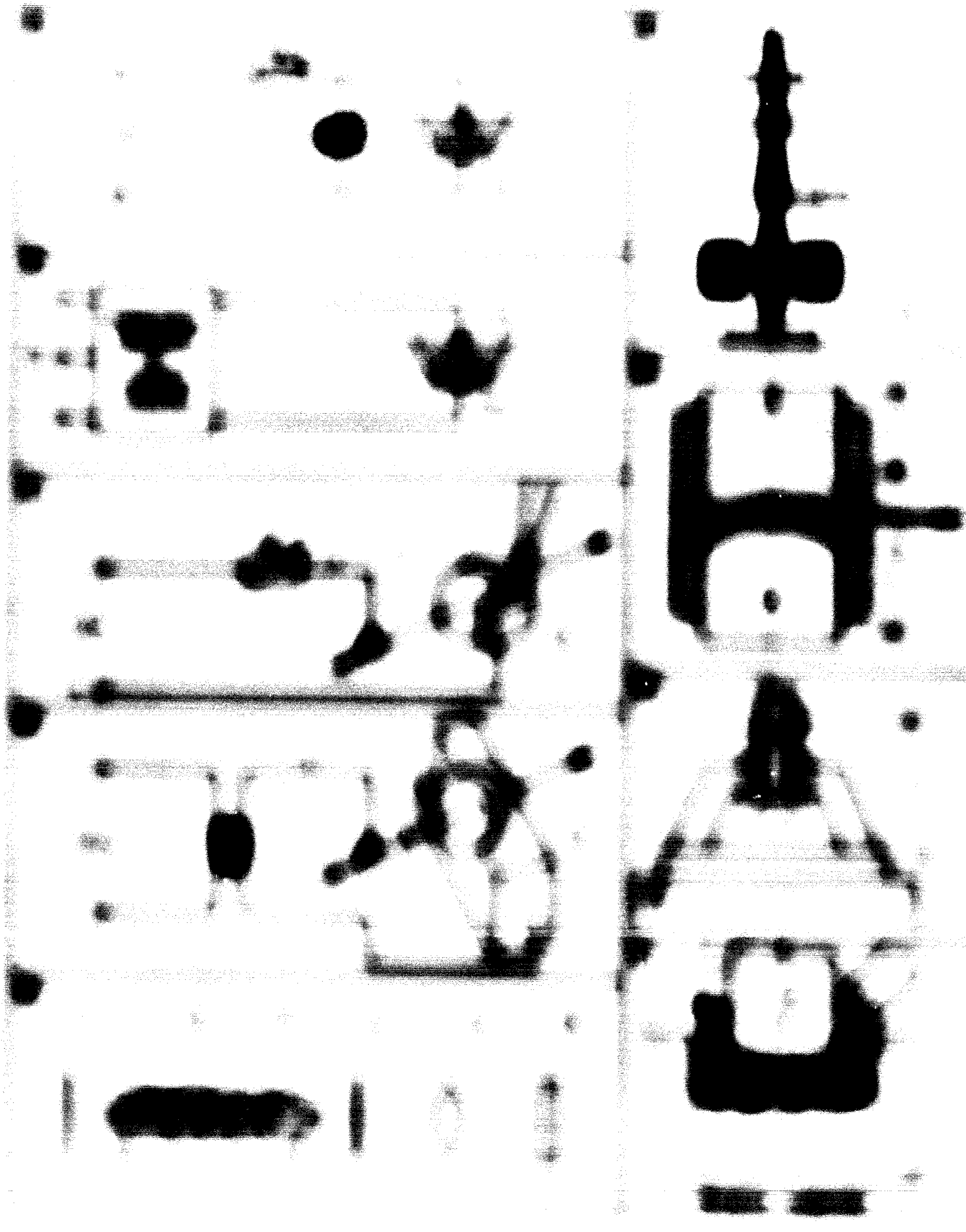

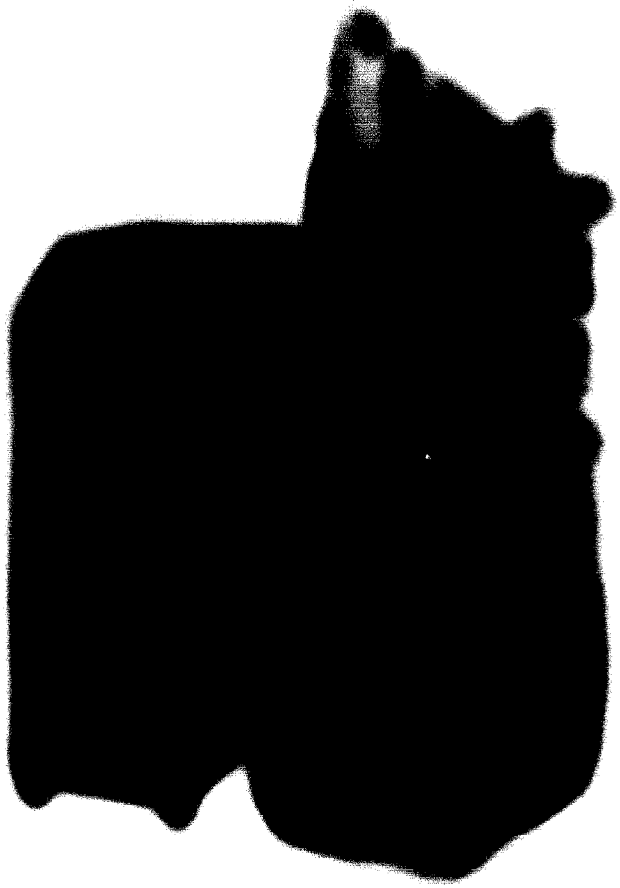

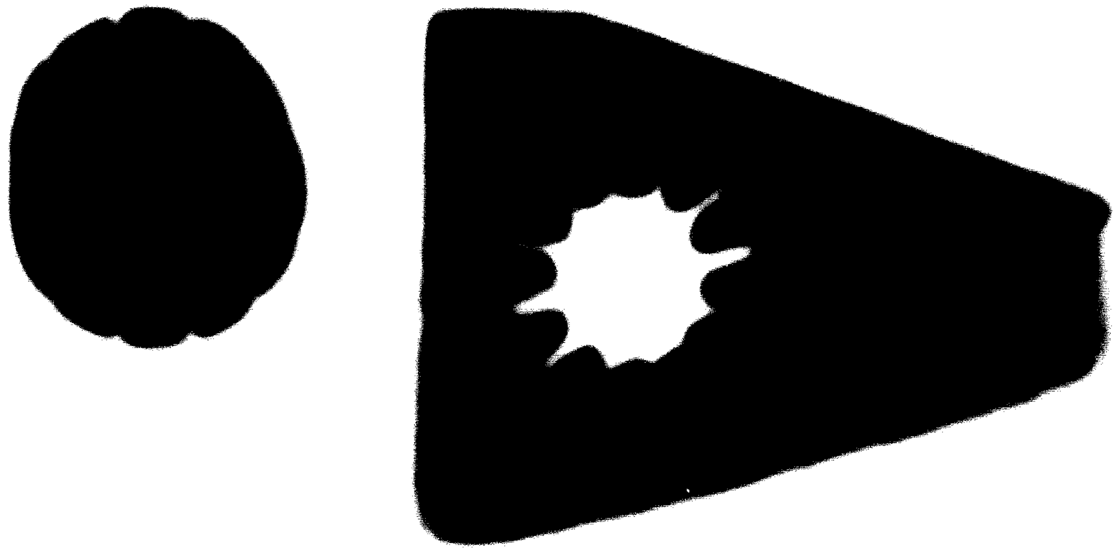

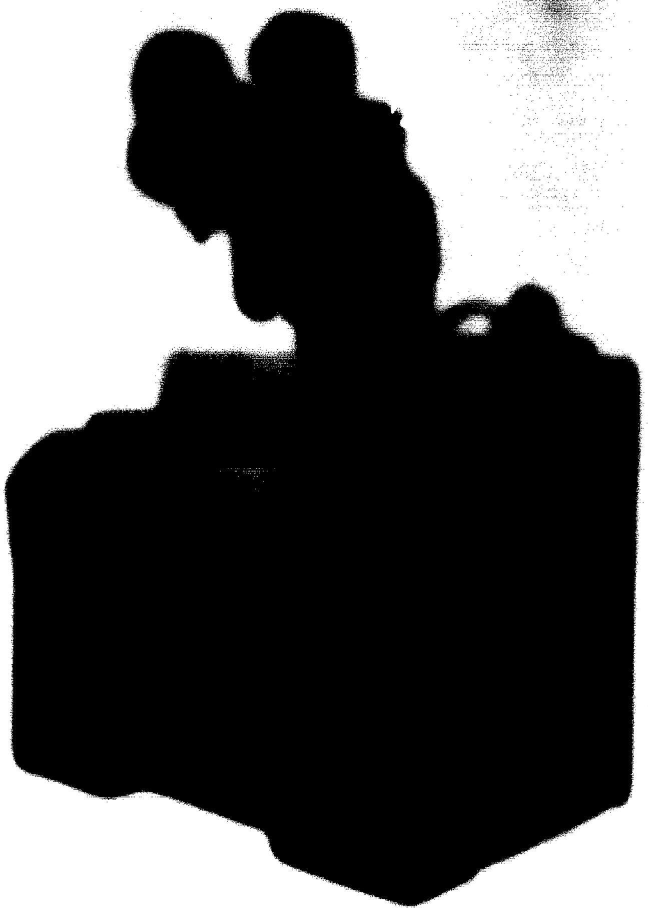

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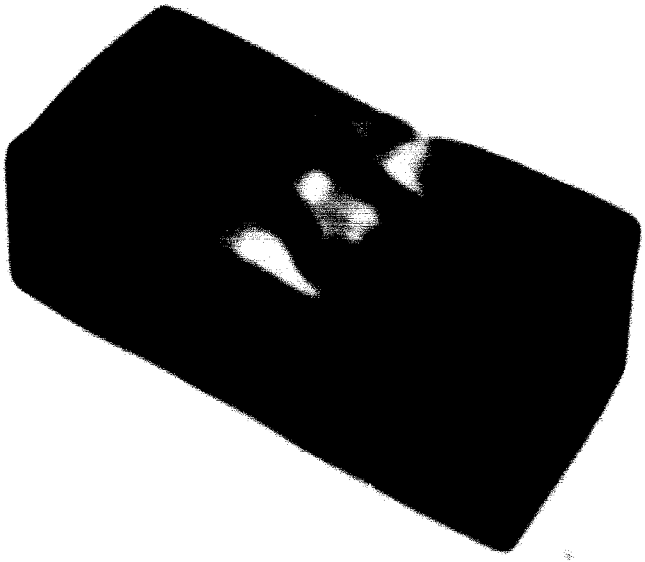

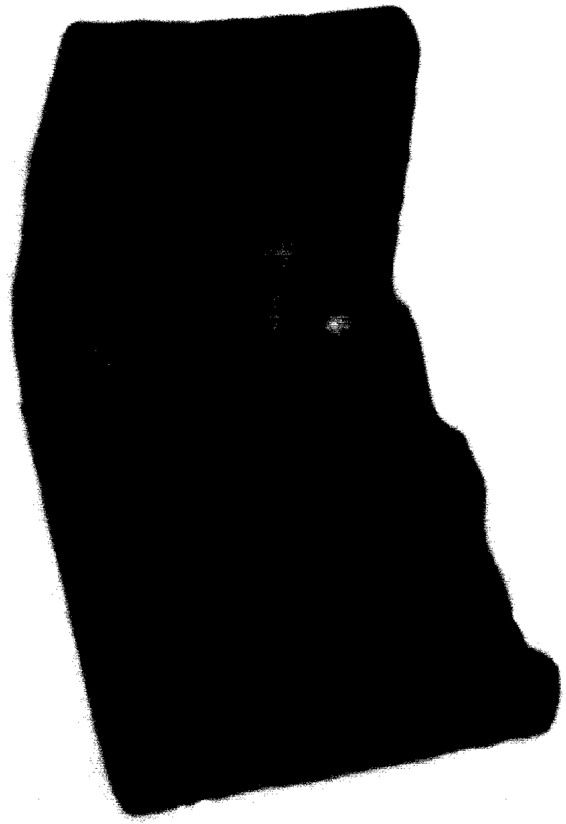

(b) Section of press-tool protector

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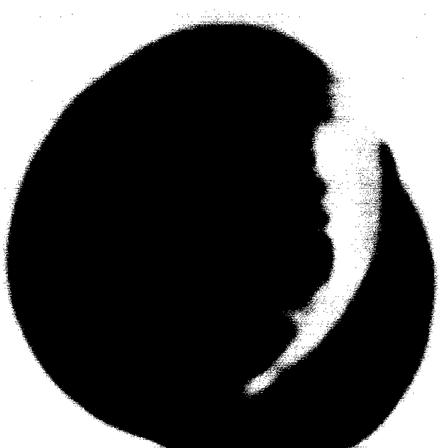

(d) Gas turbine runner

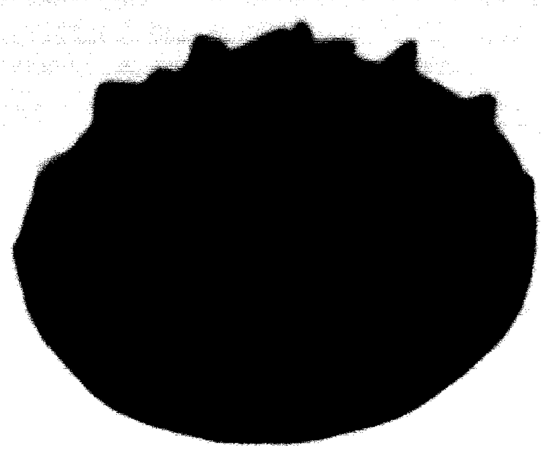

Figure [illegible]

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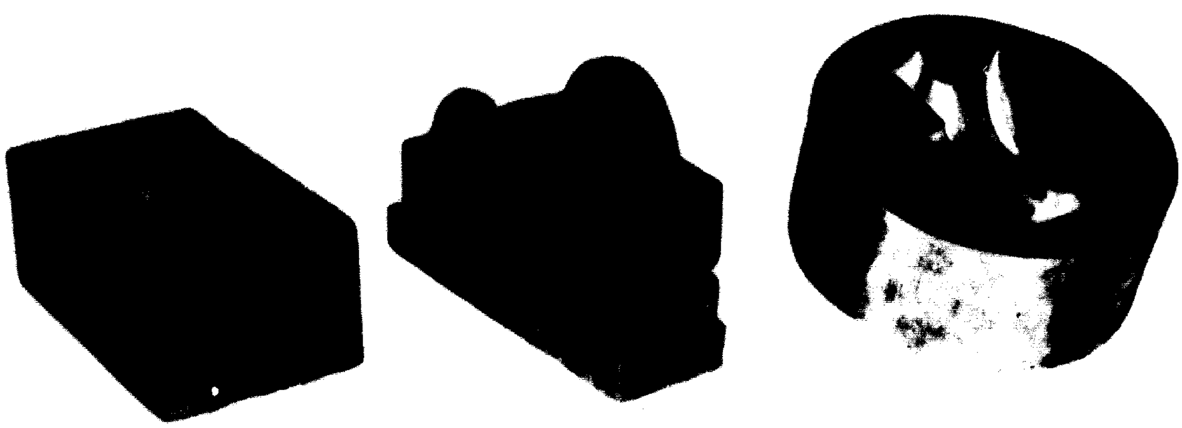


(a) (b) (c)

Note: The first electrode is made of graphitized material on the electro-impulse machine by fitting, in 6 hours; it is then used for machining the metal cutter (a), which is done in 3.5 hours. The cutter (a) serves for reproducing the replica (b) of the first electrode on the vortex machine in 15 minutes. The stamped valve (c) is machined on the electro-impulse machine in 3.5 hours instead of 8 hours when machining on the miller with subsequent fitting.

Figure 7

SUCCESSIVE STAGES IN MAKING TOOL ELECTRODE (VALVE) BY VORTEX METHOD

This method is preferred for severing blank pieces of special-grade steels which may be up to 750 mm in diameter (see fig. 3) and for the internal and external grinding of sintered carbide bushings and draw plates.

4. *Electro-contact machining*

Electro-contact machining (electric-arc process) is another branch of the electro-erosion method. It is performed in the air by using rotary discs. Formed between the disc and the workpiece is a powerful alternating-current arc (25,000 ampere up to 40 volts). A step-down transformer with power ranging from dozens to hundreds of kW (shown in fig. 2d) is used as a source of energy.

The maximum rate of metal removal achieved by electro-arc milling amounts to 0.5 ton of metal per hour. This method can be successfully used for roughing special-grade steel ingots before rolling them, machining such shaped surfaces as those of hydro-turbine blades, slicing metal etc.

B. *Beam machining methods*

The second group of methods which is used for machining both conducting and non-conducting materials comprises beam machining methods, i.e., those based on the removal of metal by attacking it with concentrated beams of high-density energy. In a manner which is similar to electro-erosion machining, the metal removal is accomplished by converting this energy to heat directly within the zone of machining. The beam methods include machining by light, electronic or ion beams.

1. *Light-beam machining*

The coherent light beam, which is generated by a monochromatic optical quantum generator (laser), is

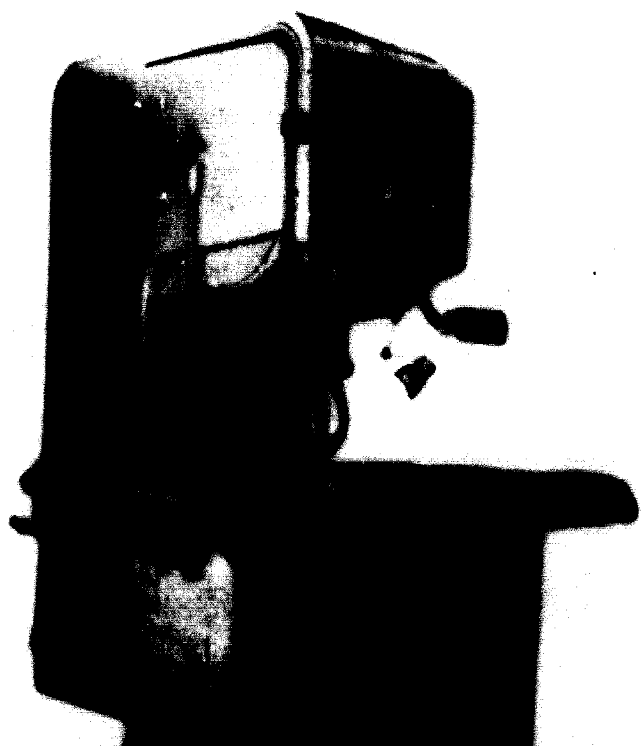


Figure 8

BAND-ANODO MECHANICAL CUTTING-OFF MACHINE, Mo 41 4A822 d[illegible]ted through the optical system of the workpiece being machined (see fig. 2e). The beam is focused to have a diameter of a few microns, with a high temperature ([illegible]00 degrees) arising in its working zone. The method is good for making small-diameter holes in any material to produce diamond draw plates, fine screens, draw plates for producing man-made fibres and for other similar purposes. The machining is carried out in the air. The efficiency of the method is from 30 to 60 holes (from 0.03 to 0.5 mm in diameter) per minute with depth ranging from a few tenth fractions up to a few whole millimetres with a power source of a few dozen kW.

2. *Electron-beam machining*

In electron-beam machining, the cathode-radiated electrons (in deep vacuum) are accelerated in a powerful electric field and are focused to become a narrow pencil-beam directed to the workpiece anode. During this process, the kinetic energy of electrons is converted to thermal energy, thus allowing the piercing of small holes and the making of slots which are a few dozen microns in size. The method is applicable for machining precision components employed in radio and electronic instruments etc.

3. *Ion-beam machining*

Ion-beam machining makes use of cathode spraying, which takes place as the gas is being discharged. The electrons initiated by the cathode ionize the gas molecules. The ions accelerated by a strong electric field are focused in a narrow place whose apex is on the workpiece. Such a method is possible to pierce holes which are 5 microns in diameter, and over, in thin sheets.

With regard to the kinematics of the forming process, the beam machining can be compared to machining by means of a thin liquid jet of extremely high pressure, which is also capable of piercing holes and cutting sheets.

C. *Ultrasonic method*

The third group comprises a method of impulse percussion mechanical effect applied to material. This method is known as ultrasonic because the frequency of impacts produced corresponds to the range of inaudible sounds. The method is successfully used in machining hard and brittle materials whose particles can be removed by impacts. Strictly speaking, the ultrasonic method cannot be considered one of the EPECh methods: rather, it belongs to one of the kinds of mechanical machining wherein chips are removed as mechanical energy is brought to the workpiece, and it also does the work of [illegible]ving metal. The type of energy agent mechanical [illegible]on governs the impulse process of a brittle [illegible]ture. This method is referred to as one of the [illegible]ophysical methods only arbitrarily, the reason for [illegible] classification being that it is based on high-frequency [illegible]anical oscillations which are electromagnetic in [illegible]. The ultrasonic-frequency electrical oscillations [illegible]00 25,000 cycles) are converted in a special electro[illegible]anical magneto-strictive transducer consisting of a [illegible] nickel or Permendur (iron-cobalt alloy) plates capable of changing their linear dimensions into mechanical in an alternating magnetic field. The tool tip receives oscillations through a system of acoustic concentrators. The machining zone under the tool tip is supplied with slurry of small abrasive grains suspended in water (see fig. 2i). The tool oscillating under the ultrasonic frequency strikes against the abrasive grains which [illegible] the particles of material, thus reproducing the shape of the tool on the blank. The power source is represented by an electronic oscillator with power ranging from hundreds of watts to a few kilowatts (see fig. 9).

The method is useful for machining hard and brittle materials, including those which are non-conducting, e.g., ceramics, quartz, rubine, diamond, glass, porcelain, germanium and silicon, as well as sintered carbide.

The technological output characteristics of the method are as follows: the maximum rate of metal removal for work on glass is 9,000 mm^3 per minute, for work on sintered carbide, 200 mm^3 per minute; the [illegible] surface is up to class 10. Relative wear of the tool for work on sintered carbide is 40 60 per cent. The [illegible] rate and surface finish under a particular [illegible] are the highest, as compared with all the other methods.

The method is preferred in making punch and embossing dies of sintered carbides, cutting [illegible] of germanium and silicon, machining diamond and sintered carbide draw plates, rubine bearings, etc. (see fig. 10).

D. *Electrochemical methods*

The fourth group covers electrochemical methods used for dimensional machining. Such methods [illegible] anodic solution, the essence of which is that when current passes through electrolyte the electrode connected to the positive pole (anode), dissolves (see fig. 5). During the process the blank metal is transformed [illegible] and is taken away from the machining zone by the flowing electrolyte. The material mainly used as electrolyte is an aqueous solution of sodium chloride pumped through a very small (0.10 0.5 mm) interelectrode gap. The process results in the tool shape being reproduced on the workpiece, as the workpiece sections nearer to the tool [illegible] dissolve more rapidly. When an [illegible] tool [illegible] electrode is used, smooth surfaces which are [illegible] 0.2 0.9 mm are reproduced. The method is especially advantageous when used for machining such [illegible] as those of blades, since [illegible] the [illegible] electrolyte flow are the best and [illegible].

The electrochemical process can also be used in conjunction with grinding by [illegible] conducting bond (electro-[illegible] machining) depending upon the [illegible] trode rotary disc. With the method the [illegible] solution facilitates the metal removal [illegible] efficiency by one and one half [illegible] diamonds.

The electrochemical method [illegible] ining turbine blade type [illegible] chemical grinding and sharpening [illegible] and other machine components, etc.

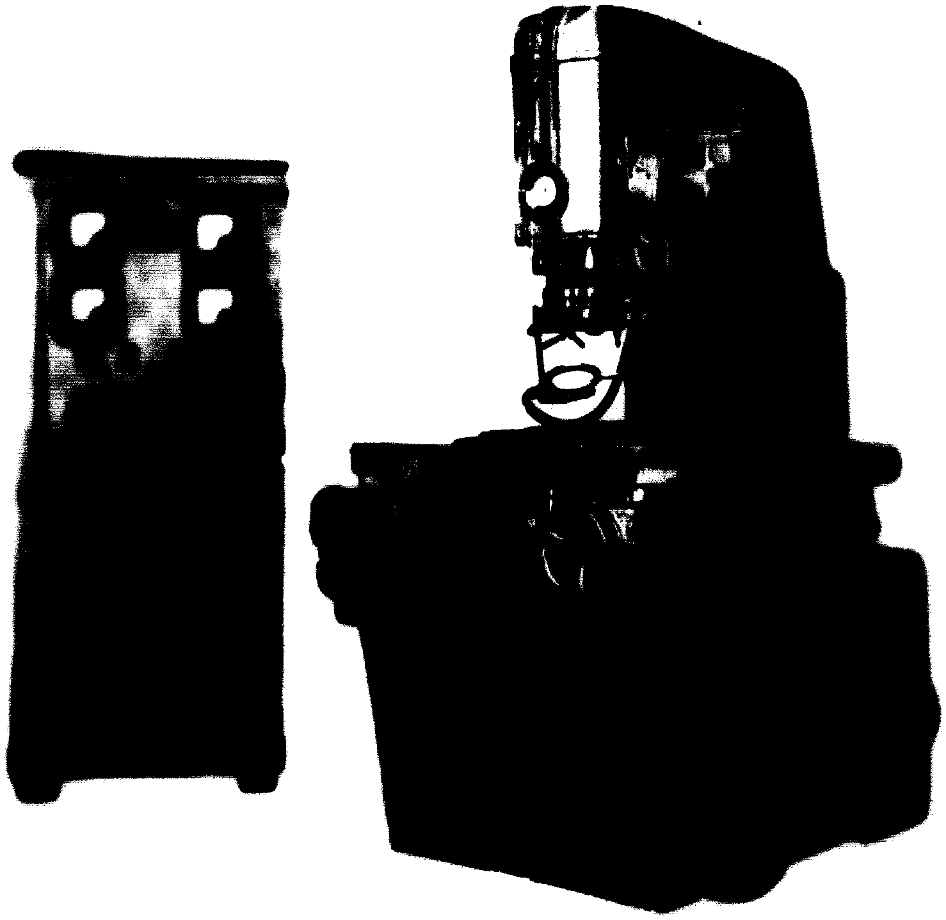


Figure 9

UNIVERSAL ULTRASONIC MACHINE, MODEL 4773A

[illegible] feature of the process is the high [illegible] is attained with good efficiency [illegible] while consuming as [illegible] per kg.

[illegible] group are the chemical machining [illegible] current and known as [illegible] metal being removed by dissolving [illegible] alkalis. The rate of [illegible] aluminum amounts to 0.5–1 [illegible]

The [illegible] above are physical [illegible] fourth is an electrochemical [illegible]

[illegible] third and fourth groups allow [illegible] on all the three co- [illegible] second group permit [illegible]

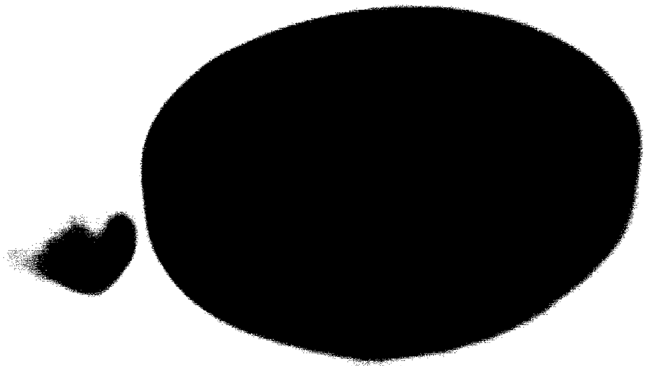
[illegible] AND ELECTRO- [illegible]

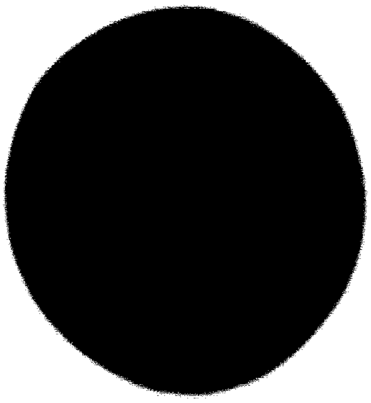
[illegible] have found the widest appli- [illegible] machine tools are [illegible] operations, while one- [illegible] This ratio, however, does [illegible] and the actual compara- [illegible] This is especially true with respect to [illegible] has not been developed [illegible] that it is not yet [illegible] the technological powers [illegible] methods and takes into [illegible] large-scale production of the [illegible] may assume that in the [illegible] electrochemical machines [illegible] that of electro-erosion [illegible] and that of ultrasonic [illegible] number of electrophysical and [illegible]

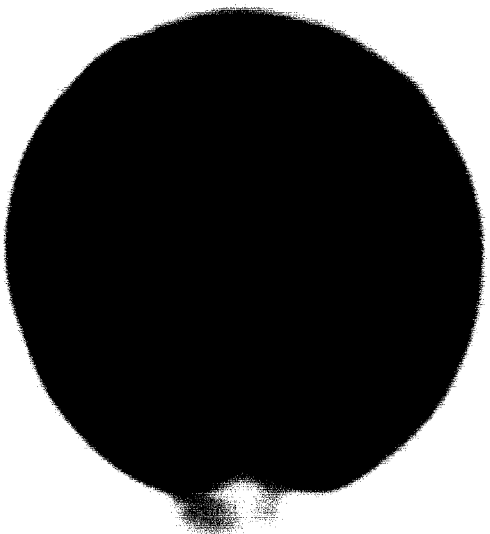
The foregoing ratio has been, of course, [illegible] out including new machining [illegible] which are not yet known and [illegible] mit the extension of the [illegible] methods.

Compared with the over-all [illegible] ting machines, the proportion of [illegible] electrochemical machines [illegible] hundredths to tenths of 1 per cent [illegible] country. This branch of the [illegible] developing very rapidly, however [illegible] an increase in the above-mentioned figures [illegible] orders.

Nevertheless, these facts do not [illegible] role of machining methods in modern [illegible]







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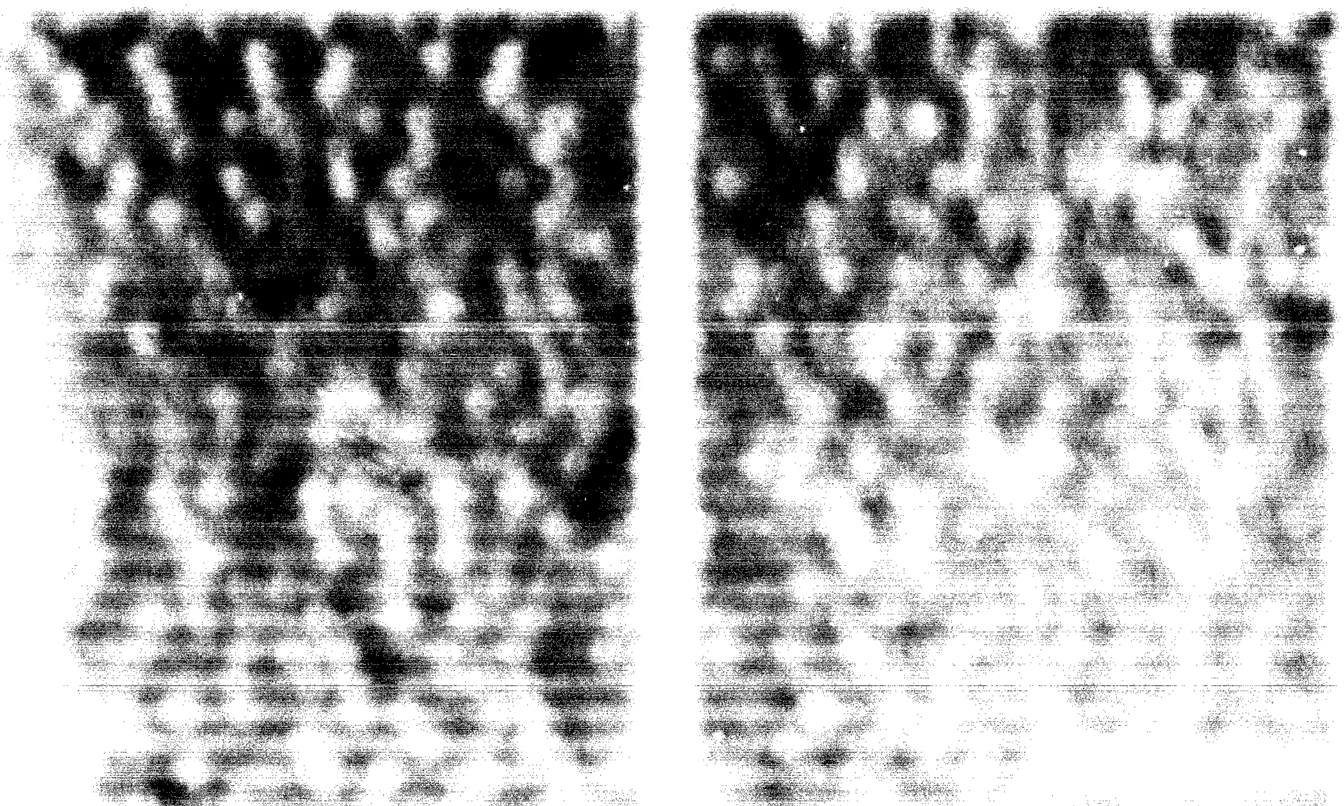

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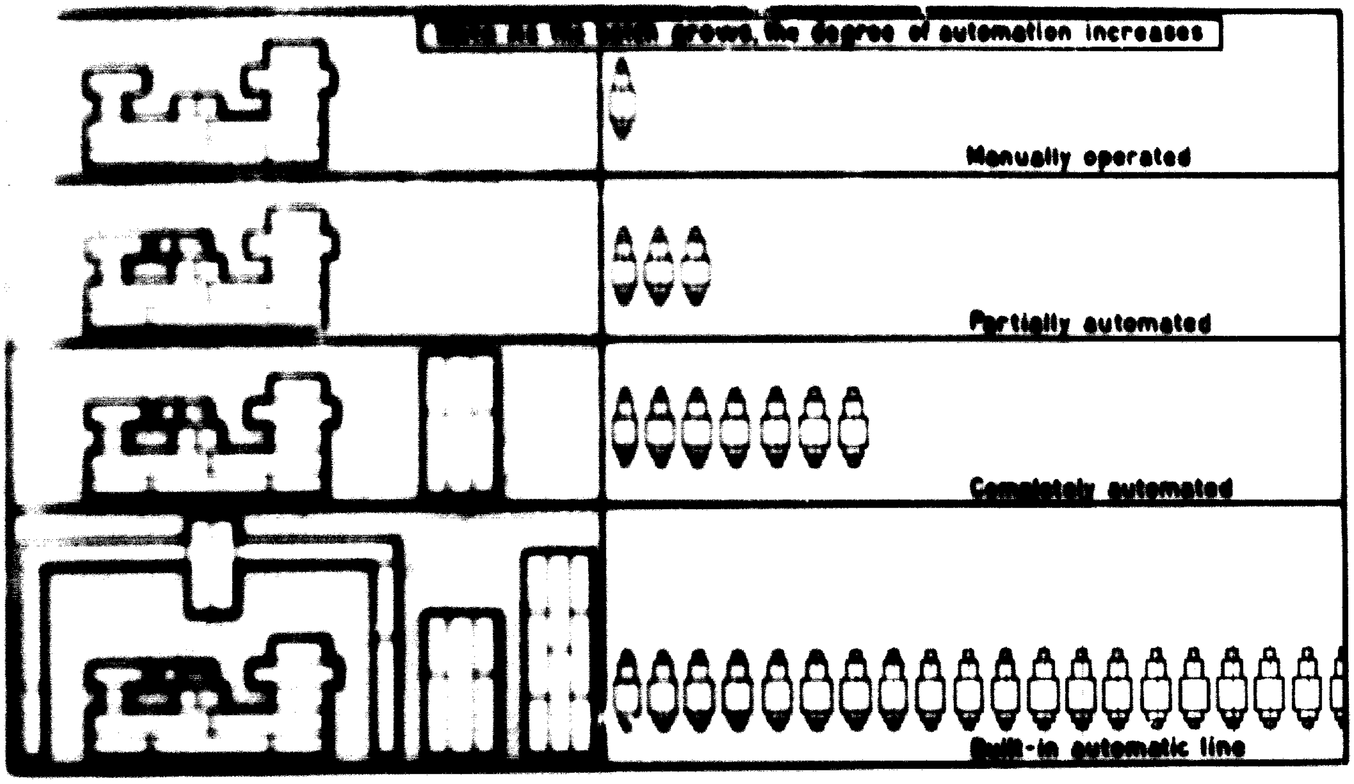


Figure 2

[illegible] FROM CHILDREN'S DESIGNING SET

[illegible]

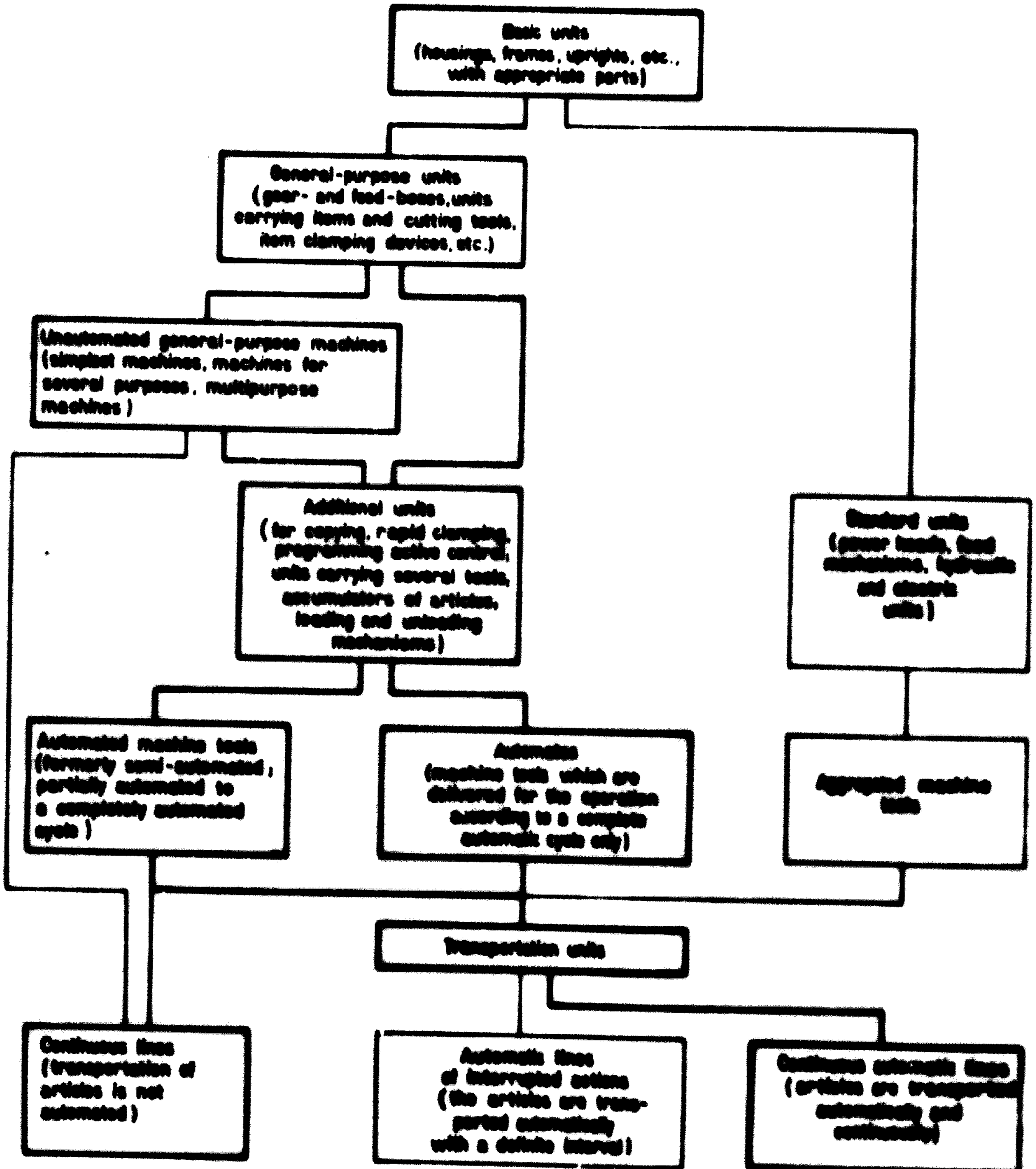
[illegible]

[illegible]

a planer type of milling machine. The individual groups of units may be clearly seen in this figure.

The designing row of multiple-spindle automatic turning lathes shown in figure 5 is a typical example of the manifold application of identical units in machine tools of the same dimensional type, but of different design. Here, the basic units of four dimensional types (100, 63, 40 and 25) are used to assemble sixteen machine tools of various design. The lathe bed, the driving mechanism and the spindle drum remain unchanged for one dimensional type. The headstock and the carriage, as well as the feeding mechanism, are the same for articles of equal diameter. Thus, for example, if the basic dimensional type is 40, the four-spindle chuck automatic turning lathe, type 4/160, makes use of 861 parts of the four-spindle bar automatic turning lathe, type 4/40. The unified parts constitute approximately 70 per cent of the total since the chuck automatic consists of about 1,200 parts. Furthermore, all the parts securing the items and the tools, as well as the parts of the feeding mechanism, are the same in the four-spindle machine tool of basic dimensional type 40 and the eight-spindle machine tool of basic dimensional type 100 (the through-diameter of the item on both of them is 40 mm). In the eight-spindle machine tool this is equal to 8 × 65 = 520 parts out of 1,300. It is clear that such unification of construction decreases the designing expenses. The savings obtained through the designing row illustrated in figure 6 amount to almost 2.5 million Deutsche Marks (DM). In the case of serial production, the economic effectiveness exceeds this figure many times.

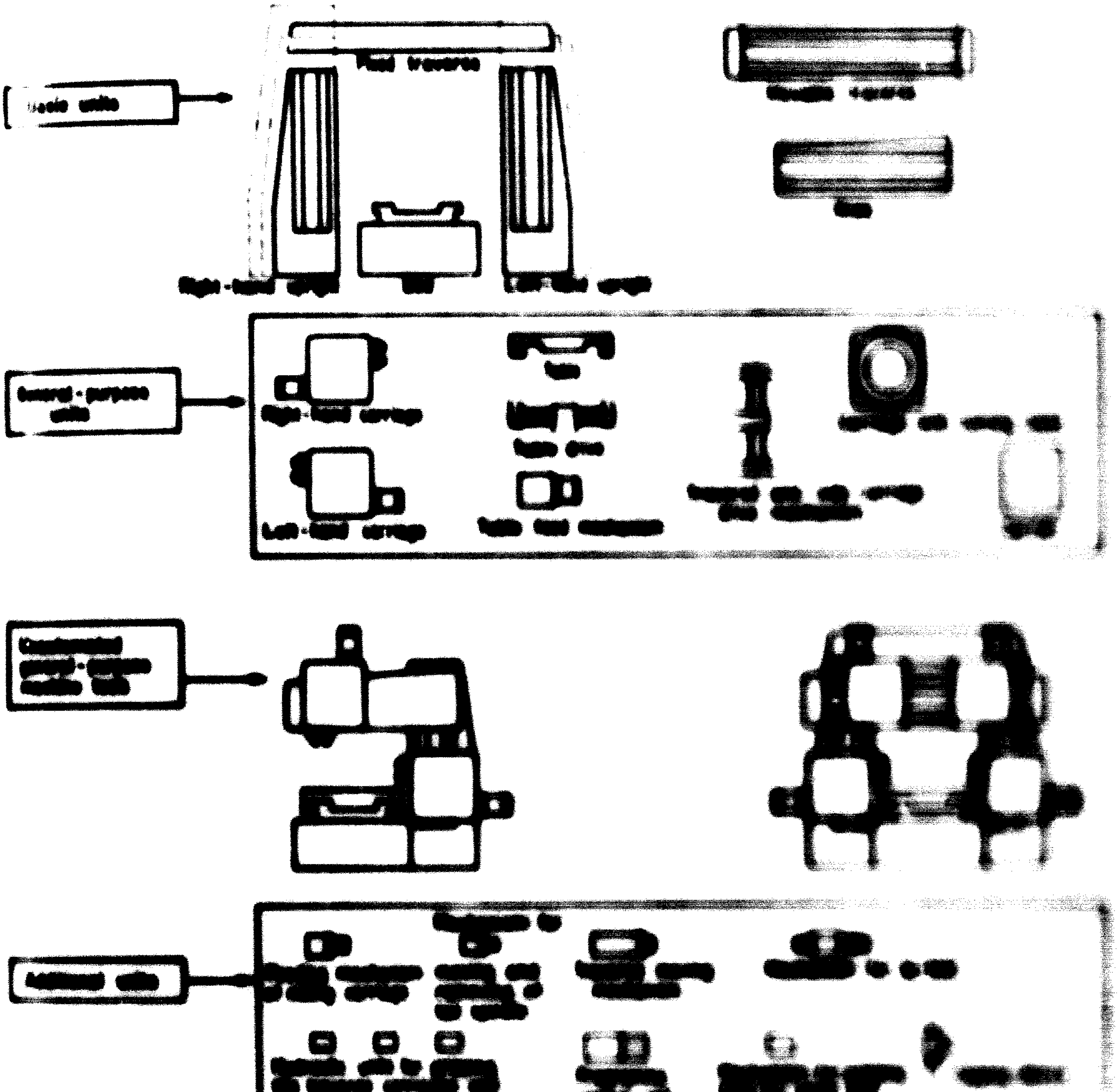
With each design change made necessary by the pro-



Note: Heavy lines indicate second stage of aggregation; lighter lines refer to the third stage

Figure 3

DIAGRAM OF COMPOSITION OF AUTOMATED MACHINE TOOLS ACCORDING TO AGGREGATE PRINCIPLE OF [illegible]


Basic units
General - purpose units
Right-hand carriage
Left-hand carriage
Table feed mechanism
Additional units

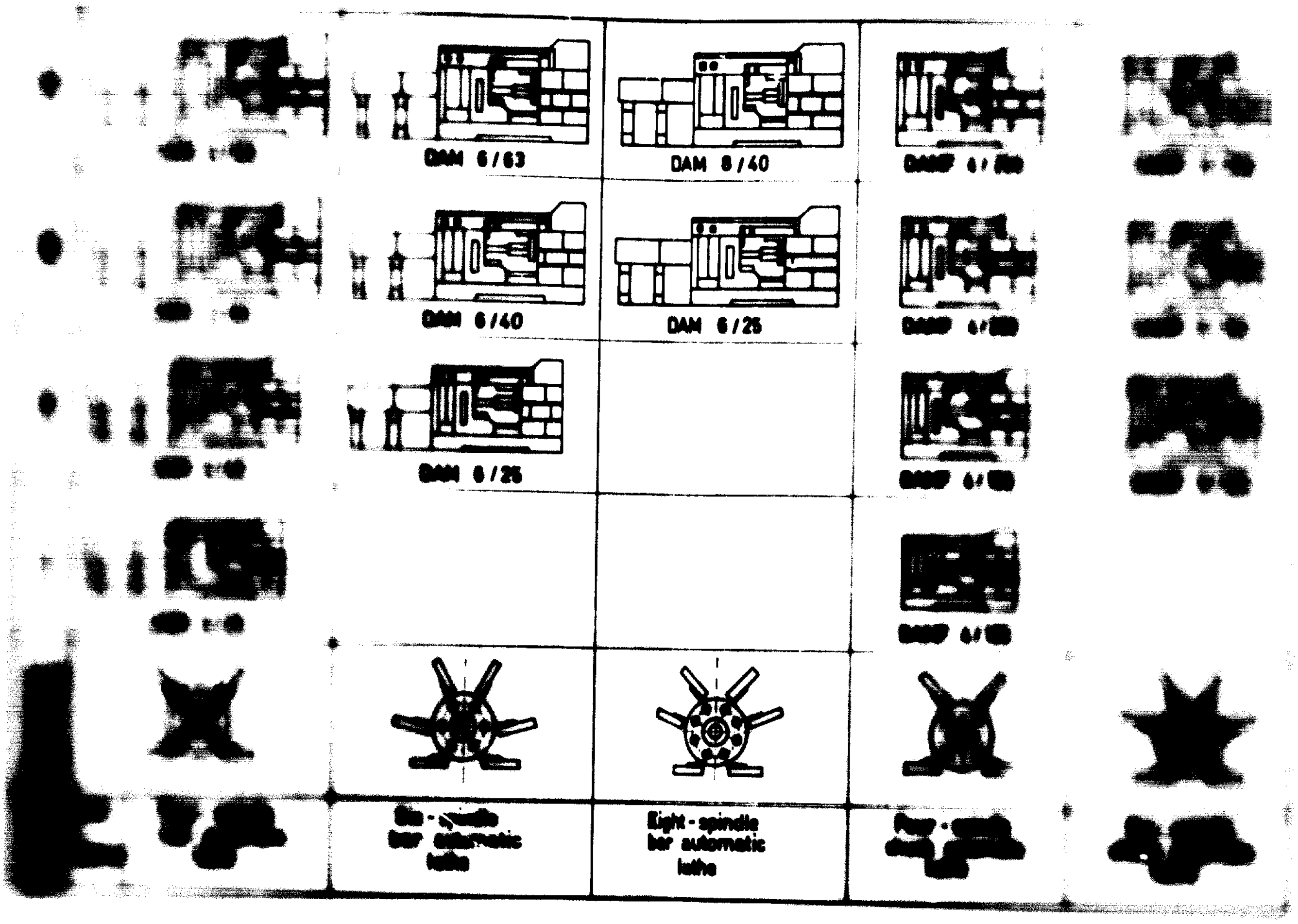


Figure 5

[illegible] OF THE DESIGNING ROW OF MULTIPLE-SPINDLE [illegible]

[illegible] consumption decreases. [illegible] designers remains the [illegible] more rapidly.

[illegible] construction forms of [illegible] to aggregate principles is [illegible] Figure 7 is related, for [illegible] and, in addition to the [illegible] unloading mechanisms. [illegible] centre-turning lathe. Its [illegible] changes brought about by [illegible] Thus, units 25 and 26 are [illegible] importance for the [illegible] dependence upon the [illegible] and the possibility of [illegible]

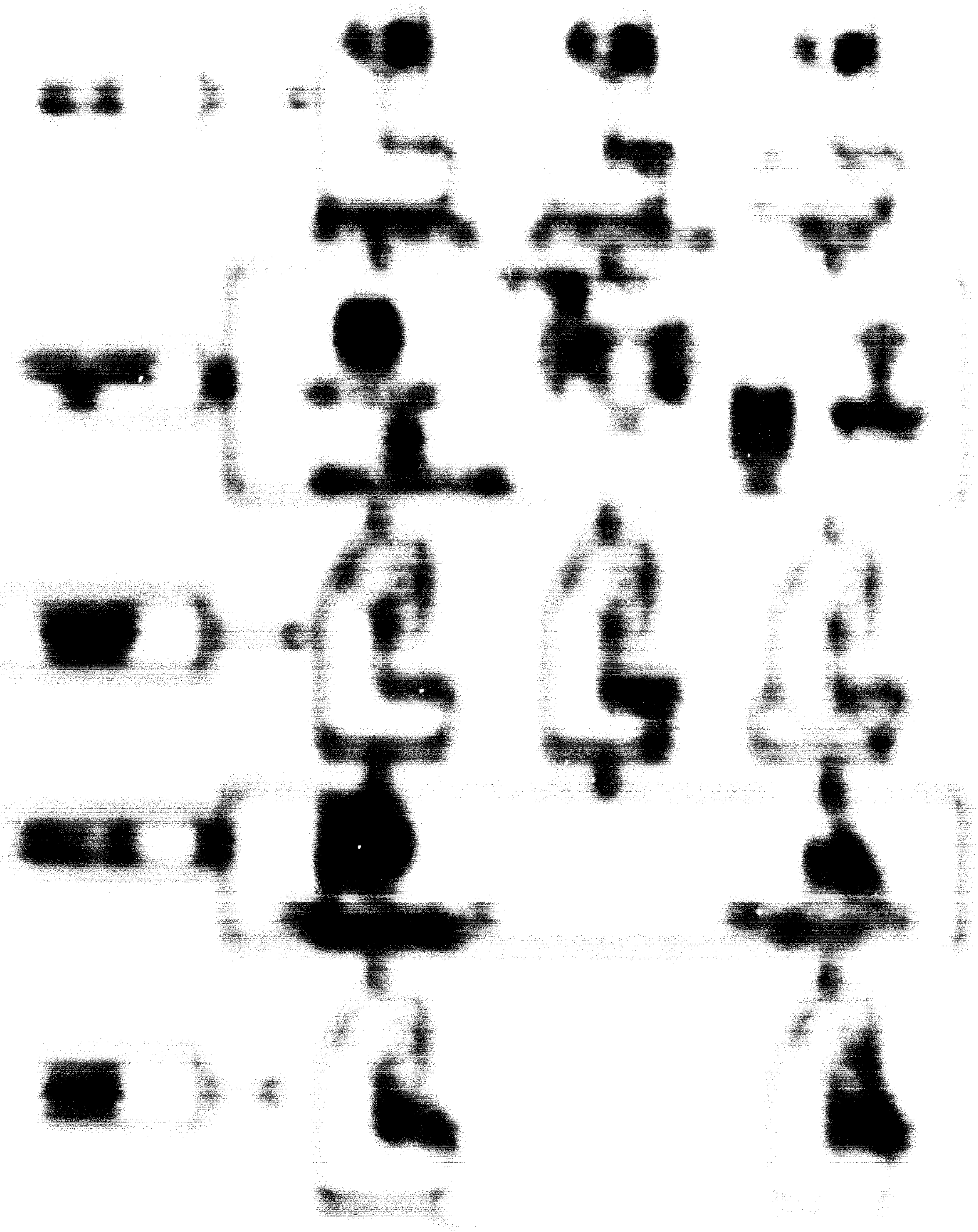
[illegible] how it is possible to [illegible] principle for the design of a [illegible] uprights (one or several) [illegible] unit, which is selected [illegible] to be achieved. [illegible] stocks are assembled [illegible] of the uprights. A [illegible] table, a pendulum or [illegible] as such a unit. Various [illegible] measuring and control mechanisms make it possible [illegible] precision machine tools.

The principle of [illegible] designing the above-[illegible] tools, but also for the [illegible] equipment. The standard [illegible] was the first machine [illegible] systematic unification. [illegible] press assembled from [illegible] figure 11 gives an illustration [illegible] are of a decisive importance [illegible] ing the presses. The [illegible] shown in figure 11.

The design of a three-[illegible] fig. 12) is also of an interest [illegible] are composed of five [illegible] six dimensions of rollers [illegible] used to bend sheet metal [illegible] 3,150 mm width.

Machines for the [illegible] a pressure of 400, 630 and 1 [illegible] posed as combinations of [illegible] units of three dimensional [illegible] the pressure and the volume [illegible] Any of the injecting [illegible]

[illegible]



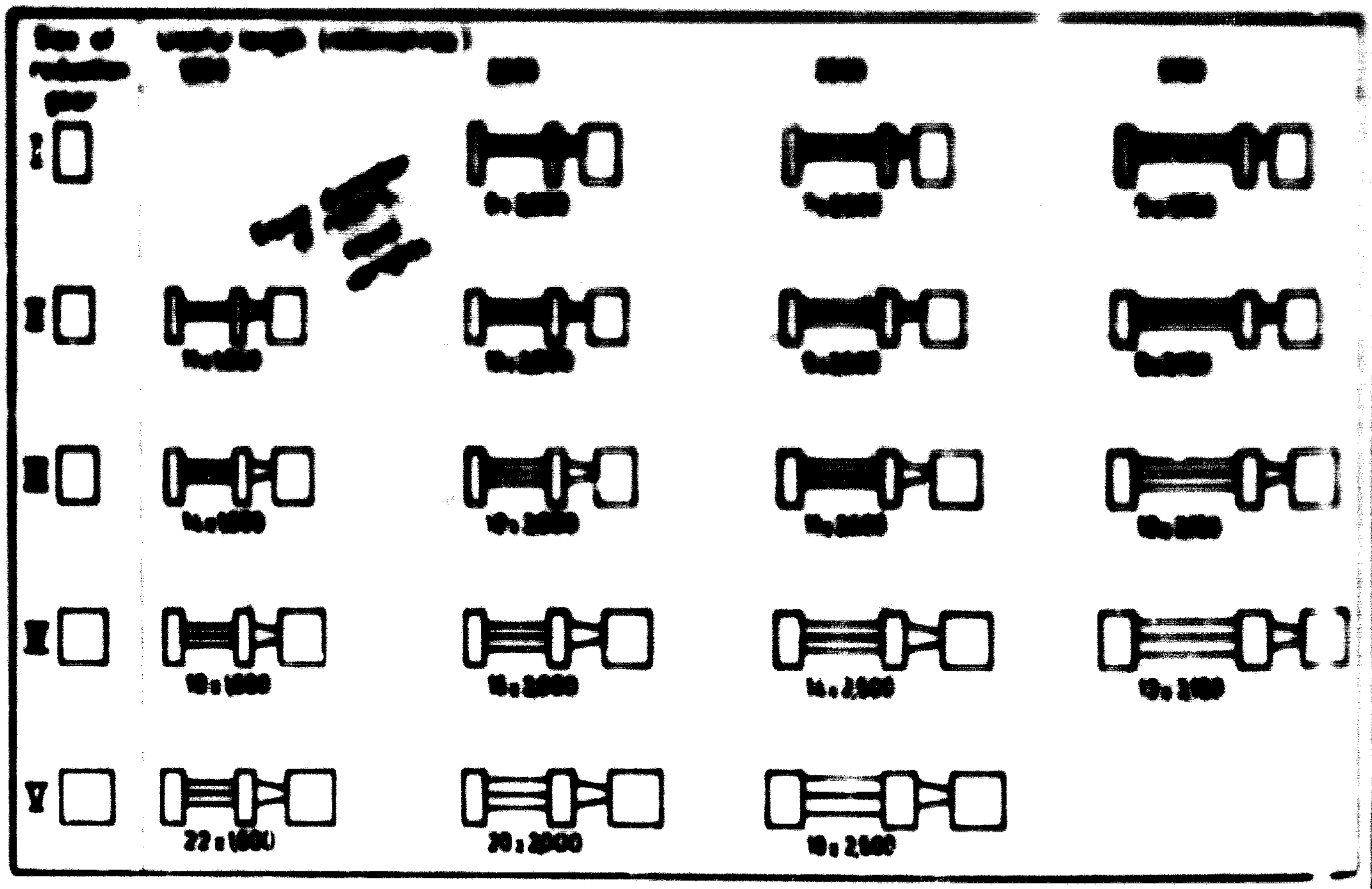


Figure 12

COMPOSITION DIAGRAM OF A ROLLER BENDING MACHINE

[illegible]

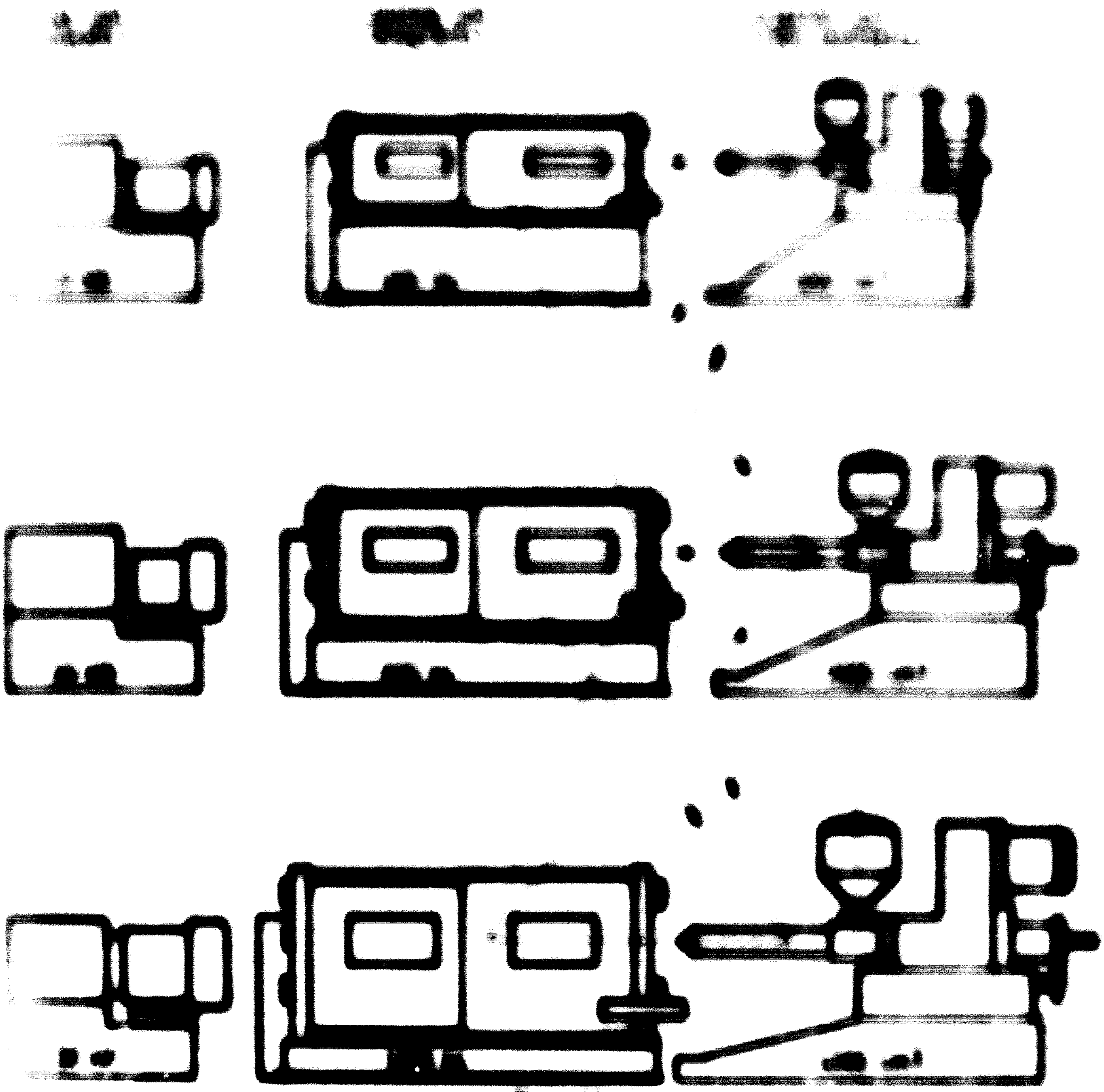


Figure [illegible]

[illegible]

[illegible]es and gauges, and it may be carried out in factor[illegible] [illegible] machine tools due to the high degree of unifi[illegible] [illegible] 80 per cent of the parts are processed [illegible] higher economic [illegible] when individual machine [illegible] are made. If one is to assume that this economy [illegible] only 10 per cent of the cost production of a [illegible] tool then the production of 100 machine tools [illegible] an economy of DM 1.5 million.

[illegible] optimal degree of unification [illegible] the [illegible] technological features of a machine tool which is being designed, for which purpose the indices are [illegible] which are the proportion of a number of standard[illegible] [illegible]fied parts and units, and the total number of parts [illegible] units. The designer should determine the following [illegible]

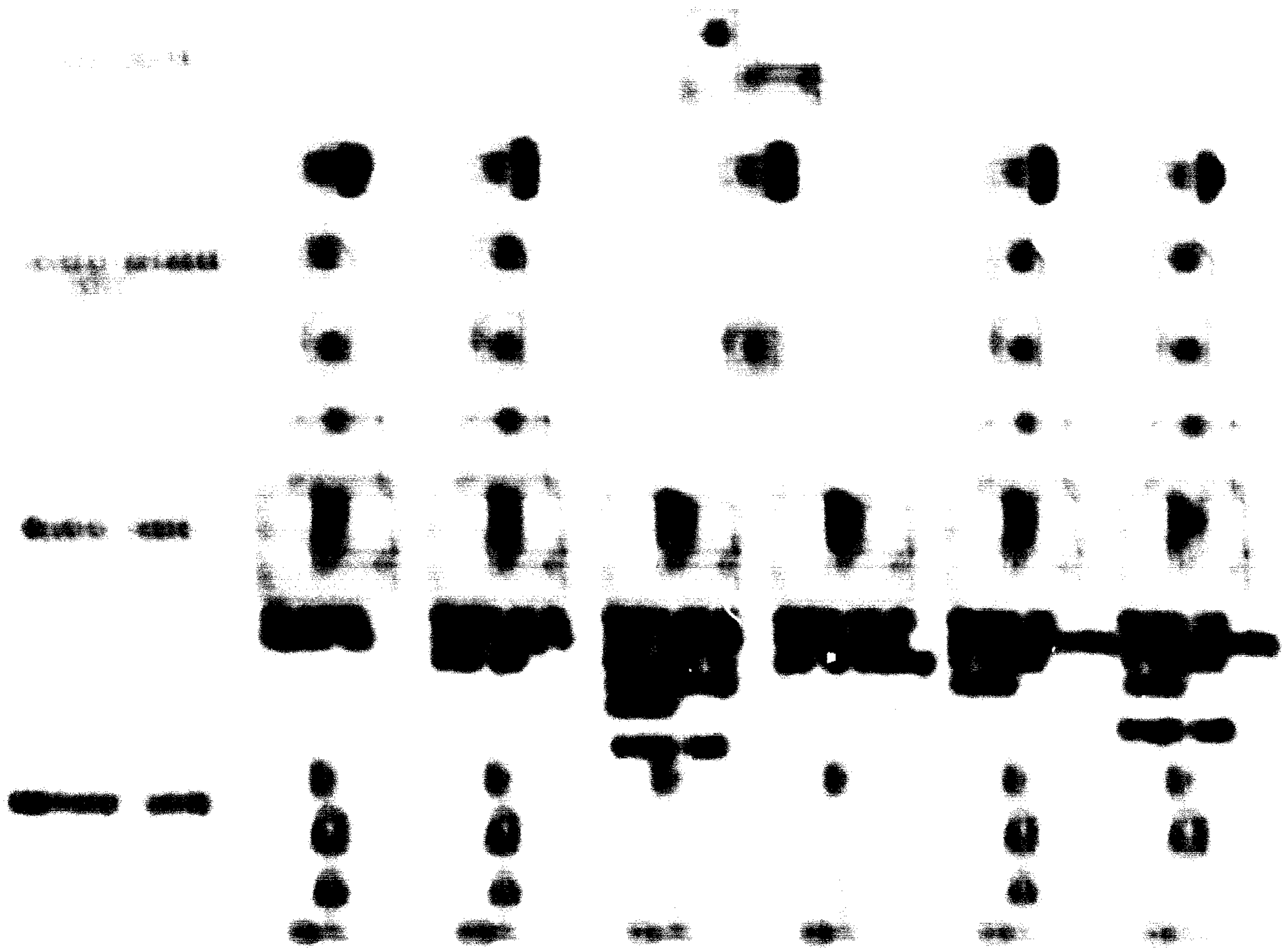
(a) The degree of unification of machine tool units of the same designing [illegible]

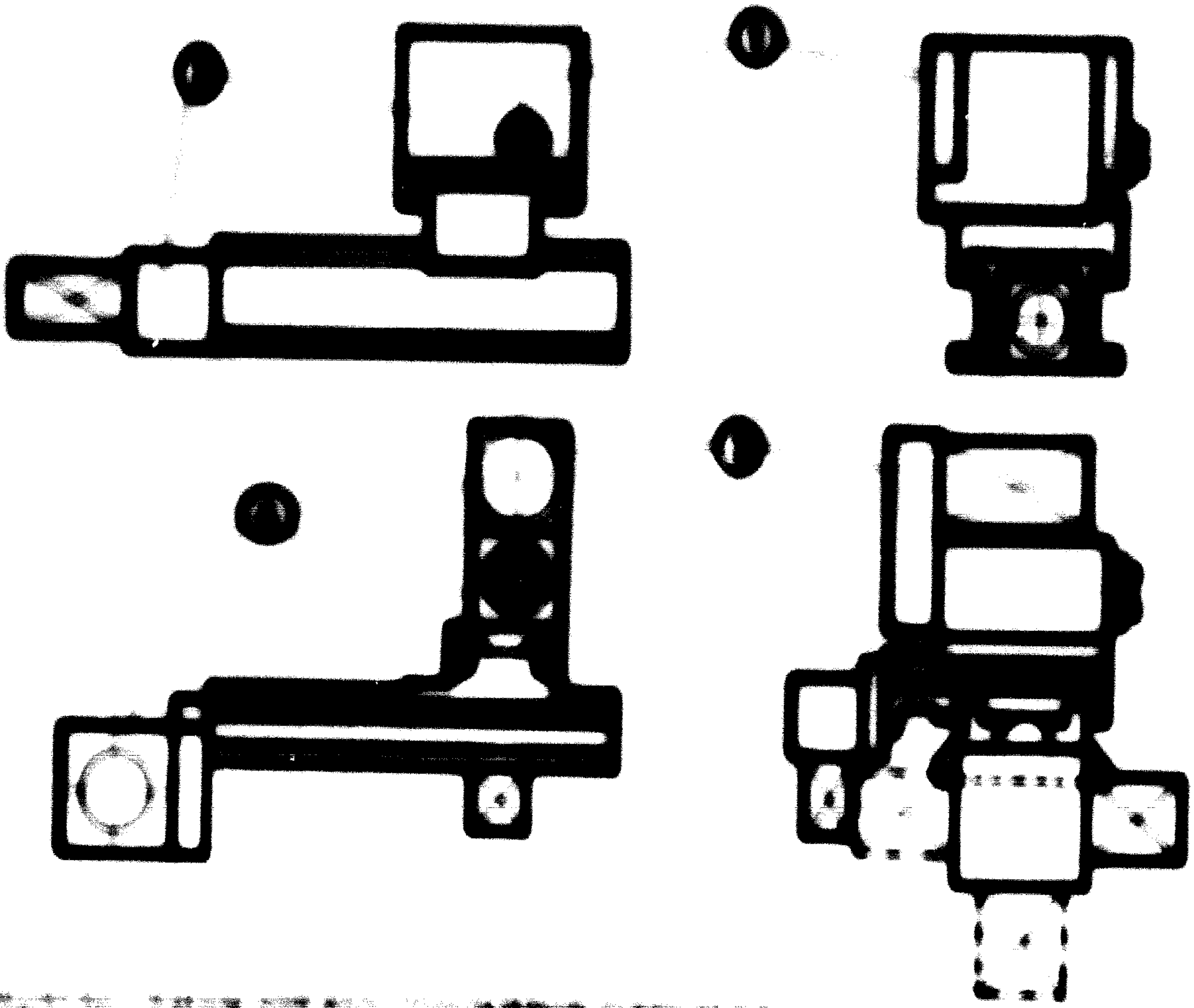
$$K_1 = \frac{Ea_1}{Ea} \cdot 100 \text{ per cent}$$

where Ea_1 [illegible] the number of [illegible] machine tools of the same designing [illegible] Ea [illegible] the total number of units in a machine tool.

(b) The degree of unification of units taken from machine tools of other types

$$K_2 = \frac{Ea_2}{Ea} \cdot 100 \text{ per cent}$$





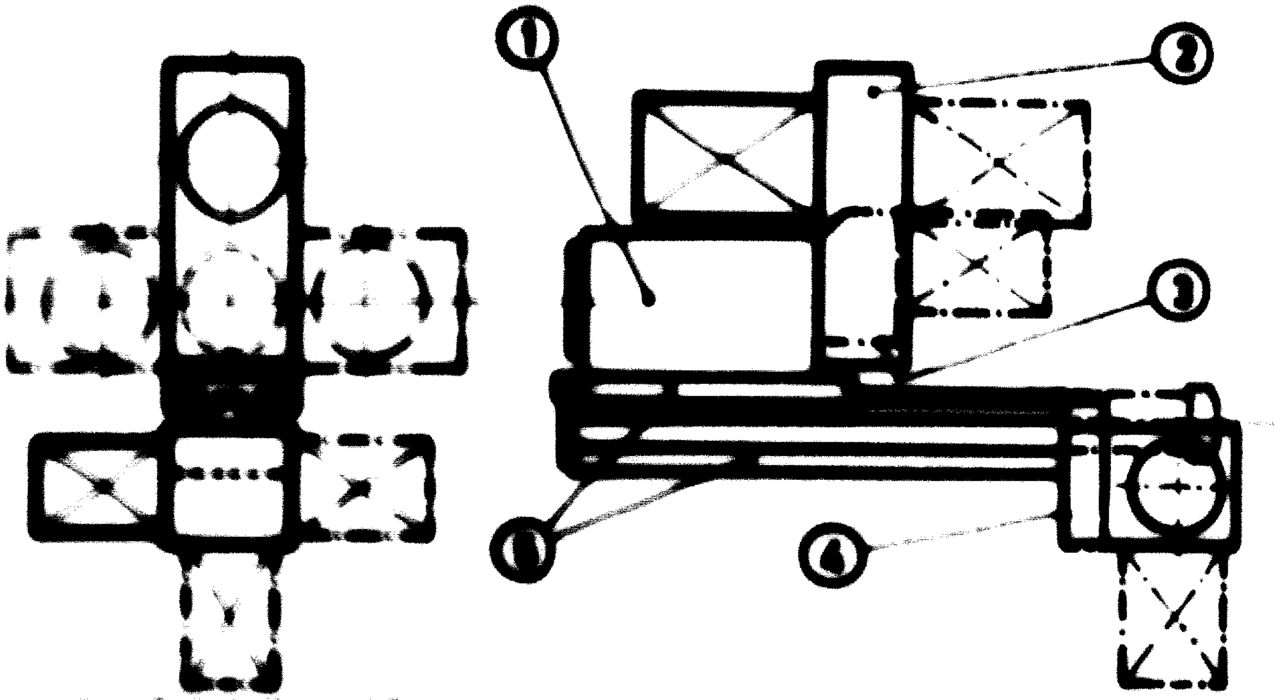


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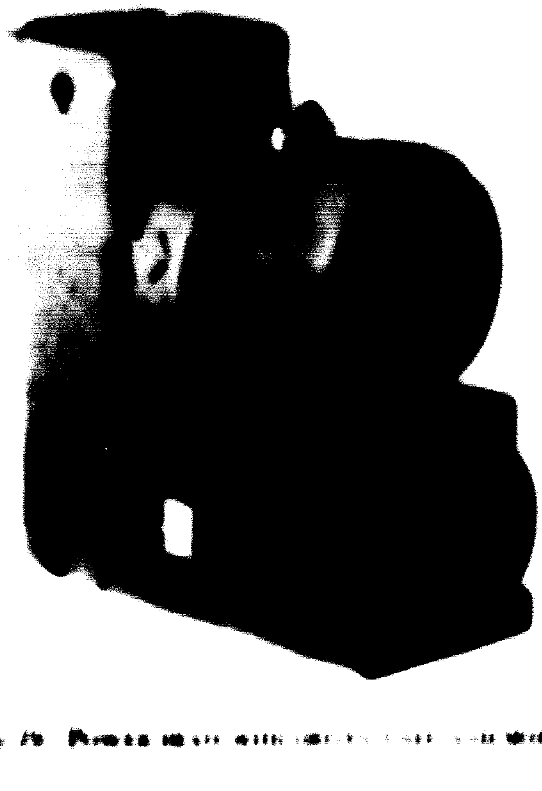
Figure 17, using an example of standard milling units, illustrates that formerly such units usually consisted of a larger number of parts, so that it was only possible to



[illegible]

posing such standard units to make machine tools for filling various processing operations are illustrated in figure 20. The power heads on single-, double- and triple-direction machine tools are placed around the fixed table, which is also a standard unit. One or two heads may be installed in the vertical position for processing from the top. If the machine tool is equipped with a round indexing table, the power heads are placed around the table with a vertical axis of turning (rotating) spindles. On a drum type of machine tool, the drum which may be turned around the horizontal axis (the standard unit of a

drums are arranged on both sides. [illegible] of aggregated [illegible] power heads. From these [illegible] it is possible to understand the extremely large number of [illegible] which are possible. Beginning with the simple so-called aggregate machine tool and ending with an automatic line of aggregated [illegible] of the possible applications of the [illegible] of aggregates.

[illegible] of these machine tools may be designed for processing different items [illegible]

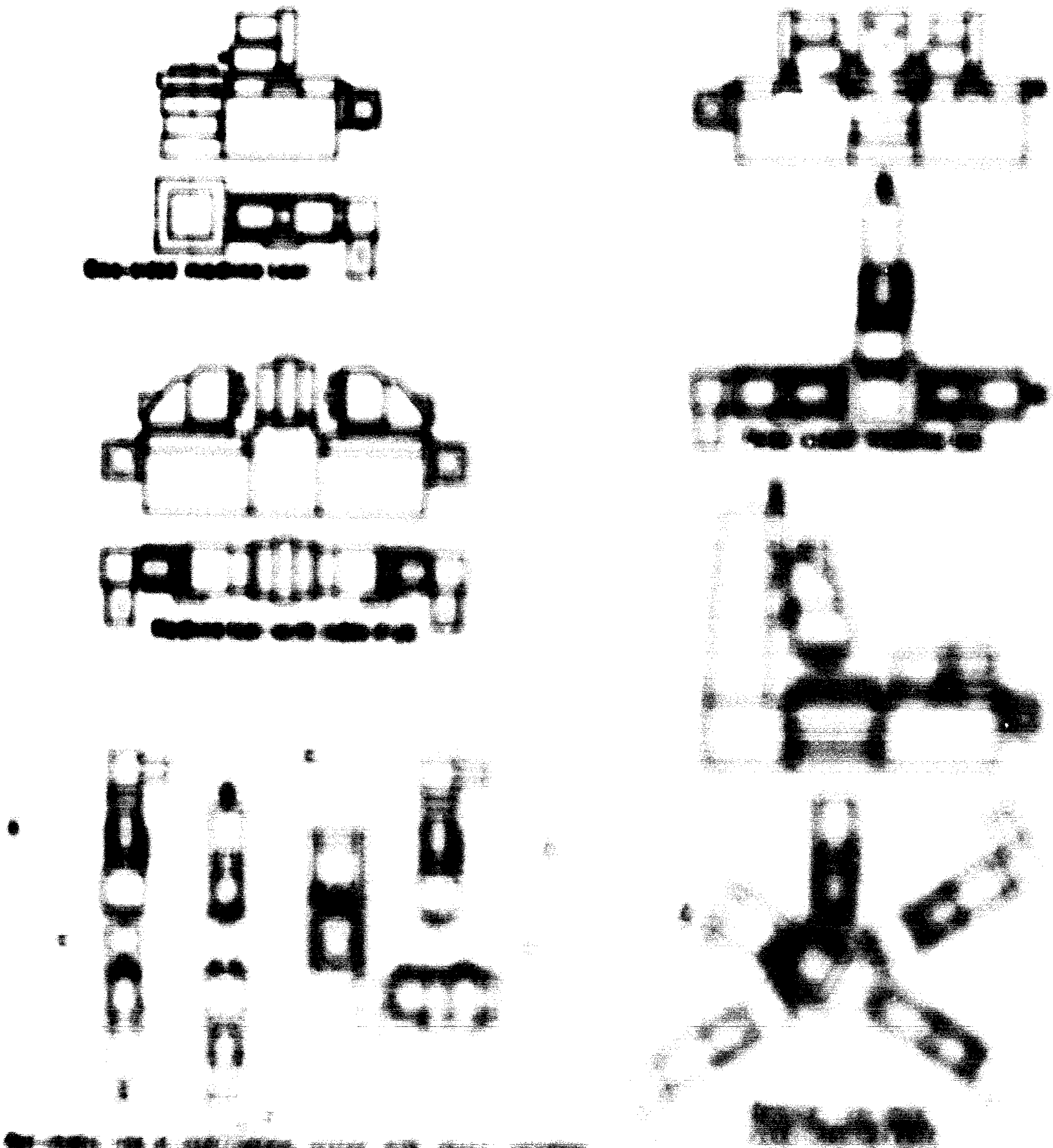
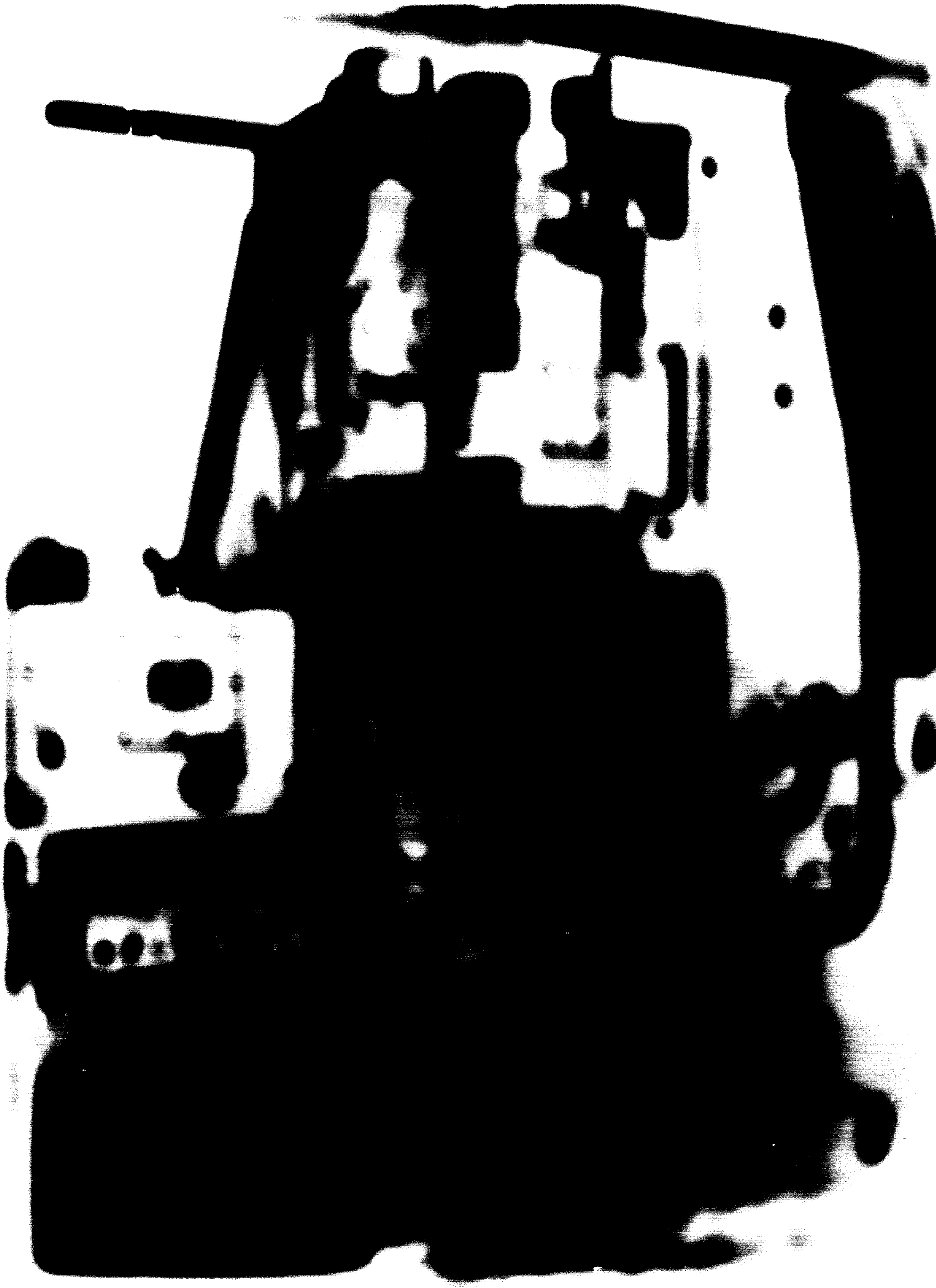


Figure 20



[illegible] the power heads are grouped around the [illegible] that a comparatively larger batch of [illegible] mass production, was considered [illegible] for the economic use of the equipment is the [illegible] specialization on one item. In a [illegible] however the growth of productivity achieved [illegible] aggregated machine tools led to their introduction [illegible] the processing of smaller batches. For this purpose [illegible] reduce the time of readjustment. In [illegible] became economically feasible to use [illegible] lines of interrupted action for processing [illegible] similar items produced in respectively [illegible] For example, a machine tool with a [illegible] table (see fig. 21) is intended for processing bodies of forty five different geared pumps, of which the smallest has a maximum length of 90 mm and the biggest a maximum length of 260 mm. It takes about [illegible] for readjustment. The complex automatic line of interrupted action (see fig. 22) is used for processing [illegible].

The further development of machine tools designed [illegible] stages of aggregate designing will [illegible] in the direction of increasing the mutual [illegible] of the units obtained at those stages: in [illegible] the degree of their standardization will increase. [illegible] a larger number of machine tools will [illegible] It will be possible to compose the [illegible] the item with the power heads in any way [illegible] with the aggregated and the universal machine tools. Standard units are [illegible] purpose machine tools; an example of this is the [illegible] machine tool on an upright of two sections (see fig. [illegible]) where the standard unit of [illegible] As a result, 80 per cent of its parts are taken from [illegible] standard units. On the other hand, the [illegible] planer type of milling machine is converted into aggregated machine tools through the use of [illegible] beginning at least with the unification of its [illegible] (see fig. 24). A modern technique [illegible] new equipment will demand that the [illegible] correspond as precisely as possible to the [illegible] dimensions and forms [illegible] and that the power head [illegible] are of exactly the same [illegible] to the item, in the most expedient way for processing [illegible] tending those items precisely.

It may be seen, therefore, that metal-cutting equipment is more and more frequently produced by [illegible] composing rather than by means of designing [illegible] skilled designers are [illegible] development of the remaining small number of [illegible] structions which are necessary.

D. *Fourth stage*: [illegible] designing

The systematic [illegible] out the entire industrial [illegible]

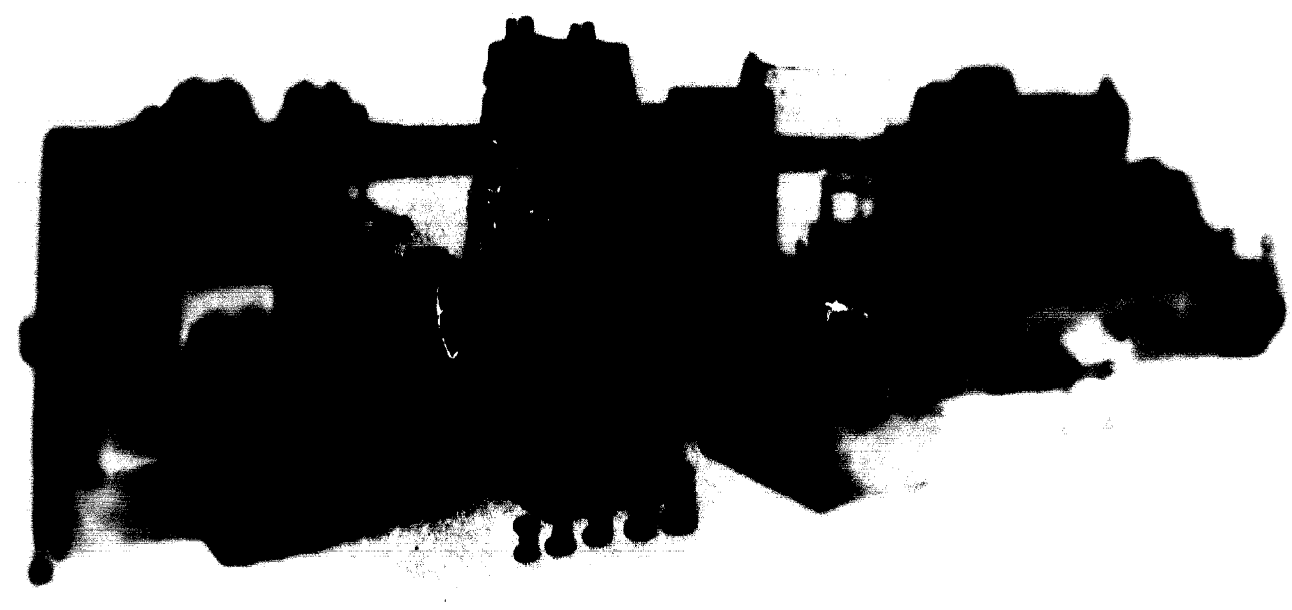
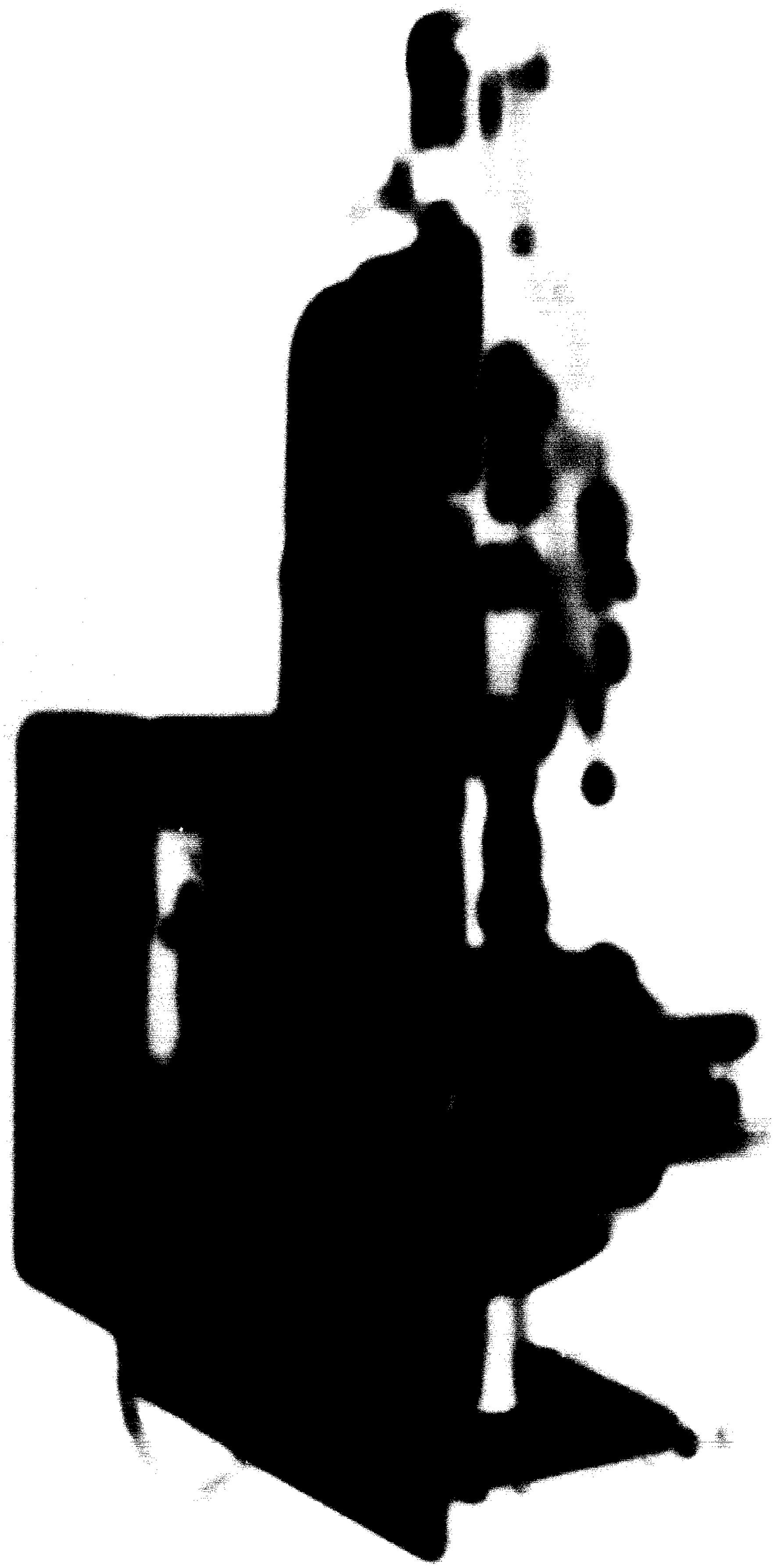


Figure 22

AUTOMATIC LINE OF INTERRUPTED ACTION FOR VALVE [illegible]



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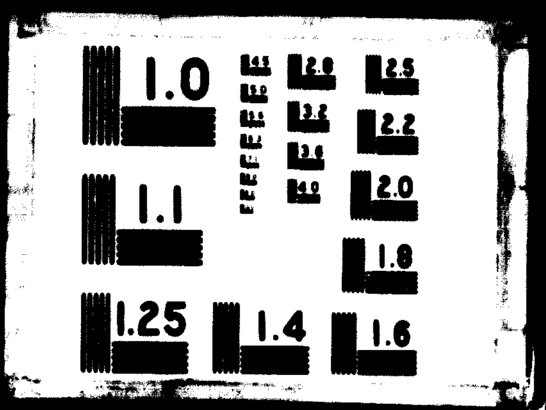


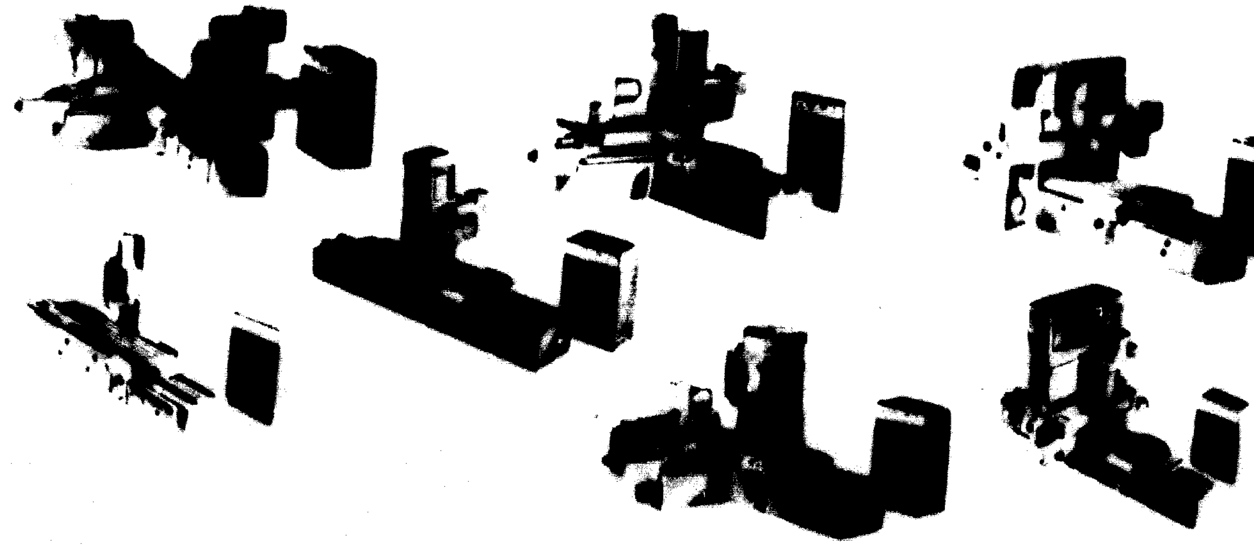


Figure 24

AGGREGATED PLANING MACHINES

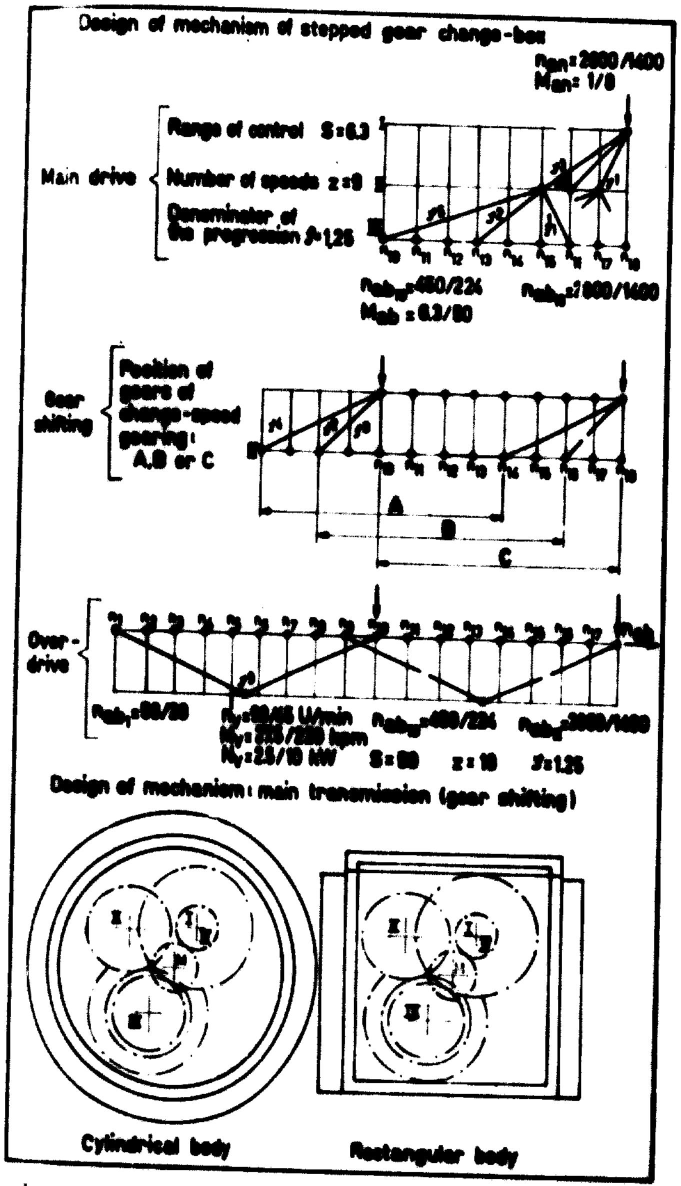
ting equipment produced, i.e., the optimal and complete use of the advantages of the aggregation principle of designing, may be indicated as the fourth and final stage. In this stage, it is necessary to move forward step by step, persistently studying every unit used in this branch of industry from the point of view of the possibility of using it universally for various purposes. It is then necessary to find the best design solution based scientifically, economically and technically, to check it in laboratories and in practice, and then to make it a standard. In each individual case, this should give the maximum economic effect and should be concluded with the centralized production of those units which have become standard.

The group of beds and uprights is one of the groups of units to be subjected to standardization. Scientific research yielded information on the most favourable proportions of size, heights and cross sections of the beds and uprights which should be employed in turning lathes, milling and planing machines, machine tools for grinding guideways and combined machine tools of various types. A designing row of beds and uprights, in which the proportion of sides, cross-section and height are in a geometrical gradation which would ensure the maximum rigidity with the minimum consumption of materials and the minimum labour expenditures in processing, is currently being developed.

Stepped reduction gears (see fig. 25) for use in the speed and feed-gear change-boxes of turning lathes, milling, boring and drilling machines, as well as in other machine tools of similar purpose, are included in another group of units. These reduction gears are developed according to the geometrical grading in power, speed and level of the speed range. The minimum number of modules of gears, various clutches etc. is established. The reduction gears may be used either as a unit with a housing or in the form of a kinematic chain consisting of gears, shafts and clutches assembled, in the case of an appropriate machine tool, in the most expedient way.

The next group of units are those carrying items and tools. Here, the base-rests, with and without a turning basis, are being developed. These are equally efficient for composing the central zones of aggregated machine tools and for horizontal boring, turret lathes and milling machines. It is especially clear from the example of this group that the all-purpose machine tools which have been considered individually until now have many things in common with the aggregated machine tools.

Although it is true that the instrument-carrying units must be of various forms, depending upon the peculiarities of the tools and the methods of placing them in the working position, a deeper analysis of the wide spheres of application in the entire branch will make it possible to ·scover many common requirements. This will lead to ·e creation of the designing rows, which promise gr. advantages from the point of view of improving the qu. ·y of design and the reduction of the cost of production in case they are used repeatedly.



N·te: n_{an} – speed of the driving shaft; n_{ab} – speed of the driven shaft; n_V – speed a· full power capacity; M – torque; N – power.

Figure 25

DIAGRAM OF SPEEDS FOR A STEPPED STANDARD GEAR CHANGE-BOX

·n the course of such a radical recons· ·eration of the pr· duction programme, all the results of prospective a· · even prognosed designing are used with success. In t· ·phere of units of carrying tools, the development t· · place from the cylindrical spindle sleeve (tail · dles) on the guideway or roller guides through u· ·ed turrets to the automated magazines of tools. ·e units of the measuring, control and adjustment g· ·p are most widely used because they are easily subdivided into small complexes of elements with simple fastening surfaces.

The foregoing examples of the wide assortment of optimized and standardized units are sufficient to explain the essence of the important process of wide aggregation for both the construction of equipment subdivided into unified or standard units and the application for production where the central or the standard units are produced by specialized enterprises, while the chief supplying plant deals mainly with assembly.

II. Advantages of aggregation system

In conclusion, it is necessary to comment on the economic significance of the aggregation system from the point of view of both production of the means of production of all types and their operation. In the process of production, especially of metal-cutting equipment, the significance lies in the numerous advantages in designing and production:

(*a*) When developing the first machine tool of a designing row, the labour required for designing is larger when developing multipurpose units for use in a system which is being permanently improved than that required when designing a unit to be used for one purpose only. This labour consumption decreases sharply, however, if one considers the establishment of designing rows and dimensional types using identical units repeatedly and on different enterprises. It becomes even smaller after a definite fund of unified and standard units is created. Aside from the units which have to be designed individually for some of the machine tools, this fund includes a large number of small or large unified groups of elements delivered by the centralized enterprise and the ever-increasing number of standard units. The quality of production increases simultaneously with the wide application of constructions which are optimal from the scientific and technical points of view;

(*b*) The creation of constructions meeting world standards and their continuous perfection becomes easier, the number of designers being the same because of the repeated use of identical units;

(*c*) The time required for designing special models and special machine tools is considerably reduced;

(*d*) The maximum repetition (of large batches) of parts and units makes it profitable to use a higher form of technology (i.e., fixtures, special devices, automated machine tools, special cutting and measuring instruments); the productivity as well as the quality and the homogeneity of the product, increases;

(*e*) The specialization of producing enterprises in a particular branch of industry and the centralized production of the parts and units used by different plants of this branch to complete different kinds of equipment, in turn, facilitate the production of increased batches of manufactured items, thus improving process conditions. Centralized production facilitates the planning and material supply and results in a more efficient consumption of materials and, hence, their saving;

(*f*) It is possible to achieve short terms of delivery for even very complex machine tools and automatic lines adjusted for the required technological process and the form and dimensions of the items;

(*g*) In the majority of cases, those machine tools can be brought into operation in an extremely short period of time;

(*h*) The commitments of the producer on an urgent delivery of spares and rapidly worn parts can be fulfilled more easily;

(*i*) Unification of fastening dimensions and the fastening apertures on the machine tool for additional units makes it possible to modernize machine tools which are already in operation by installing additional units or exchanging them for the old one. That is why the machine tools produced earlier can be used if they are developed further.

It is possible to understand fully the extremely large economic significance of the aggregation principle for the consumer if one imagines that the stock of equipment of an entire country, or even of a group of countries, consists of such machine tools. This stock of equipment based on aggregation would have created extremely wide possibilities to increase productivity. As this is currently the most important problem of industrial production, the economic significance of the aggregation principle cannot be over-estimated, and it should lead to a more intensive and, consequently, a more rapid introduction of this principle into all the branches under consideration.

A number of the advantages obtained by the producer from equipment according to the aggregation principle have a direct effect on the consumer:

(*a*) Reduction of labour consumption in designing and production of machine tools, including tools which are specially made from units delivered in batches to the warehouse, cut down the terms of delivery. The new technique is introduced more rapidly, which is accompanied by an appropriate economic effect;

(*b*) The delivery of interchangeable units from the plant-producer (warehouse) makes it possible to cut down the idle time caused by repair, to make the storage cheaper, to develop the equipment in operation and to modernize it without large adjusting operations;

(*c*) When buying new equipment and when modernizing the existing equipment, the repeated use of identical units guarantees the immediate reliable operation of the equipment as these units have already been repeatedly checked and, consequently, have been subjected to a continuous test. There is no risk in buying a new machine and no period is required to master it, which, as a rule, must be taken into account when calculating;

(*d*) It is possible to buy for immediate use the least expensive and most reliable machines, as it is possible to readjust them at any time to fulfil new functions by adding the appropriate units. The residual value of such equipment is always maximum;

(*e*) The possibility of obtaining equipment for special purposes and with the required degree of automation is ensured, and it is possible to use the identical standard units in various ways, depending upon the necessity. Thus, the price of a special three-sided drilling machine tool is about one-half of the price of the machine tool if it is developed individually for the same purpose without use of the aggregation principle;

(*f*) It is possible to solve complex technological problems by means of a free joining of universal machine tools to form automatic lines or by means of assembly of standard power heads along the flow of item on aggregated machine tools or a continuous line. This ensures the shortest ways and smallest losses of time in transportation;

(*g*) The consumer himself could make special machine tools intended for the actual individual needs of his branch of industry by using whatever is possible from the continuously growing nomenclature of unified and standardized units of the machine tool industry. This is inevitable, as only the consumer possesses the actual experience and necessary means to develop and test the remaining special units required;

(*h*) Identical fastening surfaces of the items and of tool-clamping units and their cutting parts in all machines of the same type and of the same make, as well as those at other enterprises of the country, make possible the increasingly wide application of the tools and the clamping units within one enterprise and in interplant co-operation. When some individual machine tools are out of operation and during the major overhaul, the clamping units and tools may be used on other machine tools;

(*i*) This is also valid for various additional units, for example, copying devices and units of automation, loading, measuring etc., which can be installed in the places envisaged for the purpose on a machine tool which has been constructed according to the aggregation principle;

(*j*) Equal grading of the speeds and number of double strokes, transverse and other feeds creates the condition for a uniform technological processing, thus facilitating the economically profitable application of a new technology, i.e., one needs less information to calculate the time for processing one item and also a smaller number of normals for instruments and fixtures, etc.;

(*k*) The same maintenance of the equipment and its attachments with electric, electronic, hydraulic, pneumatic, lubricating and other devices makes it easier for the people attending the equipment, as well as for the technologists to study better the technical peculiarities of equipment and the possibilities of its use.

It goes without saying that for each individual application of equipment built on the aggregation principle, the economic effect will be different. Furthermore, this principle could be more profitable if the consumers also understood all the advantages.

METHODS OF PROCESS CONTROL IN ENGINEERING INDUSTRIES

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I. General problems

A. *Process control as a way of increasing efficiency of production*

An industrial process is that procedure which converts materials and half-finished products into end-products by means of labour. Labour can be spent by direct activity in the form of living labour or in the form of past labour, embodied in the machines formerly manufactured. One objective of technological progress is to decrease the amount of labour realized in products in the process of manufacture; the total amount of labour embodied in the products and equal to the sum of living labour and labour realized in products should continuously decrease. At the early stages of technological progress, the share of living labour prevails in products, but along with technological development, its share decreases. In the process of decreasing of the share of living labour, automation gains the leading role.

The introduction of automation changes the nature of labour: manual labour is gradually replaced by mental work; man ceases to participate directly in industrial process, but begins to carry out the functions connected with the creation of controls and maintenance services of machines. From being a direct participant in the manufacturing process, man, as Karl Marx said, becomes "a supervisor and controller of this process".[1]

B. *Scales of production and their effect on the level of automation*

At the current time, nearly every level of automation is technically feasible, but it should be taken into account that automation is associated with complexity and with an increase in the cost of equipment. Therefore, its reliability and economical efficiency become of prime importance. The increase of requirements with regard to the servicing of more complex and more expensive equipment is also of great significance. For instance, poor quality of tool shaping or the absence of a proper system for its adjustment and storing can depreciate all the positive properties of an automatic machine or a system of machines where this tool is used. This is also the case with the maintenance service arrangement and other services in the process of manufacture.

Automation can be realized either by reconstruction of the existing technological equipment or by designing new equipment. It can cover all operations of the machining of workpieces or only part of them. The reasonable degree of automation depends upon technological features of the manufactured products, the required yield, the layout of equipment, the degree of its universality and other factors.

In order to find an optimal solution, the question of expediency of automation should be considered differentially for each group of operations, and the most efficient measures should be chosen by realization.

C. *Ways of decreasing the cycle or out-of-cycle time requirements*

One of the main criteria of equipment efficiency is the possibility of ensuring its required productivity. The time required for the production of workpieces is summed up from the cycle and out-of-cycle time requirements. The cycle time requirements include technological time of machining, consisting of the shaping time, the time of reciprocal travels of tools and workpieces, and the time for change of workpieces at the machining stations of technological units and transportation of these workpieces between machining zones. The out-of-cycle time requirements include regular down-time of the equipment connected with rehabilitation of the equipment components' capacity for work and the imposed down-time occurring because of malfunctions of other equipment combined with the first one into a co-ordinated operating system.

Separate elements of the cycle and out-of-cycle time requirements can be partially matched with each other. The degree of matching depends upon the nature of the technological process and the adopted layout of the equipment. For example, in machining on rotary-table machine tools, the time required for the change of workpieces can be nearly completely matched with the technical machining time; in work on centreless grinding machines and on drum milling machines, the complete or nearly complete matching of cycle time with shaping time is possible, so that efficient operation can be achieved; in an automated machine-tool line with flexible link, it is possible to match the idle times of one part of the equipment with the operation of its other part.

Ways of decreasing cycle and out-of-cycle time requirements on automatic machines and automated machine-tool lines are discussed in detail in sections II and III.

D. *Readjustment and reconstruction of means of production*

Automation is more readily feasible under conditions of mass production, since in this case the sound solutions

[1] Karl Marx, unpublished manuscripts of 1857/58, ***Bolshevik*** [illegible], Nos. 11-12 (1939), p. 62.

may be of partial character, which is more adequate for the properties of the given product. It is also important, however, to provide for a possibility of utilization of automatic equipment in some changes of pieces or technological processes. For this purpose, the nature of possible changes should be determined prior to the development of corresponding equipment. The rapidity of realization of the required reconstruction is of secondary importance in this case, since changes in mass production take place relatively rarely.

Under conditions of batch production, it is necessary not only to provide for a possibility of readjustment of means of production for machining a piece, but also to minimize time requirements. Apart from this, the character of the required readjustment may become more complicated. These requirements are intensified with the growth of productivity of the used means of production and with the decrease of the batch pieces due to the increasing frequency of the required readjustments. Thus, automation of batch production becomes considerably complicated as a result of the growing requirements for the universality of the utilized means.

To simplify the problem, the method of selecting the nomenclature of technically allied pieces is used. In this case, the required readjustments are reduced to the minimum. At the current time, the problems of development of rapidly readjusted automatic loading and handling devices have been less studied. Therefore, the automation of batch production is usually reduced to partial automation by conventional means, i.e., through the use of automatic and semi-automatic machine tools equipped with the adjustments of turret lathes and readjusted automatic lines.

One of the most complicated problems in the field of machining automation is that of small-batch production automation, which, in engineering industries and metal-working, constitutes not less than 30 to 40 per cent of the total volume of production. Within the past eight to ten years, the solution of this problem has been advanced considerably by way of the design and commercial use of the so-called "programme-controlled" machine tools.

II. Automatic and semi-automatic machine tools

The automatic and semi-automatic metal-cutting machines refer to the group of so-called "technological" or "working" machines. The importance of the technological machines is rather great. It is known that the industrial revolution of the eighteenth century, which resulted in manual production being replaced by machine production, was caused by the wide application of technological machines rather than of engines only. The invention of mechanical engines stimulated the growth in the size of technological machines, the increase of speeds and productivity. However, the possibility of transfer of any branch of industry to machine production occurs only after the corresponding technological machines have been designed.

A. *Structure of the operating cycle and methods of shortening its duration*

The working cycle on metal-cutting automatic machines involves the following operations: feed of materials or blanks; execution of shaping operation on them; transporting from one position to another; fixation; clamping and release; moving forward and removal of working organs; and the switching of separate mechanisms. All these operations require a certain amount of time. On some automatic machines, the machining, readjustment and, occasionally, the change of tools are carried out by automatic control.

The out-of-cycle time requirements consist of the time for change, installation and adjustment of tools; the time for rehabilitation of working capacity of automatic machine mechanisms in failures; and the waste losses and time taken by organizational matters.

The basic way to increase the output of automatic machine tools is the simultaneous decreasing of both cycle and out-of-cycle time requirements. The decrease of cycle time requirements should involve simultaneously both the time for the main shaping operations, t_p, and the time for auxiliary operations, t_x. The decrease of only the time t_p without a simultaneous decrease of the time t_x would lead to the increase of the share of the latter and, consequently, to the decrease of the efficient use of the equipment for direct machining.

The problem of decreasing the cycle requirements is solved by both the development of advanced machining methods and the improvement of mechanisms for realization of working and idle running. At the same time, the concept of matching the separate elements of the cycle time requirements is applied. For instance, for decreasing the value t_p, it is possible to (*a*) time-match different idle-running operations; and (*b*) time-match idle-running operations with working ones. For decreasing the value t_x, two methods are also possible: (*a*) the simultaneous machining of pieces in one position with several tools (multiple-tool machining); and (*b*) the simultaneous machining of pieces in several positions with several tools (multiple-position machining).

The decreasing of out-of-cycle time losses connected with the change and adjustment of tools is rather a difficult problem, particularly with regard to multiple-tool and multiple-spindle machines, when numerous tools operate simultaneously. The main problem in this case is the determination of the optimal intensification of machining conditions and of the degree of concentration of the technological process.

The losses connected with the rehabilitation of the working capacity of the automatic machines' mechanical unit depend upon the durability and reliability of these units. Each machine has, along with units which are quite reliable and durable, units of lower durability. For example, in automatic bar lathes, such units are the split-socket clamping mechanisms, cams and push rod supports; in automatic internal-grinding machines, the comparatively short-lasting units are the rolling bearings of high-speed spindles which, in grinding small parts, r[illegible] at the speed of tens of thousands of revolutions pe[illegible] minute.

[illegible] order to increase the durability and reliability of au[illegible]matic machine mechanisms, it is necessary:

([illegible]) To achieve, by means of constructive measures, as we[illegible] as by improving the quality of production, prolon[illegible]ation of the service period of such mechanisms, po[illegible]ibly without increasing their size and weight;

(b) To strive for the development of quickly replaceable units and parts, and for a decrease in the time required for repair and replacement of the mechanisms which fail.

B. *Methods of automatically securing the required machining accuracy*

In the main branches of mass production, technical control is required for about 40 per cent of production operations. Therefore, the automation of technical control is important to these areas of production. The problem of choice of a system and of control facilities is simplified in cases when automatic production utilizes machines of modern, tested types. It is more difficult to solve this problem for new types of machines. For new machines, over-estimation of both the stability and the accuracy of the design may occur; and, due to this unreasonable failure of control of important dimensional parameters of pieces and the like, it is possible to make unreasonable solutions concerning the necessity of introducing 100 per cent taking-over control and of designing for this purpose sophisticated control facilities.

1. *Active and passive controls and their applications*

Automatic-control devices are divided into two main groups: those operating by "passive" control; and those employing "active" control. The first group includes:

(a) Devices for taking-over control which sort workpieces into valid and faulty ones;

(b) Devices for the classification of valid pieces into a number of dimensional groups for selective assembly;

(c) Devices for control of definite important parameters prior to machining in order to prevent damage to machines or instruments as a result of a discrepancy between these parameters and the established requirements.

In the passive-control method, the control devices normally are not connected with the machining process an[illegible] cannot affect the machines' working components. O[illegible] the contrary, the active-control devices can, according to the results of measurements in the process of work or rig[illegible] after it, actively interfere with machine control and g[illegible] instructions for changing operating conditions or st[illegible]ing the machine after achieving the desired dimensi[illegible] of machined pieces. The active-control devices w[illegible] control pieces after machining can also carry out th[illegible] following functions: make adjustments, i.e., change th[illegible] working-tool position; classify valid pieces into g[illegible]s; stop the machine in case of tool failure.

[illegible]ive-control devices are used in various branches o[illegible] [illegible]ss production and, first of all, in systems of machines. Different types of grinding and lathe machines are equipped with these means.

2. *Automatic tool-wear compensation*

The active control and automatic adjustment of tools are currently used mainly in grinding operations and quite rarely in lathe and boring operations, where greater accuracy and better machining quality are required. For such operations, the adjusting devices are designed mainly for individual pieces and are not of a universal nature. In this category are adjusting devices for automatic lathes which machine railway bearing rings, motor-car axles, valves and the like. In some automatic machines (for instance, drilling and boring of heatproof valves) mechanisms for the automatic changing of worn and failed tools are also introduced.

Devices for the adjustment and dressing of tools of grinding machines have found the widest application. Two main modes of grinding operations are:

(a) Grinding on a machine, with an automatic cycle and control "along the path" (indirect control of machine components' moves);

(b) Grinding on a machine with an automatic cycle with grinding-process controlling by active-control instruments with machine adjustment on the basis of measurement results.

The first mode is cheap and simple because it does not require complex measuring equipment and servicing by highly skilled personnel. Thus far, however, it is not possible to achieve high accuracy of machining by this method, due to the fact that it is based on indirect measurements of the path of transfer of the grinding-wheel centre with respect to the piece, and the actual dimensions of pieces are not controlled directly.

The second method uses active-control instruments which determine the direct result of machining during the whole cycle of machine operation and give instructions for changing operating conditions or the stoppage of grinding. In this method, complicated measuring instruments and apparatuses, as well as programming, are necessary; and their cost is often equal to that of the machine itself.

The ever-increasing requirements as to the machining accuracy on grinding machines give rise to the study and analysis of the reasons for their inaccurate operation. One should distinguish two groups of these reasons: random and regular errors. The random errors lead to dispersion of the pieces' dimensions. These errors do not depend upon the duration of work and are associated with specific features of machine design, measuring instruments and their quality. These are irregularity of feed (usually transversal), non-rectilinearity, insufficient system rigidity, random instrument errors, illegibility of fulfilling instructions, etc. The random-error distribution law is usually normal. Systematic errors depend upon the time of operation; they are accumulated slowly and cause gradual change of the shape and size of pieces. These errors can be periodic or growing. Systematic errors include the wear of the grinding-wheel, diamond wear, machine and piece heat deformations, deformations associated with blunting of the grinding-wheel and systematic errors of instruments and transfer mechanisms. Systematic errors are eliminated by means of adjustments.

The piece dispersion zone connected with both random and systematic errors should correspond to machining-accuracy requirements. This correspondence is expressed in that the dispersion zone should be located within the production tolerance zone, and the sum of systematic errors should not accumulate rapidly, since this would cause the frequency of adjustments to be very high.

3. *Dressing and adjustment of abrasive tool*

In rough works on face grinding machines operating by the butt end and on centreless and circular grinding machines, diamond substitutes, the so-called "milling-cutters" or "abrasive discs", are widely used for the dressing of grinding wheels. In the case of an automatic cycle and automatic grinders, the diamond dressing of wheels with the aid of special dressing tools having diamond automatic feed and wheel-wear compensation mechanisms is mainly used. In order to avoid the dressing by blunted diamond, which leads to smoothing (over) the grinding-wheel surface and deterioration of its cutting properties, it is desirable to use tools which have automatic rotation of the diamond holder. Recently, tools having special rotary mandrels with several diamonds have found wide application. The application of such "multiple-blade" diamond tools makes it possible to increase the speed of dressing and to obtain a higher accuracy. For the dressing of shaped wheels, the following methods are applied:

(*a*) Dressing with a single-blade tool by the diamond along the former. In the dressing of profiles having steep zones, occasionally two diamond tools are applied separately for longitudinal and transverse profile sections;

(*b*) Dressing of shaped wheels with a knurling roll has found wide application. This method has a number of advantages: relative simplicity; high productivity; and the possibility of dressing steep profiles. The disadvantages of the method are: the low resistance of knurling rolls; their high cost; and non-stability of the abrasive waste due to quick wear of rolls;

(*c*) A new method of wheel dressing with rolls covered by a layer of diamond fines is of great interest. This method has a number of advantages, as compared with the earlier methods used. These advantages include: a reduction of dressing time by thirty to sixty times; the simplification of shaped-wheel dressing; and a reduction of dressing cost since tools with diamond fines have a very long service life and diamond fines are cheaper than large diamonds.

III. Automatic machine tool lines

A. *General layout concepts*

The connecting of several technological aggregates into a co-ordinately operating system, or automatic machine tool line, is always associated with a certain limitation as to the independence of their operation. This limitation displays itself specifically in the fact that during the operation each aggregate of the automatic machine tool should stand idle for some time, not only for rehabilitation of its own working capacity, but also due to failures of other associated aggregates. The degree of limitation of the aggregate independent run of the automatic machine tool line depends upon its layout. Therefore, the general principles of the line layout, i.e., the methods of interconnexions of the units involved, considerably affect its productivity.

As mentioned above in section I, the time requirements for making workpieces on an automatic machine-tool line are composed of cycle and out-of-cycle time requirements.

The cycle time requirements include:

(*a*) Technological machining time on the line, consisting of shaping time and the travel time of mutually accelerated tools and work-pieces.

(*b*) The time for the change of workpieces, which includes the change time in the machining station of an aggregate and the time for transporting workpieces from one machining zone to another.

The out-of-cycle time requirements include:

(*a*) Idle standings of the line equipment associated with rehabilitation of the working capacity of the components of this equipment;

(*b*) Imposed idle standings occurring as a result of failures of other equipment combined with the first one into the co-ordinately operating system.

The layout of the automatic machine-tool line determines the character of the transporting-loading motions within the line and the intercommunication of individual groups of its equipment. Therefore, the layout affects the time elements enumerated in (*b*) of both kinds of requirements, that is, the time for workpiece change and the degree of matching of imposed idle standing of the line.

Consider the effect of the layout on each of the enumerated kinds of time requirements.

1. *Cycle requirements*

The cycle time requirements for the change of workpieces in the machining zone and for transporting them between machining zones consist of a number of elements. The release, taking down, setting up and clamping of the workpiece take place in machining zones, whereas the forward and backward motion of the workpiece transporter, as well as the different rotations and tipping of workpieces for their transfer with respect to zones of technical actions, take place between the zones. Depending upon the adopted layout of automatic machine-tool line, the elements of cycle time can, to some extent, coincide with each other. This leads to a reduction of the rated cycle of line operation, which, in the limit case, may include only technological time or even the shaping time only.

2. *Out-of-cycle requirements*

According to the nature of the intergroup link, the automatic machine-tool line can have rigid or flexible con xions. In the first case, the active interoperational pre rations do not exist between stations of the automat machine-tool line and the transportation connex ns are of a synchronous character. The stopping of one of the units of the line immediately causes the stopping of the whole line. The imposed idle standing cannot be coincided and reach maximum quantity.

Automatic machine-tool lines with flexible connexions are characterized by the presence of active interoperational preparations or several parallel flows connected by an asynchronous interunit link. In this case, the technological aggregates of the line operate more or less independently and the failure of part of them does not cause direct stopping of the whole line. The imposed idle standing times can coincide with each other and their total value can be considerably decreased.

The above-described general principles of automatic machine-tool lines have been developed at the Design Office-I of the Experimental Research Institute of Metal-cutting Machines (ENIMS) and other design offices which are working on the analysis of structural schemes of automatic machine-tool lines and on the determination of the efficiency of their use.

B. *Reconstruction and readjustment of lines*

The field of application of automatic machine-tool lines designed for the machining of only one workpiece, the so-called "single-item" or "single-nomenclature" lines, is limited by the requirement of a sufficiently large output of workpieces because one of the conditions of the economic efficiency of lines consists in high productivity. In the last few years, however, both in the Union of Soviet Socialist Republics and abroad, multiple-item autom atic machine-tool lines have been developed, on which the machining of several different workpieces is possible, either directly or with little readjustment.

The application of such lines may be sufficiently effective even with a relatively small output of each item.

The following main types of multiple-nomenclature automatic machine-tool lines may be mentioned: (*a*) non-readjustable lines; (*b*) lines with manual readjustment; (*c*) lines with automatic selective operation of machine; and (*d*) readjustable programme-controlled lines.

It is easier to solve the problem in the case of the machining of similar workpieces, whose design difference does not affect the outlay of the line. In this case, several (normally two or three) workpieces of similar configuration can be machined without any readjustment.

In other cases, the automatic machine-tool line has to be readjusted manually when machining similar workpie s. This may involve changing the cutting tool and jig ushes, and the transposition of control stops. Oc sionally, auxiliary power packs have to be switched on   switched off manually. The time required for such re istments is different and lasts from several minutes to   shift-period.

  disadvantage of the lines with manual readjustme , apart from time losses for readjustment itself, is als he necessity of working out or removing workpie of the same type from line-stations and after readjustment—feeding them with workpieces of another type.

Both in the Soviet Union and in other countries, a certain number of multiple-item lines with automatic readjustment have recently been built. They are also known as lines with "selective operation of machines".

Lines of this type permit the machining of several workpieces, mainly of two, in any sequence without requiring manual labour for readjustment and without the necessity of removal of workpieces and feeding-line transportation systems with other type of workpieces. The conveyors of such lines are adapted for the transfer of workpieces having different sizes. The lines are equipped with identification devices for determining the type of workpiece or satellite and for switching on the power packs. Several multiple-nomenclature lines have been designed on the basis of the specimen described here. Each of these lines is designed for the machining of two workpieces of different size. The increase of nomenclature leads to a considerable complication of the design and to difficulties in determining the type of workpieces, as well as to some difficulties in readjustments.

For small-batch production, the solutions described here may turn out to be of low efficiency. In these cases, the questions of sufficient universality of the used means of automation and the speed of tool readjustment become of great importance. In a number of foreign and domestic designs, these questions are solved through the use of programme control. The machines of the lines are equipped with tool feeders containing a considerable number (up to thirty) of various tools.

The tool changes, as well as a number of other elements of readjustment, are done automatically with the aid of various programme-control systems. At the end of the 1950's, some periodicals in the United States of America published information on programme-controlled automatic machine-tool lines of the Hughes Aircraft Company, for the machining of workpieces of interceptors; and of another machine manufacturing company for the production of piston rods for slush pumps. In the USSR, an experimental readjusted line for the machining of nine sizes of beds for crane motors was designed in 1963.

Automatic machine-tool lines for the machining of rotating workpieces usually permit the handling of workpieces of one type with slightly varying dimensions with the aid of manual readjustments. In this case, the technological equipment, measuring and controlling instruments and electrical automatic devices are readjusted. The conveyors, gutters and tool feeders require no readjustment. The duration of such readjustments usually does not exceed one shift-period.

Apart from readjustment, the so-called "rebuilding" (reconstruction) of automatic machine-tool lines is currently practised. Reconstruction is undertaken when the manufactured products suffer cardinal modifications or are replaced by other simil r products which are more or less different from the previous ones. The concept of reconstruction is broader than that of readjustment and usually includes the latter as one of the elements. In reconstruction, in addition to the readjustment of technological and control equipment and electrical automatic equipment, the reconstruction (rearrangement) of conveyors and gutters takes place. It is more difficult to reconstruct tool feeders; very often one has to replace them with new ones and only in certain cases is it possible to replace some units and parts, rather than the whole.

C. *Satellite devices*

The mode of conveying workpieces on automatic machine-tool lines is determined to a considerable extent by their shape.

For instance, the cylindrical blanks of small length-to-diameter ratio (rings, flanges, etc.) very easily move along gutters; the blanks of box-body parts with large flat surfaces can be easily pushed through over slideways with the aid of side-guiding planks for elimination of shifting. Due to the complex shape of workpieces, it is often impossible to convey them directly over slideways. In these cases, the workpieces can be clamped into intermediate device-satellites, which may be especially shaped to simplify the conveyance of workpieces of simple shape. If they are made from insufficiently hard materials, however, their bearing surfaces may be damaged in sliding along the conveyor slideways.

Some companies use satellites for operations which require the rotation of workpieces in machining. In such cases, a satellite consists of a spindle with a chuck for clamping the workpiece. The driving mechanisms are placed in stationary position on the line working-stations and are equipped with clutches for transmitting rotary motions to the satellite spindles. Such devices have been used by the Excello and Cross Companies (United States of America) and the Honsbery Company (Federal Republic of Germany).

The use of the automatic machine-tool line layouts with satellites is connected with a number of peculiarities of both a positive and a negative character. The main advantages of the use of device-satellites are as follows: the possibility of machining on automatic machine-tool lines the difficult-to-convey pieces of complicated shape or of insufficient hardness; the high reliability of orienting workpieces in conveying; the possibility, in individual cases of simplifying the construction of stationary devices; and the simplification of conditions for cleaning and washing of surfaces basing the blank.

There are, however, some disadvantages in using the device-satellites.

First, the introduction of satellites requires extra, often rather considerable, expenditures. The cost of production of satellites is usually high since they must be interchangeable and must have sufficiently long durability, and the number of them, particularly in large automatic machine-tool lines is considerable.

The other disadvantage connected with the use of satellites is the necessity of introducing additional surfaces for jointing, basing and fixation. For these reasons, the range of tolerances is reduced to cover the errors of technological operations, which, in this case, should be performed with higher accuracy than those on the lines without satellites.

The third disadvantage of the layouts employing satellites consists in the complication of the conveying systems of the lines. This complication is connected with the necessity of returning the device-satellites from the last to the first position of the line, with the introduction of stations for automatic cleaning and washing of the satellites and with the introduction of devices for clamping and release of workpieces on satellites.

Finally, one more disadvantage of the layouts of automatic machine-tool lines using the device-satellites consists in the difficulty of accumulating interoperation stocks between their stations. In the stock accumulators of such lines, the workpieces should be allocated with the satellites, which leads to an increase of the necessary number of satellites and a complication and increase of the dead load of feeder construction, as well as to the total rise of the line cost. For these reasons, the device-satellites are rarely used on multiple-station automatic machine-tool lines with flexible links.

D. *Stock accumulators*

In modern automatic machine-tool lines, stock accumulators find a wide application. At the same time, the theoretical premises for their efficient use are developed. The basic conclusions in these respects are as follows:

(*a*) Accumulators of larger capacities should be chosen to correspond with longer average single idle standings of units of automatic machine-tool lines;

(*b*) It is not reasonable to use very large, cumbersome accumulators because, along with the increase of their capacity, the intensity of decreasing losses conditioned by their presence becomes lower;

(*c*) From the point of view of losses decreasing, it is preferable to have a greater number of low-capacity accumulators than a smaller number of higher capacity accumulators (it is assumed that the sum of accumulator capacities is the same in both cases).

In automatic machine-tool lines of different types, two kinds of accumulators are mainly used—dead-end accumulators and continuous-path ones. The first are located outside the main conveying path of the line and run only when failures occur in the line sections for which they are designed. In normal operation of the line, the dead-end accumulators do not work, and their own idle standings do not occur at that moment. The continuous-path accumulators, on the contrary, are located on the main conveying path and operate during the whole line operation time. In fact, they constitute a part of the interstation conveying system of the line.

Both types of accumulators possess positive and negative properties which make it difficult to give unequivocal recommendations on the use of one particular type.

For example, the dead-end accumulator is more advantageous than the continuous-path one from the point of view of its effect on the total efficiency of the automatic machine-tool line. Furthermore, it usually occupies a smaller production area. On the other hand, the dead-end accumulators have more complicated automatic-control systems and interlocks, and worse possibilities for the compensation of losses of the autom·· machine-tool line sections for which they are de· ·ed. The latter property is explained by the fact tha· ·e dead-end accumulators are connected synchron-ou· with the line-stations' work and cannot compensate idle ·andings with a duration which is less than these cycl· . Apart from this, the dead-end accumulators may acc·mulate and store for a long time a considerable amount of semi-finished workpieces. The continuous-path accumulators which are manufactured in the form of drive rotary trains are cheap and reliable. Due to the constant additional pressing of workpieces to the zone of use, these accumulators compensate all kinds of idle standings, irrespective of their duration. The continuous-path accumulators of this type can be distributed on the line with higher density than can the dead-end ones, and with the same total capacity they are able to decrease more intensively the losses of the neighbouring stations of the line. Maximum reliability and simplicity are obligatory conditions for the working capacity of both types of accumulators.

The study of accumulator operation has not yet been developed and the experience of their operation is insufficient.

In automatic machine-tool lines of building-block machines, blind-path accumulators are sometimes used. These are located in the points of technological discontinuities of the line, i.e., in the points of tipping of the workpieces or of transferring them from one station to another. The capacities of these accumulators are usually rather large and provide for a continuous run of the line during one-and-one-half to two hours. The locations of these accumulators often do not satisfy the requirements of equality of idle standings of the neighbouring stations. The operation control of such accumulators is usually completely automated and rather complex because it requires consideration of the state of the neighbouring stations in the automatic switching of the accumulator. The above-described accumulators do not always operate successfully. This is explained by both the complexity and the insufficient reliability of automatic control systems and the reasons of the organizational order, consisting in incomplete leading of the line (especially in the initial stages of operation) and the absence of necessity in the accumulation of workpieces, as well as the low exploitation level of comparatively complex accumulators.

The other type of accumulator for automatic machine-tool lines of building-block machines is a continuous-path accumulator of the driven roller path type. Such accumulators are integrally connected with the common conveying system of the line and cannot be disconnected arbi·rarily. Due to the advantages listed above, these acc·mulators are often applied by foreign companies in the ·nes of machining of body parts.

I· ·utomatic machine-tool lines for the production of ·ll-size workpieces of the rotating type (bearing rin· valves, piston pins, bush sleeves etc.), the con-tin· ·-path accumulators are mainly used. Some of the ·or instance, brush feeders for bearing rings, have a· ·e application and are sufficiently reliable and pe· designs.

E. *Control-interlocking and signalling devices*

Various control methods and different types of control devices for maintaining the necessary machining accuracy are used in automatic machine-tool lines:

(*a*) Checking procedure which is done manually by an adjuster;

(*b*) Automatic active control in the process of operation by measuring built-in instruments of the automatic machine-tool line;

(*c*) Automatic active control after an operation with the aid of built-in measuring instruments, which automatically adjust the instruments on the basis of the measurement results;

(*d*) Automatic interlocking control carried out for the purpose of eliminating workpieces which do not meet the standards set;

(*e*) Final automatic control after machining on the line.

The most comprehensive application of the above-mentioned kinds of control takes place on automatic machine-tool lines for the machining of small parts of the rotating type requiring precise machining: rolling-bearing rings, valves, wrist pins, bush sleeves and the like.

On the building-block machine lines, provision is made for a manual checking procedure, as well as for automatic control of the performed operation, with the aid of the measuring devices built into the lines. Usually, the diameter of the precise ports and the depth of precise grooves are controlled; the ovalness and taper of ports can be checked during the adjustment cycle.

F. *Tool consoles*

As a rule, a considerable number of tools operate on modern automatic machine-tool lines. On large lines of building-block machines, there are 800–1,000 tools. Variable tool endurance and the absence of operators hampers the supervision of the state of the tools. However, the reliability and efficiency of the line performance depend, to a considerable extent, upon the state of an instrument and its timely replacement. It is desirable that the tools be positively changed within a predetermined time after receiving signals from cycle counters located in special tool-storing cabinets.

The counters, after reaching the definite (for the given group of tools) minimal cycle number, warn the adjuster of the necessity of a change of this tool group; and, after reaching the maximum cycle number, they stop certain sections of the line.

Experience has shown that the use of tool cabinets and cycle counters does not always give a possibility of passing over to positive tool change. The reason for this is the wide range of variation of tool durability periods. The durability depends upon a number of factors, for example: quality of sharpening · rigidity of tool clamping; constancy of allowance; and hardness and state of the machined workpiece surface. Depending upon some of these factors, the tool durability may vary tens of times. In general, durability periods are considerably random values with a large range of variation. Therefore, the determination of real terms for tool change by guide-tables and durability formulae does not give satisfactory results.

It would be incorrect, however, on the basis of the foregoing, to neglect the use of tool cabinets and cycle counters. The tool cabinets provide convenient storage of tools, control of their availability and simplification in finding them. Counter recording of the number of pieces processed by each group of tools after resharpening is also useful. It seems reasonable to introduce, instead of positive tool change, their forced inspection by the cycle counter signals, for instance, each one-third of the rated mean period of durability. While inspecting, the adjuster should change only those tools of the given group which turned out to be blunted. Such a scheme of inspection and tool-changing decreases the hazard of breaking the tool at the minimal time of its change, because the adjuster must change only those tools which need changing.

The decrease of time losses for tool change is achieved by the introduction of the high-speed setting-in of tools and the preliminary off-line adjustment of them with respect to the size on special instruments.

In performing accurate finishing operations, the dimensional durability of cutting tools and their adjustment plays the main role; therefore, automatic tool adjustment on accurate lathe and milling operations is often introduced on automatic machine-tool lines which produce accurate workpieces. In modern lathe and boring machine tools designed for work in automatic machine-tool lines, mechanisms for the automatic change of worn or broken tools are used.

G. *Conditions and field of efficient application of automatic machine-tool lines*

The shop prime cost of mechanical workpiece machining in mechanical engineering is summed up from the main wages of industrial workers and the so-called "shop expenditures", of which the basic ones are depreciation and maintenance of the equipment, the cost of tools, electric-power, wages of technical personnel, labour and so on. The introduction of automation usually decreases expenditures for the main wages of industrial workers, whereas it increases expenditures for depreciation and maintenance, the total value of production cost being decreased. The degree to which the production cost is decreased is one of the main points of automation efficiency.

The efficiency of introduction of automatic machine-tool lines depends basically upon the following factors:

(*a*) The nature and degree of improvement of the technological processes realized in the line;

(*b*) The availability of standard sizes of specialized reliable and cheap equipment which is suited for use in an automatic machine-tool line;

(*c*) A sufficiently large scale of production;

(*d*) Rational organization of works connected with the exploitation of an automatic machine-tool line.

Various technological operations are, thus far, not suitable for automation. It should be taken into account that the modes which are performed manually with difficulty are often easily and simply carried out with mechanisms; and, on the contrary, the model easily carried out manually often require complex mechanisms in automation. This is explained by a number of principal differences between the peculiarities of the human body and the kinematics of the machine. Not a single organ of the human body has, for example, the continuous rotary motion widely used in machines. Man, however, easily performs spatial transfer, whereas the overwhelming majority of mechanisms of modern machines carry out only planar movements of working organs. Man's arms are a very perfect tool and can perform various and complex motions, whereas the working parts of a machine fulfil only relatively simple motions. It is relatively easy to automate working and idle motions of working organs of technological machines, but it is more difficult to handle auxiliary operations associated with the maintenance of machines and to include transfers of machined articles from one machine to another, loading and unloading of machines, clamping and releasing of workpieces and the like.

Great difficulties are encountered in assembly automation. Assembling operations usually consist of a number of manual tasks which are very difficult to automate. Among these are, for instance, operations associated with the change of position of workpieces and assemblies, and with their mutual orientations, the operations of pre-screwing nuts, the assembling of ball-bearings, etc. Recurring difficulties are often connected with automatic conveying and feed from bind of such workpieces as spiral springs, slotted rings and the like; these are easily coupled into chains and balls, which prevents their piece-by-piece feeding.

In the cutting machining of workpieces, some difficulties arise in the automation of precise finishing operations whose performance is accompanied by stops for change and adjustment of tools, and for checking of machine tools and devices.

Realization of advanced technological processes is largely dependent upon the availability of quality, reliability and cheapness of metal-cutting equipment. This problem can be solved by the design and improvement of the complex of standard technological and transportation equipment which is suited for incorporation into automated machine-tool lines. Due to the stability of standard types of such equipment and the larger scale of its manufacture, the cost may be considerably lowered, compared with special equipment manufactured on an individual basis. The reliability of such equipment may be higher.

With the decrease of production, the cost price of machining rises, due to increased time losses for readjustment of the equipment. The readjustment problems on automatic machine-tool lines are complicated by the necessity to readjust not only the technological equipment, but also the conveying and loading devices and feeders. Therefore, the single-item automatic machine-tool lines designed for the manufacture of a standard size of article can be efficient only in case of comparatively large batches of production. The problems of quickly readjustable automatic machine-tool lines, as mentioned ab··· , are rather complicated and are currently far from bei··· solved in a satisfactory manner.

T··e idle standings occurring in the course of running of ··· lines are the consequences of a number of factors, which are basically divided into the following three groups: (*a*) idle standings due to technical reasons; (*b*) idle standings due to organizational reasons; and (*c*) imposed idle standings.

The first two groups of idle standings are subdivided in turn into a number of smaller groups, for example, the idle standings associated with the work of tools, mechanical devices of the line, electric and hydraulic apparatuses, the lack and quality of blanks, the lack of power, the skill of maintenance personnel, waiting for adjusters and the like.

The detailed division of idle standings due to real reasons is difficult in a number of cases and may be of a subjective character. For instance, the idle standings associated with tool change depend not only upon a number of design factors, but also upon the arrangement of tool-keeping, i.e., upon the area in which tools are stored, how their sharpening and adjustment are arranged etc. The length of idle standings due to failure of mechanical, electric and hydraulic devices depends upon design factors, the quality of manufacture and assembly, the number and skill of maintenance personnel, the organization of technical services etc. The situation is often complicated by the absence of reasonable data on the determination of the necessary number of maintenance personnel, the payment system for this personnel, the organization of tool and repair services and so on.

In general, the defects in different stages of the building of automatic machine-tool lines, i.e., in design and manufacture, become most strikingly apparent during the operation of the lines. Therefore, the acquisition and practical analysis of data on running automatic machine-tool lines is an important measure which contributes to the improvement of their construction and the quality of their manufacture.

At the current time, automatic machine-tool lines are used mainly for mass production. The lines of building-block machines usually handle large and medium-size body parts, as well as parts of the roll type, crankshafts, oscillating and rear axles, connecting rods etc. Preparatory operations on milling, drilling and boring are mainly carried out on such automated lines, whereas the finishing and precise operations are mostly carried out off-line.

M···ss-produced articles of one type, e.g., rolling cont···ct bearings, valves, piston pins, straight axle sha··· and bush sleeves, tap borers and threading discs, are ···machined on automated machine-tool lines of spec···l and specialized automatic machines: lathes, grin···rs, milling and broaching machine tools, etc.

P···jects on the extension of the field of application of ···tomatic machine-tool lines are being carried out ma··· in the direction of the development of readjusted line··· which are suited for multiple-item machining. As me··· ···ned above, the use of these lines may turn out to be ··· cient even in relatively small-scale production of parts of each nomenclature, apart from their efficient application in series production.

IV. Automation of Mechanical Processing with Programme-Controlled Machine Tools

Until recently, works on the automation of small-batch production in machine-building enterprises were directed only towards solving individual problems concerning parts. However, the problem as a whole did not find a solution. The extensive development of electronics and computing techniques in the USSR has become a basis for the complex automation of industrial processes in small-batch machine-building operations with the aid of programme control of machine tools and other production mechanisms.

The programme control of metal-cutting machines makes it possible to solve a number of complicated problems of automation of universal and specialized machine-tool equipment.

Some of them are the following:

(*a*) Automation of machine tools working in small-batch or individual production, which currently comprises no less than 60 to 70 per cent of the total mechanical-engineering production, with provision for the rapid readjustment of machine tools for other pieces or batches;

(*b*) Provision of highly productive automatic machining of workpieces of complicated shape without preliminary production of master forms, special tools or camshafts, and the carrying out of similar labour-consuming works;

(*c*) Automation in series production and even in large-scale production brings about a sharp decrease of the number of special-design machine tools and the maximum unification of controlling devices, including machine tools of different designs and groups;

(*d*) Radical facilitation of the introduction of corrections into the kinematic scheme of accurate machine tools for elimination of production errors and wear compensation of individual components in the process of work;

(*e*) The foundation on a uniform constructive basis of a range of machine tools with different degrees of automation, according to the requirements of customers with different production conditions.

The systems of programme control of machine tools are divided into two classes: numerical and cyclic. Each of these classes has its own field of rational use.

Numerical systems are distinguished by relative complexity and by principally new, for machine-tool building, technical solutions and means (use of electronic circuits, methods of computing technique, complicated electric drives and data-input devices, programme writing on magnetic tapes, punch cards and tapes, etc.). Numerical systems are intended to resolve the problems associated with the processing of complex shapes.

Cyclic systems, being simpler in construction and using sufficiently commonplace means and methods for modern machine-tool building, more successfully solve the problems of unification of equipment and control devices, as well as the on-line readjustment of régimes and sizes on a running-station.

The construction of programme-controlled machines has been undertaken in Soviet industry for seven or eight years. The introduction of separate assemblies with the use of cyclic programme control in machine tools began considerably earlier, approximately at the end of the 1940's.

A. *Numerically controlled machine tools*

A whole set of numerically controlled (NC) systems of metal-cutting machine tools has been developed: these NC machine tools can be divided into three groups:

(*a*) *Machine tools for contour machining.* This group includes millers, electro-erosion cut lathes and other machine tools for machining parts of complex configuration with simultaneous interconnected motion along several co-ordinates;

(*b*) *Co-ordinate machine tools.* This group includes boring machines, co-ordinate-boring and other machines with positional controllers; the tool is set up along the co-ordinate according to the programme;

(c) *Position-control machine tools.* These are lathes for the machining of stepped shafts, millers with linear motion along co-ordinates etc.

In numerically controlled machine tools, machining of the workpiece with the use of marking or a master form is replaced by the mathematical computation of a machining programme with a further record of computation results on punched or magnetic tape. The written programme is then transferred to the shop. The operator has only to instal the blank on the machine and to switch on the programme-control panel.

As a result of two years' operation of programme-controlled milling machines, it is possible to present the following indexes: the machine time in machining parts of complex configuration was decreased by three times; and the accuracy of machining became higher, which made it possible to avoid "locksmith" finishing. The availability of facilities on the correctness of programming permitted the elimination of control measure of workpieces. The programming of speed, depending upon the allowance, increased the durability of the tool. It is now possible to increase the speed and accuracy of machining. The machine setting-up time is considerably reduced when machining a new workpiece.

Experience with programme-controlled machine tools has confirmed the possibility of considerably accelerating the machining and improving the workpiece machining accuracy. The data on the machining of sixty-seven parts on a universal machine tool and on a programme-controlled machine tool are presented below as an example.

Table 1

MACHINING DATA FOR UNIVERSAL AND PROGRAMME-CONTROLLED MACHINE TOOLS

Indexes	*Universal machine-tool*	*Programme-controlled machine tool*
Average number of operations for 67 parts (one-shift annual operation of machine)	197.0	70.0
Labour consumption (machine time, preparatory finishing time and "locksmith" finishing time) per part (hours)	23.3	4.93
Labour consumption (machine time, preparatory finishing time and "locksmith" finishing time) per article (hours)	88.6	21.8
Decrease in labour consumption per article (one-shift machine operation during one year) (hours)	—	7,154.3

The parts machined were mainly of light alloys. Examples of such parts are given in table 2. As a result of higher machining accuracy, the parts have become interchangeable.

The accuracy obtained on programme-controlled machine tools is determined, to a high degree, by the proper selection of cutting conditions and the size of allowance.

The cost and time savings in the use of such machine tools depend upon the type of parts selected and their series production. As may be seen from the tables, a large class of parts has been determined for which the use of milling machines with numerical programme controls is rather efficient. As the computation methods and recording means develop, the field of use of these machine tools will be extended.

Table 2

DATA ON MACHINING OF SOME PARTS ON UNIVERSAL AND PROGRAMME-CONTROLLED MACHINE TOOLS

Type of part	*Material*	*Blank*	*Feed (millimetres per minute)*	*Accuracy of machining (millimetres)*	*Marking machining time (minutes)*	*Machining time on programme-controlled machine (minutes)*	*Notes*
Guard	Steel alloy	Sheet	300	± 0.07	21.0	6.0	
Sector	Steel alloy	Sheet	800	± 0.01	126.0	27.0	
Body	Steel alloy	Ingot	600	± 0.1	Decreased 4.2 times	—	
Shoe	Steel alloy	Forging	300	± 0.1	Decreased 3.5 times	—	
Fitting	Steel alloy	Compressed profile	300	± 0.1	8.5	5.0	
Link	Steel alloy	Sheet	450	± 0.1	65.0	12.0	
Pintle	Steel alloy	Roll	175	± 0.05	19.0	4.0	

A characteristic feature of the current stage of machine-tool programme-control development in the USSR and abroad consists in the use of these machine tools for individual workpieces, as well as for small-batch and series production.

In small-batch and series production, these machines provide from two to three times greater productivity, compared with reproducing machines, due to the smooth speed control in passing along the contour.

Other advantages are the facilitation of adjustment (there is no need to advance the guiding-block with respect to the workpiece), the better use of working surfaces of the machine and the elimination of storage space for guiding-blocks. The latter is of particular importance for large machine tools.

The experience of machine-building plants has shown a high efficiency of such machines in the production of lots of parts ranging from 1,000 to 10,000 pieces at machine times of processing ranging from 10 to 30 minutes per part.

Another specific feature of programme-controlled machine tools, which has been clearly revealed within the last few years, is the construction of sections and shops equipped with these machine tools.

By grouping the programme-controlled machine tools in separate sections, their use becomes still more efficient. This has been especially successful in a number of machine-building plants. Those plants which combined programme-controlled machine tools into sections were able to provide for their uninterrupted operation. With more than five controlled machine tools, the establishment of a technological group for designing and writing programmes at the plant, as well as the use of general-purpose electronic computers, becomes justified. When a plant has a considerable number of programme-controlled machine tools distributed at different shops, the provision of multiple-machine services, personnel training and maintenance becomes complicated.

Programme control leads to the possibility of employing workers with less skill and to a decrease in manual labour requirements.

A number of the programme-control systems which have been developed in the USSR are applicable to various types of machine tools (drilling and milling machines, lathes etc.)

The milling machine tools of Model 6H1319-2, which are equipped with a step programme-control system, have been used in industry since 1960 and are highly appreciated by the users. The system is fully transistorized. The machining programme is written on magnetic tape. The world's highest speed stepping motors and original hydraulic servo-systems have been developed. The step-control system has, at the same machining accuracy, fewer electronic components than other programme-control systems performing the same functions. This system was borrowed from the USSR by the Japanese Fuji Company.

The Experimental Research Institute of Metal-cutting Machines, in co-operation with a machine-tool works, has developed a range of highly productive and precision programme-controlled machine tools. The milling machine plant in Gorky has begun the manufacture of multiple co-ordinate milling machines of four size-types with a step programme-control system.

The use of a programme-controlled electro-erosion machine tool designed for the shaped cutting of a die from hard alloys has proved very effective.

Programme-controlled systems for unique metal-cutting machine tools have been developed and commercially used.

The factories of the heavy machine-building industry produce heavy plano-boring and plano-milling programme-controlled machine tools (the longitudinal travel is equal to 25 metres).

Programme control changes the aspect of metal-cutting machine tools. Machines with entirely new kinematic schemes have appeared, for instance, four- and five-co-ordinate millers, four-co-ordinate turret lathes, drilling machines with turret heads and combined machines with automatic tool change.

At the current time, the whole complex of programme-control equipment for machine tools has been developed. This complex includes the facilities for programme preparation, consisting of puncher, code converter and co-ordinatograph for control plotting of the given component configuration on paper. The programme preparation sets are available for both individual machine-building plants and interplant centres where programmes are prepared.

To ensure better saving of the programming time, a system of automatic programming with the use of high-speed electronic computers has been designed. In this case, the programming time is reduced from five to ten times, as compared with manual programming, which increases still further the efficiency of the use of programme control.

The computing centre established at ENIMS fulfils orders for compiling and writing programmes for plants. The establishment of such centres has been also planned for other cities.

Programme control makes it possible to solve many problems of production organization in a new way. For instance, it is possible to write a programme while a new component is still in the process of design and to pass it over to the manufacturer together with the component drawings. If the production of a new machine is carried out by several manufacturers, the design office provides them simultaneously with an identical programme.

In this case, the numerical programme is written by the leading enterprise in manufacturing a pilot machine and is given, together with technical documentation, to the plants for series production of the machine. Thus, the commercial production time of new types of machines is considerably reduced. This yields a great economic benefit.

The Institute has developed standard methods for manual and automatic programming of two co-ordinate processing.

In the case of manual programming, the design data are recorded in tables and the tape is then punched. The punched tape is fed into the interpolator, which yields the programme in the form of an impulse sequence. This programme is recorded on magnetic tape. In those cases when the interpolator is installed at the machine tool, there is no need to have an intermediate programme carrier.

For control of a programme, it is plotted on the co-ordinatograph. Essential facilitation of programming is provided by a circular interpolator.

In programming with the aid of an electronic computer, the programme is obtained at the output in the form of a punch card.

The punch card can either be used directly for machine tool control, if the built-in interpolator is available, or can be used for recording on magnetic tapes. The use of magnetic tape is reasonable in small-batch and series production if a comparatively small number of different programmes is required during the year.

The enterprises using programme-controlled machine tools should be equipped with complete facilities for writing programmes.

In commercial use of numerically controlled machine tools, one should be aware of the fact that:

(*a*) Numerical-control equipment, while providing an essential extension of technological potentialities, is, at the same time, a principally new type of equipment which differs from the existing one by the quantitative and qualitative complication of the electrical equipment and the necessity of special preparation of programmes, which requires special skill of personnel and the application of complex equipment;

(*b*) The application of such equipment is inefficient without very careful technological preparation to determine the nomenclature of the components, loading of equipment and examination and correction of the technological process with regard to new possibilities and requirements;

(*c*) The application of programme-controlled equipment is inefficient without making special arrangements for repairs and maintenance, for establishment of special programming services and for training of maintenance personnel. Only the thorough realization of all the organizational and technological measures in a full complex can provide for efficient operation of numerically controlled equipment;

(*d*) The greater effect yields a group use of programme-controlled machine tools;

(*e*) Even in the use of a general-purpose electronic computer, the programming should be carried out with the participation of a skilled plant technologist.

For provision of the most rapid commercial use of numerically controlled machine tools and to obtain the economic benefits, it is necessary to make the arrangements discussed below.

It is most economical to concentrate programme-controlled machine tools in groups of not less than five or six. It is necessary to group the plants with similar technological processes and to begin commercial use of programme-controlled equipment with most advanced works, arranging it in an item-classed or specialized section. Such a section should include, as a rule, some units of programme-controlled equipment; the organizational and technological principles of programme-controlled machine operation should be checked, and some recommendations as to equipping other enterprises with programme-control facilities should be worked out.

Secondly, taking into account the novelty and complexity of programme-controlled equipment, as well as the difficulties involved in programme preparation, it is expedient that machine-manufacturing plants should provide users, at least during the initial stage of using the machines, with assistance in repairing and adjusting the programme-controlled equipment, in training personnel and in writing programmes for the processing of complicated parts with the use of computers.

B. *Cyclic programme-controlled machine tools*

The systems of programme control of cycles and régimes of machining differ from numerically controlled systems mainly by the absence of numerical programming of sizes and, consequently, displacement or position transmitters, as well as electronic or complex relay circuits ensuring the obtaining of desired sizes.

In cyclic systems, the sizes are controlled, in most cases, by track switches of either conventional or special (small-size) types, which are effected by transposed stops. Such an arrangement of cyclic systems provides, on the one hand, for their essential simplification, as compared with numerical systems, and, on the other hand, defines the field of their use, mainly in batch production.

It is true that such machine tools only permit the machining of components with contours which are parallel to the axes of tool co-ordinates, but the operation of such machine tools is extremely simple and their cost is only a little higher than that of universal machines.

Such machine tools (of practically all groups) are manufactured in great quantities by the machine tool industry. As the number of operations which can be programmed increases, the field of use of these machines will be extended.

The prevailing commercial use of cyclic-control systems is dictated not only by their lower cost, simpler arrangements for commercial production and easier manufacturing and adjustment, but also by the absence of the necessity for programming services and by lower maintenance cost.

One should take into account, however, that the economic efficiency of commercial use of these machine tools and the level of production automation is considerably lower than that of machine tools with a numerical system of programme control.

C. *Development of numerically controlled machine tools*

The advance of programmed control of machine tools tends towards the development of a self-adjusting system. In a self-adjusting system, the feed is set up according to the condition of maximum machining accuracy, productivity or tool endurance.

Here, the programming and computation of machining technological parameters are considerably simplified, and the scattering of machining parameters (difference in the hardness of metals, allowance of blanks, blunting of tools etc.) is compensated.

These systems are particularly important for work-pieces of hard-to-machine materials. Many types of machine tools are equipped with self-adjusting combined systems. The operation of such machine tools has shown that the insignificant complication of the control system for providing feed self-adjustment is fully justified.

Together with control-system improvement, the introduction of automatic tool-change for increasing the efficiency of programme-controlled machine tools is rather essential.

D. *Technical and economical indexes of operation of numerically controlled machine tools*

On the basis of published sources and the analysis of the operation of numerically controlled machine tools (domestic and foreign), the following average indexes of their operation can be outlined:

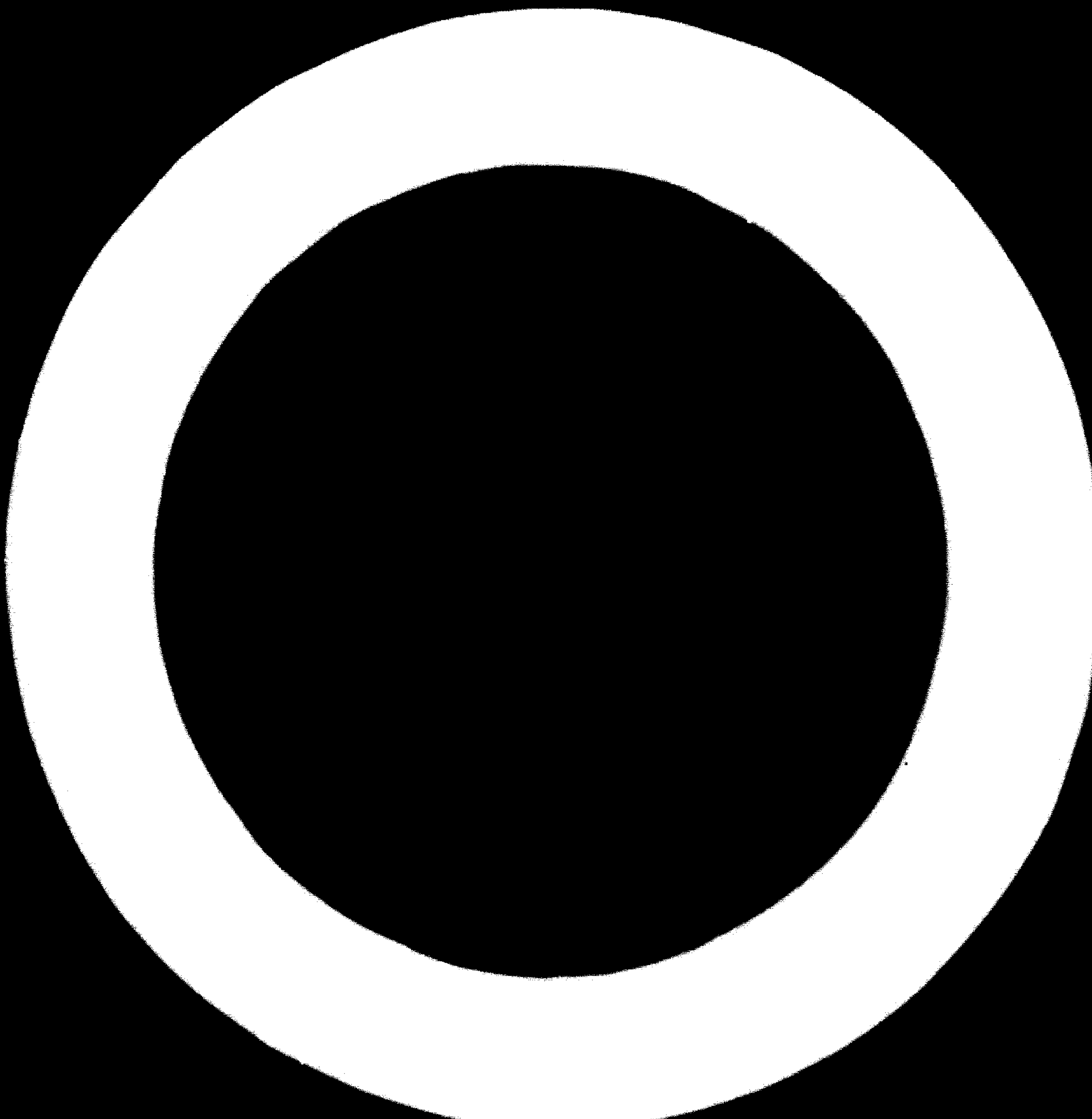
(*a*) Productivity increases by two to six times;

(*b*) Pay-off: up to two years, 20 per cent; up to three years, 67 per cent; up to five years, 13 per cent;

(*c*) Technical and economical efficiency in the use of numerically controlled machine tools (according to published data on experience in the United States of America), is as follows:

(i) Labour cost decreases by 70 per cent;
(ii) Tool cost decreases by 67 per cent;
(iii) Productivity increases by 51 per cent;
(iv) Improvement of product quality increases by 42 per cent;
(v) Improvement of utilization of means of production increases by 26 per cent;
(vi) Other expenditures decrease by 31 per cent.

Of all the currently existing technical solutions of automation of mechanical processing in small-batch and series production, the use of programme-controlled machine tools is considered to be the most efficient from the economic point of view. Apparently they will have good perspectives in the future.



PRODUCTION AUTOMATION IN DEVELOPING COUNTRIES

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INTRODUCTION

Conflicting reports of social upheaval, on the one hand, and of vast increases in productive capacity, on the other, arise when automation of a process or an industry becomes the point of discussion.

For present purposes, much clarity may be obtained by directing attention to the basic ingredient of all automated processes, rather than to specific details of one application. A machine or process is not automated, in the sense used here, just because it may have some electronic controls, a variety of sensors and actuators, or an impressive array of fixtures—although most automated equipment makes use of these devices. The power of automation comes from the design and organization of intelligence, processing skills and control features "within" the equipment, rather than having these necessary ingredients of production added at will by human intervention at the time a product is made.

The more it is possible to rely upon this pre-designed, built-in and self-controlled part of the production operation, and the less decision-making and special action the operator is required to make at the instant of execution, the more automatic, or automated, one may say the process or equipment is. For example, of the wide range of automatic metalworking tools available, such as those displayed at the Machine-Tool Show held in Chicago (United States of America), 26–30 September 1965,[1] those which are more "autonomous" and can work alone would be considered more automated than those which require more immediate direction.

This point is central to the thesis of this paper, which is that automated equipment and processes, contrary to popular belief, can provide a net gain to emerging nations in both their economic and their social development. The gain comes when packaged intelligence quickly and inexpensively supplements or provides otherwise scarce or unavailable production and control skills, thereby balancing over-all productive ability and thus increasing in total the number of workers who can be put to work.

Similar arguments have long been made for the selective use of scarce human skills. For example, the division of labour, as proposed by Adam Smith in *The Wealth of Nations*, was to be beneficial because workers who specialized in one job would, by habit and experience, become more proficient and therefore more efficient in that single task because they did none other. In this way, the set-up and learning time required when going from one job to another would be eliminated. This was a forward step in the advance of human productivity, but not the critical point in terms of cost, or in the use of rare skills.

Charles Babbage, who thought in more modern terms, agreed with Smith, but argued more cogently. To him, the real benefit in the division of labour lay not only in the learning-time saved for the average worker, but also in the economical employment of more highly priced talent. When a single worker completed all the operations required for the production of the finished product, he had to be paid at a rate determined by the individual or selective skills needed for the completion of specific job segments. Thus, the worker of highest skill, often required in small quantity of time per unit of production, could be rewarded individually at a differentially higher rate than the worker who performed "ordinary" operations. The net result was to reduce the total cost per unit of the product, since less expensive labour could be assigned to the majority of job segments requiring lesser skills.

For the purposes of this paper, the argument proposed by Babbage can easily be extended to cover over-all productivity. If the highest skill required for the production of a given product is in scarce supply in the face of abundant "ordinary" labour, then this scarce skill becomes the limiting factor or bottle-neck in the total productive potential of the operation. Not only can the higher skill that is scarce be highly rewarded in this instance, but any strategy that will make available more of the scarce skill will also multiply the total productive ability of the economy. Greater employment of more ordinary skills, as required in the usual technological distribution of job segments in a total job, follows naturally as the obstacle to total productive potential is removed. Moreover, the more rapidly such an obstacle can be removed, the more rapidly can such productive potential be realized and the more rapidly can the average citizen (who may be unemployed or employed "unproductively" if the rare skill is absent) improve his lot.

If the rare skill is not present in the developing country and if the time required to produce that skill is long, then the use of an automated device or process which can supply the needed skill in a package (by virtue of the intelligence designed into the machine or stored in programmed instructions within the machine) provides a powerful strategy for accomplishing the ends Babbage had in mind. In those terms, many unbalanced productive

[1] For a report, see *Business Week* (25 Sept. 1965), pp. 47–53; and [illegible] *of Engineering* (Nov. 1965), pp. 109–113.

operations and many emerging nations with an unevenly developing economy find themselves in the position of Shakespeare's King Richard, shouting for "A horse! a horse! my kingdom for a horse!". The use of automation to provide a selective, yet a rapid infusion of scarce skills into the productive enterprise or developing economy, may be the "horse" that is needed; and, in this sense, the use of automation provides one obvious area of interest for planners who are beset with the dilemma we have described above.

1. Operation of automatic controls

To emphasize the implications of this thesis, one may mention some examples from the metalworking industries. In what way does an "automated" machine tool provide scarce skills? How is "intelligence" stored in these machines? How can they be "taught" skills in a flexible, swift and economic way?

As an example, consider the numerically controlled machine tool, so-called because it receives instructions on a step-by-step basis from a pre-recorded list which may be stored on punched cards, in the holes of a paper tape, in the magnetic spots of an exide-coated film or in other media.[2] The simplest and smallest of these devices (which is used for simplicity of illustration rather than for other reasons) is the numerically controlled punch press (or drill press) which is used to create holes or other shaped apertures in a metal sheet. This is a "point-to-point" machine, since the operator (or the tape instructions) must provide only the specific hole locations (x and y co-ordinates) to which the tool or the work must be indexed before the tool operation (a z-co-ordinate motion) takes place.

With such machines, construction design normally fixes the vertical tool axis rigidly above a table which is free to move in both the x and y directions relating to the tool axis. Actuators, usually with "feed-back sensors" to assure correct table position, move the table in response to co-ordinate information provided by the input tape. To perform work, the workpiece is bolted firmly to the movable table (which is usually a frame that allows tool penetration through the workpiece), the table is indexed to the x-y position specified by an input instruction, the tool is actuated to produce a hole and the table moves to the next specified x-y position, continuing the pre-recorded or stored input programme of steps until the job is done.

The physical construction of the machine is less important to the present discussion than is the construction of the programme of steps the machine is to follow. For example, suppose four ½-inch holes are to be punched in a 10-inch × 10-inch metal plate. Assume also that the machine operator has set up a ½-inch punch in the machine, so that workpiece positioning is the only remaining operation required. If one sets the lower left-hand corner of the workpiece as the reference point $x = 0$, $y = 0$, and if one wished to punch the holes with a centre 1-inch in from each edge at each corner, one could prepare a series of instructions as follows: "x1.00, y1.00, z; x1.00, y9.00, z; x9.00, y9.00, z; x9.00, y1.00, z".

In the sequential list of instructions, the table would assume the stated x and y positions (in inches from the origin); the tool motion would then be actuated by the z-instruction; and the subsequent movements and tool operations would follow in order until the list was completed. By constructing the machine with a turret containing a number of different tools and selecting the desired tool by an appropriate z-instruction, such as 1z, 2z etc., the versatility of the machine could be enhanced, and a variety of products could be made without the need for manual tool change.

Now the important point in the operation of this machine is that the machine's programme of instructions, once written, need never be written again. If the operator wants to produce more punched sheets of the same type, he simply places new sheets on the table and runs the instruction list through the machine's control "reader" (a device that converts the input tape into table and tool motions) again and again. The skill needed to cause table movements to precise locations is not left to the operator, but is built into the machine and the programme of machine instructions.

It is, therefore, possible to produce reliably and accurately identical products and to predict the time required to produce each of them, since the control of the machine is left to the instruction list and the machine, not to the whims of the operator. Even further, in specifying how the product is to be made, its designer may eliminate the usual blue print and the operator does not have to consult one: everything that needs to be known is contained in the instruction list and a few simple material loading instructions. Even though some skill might be needed to set the original reference point $x = 0$, $y = 0$, this can be fixed for a large class of products (say, all rectangular sheets of metal within the table capacity of the machine) by providing precision steps at the origin, which are set once by the manufacturer or by an expert set-up man.

Continuing with the same example, suppose that in addition to the instruction list given above, the operator had available to him a file of instruction lists, reduced to the paper tape form the machine could read. Then, as various kinds of plates were required, the operator could extract from his file the appropriate instruction list and material-loading instructions for each product, load the machine with material and programme, set the machine in motion and so produce the variety of products needed without further intervention. The file or "memory" of jobs for which instructions are available could, of course, be augmented by the product designers as time went on so that a large library of possibilities would be available to the operator. The instruction tapes, which could be prepared anywhere in the world and dispatched to the operator in compact form, provide the intelligence for operating the machine.

In addition, the designer of new products benefits from

[2] The historical antecedent of the numerically controlled machine tool is the Jacquard loom, which is used to weave intricate patterns in cloth under the direction of holes punched in cards. Although this device works mechanically to feel the pattern holes in the cards, rather than through electrical signals as do the modern numerically controlled machine tools, the concept of the "stored programme" is the same.

the stored instruction lists which have already been prepared. New product designs that contain major "pieces" of old designs (as is usually the case) can be "pieced together" by editing and "pasting up" combinations of what has already been done. There is no need to repeat the clerical drudgery already accomplished; thus, both design and production lead times are drastically reduced. (This form of product design may be compared to "adult learning" which usually proceeds by combining large blocks of previously acquired knowledge, rather than the bits-and-pieces combined by the infant.)

The example of the simple numerically controlled point-to-point machine illustrates how intelligence can be built into the automatic machine by a combination of machine design and programmed-instruction design and storage. Although somewhat more complex in application, the same concepts may be extended to metal-removal tools that operate continuously over a surface, for example, milling machines, and to the design of machines that combine point-to-point and continuous abilities.[3]

For example, using the intermediate services of an electronic computer, it is possible to create the specific step-by-step instructions required numerically to direct a "continuous" milling machine according to the requirements of a mathematical formula. Such machines can cut complex mathematical sections having far greater quality and precision (with respect to the mathematical specification) than even the most skilled machinist could hope to accomplish by "hand" direction. Therefore, these machines have wide application in the production of aircraft parts, turbine blades, die sets and other products requiring mathematical precision at every point on a surface.

II. Organization of work of automatic machines

It is now convenient to extend the discussion of automatic machines to the organization of the work and the tools used. The purpose of this detour is to illustrate the range of flexibility available with different forms of automated organization.

In the mass production of a single product that has both high volume requirements and a stable demand, the automation of the process follows the organization of an assembly line.

For example, in high-volume metal-removal processes, it is common to develop highly specialized tools which are "fixed" in a given physical location. The work is then moved from one fixed tool-station to the next. The capacity at each station is adjusted so that a smooth flow of work can be achieved. When the material handling can be mechanized, so that there will be a synchronized movement of work between stations, the total production line can be made automatic, with automated self-control features built in as desired. The "transfer machines" commonly used in the motor-car industry (to produce the many operations required to machine an engine block) are an example of this route to automation.

At this extreme of automation, the intelligence of the productive process is designed into the fixed specialized tooling and the fixed sequence of work flow. Thus, although this product flow arrangement results in the lowest production cost per unit at high volumes of production, the set-up is rigid. The automated line can produce products with only a small variation in design, if any. Small changes in design require variations in tooling (which is not possible when the tools are extremely specialized and fixed in position). Furthermore, any change in product type usually "unbalances" the line, even if the same specialized tools could be used on different products.

The initial cost of this approach to automation (which corresponds by analogy to the installation of a chemical-process plant, which produces volume, as opposed to the operation of an apothecary shop, which produces variety) is also relatively high—in the millions of dollars for typical installations.

Nevertheless, the "rigid" approach to the automation of an entire process has its place in the production of basic raw materials (steel, glass, synthetic materials), utilities (water, electric-power, sanitary disposal) and widely used consumer goods (radios, electric-meter housing, water-pumps). It is in automation of this kind that one becomes concerned about the gross elimination of jobs.

Thus, the "rigid" approach to automation may be appropriate in an emerging economy if there are a certain few "high-volume" industries or processes which limit the productive possibilities of the rest of the economy.

In such cases, the complete elimination of that bottleneck—even though automation would eliminate job possibilities in that sector of the economy—can have a beneficial over-all effect. Even though one may have to deal with larger "blocks" of automation, a deliberate search for the large, critical blocks which deserve complete automation in the economy is sensible strategy if there is a large imbalance in the productive system of the country. Indeed, the complete, rigid-automation approach may be the only possible alternative for those productive sectors of the economy which are not easily improved by adding more human workers, regardless of their skill (e.g., in electric-power generation).

By contrast, the numerically controlled machine tool, previously discussed, is a flexible machine. The organization of the machine follows the work pattern of the individual craftsman. In most designs, the workpiece is fixed, and general-purpose tools are programmed to come in sequence to the single workpiece and to operate upon it.

For example, a machine tool (the NumeriCenter-H) made in the United States of America by the firm of Giddings & Lewis provides as many as sixty-three different milling, drilling, boring and tapping tools from a turret ring to operate upon the workpiece under instructions from the control tape.

Although this type of equipment is not usually economical for high-volume production of a given item (various studies show that optimum production runs

[3] For illustrations and case studies of the use of this type of equipment, see H. C. Morse and D. M. Cox, *Numerically Controlled Machine Tools* (American Data Processing, Inc., Detroit, Michigan).

with such equipment are in the range of 50–100 units, depending upon the job), it does allow the greatest flexibility for producing a variety of items at essentially no set-up cost other than the one-time cost of preparing the instruction tape for each product type. Clearly this form of tool organization is ideal for job shops where change-over time usually reduces effective machine capacity, where the length of the production run will not justify special tooling and where extreme precision and quality may be required.

The numerically controlled machine tool, in addition to its flexibility of application, is an order of magnitude less expensive to acquire than the transfer machine or "packaged process". Prices currently quoted in the United States of America range from $10,000 to $300,000. For example, the price of the Kearney & Trecker Milwaukee-Matic Model Eb, a numerically controlled machining centre with some contouring ability, averages about $117,000; the Pratt & Whitney Tape-O-Matic point-to-point Model C tape-controlled drill is about $25,000, with some types costing less than $10,000. Semi-automatic equipment of the same type is, of course, correspondingly less costly.

Moreover, jobs are not necessarily eliminated by this type of equipment. One numerically controlled machine tool may be used to provide the skills which will amplify the ability of many manual portions of a production process. The effect is usually to shift the required job skills, however, from the manual operation of the machine itself to the preparation of the instruction tapes for new jobs, if these are done locally.

Finally, as an intermediate between the two extremes mentioned above, one may have semi-automatic devices to serve as semi-specialized work-stations that yet may be arranged flexibly in the production work-flow to eliminate bottle-neck operations.

Typical of this class are the inspection and test stands which are often inserted in a production sequence to assure quality, to maintain dimensional tolerances and to provide other production tests which may require higher than average consistency, precision or skill.

Use of such equipment with some programmed features often permits a complex test to be reduced to a simple "yes-no" result, or permits a series of such tests to be performed without human intervention.

Moreover, general-purpose equipment of this type can be made more efficient by the use of specialized, yet inexpensive, jigs and fixtures that allow the worker to adapt manually the general machine to the specific requirements of a given product. For example, precise optimal comparison of the dimensions of a part may be made against a template that provides the dimensions for that part. The intelligence for use of this type of comparator, a general-purpose device, resides in the template prepared and in the file of templates which would be provided for checking a variety of parts.

The semi-specialized work-station machine is another order of magnitude which is less costly to acquire than the general-purpose numerically controlled equipment. In this class, one may include semi-automatic lathes, specialized work-stations for critical steps in a work flow and many mechanized material-handling machines. Comparable purchase cost for such equipment is in the range of $2,000 to $50,000.

This class of equipment is also in many ways the most effective in increasing the efficiency of a manual series of steps, if the level of the economy or other consideration dictates that only a small block in the process can be automated. Usually, the majority of job skills are not affected by the introduction of such devices; only the operator of the specialized station must be trained to use it, and the relatively inexpensive automation of the selected step in the process may enhance the over-all productive capacity of the manual system, so that in the end the number of manual positions available may be increased.

With this background, one may conclude that the latter two classes of equipment are of more interest if one is seeking to balance or partially to automate a given production process, rather than completely to automate a critical industry.

Moreover, it may be possible to find a critical step within a critical industry that, when automated, will doubly multiply the over-all result for the economy. Given the industry, the methods for selecting those process operations which should be automated are work-flow analysis, studies to pin-point critical scarce skills and isolation procedures to indicate the process steps which require great precision or which currently generate undue waste of scarce materials.

When one can find critical steps in a productive process which—when automated—will greatly amplify the results of the automation effort, the introduction of automatic devices may proceed on a step-by-step basis, with major attention being directed to a few critical steps in a process. When one cannot find such critical steps, it may be necessary to abandon the idea of automation or to turn to the more heroic measures of complete automation of the entire process.[4]

In summary, there is a wide range of automation possibilities in terms of equipment types, methods of organizing automation efforts and configurations of automated steps. Thus, it should be clear that the first problem encountered when introducing automation is in decision-making. The key to the effective automation of an industry or a process is to select from the wide range of possibilities the degree of automation and the point of automation in a given economy or process that will provide the greatest returns for the effort expended. This selection process and the difficulties associated with it represent an essential planning step, particularly in the emerging economy, since random automation is seldom beneficial and may, by its consumption of scarce resources

[4] Historically, the mechanization of industrial operations has usually gone forward on a piecemeal basis, with an improvement in organization here and a new piece of equipment there. Without some care, however, this approach can lead to unbalanced development for the production system as a whole, and recent trends are to apply systems analysis to the problem of mechanization and automation, so that over-all improvements may be realized in a controlled manner. See M. K. Starr, *Production Management: Systems and Synthesis* (Englewood Cliffs, N.J., Prentice-Hall, 1964) and V. C. Hare, Jr., *Systems Analysis—A Diagnostic Approach* (New York, Harcourt, Brace and World, Inc., 1967).

in an unproductive manner, be ruinous when capital is limited.

For example, to decide upon the priority of investment in a given equipment type, or for given points in a process or economy, one must be able to rank or scale the available alternatives by a "measure of effectiveness" or a merit rating showing the contribution of each alternative to the over-all investment or to social goals. With such a measure of effectiveness, one would then usually prefer first that alternative which, for a unit of capital invested, produces over a given time period the greatest marginal increase in the chosen measure of effectiveness, assuming that the absolute increases possible are not unduly restricted. A somewhat simpler criterion would be to eliminate from consideration all those alternatives which produce less than a threshold or cut-off value in the measure of effectiveness, which might be, in the simplest case, a minimum return on investment of X per cent, or a minimum increase in productivity of Y per cent.[5]

In either case, it is necessary to know the benefits and drawbacks of automation which will, to a greater or smaller degree, affect the measure of effectiveness, and one must know some of the major constraints of the economy or process that will either require minimum performance or limit maximum potential.

III. Economic considerations

A. *Advantages of automation*

In addition to the rapid acquisition of advanced technology and productive output in selected areas of need, the advantages described above may be amplified.

Thus, the quality and precision of a given operation, the reliability of production schedules, the length of design and production lead times may all be improved by automation. In many cases, the cost of jigs and fixtures, and the skill required to make them, may be eliminated or reduced. Moreover, the "programme of instructions" prepared for an automated machine does not wear out like the usual jig or fixture, so an accumulation of technical, cost and control data becomes available for management use as a by-product of continued use of programme-controlled equipment. Each new job adds a permanent increment of growth to the versatility of the operation.

Other advantages include reduced factory-space requirements, improved safety and the elimination of finished inventory losses due to engineering changes (since the product may be made very nearly to order). With stored programme equipment, the need for blue prints, costly templates, process sheets and detailed drawings is eliminated, and the machine programme that replaces these production instructions may be prepared anywhere and acquired in large blocks or files which provide immediate machining capability. When the automation of a critical process step results in a high degree of utilization of the automated step (as it must to justify automation), the productive output of the equipment rapidly amortizes the investment made in it.

The total cost of machines for a shop may also be reduced by the selective use of automation, since one automated machine may replace many others. Since the output of the automatic machine is predictable within narrow limits, management ability to control the automated application is enhanced, cost estimates are more accurate, machine loading and scheduling problems are alleviated and cost-accounting practices can be sharpened.

Automated equipment using stored programmes of instructions permits the production of a wide variety of products in short runs at almost "mass production" costs. This fact is important to the industrialized economy (in the United States of America, an estimated 75 per cent of all items machined are in runs of seventy-five units or less) and even more important to the developing economy, where short runs are likely to be even more prevalent. The development of marketing strategy, vendor and subcontractor relationships, research and development practices and factory management methods are all affected by this new ability to handle variety economically.

Although it is not possible to give a general prescription for the mixture of advantages that will be more relevant in a specific application, a review of the benefits suggested will usually reveal those which are of most value. As a general statement, the ability to share world technology and management science rapidly and at low cost (by virtue of the acquisition of stored programmes of machine instructions) would come near the top of such a list. Although operator training is required for the automated equipment, the time required for that training is measured in months, not years, and far fewer workers need to be trained. Moreover, as will be seen later, the training differs substantially in kind from the historical tradition, which, with the current "state of the art", is obsolete.

B. *Disadvantages of automation*

Several constraints limit the advantages of automatic equipment, and these should form another phase of analysis in any application. Automatic equipment, when used in a process step, produces a high volume of output and depends for its profitability upon the efficient use of the equipment, either by itself or by removing an obstacle and increasing the potential of a larger productive system. Certain prerequisites to this result are apparent. The equipment must receive adequate, reliable and consistent input volume, either of raw materials or semi-finished products from a previous production stage. The equipment must have maintenance to keep it in operation. Furthermore, the equipment requires "service" supplies, such as electric power, lubrication and coolants, which are reliable and stable to specification. The automatic machine or process must also find consumers who can

[5] These points are well made from the economists' viewpoint by R. Dorfman, P. A. Samuelson and R. M. Solow in *Linear Programming and Economic Analysis* (New York, McGraw-Hill Book Co., 1958). The same arguments are stated in military terms by C. Hitch and R. McKean in *The Economics of Defense in a Nuclear Age* (Cambridge, Mass., Harvard University Press, 1960). The decision-making problems of the developing country operating under a limited total national budget are essentially

absorb its large output, so that the flow of production may be maintained at a high total value (even though the total may consist of a variety of short runs).

These constraints suggest several organizational requirements in using automatic equipment. The source of raw material must be reliable. If great distances and variable transportation times intervene between the process and the raw-material source, some raw-material inventories will be required to support the automated operation. The maintenance and service supply requirements (as well as transportation requirements) also suggest a geographical clustering of automatic equipment in a given locality so that scarce maintenance facilities, personnel and parts may be shared—and the clustered volume of service needs can justify or exploit adequate power and similar resources. Even in industrialized economies, such industrial clustering is found for similar reasons. As a simple example, if scarce maintenance personnel must travel between distant service locations, not only will their effective capacity be reduced, but the equipment to be serviced will be idle longer and peak crises will be more difficult to avoid.

Although the basic constraints outlined are stringent, they are not insuperable. They do argue again, however, for the selective use of automation first in critical process steps and industries, and then in locations where the stated constraints may be satisfied.

After selection of the step and location which are the potential subject for automation, two additional problems arise: they are financial and social. The latter is the more serious.

The block of capital required as an initial investment in automatic equipment may represent a substantial commitment for an emerging industry (or economy) as a percentage of the total reserves currently available. This fact, coupled with political unrest, raises immediate questions about the stable growth of the emerging economy (or industry) which will undertake the commitment for purchase or lease of the equipment. Possible local and international instabilities raise risk questions for both the seller and the purchaser of automated equipment.

As one solution for the seller, to date, most machine tool producers in the United States of America make sales chiefly to divisions of large international corporations which, in their total operations, provide the financial stability required and protect the seller from local upheavals. Other sources of automatic equipment, which today are numerous, have effected similar guarantees in the form of raw-material commitments, trade concessions and the like.

Apart from the acquisition problem, which is again discussed below, the problem of capital commitment must also become an important question for the purchaser, who, in the face of instabilities in raw-material supply, market or political regulation, may decide on the grounds of risk (rather than average increases in production potential) not to exploit the possibilities that automation can provide. Stable economic growth is, then, another prerequisite for automation—as it is for any major capital investment in a single facility.

Several social problems also plague the proposed use of automatic equipment.

In many countries where capital equipment is scarce, a pride of personal ownership develops, which runs counter to the efficient use of capital equipment. The artisan owns his own tools and lets no one else use them. Frequently, this attitude carries over to capital equipment. The owner of the only motor-car in town may refuse to let others drive it for fear of damage; and, unfortunately, operators of locomotives, aircraft or automated machine tools may, by tradition, also adopt the same attitude, limiting the use of scarce equipment to those hours when personal attention of the single operator or crew can be provided. Since continuous utilization is required of most large-scale capital equipment, this social pride of possession must be overcome to employ the equipment successfully in the developing economy.

Next, the development of the semi-specialized skills required to operate and manage the automatic equipment often produces a thin layer of *élite* workers and managers, leaving a vast gulf of education, experience and income between the *élite*, whose efforts and decisions are multiplied in effect by the machines, and the vast majority of workers in the population who cannot comprehend the objectives, actions and attitude of the *élite* segment. In short, the introduction of automated equipment into a developing economy can aggravate the relative disparity between one social group and another, which may already be the cause of much economic and political instability in the society. Indeed, this result may occur even though the absolute lot of the average worker is improved, because the relative spread in social and economic positions of the average and the *élite* workers has increased. Symptoms of increasing relative deprivation appear in the early history of most economies undergoing industrialization, as conspicuous power, affluence and control are embraced by the few. The more rapid industrialization offered by automation can heighten the rate at which the relative distance between groups increases and make the gap more apparent. Measures to offset the social instabilities caused by this gap must usually be taken by administrative officials. As a tragic extreme, the failure of Louis XVI and his officers to notice and care for the motivating effects of relative deprivation ended in the French Revolution and his death.

The manner in which the training necessary for uplifting an economy shall be administered is a final point to consider in view of what has just been said. One problem occurs with the *élite* group mentioned above and another with the average worker.

Most frequently, the *élite* group's training or education must be conducted abroad, because of the limited resources of the developing country concerned. These few workers, upon whom the success or failure of the automation effort rests, always acquire some of the social tradition and attitudes of their hosts, in addition to their technical skills. Moreover, later dependence upon the producers of the automatic equipment selected (usually the host country) for technical advice, repair services and further instruction may lead to a political and social loyalty which is foreign to the desires of the developing economy. This is an ever-present problem in training, not unlike the concerns of a father who sends his son away to school. Again, however, automated equipment and its possibly critical nature in the economy heightens a normal worry into one that can become a major concern in the introduction of automation into an emerging economy. With extreme automation, control of the *élite* technicians means physical control of the productive facilities, and the administration and placement of this control may decide the political fate of the economy. There may also be difficulties in maintaining the physical presence of the trained *élite*, as well as their loyalty. Since there is a world market in technical talent, there will be substantial pressures for the *élite* to seek the highest wage for their new skills—and the source of the highest wage usually will not lie in the developing country.

For the average worker, the administration of training presents problems no less severe. In planning for the development of a society, there is always the conflict between the desire to upgrade the general level of the population, on the one hand, and the desire to develop selected areas of the economy quickly, on the other. With limited resources, this conflict is heightened.

In particular, for the average production worker, the following question arises: should an attempt be made to gain over-all increases in productivity by increasing the skills of a large number of production workers by a small amount or by increasing the skill of a few workers by a large amount?

Although, for many social reasons, the former choice may be preferred, the advances in world technology argue against it. Thus, if the productive economy is to compete in the world market, it is competing with the most advanced technology available to all. As a consequence, to follow historically time-consuming and technologically obsolete steps in industrial development and training is to subject the economy to a constantly worsening disadvantage in the market-place. In short, a substantial "jump" in the level of technology is required, and even in the most industrialized societies, such a jump is difficult or impossible to produce except in selected areas of the economy. Although the problem of education for the general society remains, education for the technologically skilled few, with its attendant problems, is often of first priority and corresponds to the necessities of automation as well as world marketing.

C. *Need for selective automation*

Although some of the major obstacles to automation in the developing country have not been mentioned, they do not set aside the present theme: that selective automation can not only be beneficial, but indeed may be necessary. If a developing economy is to make the gains in technology which are required for it to compete in a technologically developed world market, automation of selected steps in a process or selected industries in the economy may be the only route to survival. And by careful handling of selected cases, many of the constraints and possible disadvantages can be handled.

Moreover, the developing country has greater ability to use automatic tools at a faster rate than has the developed economy which is already equipped with many non-automatic tools and a large current investment. The developed economy must dispose of this older, possibly obsolete equipment before introducing new automatic tools. This necessity has often slowed down industrial automation in developed countries. Sectors of the economy can be tied not only to old machines, but to traditional methods of production. This is not the case in developing economies, where the first introduction of mechanized equipment can represent the latest technological advances without loss of previous investments. This difference in automation in old and new industries, and in old and new industrial locations, is strikingly illustrated by a tour of any highly industrialized nation. The newest equipment, latest technology and greatest automation are to be found in the newest industries located in the most recently developed industrial areas. In the new setting, the acquisition of new tools provides a fresh start.

In conclusion, consideration may be given to the problem of acquisition of a given automated machine, for which a process step or industry has been selected. First, it should be mentioned that most manufacturers of automatic equipment have not yet taken advantage of modern construction principles, such as rigid standardization of design, modular construction, interchangeable parts between machine types and standardization of material-loading and programmed-instruction formats; nor have they mass produced a narrow product line which would provide a reliable, easy-to-service, inexpensive automatic tool.

In the past, most machine tool builders have created specially designed, custom-made, custom-serviced machines. The result has often been ingenious—but expensive. Only the scarcity of the custom-made machine created real benefit for the owner, who could increase his output and reduce his cost, yet control his price because of his technological monopoly. And machines are often specialized and designed to that end.

In other industries, such as electronics design practice has been different. Attention has centred on modular design, standardization of practices and the use of various combinations of standard components (which are relatively few) to obtain the variety of final devices desired (at a drastically reduced price and increased reliability).

Although many automatic tools may be justified at current prices (based on the substitution of rare skills in a bottle-neck operation, as outlined above), the important point here is that when the steps of modular design, standardization and mass production are finally exploited in the automatic machine tool field, the range of applications available to the developing country will be vastly increased. In the trade between skilled-labour hours at the bottle-neck and machine hours, the machine will become increasingly more attractive.

The fact that the same type of automatic tools will become also progressively more attractive to the technologically developed countries (and at a possibly faster rate) provides both a warning and a substantial opportunity for the developing economy, for if no automated installations are contemplated and made early, the technologically developed economics will further spread the difference in productivity. If the developing economy does exploit the selective areas which can use automated tools and does so rapidly (insisting on standardized, modular, mass-produced, reliable equipment) the desired technological and economic jump may be achieved. It certainly will not be achieved by the use of traditional methods. Thus far, the acquisition of automatic equipment by developing economies has usually progressed in one of two ways:

(*a*) A co-operative effort or joint venture with a major international corporation;

(*b*) A government purchase, loan or guarantee. At the current time, manufacturers usually require an escrow payment to be delivered upon shipment of the equipment or the credit standing of an international corporation (or a Government) to back payment.

The sources mentioned above are also the most common since the use of automation may require a broader view of a production process or an economy than may be available to a small manufacturer without technical assistance.

In the joint-venture approach, the developing economy may induce an international corporation to construct and operate an automated plant in the country by providing trade, tax, material or other concessions. Various degrees of domestic and foreign ownership are also possible and vary widely from one economy to another. However, the point is that instead of purchasing the equipment or technology directly, it is purchased by concession, partnership or other form of payment in lieu of immediate cash. Various limited versions of this approach are also in use, such as royalty agreements in exchange for technical advice and some tooling, the exchange of products for tools and the like.

In the second approach, a Government, convinced that a proposed automation project is of long-range social benefit or immediate monetary benefit, provides the purchaser with a loan, or the seller with a guarantee. This Government may be either the buyer's or the seller's. Usually, the transaction then takes place through normal banking channels.

For example, in India, Air Refrigeration Co., a locally owned firm manufacturing compressors and other refrigeration equipment and situated about 200 miles from Bombay, installed in late 1965 a Pratt & Whitney Tape-O-Matic Model C tape-fed numerically controlled machine tool at its plant.[6] This equipment, which sells for about $25,000, is to be used to drill and process compressor-head top-plates and for similar applications. Financing was handled through the Export-Import Bank (Washington, D.C.), which provided the manufacturer with escrow funds payable upon shipment. Air Refrigeration also is reported to have licence agreements with a foreign refrigeration manufacturer to provide technical information. In this example, the drilling steps require repetitive precision and the value of the casting is relatively high, so that operator mistakes and inaccuracies are highly undesirable. This critical spot in the production process thus provides a typical subject for packaged technology or automated equipment.

By relying on the built-in skills transferred to the operation by the programmed tape, the operation benefits today from the application of automation—by multiplying the effects such added skills can produce in one production operation of a developing economy.

[6] In the United States of America, Pratt & Whitney has moved furthest in the standardization and use of modules, and in mass production of a limited line of module types. The result has been drastic cost reduction in numerically controlled machines, with one point-to-point machine priced in the vicinity of $8,500, which is 30–40 per cent less than the price of their closest competitor in that country.

SIMPLIFIED SYSTEMS OF PROGRAMME CONTROL FOR UNIVERSAL MACHINE TOOLS

Ede Sador, Director, Development of the Machine Tool Works, Hungary

One of the problems encountered in preparing the present paper was the fact that the "level of industrial development" of the countries concerned must be considered a very large spectrum of development. However, depending upon the concrete fundamentals prevailing in the various countries, it is not obligatory for those countries to undergo all the steps of evolution which were experienced by the more industrialized nations during the industrial revolution and in their subsequent development. Rather, it is necessary for the developing countries to become familiar with the current technology, to become initiated into it and to introduce it into the developing national industries. This procedure evidently requires—in addition to the necessary investments—the accelerated education of specialists.

The industries which provide the means of production, including mechanical engineering and the machine-tool industry, must receive top priority in the development of the national industry. In this way, each country may, at the same time, safeguard its economic independence.

The current world-wide technical revolution tends increasingly towards automation. The metalworking field is being revolutionized by programme-controlled machine tools. The highly developed, automatic machine tools permit the organization of standard-quality production with only a certain number of specialized craftsmen and a larger staff of trained workers, which hitherto could only have been achieved by employing a large number of high-quality workers having ample experience.

This paper deals with the simplified programme-control systems for machine tools. It does not touch upon the numerical controls of machines, machine systems and production lines. Neither do the limitations of this paper permit the discussion of detailed theoretical principles. The aim is, rather, to present a methodical review of the question, to outline the development and justification of programme control, to introduce some examples of the control types which are currently being applied more widely and to draw attention to the economic and perspective features of the question. At the same time, this paper presents an account of the industrial development and training of specialists which have been achieved in Hungary.

I. DESCRIPTION OF CONTROL SYSTEMS AND DEFINITION OF TERMS

In the operation of machine tools, the working process and its direction are to be discerned. Direction is an operation by means of which the beginning or termination of a process, as well as the desired quality of its progress, can be ensured. Two cases of the directional operation are the control and the feed-back control. Automation is the realization of the directional operation by means of a directing equipment functioning independently from human interference. Automation is, consequently, the mechanization of the directional operation (see fig. 1).

Figure 2 summarizes the tasks of automation in connexion with metal-cutting machine tools.

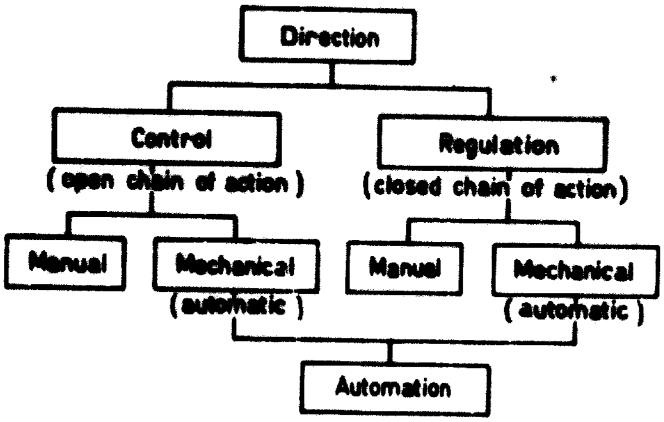

Figure 1

RELATIONSHIP OF THE CONCEPTS OF DIRECTION AND AUTOMATION

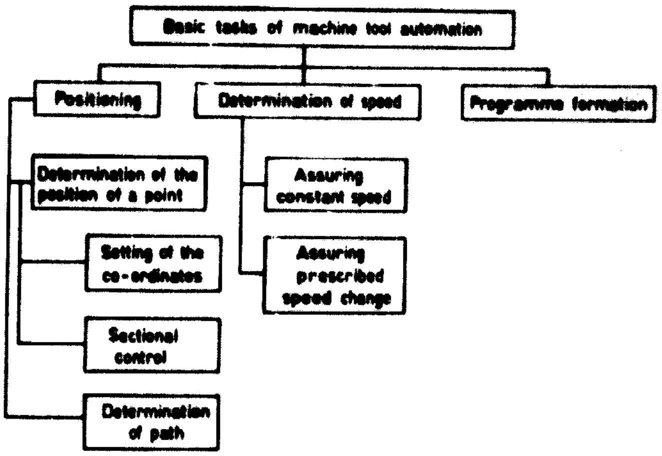

Figure 2

BASIC TASKS OF MACHINE-TOOL AUTOMATION

The task of positioning is to define the size values of the co-ordinates which determine a point, or some points, of a co-ordinate system. Definition of speeds means the determination of the characteristics of rotating and advance main and secondary motions according to the postulate of the technology, as well as the ascertainment of their occurrence. The programme is the prescription defining the directed characteristics of the directed process, as well as their interconnexion. The connexions of the directed characteristics are defined basically by space or time co-ordinates. The space-based programme can be a neat-movement programme; in this case, the contour will be formed by a corresponding spatial placement of the major cutting edge. In the case of a movement programme combined with a programme tool, the shaped tool with an appropriately long cutting edge has to perform only a unidirectional movement (see fig. 3).

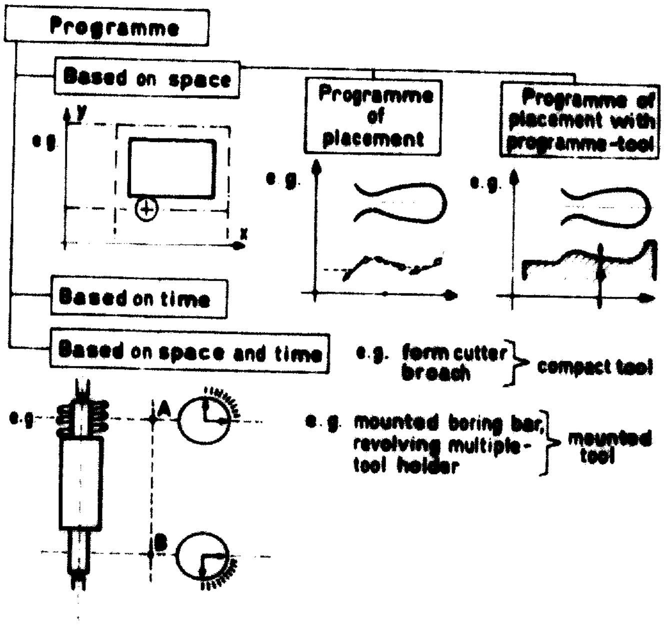

Figure 3

TYPES OF PROGRAMMES, DEPENDING UPON BASIC VARIABLE

The programme generally comprises the whole machining process to be executed on one machine. Direction in accordance with the programme of the machine is ensured by the automatic directing device, i.e., the programme-control equipment.

Depending upon the extent and elasticity of the programme the following systems can be discerned:

(*a*) Cyclic programme-control systems serve for the realization of certain typical cases of the space-based programmes. The cycles are reiterative process-sections, built up identically of movement-sections of equal speed and generally forming a closed movement-circle (see fig. 4);

(*b*) The programme-switch control system is a more complex system, if compared with cycle control, as regards the variety of parameters to be directed. In this system not only the lengths of ways, but also the related speed-values, can be programmed. The continuous course of the process, however, is not automatic;

(*c*) In the case of programme-controlled machines the composition of the programme is elastic, as regards the dimensions of the movement-programme and the special values of the main and secondary movements belonging to the various sections, as well as their interconnexion; this control generally produces a semi-automatic operation.

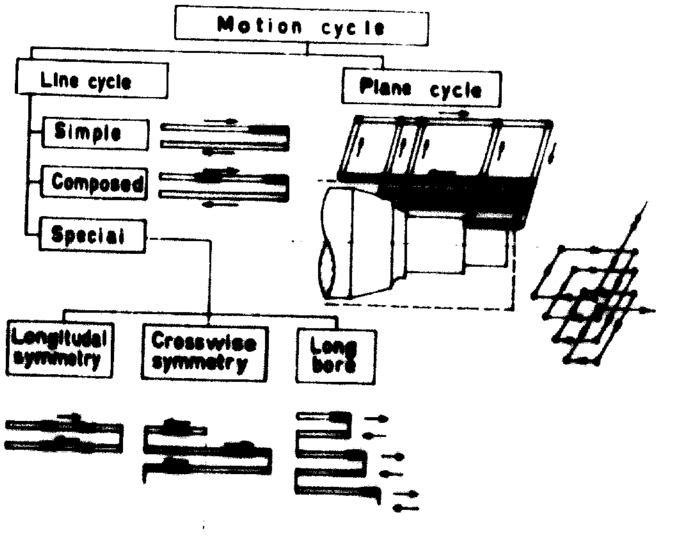

Figure 4

CHARACTERISTIC MOTION CYCLES

The connexions of cycle control, programme-switch and programme control are shown in figure 5.

Programme-control systems differ in the way in which they communicate the programme data to the machine: (*a*) in control systems with stops, the programme carrier is the direct contact with the machine; (*b*) in numerical-control systems, the programme carrier is in indirect contact with the machine. A control system with stops requires manual setting of the stops.

The essential characteristic of numerical control is that the size of the characteristics of the directed process—ways of displacement, speeds etc.—is expressed by

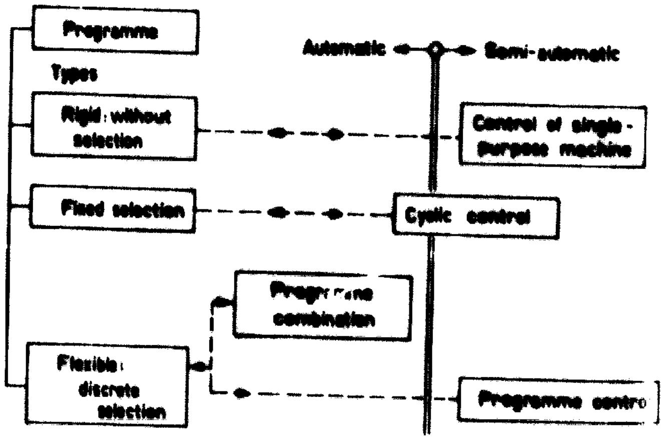

Figure 5

TYPES OF PROGRAMMES AND CONTROL SYSTEMS, AND THEI RELATIONSHIP ibers. These are written by means of symbols of some ie of expression on the programme carrier (which idependent of the machine) and are fed into the hine through its directing equipment.

igure 6 presents a further division of the stop-control and numerical-control systems according to their basic operating characteristics.

System of programme communication / Character of task	Stop control (direct)	Numerical (indirect)
Point-position and discontinuous control	Positional programme-switch Cyclic control Programme-switch Programme control	Positional (in free running) Process control (in free running and under load)
Path control	Copying	Interpolated or computerized

Figure 6

BASIC CHARACTERISTICS OF MACHINE-TOOL DIRECTIONAL EQUIPMENT

This paper aims at the review of simple programme-control systems. Stop controls are considered simple programme controls, as in their case no special command-transfer (code and logic, etc.) systems are needed for the determination of programme commands and for the realization of the directional process.

II. Brief survey of the development of machine tools

In the development of machine tools there are three main periods to be discerned; there is, however, a very intense temporary overlapping of these periods. The first period was characterized by mechanical devices and the second, by the combined (mechanical, hydraulic and electric) solutions and controls connected with weak-current electronics, while semi-conductor techniques are illustrative of the third period.

In the first period (up to approximately the 1920's), the development of machine tools tended towards the satisfaction of the continually widening circle of technological demand by means of increasingly mechanized and motorized appliances in the field of universal machine tools. After solving the main displacements of the machines by central drive, the power engine, the first task was the mechanical feed of slides and tables. Individual es and mechanical main and secondary drives, as ll as different mechanical disconnecting stops and ices for the disengaging of mechanical feed, were ited through the development of metalworking tools the frequent alteration of the technological parameters.

onsiderable economy in accessory time has been zed by one-arm control systems and the so-called ntrol stick". The second half of this period was acterized by mechanically constructed pre-selection pment, which permits the pre-selection of the technological values of a following operational sector during the effectuation of the technologies belonging to the various working sectors. After finishing a certain operational sector, the technological values relating to the new sector can be communicated to the metalworking machine with one single phase by setting a handle into action.

In the second period of development (until the 1950's and continuing up to the current time), control solutions were found suited to the continuous automatic direction of the complete machining process to be performed on the machine. It is no longer possible to satisfy these requirements economically by merely applying mechanical constructions. Various hydromechanical, electromechanical and other solutions are being applied, as mixed systems prove most expedient in the specific cases. Hydraulic copying attachments were evolved and have promoted the automation of the processing of shaft-shaped and other contoured workpieces. Various programmable main and secondary drives to be switched under load have been developed in order to change the technological parameters belonging to certain sections of the automatic working process according to the programme. Semi-automatic machine tools with programme-switching using various position sensors and stops, as well as with programme-control provided with limit stops, serve to ensure the continuous automation of the complete machining process. These machines although having a universal character can be employed most economically in large-batch production.

The demand for automatic machining equipment which can be employed economically in individual and small- and medium-batch production lays the foundations for the third period of development (which began in the 1950's); this period is characterized by weak-current techniques and semi-conductor techniques. Governing systems using these techniques perform the positioning and the setting of other technological parameters according to numerical information. Automatic tool-changing mechanisms and tool-pre-setting equipment have been developed for small-batch production. Automatic programmings have been originated in order to diminish the preparation of the programme; and, in order to realize the mechanization of the definition of the optimal technology and the different systems of programming, languages have been developed.

In summation, the development of machine tools and their control has always been brought about by the demand for increasing productivity and economical machining. The equipment employed was always characterized by the technical level of the given period.

III. Technological justification and postulates of technology

The necessity for and technological justification of programme control can be ascertained by an examination of the production time. The production time (T_1) related to the machining of one workpiece is composed of the following time elements:

$$T_1 = t_1 + t_2 + t_3 + t_4$$

where t_1 = preparation time, t_2 = main machining time, t_3 = subsidiary time and t_4 = time for technical and organizational servicing of the work-station and lost time.

One must consider the fact that only 20–25 per cent of the production volume of the industrialized countries runs in large batches or in mass production. The remaining three-quarters of the mechanical-engineering production is carried out individually or in small or medium batches. This fact emphasizes the necessity of automating the machine tools used for individual, small- and medium-batch production, as well as of creating machine tools which are adapted to such production conditions. If one substitutes general practical values in the formula given above, one obtains the following results (in percentage) for small- and medium-batch production on universal machine tools:

$$T_1 = t_1 + t_2 + t_3 + t_4$$
$$100 = (4\text{–}2) + (20\text{–}40) + (50\text{–}70) + 6\text{–}8)$$

Thus, it is obvious that 20–40 per cent of the time is employed for the machining process, while 50–70 per cent of the production time is allocated to subsidiary time.

By automating the subsidiary operations and performing them simultaneously with the machining, the productivity can be considerably increased. Upon examination of the time-fractions employed for the different elements of subsidiary time, one finds, for various machine tools, the following data:

(*a*) Control of the machine (0.3–0.7) t_3;
(*b*) Clamping and unclamping of the workpiece (0.1–0.45) t_3;
(*c*) Tool change (0.1–0.15) t_3;
(*d*) Measuring (0.06–0.25) t_3.

These data provide roughly outlined information about the tasks to be solved and the technological and economic need for automating the subsidiary time elements. Considering that the quota of subsidiary time employed for controlling purposes is decidedly high, the primary aim of the development of machine constructions consists in their reduction, and this tendency manifests itself, in the case of small- and medium-batch production, in the propagation of the different variants of programme controls. Another possibility of reducing subsidiary times is the introduction of grouped machining technology; this is an effective technological medium of the production process not only with manually controlled machine tools, but also with those which have been automated to a certain level.

Technology puts various demands upon the machine itself, as well as upon its control equipment.

Programme-controlled machines must—as a matter of course—possess the technical characteristics of the traditional machines, but they must also have increased accuracy and rigidity.

Programme-control equipment must be able to direct the various movements, i.e., perform the positionings with adequate accuracy; direct the switchings of speeds and the different units as needed; and it must, in compliance with the foregoing, possess an appropriate programme-storage capacity. It is a postulate, furthermore, that the programme should be prepared at a minimal cost, but it must be easily alterable. It is an important requirement that the possibility of manual intervention should be guaranteed in order to modify metal-cutting data and to correct tool wear.

IV. Examples of stop controls

A. *Discontinuous controls*

As an example of cyclic control, a brief description of an internal-grinding machine model KL-100 (see fig. 7), which was developed and is produced in Hungary, is given below.

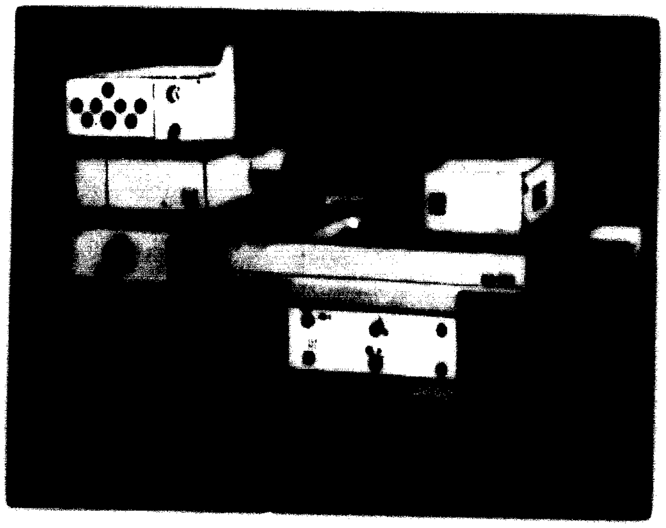

Figure 7

Semi-automatic internal-grinding machine, Model KL-100

This machine is suitable for the manually controlled or semi-automatic cycle-controlled machining of passing-through and blind holes. Setting of working cycle consists of setting the respective positioning stops and the selective switches of the electrical-control equipment.

In accordance with the pre-set working cycle, the machine performs the following tasks: rough grinding, automatic dressing and compensating of the grinding-wheel, switching from roughing to finishing and stopping automatically after having attained the pre-set size. At the end of the cycle, the grinding slide runs in its initial position; the cut is automatically interrupted; and, after changing the workpiece, the next cycle can be started with the push-button. The machine is electro-hydraulically controlled and it performs this fixed cycle continuously (see fig. 8) with such amplifications as are provided for by the pre-selection switches, e.g., the setting of single or double dressing etc.

Perception of the final size can be effectuated in three different ways:

(*a*) If only normal accuracy is needed or a blind hole is to be ground, automatic differential measuring can be applied. This means, essentially, that the machine being controlled by the pre-set stop—automatical

...ses the mantle of the grinding-wheel 0.05 mm before ...hing the final size. The machine grinds the 0.05 mm ... the dressing position;

...) When grinding a larger number of workpieces and p...ing-through holes, a size-gauging control is advisable. I... essentials are as follows: the gauge enters the ground h... when final size is attained and sends a signal in order to stop the machine;

(c) Active measuring equipment can be applied in all grinding cases, its substance being the following: by means of the gauge of the measuring equipment, which is extended into the hole, the diameter of the ground hole is felt continuously. The control switches automatically from roughing to finishing, according to the pre-selected technology, and stops the machine after having obtained the final size.

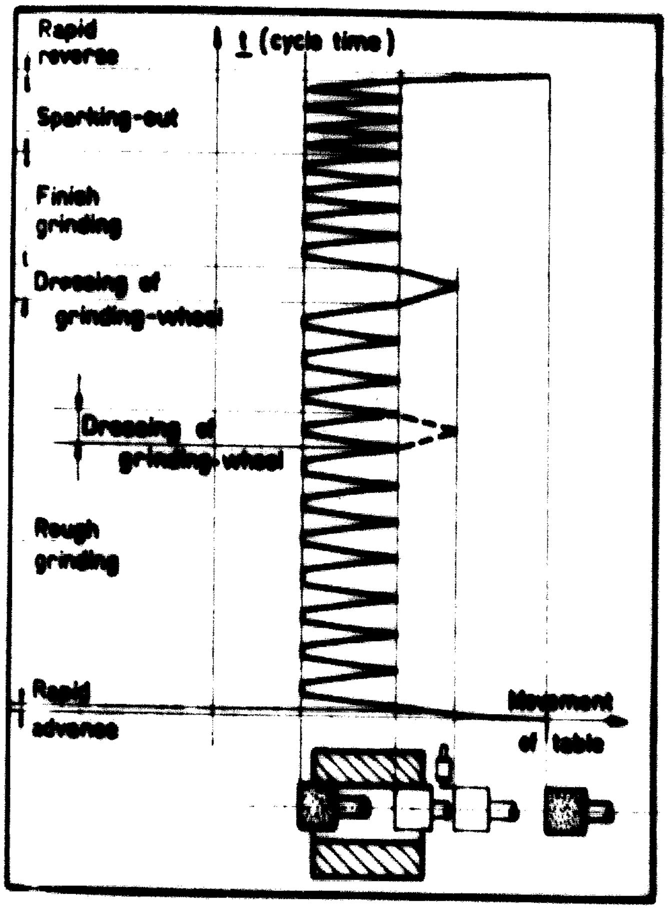

Figure 8

CYCLE DIAGRAM OF SEMI-AUTOMATIC INTERNAL-GRINDING MACHINE, MODEL KL-100

Loading equipment can be inserted in the automatic ...le and mounted on the machine, thus ensuring its ...lly automatic operation.

As an example of a programme control with stops, ...re 9 shows a programme-controlled milling machine, ...del MUL-320, which is produced in Hungary.

The machine can be operated as a basic type or with ...ic control, or it can be programme-controlled with ...h cards.

In the basic machine starting of the milling spindle, its braking, its feed or the rapid motion of any part of the table can be switched by means of push-buttons.

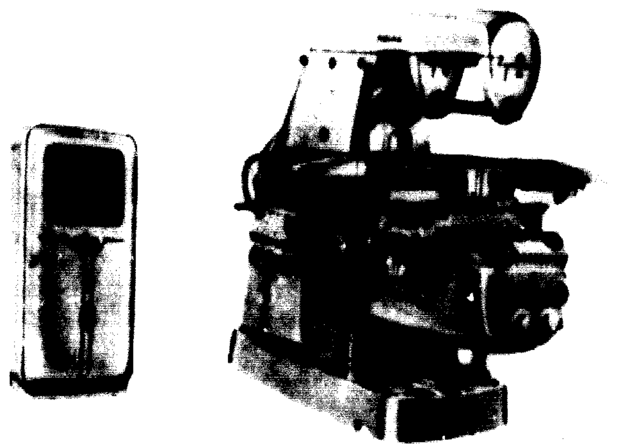

Figure 9

PROGRAMME-CONTROLLED MILLING MACHINE, MODEL MUL-320

Various cycles or simple programmes can be set in all three directions on the cycle-controlled machine by means of stops and switches.

With a simple cycle, the table returns to its initial position after having performed the machining process. In the receding cycle, the workpiece retires from the tool, thus ensuring that the tool leaves no scratch marks on the workpiece during the rapid reversion of the table.

Two workpieces can be clamped simultaneously on the table in the pendulum type of cycle, and the machine automatically switches the rotation of the main spindle according to the placement of the table.

The machine automatically switches the necessary movements of the table when executing a simpler programme, e.g., milling all sides of frames, and it stops at the end of the programme.

In the case of punch-card control, the punch card is prepared according to the determined technology and the plug-field is plugged in conformity with the card. The machine automatically performs the programme fixed by the plugs. The programme can consist of forty subsequent sectors.

Any discrete placement of the machine can be obtained within each sector by switching fourteen different circuits according to an appropriate combination. The programme board is thus a switching field consisting of forty rows of contactors, fourteen in each row, with their overall number consequently being 560.

The fourteen programme points of the programme board are, from left to right, the following: A, main spindle to right; B, main spindle to left; C, traversing slide to right; D, traversing slide to left; E, cross-slide advance; F, cross-slide retire; G, knee up; H, knee down; J, change of feed and rapid motion in similar direction; K, rapid motion; L, slow motion; M, change of speed of main spindle and feed; N, stepping device in final position; O, change of group, by stops.

When changing from one programme section to the next during operation, the stepping device—known from telecommunication techniques—is actuated by the impulse supplied from the position switch, which itself is operated by a stop fastened to the prescribed spot. The stepping device switches out the respective horizontal row of the programme field by means of its wipers and switches on the underlying row. The stepping device has twenty-five arc terminals, and it executes one interval at each impulse, which means the changing over from one row to the following one. One unit of the manual plugboard having twenty rows, the stepping device steps the surplus five terminals automatically in open circuit.

Two groups of stops can be employed on the machine, evidently by employing two stepping devices also. Only one group, however, can operate at one time; the stops belonging to the other group remaining ineffective despite their impact. When programming a change of the stop groups, the position switches and stops of the other group can influence the switching. Such a separation of the stops ensures the possibility of operating the second group of position switches in some other programme row and advancing in the same direction, after having finished a certain milling operation; thus, it will be possible to machine longitudinal sizes differing from those of the previous milling.

If an accurate stoppage is required at the end of a certain programme section, this should be programmed by the plug L—slow motion—and, in such cases, the table stops within a range of $\pm$ 0.03 mm.

The machine can effectuate any desired number of rapid-motion feed changes within one programme section, that is to say, within similar direction of the table, by employing plug J (the number is limited only by the geometric sizes of the stops). Two main spindle speeds and two feeds can be employed according to programme; one of these can be set on the machine, with the speed-change disc, while the setting of the other is effected in the programme box. These can be interchanged optionally by means of the plug M.

Plugs A and B, which determine the direction of rotation of the main spindle, elicit the braking and re-starting of the motor within the identical programme sector. Should the machine have completed the operation which consisted of only fourteen sectors, it stops at the end of the fourteenth sector; from the fifteenth row of the programme board, only plug N is needed to unreel the stepping device into its initial position.

The machine stops after having completed a whole programme operation and its re-starting is effectuated by pressing the starter-button of the cycle.

B. *Path control*

Contouring tasks can be solved without a measuring system by means of copying systems. These systems ensure, at a prescribed accuracy, the relative position of the workpiece and the tool along a plane or space curve determined by some template, that is to say: they control the position.

As regards their operational principle, they can be divided in two main groups: (*a*) continuous operation; and (*b*) discontinuous operation.

In continuous contouring, the gauge touching the template gives a continuous signal and the movement of the tool (or the workpiece), that is, the controlled characteristic, is continuous also.

In discontinuous systems, the gauge gives signals only in case of those placements which are similar to discrete placements of the controlled characteristic. Discontinuous systems are mainly employed on milling machines and on milling and boring machines, whereas continuous systems are frequently found on lathes, because of the smaller bend radius of the tool.

From the point of view of the control direction, the copying attachment can be one- or two-dimensional. The executing system used is most frequently hydraulic, electric or electro-hydraulic.

A semi-automatic copying lathe, Model EM-250, which is produced in Hungary, has cyclic control with stops also (see fig. 10).

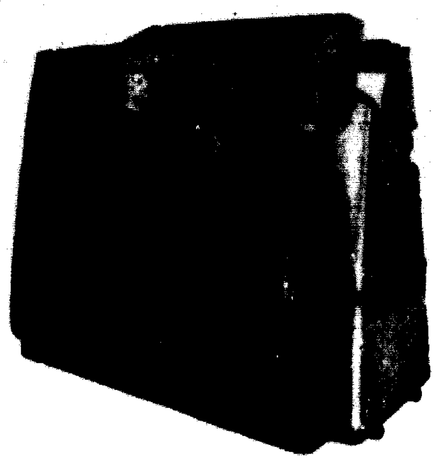

Figure 10

SEMI-AUTOMATIC COPYING LATHE, MODEL EM-250

This machine was constructed for the machining of shaft-shaped workpieces with diameters ranging from 18 to 40 mm. Its main drive has eight stages, two of which can be programmed automatically by means of a change-speed motor.

It possesses an infinitely variable feed range. In addition to the pre-selected feed, two additional feeds can be programmed: one for the bisection of the feed when machining shoulders; the other for finish copying.

The cycle-controlled hydraulic copying attachment mounted on the carriage can execute five roughing and two finish-copying phases. Feed can be effected only in direction of the main spindle, and it has a rapid reversing motion.

Figure 11 shows the structure of the cyclic control. The copying attachment has one main gauge and one secondary gauge. The secondary gauge, No. 1, touches the stops, No. 2, for depth of cut, according to the pre-selected depths of cut of the roughing phases. The e

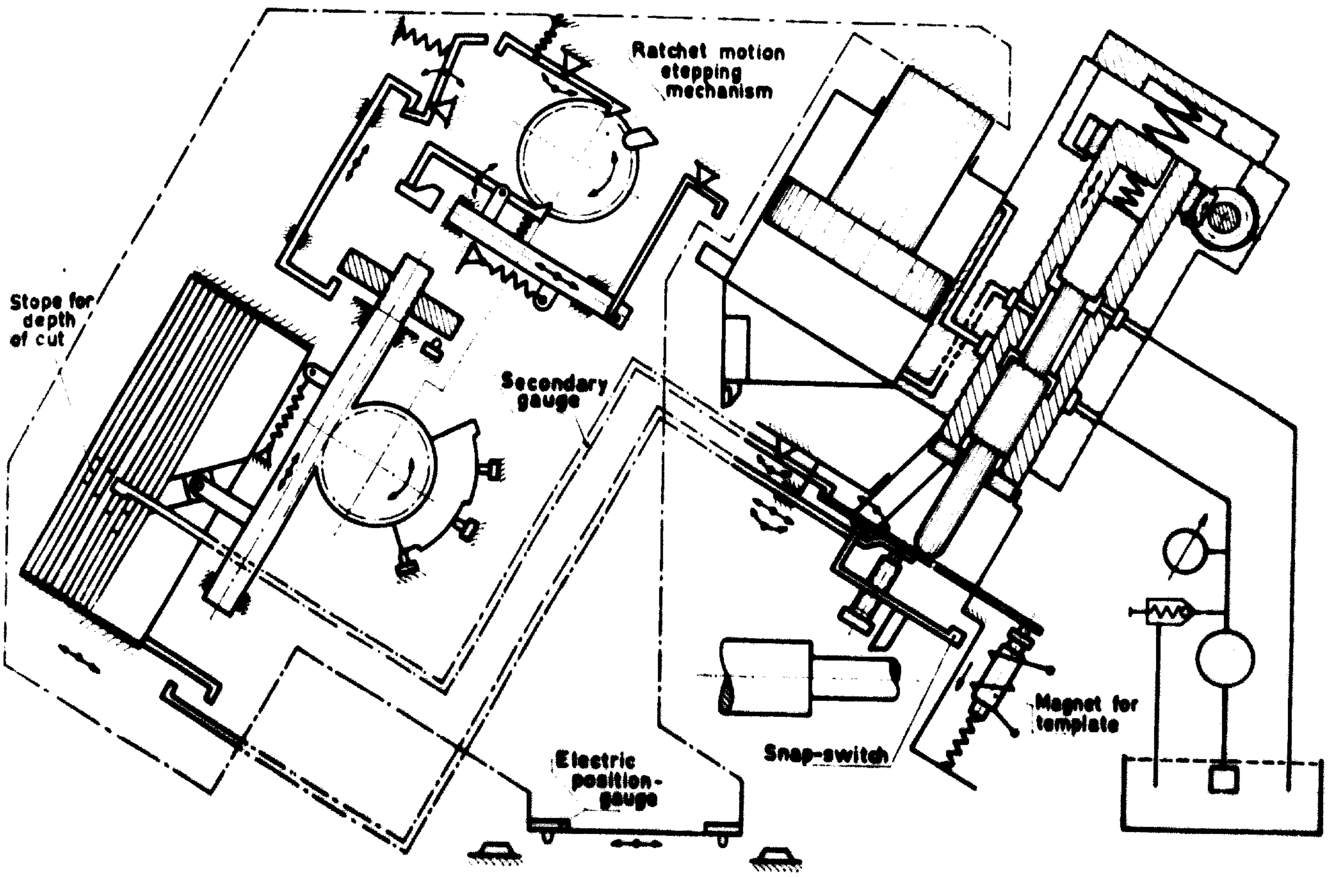

Figure 11

SKETCH OF CYCLE-CONTROLLED COPYING ATTACHMENT

stops for depth of cut are situated in an easily extractable flapper which can be set outside of the machine.

The snap-switch, No. 3, which is located under the main gauge, initiates, in the roughing phases, the reversing of the copying slide when the gauge bumps against the shoulder of the template (the magnet No. 4 releases), and it also initiates the reversing of the carriage. During the reversing of the copying attachment, the ratchet motion stepping mechanism, No. 5, lifts the next two stops for depth of cut into the impact plane of the secondary gauge.

The snap-switch, No. 3, is ineffective in the rough-copying or finish-copying phase. Reversing of the copying slide and the rapid retraction of the carriage are switched by the electric position-gauge, No. 6, which is actuated by the carriage. This construction shortens considerably the programming time, because the template itself serves as a longitudinal stop. Switching of the bi-se..ons of feed when machining the shoulders in the co...ing phase is also effected by the template. In the co...se of programming, only the following organs have to ..e set: template; stops for the depth of cut; pre-se...ted main spindle speed; and basic feed.

..e necessary number of phases for the machining of o.. workpiece can be set optionally for either the rough-ir.. r the copying phase. Such pre-selection and setting i.. ..o possible when only a copying phase is inserted ir.. he machining of the workpiece.

V. ECONOMIC APPLICATION OF PROGRAMME CONTROLS

Machines belonging to the same type, but possessing different control levels, have, respectively, specific fields of application in which they can be employed with the optimum efficiency. The technical conditions of application have to be ensured primarily. The operation of machines with a higher level of control sets up continually greater claims on the works organization and on the technical standards of the whole factory, in proportion to the complexity of the control (e.g., technological matters, tooling, production programming, etc.).

"Rentability" of production means essentially to produce high-quality products at the least possible cost. It cannot be decided, in general, which batch size makes a certain machine with a simple programme control economically preferable, in comparison with a manually controlled universal machine or with a machine of some other control system.

Individual calculations have to be made. Those parts of the production costs which are influenced by the different types of machines must be examined.

Figure 12 shows the different components of the production costs and refers to the changes in the proportions of the costs when comparing programme-controlled machines with manually controlled types.

In order to present an example, a determination has been made of the production time of the workpiece for a universal centre lathe (see fig. 13a) and for the semi-

Cost components	Base of reference	Influencing factors	Relative change of costs, compared with manually controlled machines
Productive wages K_2	Hourly wages for work-time	t_1 t_2 t_3 t_4	↘ ↗ ↘ ↘ ↘
Machine costs K_3	Machining time for one piece	Price of machine (amortization, interest,) maintenance, yearly time-base of machine	↗ ↗ ~
Factory overhead K_4	Productive wages	Technical preparation Production engineering Serving Energy Building Others	↗ ↘ ↘ ↘ ~
Cost of production equipment K_5	All pieces machined	Type of machine workpiece (fixture), etc.	~ ↗
$K_1 = K_2 + K_3 + K_4 + K_5$			
↗ increasing	↘ decreasing	~ identical	

Figure 12

COMPONENTS OF THE PRODUCTION COST OF ONE WORKPIECE (K_1): TREND OF CHANGE IN COSTS WITH USE OF PROGRAMME-CONTROLLED MACHINES

automatic copying lathe Model EM-250 (shown in fig. 10), which has cycle control.

Figure 13b illustrates the production time, t_{gy}, in the function of the batch size. It can be observed that the cycle-controlled copying lathe is more productive if the batch contains more than approximately eight pieces. Figure 13c, however, draws attention to the fact that only in case of $n > 15$ can a real economic profit be expected of the semi-automatic, cycle-controlled copying lathe. This is due to the differences between preparation times, wages of the operator, prices of the machines and other incidental costs (see fig. 12).

In the case of the previously reviewed internal-grinding machine (Model KL-100), cyclic-control system and automatic measuring reduce the production time of one workpiece to such an extent that the employment of the stop-controlled machine is economical, notwithstanding its higher price and its more expensive operation, even in the case of very small (eight to ten pieces) batches. Gauge control raises somewhat the preparation time of the KL type of machine and this extends the limit of the economical batch size to about twenty to twenty-five pieces. The KL type of machine is more productive in grinding bores of, e.g., 25H6, even for five pieces or upwards; and the production time diminishes by 30 per cent if the batch comprises twenty workpieces. As regards economic feasibility, the employment of this machine is advisable for batches from ten pieces and upwards.

Both types referred to in the examples can be operated according to the system whereby several machines are handled by the same operator.

There are, of course, several factors in addition to those already mentioned which exert considerable influence on the problem of application. As mentioned before, the advisability of adopting some machine with one or another advanced control is decided mainly by the technical level of the production. As the level of the adopted control increases, the intellectual performance expected of the operator decreases, but in this case, the tasks concerning the technical preparation of the production also show a considerable upward tendency. There is no doubt, however, that—under appropriate conditions—the productivity and "rentability" of the production as well as the interchangeability of the machined parts, can be substantially increased by the employment of machines with simple programme controls.

VI. CONCLUSION

This paper has dealt with control systems belonging to the second period of the development of machine

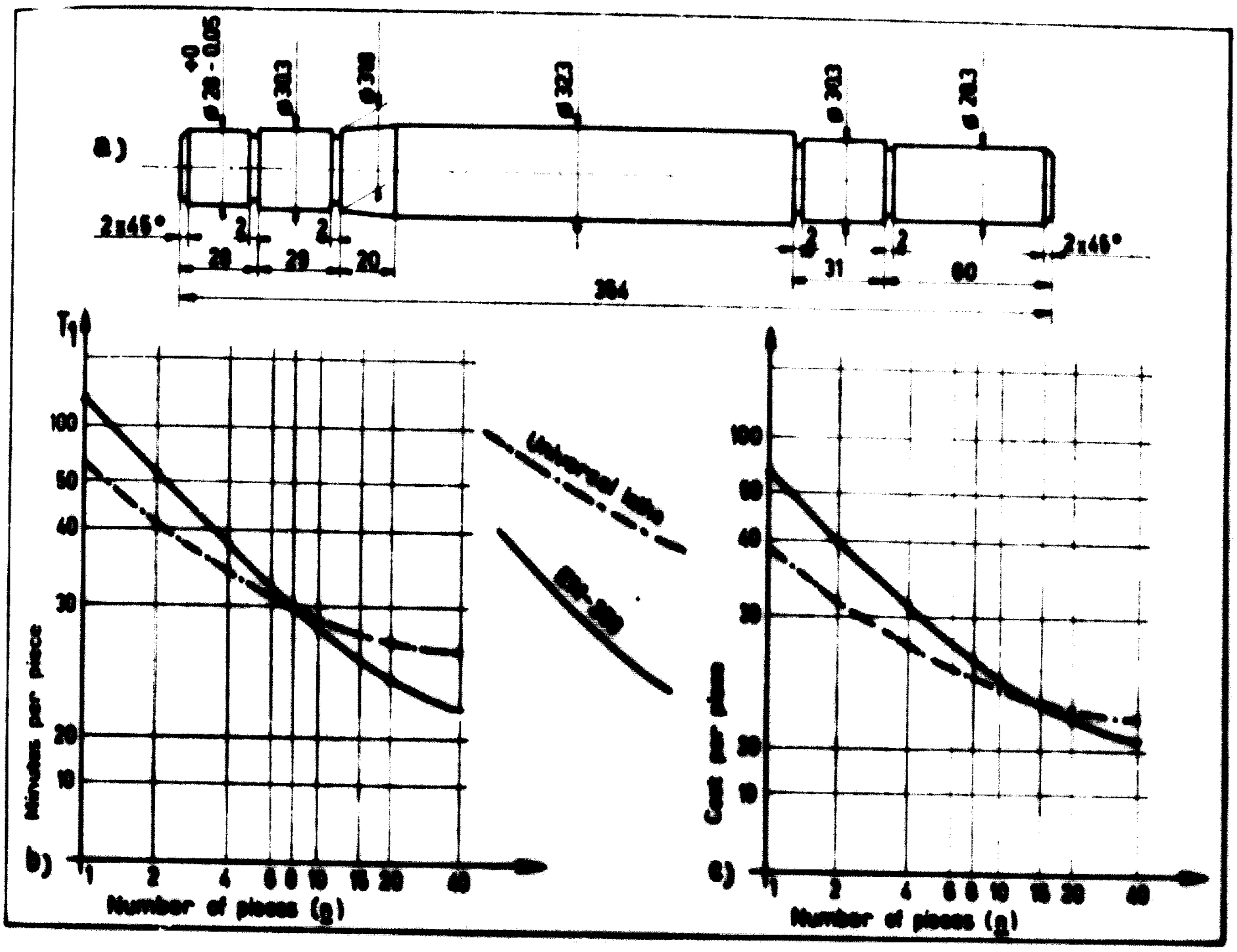

Figure 13

EXAMINATION OF THE ECONOMICS OF SHAFT PRODUCTION

tools—more precisely, to the last phase of this period. Simplified controls are being increasingly employed in the metalworking industry. The trend of future development points towards simplified constructions, increased operational reliability and further improvement of the ratio of unproductive and productive (machining) time.

Although this paper does not take into consideration the numerical controls which are characteristic of the third period of development, it is, nevertheless, necessary to point out their progressive importance in revolutionizing small- and medium-batch production. A tendency towards simplification is to be observed in the realization of numerical control also. Considering the great number of types of numerical controls which are available, great importance must be attached to international unifying and standardizing activities.

Hungary has also endeavoured to pass on its experiences to the specialists of developing countries, in the forms mentioned below:

(*a*) Hungarian experts have installed industrial equipment delivered to developing countries and have transmitted their own operational and handling experiences;

(*b*) Several specialists from the developing countries have taken their degrees at Hungarian universities and this programme is continuing;

(*c*) Hungarian lecturers and professors have travelled to several countries, at the invitation of those countries, in order to promote the education of specialists.

Within the bounds of its possibilities, Hungary wishes to continue to serve the accelerated technical evolution of the developing countries.

PRODUCTION MANAGEMENT FOR DEVELOPING COUNTRIES

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INTRODUCTION

"The highest efficiency in production is obtained by manufacturing the required quantity of product, of the required quality, at the required time, by the best and cheapest method." This is the way L. P. Alford and J. R. Bangs defined efficiency in production systems in their *Production Handbook*,[1] and this definition was subsequently adopted in later editions. It summarizes in a sentence the major problems that production managers have had to contend with during the past century, and it defines the prevalent parameters that a control mechanism in a production system must incorporate. And in spite of the vast development in production and control techniques in the past two decades, the formulation of the new analytical tools which managers have now at their disposal, the advent of computers and the sophisticated data-processing systems and the penetration of automation to the shop floor, the basic objectives of a production system remain unchanged. In fact, it can be argued that all these developments have come about in order to provide better means of achieving the objectives which are defined in terms of quantity, quality, time and cost.

It is interesting to note that the first three factors are defined as constraints, not as objective functions which one wishes to optimize. There is no advantage in producing more than is required (in fact, it can cause an embarrassment if it leads to excessive carrying costs or too severe a reduction in price); there is no virtue in producing too high a quality if such a high standard is not required (this will merely increase production costs); there is no need to complete the task too early in time (as this will just lead to unnecessary storage costs before the good are due for delivery). On the other hand, the constraints do set a "minimum" standard of performance, which it would not be in the interest of the firm to violate, as the penalties involved could be quite severe and could obviously lead to loss of future business. Certain margins of safety can, therefore, be built into the production framework—margins that will safeguard with a reasonable probability level the attainment of given specifications for quantity, quality and time.

Within these constraints, efficiency in production is achieved by using "the best and cheapest method". What does this phrase mean? It implies that, in many cases, several alternative methods can be designed to attain an objective and that these alternatives have to be evaluated before a final choice is made. The statement also seems to imply that there is a "best" method of performing a task, and this implication was generally accepted during the earlier days of industrial engineering, particularly by work study practitioners.

Curiously enough, this search for the "one best way" (as coined by F. B. Gilbreth, the pioneer of work study over forty years ago) was again revived after the Second World War, when operational-research techniques began to develop and when mathematical models were devised with the view of optimizing some objective function, whether it be the minimization of costs, the maximization of profit or any other predetermined objective. There is a difference, however, between the two movements. In the first, the selection of "the best method" was based on comparing a limited number of alternatives, and although one could state with some conviction that the selected method was better than some others, one could not assert that all the possible alternatives were really exhausted in this way. Some operational-research models, however, do exhaust all the alternatives, so that for any given model and a given set of data it is possible to state that a certain solution is truly the best.

There are many models, however, in which an exhaustive search is either too lengthy or too expensive, or sometimes just impossible, by the very nature of the problem or the limitations of the model. An obsession with optimization under these circumstances is clearly a waste of time, and a conscious effort must be made to relate the cost of finding a solution to a given problem to the expected benefit to be derived from such a solution. It is essential to bear this point in mind in applying modern management techniques to the control of production operations.

Production consists of a sequence of operations designed to transform materials from a given to a desired form. The transformation may be accomplished in one, or in a combination, of the following ways:

(*a*) Transformation by distintegration, i.e., by having essentially one ingredient as input and producing several outputs. This type of transformation is almost invariably accompanied by changes in the physical shape of the input, such as changes in the physical state or in the geometrical form. Examples: producing lumber in a sawmill; rolling steel bars from cast ingots; making components from standardized materials on machine tools; oil-cracking which yields several products; etc.;

(*b*) Transformation by integration or assembly, using several components as inputs and obtaining essentially

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[1] L. P. Alford and J. R. Bangs, *Production Handbook* (New York, Ronald Press, 1952).

one product as output. Examples: producing machines, furniture, household appliances, motor-cars, radio and television receivers, alloys, sulphuric acid, concrete etc.;

(*c*) Transformation by service, where virtually no change in the object under consideration is perceptible, but where certain operations are performed to change one of the parameters which define the object. This may include: operations for improving the tensile strength, density, crystallographic structure, wear or other mechanical properties of the object; operations that change its locality or state by transportation or handling means; maintenance operations. Examples: sizing and coining in presswork; servicing and light repairs of motor-cars; loading and unloading of lorries; etc. Many purely service operations are not considered to be part of industry, but the planning and control of such operations is basically similar to those of industrial operations. By analogy, one could say that "the highest efficiency in servicing is obtained by processing through the service station the required volume, offering the required quality, at the required time, by the best and cheapest method".

The analogy between the third category and the first two emphasizes the fact that management methods are equally applicable to manufacturing and non-manufacturing operations. Thus, the techniques used in work study or in studies of plant layout or materials handling have had a wide appeal and have been applied to the study of warehouses, transportation systems, office blocks, ports or even farms. Operational-research techniques are widely based also, with no specific industry or manufacturing activity in mind. This means that methods and concepts of production control can be usefully applied to situations where no "production", in the conventional sense, takes place; and, similarly, that one can learn from experience in areas other than one's own in designing better control methods for "production" systems.

I. Utilization of resources

The purpose of production management, therefore, is to make effective use of the resources available to the enterprise. These resources may be classified under five categories (*a*) manpower; (*b*) materials; (*c*) machines; (*d*) money; and (*e*) methods. These categories generally relate to the way in which the production costs can be accounted for: first, labour costs, direct and indirect, including, of course, any allocation of overheads; secondly, the cost of materials from which the product is made; thirdly, the cost of using machines and processes; and so on.

The effective utilization of manpower is an obviously desirable objective. With the increase in standards of living in industrialized countries and the inevitable resulting increase in labour costs, more and more attention must be paid to increasing the level of productivity, that is, the amount of ouput per man than can be obtained. This has been the greatest impetus to the development of work study techniques in the United States of America, under the name "time and motion study", and this title well signifies the detail in which particularly manual tasks have been studied, down to the recording and investigation of every element of motion of the operator's hands, with a particular emphasis on the time element. The more one can reduce the labour content of any given task, the more there is a chance of keeping prices down when labour wages increase, and this has been the central theme in most productivity drives in many European countries in recent years.

Raw materials constitute a tangible part of the cost of the product, and any effort to reduce this cost will evidently make the product more competitive. Studies on the use of raw materials can take several forms, such as investigations of causes for waste and scrap or assessing the possible use of alternative materials in the production process.

Similarly, the effectiveness of machines is often a central point in a productivity study, involving such typical problems as:

(*a*) Is the machine suitable for the job in question? What are the alternatives?

(*b*) Is the machine working at its optimum running conditions?

(*c*) What is the utilization (in percentage of the total machine time available) of the equipment and how can it be improved?

(*d*) Is it better to have special-purpose machines or general-purpose ones (the latter having more flexibility in being adaptable to a wider variety of jobs, but generally operating at a lower performance level than a special-purpose machine)?

(*e*) Should machines and mechanical devices take over manual tasks? The problem of mechanization and automation presents important economic and organizational considerations for the firm, in relation to both the type of tasks that should or could be mechanized and the capital outlay involved in the installation of such devices.

The cost of using financial resources is generally regarded as being outside the responsibility of production management, particularly when it comes to considering the allocation of these resources, the evaluation of alternative investment schemes or the method of raising money. But there are many decisions which affect the use of financial resources and in which production management is closely involved: the selection of processes; replacement and installation of plant and equipment; holding of stocks of raw materials or semi-perishable goods; or decisions about "what to make and what to buy".

The fifth resource mentioned above is "methods", and although it is not a resource in the conventional sense of the word, it does represent the body of knowledge, the "know-how" (both technical and administrative) that the firm can employ in order to make good use of the other resources and, like the others, it costs money to acquire and develop.

An historical review of the industrial development in technological innovation and design—the effective utilization of resources has played a prominent role in accelerating the rate of industrial progress. Every phase of this development obviously had its own problems and attention was focused on specific techniques to solve their problems. But they all had this in common—that resources which were costly or in rare supply should not be wasted. This history and past experience of highly industrialized countries can be a salutary lesson for developing countries, not with the view of blindly copying all the techniques and methods that have emerged over the years, but with the intention of trying to relate these techniques to the problems they are designed to solve and of determining their relevance to the problems which those countries have to face. There is little point in imitating a particular procedure or recipe, irrespective of how elegant or fashionable it happens to be, if its application will make only a marginal contribution, when there are perhaps more effective methods that can be employed. And one must also remember that, to a certain extent, manufacturing and control techniques must be a function of the social environment in which they have to operate.

II. THE FACETS OF PRODUCTION MANAGEMENT

The next items to be considered are the planning and control of production operations. In discussing planning activities, one must first distinguish between short-term and long-term planning. The first relates to a framework of resources which are already defined, the planning function is then confined to designing and evaluating alternative schemes for achieving the production goals set by top management. Long-term planning, however, is concerned with the resources not as they are but as they should be, that is, with the acquisition of resources to fit future goals of the enterprise. Although production management is mainly associated with the first, there are many problems in long-term planning in which it must be involved, such as the replacement of machines and equipment due to wear and high maintenance costs or due to the technical innovaton incorporated in new designs, the rate at which the production activities should be mechanized or the kind of skills which will be required of operators in the future.

The main activities and methods of production management, particularly in relation to short-term planning and control, can be conveniently grouped under two catgories, the first called "production planning and control", the second, "method engineering". These categories are briefly summarized in table 1.

A. *The production-consumption cycle*

The way in which all these activities are interrelated becomes clear when one considers the production procedure described in figure 1, where the main flow-channels of instructions, information and materials are shown. The production-consumption cycle begins and ends with the customer, as may be seen from the following sequence of operations:

(*a*) The sales department studies the reception of products in the market and consumer reactions to new modifications and designs. Market research is also carried out regarding proposed new products;

(*b*) The collected data are analysed by the sales department, which prepares a sales forecast with a breakdown of products and models as a function of time periods. The detailed forecast is submitted to management;

(*c*) A production budget is prepared by the financial department, in consultation with the manufacturing

Table 1

INDUSTRIAL ENGINEERING FUNCTIONS IN AN INDUSTRIAL ENTERPRISE

Production planning and control	*Methods engineering*
Materials: records, availability, procurement, storage, issue, control	Work study: method study (including workplace layout), work measurement
Methods: choice from available facilities for manufacture; tool and jig design	Process evaluation: comparison of processes, new processes
Machines: specifications, availability, loading	Machines: equipment policy, maintenance, renewal
Routing: sequence of operations, work flow, machine assignment	Layout: flow of work, location of machines and departments, material-handling systems, effect of expansion plans
Estimating: operation times	Quality control: inspection procedures, testing laboratories, cost of quality
Scheduling: time-table of production activities	Standardization and simplification: of products, methods, auxiliary equipment, recording systems, procedures
Dispatching: releasing of production orders	Safety: instructions for handling materials and machines
Expediting: recording of progress, corrective action	Incentive schemes: wage and other incentives
Inspection: concerned with inspection results and their effect on schedules	Suggestion schemes: feedback and new ideas from operators
Evaluation: effective even on a short-term basis, particularly for future routing, scheduling and stock control	

Source: Adapted from Samuel Eilon, *Elements of Production Planning and Control* (New York, Macmillan, 1962), chapter 4.

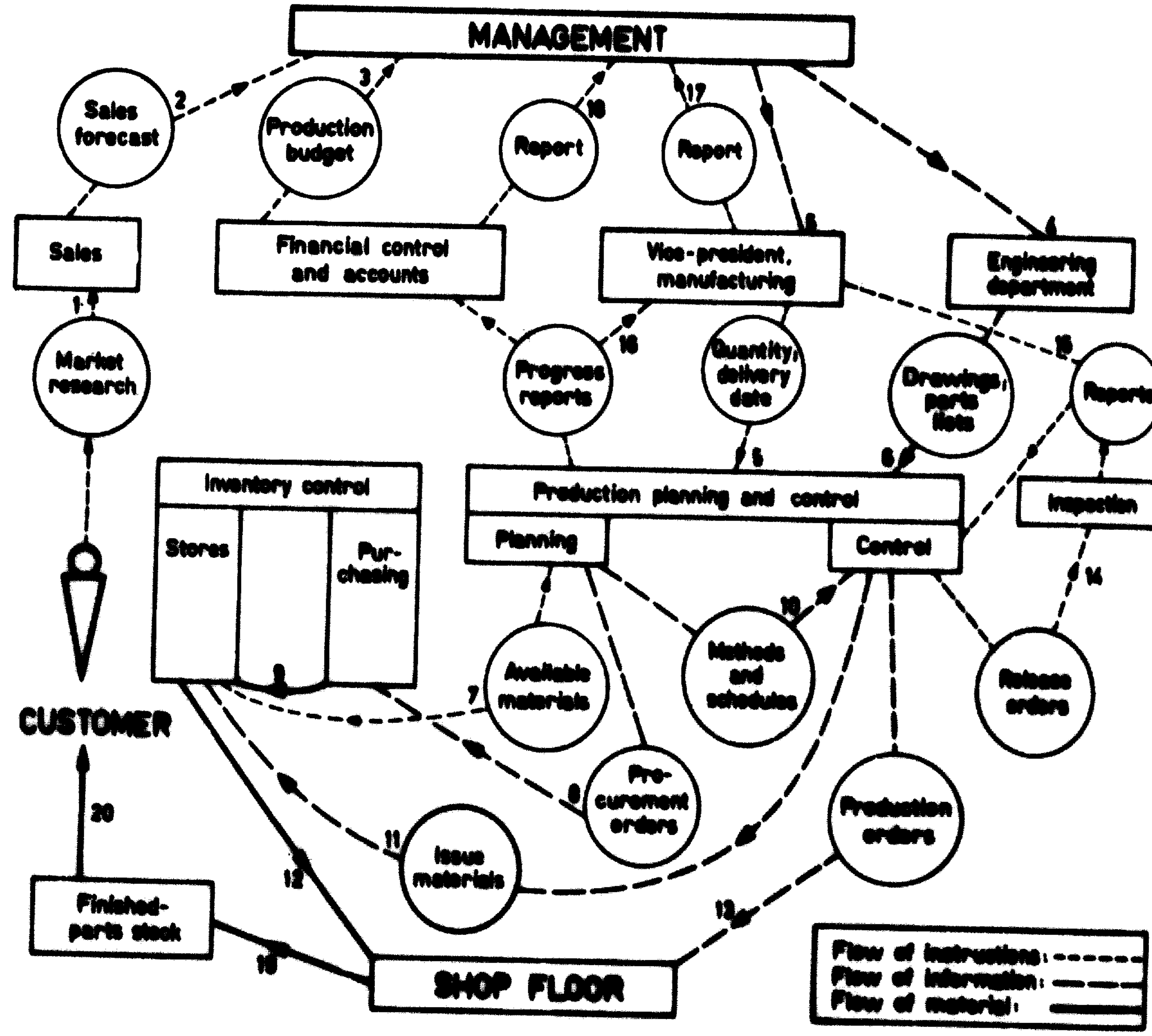

Figure 1

THE PRODUCTION-CONSUMPTION CYCLE

department. The proposed budget and the sales forecasts are closely scrutinized by management, and a decision is taken regarding the annual or semi-annual quantity to be produced;

(*d*) The engineering department is instructed to prepare drawings, parts lists and specifications, or to check and modify existing ones. The manufacturing budget is then adjusted accordingly;

(*e*) The vice-president or the head of the department responsible for manufacturing is authorized to begin production, and instructions are issued to the production planning and control department, specifying quantities, delivery schedules etc.;

(*f*) The technical information is obtained from the engineering department (including drawings, parts lists, specifications, standards etc.) and is passed on to the planning section;

(*g*) One of the first functions of the production planning and control department is to be well-informed about the availability of materials and expected delivery dates of materials already ordered. Production planning is carried out and detailed schedules are prepared;

(*h*) The inventory levels are checked to determine the orders for procurement of materials and standard parts that have to be issued. Parts and assemblies that are subcontracted are also ordered by the purchasing department;

(*i*) The purchased materials and parts are inspected prior to acceptance and are stored until instructions are obtained to release them to the shops;

(*j*) The production planning section supplies complete data on methods, machine loading and utilization as well as on production schedules, to the control section for dispatching;

(*k*) The control section releases orders for materials, tools, fixtures etc;

(*l*) Orders are issued to the shop;

(*m*) Detailed production orders are dispatched to the shown by the production control section, specifying what, how, when and where operations should be performed. The control functions are carried out throughout the manufacturing period, and progress is constantly compared with the planned schedules so that suitable modifications may be considered and incorporated when required. This necessitates a close and permanent contact between the control section and manufacturing departments, to facilitate a constant flow of information and instructions;

(*n*) Inspection orders are released. The purpose of quality control during the production processes is to ensure that the specifications as laid down are conformed with. Final inspection of the parts is carried out before the product leaves the shop and moves to the finished-parts or products store;

(*o*) Evaluation of the prodution operations is the main pillar of the control function and has to be carried out both during and after these operations. Inspection reports are one facet of evaluation, and they form the basis for corrective actions in the processes or methods, and sometimes even for modifications in the specifications of raw materials;

(*p*) The production planning and control department reports on the progress of the work to the vice-president responsible for manufacturing. These reports are also studied by the financial control department. The control section also evaluates data obtained from the shops about operation times, idle time of men and machines, causes and effects of breakdowns, trends in the fluctuations of output etc. Action initiated by the control section as a result of such reports has to be followed up, and its evaluation should also be reported to the vice-president;

(*q*) Management receives interim and final reports from the vice-president of manufacturing;

(*r*) Management also receives a report from the financial department, after which a final evaluation can be made;

(*s*) The finished product is transferred (after inspection) to stock;

(*t*) Finally, the product is sold to the customer, who, after comparing the product characteristics with those of its competitors and with his expectations, is ready to contribute his views and reactions to market researchers.

It is evident from this outline that the production procedure involves the co-operative and co-ordinated effort of all the departments of the enterprise. Even when the functions of each department are clearly specified and well understood, the departments cannot operate independently. They have to perform as parts of an integrated body, and the purpose of the procedure described above is to specify where and in what form their efforts are required, and what kind of flow information should be constantly maintained.

B. *The control function*

After the potential capabilities of resources have been critically evaluated, a programme can be set up to include production targets and the way in which the organization will utilize its resources to attain these targets. This is, in fact, what the planning function is supposed to do.

The control activity begins as soon as the proonducti operations begin. Control has two main functions: the first is to ensure that operations are performed to plan, by taking corrective action, by adjusting the plan and by "chasing" tools or materials (this is why the name "progress chasers" is often given to production controllers on the shop floor); the second is to evaluate the production plan and to determine if a better one could not be devised in the light of the experience gained (this exercise is particularly valuable as feedback to future planning activities).

Thus, control consists of four stages:

(*a*) Observation and recording of progress;

(*b*) Analysis of data and comparison with plans and objectives;

(*c*) Immediate corrective action to modify plans and redirect activities;

(*d*) Evaluation of the planning function and the effectiveness of the control procedures for future reference.

These states apply equally to the control of processes, to the control of inventory, to inspection and to cost control, as summarized in table 2.

Table 2

CONTROL OF PROCESSES, INVENTORY, INSPECTION AND COST

	Processes	*Inventory*	*Inspection*	*Cost*
Observation	Active processes: output *versus* time; Idle processes: machine idle time; breakdowns	Records of stock level	Process control; Control charts	Collect cost data
Analysis	Compare progress with plan	Distribution of demand; Trends; Seasonal fluctuations	Process capabilities; Trends	Compute costs and compare with estimates
Immediate action	Expedite	Issue production and procurement orders	Initiate 100-per cent inspection; Adjust processes	Adjust sales price (if possible)
Evaluation	Process capacity: maintenance schedules	Replenishment policies; Inventory systems	Reassessment of specifications; Process improvement; Inspection procedures	Economic evaluation of processes; Preparing better data for future estimates

Source: Adapted from Samuel Eilon, *Elements of Production Planning and Control* (New York, Macmillan, 1962), chapter 15.

III. The tools of production management

This is not the place to review the various tools of production management in detail. One can postulate in general terms about their potential usefulness for developing countries, but conditions in different countries vary so greatly that it would be foolhardy to suggest universal procedures.

Of the vast spectrum of tools, those which have been selected for discussion in the paper are (A) work study, (B) problems of machine capacity, (C) machine capacity for multiple-product plants, (D) control of product variety and (E) operational research. This is not because the author regards other tools as being unimportant. Production scheduling, design for production, selection of materials, standardization, tooling, selection and evaluation of processes, maintenance of plant, quality control and even packing and dispatching are all important facets of production; and, indeed, one could widen the brief to include problems of organization and industrial relations. But first, all these would be even more difficult to generalize about, and, secondly, to do justice to these issues a book of considerable length would be needed. The topics which have been selected for further discussion here perhaps serve to illustrate most poignantly that what production management is concerned with is the effective use of resources, but it is certainly not the intention to convey the impression that other tools have no contribution to make to this end.

A. *Work study*

Work study has long been recognized as one of the primary tools used by industrial engineers to increase the level of productivity in their plants. As the term implies, the purpose of work study is to investigate the factors that determine the effectiveness of executing tasks and to suggest alternative methods which will improve the performance of the operators and the equipment engaged on the task.

This term, which is widely used in the United Kingdom of Great Britain and Northern Ireland, is probably better than the conventional name "time and motion study", because it does not confine investigations to the study of times or motions associated with the task, but takes a broader view of the problems which are likely to be encountered.

Work study consists of two main areas: method study, which aims at improving the methods used in the operator–machine system; and work measurement, which attempts to determine the times tasks take or should take. Although the measurement of time can be helpful in method study in that, in some cases, it provides a yardstick for the effectiveness of certain methods or for assessing the improvement suggested by new methods, there are numerous work study projects which can be carried out successfully without any time measurement, particularly when problems of work flow or the right sequence of operations are involved. The objectives of method study and work measurement are summarized in table 3 at the foot of the page.

The work-measurement area is often associated with rate fixing and wage-incentive schemes, and this is unfortunate. Admittedly, in firms which have piece-rates or other wage incentives which are closely linked with the output of individual operators, rate fixing is inevitable, but it should be realized that this is by no means the only purpose of work measurement. Even in firms which have no wage-incentive schemes, there is sometimes a need to determine the times of operations for planning and scheduling purposes.

How much of all these is relevant to developing countries? Generally, work study (and in particular method study) has a lot to offer, as it reveals the main interactions between such activities as operation, transportation (or handling) and inspection, it identifies delays and determines where they occur, and it highlights breakdowns and traces their causes and effects. In short, it helps to present the domain of the industrial tasks in an orderly and rational fashion, and, as such, it provides valuable information for those who attempt to control these tasks and to ensure that work proceeds along its pre-ordained course.

But this does not mean that all the techniques are equally useful. The very detailed study of work through various means—e.g., micromotion analysis, observation of elemental motions through the use of films and operation charts which identify and record the distribution of motions to the two hands or even to various fingers—is justified only when such studies are concerned with highly repetitive tasks involving comparatively short cycle times and when the cost of labour is a significant component

Table 3

Objectives of method study and work measurement

Method study	*Work measurement*
Define the operations and their relationships	Provide information for method study
Determine whether operations can be eliminated or modified	Provide data for scheduling
Explore alternative processing methods	Assist production control in checking to determine if activities run according to plan
Eliminate or minimize delays	Provide a basis for wage-incentive schemes
Improve work-place and plant layout to simplify handling	
Allocate jobs to men with appropriate levels of skill	
Provide information useful for product design	

in the total cost structure. Under such conditions, even a marginal decrease in the cycle time can have a noticeable effect on the rate of output and on costs. Indeed, it is for this reason that micromotion has been used in numerous mass production or large-batch production lines in highly industrialized countries, with tangible contributions to the improvement of productivity. In many developing countries, such conditions are not widely encountered and it is a mistake to allow uncurbed enthusiasm for work study to employ such tools indiscriminately. Not only can these techniques be expensive and time-consuming, and the potential benefit minute, but the detailed analysis may cloud the issue; it may divert the attention of the investigator from the basic problems which the firm has to face. Management techniques, like the artisan's tools, must be suitable for the job and they must, therefore, be selected with care.

B. *Problems of machine capacity*

Machine output is inversely proportional to the cycle time, that is, the time required to complete a set of activities associated with the manufacture of one unit of product. In order to utilize the machine capacity to the maximum, it is often useful to study in detail some of the components that make up this cycle time.

A typical sequence of activities in a man-machine system employed on repetitive operations may consist of:

Operator	*Machine*
Unloading the machine	Being unloaded
Inspecting the workpiece	Being started
Loading the machine	Performing operations on the workpiece
Starting the machine	Being unloaded
Transporting work to and from the machine	

All these activities may be grouped under two categories:

(*a*) *Concurrent activities:* these are tasks that require the simultaneous "attention" of both operator and machine (such as loading and unloading; let the total length of these tasks per cycle be a);

(*b*) *Independent activities:* these are tasks which the operator and the machine can perform independently of each other (the operator: inspecting and handling, totalling b per cycle; the machine: running automatically for a time t without supervision).

In addition, one may have idle times incurred by both the operator (i_o) and the machine (i_m) during the cycle, so that the cycle time T for the operator is

$$T = a + b + i_o$$

and for the machine

$$T = a + t + i_m$$

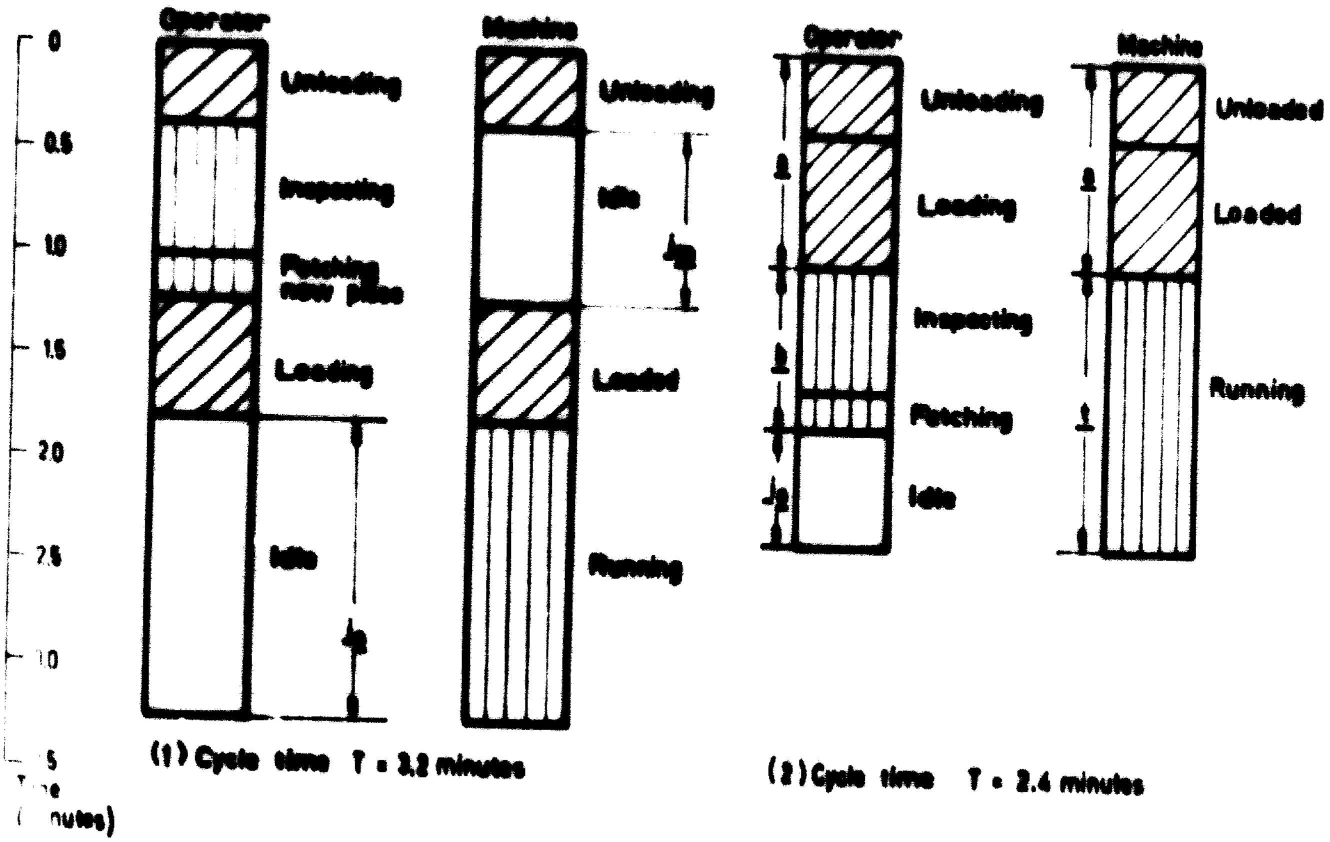

Figure 2

Reducing the cycle time

An example is shown in figure 2, from which it may be seen that:

a = unloading + loading = 1.0 minute;
b = inspecting + fetching = 0.8 minute;
t = machine running unattended = 1.4 minutes;
i_o = operator idle time = 1.4 minutes;
i_m = machine idle time = 0.8 minute.

The sequence of operations as shown in arrangement (1) in figure 2 is 3.2 minutes, but if this sequence is rearranged as in (2), machine idle time is eliminated and the cycle time is reduced to 2.4 minutes, leading, in this case, to an increased output of the machine by one-third. The secret is simply to ensure that idle time is not incurred by both

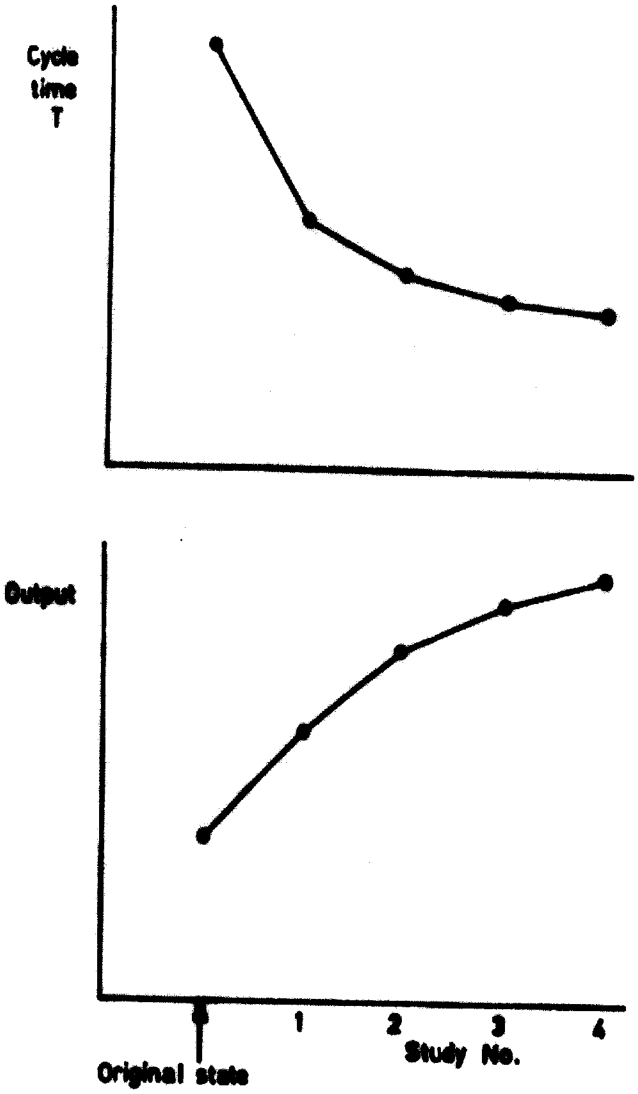

Figure 3

DIMINISHING RETURNS ON SEQUENTIAL STUDIES

man and machine. One may then turn to the constituents of the new cycle and see whether further reductions can be made, mainly through work study methods, and naturally attention will then be focused on the activities of the "busy partner", namely, the one which has no idle time (in case (2) in figure 2 the busy partner is the machine). To summarize, reduction in cycle time may be achieved by:

(*a*) Eliminating idle time for one partner in the man-machine system by rearranging the sequence of operations and by avoiding delays at the beginning and at the end of the cycle;

(*b*) Reducing the independent activity time of the "busy partner";

(*c*) Reducing the concurrent activity time by devising more efficient methods for loading and unloading the workpiece.

The effect of such sequential studies often follows the law of diminishing returns, as is shown in figure 3. At first, the improvement is substantial, but as more and more studies are conducted, the level of sophistication and, with it, the cost of the study rise rapidly; and as the work becomes more rationalized, there is less room for manoeuvre and the resultant benefit shrinks further and further. It is, therefore, important not only to know when to begin an investigation into an industrial activity, but also when to stop and divert the investigators and their resources to new problems, or to devise new approaches to the old ones.

C. *Machine capacity for multiple-product plants*

One of the major problems with which production management is constantly faced is whether the manufacturing capacity is adequate and to what extent it is affected by the product-mix in multiple-product schedule. As an illustration of the way in which this problem can be analysed, one may examine the following example: a plant produces two products, A and B, and five machines are involved in the production process. The rates of production are given below:

	Rates of production (units per day)	
	Product A	*Product B*
Machine		
1	300	300
2	400	200
3	150	—
4	—	350
5	200	300

Thus, machine 1 can produce either 300 units of product A or 300 units of product B, but, of course, it is possible also to produce a mixture of A and B. The various combinations are represented in figure 4 by the line PQ. Point P indicates the production of 300 units of A and none of B, whereas point Q indicates the production of product B only. Any point on the line gives us a possible combination, for example, point R signifies 200 of A and 100 of B, and S stands for 50 of A and 250 of B.

The line PQ therefore represents the full capacity of this machine; any point below the line also signifies a feasible product-mix, although in the region below the line the machine is no longer being utilized to its full capacity. Point T, for example, stands for 150 units of A and 50 of B, but for this level of production of A, one can increase the output of B to 150 units before reaching the full capacity line.

Similarly, any point above the line PQ is not a feasible product-mix, because it requires more capacity than is available. Point U, for example, represents an output of 250 units of A and 150 of B, whereas the full-capacity

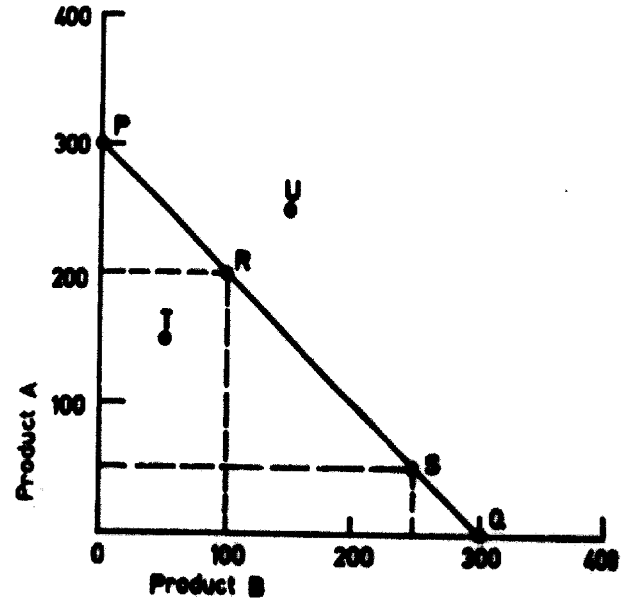

Figure 4

MAXIMUM CAPACITY LINE FOR A TWO-PRODUCT SYSTEM

line indicates that for 250 units of A only 50 units of B can be produced.

One may then turn to machine 2 (see fig. 5) and represent its full capacity line in the same way as that for machine 1. There are now two lines, one for each machine and they intersect at point R. To the left of R, line 2 is above line 1; this implies that any product-mix which involves using machine 2 to its full capacity is above the capacity of machine 1 and is therefore unacceptable. Any feasible product-mix for machine 1, however, is also feasible for machine 2, although it will result in machine 2 not being fully utilized. To the right of point R, the position is reversed: line 2 is below line 1, so that line 2

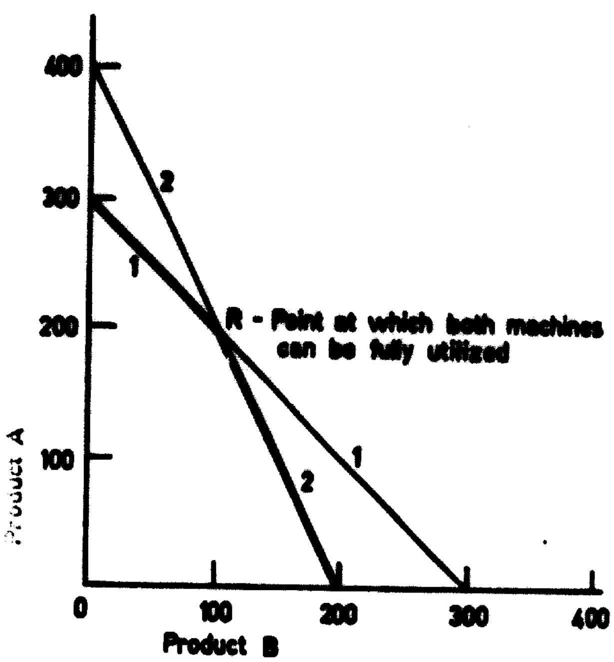

Figure 5

MAXIMUM CAPACITY OF TWO MACHINES

represents the limiting capacity available, whereas machine 1 will not be fully utilized. The heavy line, therefore, gives the full capacity for the two-machine system; any point below this line is feasible, any point above it implies that at least one of the two machines does not have adequate capacity. And only at one point, namely R, can both machines be fully utilized.

One may then superimpose capacity-restriction lines for the other machines, as shown in figure 6. Line 3 is horizontal, since machine 3 is used for product A only and it does not restrict the output of product B in any way; similarly line 4 is vertical because machine 4 is used for product B only.

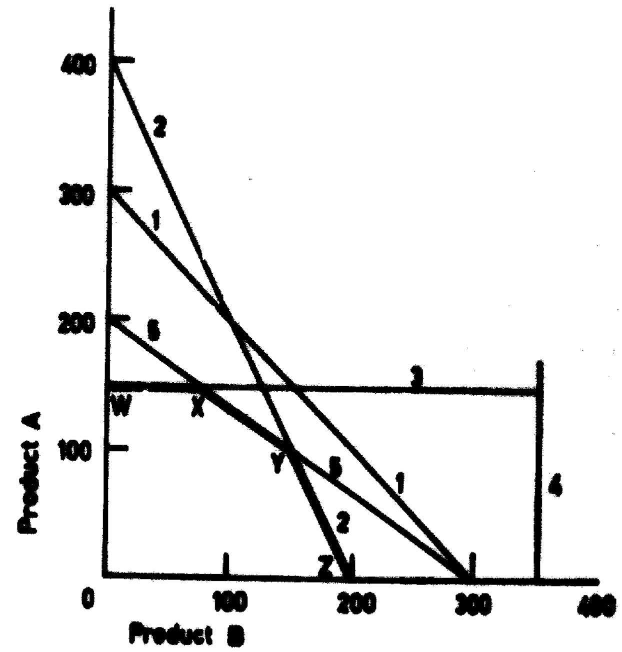

Figure 6

FEASIBLE PRODUCT-MIX

Following earlier arguments, the lowest line represents the global capacity restriction of the plant, because on that line one machine is fully utilized, and that machine can be described as the "bottle-neck". Other machines may be capable of a higher output, but the output of the plant as a whole is always determined by the bottle-neck.

The capacity restriction in this case is given by the broken line WXYZ. The portion WX represents product mixes for which machine 3 is fully utilized and all the others are underutilized. At point X machine 5 is used to its limit and along the portion XY this machine becomes the bottle-neck. As one moves along XY towards point Y, increasing the output of product B and decreasing the output of A, one gets further and further from line 3, which simply implies that increasingly more idle time on machine 3 is incurred. And at point Y, both machines 2 and 5 are fully utilized, whereas along the portion YZ, the capacity restriction of machine 2 is the significant one.

The polygon OWXYZ is the space within which product-mixes are feasible, although any point below WXYZ means that all the machines are under-utilized.

This is obviously a very useful analysis. One finds, for example, that in this case a product-mix is preferable to producing only product A. The maximum output of A is given at point W as 150 units, but on can produce up to 75 units of product B without having to reduce the output of A (at point X); and, provided product B is at all profitable, it is certainly better to operate at X than at W. One also gets useful data in considering such problems as:

(*a*) Is it worth while increasing the capacity of certain machines, and, if so, which?

(*b*) When the bottle-neck is removed (the capacity of the limiting process is increased), where is the new bottle-neck? (a bottle-neck will always exist, if one wishes to maximize output; however, it may shift to another machine);

(*c*) Should the product-mix remain the same for the new capacity restrictions?

Those familiar with linear programming will recognize it in the foregoing discussion, and it goes without saying that when a product-mix of more than two products is considered, graphical presentation becomes difficult—if not impossible—and one must then resort to formulation of the various restrictions in an algebraic form. But this does not detract from the value that may be gained from such an analysis, which can be and often is very useful even for small plants.

D. *Control of product variety*

One of the major problems with which production management is constantly faced is the control of the variety of products, materials and methods. The variety of products is stimulated by the whims of customers and by the natural desire of the salesman to satisfy them. Variety is like entropy in thermodynamics; it has a tendency to grow unless a conscious effort is made to put it under control. The advantages and disadvantages of having a wide variety of products are summarized in table 4 at the foot of the page.

There is little doubt that a small range of products enhances the efficiency of production methods, as well as the planning and control procedures of production activities and inventories, but there is a limited number of products for which demand is high enough to justify exclusive production lines working on a continuous or mass-production basis. Even in highly industrialized countries with well-established markets, the development of production processes has generally more than kept pace with increasing demand; the desire to keep production facilities busy, and the fact that customers increasingly prefer some variations of the basic product to the standard model always lead to a diversification of products. In addition, financial managers and salesmen are often very unhappy about over-specialization. It makes the company too vulnerable, they argue. First, it commits the company to a narrow and often rigid set of specifications, thus allowing ample opportunities for competitors to consolidate their position in the market; secondly, by utilizing its resources for a single product, the company can be seriously challenged by new products which threaten to replace or make obsolete the current one. The balance between the convincing technical and administrative advantages of specialization and the philosophy of risk spreading by diversification is obviously a delicate one, and it is probably one of the major factors in determining the productivity of the plant.

The growth of variety is often effectively demonstrated in a distribution of sales income curve, as is shown in figure 7. The products are arranged in a descending order of their sales income, and the cumulative income is then plotted against the percentage of the products offered by the firm. In this curve, it may be seen that some 25 per cent of the products account for 75 per cent of the total income, and this is by no means uncommon in firms which tend to diversify their product range. In fact, cases in which 10 to 20 per cent of the products are

Table 4

ADVANTAGES AND DISADVANTAGES OF PRODUCING WIDE VARIETY OF PRODUCTS

Pro variety	*Against variety*
Satisfy a wide range of demand	Reduce stocks of materials and finished goods
Closer contact with the market	Reduce investment in plant and equipment
Avoid losing orders for more profitable goods, if customer directs all his orders to other suppliers	Save storage space
Create new demand	Simplify production planning and control procedures
	Simplify inspection methods
	Reduce range of required skills
	Simplify training methods
	Reduce sales price as a result of higher productivity
	Simplify dispatching to customers, reduce waiting times of orders

Source: Samuel Eilon, *Elements of Production Planning and Control* (New York, Macmillan, 1962), Chapter 5.

responsible for more than 80 per cent of the sales income have been recorded. Figure 8 also shows this point in a histogram form, and the level of profit or loss accorded to each product is also indicated. In the case described in figure 8, one finds that some of the popular products (Nos. 2, 5 and 6) are not very profitable, and one must immediately suspect that the costs of production are unduly high or that there is something wrong in the pricing policy. It is not difficult to see that when the distribution of sales and profits take this form, an elimination of the tail-end of the product range (involving more than 25 per cent of the products) will reduce the

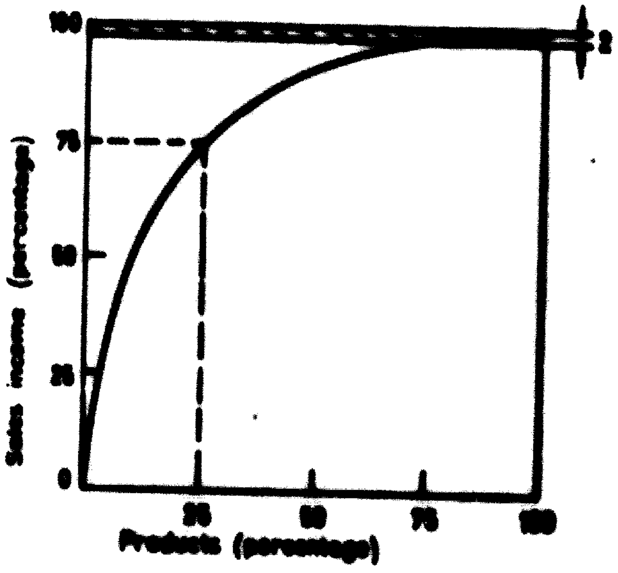

Figure 7

CUMULATIVE SALES-INCOME DISTRIBUTION

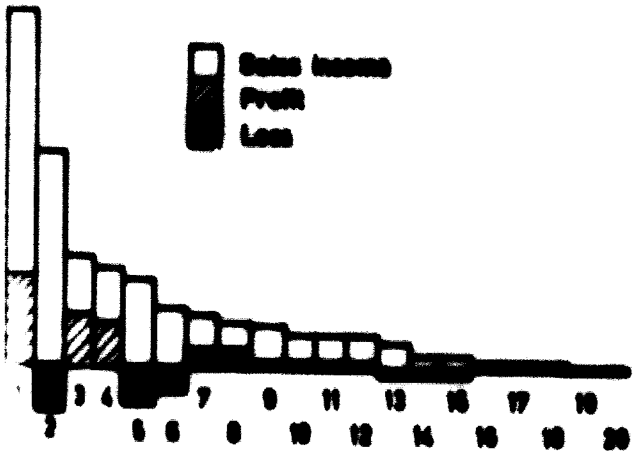

Figure 8

SALES AND PROFITS HISTOGRAMS

total sales income by little more than 2 per cent, and this is an obvious course of action that, under these conditions, must be further investigated.

Many readers will be familiar with the break-even chart method shown in figure 9. This is a useful analysis in studying the profitability of any particular product. The total costs are assumed to consist of two major components: fixed costs (F) and varible cost (aQ). The fixed costs are assumed to be unaffected by the volume of production, the direct or variable cost (a) is the cost of materials, machines and direct labour associated with the production of one unit of the product, so that the direct cost of Q units is aQ. If the sales price, or income, is b per unit, one obtains a break-even point at the intersection of the line $F + aQ$ with the sales-income line bQ. Activity below this break-even point incurs a loss to the firm; activity above this point yields a profit. It follows, therefore, that the greater the production volume, the greater will this profit be.

This analysis is, of course, a gross over-simplification of what happens in real life, and there are many assumptions that could be challenged:

(*a*) The direct costs (a) may well depend on the level of activity (Q). If Q is high, there is more incentive to introduce labour-saving devices; furthermore, operators have a better opportunity to become proficient at their job and thereby reduce the labour content per unit of product;

(*b*) The sales price (b) is not necessarily constant and the introduction of quantity discounts to customers will make the sales-income line of a somewhat different shape than that shown in figure 9;

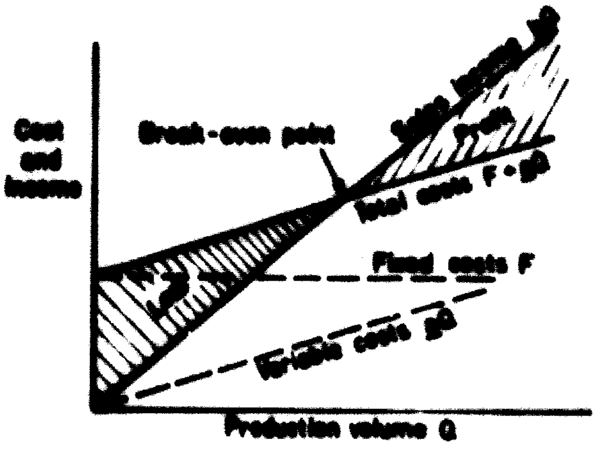

Figure 9

A CONVENTIONAL BREAK-EVEN CHART

(*c*) The fixed costs (F) may well depend on the level of activity of the firm and could, in fact, assume a step-wise function when plotted against the activity (Q).

(*d*) While it is generally not difficult to determine the level of the fixed costs when the firm is engaged on producting a single product, there is some uncertainty about the way the fixed costs of the whole plant should be allocated to several products. One popular method is to perform this allocation according to the relative proportions of sales incomes of the various products, but this raises the problem of reallocation when production volumes are adjusted or when some products are eliminated.

All these appear to be serious objections, but, in fact, the break-even analysis can be easily modified to take account of the first three.[2] The fourth difficulty can be overcome also by using a multiple-product break-even chart and by comparing the marginal benefits $(b-a)$, which can be regarded as a profitability index: the higher it is, the larger the production volume of this product at which one should aim. One can see that the products can be arranged in order of preference, according to their profitability indexes, and a sales policy can then be formulated to discourage the sales of products with a low index and to encourage the sales of those with a high index.

Another problem that needs to be looked into is that of "interdependence of products". A customer may require a range of products which he generally purchases from one supplier, and these products may include some "bread-and-butter" lines which have a high profitability index and some which are less profitable from the manufacturer's point of view. If the manufacturer were to eliminate his less profitable lines, the customer might well decide to change his supplier altogether, so that the sales of the profitable products could be adversely affected. If this effect were to be significant, the manufacturer might well find that he must continue to offer products in the tail-end of his sales-income distribution in order to enhance the sales of the products that he is primarily interested in promoting.

However, once the interdependence factor is properly identified and quantified, it is possible to proceed with a detailed analysis of the likely effects of a variety reduction programme, as well as with the possibility of introducing a pricing policy which would increase the relative profitability index of the less popular products. If such a policy actively discourages the sales of these products in favour of the others, then variety reduction is achieved by an evolutionary process, which is perhaps more palatable to suppliers and customers; if, on the other hand, the sales of the less popular products persist, at least their profitability index and their sales-income contribution have been improved.

One of the main problems in variety control in developing countries, particularly in the consumer goods field, is that with relatively small governmental encouragement (in the form of excessive duty on imports to protect local industry, or of subsidies and other benefits to local manufacturers) a comparatively large number of manufacturers may emerge, all competing in a relatively small market. In one country with about 2 million inhabitants, well over twenty manufacturers of washing machines were recorded a few years ago, some producing more than one model. Similar instances can be cited for other domestic appliances, material-handling equipment, machine tools, components for the building industry, electric motors and switch gears etc. The proliferation of competitors in a relatively small market does not give any of them a chance to rationalize their production methods and attempt to export their goods, and the customer does not benefit either because production of small quantities tends to keep prices high. Variety control in small markets is, therefore, of paramount importance, probably even more so in the developing countries.

E. *Operational research*

"Operational research is the attack of modern science on complex problems arising in the direction and management of large systems of men, machines, materials, and money in industry, business, government and defence. The distinctive approach is to develop a scientific model of the system, incorporating measurements of factors such as chance and risk, with which to predict and compare the outcome of alternative decisions, strategies or control. The purpose is to help management determine its policy and actions scientifically."[3]

The theme is again that of effective use of resources, and some of the problems which were discussed earlier can be legitimately regarded as being within the operational-research orbit. The evaluation of plant capacity and the allocation of machines to various jobs or products, or the analysis of the profit function for different product-mixes, can be treated as linear-programming problems, in which mathematical models are set up with linear constraints describing maximum machine capacities, limitations on the supply or use of certain materials, maximum or minimum production volumes which must be observed for certain products etc.

Problems of congestion in production departments—for example, semi-finished products piling in front of machines or inspection stations, long delays in tool-rooms or in getting materials and tools from stores, delays in the dispatch area—are problems in which the theory of queues can be of some help.

In the queuing model, one visualizes a stream of customers arriving at a service-point and demanding service. A customer can be served if one of the servers in the system is free; and when the service is completed, the customer is discharged from the system and a new customer can be attended to. If customers arrive and none of the servers is free, the customers have to wait in a queue. In the production environment, the components waiting to be processed are the "customers"; the machines are the "servers"; the operators waiting to be served in the store are "customers"; the storekeepers are "servers"; and so on. The type of problems in which operational researchers are interested when faced with congestion situations are:

(*a*) How long does a customer expect to wait before he obtains service?

(*b*) What is the probability of his having to wait longer than a given time period?

(*c*) What is the average length of the queue?

(*d*) What is the probability of the queue exceeding a given length?

(*e*) What are the expected utilization and idle time of the server?

(*f*) How many servers should there be to attain a

[2] L. P. Alford and J. R. Bangs, *Production Handbook* (New York, Ronald Press, 1962), chapters 5 and 20.

[3] Definition suggested in 1962 by the Operational Research Society of the United Kingdom.

desirable level of service (which can be defined in terms of queue length and waiting time)?

(c) How can arrivals and service time be regulated to reduce congestion?

(d) Should priorities be given to certain customers, and, if so, what will the effects be?

Operational research has also contributed to a more effective control of inventories. The main problem here is to determine a sound replenishment policy, so that stocks of materials, components or finished goods are available when required, yet the stock level is not so high as to incur excessive holding costs. This is a typical problem of conflict of interests. If demand for the commodity in question is variable, probability of running out of stock can only be attained if a comparatively high safety stock margin is maintained, and it is this balance between having a reasonable stock level and an acceptable incidence or risk of run-out that an inventory control policy attempts to formulate.

Another important area in which some useful models have been developed is that of plant maintenance and replacement. Numerous maintenance policies can be formulated, ranging from one extreme, which specifies maintenance only when plant breakdown occurs, to the other, which calls for scheduled preventative maintenance at very short time intervals. The purpose of preventative maintenance is to reduce breakdowns, but the more frequent it is, the more costly it is and the less the potential plant capacity which is available. Maintenance costs are also an increasing function with plant age, and this raises the problem of deciding when is the best time to replace the plant with a new one.

Scheduling is another theme on which numerous operational-research studies have been carried out. Scheduling is the projecting of activities and their sequences, generally on a time scale. In production scheduling, one is not only interested in stating the allocation of jobs to machines or men, but also in the sequence in which these jobs should be carried out. The complexity of the scheduling activity naturally depends upon the type of production (whether it is continuous, batch or job production), upon the number of operations or machines involved in the production sequence and upon the degree of variability in the demand or in the pattern of incoming orders.

In the case of continuous production, the problem is to control the production level in relation to fluctuating demand, particularly when the demand has a seasonal pattern. Two extreme alternatives can be adopted: the first is to have a constant level of production and a large enough inventory to serve as a cushion between the factory and the market. The fluctuating demand is then absorbed by this inventory, which is replenished at a constant rate. The second is to reduce inventory to a minimum and to transmit the demand fluctuations to the production line, so that production levels will also fluctuate. The advantages of the first method are that with a stable production level, resources can be more effectively utilized, i.e., machines can be kept running at a high performance level, and, what is more important, the labour force can be maintained at a constant level without fear of redundancy at short notice. But if carrying high inventories during a slack season is very costly, the firm may be forced to allow some of the market fluctuations to be reflected in the production programe, and the problem of finding a compromise solution can then be solved by using suitable linear-programming models.

Batch production presents problems of a somewhat different character. When the rate of production is higher than the rate of demand, the stock level will increase at a rate which is equivalent to the difference between the rate of production and the rate at which stock is withdrawn from the store to meet the demand. Therefore, one has to resort to batch production: the store is replenished with a batch, then the stock is depleted at a relatively low rate, until it is time to produce another batch to replenish the store. Between the two batches, the equipment is available to produce other products; the purpose of the scheduling activity under these conditions is to produce a programme in which the batches of the various products are dovetailed in such a manner that the stock level for each fluctuates between acceptable levels and that the equipment is effectively used with as little idle time as possible. In other words, it is necessary to determine a production cycle, in which the appropriate quantities for each product are manufactured in turn.

In batch production, therefore, some regularity in the production schedule can be perceived, even if the production cycle is subject to variations in order to accommodate fluctuations in demand. In job production there are no such regular patterns. Jobs differ in their characteristics and specifications; they often arrive at random and the amount of processing and the machines required may vary with the job. In addition to the obvious objective of keeping the machines as fully employed as possible, one may have to bear in mind the delivery dates which have been promised to the customer. Job shop-scheduling is a vast and intricate queuing problem, and simulation exercises can be of tremendous help to the scheduler in pointing out the vital parameters in the system and in suggesting what priority rules can be adopted when the schedule is constructed.

Another important scheduling problem occurs in project planning. Large-scale projects—such as the building of dams, bridges, industrial or residential estates, airports, harbours, ships, motorways etc.—involve large commitments of finance, machinery and manpower. A project can be broken down into individual jobs which may well depend upon each other (certain activities can begin only when others have already been completed), so that the successful management of a project largely depends upon co-ordinating the various activities and upon using the resources effectively. Here, network analysis has made a major contribution in providing indispensable aids to management for evaluating progress and controlling the execution of project work.

CONCLUSION

Modern management is becoming increasingly conscious of the need for analytical tools, reliable data and purposeful control. Can new techniques, such as those of operational research, be of use to developing countries? The evidence so far indicates that they definitely can. On the national scale, every Government is concerned about the allocation of financial resources, about the relative merits of various development schemes and about the rate of industrialization; these are areas in which analytical tools can make a significant contribution. Certainly at the level of undertaking large-scale projects, and even for production management in factories, modern scheduling methods can be very helpful.

The secret is not to copy blindly management practices from highly industrialized countries. Control tools must be related to the industrial and economic needs of the country and they must fit into the social environment in which they have to operate; and the selection and adaptation of these tools is an art of no mean complexity.

MASS PRODUCTION METHODS IN THE MACHINE-TOOL INDUSTRY IN THE UNION OF SOVIET SOCIALIST REPUBLICS

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Introduction

The Krasny Proletary machine-tool works is one of the oldest industrial enterprises in the Union of Soviet Socialist Republics. The works is more than 100 years old. For over fifty years, machine tools have been on the works' production programme. The Krasny Proletary works is currently specializing in the production of metalworking lathes and is a major machine-tool manufacturer in the Soviet Union.

The 14,000 machine tools turned out annually place the works in the forefront of machine-tool manufacturers, not only in the Soviet Union, but also throughout the world. The huge volume of production indicates that the works' production is characterized by large series.

The planned specialization in the USSR has made it possible to concentrate the production of a single type and size of an engine (universal) lathe (200–215 mm in centre height) at an out-works.

This created conditions which were conducive to a substantial increase in production series and to the introduction of mass production methods, first of all, to turn to account the highly efficient technology and production techniques developed by motor-car and tractor manufacturers.

The Krasny Proletary works has thus become a pioneer in the introduction of mass production methods in the machine-tool industry.

I. Development of production lines

As early as 1944, the works was the first in the world machine-tool industry to install a production line for the assembly of lathes, model 1D62 (DIP 20). Then in 1945, a modernized lathe, model 1D62 (DIP 20) was put on the production line in the mechanical and assembly departments. The subsequent years saw further work in the development and improvement of production-line methods in machine-tool building until, in 1949, model 1A62 lathes were put on the production line in the entire mechanical-assembly cycle.

In 1956–1957, production lines at the works were completely rebuilt as part of the routine reconstruction of large-series production departments and the change-over to a new lathe, model 1K62.

Later, additional steps were taken for the mechanization of all production lines in lathe manufacture at all departments. At the current time, in large-series production departments, there are sixty production lines in operation; the conveyors in service attain 1,300 metres in length; rolling-tables total 2,000 metres in length, there are 200 units of hoisting and transportation equipment and over 10,000 varieties of technological fixtures.

The experience in production-line methods which has been accumulated by the works over the years is quite considerable. The engineering and technical staff, production engineers and designers of fixtures and mechanization facilities have contributed greatly to the solution of problems involved in setting up a production line system.

It is no wonder, therefore, that the works' experience is continuously explored and drawn upon by the machine-tool industry, as well as by other machine-building enterprises in the Soviet Union and other centrally planned economies.

It is worth noting that the Krasny Proletary works rendered help to mainland China in setting up the mass production of lathes in 1956–1957.

In 1962, the Colchester, in the United Kingdom of Great Britain and Northern Ireland, was the first among the manufacturers in free-enterprise economies to introduce production-line methods in machine-tool manufacture.

During the past twenty years, every machine-building industry, including machine-tool production, has accumulated enormous experience in production-line methods and the literature on the subject is extremely rich; it seems, therefore, superfluous to dwell on basic concepts and general statements relating to mass production.

It is worth while, however, to draw some conclusions on the essential features of production-line methods as applied at the Krasny Proletary plant. The work for setting up mass production had the following objectives at every stage: (a) a sharp reduction in labour consumption and, consequently, an increase in labour productivity and a decrease in production costs; (b) to raise substantially the output of machine tools at the same or insignificantly expanded production areas, and (c) to curtail essentially the manufacturing cycle.

At every stage of the work for setting up mass production, and such stages were, as a rule, connected with a change-over to the manufacture of some new machine-tool models without stopping the production of those introduced earlier, the works' personnel successfully coped with the above-mentioned targets.

This is borne out by the following figures. In the years since a change-over to production line methods, the output of machine tools has increased more than twice and labour consumption has diminished by 72 per cent, although the growth of production areas was as insignificant as 8 per cent.

Summing up the many years of experience in setting up mass production, one may safely state that the principal factors involved were: highly efficient technology; group-production and group-finishing methods; and a complex solution of all the problems involved, covering the entire production cycle and introducing mechanization into principal and auxiliary operations.

Undoubtedly, one of the principal factors in the work was the effort to achieve maximum product quality.

A. *Highly efficient technology*

Even prior to beginning the work for a change-over to mass production, steps had been taken to introduce the highly efficient production methods evolved in the motor-car and tractor industry into the serial production of machine tools, particularly the special-purpose equipment used to finish machine-body components. Further work for setting up mass production permitted the elements of highly effective technology to be introduced with even greater success. Of course, the methods typical of mass production had to be adapted to suit the conditions of serial production.

Success in the solution of technological problems was mainly due to the perfection of machine-tool designs in those aspects, account being taken of every stage in component manufacture and in the assembly of separate machine units and of the machine tool as a whole. This proved to be a crucial factor.

Therefore, production engineers at Krasny Proletary give much thought to the technological aspects of a new design as a part of the preparations for its serial manufacture on the production line. In the process of developing an experimental model or an experimental batch, great consideration is given to perfecting the design, with many improvements usually being made in both the design and the technological features of the new machine tool.

Thorough work on the technological features of the 1K62-machine tool (see figure 1) permitted, first of all, the use of advanced methods in the production of blanks usually known as component-forming methods. In other words, steps were taken to obtain blanks with minimum allowances or to shape them so as to bring them as close as possible to finished components.

Modern technology has enormous potentialities in this respect. Over 50 per cent of all the components at the plant are currently manufactured with the use of advanced shaping methods.

Along with conventional grey and malleable cast-iron castings produced from patterns made of metal, the works is using precision casting under pressure and to cast patterns, as well as core casting. Conversion of ten items to this type of casting permits the plant to save 4.7 kg of cast-iron per machine tool and brings down labour consumption by 30 minutes.

Pressure casting of zinc alloys is used to obtain sixteen items of machine components, e.g., panels, boxes, rings, joints etc. As a result, metal consumption goes down three times and labour consumption two times, on the average.

The casting to cast patterns is used to obtain thirty-five components ranging in weight from 30 grams to 2.5 kilogrammes—discs, rockers, planks, forks etc. This permits the reduction of mechanical processing by as much as 85–90 per cent and saves 28 kg of metal per machine tool.

The lack of an adequate centralized system for the delivery of precision castings interferes with the even wider application of this highly effective casting method.

The works has no foundry department of its own, and for this reason, the technological aspects are worked out in co-operation with casting suppliers.

Hot stamping on power forging presses, stamping hammer and horizontal forging machines yields 100 items of components: gears, handles, rings and spindles ranging in weight from 100 grams to 57 kilogrammes.

This is the reason that mechanical departments obtain blanks with allowances as low as within 1.5 mm on either side.

A widely applied procedure in the semi-finished products department is the cutting of blanks on presses prior to stamping. For diameters of 100–200 mm, the cutting is conducted, lest cracks should appear, with heating in a special mechanized gas-furnace attached to the press.

Much attention has been paid at the works to the introduction of stamped and stamp-welded sheet structures. By this method, 275 items are produced from sheet metal of 1.5–3 mm thickness and varying in weight from 15 grams to 33 kilogrammes. The Krasny Proletary plant was the first among machine-tool manufacturers to introduce large-size fully-stamped parts (troughs, trays etc.) and to use deep extrusion in the cold stamping of housings, shells etc. (up to 175 mm deep). Recently, new efforts have been made to expand the application of sheet components, and cast-iron parts have been converted to sheet stamping to some extent. Although this has involved a radical change in design, the effect has been very substantial. For instance, in converting the gear-box cover in the 1K62 machine tool from cast-iron to sheet stamping, the economy achieved was as high as 33 kg.

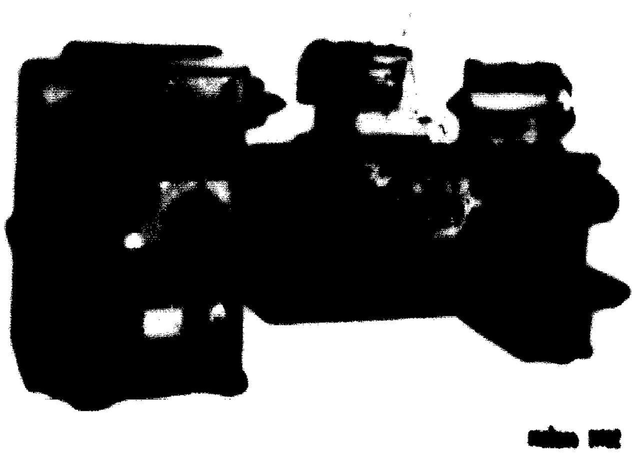
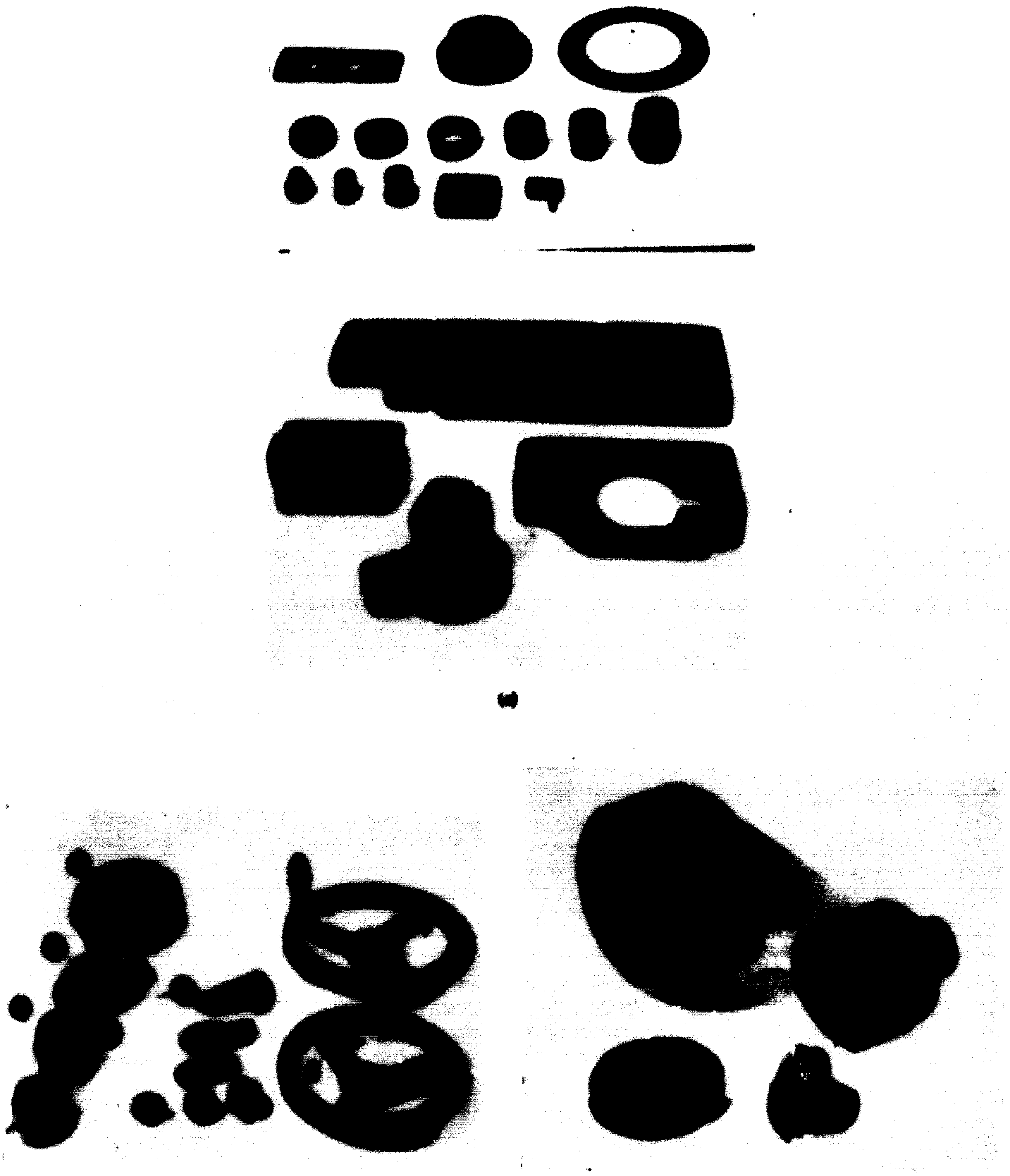


Figure 1

TYPE 1K62 THREAD-CUTTING LATHE



(a)

(b) (c)

Figure 2

PLASTIC MEMBERS USED IN TYPE 1K62 THREAD-CUTTING LATHE and in converting the minor submotor plate, as high as 1.3 kg.

In collaboration with the Stankoagregat works, where centralized stamping-welding production is being set up, the Krasny Proletary works is engaged in experimental work on a welded bed for the IK62 lathe. Compared with the cast-iron bed, it weighs 300 kg less.

In the past seven years, every effort has been made to introduce components from polymeric materials. Such materials as phenoplast, fibre-filled moulding material, capron and polystyrene go into the manufacture of fifty-five components for the IK62 machine tool (see fig. 2). This trend is going to continue. Apart from their use in various control components (handles, knobs etc.) and lubrication devices (oil indicators, plugs etc.), plastics are used in the manufacture of loaded components (pulleys, covers, levers etc.). Experience has shown that plastics are highly effective with the works' scope of production. The reduction in component weight amounts to 70–90 per cent and in production costs, to 20–70 per cent. Every year as much as 1,100 tons of metal and over 150,000 roubles are saved by the plant.

It should be noted that, thus far, the introduction of plastic components is a rather complicated process. In the conversion to plastics, it is not possible merely to reproduce the shape of the former metallic component: further design work is needed. Such work is usually undertaken by the plant in co-operation with the specialized supplier enterprises. To produce plastic components, complicated press-moulds are needed. This explains why the process of putting into service plastic components takes quite a long time. Before being put into serial production, plastic components, taking account of the novelty of the material, must be subjected to prolonged laboratory and workshop tests. Therefore, the introduction of plastic components is undertaken in collaboration with various research institutions (All-Union Research Institute for Plastics, Experimental Research Institute of Metal-cutting Machines (ENIMS) etc.).

There are available numerous new plastics with highly valuable properties, in so far as machine tool building goes (fibreglass plastics, polypropylene, polyethylene etc.). However, they are still too expensive to have much effect.

Meanwhile, profile-rolled stock, for instance, could be effectively applied in the plant's serial production. With such components as cutter-holders, racks, splined shafts etc. converted to profile rolling, the economy of metal at the works could be as high as over 300 tons per annum.

Figure 3

NINE-SPINDLE MILLING MACHINE FOR MACHINING TYPE IK62 LATHE BEARINGS: VIEW ONE highly efficient machining technology cannot be achieved unless high-capacity equipment, such as special-purpose and unit-type machine tools, are put to use. They permit the maximum concentration of machining processes, the use of multiple-spindle and multiple-cutter tools and the introduction of automatic cycles, and make it possible for several machine tools to be attended by a single worker.

Machining of plane surfaces in the mechanical department is mainly coped with now by milling, instead of planing, and by grinding, instead of milling. Illustrations of such high-capacity concentrated surface-machining may be found in figures 3 and 4, which show the special-purpose nine-spindle machine tools GEFS, models GF479 and GF480, which perform roughing and semi-finishing operations of the type 1K62 machine-tool bed. Each of them is equipped with seventeen hard-alloy milling-cutters so that their efficiency is three to four times higher than that of planing. The machine set up with this number of cutters is shown in figure 5.

The milling of feed-boxes on six sides is carried out on a four-spindle longitudinal milling machine set up for combining three operations with the use of a six-seat hydraulic fixture. By changing the position of components in this fixture, one pass of the machine-table results in two feed-boxes being milled on six sides. Similarly, a hydraulically clamped multiple-seat fixture is used on a four-spindle milling machine for the apron-body surfaces to be machined (see fig. 6).

The concentration of operations is particularly great in boring and drilling of type 1K62 machine-tool body components: speed-box, apron, feed-box etc.

The speed-box body is subject to boring and drilling on six unit-type machines with the number of spindles varying from twenty-one to fifty-two, using hard-alloy multiple-edge combination tools.

The simultaneous application of twenty to thirty cutting tools, for instance, has permitted a reduction of 12–15 minutes in the labour required for longitudinal boring.

The apron body is machined on four machine tools having a total of 206 spindles (see figs. 7, 8 and 9), and the feed-box on three machines with a total of 147 spindles.

These are all semi-automatic machines with machining times varying between 6 and 12 minutes, so that several

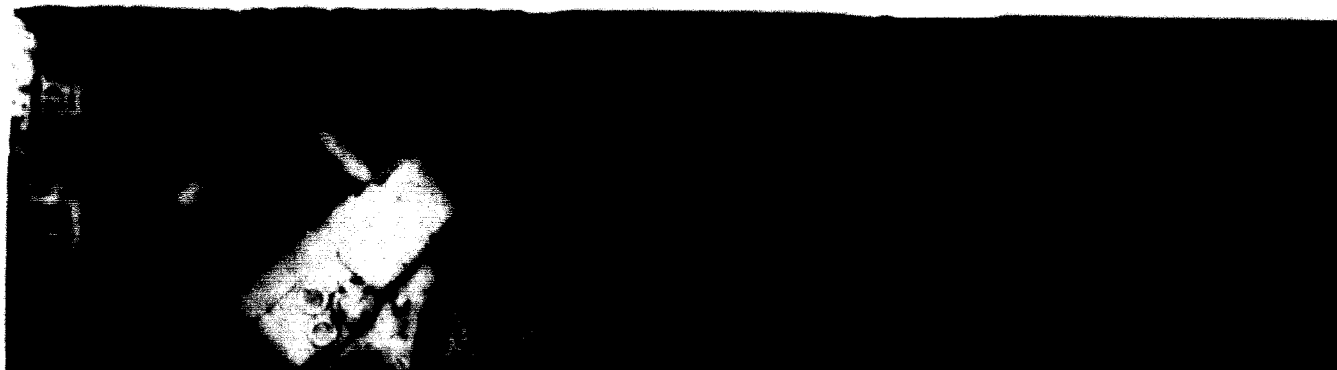


Figure 4

NINE-SPINDLE MILLING MACHINE FOR MACHINING TYPE 1K62 LATHE BEARINGS: VIEW TWO

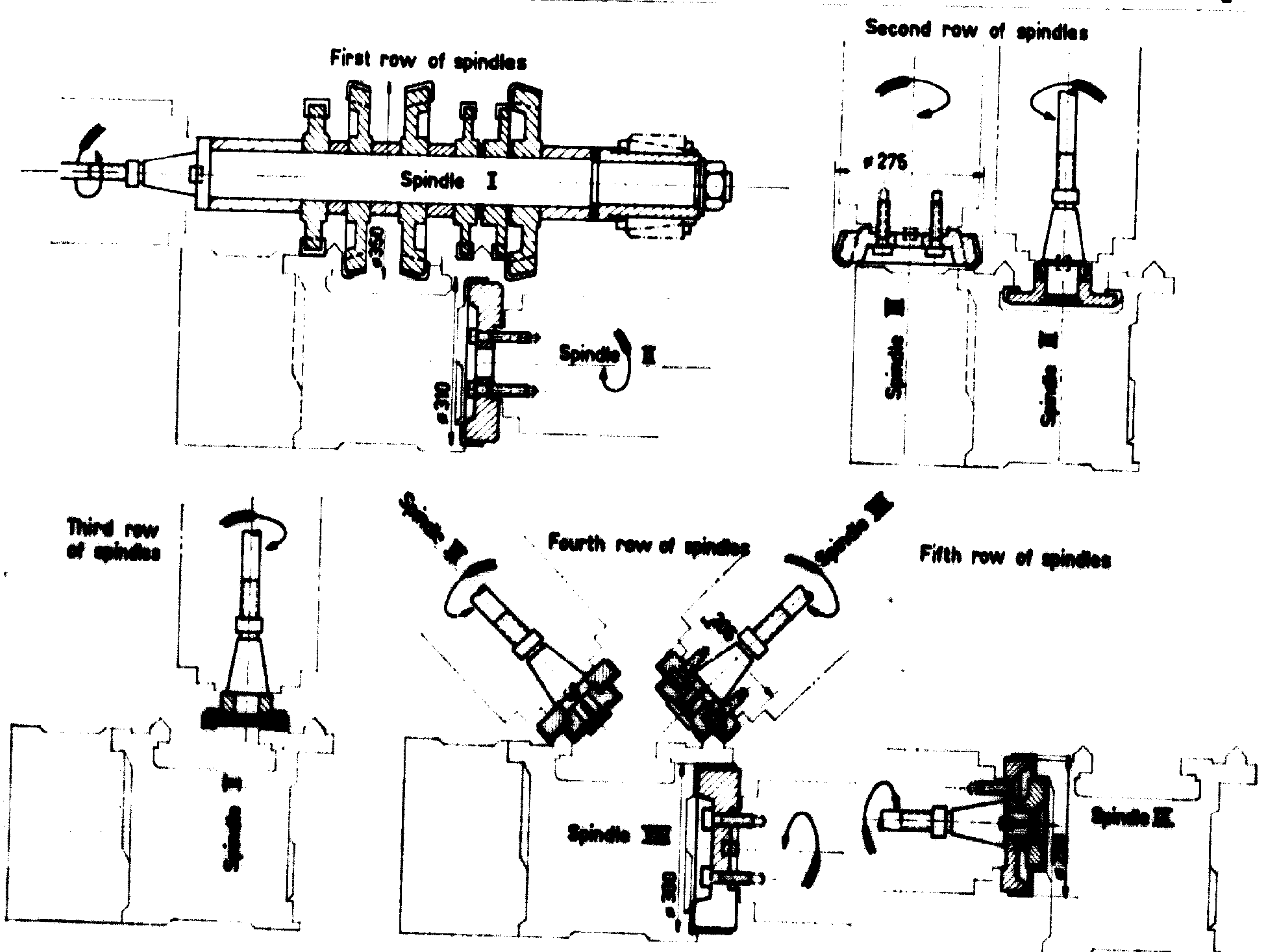


Figure 5

TOOLING DIAGRAM OF A NINE-SPINDLE HORIZONTAL PLANO-MILLING MACHINE FOR SEMI-FINISHED MILLING LATHE BEARINGS

machines can be entrusted to one person. The worker is responsible for loading and unloading the machine tool with the aid of individual hoists, for starting the machine and for keeping a check on the performance of the mechanisms and cutting tools.

This equipment has permitted labour consumption to be reduced by 50 per cent, compared with previous methods. It pays off within two to three years.

The turning processes are mainly handled by copying, multiple-cutter, multiple-spindle horizontal and vertical semi-automatic and fully automatic lathes using power clamps and gang set-ups.

Altogether, special-purpose machines account for 30 per cent of the total number of machine tools. The balance is universal equipment relying on such special fixtures as clamping chucks, jigs, drill heads, milling and other attachments, etc.

Thus, highly efficient technology is impossible without a great number of special technological fixtures. The number of fixtures (including mandrels), dies and press-moulds for the 1K62 machine tool totals 5,000 articles, i.e., the equipment factor in this group of fixtures is as high as six. The cutting, auxiliary and measuring tools and instruments used in connexion with the 1K62 machine also amount to over 5,000 items.

These fixtures are characterized by high reliability securing the required accuracy in operation at high speeds and feeds, in both single-seat and multiple-seat attachments. Mechanization of workpiece clamping sharply reduces the time consumption and makes for easier manual effort.

The production engineers and fixture designers have devoted much energy to developing highly efficient fixtures with advanced clamping elements: pneumatic, hydraulic, electromechanical and pneumatic-hydraulic.

Pneumatic clamps are finding a particularly wide application on lathes and multiple-cutter machines, while pneumatic-hydraulic clamps are used on milling, drilling and other machine tools equipped with single-seat and multiple fixtures.

A standard design of the piston type (pump-free) of pneumo-hydraulic amplifier (see figure 10) has been developed by the works' engineers and is now used in fixture design. Many years of experience in using fixtures in combination with such amplifiers have shown them to be highly dependable, and they are rarely in need of repair. A hydraulic amplifier of this type with an amplification ratio as high as 25, in the case of 4–5 atm of air pressure, will be used for a preliminary clamping at 4–5 atm and ultimate reliable clamping of up to 100–125 atm.

The application of hydraulic amplifiers has made it

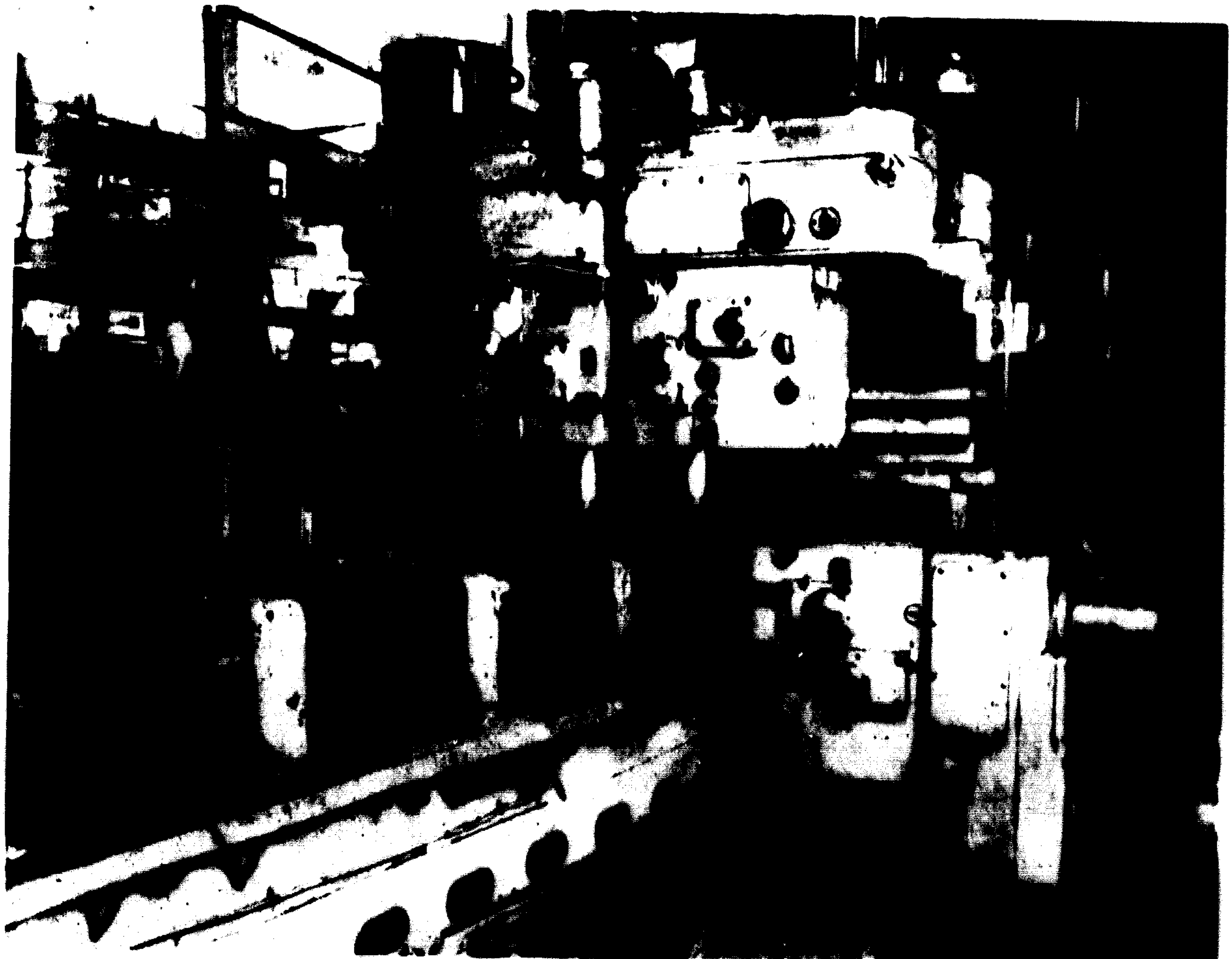


Figure 6

MILLING MACHINE FOR MACHINING TYPE 1K62 LATHE APRON PLANES

possible to reduce the auxiliary time in workpiece clamping, in such operations as machine-bed and tailstock machining or feed-box milling, to 3-5 seconds instead of the 2-5 minutes previously required (see figures 11 and 12).

Special-purpose cutting tools (for use at either special-purpose or universal machine tools) are usually manufactured by the works as combination, multiple-edge, hard-alloy tipped pieces. Among them are drills, countersinks and reamers.

Threading on the unit type of machine tools is effected through the use of high-speed tapping set-ups. The chip-forming groove on the hard-alloy lathe cutters is produced by the electro-erosion technique. Incidentally, the electro-erosion set-up is successfully applied also where machine-body components are manufactured for the remnants of tools (drills, taps), if ruptured, to be burnt out from the components' holes.

Production line methods demand that inspection and measurement procedures be on a high level and that high-quality measuring fixtures be available. In the manufacture of the 1K62 machine tool, as many as 2,500 special measuring devices, among them over 300 items of inspection set-ups and gauges, are used.

Recently, various appliances for active control have increasingly been used in grinding and honing jobs.

A highly efficient technology presupposes a large-scale mechanization of manual labour.

In the assembly shop, the assemblers' work-stations on the production lines for unit and general assembly of the 1K62 type of machine tools are provided with diversified mechanical fitters' tools, such as nut runners, screw runners and threaders, as well as pneumatic-hydraulic pressing appliances. For sleeves to be pressed into unit bodies, special stationary pneumatic-hydraulic fixtures have been developed (see figure 13), while suspension hydraulic-brackets are useful to have shafts, spindles and flanges pressed in (see figure 14).

The works' engineers have long been working on the problem of introducing grinding as a substitute for scraping. Tailstock slides and, partly, carriages have been converted to grinding in place of manual scraping. As a result, scraping time has been reduced at least by two hours. A new development in this field is that the grinding machines which are used in place of scraping are set up directly in assembly lines.

Electric panels for the 1K62 type of lathe are currently delivered by a specialized electrical enterprise. Earlier,

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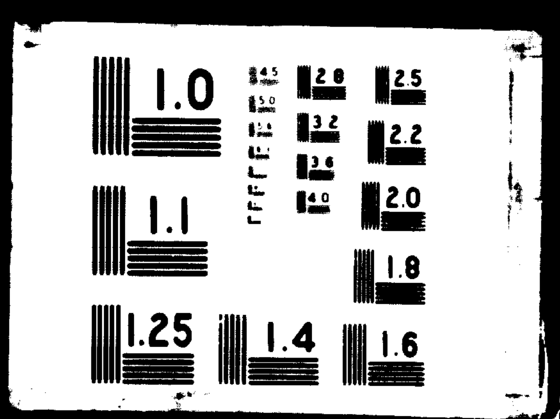


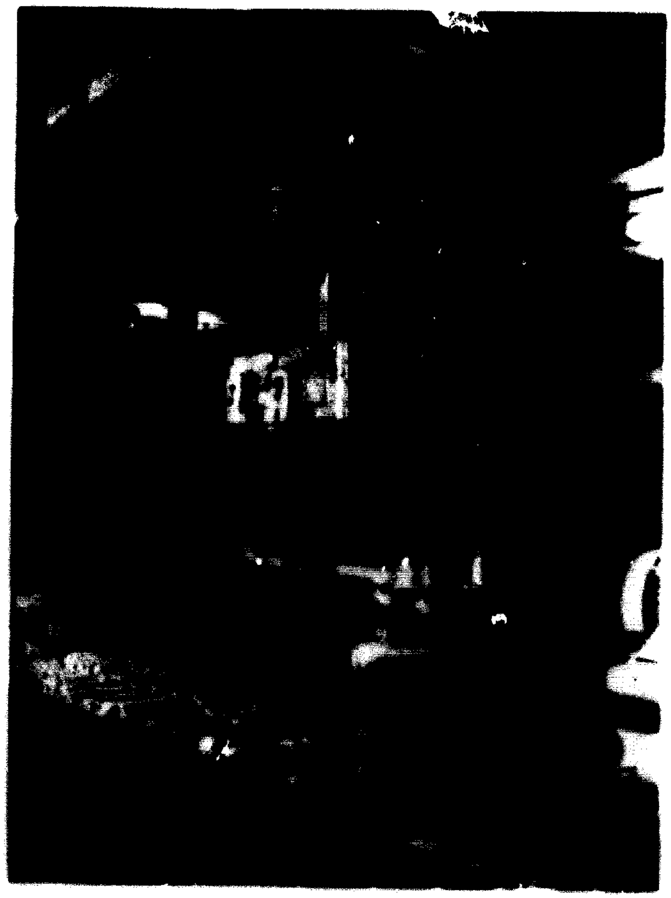


Figure 7

PLANT UNIT MACHINE FOR TRANSVERSELY MACHINING TYPE 1K62 LATHE APRON HOLES

Figure 8

PLANT UNIT MACHINE FOR LONGITUDINALLY MACHINING APRON HOLES FOR TYPE 1K62 LATHE

Figure 9

PLANT UNIT MACHINE FOR DRILLING AND CUTTING SMALL-DIAMETER HOLES IN AN APRON SHEET OF TYPE 1K62 THREAD-CUTTING LATHE

when the panels were manufactured at the Krasny Proletary works, a good set of fixtures for introducing mechanization into a number of manual operations in electric wiring, such as wire cutting and dressing, ring and connectors bending, were produced.

Mechanization is especially difficult in such painting operations as the filling and grinding of filled surfaces. Pulverization is applied as a filling method for small components having no large painted surfaces, e.g., hand wheels etc.

In the painting department, fibrous abrasive wheels, which are fitted to compressed-air grinding machines manufactured at the works in several versions, successfully cope with the grinding of filled-up component surfaces. Set-ups for airless painting have now been introduced at the Krasny Proletary plant to deal with the painting of machine components and entire machine tools. The new technique reduces the consumption of paint and simplifies the exhaust-ventilation systems.

It is clear, therefore, that the works' production engineers and technicians have done much to introduce mechanization in manual operations. Nevertheless, the finishing and assembly operations on the 1K62 machine tool are 40 per cent manual, and painting operations are 65 per cent manual, so the production engineers and designers still have quite a lot to do in this field.

B. *Group production line: group machining*

Because the Krasny Proletary works is engaged in large-batch production, the new form of production flow, viz., the group production line, has come to the forefront since the introduction of production line methods in the various plant departments.

The machining of frame components and those involving much labour, such as machine beds, unit bodies, spindles etc., is handled by fifteen individual production lines equipped with delivery arrangements, i.e., rolling tables for components to be transported from machine tool to machine tool, and individual hoists for loading and unloading the machine tools.

Components involving finishing operations of short duration (1.5–12 minutes), such as bushings, flanges, gears, shafts, covers, racks etc., which are most numerous in the 1K62 machine tool, are handled by thirty-three group production lines set up in mechanical departments.

The peculiarity of these production lines lies in the direct flow of components with respect to technological equipment and in the alternate finishing of the components assigned to the production line equipment according to design and technological similarity. The universal and special-purpose equipment installed on the group production lines permits readjustment, in the case of a standardized production process, to be effected within a comparatively short period.

As a result, the engineering facilities have been turned to better account and labour efficiency has considerably increased.

As an appropriate example, the group production lines installed at the gear section to finish as many as eighty-eight varieties of components are discussed below.

According to the design and technological features, the gears are classified into five categories, for which group production lines have been set up. The first handles as many as 14 varieties of components, the second, 25; the third, 22; the fourth, 21; and the fifth, an automated one, 6 types of gears.

As may be seen, the world's first automatic production line for gear manufacture (see figure 15), which was developed by ENIMS and which has been in operation at the works since 1958, is a group line. It comprises nine machine tools with two men in attendance and has brought about a three- to fourfold increase in labour productivity. Readjustment from one component to another takes 4–5 hours. The short readjustment time is accounted for by the specially designed setting fixtures which permit, for instance, cutter set-ups etc., to be replaced as a whole.

Another automated group production line for the manufacture of thirteen varieties of shafts and consisting of eight machine tools is in operation in the same department, it also was developed by ENIMS.

It can be stated for sure that the group production method alone has made it possible, under conditions of large-batch manufacture, to secure a profitable

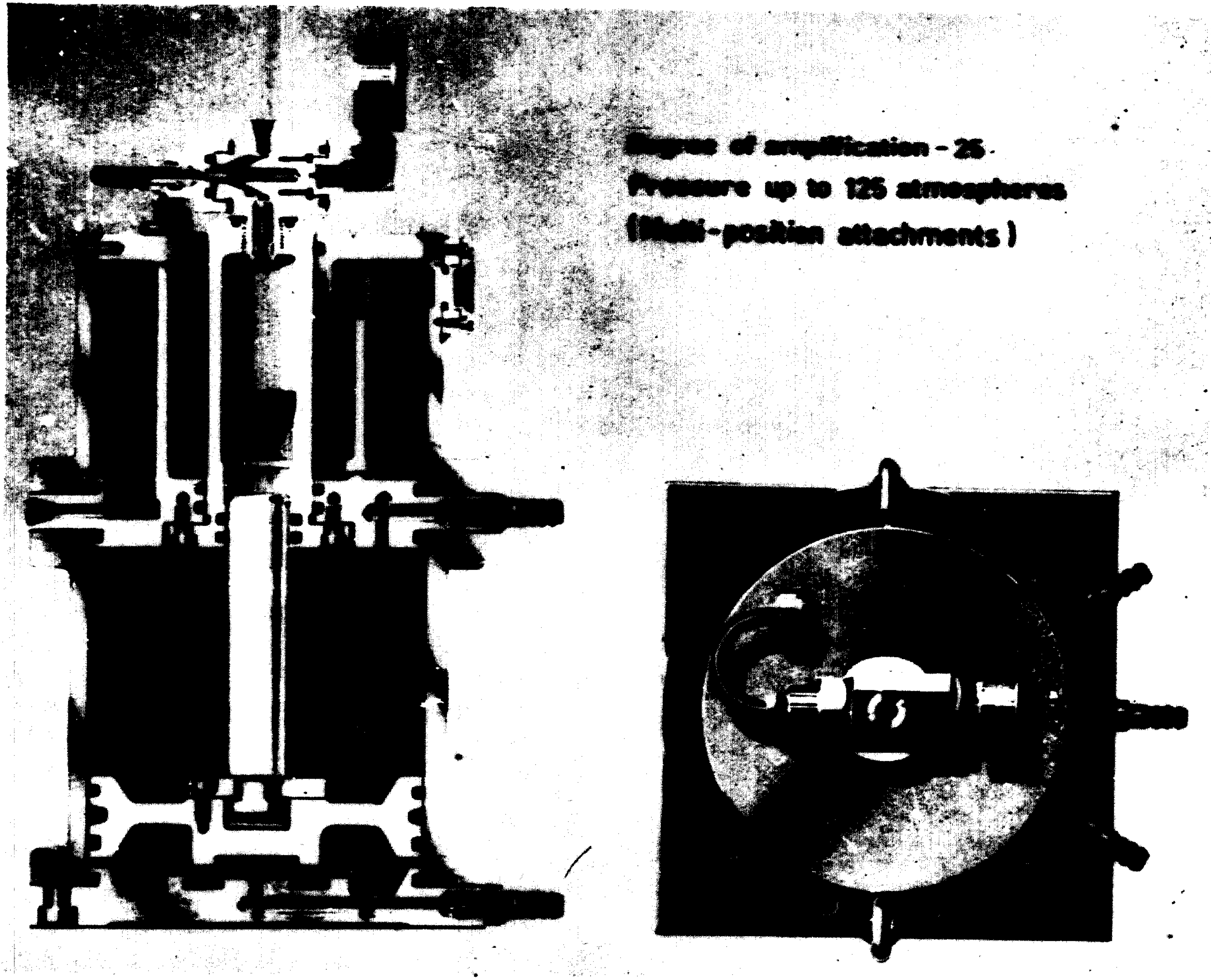


Figure 10
PNEUMO-HYDRAULIC AMPLIFIER

Figure 11

MULTIPLE-POSITION DEVICE WITH AUTOMATIC CLAMPS FOR MILLING A REAR MANDREL SHELL OF TYPE 1K62 THREAD-CUTTING LATHE

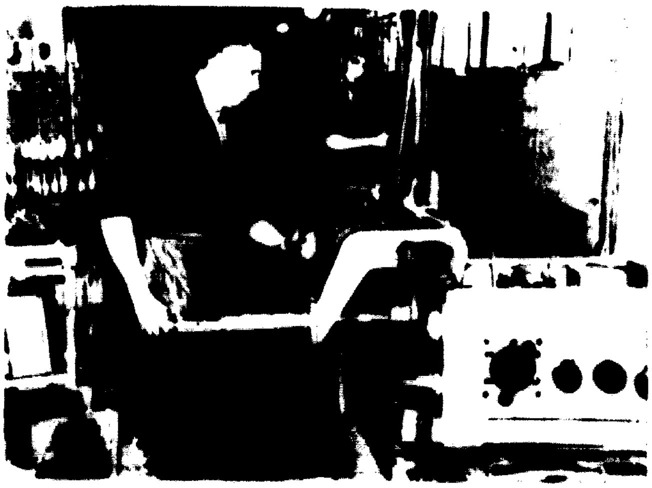


Figure 14

OVERHEAD HYDRAULIC CLAMP FOR PRESSING BOTH FLANGE AND SHAFT INTO A GEAR-BOX FOR TYPE 1K62 THREAD-CUTTING LATHE

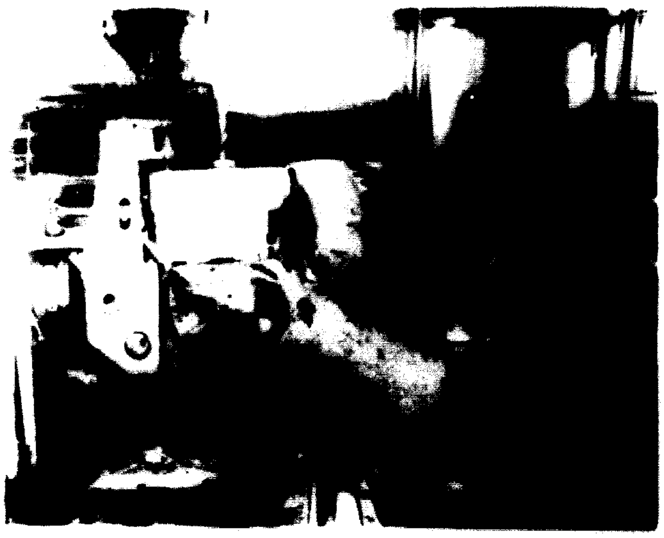


Figure 12

REVERSIBLE DEVICE WITH PNEUMATIC-HYDRAULIC CLAMP FOR DRILLING A REAR MANDREL SHELL

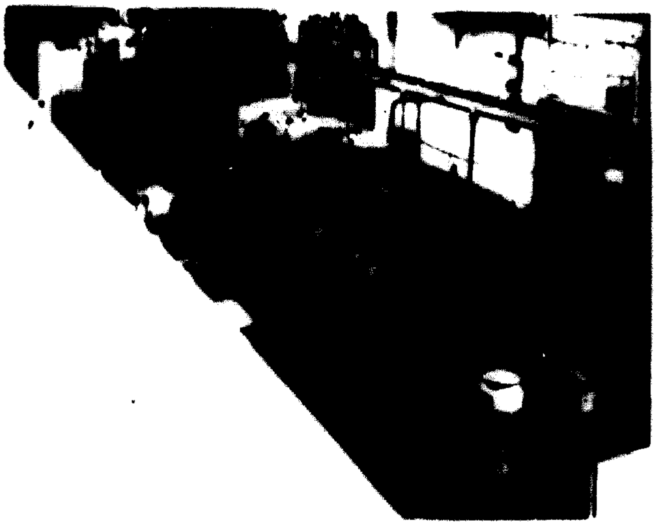


Figure 15

TRANSFER LINE FOR GROUP MACHINING OF GEARS FOR TYPE 1K62 THREAD-CUTTING LATHE

Figure 13

STATIONARY DEVICE, MOUNTED IN A ROLLING-TABLE LINE AND DESIGNED FOR HYDRAULICALLY PRESSING A BUSH INTO A GEAR-BOX SHELL FOR TYPE 1K62 THREAD-CUTTING LATHE operation of automated production lines. Although the first production lines built at the experimental Stankokonstruktsia works were equipped, as a rule, with individual machine tools, the lines were found to pay off in somewhat over five years.

Speaking of automation at the Krasny Proletary works, one cannot help mentioning certain failures encountered in equipment modernization. It was assumed that the automation of operating equipment was an important factor in raising labour productivity. At first, therefore, it was planned to introduce automation into entire individual production lines set up on the basis of operating equipment, for instance, in finishing spindles, flanges, chucks etc.

However, further work on the technical project for introducing automation into such lines revealed this solution to be absolutely unsatisfactory with regard to economic considerations for the works' scope of production. Computations showed that the costs would not pay off in less than fifteen to twenty, or even sixty years. The works, therefore, rejected such a broad automation of production lines and proceeded to introduce automation into separate operating machine tools.

In this respect also, a conclusion has been reached that, along with developing a reliable design for equipment automation, taking into account the large production series, a rational solution is obtainable solely with group-machining methods, which are being applied in different modifications to the operation of separate production lines, equipment and fixtures.

Group set-ups are widely used at the works in connexion with bar and chuck single-spindle and multiple-spindle automatic lathes and, partly, turret lathes. Such set-ups contribute to the manufacture of over 200 types of minor components and standardized pieces.

The application of standardized set-ups at multiple-cutter lathes has permitted the time involved in readjustment from one to another component to be reduced to within 20–30 minutes in the case of over 100 items.

The introduction of group-processing methods was found to be most difficult in connexion with special-purpose and unit machine tools. Nevertheless, the plant has succeeded in developing a range of new solutions. Given below are some instances of components, similar in design, dimensions, material and technology, being finished by group processing.

Eight-spindle semi-automatic lathes (models 1282 and 1284B) are used in conjunction with rapidly resetting gang-fixtures (turret-type cutter-holders, as shown in figure 16, chuck jaws etc.) to finish such components as flanges, gears and chucks. Resetting from one to another component has been reduced to three or four hours, compared with three or four shifts in the case of specialized fixtures.

The unit type of machine tools (models 2A921, 2A925, 2A927 etc.) handling such operations as drilling, countersinking and reaming, which are specially designed to cope with group processing, are used to finish from two to seven different components, e.g., forks, levers, brackets, covers and legs. Some of the machines are adapted to deal with a number of components without resetting (see

Figure 16

TURRET TYPE OF TOOL-CARRIER MOUNTED ON A VERTICAL EIGHT-SPINDLE SEMI-AUTOMATIC LATHE FOR GROUP MACHINING

figure 17). Some machine tools are changed over to other components within 20–40 minutes (resetting of cutting tools, guide prism, clamps etc.).

A special-purpose ten-spindle milling machine (model 2F367) is used to finish three dovetailed components, the

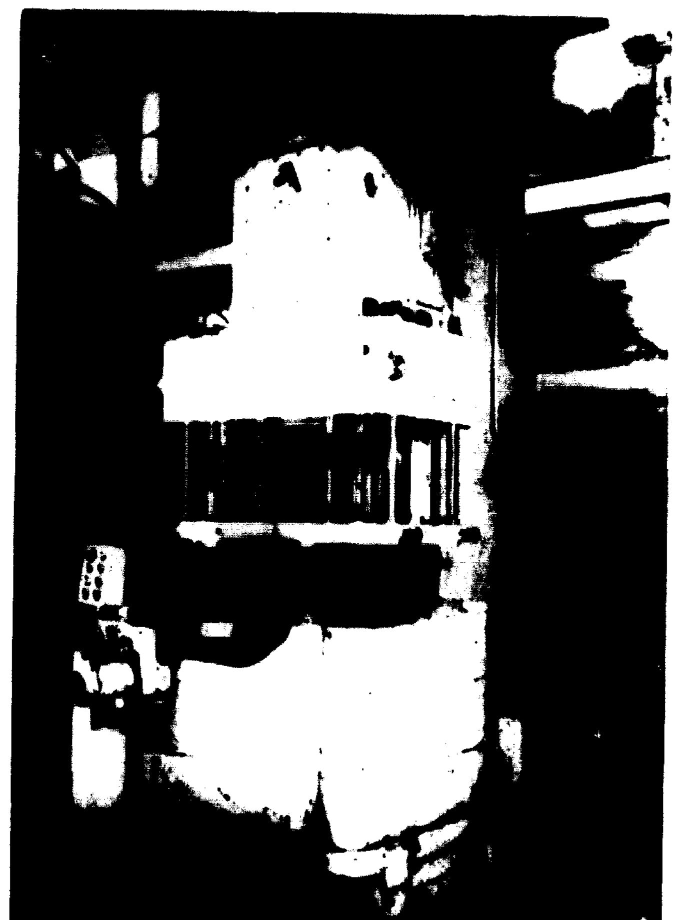


Figure 17

PLANT UNIT MACHINE FOR GROUP MACHINING BATCHES OF SEVEN ITEMS ming process extending to every surface of the components. The components are set up in a multiple-seat hydraulic fixture.

Owing to reduced time spent on resetting and the reduction by 2.5–3.5 times in total labour consumption, this equipment was found to be profitable for group processing in serial manufacture, with the pay-off period amounting to 2.3–3 years.

An important place also belongs to the gang type of technological fixtures, which take account of the peculiarity of large-batch production. The peculiarity lies in the fact that the works has developed highly efficient fixtures to secure, as mentioned above, both the required accuracy and the high operating speeds and feeds with the workpieces speedily and reliably clamped. Accordingly, the technological fixtures are largely individual. With large-batch production, it is quite justifiable because the fixures pay off within a short time.

In designing fixtures of this type, a very important aspect is the maximum reduction of the resetting time in a change-over from one to another component and from one to another fixture. In this respect, some interesting solutions have been found by the works' production engineers and designers.

Radial drilling machines have been equipped with rotary-tables for several jigs to be set up permanently to hold various components assigned to the machines, while they are being drilled. Such tables, which are circular or square, are provided with a centralized oil-supply to the hydraulic clamps. The resetting of the machine tool is reduced to turning the table with the required jig into a working position and switching on the hydraulic clamp, all of which takes 5–10 minutes, compared with the former time of 30–60 minutes (see figure 18).

Figure 18

REVERSIBLE TABLE FOR GROUP MACHINING OF PIECES ON A RADIAL DRILLING MACHINE

Circular rotary-tables installed on vertical drilling machines, models 2125 and 2135, and using a number of multiple-spindle heads for different components to be drilled, have brought down the resetting time to 5 minutes, compared with the former time of 30–40 minutes. In this case, the resetting consists of several simple operations: releasing the table to permit its being turned into the working position; and retightening it (see figure 19).

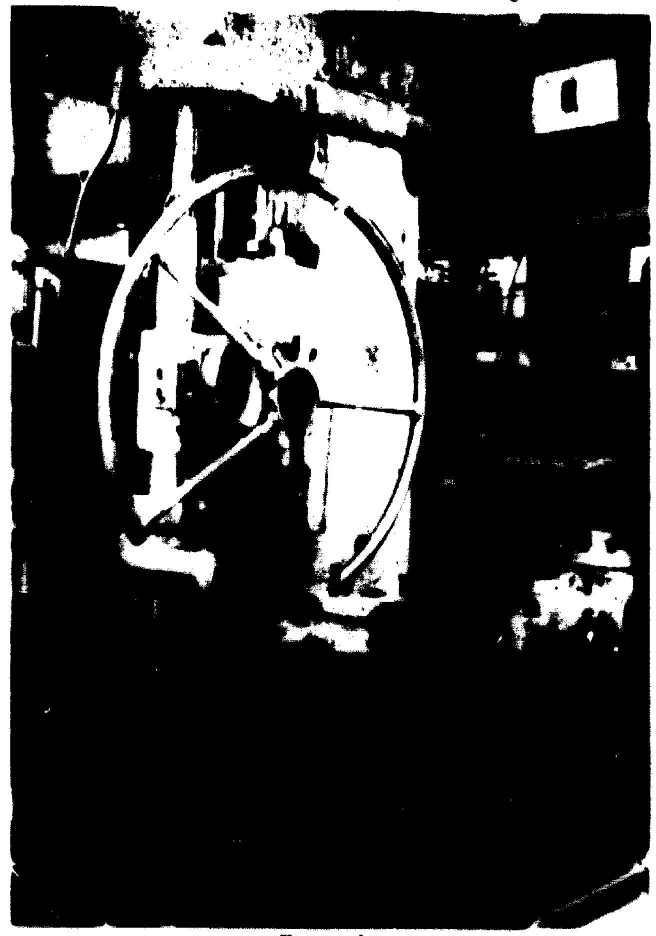


Figure 19

REVERSIBLE TABLE MOUNTED ON A VERTICAL DRILLING MACHINE WHEN A SET OF MULTIPLE-SPINDLE DRILLING HEADS IS USED

The use of readjustable tables for continuous milling with the aid of hydraulic clamps has considerably reduced labour consumption and has made it possible for several machine tools to be attended by a single workman (see figure 20).

Figure 20

TABLE DESIGNED FOR CONTINUOUSLY MILLING PIECES

Good performance in drilling is shown by the quick-setting chucks with curved jaws used for clamping such components as flanges, gears and sleeves; clamping time is 8 seconds less, as compared with clamping in conventional three-jaw chucks; reduced manual effort is another result.

The group production methods have not been applied in mechanical processing alone. They have proved their worth also in the preliminary painting of components. Here, group conveyor lines have been set up to handle groups of machine components which are similar with regard to the technological process involved (see figure 21).

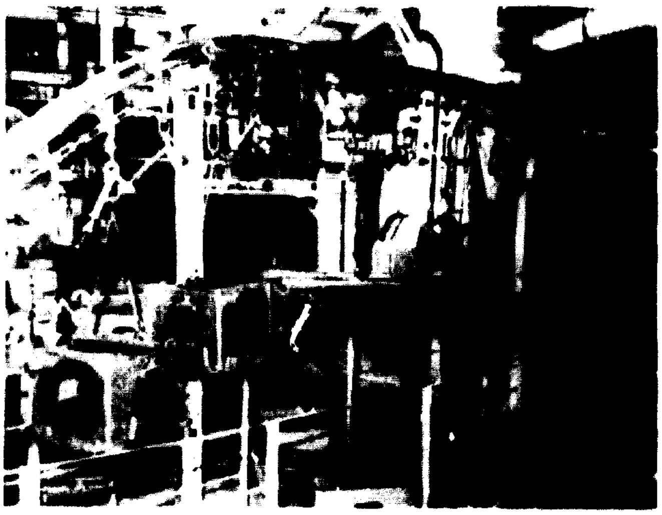


Figure 21

GROUP MECHANIZED TRANSFER LINE FOR PREPARATORY PAINTING OF MEMBERS OF TYPE 1K62 THREAD-CUTTING LATHE

In summing up, it should be mentioned that group production lines account for 90 per cent of all the components for the 1K62 machine tool and comprise 80 per cent of all the production equipment in operation. The rest of the equipment is installed in individual production lines.

C. *Complex flow, complex technology and mechanization*

The production line methods at the works embrace in a complex way all the stages of production technology in the manufacture of the 1K62 type of lathes: forging and preliminary operations; processing machine tool assembly; painting; and packing. Only with this complex coverage with production line methods is the efficient operation and regular manufacture of machine tools possible.

The group production lines in the forging preparation department are set up to deal with the hot punching of components on hammers and power presses. The heating furnaces, punching set-ups and cutting presses are interconnected with mechanical delivery facilities, e.g., track conveyors.

Production lines in mechanical processing have already been discussed.

The individual production lines in the assembling department are in the form of continuous-chain conveyors dealing with the assembling of speed-boxes, aprons and feed-boxes, as well as in the form of a drag-line conveyor for an over-all assembly of the machine tool (see figure 22). Production lines of the rolling-table type cope with the assembling of slide, carriage and tailstock.

Figure 22

HYDRAULICALLY PULSATING CONVEYOR OF PRINCIPAL MOUNTING FOR TYPE 1K62 LATHE

The preliminary painting of cast-iron components takes place prior to mechanical processing and is effected on four conveyors dealing with three groups of components. The conveyors run through washing, painting and drying chambers. The surface-sealed components at the works are artificially dried at a temperature of 50°C. This has contributed to high surface quality and has reduced the cycle of component processing by more than ten times. The painting of sheet components is also handled by a suspension conveyor comprising a washing unit, thermo-radiation drying and painting chambers.

The ultimate painting of assembled machine tools is carried out on two conveyors. The pallet conveyor is the place where first dressing and sealing work is done, while a circular conveyor running through three nitro-chambers handles the machine tool for triple painting with the use of spray-guns and airless-painting sets (see figure 23).

The packing of machine tools in packing boards is carried out on a manœuvrable bar type of roller conveyor.

Production line methods presuppose the large-scale mechanization of all production processes. Mechanization problems should be solved in a complex way, i.e., in relation to both main and auxiliary operations. At first, while introducing production line methods, the works' attention was focused primarily on bringing mechanization into the main operations. Later, mechanization was extended to a great many auxiliary jobs, and the results were quite satisfactory in a number of cases.

Figure 23

RING CONVEYOR FOR PAINTING TYPE 1K62 THREAD-CUTTING LATHE

The mechanization of auxiliary operations in the main departments proceeded along three lines: mechanization of chip removal; mechanization of handling; and mechanization of storage operations.

The system of chip removal consists of conveyors which are arranged between the rows of machine tools and are in metallic boxes sunk under the floor: a scraper-bar type of conveyor handles cast-iron swarf and a rag-bar type of conveyor deals with steel, usually spiral chip.

The chip from the machine tools is dumped onto these conveyors either with the aid of special worm-screw conveyors or directly by the workmen. The conveyors deliver the chip for dumping onto the central conveyors, which take the chip to the place where it is compressed in briquettes.

Prior to briquetting, however, the steel chip is crushed in hammer crushers. The combination of chip removal and chip briquetting permits the works to save as much as 100,000 roubles per annum, the pay-off period being 1.5 years.

Under conditions of serial production, the organization of indoor interoperational handling poses some serious problems.

For trouble-free work in all operations, it is necessary, along with delivering the components from operation to operation, to make arrangements for storing up reserve pieces at the work-station and, what is more, not in one but in several varieties of components.

Rolling-tables are used as transportation facilities for the majority of production lines in the mechanical departments. These tables deliver from machine tool to machine tool or from the department to the storage area either separate machine-body components or small-size pieces in standardized tray or pin packages.

Under the conditions prevailing at the Krasny Proletary works, this type of transportation, in the case of machine-body components in combination with rolling tables, is quite justified in some cases. On the lines of small-size components, however, the rolling tables have lost manœuvrability and, as the component batches grow in scope, are being increasingly converted to a kind of storage place. For several years, the plant has been in search of an adequate indoor transportation solution, but it has not yet discovered a system that would fully meet its requirements; therefore, the work on the problem is continuing.

The address type of conveyance system was rejected because of the great complexity and high cost of the equipment involved.

A simplified system of monorail transport is currently being used at a number of production areas. To this end, the storage of machine components is achieved in iron containers which can be stored in several tiers, or the components are kept in special containers and moved along the rolling tables.

The large-capacity containers in use at several production sections permit the storage of components in several tiers.

Highly interesting mechanizational facilities are used at the works for intermediate component storage and for delivering components from the mechanical department or from the storage area to the assembly department.

Transportation of components without replacement is handled by standardized containers in the form of hollow punched trays or trays with pins. The trays with components delivered for storage via rolling tables from the mechanical department are stacked by special stackers. One stacker takes care of two rows of stacks. For the trays with components to be delivered from the storage room assembly places, a suspension conveyor is put into operation. The conveyor is loaded with the aid of the stacker and special elevation tables installed at the storage loading-station. Along the conveyor route, there are unloading stations at three assembly places.

The component-filled containers are addressed from storage to any one of the three unit assembly places and are unloaded there automatically. Having been brought to an assembly section, the trays with components are deposited on roller-mounted stacks in direct proximity to the assemblers' work-stations. The emptied containers are hung on the conveyor's idle grips to be brought back to the storage section and further to the mechanical department.

Highly effective mechanization has been introduced into storage operations and into the delivery of components from the storage to assembly via a suspension conveyor, in combination with standardized containers. The multiple reloading of the components has been eliminated thereby reducing damage (dents) caused to components, and the storeman's labour has become far more effective and easier. The storage capacity, as well as the capacity of the magazines, of the work-station storage receptacles, have been raised also. The check of component movement has been facilitated.

Transportation of machine-body components from the mechanical to the storage departments is handled by a special underground conveyor which, bypassing the storage area, delivers components directly to the three sections on the first and second floors of the assembly department. At the section areas, step conveyors are used to deliver components to the work-stations.

In the assembly department, the assembled units (headstocks, saddles, aprons and feed-boxes) are handed over for mounting and tested machine tools are turned in for trimming via special conveyor.

These mechanization facilities have reduced by half the number of workmen employed on the delivery of components and units, and on storage attendance, the pay-off period somewhat exceeding a year.

However, not all of the auxiliary jobs at the works, especially those relating to the all-works handling/storage facilities, have yet been adequately mechanized. Auxiliary jobs have been mechanized 46 per cent, whereas in the main production operations, the share of mechanized labour is as high as 70 per cent. New efforts are currently being made to introduce mechanization into auxiliary jobs.

It should be noted that the works has developed detailed technological procedures in basic production operations, and time rating is maintained. The auxiliary jobs, on the other hand, have not yet been subject to technological regulations and are, consequently, rated but insignificantly. For this reason, a technological bureau has been set up at the chief production engineer's department to deal with auxiliary jobs. The function of the bureau is to draw up production procedures for handling, storage and auxiliary jobs. Such procedures will furnish a basis for rating to be introduced into auxiliary jobs and for more rational solutions to be evolved for various mechanization problems. Thus, a complex production technology is being devised for the entire production cycle at the works, beginning with the reception of materials and ending with the delivery of finished products.

II. Prospects at the works

Large-scale reconstruction is under way at the Krasny Proletary plant, which will serve as a model works as regards the level of mechanization, organization of production and working conditions.

A new building for the manufacture of vertical multiple-spindle semi-automatic lathes was built and has been in service for over a year. These machine tools are also being manufactured on a production line with the use of group production methods. Efforts are being made to introduce special-purpose equipment, gang fixtures and complex production methods, i.e., along with basic operations, mechanization is being extended to such auxiliary jobs as chip removal and component handling.

Preliminary computations show that labour consumption on the machine tools manufactured in the new building will be reduced by nearly two times.

Much work is to be done in connexion with further perfecting the production line methods in the manufacture of lathes in departments now in operation.

Additional quality improvements on the machine tools now being turned out will receive a great deal of attention. The problems of quality are being approached, first of all, from the standpoint of improved accuracy, reliability and long life of both the separate components and the machine tools as a whole.

To solve properly the problems of quality under the conditions of production line manufacture, it is necessary to undertake extensive and serious preparations for putting into effect whatever measures have been conceived.

The works' designers and production engineers face the prospect of great creative work on these lines. This work is organized in collaboration with a number of research and design institutions—ENIMS, the Central Production Research Engineering Institute (ZNIITMASH) etc.

The new model of a universal screw-cutting lathe (16B2OP), which was designed in the works' design department, will be superior to the current 1K62 model in accuracy and service life. The first experimental specimen was manufactured at the end of last year. The designers and production engineers are taking steps to put this new model into serial production. This will be preceded by thorough work on the technological aspects of the new model's design and by the manufacture of experimental batches of machine tools.

In addition, work is in progress to introduce some modifications into the 1K62 machine tools now being manufactured by production line methods. For their accuracy to be improved, the finishing and trimming operations must be more numerous, the composition of the production lines revised, the production equipment layout altered and new supplementary fixtures developed. All this must be realized without stopping the production of machine tools; therefore, each measure is subjected to a carefully compiled schedule which envisages the entire volume of design and technological preparations, and laboratory and production tests before the measure can be finally incorporated into serial production.

Special attention is currently being paid to quality improvements in such important parts as the machine beds and gears, by resorting to various technological measures. For many years, the machine beds have been m...ufactured with the aid of high-frequency currents, w... their ways hardened, which makes them highly wear-re...tant. This operation is handled by a high-frequency cu...ent set-up installed in the production line and compr...ng a special mobile table for the machine bed to be pu...on (see figure 24).

Figure 24

TYPE TB INSTALLATION FOR TEMPERING SLIDE BARS OF TYPE 1K62 LATHE BED

In the past year, the works has introduced a new ad-vanced method for grinding the hardened machine-bed ways with the grinding-wheel's periphery. Apart from raising labour efficiency by 30-40 per cent, this method also improves the quality of machine beds in the geometry of their ways.

Modernization of the high-frequency current set-up for the hardening of machine-bed ways has reduced de...rmations and improved hardness stability.

The foregoing examples of efforts aimed at quality im...rovement reveal that the current work in raising la...our productivity must be coupled with measures ca...ng for the larger labour consumption required by extra finishing and other operations. These problems directly affect the works' economy. For instance, the flanged spindle, which was introduced on the 1K62 type of machine tool and which has substantial advantages over the former spindle (with a threaded end), has accounted for an increase of 16 kg in metal consumption and an increase of over three hours in finishing time. Therefore, every measure aimed at quality improvement, under the conditions of mass production, must be taken in consultation with all of the works' services, including economic services.

In the light of the problems currently facing the works, the creative activities of production technology personnel, production engineers among them, become highly important. Production engineers are, in fact, the creators of new technological processes, the organizers of production lines and the sponsors of ideas relating to the mechanization of production processes.

At the current time, the growth of the technological cadre and the improvement of their skill and "know-how" is no less important than the growth of the staff of designers.

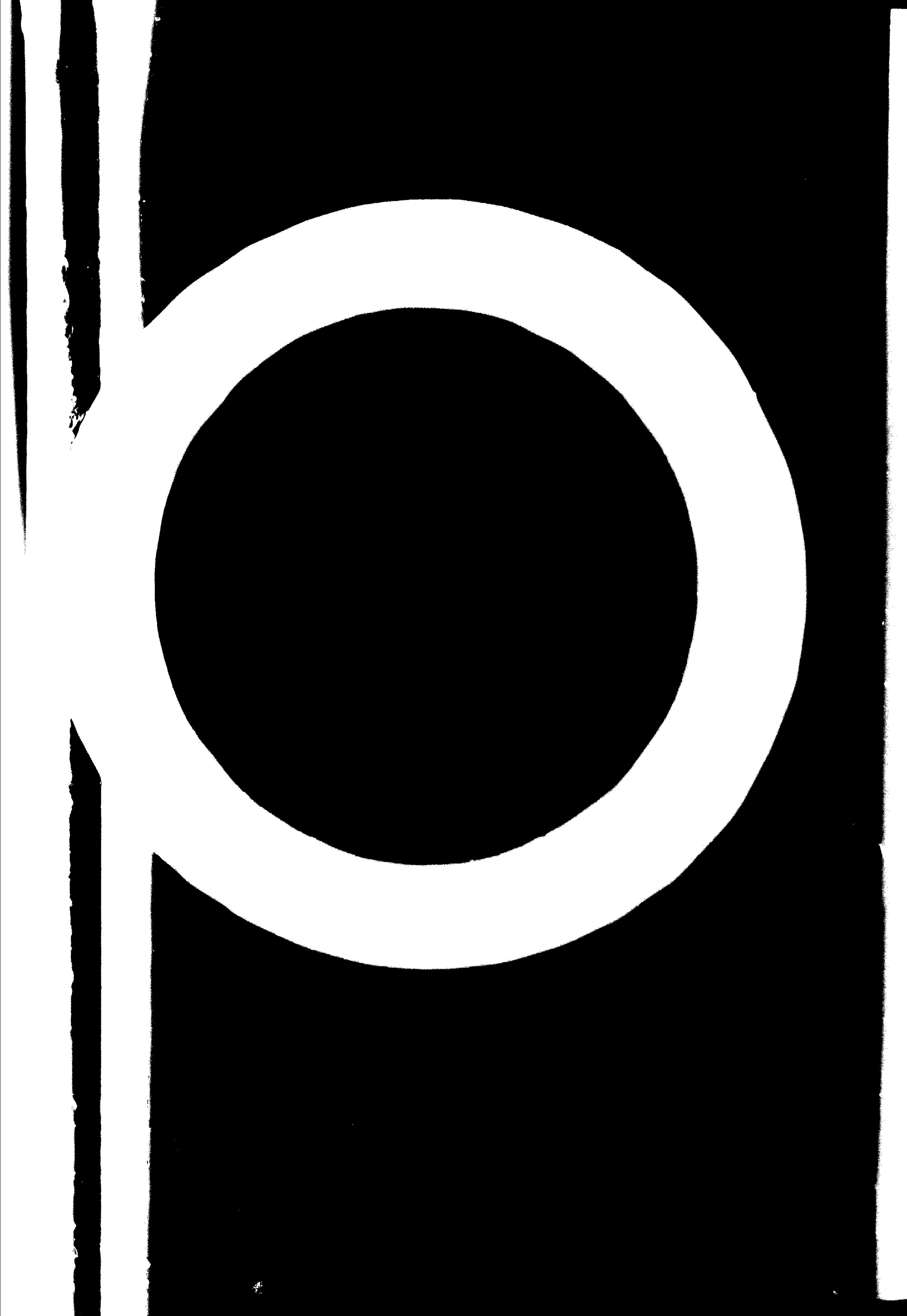
The experience accumulated by the Krasny Proletary works is large enough for the problems facing it to be solved. The works is well known throughout the world, it has extensive economic contacts with other countries and delivers machine tools to nearly sixty of them.

During the period 1930-1932, the works' personnel were engaged in preparations for the manufacture of a new lathe model called "DIP", which stood for the words "overtake and leave behind", to signify that the Soviet Union would become the leader in the world machine-tool industry. The men at Krasny Proletary were very enthusiastic about beginning the new production programme and introducing the novel production procedures. The target, "to overtake and leave behind", was achieved within a short time by the works' personnel.

The path covered by the works since that time has been marked by persistent efforts for technological and organizational improvements. Many highly skilled specialists in machine-tool building have been educated at the works, among them production men and designers who are now working there, as well as at numerous establishments elsewhere, in both the machine-tool industry and other fields.

Many of those who made parts for the first machine tools and assembled them now hold top-level posts at industrial establishments or are engaged in important engineering work, either at Krasny Proletary or elsewhere.

All these facts emphasize the correctness of the path taken by the works in setting up production line systems in machine-tool building and in making use of mass production technology and manufacturing methods



AN EXAMPLE OF MACHINE-TOOL PRODUCTION METHODS

C. A. Sparkes, H. W. Kearns and Co., Ltd., Manchester, England

INTRODUCTION

The machine-tool works of H. W. Kearns and Co., Ltd., is situated in the county of Cheshire, about ten miles from Manchester, a city which may be regarded as being approximately at the hub of the industrial revolution. Therefore, for generations it has been considered one of the world centres of engineering, as well as the birthplace of a number of prominent machine-tool manufacturers. Manchester has also been noted for many years for its university, together with its college of science and technology, whose interests have been closely related to the engineering industries of the district. The strong engineering and educational influences have, in the author's opinion, been of considerable value to the engineering companies in and around Manchester, particularly H. W. Kearns, who have benefited from the excellent technical and practical skills which have had such fertile ground in which to develop.

Against this background, H. W. Kearns' factory was established on its present site in 1907. The original factory was 140 feet wide and 160 feet long: it had five bays and a steel framework which was arranged so that the buildings could be extended lengthwise. This careful planning has enabled the company to continue to operate on the original site, although the main building has been extended periodically until it now has a total length of 460 feet. There are four bays of 25 feet and two of 40 feet. More recently, a further extension, with a bay of 50 feet, has been added. The total floor space now occupied is approximately 110,000 square feet. New office accommodation is available in a two-storey building covering an area of about 15,500 square feet. There are also an independent pattern shop and associated pattern stores covering an area of roughly 8,000 square feet. The factory is completely equipped with overhead cranes, the largest of which has a capacity of 20 tons.

As already indicated, for almost sixty years the company has concentrated its total design and manufacturing facilities on the production of horizontal boring machines. These now range in size from 1 to 50 tons and in price from roughly £2,000–£50,000. Long experience in the manufacture of machine tools indicates that the first essential for creating a satisfactory manufacturing programme is a sound design policy. In the case of universal horizontal surfacing and boring machines, this is a complex problem because of the comprehensive range of operations which they are expected to undertake. Those engaged in the machine-tool business are also well aware of the difficulty of accumulating service experience on a particular design because of the limited number produced; moreover, these machines are rarely engaged in a similar type of production for a sufficient period of time to disclose any obscure weakness in their construction. Furthermore, if a successful machine-tool design policy is to be followed, it must be carefully planned not only to cater for the differing factors, but, at the same time, to take advantage of the latest research information. Fortunately, H. W. Kearns' case is slightly simplified by the decision to concentrate all manufacturing facilities on the production of horizontal milling and boring machines. A study of this type of machine reveals that it has two characteristic features which have a considerable influence on its design. These are the work-holding capacities of the table and the metal-removing ability of the headstocks.

I. DESIGN POLICY AND MANUFACTURING PROCEDURE

Obviously, for machining large slender frames or thin box-sections, a maximum work-holding capacity is required with, generally, a light metal-removing duty. Conversely, for heavy cast-steel components and similar items, a limited-capacity machine with maximum cutting power is needed. A combination of these two extremities is also a possibility. A solution to these apparently contradictory conditions has been found by using a carefully planned system of unit construction.

To meet the wide range of power and work-holding capacities, the machines are designed with three separate groups of units, falling approximately under driving horsepower inputs of 7.5, 15 and 25. Figure 1 illustrates these groups of units, together with a maximum/minimum work-holding capacity. The small number in the frame denotes the capacity of the machine in cubic feet. The disposition of the five main units used in each group is shown in this view. Stocks of patterns, castings and steel are kept to a minimum by arranging for a definite number of increments in the traverse length. In this particular design, the increments are generally limited to give approximately sixty-five sizes in the smallest group, with forty-five in the middle range and roughly thirty in the highest horsepower group. As typical examples of this design policy, figure 2 shows the smallest machine in the 7.5 horsepower group (it has the capacity of approximately 12 cubic feet) and figure 3 illustrates the largest machine in the 25-horsepower range (capacity of 1,500 cubic feet). In considering this design policy in relation to manufacturing, care has been taken that the completed machines are capable of accepting the simplest type of measuring systems while, at the same time, a minimum of alteration is necessary in order to accommodate the latest arrangement of numerical control. An additional

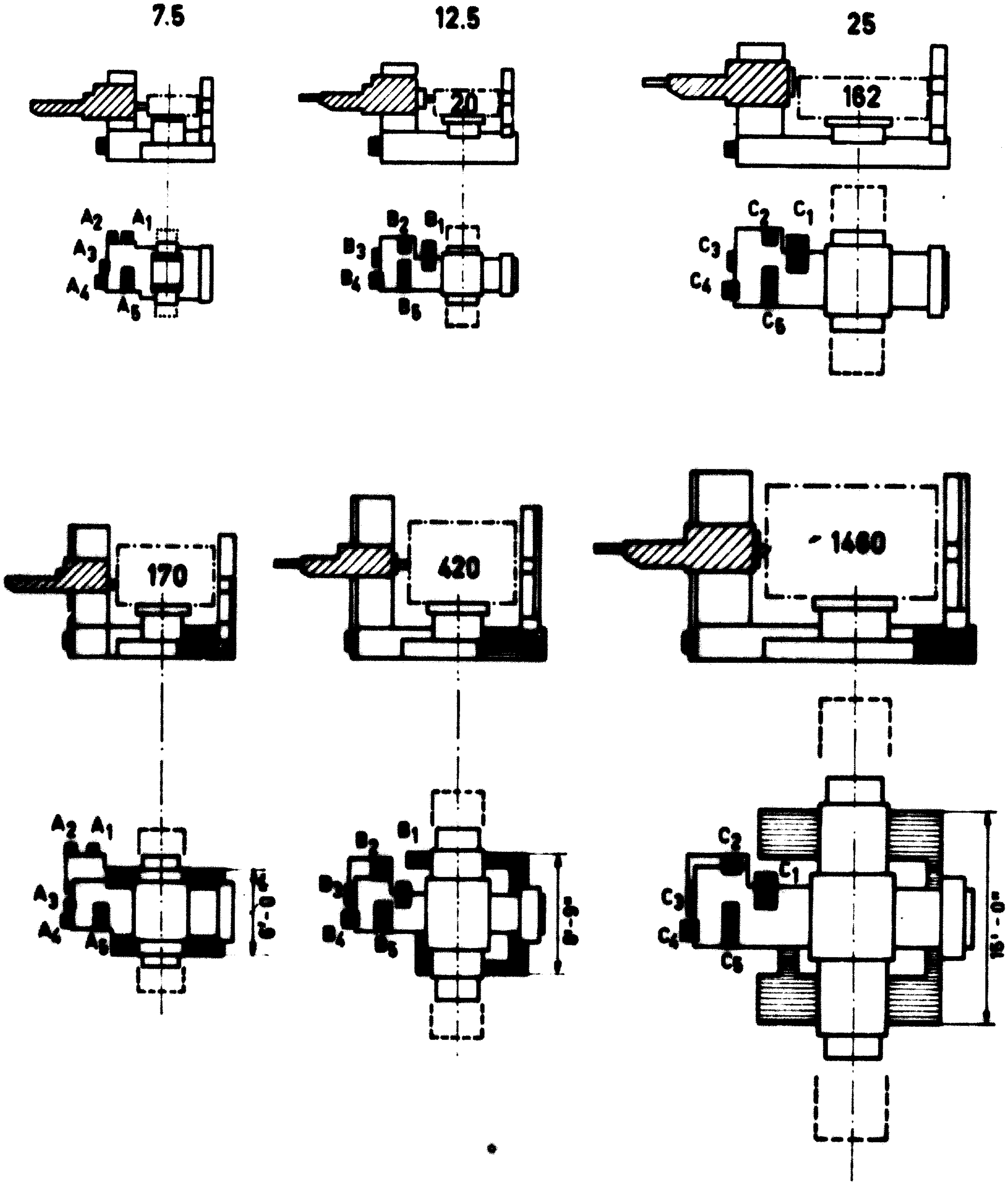
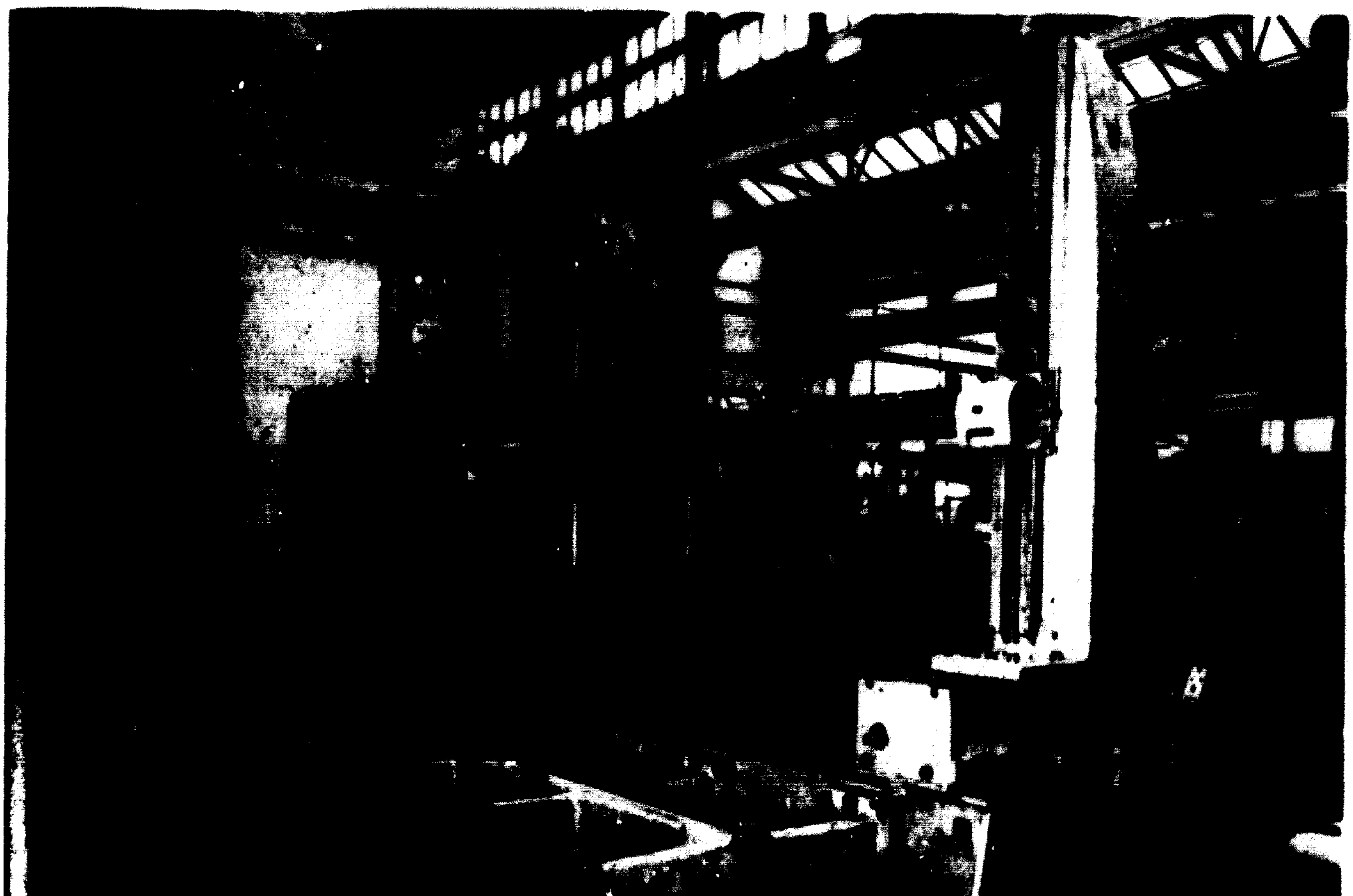


Figure 1
GROUPS OF UNITS

Figure 2
SMALLEST MACHINE IN 7.5-HORSEPOWER GROUP

Figure 3
LARGEST MACHINE IN 25-HORSEPOWER GROUP



advantage of this unit construction of manufacture is its help in keeping work in progress and stocks to an absolute minimum. This is extremely important when considering the high skill content and the currently increasing cost of the more complicated optical, electrical and hydraulic mechanisms which are now being provided with these machines. Recent indications are that the factory has approximately £100,000 of work in progress with stocks approaching £300,000.

The value of following a closely integrated design policy with manufacturing methods is perhaps best illustrated by the example of the main bed of the 7.5-horsepower group of machines. Figure 4 shows the arrangement for milling a bed on a plano-milling machine having a capacity of 14 ft × 6 ft × 5 ft. All slideway surfaces, including the location of facings for the main gear-boxes, are milled at this stage, and the cutter is set with reference to a template mounted at the end of the milling machine table using a 0.010-inch gauge. The template is carried on slides that provide for transverse and height adjustment, which may be necessary for conveniently setting the template in relation to the castings. From this illustration of the main bed, it will be noted that the facings are carefully arranged on a minimum number of planes in order to reduce machining times. Furthermore, by employing a system of unit construction, it is possible for the gear-boxes and other items to be manufactured at the same time the main bed is in production and, therefore, to reduce the total over-all time necessary to produce the machine. Figure 5 shows this main bed with a number of the units in position. These include the distribution box, together with the main

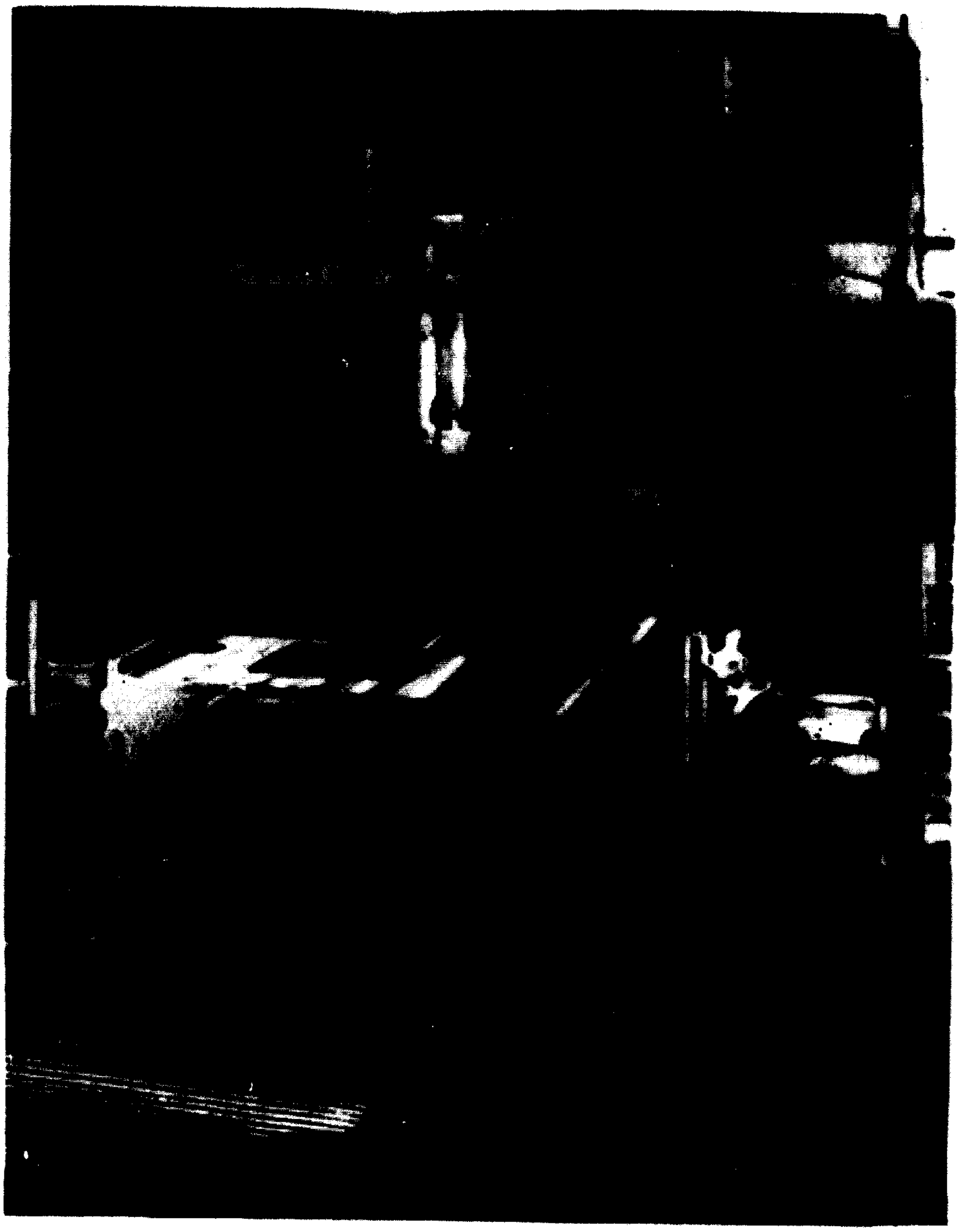


Figure 4

MAIN BED FOR 7.5-HORSEPOWER GROUP ON PLANO-MILLER

…ive and rapid traverse units. Final assembly of these separate units is undertaken alongside the main assembly bays, and a general view showing these in the course of manufacture is given in figure 6.

Figure 5

BED WITH UNITS IN POSITION

As mentioned previously, the machines are designed to be capable of accepting not only a simple vernier-scale system of measurement for setting, but also the most advanced numerical control and optical arrangements. To meet these exacting requirements, it is necessary for the slideways and guiding surfaces to be machined to an accuracy of within .0005 inch over a distance of 50 inches. To achieve this high degree of accuracy with a minimum of hand operations on these main bed components, they are ground on the machine shown in figure 7. It has been found essential to complete all the machining operations on this bed, including the drilling and any boring necessary, leaving only the slideway grinding as the final operation. Furthermore, it has been found essential to eliminate all clamping bolts and when the main bed is on the grinding machine, only end location stops are used for maintaining the component in position on the grinding-machine table.

A further interesting point is the supporting of this main bed casting, during the grinding operation, on its actual levelling screws, which will be used when the machine is installed in the customer's works. This method of support on the actual levelling screws to be used during its final assembly ensures that the sliding ways will be correct when the machine is placed in

Figure 6

UNIT ASSEMBLY BAY

Figure 7

GRINDING MAIN BED

position on its own foundation. No attempt is made to carry out any system of normal or artificial ageing of this main casting, following a full and complete investigation into this subject with the British Cast Iron Research Association. Their findings indicated that in view of the metal distribution on this casting, no significant benefit could be obtained by artificial or normal ageing methods, providing the metal removed from the machined surfaces was in the region of ½ inch and the chemical composition of the cast iron was such as to give a Brinell figure in the region of 180 without the need for excessive chilling. Where chilling must be undertaken, this is accomplished by the use of refractory brick or similar material in preference to heavy cast-iron chills.

Reference was made earlier to the system of unit construction. In the case of this main bed, the units employed are a mechanical main-drive box containing nine spur gears to give a corresponding number of speeds to the ouput bed pulley and a main feed gear-box containing a spur-gear system and clutches providing a total of twelve feeds to all motions on the machine. In this main bed, there is also fixed a well or distribution box, which provides a feed drive to the vertical, longitudinal and transverse movements of the compound tables. Finally, there is a rapid traverse unit consisting of a constant-speed, alternating-current (AC) motor, which drives the cross shaft in order to provide rapid traverse to the three motions just mentioned. The reference planes for fixing these various units in position on the main bed are the top surface of the main bed and the guiding edge in the centre channel. These boxes are located in place by means of a simple fixture on which are provided location faces to suit those already machined on the various units.

A special and patented feature of this main bed is the use of a centre channel for supporting the saddle on which the compound tables are mounted. This channel, in addition to supporting and guiding the saddle in the longitudinal direction, also carries the longitudinal screw and shaft, all of which are immersed in the oil with which this centre channel is filled. The outer ways of this bed support the saddle on four large-diameter rollers mounted on anti-friction bearings. To facilitate assembly of this saddle, master bed sections are installed in the main fitting bay, a typical example of which is shown in figure 8. Each saddle is first carefully set to the central guideway and checked for squareness with a master saddle section mounted on the bed before the taper gib strip is fitted. This master saddle section is clearly visible in the main saddle unit. The anti-friction bearings in these rollers are carried on an eccentric shaft. This shaft is rotated

Figure 8

SADDLE ROLLER ASSEMBLY

until the top surface of the saddle is parallel with the main bed sliding ways. When this position has been found, the eccentric shafts are fixed in position by means of four small screws. Lubrication on all slideways is given special attention; and the oil grooving, which is of the chicken-ladder pattern, is machined on a router, as illustrated in figure 9. A cutter with two teeth equipped with Wimet Grade N carbide is employed and operates at a speed of 2,000 rpm. The shape of each groove is controlled by an aperture in a sheet-metal template clamped to the work. The depth of the groove is governed by a stop to which the cutter head is set down under hydraulic power. This machine is also employed for the light facing of casting guards and similar components made from aluminium-based materials, of which a considerable number are now being used.

Because of their high efficiency in manufacturing operations, a large number of boring machines are employed in the production of various components. A number of these horizontal boring machines, all of which are of the Company's manufacture, are fitted with trip systems, punch-card control or punched paper tape operation. A typical example is the boring of a large 8-inch square revolving table for use on one of the machines with larger capacity. The machine used for this purpose is illustrated in figure 10. From this photograph, it will be noted that this model is equipped with servo-motors for the vertical and transverse motions controlled by a direct-current (DC) drive system. All positioning is obtained by special microptic units. The table being machined in this case weighs approximately 10 tons and is carried on one of the latest multiple-jack revolving tables, which incorporate six jack screws for carrying the load when rotating this unit on a large-diameter ball race. The ball-tracks are not constrained, in order to prevent interference with the centre pivot pin on which the table is rotated and controls the accuracy of rotation. Certain machines have their built-in facing chuck mounted on a large-diameter sleeve carried on plain bearings. The headstock containing these bearings are machined by the method illustrated in figure 11. The semicircular tool-holder is fitted with a pre-set tool fixed to position in the tool-room. This holder is mounted in an angular groove in the boring bar and a socket-head screw in this

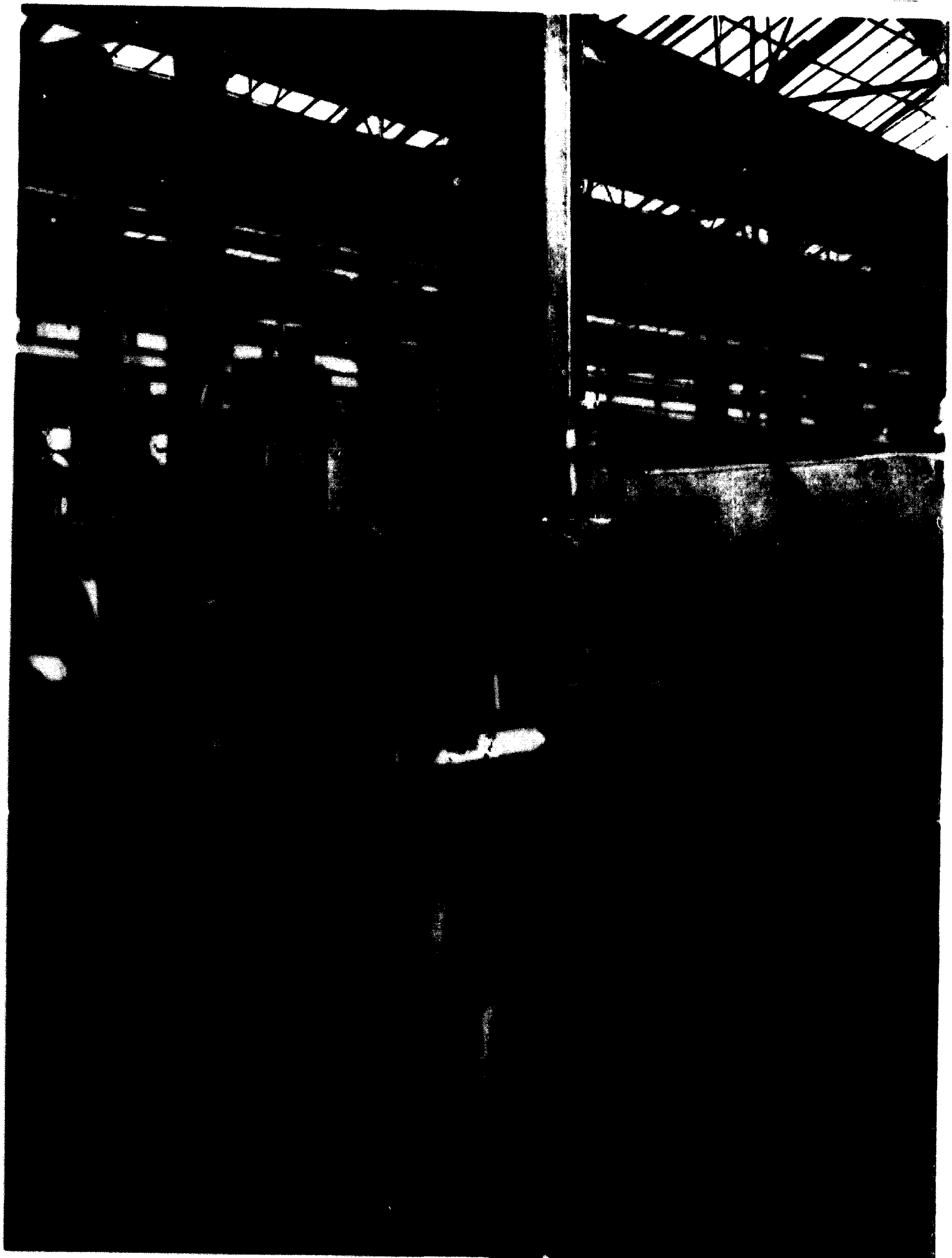


Figure 9
OIL GROOVING ON ROUTER MACHINE

Figure 10
BORING A LARGE REVOLVING TABLE

bar passes through the large end of the keyhole slot in the boring head. Bearing on the bottom of the groove and located endwise by the side faces, the holder is turned to engage the screw with the small end of the keyhole form. In this position, the screw is then tightened to lock the holder in the bar. This method of tool holding has proved extremely successful and permits holes to be machined with a variation of less than 0.0005 inch for bores up to 10 inches in diameter. In view of the importance of spindle bearings, a careful schedule of operations is prepared for the fitting and mounting of these facing-chuck sleeves into the large-diameter plain bearings. Figure 12 shows one of these sleeves being locked into the main bearing. This bearing, which is approximately 5 inches in diameter, operates over a speed range of 4 250 rpm, and the clearance is less than 0.0005 inch.

Special care is taken with the lapping compound, which, in this case, is of the water-bound type and 320 grade. All traces of this must be removed before the machine is finally assembled. One precaution which is taken to meet these conditions is the filling of the recesses of the various screw holes for holding the phosphor-bronze bush in position with a compound which fills these cavities level with the main bearing surface. Before final assembly, the bearing is thoroughly washed in order to remove completely all traces of the lapping compound. Special tests using the latest research techniques have been employed to examine the success of this washing process, and these show that bearings manufactured by this method are capable of operating for over ten years without any appreciable wear. On the smaller range of machines, the spindle is carried on a sleeve which is mounted in high-precision anti-friction bearings. In order to achieve the accuracy required, these housings must have a finish which is equivalent to the outer race and must be round to at least 0.0001 inch. This rather difficult production

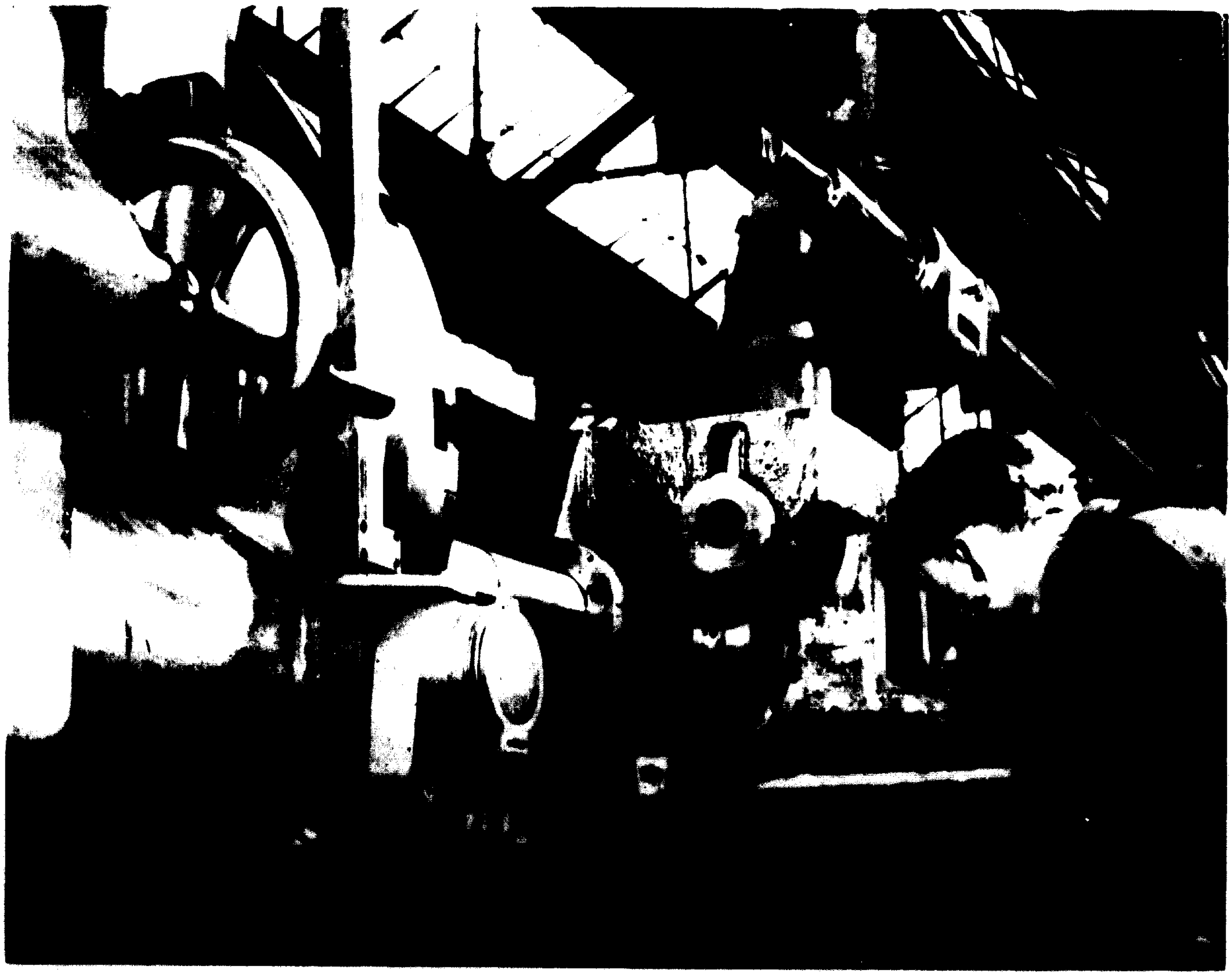


Figure 11

BORING MAIN SPINDLE BEARINGS WITH PRE-SET TOOL HOLDERS

problem, especially with large-diameter ball races, is overcome by the use of a special hydraulically adjusted lap, which remains circular throughout its full range of adjustment.

Equally important is the alignment of the front and rear bearing housings and this is obtained by using a large-diameter piloted bar for the lap, the free end of which is supported in a three-point steady. Figure 13 shows a lap of this type in use on a 7.5-inch diameter bearing housing of the small spindle slide unit. One of the most important items on a horizontal boring machine is the main travelling spindle. In the case of the Kearns machines, their size is 3–6 inches in diameter and 3–12 feet in length.

The company's recent patent on the special device for tool clamping and hydraulic release to these spindles has led to a demand for this arrangement in preference to the normal Morse tapered arrangement. Figure 14 shows a sectional drawing of this tool-holding arrangement. From this drawing it will be noted that a hole is required throughout the full length of the travelling spindle and this is achieved by a trepanning method of machining, which produces a round and accurate hole. This is essential in order to minimize the out-of-balance when rotating the spindle at high speeds. These spindles are manufactured from a nitriding steel, which, during the process of manufacture, is returned to the steel suppliers for a suitable heat-treatment process following the first rough turning operations. Before grinding, the two taper key-ways are produced on a planing machine with a special setting device. This is necessary in order to ensure that the two key-ways will be exactly 180° apart and to ensure also that the taper sides of the key are in correct relationship with each other. Figure 15 shows a photograph of this operation. From this, it will be noted that a setting gauge is inserted in the taper socket at one end of the spindle. One face of this is carefully set parallel to the top of the planing-machine table. A cross member on this gauge is set horizontally with the aid of a precision level, and feeler gauges are then used to align the planing tool with a slot in one side of the member, which is on the vertical axis of the work. On completion of the first key-way, the spindle is turned 180°, the cross member is relevelled and the tool is set in relation to the slot in the opposite side of the gauge for the planing of the second key-way 180° from the first. On completion of this opera-

Figure 12
LAPPING THE MAIN SLEEVE IN THE BEARINGS

Figure 13
LAPPING BEARING HOUSING

tion, the spindle is sent to the grinding department before being dispatched to the steel suppliers for a nitriding process. On return to the factory, the previously planed taper key-ways are ground on the machine shown in figure 16. This particular machine was constructed in the company's works, mainly from standard units used in the manufacture of horizontal boring machines. The main bed and table are units from the planer-table type of machines, and the two vertical columns have been made from normal outer supports. On this machine, the table is hydraulically traversed from an independent unit, which is remote from the machine in order to minimize the difficulties of distortion due to heat. From the illustration, it will be noted that a circular cross-rail carries the wheel head, which can be rotated to provide a fine height adjustment. For coarse movement, the rail is moved by power or manually. The grinding head has two spindles, one horizontal and the other vertical, and these are driven by a 3-hp built-in stator and rotor units. As in the case of the planing operation, the key-ways are carefully located by means of a gauge inserted in the Morse taper end of the spindle.

Modern high-speed horizontal boring machines demand that the finish on the spindles should be at least to an accuracy of 3 to 5 microinches. This is achieved by a simple superfinishing machine, also built in the company's works and illustrated in figure 17. A spring-loaded stone carrier is employed and water is used as a lubricant. During lapping, the spindles are rotated at approximately 150 rpm and the slide on which the stone carrier is mounted is operated by means of a yoke mechanism driven from a separate electric motor. The slide is supported on a carriage, which is moved along the bed by a central feeding-screw. This machine, which operates automatically, is attended to by one of the grinding-machine operators. The majority of the machines produced in the works have a simple slide with a facing chuck combined with a travelling spindle. In order to achieve a compact, yet powerful, feeding mechanism to this facing slide, considerable design and development work has been done on this unit. The most recent and patented arrangement now consists of a single large-diameter worm gear into which engage two spirals. Into these engage two helical racks which are bolted on to the facing slide. Figure 18 shows the three units in position. This system of using two helical racks for the final feed-drive provides a robust arrangement which is capable of transmitting the full horsepower of the main driving motor during heavy facing operations. One extremely important component in this mechanism is the large-diameter worm gear. Figure 19 shows this component being produced on a 36-inch vertical turning and boring mill. The gear to be machined is manufactured from a ring forging in

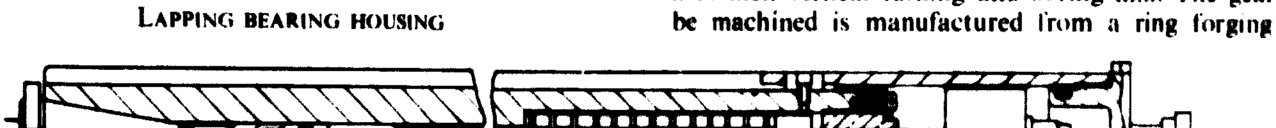


Figure 14—PATENTED TOOL CLAMPING AND HYDRAULIC RELEASE TO MAIN SPINDLE

Figure 15

PLANING TAPER KEY-WAYS IN MAIN SPINDLE

l and includes the cutting of the ½-inch pitch read, which forms the worm tooth. One com- ...n of the thread in excess of the actual require- is cut in order to minimize distortion, and this is ...ly removed on a simple milling machine. Roughing ...d finishing cuts are taken, using a special threading tool-holder, with each shank being finished separately and a maximum of 0.005 inch of metal being removed during the final machining.

The two spiral gears which are shown in figure 18 engaging with the single-thread worm gear are manufactured from aluminium bronze, which has a reasonably high tensile strength, in this case, approximately 15 tons per square inch. It has good shock-resisting properties also and, therefore, is capable of absorbing intermittent loads during facing operations on components with an irregular surface to machine. The helical teeth in these spiral gears are cut with the rack type of cutter which is being used on the vertical boring mill mentioned previously, thus ensuring that the two-toothed sections are identical. Special care is taken during the assembly of the facing chuck in order to minimize any backlash which, if present, would be an embarrassment when using the machine for accurate bore-diameter setting.

In order to reduce the time required to fit the two helical racks into the facing slide, these are provided with a slightly tapered face at either end, so that a small key with a similar taper surface is used to move the racks longitudinally in order to reduce the backlash in the mechanism to a minimum. The large-diameter sleeve, which carries the facing chuck in which this feeding mechanism is incorporated, calls for a high degree of precision in its manufacture. This is essential if the bearings carrying the inner spindle, which are mounted on the inside of this sleeve, must rotate accurately not only in relation to the sleeve, but also in relation to the main spindle bearing in which the facing-chuck sleeve is mounted. During final inspection tests on the finished machines, a concentricity of less than 0.0005 inch is achieved between the facing chuck and spindle.

Special precautions are necesssry during the manufacture of this facing-chuck sleeve, in order to achieve the high degree of concentricity between the anti-friction bearings of the spindle mounted inside the sleeve and th

Figure 16

GRINDING TAPER KEY-WAYS IN MAIN SPINDLE

Figure 17

SUPERFINISHING THE MAIN SPINDLE

Figure 18

FACING SLIDE FEEDING MECHANISM

Figure 19

MACHINING LARGE-DIAMETER WORM FOR FACING MECHANISM

outer diameter, which rotates in the plain bearings illustrated earlier. The first operation on the sleeve, which is produced from a forging, is to rough-machine it all over and, when finished, to turn the outside diameter in a centre lathe, which is followed by a grinding operation on the bearing diameters. This sleeve is then returned to the centre lathe and, with one end mounted in the chuck, the other is supported in an accurate steady. The final bores for the main spindle anti-friction bearings are then produced on the lathe, being truly concentric with the outer diameters which have previously been ground. The forging from which the facing-chuck sleeve is manufactured is made from a 45–50 ton tensile strength high-carbon steel. Considerable service experience in using these large-diameter plain bearings has indicated that they have an extremely long life, but that they are exceptionally critical to the type of oil used, which, in this case, is a low-viscosity compounded oil with a mineral base.

One extremely important feature of the Kearns range of horizontal milling and boring machines is the policy of reducing to a minimum the motors or high-speed gearing and shafts in the headstock. This is in order to reduce to a minimum any distortion of the spindle bearings due to heat generation from unnecessary shafts and mechanisms in the headstocks. This design policy allows these headstocks to be made with exceptionally large proportioned facing-chuck sleeve and spindle bearings and also enables the designer to provide for the maximum stiffness in the headstock in order that the bearings should remain in a true position, especially under heavy cutting conditions. This is also essential if the very fine bearing clearances are to be maintained without the risk of seizing due to the generation of undue heat caused by a physical contact when using the low-viscosity oil mentioned above.

The vertical column on which this headstock slides is provided with square guides, and these are produced on a plano-milling machine similar to that previously described. The top and bottom faces of this upright are produced on a horizontal boring and milling machine similar to that illustrated in figure 20. From this illustration, it will be seen that a large milling-cutter, in this case, 20 inches in diameter, is bolted directly on to the facing-chuck body. Feed rates in the order of 15 inches

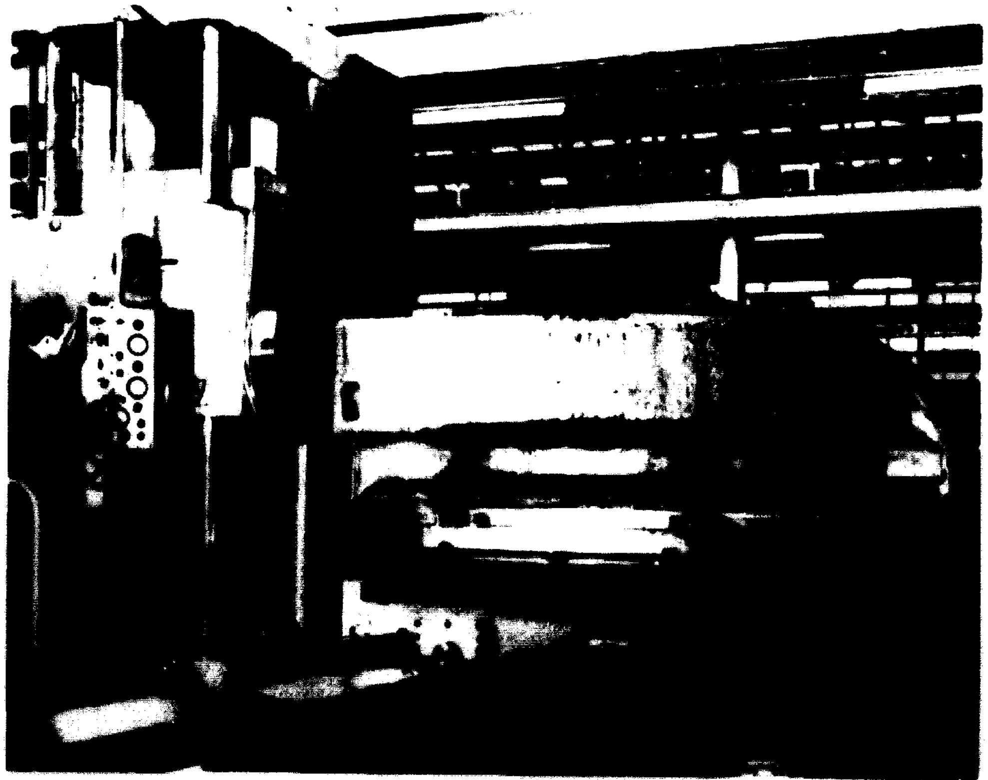


Figure 20

MACHINING VERTICAL-COLUMN BASE

Figure 21

FITTING THE SPINDLE SLIDE TO THE UPRIGHT ON VERTICAL COLUMN per minute are employed, and the metal removed approximately ½ inch. On completion of this operation, these uprights are placed on a test bed and are checked for vertical squareness from the base. Should any adjustment be necessary, the part is returned to the machine shown in figure 20, and the sliding ways are set to the required angle in order to give the necessary correction when milling the upright base. When received at the factory, all castings, including this upright column, are first shot-blasted and then given a priming coat of paint before being sent round the factory for the machining operations just described. Following the inspection test referred to above, the column is returned to the paint shop, where the necessary filling and final painting are completed. In the case of the upright, this is then sent to the fitting bays, where the vertical screw is set in position by means of a simple fixture. This method of setting is clearly illustrated in figure 21.

As previously noted, a large number of boring machines are employed for the production of various components. A typical example is the boring of an eight-speed gear-box on the machine illustrated in figure 22. This model is equipped with servo-motors for the vertical and transverse motions, and is controlled by a DC-drive system. All positioning on the vertical and transverse motions is obtained by means of punch cards prepared by the planning office. This machine, which is typical of those which have now been in service for over ten years, is capable of positioning to an accuracy of less than 0.0002 inch.

At this stage, it might be valuable to review the design and production of the major cast iron units which are similar to the upright just described. Earlier, reference was made to the policy of unit construction throughout the full range of the Company's products. A more detailed explanation of these various units as used on the 3, 3.5 and 4 inch spindle machines will be obtained from examining the two diagrams shown in figures 23 and 24. The numbers in the lower left-hand corner of each outline drawing denote the work-holding capacity, which is obtained by calculating the product in cubic feet, the distance from the spindle nose to the outer support, the vertical traverse of the headstock and the transverse traverse of the table. Where two work-holding capacities are given, alternative tables can be used. The disposition of the five standard units are shown in the

Figure 22

BORING EIGHT-SPEED GEAR-BOX ON NUMERICALLY CONTROLLED MACHINES

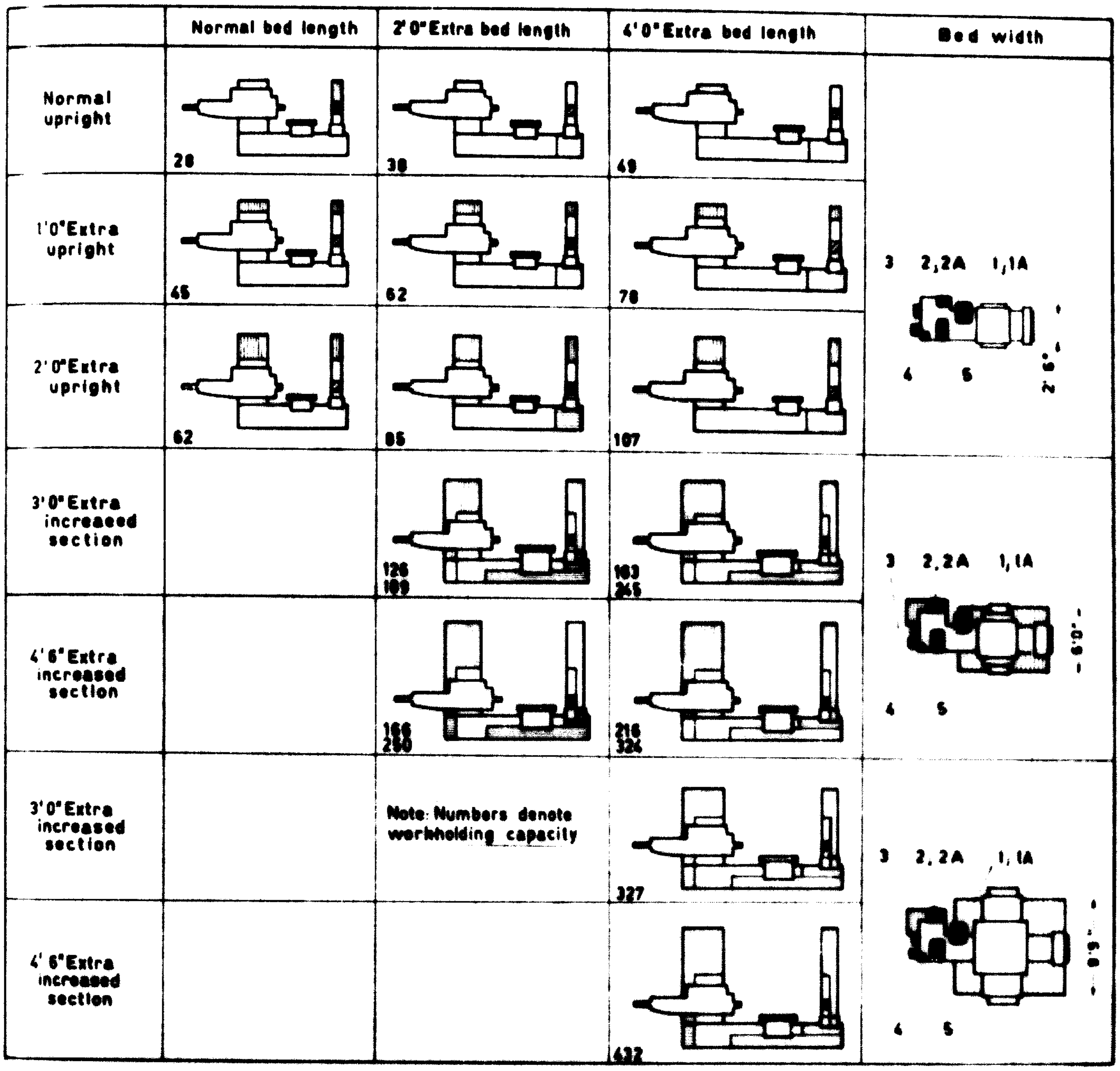


Figure 23

UNIT CONSTRUCTION DIAGRAM FOR 3-INCH SPINDLE MACHINE

right-hand column. The work-holding capacity of these machines ranges from 28 to 560 cubic feet and their metal-removing ability is of two orders, dependent upon the size of the headstock, yet five standard design units are used in their construction. These are as follows (as numbered in figures 23 and 24):

1. Eight-speed reversible main drive box;
1A. Eight-speed reversible main drive box with built-in electric motor of the stator and rotor type;
2. Mechanical rapid-traverse box;
2A. Rapid-traverse box with built-in stator and rotor unit;
3. Feed drive box.
4. Twelve feed and screw-cutting gear-box;
5. Distribution gear-box.

The Company does not have its own foundry, but these various patterns are produced in its own pattern shop. The method of construction adopted in this pattern shop for the manufacture of the upright and main bed patterns is very similar. Figure 25 shows the upright pattern in the course of manufacture. From this illustration, it will be noted that the pattern is constructed with long beams fixed to the base and sliding into the main body of the pattern.

When the base of the pattern is close to the body a casting of normal height is produced. With the beams fully

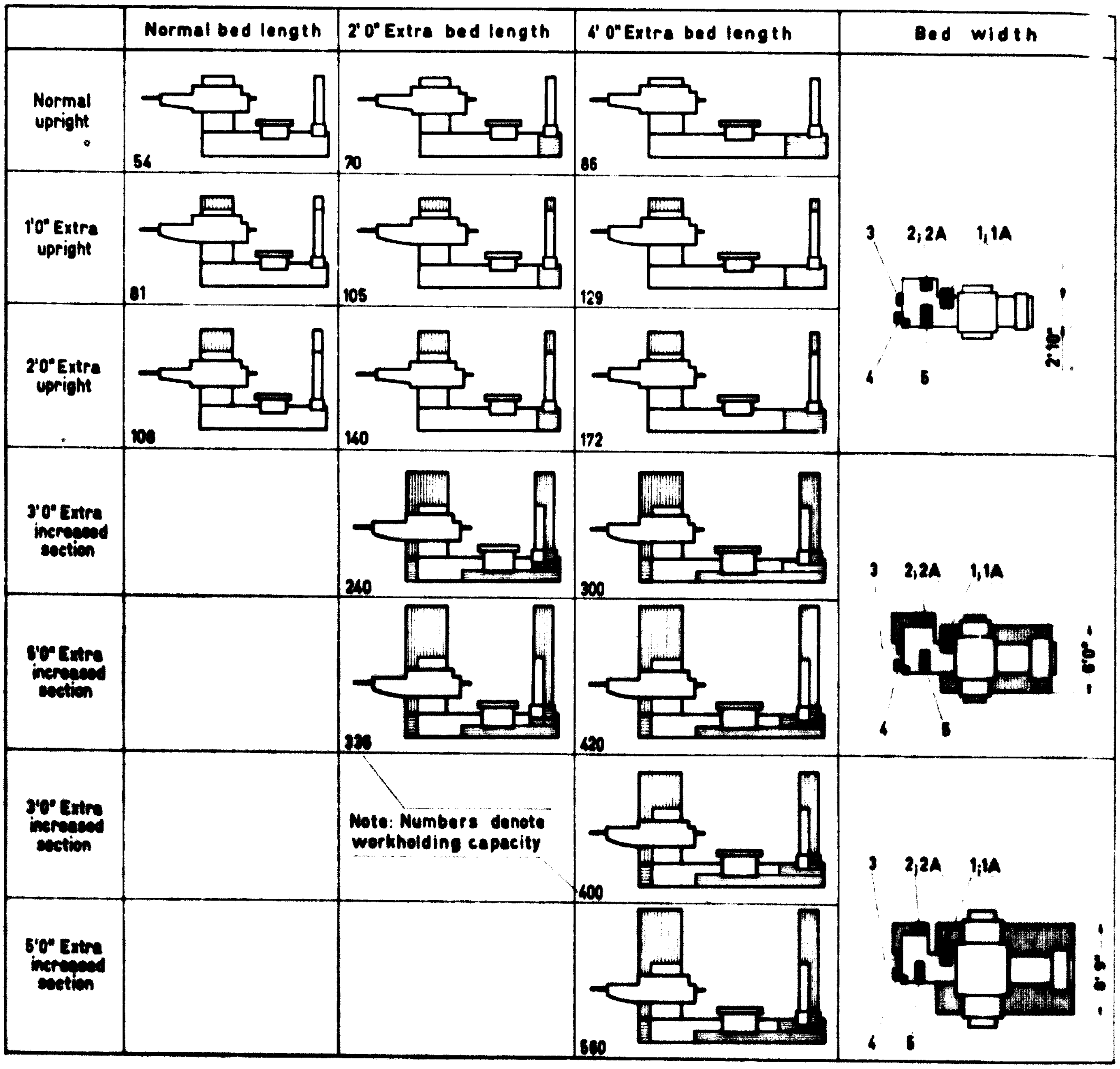


Figure 24

UNIT CONSTRUCTION DIAGRAM FOR 3.5-INCH AND 4-INCH SPINDLE MACHINE

extended a column giving an increase of over 70 per cent in vertical adjustment is available from the same pattern. This not only helps to reduce costs, but also minimizes the problem of pattern storage. Brief mention has been made of the treatment of castings upon arrival from outside suppliers. The full treatment, however, of these main units is extremely important and can, in fact, amount to approximately 5 per cent of the total manufacturing cost of the machine. Great care is therefore taken in the design stage to try to produce casting outlines which are easy to clean, fill and paint. A typical design of the type of casting which has been found satisfactory from this point of view is shown being sprayed in figure 26. Briefly, the treatment these major castings receive upon arriving at the works is as follows:

(*a*) Shot-blasting and trimming the casting;

(*b*) Spraying a coat of protective paint to form the seal;

(*c*) On completion of machining, components are returned to the paint shop and are completely cleaned;

(*d*) Finish trimming the casting;

(*e*) Filling applied by knife and component rubbed dry, mainly with mechanical devices;

(*f*) Brush priming-coat applied;

(*g*) Butts filed with sandpaper, applying large quantities of water;

(*h*) Clean machine faces;

(*i*) Paint by brushing;

(*j*) Machine completed and a finish coat of paint applied.

Figure 25

UPRIGHT PATTERN CONSTRUCTION

The insides of the majority of main gear-boxes are given a coat of hard-drying white enamel, which is naturally oil-resistant.

Returning to the manufacture of small components, including gears, shafts and similar items, these are, where suitable, produced on modern centre lathes or turret lathes. A general view of this section is shown in figure 27. In some cases, the traverse screws, all of which have 1-inch Acme thread, are dealt with on a thread-whirling machine, which is illustrated in figure 28. These screws are all manufactured from EN.9 steel, and the component shown is 6 feet 9 inches long and has a 2.5 inch diameter. The two t.p. thread is 5 feet long. The thread is cut in a plain bar, which has been groove-machined at each end for entry and exit of the cutters, the ends being finish-machined after the thread-whirling operation. Soluble oil mist is used as a coolant and the thread is cut with reference to a graticule in the built-in microscope of the machine. Screws ranging from 3 feet to 12 feet in length and from ¾ inch to 3 inches in diameter are produced on this thread-whirling machine. Compared with normal centre-lathe screwing-cuttings, experience indicates that this method is approximately three times as rapid, with an excellent thread being produced, providing care is taken in maintaining good cutting tools and these are accurately set in the thread-whirling head. It is important to record that none of the screws are intended for measuring purposes, being merely for feeding the appropriate unit to which they belong. In order to improve the stiffness, in certain cases a special reduced depth of ½-inch pitch Acme thread is employed. The faster bronze nuts which are used with these screws are produced on a turret lathe by means of a ground thread tap having the forward cutting tools arranged to remove the metal alteratively from the top and shanks of the screw thread, with the final section of the tap with a full-section thread which produces the final shape.

In view of the comprehensive range of components with which these horizontal boring machines are expected to deal, it is regarded as essential that they should have a very wide range of speeds and a large number of speed changes within this range, in order to make them acceptable for the work and the materials of the components which they will have to machine. As mentioned previously, a special feature of the Kearns machines is the policy of incorporating a minimum number of gears and bearings in the headstock. To deal with the range of spindle speeds required, therefore, the main drive gear-box is usually mounted in the bed of the machine. Drive to this gear-box is from a constant-speed AC motor mounted at the back of the main bed through a toothed belt drive. The gear-box generally has nine changes obtained from nine gears, with drive from the output side of this gear-box to the main spindle being through a nylon/plastic belt operating at a high velocity. To assist handling and manufacture, the gear-box is produced in light alloy and manufactured on one of the company's own punch-card numerically controlled horizontal boring machines. These gear-boxes are expected to operate continually at high speed and with a minimum of vibration. The design is therefore arranged with large-diameter short shafts, and all gears are hardened and ground. The shafts are produced on a spline grinding machine in order to ensure concentricity of the ground gear on its shaft. The driving gears are manufactured from a 3 per cent nickel steel and are suitably heat-treated. The factory is equipped with two gear-grinding machines, one of which uses a formed wheel with an index plate for locating each tooth. In the case of wheels of up to 10 inches in diameter, these are produced on the latest type of gear grinder using a grinding-wheel in the form of a worm, with the component to be cut fixed to a vertical spindle and operating like a continuous generating machine. Ground gears produced by either of these methods allow a pitch-line velocity on the gears

Figure 26
CASTING DESIGNED FOR EASY PAINTING

Figure 27
CAPSTAN AND TURRET LATHE SECTION

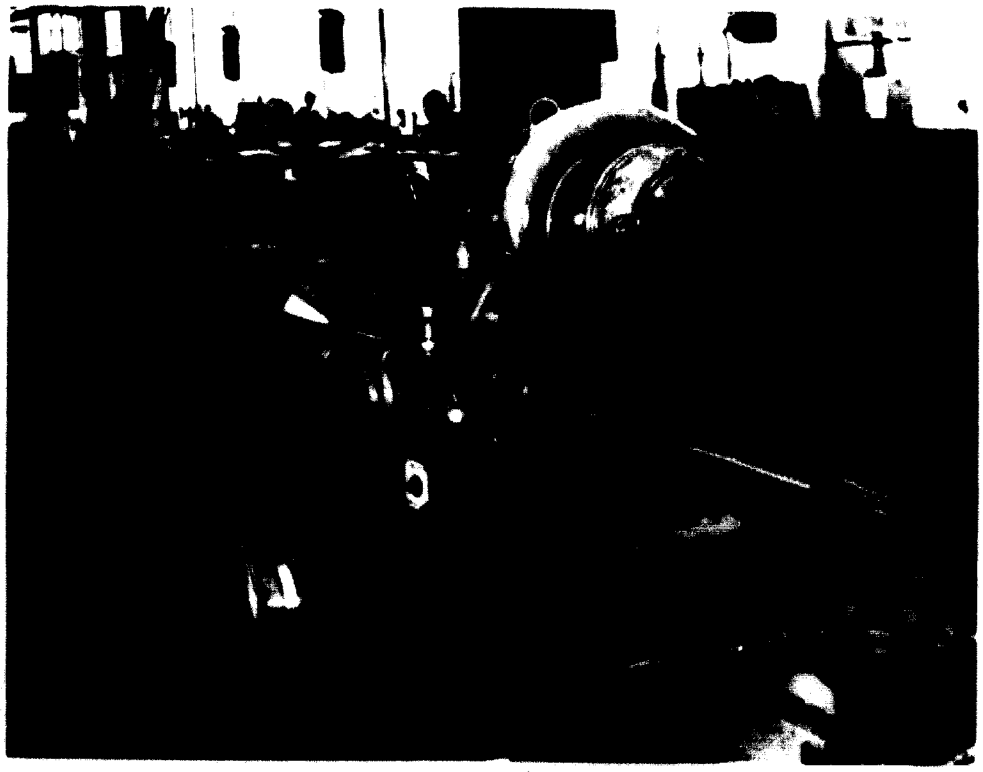


Figure 28

THREAD-WHIRLING MACHINE

Figure 29

MAIN BED READY FOR ASSEMBLY LINE

of 1,000 feet per minute, to be accomplished with a minimum of noise, and the production of a toothed form which proves satisfactory when using the machine on milling operations where a minimum of backlash is essential. All gears are designed with a 20 pressure angle and the gear centres on which they operate are manufactured to 0 0.001 inch centres.

11. Final assembly and testing

The factory operates on the principle that the single components already described are sent to stock and are then recalled together with the appropriate purchased materials, i.e., ball races, screws and other items. These are then assembled into individual units. These units are built in batches of ten or more, depending upon the demand, while the individual components for these units are produced in quantities which give a certain stock value, rather than the actual number of items produced. This method of manufacture proves more efficient than attempting to balance the exact number of items required for each component, especially when these may consist of simple struts, flat plates or collars. From instructions issued by the Production Control Department, the various sections assembling the individual units draw their items from stock and proceed to manufacture a complete unit. As the actual specification for the machine to be built depends upon the customers' requirements, this information is prepared by the sales office, which issues an office order detailing the customers' exact requirements. From this, the planning office determines the types and specification of the individual units required in order to complete a single machine. As an illustration of the final assembly stages of these units into a completed machine, a model in the lower horsepower group has been selected. In accordance with the customers' requirements, a main bed of the appropriate length is provided from the unit stores and is received by the fitting bench in the condition shown in figure 29. From this illustration, it will be noted that the bed is completely machined, including the faces for the various units which must be inserted into this item. The rectangular end facing on this bed accommodates the main driving gear-box together with the change feed-box, both of which are shown in position in figure 30. The distribution or well box, a mechanical version of which is shown in figure 31, is then fitted during the final assembly stages into the main bed casting. Other units follow in a similar manner, including the saddle, main table and revolving table; finally, the vertical column and spindle slide are bolted into position, as is illustrated in figure 32. This illustration shows the spindle slide in position with the front cover removed so that during this final assembly stage the machine can be rotated and the automatic lubrication system can be fully inspected in operation.

During the final assembly stage of these machines, in addition to undergoing static testing, they also are required to complete a standard test piece which covers the majority of movements on the machine. This test piece being forwarded with each individual machine. The range of static tests is covered by diagrams of tests

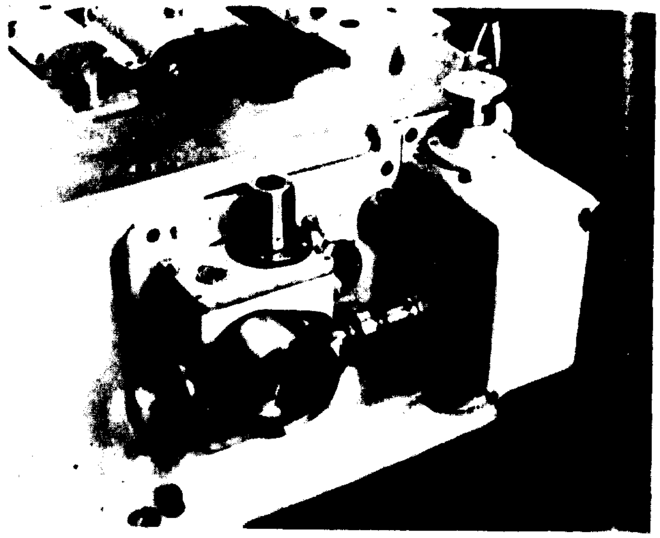


Figure 30

Drive and feed-box in position on main bed

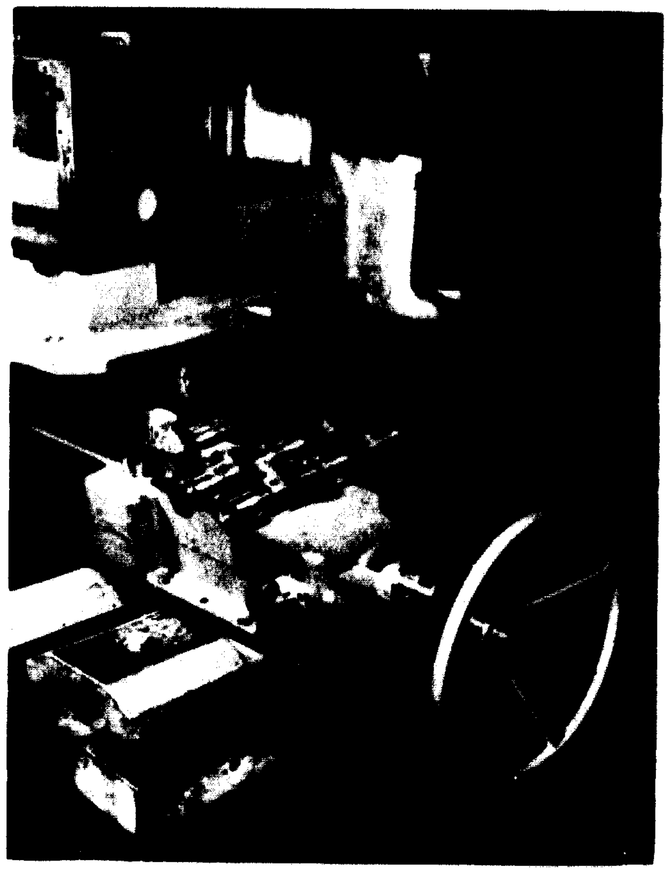


Figure 31

Fitting distribution-box in main bed

Nos. 1–16, shown in figures 33–36. As the majority of the machines are arranged with a built-in facing chuck combined with a travelling spindle, the series of tests have been devised in order to meet the exacting requirements of a machine of this type. Test No. 1 shows the levelling of the main bed. This test is designed to check the bed for levelling in both the longitudinal and transverse directions, and a permissible error of 0.001 inch in 48 inches is allowed. A problem of considerable import-

Figure 32

FINAL ASSEMBLY OF MACHINE

ance in the case of horizontal boring machines is the accuracy of the vertical column in relation to the main bed. This must be carefully checked and from the figures given in Test No. 2, it will be seen that the maximum permissible error is 0.001 inch in 24 inches. As this upright must be square, not only in the front but also in the end elevation, a further test, illustrated in Test No. 3, is required. Having produced the column at right angles to the main bed, it is now necessary to check the axis of the main spindle to the upright guide. This is shown in Test No. 4. During this test, it is important not to use a dial indicator which is fixed to the spindle and, therefore, changes its position as a result of reflection. During this inspection on the Kearns machines, a stiff bar is bolted to the facing chuck and a small block, complete with a dial indicator, is first used to check the top position between the side of this bar and the upright guiding edge. A similar test is then made in the bottom position. Using this method, it will be noted that the dial indicator is always used under similar conditions. Test No. 5 shows the setting of the axis of the spindle parallel with the guiding edge of the main bed. This is achieved by extending the spindle and then moving the tables longitudinally along the main bed, when a permissible error not exceeding 0.001 inch in 24 inches is allowed. Test No. 6 shows the allowable error when running the spindle in a 12-inch extended position; error must not exceed 0.0012 inch. A test for checking that the top of the main table is parallel with the top of the bed is shown in Test No. 7. In view of the importance of boring a component

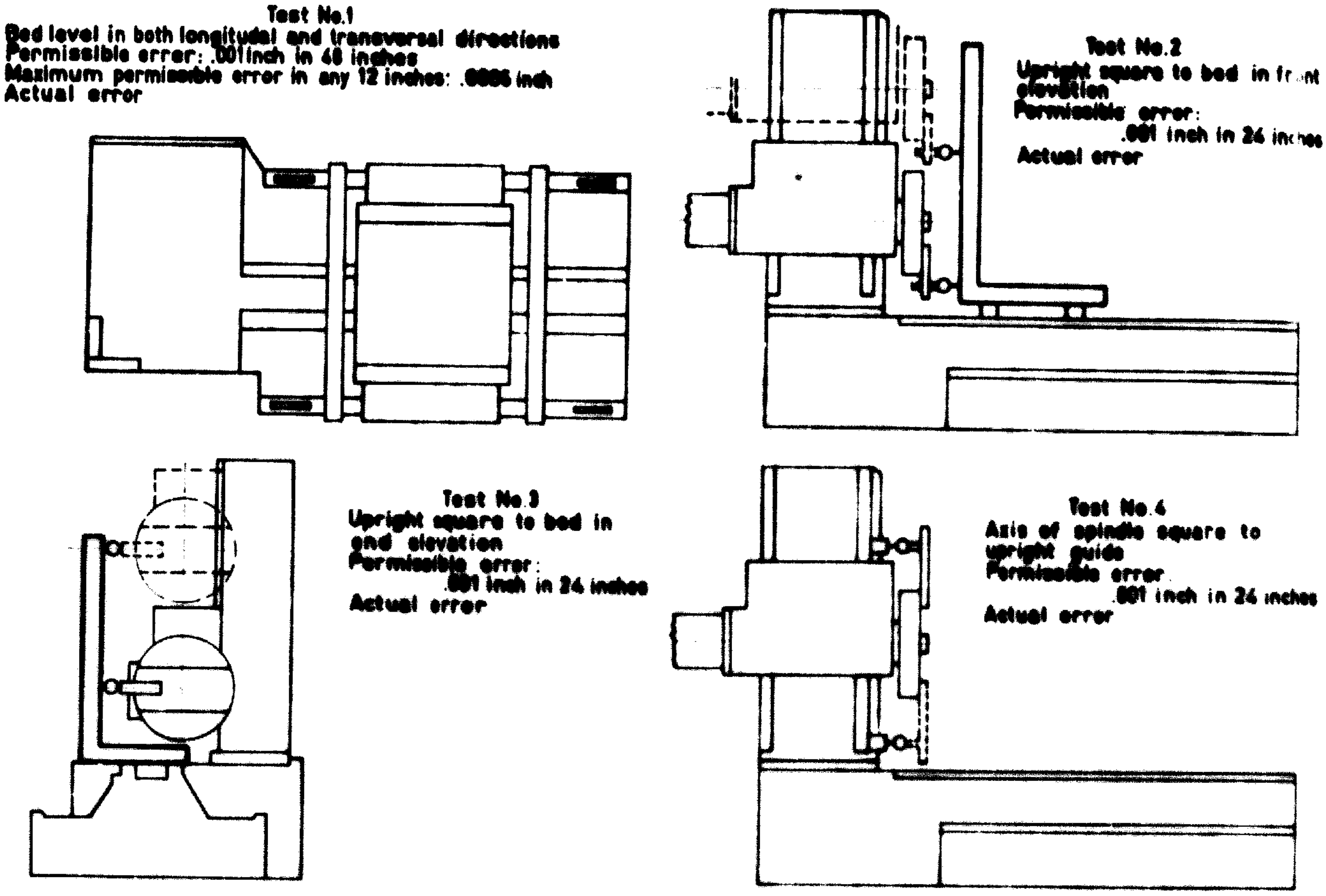


Figure 33

STANDARD TESTS FOR MACHINE: TESTS 1–4

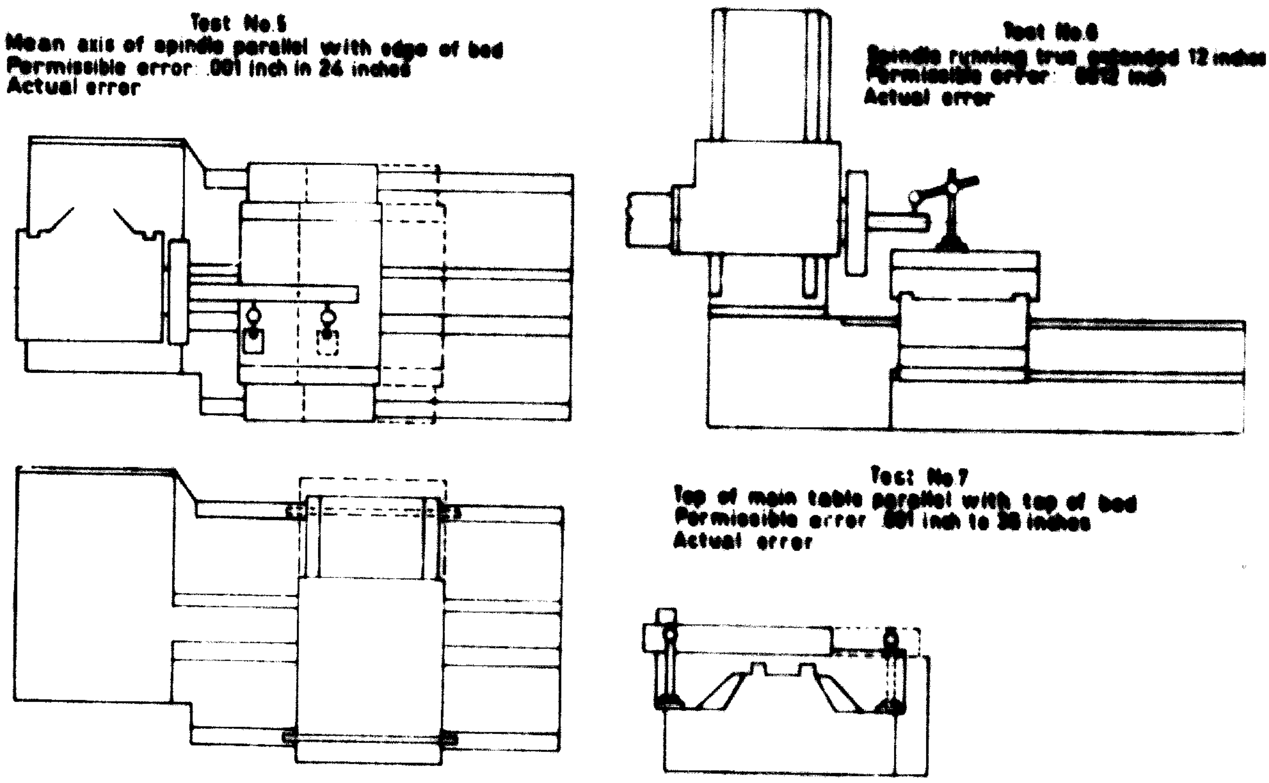


Figure 34

STANDARD TESTS FOR MACHINE: TESTS 5–7

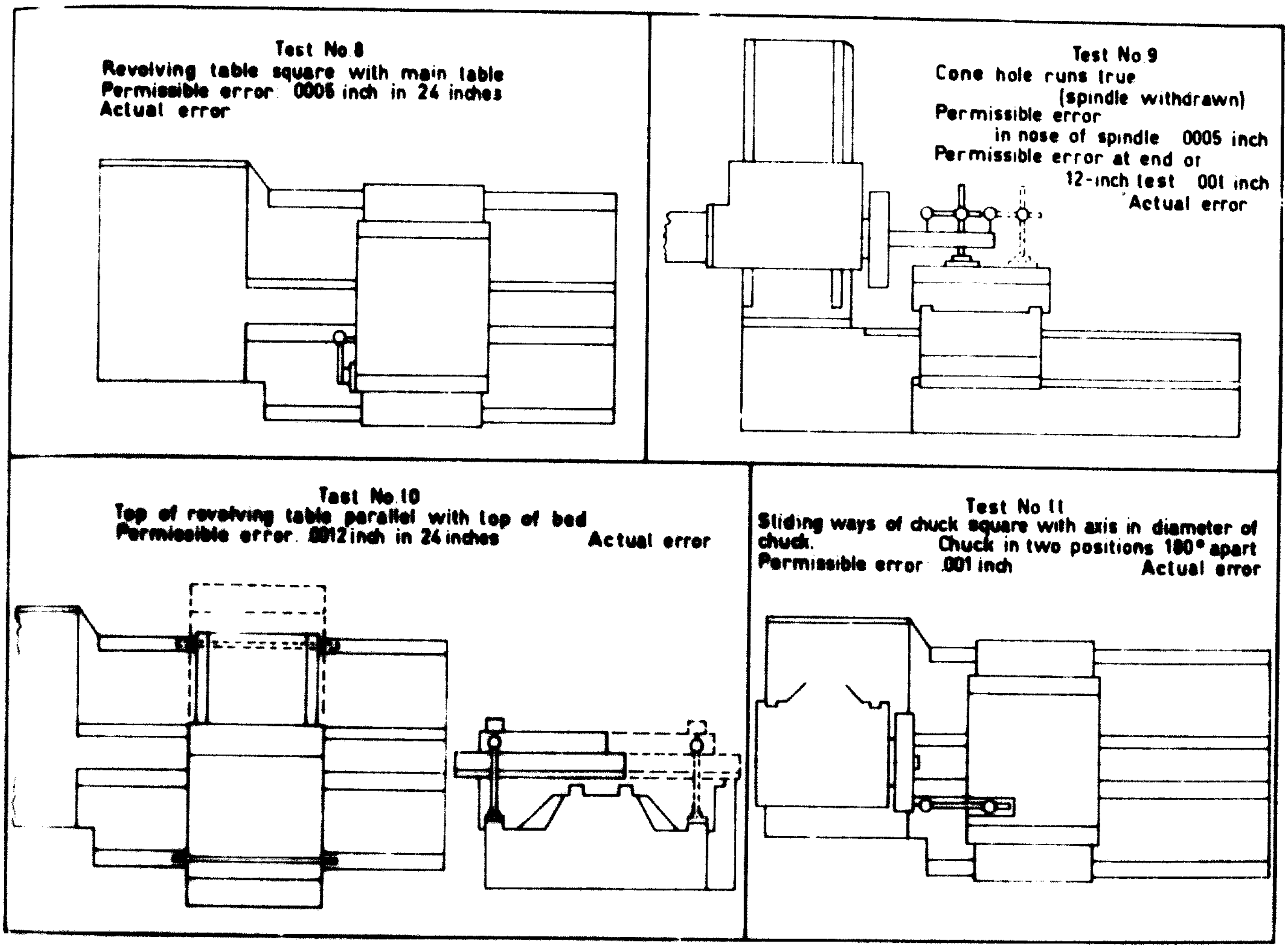


Figure 35

STANDARD TESTS FOR MACHINE: TESTS 8–11

first on one side and then rotating the table 180° and boring a second hole in line with the first, it is essential that the revolving table should have a high degree of accuracy when rotated. From Test No. 8, it will be seen that, in this case, the permissible error at the extreme end of the table should not exceed 0.0005 inch in 24 inches.

These and other tests, up to test No. 16, must be completed on every machine to the entire satisfaction of the chief inspector, his being the sole authority in determining when the machine is satisfactory. This policy of allowing a chief inspector the final decision in these matters is, in the case of H. W. Kearns, regarded as extremely important, as, although in the final result it means that the chief inspector is determining the output of the factory, he and he alone must ensure that the machines have reached a satisfactory level of accuracy before they leave the final assembly bays. Any interference with this authority would mean that the inspection staff would lose their authority and tend to turn to management for decisions which rightly should be theirs. As mentioned previously, in addition to undergoing these static tests, the machine performs a number of operations on a special test piece designed to cover the principal movements on the machine. For example, one of these test-pieces nearing these final stages is shown in figure 37.

Thus far, no reference has been made to the work on design and development which is undertaken on the machines before they are released to the factory for normal batch production. Over fifty years of specialization in the manufacture of horizontal boring machines has shown that the time required to develop and produce the first of a new range of machines is approximately three to five years. In view of this rather long and important phase, the company has decided to create the necessary departments to deal with this aspect of its business. The various departments involved in this exercise are placed under the control of the Technical Director. These include a future-design section, current-design office, development and experimental department, vibration- and model-testing section, production drawing office and a value engineering section.

Before a new model is produced, based on information received from the future-design section, the design office prepares drawings for a prototype machine to be built in the development and experimental department. A view of this section of the works, which occupies approximately 1,600 sq ft, is shown in figure 38. This department is equipped with a centre lathe, grinding and milling machine and drilling machine, as well as two horizontal borers. This equipment permits it to produce a large

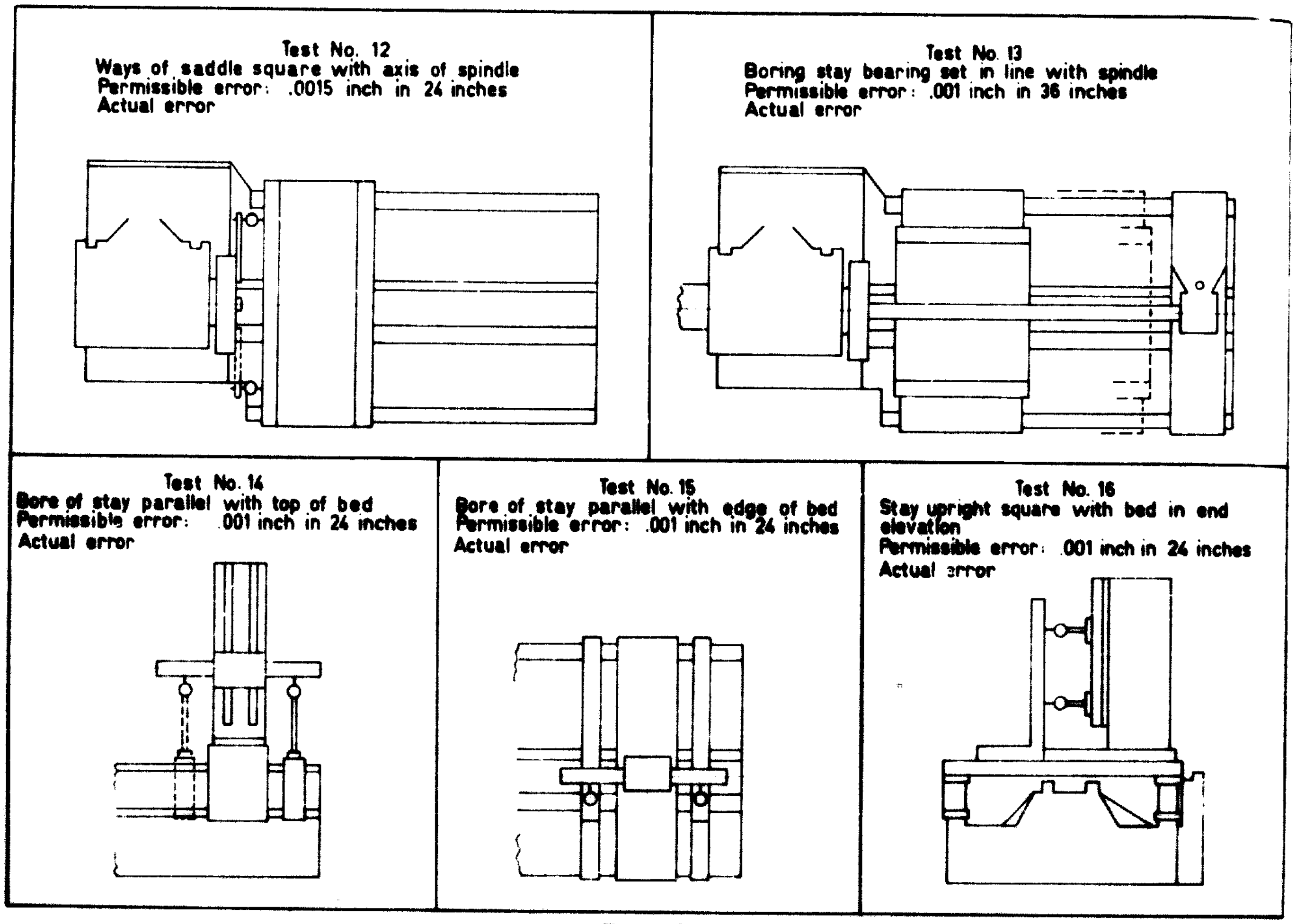


Figure 36

STANDARD TESTS FOR MACHINE: TESTS 12–16

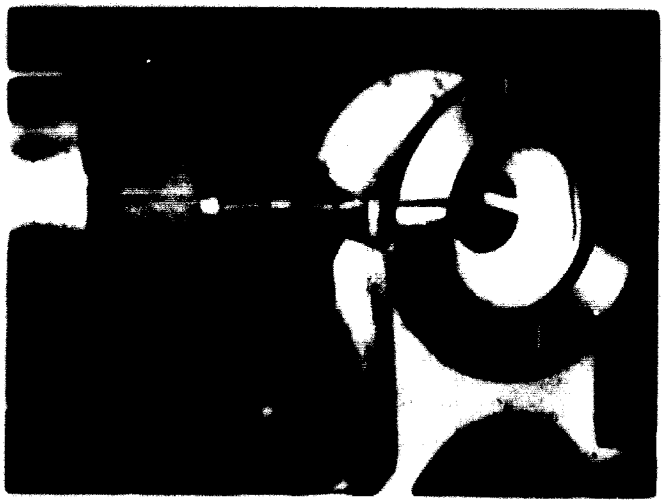


Figure 37

TEST PIECE BEING MACHINED

proportion of the new and experimental parts required without interfering with the main production shop. Regarded as equally important is the need to assemble new gear-boxes and attachments under conditions as free from foreign matter as possible, so that the greatest number of variables can be omitted from testing a new design. The department, therefore, includes a clean-air section; this is illustrated in figure 39. Also included in this development and experimental department is a section dealing with vibration and model studies. Figure 40 shows one of the machines which was recently developed undergoing a vibration study. This investigation is dealing with a machine fitted with a patented multiple-column support to the spindle slide. Figure 40 shows the vibration engineer with the oscillating equipment attached to the spindle nose and using a roving pick-up; tests are made over the structure in order to determine the phase and amplitude of the vibration. Work of this nature has proved invaluable in enabling the sales department to offer machines with a known cutting capability, while at the same time providing the factory with exact information on the degree of accuracy, material and often shape of the component which will permit the unit to fulfil its technical requirements at the minimum of manufacturing costs. This advanced work, together with a full and complete record of every one of the 6,000 horizontal boring machines the Company has produced, provides invaluable information, not only in producing and manufacturing existing models, but also in meeting what will obviously be more advanced machine tools in the future.

Figure 38

DESIGN AND DEVELOPMENT SECTION

Figure 39

CLEAN-AIR SECTION, DEVELOPMENT AND EXPERIMENTAL DEPARTMENT

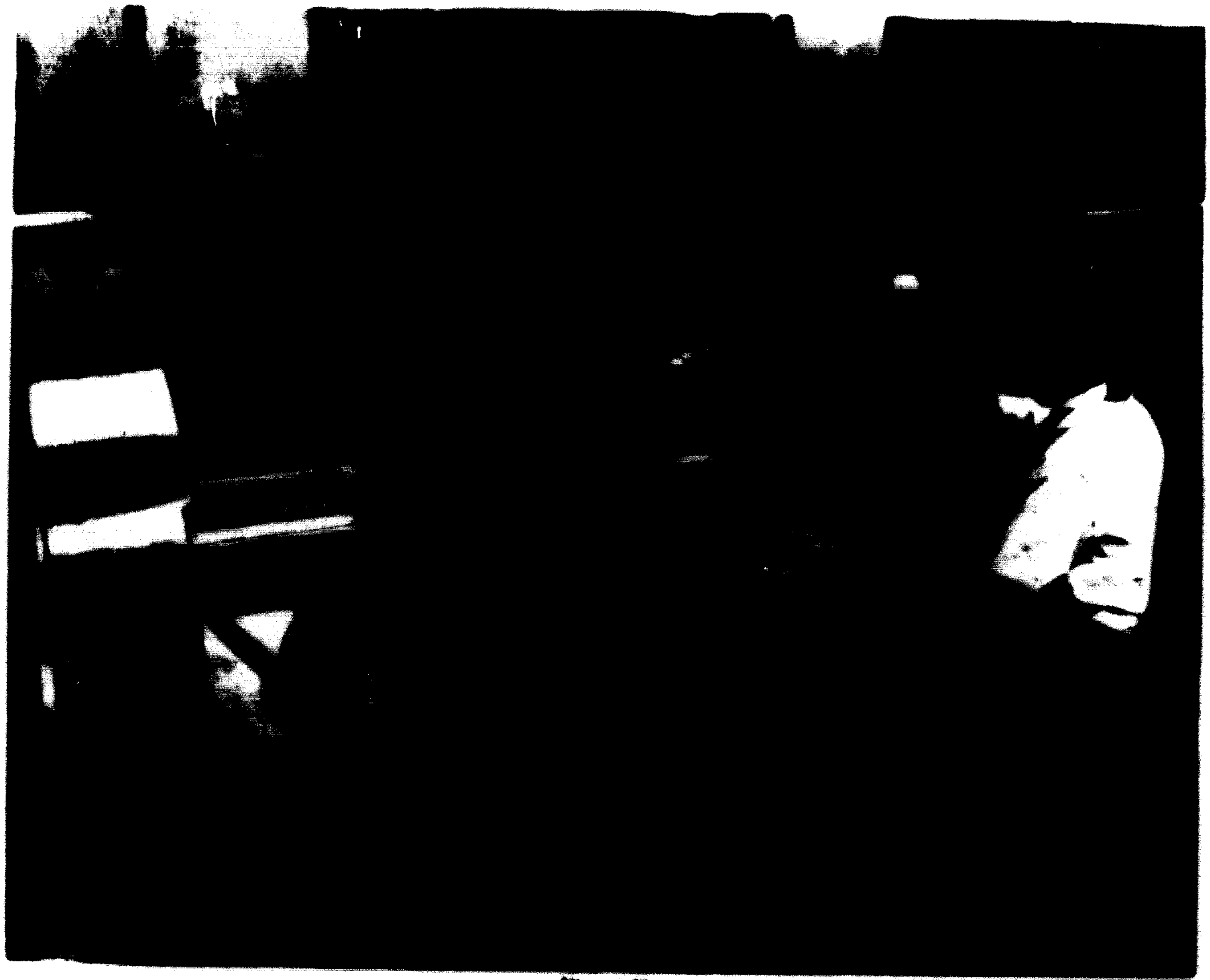
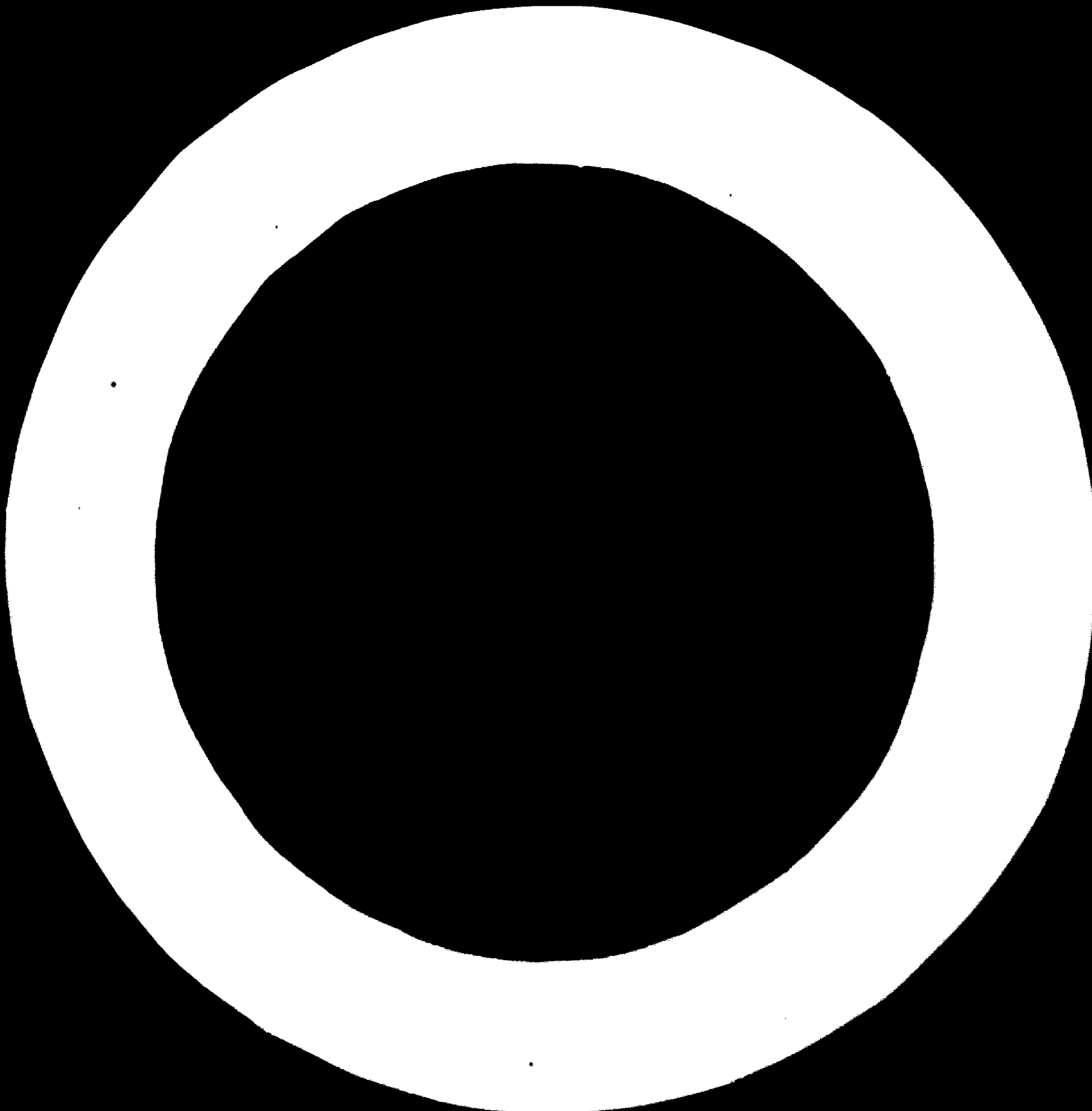


Figure 40

VIBRATION TESTS IN DEVELOPMENT AND EXPERIMENTAL DEPARTMENT



BASIC PROBLEMS IN THE EFFICIENT SELECTION OF METALWORKING MACHINES FOR DEVELOPING COUNTRIES

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INTRODUCTION

During recent years, the developing countries, which have chosen an independent path of development, have been expanding their industrial production and establishing large, modern plants and factories, both through their own efforts and with assistance from abroad.

The developing countries of Africa, Asia and Latin America currently cover most of their needs for metalworking machines by imports from other countries, with only a small number of machines being manufactured in certain of these countries, e.g., Argentina, Brazil and India. The developing countries should solve the urgent problem of organizing national metalworking machine industries in at least some countries, as well as the problem of efficiently selecting machines for importation. It is very important, if one considers that the machine-tool industry is the key branch of the machine-building industry, i.e., its base in manufacturing modern machines, equipment, tools and many other products for industry, transport and agriculture.

Statistical data on production, imports and exports of metalworking machines have been used to define the problems of the rational selection of types of metalworking machines according to the levels of development achieved and the needs of developing countries in Asia, Africa and Latin America during recent years.

I. ECONOMIC SITUATION AND REQUIREMENTS OF METALWORKING MACHINES IN SELECTED DEVELOPING COUNTRIES

Analysis of the economic situation of selected African, Asian and Latin American countries shows that these countries have large potentialities for the creation and development of national metalworking, machine-building and machine-tool industries.

A. *African countries*

The population of Africa is 250 million, of which 230 million constitute the population of independent countries. The density of population ranges from two to ten people per square kilometre.

The process of creating economic independence is going on in Africa in very complicated conditions. The unfavourable conditions in the world markets have exerted an influence upon the industrial development of African countries, where the pace remains slow. With the existing pace of growth of industrial production, it is impossible to get free within a short period of time from economic backwardness and to liquidate the gap in the levels of development, as compared with the countries with high industrial development.

The low level of industrial production is expressed in the national incomes of African countries where only 14 per cent is used for industry, including 4 per cent for mining industry and 10 per cent for processing industries.

The share of industry in national income ranges from 24 per cent in Morocco and 19 per cent in the Democratic Republic of the Congo to 3 per cent in Nigeria.

During the last two years, no essential improvements have occurred in the mining industry. The yield of almost all minerals (except oil) has remained at the same level. As for the oil yield in Africa for 1962/1963, the annual gain amounted to about 60 per cent, most of which is owing to the development of oil industry.

The construction of steel plants has been undertaken in Algeria, Morocco and Nigeria. The developing economy of Africa annually increases the demand for ferrous metals and for products made from them.

Wide perspectives are open for the development of the chemical industry, in particular, in the field of fertilizer production. Many branches have successfully developed their own manufacture; agriculture, however, still maintains the colonial structure.

The development of the iron and steel industry forms the basis for the metalworking industries, which today meet only 5 per cent of the demand for metal products in Africa.

Among the African countries, it is expedient to study the development of the metalworking industries in Algeria, Cameroon, the Congo (Brazzaville), the Congo (Democratic Republic of), Ghana, Guinea, the Ivory Coast, Mali, Morocco, the Sudan, the United Arab Republic and the United Republic of Tanzania.

Algeria. The processing industry has had little development in Algeria. In the metallurgical and machine-building industries some small enterprises are operating, e.g., a tube mill, a car-building plant, two motor-car factories, an agricultural machinery factory and a tractor plant.

Analysis of the data on imports for the past three years shows that Algerian requirements of metalworking machine tools will be no less than 2,500 pieces for the period 1966–1970. It seems expedient to provide for the designing and construction of a machine-tool plant to satisfy the demands of the metalworking industries.

Cameroon. Processing branches of industry have been created in Cameroon. Among them are a factory for manufacturing aluminium sheets and billets, a plant for manufacturing sheet aluminium rolled from billets, a factory manufacturing plastic packages for agricultural products, a factory for manufacturing plastic, rubber and leather shoes, a perfume factory, meat and fish canneries and a knitted-goods factory. These branches of industry require the establishment of repair shops for manufacturing spare parts, which, in turn, will require the importation of machines.

Democratic Republic of the Congo. Metalworking industries are only slightly developed. According to Customs data for 1963, imports of metalworking machine tools amounted to 336 pieces with a value of £779,000. Because of the planned development of metalworking industries in the Democratic Republic of the Congo, metalworking machine tools will have to be imported.

Ghana. Different branches of industry have been created in Ghana: a nail-making factory; a tyre factory, a glass-works and a factory for the manufacture of polyethylene, production of steel and rolled steel, a house-building plant, a rolled-aluminium plant etc. The mechanization of agriculture and the extension of the country's industrialization make necessary the replenishment of metalworking machine stock.

It is expedient to provide for the development of the repair factory under design for manufacturing metal-working machine tools and to provide also for the importation of machines.

Guinea. The processing industry is only beginning its development in Guinea. The development of industrial production and the cultivation of farm crops in Guinea is facing a problem concerning the necessity of expanding the use of machine tools. In the past, Guinea has satisfied its needs for metalworking machine tools by imports, the purchases being small.

For the period 1966–1970, the Guinean demand for metalworking machine tools should increase slightly.

The Ivory Coast. There are metalworking industries producing, e.g., bicycles and radio receivers. This fact makes it necessary to keep metal-cutting equipment at the proper level and to select machine tools for stock.

On the basis of analysis of imports, the existing industrial enterprises of the Ivory Coast will require various metalworking machine tools in the period 1966–1970.

Mali. The construction of oil-mills, slaughter-houses, flour-mills, cotton-cleaning plants, a tobacco factory, a textile factory etc. is planned. Enterprises of the processing industry will be constructed, mainly through foreign assistance. At the current time in Mali, the restoration and expansion of the country's vehicle fleet is being undertaken.

According to the Customs data for 1963, Mali imported machine tools.

Measures taken by Mali with regard to agricultural techniques, as well as in the expansion of the power and transport base, will require increasing purchases of metalworking machines.

Morocco. The large-scale development of the Moroccan economy and industry needs its complex unity. The absence of national machine tool and metalworking industries impedes the development of the existing branches of industry and agriculture.

According to the Customs statistics for 1963, Morocco imported 696 metalworking machines having a value of $980,000. In the future, Morocco should continue to import machines.

It seems expedient to arrange the manufacture of turning, drilling, planing and milling machines in Morocco.

Sudan. The industry is developed very slightly. In the future, however, all types of manufacturing will be increased. In particular, the Sudan has great possibilities for the development of a mining industry.

Despite the low development of metalworking industries, the Sudan imports metalworking machines, which are required for domestic industry and repair establishments.

According to the Customs data for 1963, the Sudan imported 325 machines having a value of $443,000.

For the period 1966–1970, the Sudan will need to continue importing machines.

United Arab Republic. Much work is being done towards the development of national branches of the machine-building and metalworking industries.

In recent years, imports of machines have amounted to more than 700 pieces per annum.

Due to the considerable growth of the economy as a whole, as well as the growth of the machine-building and metalworking industries in the country, the demand for metalworking machines will be increased. For the period 1966–1970, it will be necessary for the United Arab Republic to import metalworking machines.

In order to develop the machine-building and metal-cutting industries in the United Arab Republic, it is necessary to create industries for manufacturing turning drilling and milling machines, shapers, etc.

United Republic of Tanzania. The development of metalworking industries is low. The industrial share of Tanganyika in the national product is small, about 10 per cent. In accordance with an agreement in Nairobi, Tanganyika has received orders for the further production and deliveries to Kenya and Uganda of some types of equipment (lorry assembling, radio-receiver assembling, manufacture of tyres and inner tubes for motor-cars). The economy of Zanzibar is only slightly developed. The working industry of Zanzibar is represented by small oil-mills, rice-cleaning mills etc. According to the statistics, the United Republic of Tanzania imports a small quantity of machine tools.

Assuming that measures planned by the country for industrialization will be realized and taking into account the level of industrial development already achieved in Tanganyika, it will be necessary to import machines during the period 1966–1970.

General conclusions and proposals for African countries

The basis of modern industry cannot be successfully developed in Africa without the creation of national machine-building industries.

The development of the iron and steel industry has provided the basis for metalworking industries, which might satisfy the demands of Africa for metal products.

...espite the delay in the development of machine tool a... metalworking industries in African countries, dur... the period 1966–1970, imports of metalworking ...chines will be required.

...urthermore, for the developing economy of the A...ican countries, it will be necessary to build factories f... manufacturing turning, drilling, milling, shaping, p...table and boring machines in Algeria, Morocco and th... United Arab Republic.

For those African countries in which the creation of national branches of machine-tool and metalworking industries is considered necessary, the development of casting, forging, die stamping, fastening and completing products, as well as of tool manufacturing, should be provided for.

Special attention should be drawn to the organization of training of national staffs in machine manufacturing and the planning of production processes.

B. *Asian countries*

Asia has both the greatest land area and the largest population—1,500 million—in the world. The density of population varies from four to 155 persons per square kilometre. It is of interest to review the development of economies in the metalworking industries of several Asian countries: Afghanistan, Burma, Cambodia, India, Indonesia, Iran, Iraq, Israel, Lebanon, Pakistan, the Philippines and Yemen.

Afghanistan. There are no special metalworking industries in Afghanistan. However, the developing economy in this country, including agriculture, will require the setting-up of repair and maintenance workshops to keep the existing branches of industry in a proper state.

If one assumes that the requirements for repair facilities and domestic industries will remain at the 1963 level, by the end of 1970 Afghanistan will be in need of various metalworking machines. As this country is not prepared for the organization of machine tool manufacturing, the demand for them should be covered by imports.

Burma. The growth of capital investments for the development of industrial and agricultural production is being projected in Burma. This will require the maintenance of the major means of production in a highly efficient condition and the replenishment or replacement of equipment necessary for repair shops. The development of the oil and ore industries will be accompanied by the introduction of various machines and equipment, which will naturally necessitate the systematic supply of these fields of industry with metalworking machines for manufacturing spare parts or replacements of used units ... parts.

Statistics show that the purchases of machines by this c...untry have not tended towards an increase. During the l...st three years, imports of machine tools totalled 261 ...ces.

As for the next five years, the country will not be able ... create its own base for manufacturing metalworking ...chines: requirements of these machines will be covered ... imports. For the period 1966–1970, Burmese industry will require mainly metalworking machines of the universal type.

Cambodia. Equipment at existing enterprises in Cambodia should be maintained at the proper level. Repair shops should be set up, and operating shops and individual facilities should be supplied with machine tools. It will, therefore, be necessary for Cambodia to import metal-cutting machine tools during the period 1966–1970.

India. The wide development of industries, particularly of machine-building and metalworking industries, is being planned in India. This requires systematic replenishment of the stock of metalworking machines. Indian planning organizations estimate the need in machine tools to amount to 250 million rupees, or about 50,000 machines, per annum. Estimates of the demands for the past five years, however, have not covered all the requirements of the Indian economy.

Thus, it is clear that it will be necessary to develop seriously an Indian machine-tool industry, as well as to maintain a large percentage of imports of such equipment.

Indonesia. Provision has been made for the development of the iron and steel industry, the organization of machine-building production, the manufacture of machines for agriculture, light industry and the fabrication of spare parts.

There is no national base for the manufacture of metalworking machine tools. The need for machine tools in Indonesia is being satisfied mainly by means of imports. Analysis of import data has shown that Indonesia does not expand its machine stock, restricting itself to imports of machine tools in small quantities, and does not arrange to have its own base for machine-tool manufacturing.

When comparing the economy of Indonesia with the economy of India and their similar trends in the development of industrialization, it is necessary to draw attention to the necessity of developing a national machine-tool industry for manufacturing turning, drilling and other machine tools.

To meet the requirements of the Indonesian economy, it will be necessary to import various metalworking machines during the period 1966–1970.

Iran. Development of power bases is expected in Iran. Furthermore, there are a number of motor-car assembly plants and other factories. Thus, it is necessary to expand the network of various repair units and to maintain working equipment on the proper scale.

Analysis of imports of metal-cutting machines shows that Iran will need to continue to import these machines.

Iraq. Further development of the oil industry, as well as of some individual branches of domestic industry, is being planned in Iraq.

Israel. Enterprises in the metalworking industry are being actively developed in Israel.

A prominent place in the country's industrial and economic development is given to the iron and steel, electrical-engineering, textile and chemical industries, as well as to other branches of industry.

According to the data of experts and to Customs statistics, replenishment of the stock of metalworking machines in Israel is covered by imports. In 1963, Israel imported 624 machine tools. Metalworking industrial branches in Israel will require universal metalworking machines of various designations.

Lebanon. General development of the economy of Lebanon is being planned. This will require the setting-up of repair shops and the maintenance of transport and domestic shops at the required level. Requirements during the period 1966–1970 will be handled by imports.

Pakistan. Considerable development of the economy and, particularly, of the metalworking industry, is being planned in Pakistan. The maintenance of existing industrial enterprises at the proper level will require the supplement of the stock of metalworking machines in the country. Analysis of statistical data shows that Pakistan imports 1,200–1,550 machine tools *per annum*. In the period 1966–1970, the importation of machine tools will be mainly continued. It seems to be expedient in Pakistan to provide the base for the development of national machine tool industry for the manufacture of turning, drilling, planing and other machine tools.

Philippines. There is no national machine-tool industry in the Philippines. The metalworking industries meet the demand for machine tools through imports. In the period 1966–1970, the needs of various branches of industry for metalworking machine tools will be satisfied by imports.

Yemen. There are semi-primitive workshops in Yemen, and development of the textile industry and energetic system is being planned. Improvements in agriculture will certainly require an intensification of the production of spare parts, which will, in turn, require the expansion of a repair shop system. These machine-tool requirements could normally be met in the coming five-year period by means of imports.

General conclusions and proposals for developing countries of Asia

The analysis of data on imports of metalworking machine tools into the above-mentioned Asian countries for the past three years shows their tendency towards the development of national machine-tool and metalworking industries in order to achieve economic independence.

To satisfy the growing needs of the metalworking industries in these twelve Asian countries alone, the purchase of imported machines will be required.

High-quality automatic machine tools and semi-automatic broaching and other machine tools are required for the developing economy of India.

A considerable quantity of marketable small and medium-size machine tools might be manufactured in India, Indonesia and Pakistan. For this purpose, it seems to be expedient to create additional establishments for manufacturing metalworking machine tools in these countries.

The development of national manufacture of metalworking machines and of other branches of the machine-tool industry in Asian countries will require an examination of the problems concerning the setting-up and expansion of enterprises for manufacturing castings, forgings, die stampings, fastening and other outfits, as well as tools and processing equipment.

In order to use more effectively the imported equipment delivered to the Asian countries and particularly to introduce modern methods of organization and planning of production, it will be of great importance to train national personnel, both workers and engineers, who could independently direct the development of metalworking branches and of the machine-building industry in their countries.

C. *Latin American countries*

In Latin America, there are twenty politically independent States. The total area of Latin America is over 20 million square kilometres, and the population is over 250 million.

The Latin American countries are still less developed economically, despite the growing capital investments, both foreign and domestic, in industry and agriculture.

The development of industry in Latin America, as a whole, is rather poor. While this continent has 7 per cent of the population of the free-enterprise economies, its share in the production of such countries is only 5 per cent.

More than one-third of the continent's population lives in Brazil, the largest country of the continent: about two-thirds live in Argentina, Brazil and Mexico. The Brazilian share in the gross production of all Latin American countries is 40 to 45 per cent and that of Argentina, Brazil, Chile and Mexico is about 75 per cent.

Latin America far exceeds the countries of Asia and Africa in the degree of its industrial development. The total amount of wage labour in Latin America is over 50 per cent of the population, which is one-third more than in Asia and twice as much as in Africa.

Beginning with the early 1950s, an over-balance has been served in the favour of industrial production in the correlation between the industry and agriculture.

During the first post-war years, 57 per cent of all gainfully employed persons were engaged in agriculture; in 1960, only 47 per cent were so employed. The percentage of urban population supporting themselves by income from industry, utilities and trade amounts to 50 per cent in Mexico, 61 per cent in Venezuela, 66 per cent in Chile, 68 per cent in Argentina and 71 per cent in Uruguay.

The post-war period of development of the leading countries of Latin America is characterized by the following general changes:

(*a*) The change in correlation between the extractive and processing branches of industry, in the latter's favour;

(*b*) The increasing share of new branches of production;

(*c*) The growing role of electrical engineering, machine building and the chemical industry;

(*d*) The development of specialization and co-operation in industry.

The industrialization process in the Latin American countries becomes manifest when one considers the rapid growth of the processing branches of industry. The sha[illegible]

, the processing industries in the gross national product four times as much as the share of mining branches. 1963, the entire industrial production of Latin America is estimated to amount to $30 million.

The branches of heavy industry are developing in Latin America more rapidly than are light industries. The production of light industries during the period 1953–1963 increased 1.5 times and the production of heavy industries increased twofold. The production of pig-iron and steel did not exceed 370,000 tons in 1937, being concentrated only in Brazil and Mexico. According to data of 1962, the production of pig-iron amounted to 2.9 million tons and that of steel, to 5.8 million tons. At the current time, there are iron and steel industries in Argentina, Brazil, El Salvador, Chile, Colombia, Mexico, Peru, Uruguay and Venezuela. The number of steel plants in Latin America, as a whole, was forty-four in 1962, the total investments in this branch of industry exceeding $1,000 million.

The countries of Latin America are producing domestic appliances, radio receivers, television receivers, sewing-machines, electric generators, boilers for industrial use, hydraulic presses, lifting and handling equipment, road-building machines, railway cars, motor-cars and equipment for the textile, food and pulp and paper industries. In 1958, in Brazil alone, there were 4,362 machine-building plants employing 273,600 people.

The motor-car industry has become comparatively well developed. Brazil has completely stopped importing motor-cars. The motor-car industry of Argentina produces twenty-eight models of passenger motor-cars and nineteen models of lorries. The motor-car industry is growing in Colombia, Mexico, Peru, Uruguay and Venezuela.

The progress and changes in the structure of the processing industries in the Latin American countries are connected with the appearance and expansion of the machine-tool industry.

Of great significance for technical progress is the growing role of the chemical industry. Even such rapidly developing branches of industry as iron and steel, and metalworking are left behind by the growth rates of the chemical industry. Chemical products account for 12 per cent of the entire production of Latin America; of that percentage, one-third is produced by Brazil and one-fourth by Argentina.

The development of heavy industries (iron and steel, machine building, motor-cars, oil and chemicals, shipbuilding) has caused the noticeable growth in number and significance of enterprises with more than 500, or more than 1,000 employees. In Brazil, by the beginning of 1961 there were 170 enterprises which employed over 1,000 people. They accounted only for 0.15 per cent of the total number of industrial enterprises, but concentrated 17.5 per cent of all persons working in industry. Brazil now has over fifty enterprises in the steel-melting industry.

In 1959, eleven motor-car plants were employing a total of 70,000 people, and in 1961 the number of employees exceeded 100,000. The high concentration of production is characteristic of Chile; it involves all sides of the economy. In Chile, there are eleven groups which exercise control over two-thirds of the capital of all joint stock companies of the country.

The growth of industry in Latin America has increased the number of the working class and has led to concentration of labour at the large plants. More than two-fifths of proletariat (over 13 million people) are workers engaged in industry, construction and transport.

In 1960 the Latin American countries purchased over 5 per cent of the machine tools on the world market. Argentina and Brazil were the main consumers and, partially, local manufacturers of machine tools. In view of the current demand, the consumption of machine tools for the industrial development of Latin America will increase to £94 million in 1970.

Of the Latin American countries, the development of metalworking industries should be considered in Argentina, Bolivia, Brazil, Chile, Colombia, Ecuador, Mexico, Peru, Uruguay and Venezuela.

Argentina. The industrial development of Argentina is, to a considerable degree, associated with the intensive expansion of foreign capital and of that of the United States of America, in particular.

According to the Customs data for 1963, Argentina imported 3,331 machine tools for $25,551,000.

The analysis of import deliveries of machine tools testifies to the fact that the United States of America supplies a considerable number of machine tools, their cost being much higher than the machine tools supplied by the competing countries. The machine-building industry being developed in Argentina covers a short nomenclature of ordinary kinds of machine tools.

A great number of machine tools will have to be imported into Argentina within the next five years.

Furthermore, the machine-building industry of Argentina can fabricate the machine tools for its own needs. Since the demand for machine tools in the country will increase, it is expedient to provide for further development of the national machine-building industry.

Bolivia. The processing industry of Bolivia accounts for 12 per cent of the national production; less than 8 per cent of the gainfully employed population is working in it. A considerable part of the national consumption of the most significant products is imported.

Bolivia accounts for 10 per cent of the world tin production. Under one of the plans, mining of zinc and iron-ore is projected in Bolivia.

The processing industries of the country are practically not developing. The small requirement of Bolivia for metalworking machines is mainly met by imports from Argentina and Brazil, and partially from other free enterprise economies. For the period from 1966 to 1970 various imported machine tools will be required for Bolivia.

Brazil. This is one of the most developed industrial countries of Latin America. It holds first place in the volume of industrial production among the Latin American countries. The old traditional branches (food and textile industries) have the maximum share in the processing industries of Brazil, as in most other Latin American countries.

During recent years, an increase was observed in the share of the basic branches of heavy industry, i.e., the iron and steel, machine-building and chemical industries.

It is necessary to note the development of machine tools fabrication in Brazil. However, such development concerns only the production of simple machine tools for small metalworking establishments for repair workshops of textile and food industries. As for compound machine tools, Brazil imports them from the Federal Republic of Germany, Sweden and the United States of America.

The changes in the structure of various processing industries of Brazil are associated with the setting-up and further development of the machine-tool industry. The development of a machine-tool industry in Brazil is a result of its being supported by some firms from the Federal Republic of Germany and Sweden, which are establishing the machine tool plants in that country, where a number of their own machine-tool companies have been established.

Analysis of statistical data indicates that Brazil will require a considerable number of machine tools during the period 1966–1970.

The Brazilian machine-tool industry is able partially to provide for the national metalworking industries and to allot a portion of the tools to be exported to the other countries of Latin America and to Africa.

To meet the growing demand for machine tools, it appears to be expedient to set up in Brazil additional establishments for manufacturing metalworking tools.

Chile. One of the developed countries of Latin America is Chile. The most developed branch of Chilean economy is the mining industry, mainly the mining of copper, iron-ore and saltpetre.

The share of processing industries in the gross national output accounts for nearly 25 per cent. At the current time, there are about forty branches, but the majority of them are poorly developed. The iron and steel industry and metalworking industries are just beginning.

The machine-building industry is poorly developed. There is no machine-tool industry, and the chemical industry is practically unavailable. Slight development is observed in motor-car assembly and in the pulp and paper industry.

The economic development programme provides for an increase of 76.2 per cent in the output of processing industries.

During recent years, metalworking machine tools valued at £537,000 have been imported into Chile. The greater part of these machines was imported from the United States of America (45 per cent) and from the Federal Republic of Germany (38 per cent). Chile purchased drilling, boring, grinding, turning, milling, planing, gear-milling and other machines.

According to Customs data for 1963, Chile imported 214 machine tools valued at $399,000. Requirements of the growing economy of Chile will be met by imports during the period 1966–1970.

Colombia. Substantial capital investments are being allotted for the processing industries in Colombia. To develop the machine-building industry, it is planned to establish a machine-building plant in Bucaromang. The plant will produce parts for railway equipment and for agricultural machinery. The construction of a tractor and diesel-engine plant is under design. A number of motor-car assembly plants are planned. During recent years one-third of imports into Bolivia came from the United States of America. Imported metalworking machine tools are mainly those for drilling, boring, grinding, turning, milling, planing and gear milling.

According to the Customs data for 1963, Colombia imported 404 machine tools at a cost of $530,000. In the period 1966–1970, the Colombia economy will be in need of imported metalworking machine tools.

Ecuador. The development of industry is poor in Ecuador. Its share in the gross output of the country comes to 18 per cent, with 15.8 per cent of it deriving from processing industries.

Processing industries are mainly represented by small industrial establishments which are chiefly engaged in processing the local agricultural raw materials and in manufacturing consumer goods.

During recent years, growth has been observed in the branches producing synthetic materials.

According to import data for 1963, the Federal Republic of Germany was supplier of metalworking machine tools to Ecuador. During the period 1961–1963, it supplied machine-tool equipment amounting to $56,900; the shipments were mainly small-size equipment.

Machine-tool requirements in 1966–1970 will be met by imports.

Mexico. The processing industries are first in the manufacturing sector of the national product. Metalworking, fabrication of metal products and the chemical and rubber industries in Mexico account for 58 to 95 per cent of the total volume of products manufactured.

The rapidly growing industrial production imposes a high level of demand for metalworking machine tools. At the current time, provision is being made for the development of the machine-tool industry in Mexico. During recent years, 66 per cent of the imported machine tools came from the United States of America.

The imported metalworking machines are mainly drilling, boring, grinding, turning, milling, planing, gear milling and other machine tools.

According to the Customs data for 1963, machine tools imported into Mexico totalled 2,435 pieces.

The metalworking industries in Mexico will continue to require imported metalworking machine tools.

It seems to be necessary to provide for the designing and establishment of a national branch of the machine-tool industry in Mexico, in order to produce machine tools for different purposes.

Peru. The mining and non-ferrous industry is greatly developed in Peru. Repair workshops account for the greater part of the metalworking industries.

During recent years, metalworking machine tools valued at £344,000 have been imported into Peru. At the current time, Peru is developing its light industries, which makes it necessary to import machine tools for equipping new factories.

The import list of metalworking machine tools includes

...erent types of drilling, boring, grinding, turning, mill... planing, gear-milling and other machine tools.

According to Customs data for 1963, Peru imported ... machine tools at a cost of $721,000. The Peruvian ...irements for machine tools during the period 1966 ... it will be mainly met by imports.

Uruguay. A small quantity of machine-tools is used ... Uruguay. In 1960, imports of metalworking machine ...s amounted to £94,000. The machine tools were ...nly from the Federal Republic of Germany, Italy and ... United States of America.

The growth of the motor-car industry will be accompanied by an increased demand for machine tools. The *Customs Statistics Journal* for 1963 shows that Uruguay imported 110 machine tools from the Federal Republic of Germany for $145,000. Approximately the same level of requirement in machine tools will prevail in Uruguay during the period 1966–1970.

Venezuela. Processing industries account for 17 per cent of the national production of Venezuela. Metalworking plants are being built in Carabobo and Lara. In 1958, the steel plant was put into operation with a planned production of 650,000 tons of steel.

During recent years, imports of machine tools have amounted to £940,000, with one third of the imports coming from the Federal Republic of Germany, the United Kingdom of Great Britain and Northern Ireland, and the United States of America. With the expansion of production, the demand for machine tools will be met by imports.

General conclusions and proposals for Latin American countries

The industrial development of the Latin American countries far exceeds that of African and Asian countries.

The process of industrialization in the Latin American countries is accompanied by rapid growth in the processing branches. The development of heavy industry, e.g. motor-car production and machine tool manufacture, will require the importation of a considerable number of machine tools.

In addition, the expansion of national branches of the machine-tool industry will be required in Argentina, Brazil and Mexico.

The creation and development of national machine-tool industries in the Latin American countries will also require that particular attention should be given to the training of national cadres of workers, engineers and other employees who could master the minimum technical knowledge in their practical work of creating machine tools and in the field of organization and planning of production for this branch of machine building.

It will be necessary to provide for the setting-up of specialized plants for manufacturing castings, forgings, stampings and other completing parts.

I. DEVELOPMENT OF NATIONAL PRODUCTION OF METALWORKING MACHINE TOOLS AND EFFICIENT SELECTION OF MACHINE STOCK

The foregoing analysis of the economic situation in selected countries of Africa, Asia and Latin America shows that those countries are working on the development of branches of national production which can provide for them equality in international economic relations.

The weakest point in the countries discussed is the absence of an all-round association between the development of the raw material and processing branches of industry.

Support of the principle of equality in international economic relations is possible through the availability of an industrial base, particularly the expansion of metalworking industries, the setting-up of manufacture of metalworking machine tools and the correct selection of machines for the machine-tool stock in individual developing countries. The development of industrialization in each country is closely connected with the production of machine tools. In this connexion, it should be particularly noted that the machine tool-industry is the key branch of machine building, its basis in manufacturing up-to-date machinery, equipment, tools and all other products for industry, transport and agriculture.

Metalworking machine tools are machines required for the creation of various machines, equipment and modern technical means in all fields of economy of a country which has begun to industrialize.

According to the established trade ties, the developing countries of Africa, Asia and Latin America continue to meet their requirements of machine tools, which are insignificant for the time being, by imports.

The requirement of the metalworking industries of these countries accounts for less than 10 per cent of the world requirements of machine tools.

When embarking on the path of independent economic and industrial development, the developing countries are faced with the immediate tasks of setting up national production of machine tools, correctly selecting the types of machine tools to be imported, providing proper maintenance and keeping the stock of machines at the level of the more industrialized countries.

The index for the level of the industrial development of each country is the ratio of the manufacturing of machinery and other equipment to the total scope of manufacturing production in the country. It should be noted that in the most highly industrialized countries, the share of the products of the metalworking industries in the total fabricated production amounts to 22 to 40 per cent, while in the developing countries, it is only 1 to 5 per cent. Therefore, the degree of industrialization and the technological progress are closely connected with the level of the national machine-tool industry, as it is the core of machine-building production.

A. *Importance of additional development and specialization of metalworking industries in developing countries*

To establish national machine-tool industries in the developing countries of Africa, Asia and Latin America, it is necessary to study the specific features of their economies and, particularly, to determine the scope of production and fix the most significant and required types and sizes of machine tools. The great significance in the development of the machine-tool industry is also confirmed by the fact that ten years ago no more than fifteen countries in the world were engaged in producing machine tools, while at the present time, the number of these countries is doubled.

In 1964, more than 50 per cent of the total world production of metalworking machine tools were fabricated in the Federal Republic of Germany, the Union of Soviet Socialist Republics and the United States of America, and the ten largest countries of the world manufactured 90 per cent of world production, with the remaining 10 per cent being produced by twenty other countries.

It is of interest to note that some developing countries had begun to produce metalworking machine tools. However, the share of this production in world production amounted to only 3.6 per cent. Of this amount, 0.6 per cent was produced by India, another 0.6 per cent by Argentina and slightly more than 0.5 per cent by Brazil.

Another important index of the level of industrial development is the *per capita* production of machine tools. According to United Nations data, machine-tool production *per capita* amounted to: $22.40 in Switzerland, $15.20 in the Federal Republic of Germany, $10.30 in Czechoslovakia, $9.70 in Eastern Germany, $7.10 in the United Kingdom, $4.60 in the United States of America, $2.90 in Japan, $1.20 in Argentina, $0.31 in Brazil, and under $0.06 in India.

In the machine-tool industry there are many standard types and sizes which it is not always profitable to manufacture in one country. It is the branch of machine-building in which there is a great field of action in the organization of the most efficient exchange between all countries of the world. Thus, for example, in the period 1955–1960, exports of machine tools accounted for 7.16 per cent of total world production, while manufactures increased by only 35.1 per cent.

In 1960, the exportation of metalworking machine tools involved more than sixty countries of the world, and nearly 50 per cent of the volume was used by industrially developed countries.

Imports of machine tools into the developing countries in 1960 amounted to 27 per cent of total world exports. Of this share, Brazil purchased 4.3 per cent, Argentina, 3.9 per cent, India, 3.9 per cent, and Mexico, 1.5 per cent.

Due to the poor development of industry in the countries of Africa, Asia, and Latin America, the requirement of machine tools in these countries still remains insignificant. The principal consumers of machine tools are still thirty-four industrially developed countries which cover 94 per cent of the world requirement, with the share of the developing countries accounting for only 7 per cent. Ten principal consumers, who are also the principal manufacturers, utilize 80 per cent of the world requirement of machine tools. Thus, for example, for the last five years the consumption of machine tools in the industrially developed countries of Europe was sixteen times as much as that in the countries of Asia during the same period.

The average annual *per capita* consumption of metalworking machine tools in the period 1958–1962 amounted to: $4.64 in twelve free-enterprise economies of Euro[illegible], $2.96 in North America, $2.83 in Eastern Euro[illegible], $0.68 in Latin America, $0.27 in Asia and $0.1 in Afri[illegible]. The world average annual *per capita* was $1.20 during those years.

The developing countries do not occupy any significant place in the world machine-tool market. Exports of machine tools by these countries amounts to 0.03 per cent of total world exports. The annual imports of machine tools into the developing countries is negligible compared with the industrially developed countries. For example, imports were equal to less than one-seventh to Latin America, one-ninth to Asia and one-twenty-seventh to Africa.

While carrying out industrialization in the developing countries, particularly in its initial stage, it is equally important — along with completing the stock of metalworking machines by importation and the setting-up of the national production of machine tools — to organize efficiently co-operation in the metalworking industries, for which purpose it is necessary to provide for the establishment of certain shops or plants which are capable of fabricating the products and parts for various enterprises.

It appears to be very important to organize properly the specialization in metalworking industries, particularly in manufacturing the normalized fastenings, tools, forgings, castings and die stampings.

The principal thing for each developing country of Africa, Asia and Latin America is the correct organization of training for the national cadres of workers, designers and technologists.

These, as well as other issues, should be given proper care in the developing countries in the process of creating their national machine tool and metalworking branches of industry.

It seems to be expedient, beginning with 1966, to hold international seminars at which there can be discussions of the practical issues concerning the development of national machine-tool industries in the developing countries. It would be desirable to hold seminars in Argentina or Brazil for the countries of Latin America, in India for the Asian countries and in the United Arab Republic for the countries of Africa.

The most efficient form of assistance in the development of metalworking industries in the countries of Africa, Asia, and Latin America could be the completion of the number of branches in those countries through the provision of machine tools which should be removed from production in the industrially developed countries due to changes in the technological processes. Such machine tools could be supplied to the developing countries on the terms of payment which were most beneficial for them.

The planned development of national enterprises for manufacturing metalworking machines, with a mutual understanding, could be accomplished in the case of wide co-operation between individual countries, taking into consideration the community interests and location. Thus, for example, in Latin America, the setting-up of enterprises for manufacturing machine tools could be realized

... the basis of broad co-operation and proper specialization of the production. Similar problems of mutual co-ordination for the creation of national machine-tool industries in certain countries of these continents could be solved by the African and Asian countries.

The Soviet Union is going to continue to render economic and technical assistance to the developing countries in their independent economic and political development, particularly in creating metal-working industries and in setting up national machine-building and machine-tool industries.

The main factor affecting the national economy of all developing countries is the preparation of plans, that is, the programme of economic development. The method of planning is all-embracing in the State sector of the economy of developing countries.

In the more industrialized of the developing countries — for example, in India — it seems to be important also to establish certain ties not only with the State sector, but also with the private one.

The first measure to be taken with regard to setting up the machine-tool industry should be the designing and establishment of plants and factories for the manufacture of machine tools, the broader issuing of licences and the conclusion of technical-aid agreements.

When organizing technical assistance, it seems to be necessary to provide for the supply of certain parts and units for machine tools which are produced in accordance with licences.

In the next five to seven years, of great importance to India is the increased help in the growth of the machine-building and machine-tool industries.

During the next five years in the United Arab Republic, it is also necessary to direct efforts towards growth in the machine-building industry and towards the creation of a national machine-tool industry.

8. *Efficient selection of machine tools an aid to rapid industrialization and better production*

The analysis of the economic situation in the countries of Africa, Asia, and Latin America indicates that the level of development of metalworking industries in these countries still remains low. However, there are quite great potentialities for creating machine-building industries in these countries.

During the last three or four years, the countries of Africa, Asia and Latin America have been supplied with multiple types of drilling, turning, grinding, milling, boring, planing and shaping, cutting-off and other machines.

According to the *Customs Statistics Journal*, 40,800 various machine tools were supplied in these countries in 19.., the value of the tools was $188,408,000.

In connexion with the level achieved and the requirements of metalworking industries, the urgent problem in the planned development of the economy in the developing countries is the selection and fixing of the types of metalworking machine tools which are to be imported and those which are to be produced domestically.

Recommendations with regard to imports of metalworking machine tools for the countries of Africa, Asia and Latin America set forth the approximate data on the eight most important types, including drilling, boring, grinding, turning, milling, planing and shaping, gear-cutting and cutting-off-machines. Brief specifications are given for these types of machine tools.

1. *Drilling machines*

In the technology of metal-working industry of the developing countries, a considerable number of drilling machines will be required. This group includes bench drilling machines with a maximum drilling diameter of 1.5 to 12 mm, single-spindle upright drilling machines with a maximum drilling diameter of 18 to 75 mm and radial drilling machines with a maximum drilling diameter of 25 to 50 mm.

The demand for ordinary drilling machines can be increased or reduced, depending upon the nature of production (use of automatic units or automatic lines). The share of drilling machines is considerable in the general technological process in all countries of the world.

2. *Boring machines*

Boring machines compete with drilling machines in technological purposes, providing the finer machining of holes, and partially, with milling machines for the machining of planes. According to demand data in 1960, boring machines accounted for 6.2 to 11.5 per cent of the total number of exported machines. In the world trade, the share of the boring machines amounted to 7.1 per cent of all purchases in 1951, 8.8 per cent in 1954 and 9.4 per cent in 1958. The share of boring machines in the technological process in metalworking industries was 4 per cent.

In the developing countries which already have or plan to establish metalworking industries, maximum use will be made of boring machines with a spindle diameter of 60 to 111 mm and portable diamond and carbide tool-boring machines with a diameter of 125 mm for cylinder boring.

3. *Grinding machines*

Grinding machines include a universal plain grinder with a maximum diameter of workpiece not exceeding 500 mm, an internal grinder with maximum diameter of workpiece not exceeding 100 mm, a flat-surface grinder with table size 300 × 1000 mm, sharpening grinders of the universal type, tough grinders with a wheel diameter of 100 to 500 mm, honing machines with a honing diameter of 20 to 200 mm, finishing grinders with a disc diameter of 200 to 450 mm, polishing grinders with a wheel diameter of 300 to 400 mm etc.

According to experts' opinion, by 1970 the share of grinding machines on the market will account for over 11 per cent of the total number of machines purchased. The share of grinding machines in the general scope of deliveries is expected to be increased, having in view the advanced technique of abrasive machining of parts in the development of new technological processes of production.

4. *Turning lathes*

Turning lathes remains one of the important groups in the technological complex of metalworking industries, and up to 1970 they will account for a great share in the purchasing structure for machine tools. The metalworking industries of developing countries will mainly require lathes with a workpiece diameter not exceeding 400 mm, fully automatic thread-cutting lathes for turning wood-screws of 1.5 to 10 mm diameter, engine, stud and nut lathes. Turret lathes with a bar diameter of 12 to 60 mm and chucking lathes with a workpiece diameter of 500 to 800 mm may be required. The demand for lathes in 1960 accounted for 19.5 per cent to 27 per cent of the total requirement of all machines. In 1961, the United Kingdom exported 27.1 per cent of the lathes, including 10 per cent of the turret lathes, 3.3 per cent of the thread-cutting and screw-cutting lathes, and 13.8 per cent of the other lathes of the total export of machine tools of this country.

The Indian machine-building industry will require large, heavy lathes with a workpiece diameter not exceeding 2,500 mm, as well as others.

5. *Milling machines*

Milling machines account for a great share in the technological stock of metalworking enterprises. The demand for milling machines still remains low in spite of favourable market fluctuations. Thus, in 1951 milling machines accounted for 11.8 per cent of total purchases, in 1954 this share was 15.4 per cent and in 1960 it was 10.3 per cent. Purchases of milling machines in 1967 and 1970 are expected to be 9.9 and 9.5 per cent, respectively, of total purchases. Some changes may take place due to the broad development of broaching and outfit milling machines. Of the total demand for machine tools in 1960, the demand for milling machines amounted to 11.8 per cent in the United States of America, 10.3 per cent in the United Kingdom and 8.3 per cent in the Federal Republic of Germany.

This level of demand with slight changes may remain in the developing countries of Africa, Asia and Latin America. To provide for the metalworking branches of these countries, it will be necessary to have horizontal milling machines with tables which are 250 × 1,000 mm and 400 × 1,600 mm in size; vertical milling machines, universal machines, single-upright horizontal plano-milling machines with tables which are 800 × 2,000 mm, engraving machines with tables 200 × 320 mm, bracket milling machines and others.

6. *Gear-working machines*

Gear-working machines are used in all branches of machine building, but their share is, comparatively speaking, not large. It is necessary to bear in mind that the demand for gear-working machines may fluctuate, depending upon the mastering of new technological processes of gear rolling or die stamping instead of milling or planing. In 1960, the share of gear-working machines in total imports of machines amounted to 4.1 per cent in the Federal Republic of Germany, 3 per cent in the United Kingdom and 2.7 per cent in the United States of America.

The developing metalworking industries in the countri of Africa, Asia and Latin America will require, amo others, gear-milling machines for cylinder gears who diameter does not exceed 800 mm, gear-slotting machin for cylinder gears not exceeding 800 mm in diamete gear-shaping machines for straight-bevel gears with diameter not exceeding 800 mm; and gear-tooth-char fering machines for cylinder gears with a diameter n exceeding 800 mm.

7. *Shaping, planing and slotting machines*

Shaping, planing and slotting machines have only small place in the total technological stock of the meta working industries. However, such machines are require for machine-building industries, and they will be re quired particularly in the developing countries. In 196 purchases of these machines amounted to 3.5 per cent total purchases by the Federal Republic of Germany and to 2.7 per cent of the total for the United Kingdom. The share of the planing and slotting machines in the total stock of metalworking machines comes to 2.3 per cent. The recommended machine tools in this group are shapers with piston stroke not exceeding 700 mm, open-side planers having tables 1,000 × 3,000 mm in size, slotting machines with maximum ram travel of 100 to 500 mm and others.

8. *Cutting-off machines*

Cutting-off machines are required in the metalworking industries for the cutting-off of metal. It is expected that the developing countries will be in need of hack-sawing machines and cutting-off millers with saw diameters of 350 to 1,000 mm.

C. *Machine-tool requirements of India*

To meet the requirements of the Indian market it is recommended to provide the following:

(a) *Full and semi-automatic lathes* for turning wood-screws with diameters of 1.5 to 10 mm and fully automatic bar lathes for bars with maximum diameters of 25 mm, 40 mm.

(b) *Broaching machines*, both horizontal and vertical, with loads of 5 to 40 tons;

(c) *Turret lathes* for bar diameters of 12 to 800 mm and chucking lathes with workpiece diameters of 500 to 630 mm.

(d) *Screw-milling machines* for short male and female screws with diameters of 100 to 140 mm and 200 mm, and workpiece lengths of 500 to 900 mm. For milling long screws with diameters of 100 to 110 mm, the distance between centres should be 500 to 1,500 mm.

Proceeding from the mean level of metalwor g industries in the developing countries, the Soviet Unio is capable of organizing, in the form of assistance y drawing up the corresponding agreements, the delive s of 112 standard types and dimensions of machine-w ing machines to these countries during the period 19 1970, to meet various technological requirements (e annex to this report). Furthermore, the Soviet Union n

to supply other machine tools to fill orders of individual
untries.

3. PROJECTED DEVELOPMENT OF METALWORKING INDUSTRIES IN DEVELOPING COUNTRIES. INCREASED DEMAND FOR MACHINE TOOLS

According to experts' estimations, the demand for etalworking machines will amount to £1,400 million 1967, excluding the centrally-planned economies untries, i.e. 79 per cent above the 1960 level. This increase takes into account the planned expansion of metalworking industries in all countries of the world.

According to the same estimate, in order to satisfy the owing market for machine tools in the metalworking industries, it will be necessary to increase imports of machine tools to £370 million in 1967, as compared with £38 million in 1960. By 1970, the total demand of the ee-enterprise economies will exceed £1,700 million, i.e. it will be twofold, compared with the level of 1960, and imports will amount to over £400 million.

The rapid development of the metalworking branches of industry is based on the fact that during the twelve-year period from 1948 to 1960 the annual rate of growth in the manufacturing of metal products averaged 7.9 per cent in the free-enterprise economies.

ments and imports will amount to 4 per cent of the world imports. It is estimated that by 1970 the requirements will increase fourfold, as compared with the imports at the current time. Argentine and Brazil will also become large consumers of machine tools in the coming years, according to the same experts' estimation.

South and Central America purchased more than 5 per cent of new machine tools on the world market in 1960. The requirements of Latin American countries will increase to £73 million in 1967 and to £94 million in 1970, assuming stability of the demand for machine tools.

The experts noted that large regions of Africa, the Middle East and South-Eastern Asia purchase a small volume of machine tools, and their share will remain insignificant up to 1970.

Since Argentina, Brazil and India are planning to develop their domestic machine-tool industries, an opinion has been expressed that these countries may reduce their imports of machine tools; it is impossible to agree with this opinion.

The machine-tool requirements of the countries of Africa, Asia and Latin America for the period from 1967 to 1970 is estimated by the experts to be £733 million, i.e., over 500,000 machine tools, with imports amounting to £277 million, i.e. over 205,000 machine tools, as may be seen from the following data:

MACHINE-TOOL REQUIREMENTS AND IMPORTS BY DEVELOPING COUNTRIES, 1967 AND 1970

Description of continents	1967 Requirement	1967 Imports	1970 Requirement	1970 Imports
Latin America	73.0 / 68.8	46.0 / 43.0	94.0 / 88.8	53.0 / 50.0
Far East	208.0 / 74.6	59.0 / 21.2	270.0 / 96.9	60.0 / 21.6
Africa[a]	8.0 / 15.3	8.0 / 15.3	8.0 / 15.3	8.0 / 15.3
Middle East	6.0 / 6.2	6.0 / 6.2	7.0 / 7.2	7.0 / 7.2
India	44.0 / 39.2	15.0 / 12.9	65.0 / 58.8	15.0 / 0.219
Total for Africa, Asia and Latin America	339.0 / 204.1	134.0 / 98.6	444.0 / 257.0	143.0 / 107.0

Note: The numerator [illegible] millions of sterling pounds, the denominator [illegible] ousands [illegible] pieces of machine tools.

[a] Excluding the United Arab Republic.

India currently imports a great number of machine [illegible]ls to develop its domestic machine-building and [illegible]chine-tool industries. In 1960, imports of machine [illegible]ls into India amounted to £12.2 million (5.1 per cent world imports), the requirement being £16.4 million [illegible] per cent of world consumption). By 1967, the [illegible]chine-tool requirements of various metalworking [illegible]lustries will make up 3 per cent of the world require-

According to the experts' data, the world production of metalworking machines and forging and press machinery increased from $4,300 million to $4,700 million, i.e. by 6 per cent, during the last two years.

Excluding 20 per cent of the cost of forge and press machinery from these amounts, the production of machine tools in all twenty-seven countries engaged in the manufacture of machine tools accounted for $3,540 million in 1963 and $3,760 million in 1964—an increase of 5.6 per cent. The mean cost of one machine tool in the United States of America increased from $4,090 to $5,770 in 1963, as compared with 1962, i.e., it became 1.4 times as much: and it increased from $5,770 to $5,870 in 1964, as compared with 1963, i.e., a rise of 1.7 per cent.

The analysis of mean prices shows that in 1963 the mean world price of one machine tool was $5,902: being $5,560 in the countries of the North America, i.e., 6.1 per cent cheaper; $6,387 in the European free-enterprise economies, i.e., 8.1 per cent more expensive; $12,904 in the European centrally planned economies, i.e., 2.2 times as much; $4,240 in the countries of Latin America, i.e., 28 per cent cheaper; $3,880 in Asia, i.e., 35 per cent cheaper; $2,090 in Africa, i.e., 60 per cent cheaper; $11,139 in the countries of the Far East, i.e., 1.9 times more expensive; and $17,290 in Japan, i.e., almost three times as much.

Such correlation of prices testifies to the fact that the developing countries of Africa, Asia and Latin America were supplied with more light-weight and less complicated machine tools. Thus, for example, the mean weight of lathes exported from the United States of America in 1963 was 1.37 tons, with the mean world weight of machine tool of this group being 2.57 tons.

Taking into consideration the development of techniques and assuming $6,000 as the highest world mean price of one machine tool, the world manufacture of metalworking machine tools amounts to 590,000 pieces in 1963 and 623,000 pieces in 1964, the increase being 6.6 per cent. It should be noted that the USSR and the United States of America manufacture more than 50 per cent, by quantity, of the total number produced in the world. Assuming the mean annual rate of growth to be 5 per cent, the world production of metalworking machine tools will increase to 750,000–780,000 pieces in 1970.

During the period 1966–1970, purchases of machine tools for the developing economies and metalworking branches of industry in the countries of Africa, Asia and Latin America will account for not more than 40 per cent of the current world annual production, and it will account for a little more than 5 per cent of the world production during that five years, as the preliminary data read.

IV. Major problems of developing countries in meeting machine-tool requirements, establishing plants and training personnel

To provide the developing countries of Africa, Asia and Latin America with metalworking machine tools, it appears to be expedient for those countries which are members of the United Nations and which produce metalworking machine tools to consider the preliminary calculation of machine-tool requirements and to find the ways and means for their provision.

Of particular importance is the problem of training staffs of engineers and workers for the national machine-tool industries in some developing countries.

In this connexion, in order to use most effectively the machine-tool equipment imported for work in the developing countries of Africa, Asia and Latin America the Soviet Union would pledge itself to train the national staffs of workers in the efficient control of machine tools and in the correct technical service, both on the job and at the specially arranged training courses and seminars, depending upon local conditions.

Lathes and drilling, milling, planing and cutting-off machines, as well as some boring, grinding, fully automatic, broaching, large-size and heavy general-purpose machine tools could be supplied by the Soviet Union to the countries of Africa, Asia and Latin America during the period 1966–1970.

In connexion with the level achieved, the requirements of the metalworking industry and the outlined increase in national production in the developing countries of Africa, Asia and Latin America the necessity arises to create and develop machine-tool building industries in the ten most highly industrialized countries of these continents.

Economic and technical assistance should be rendered to the developing countries in designing, construction, training of personnel and procurement of technological-process equipment. Recommendations on certain types of machine tools can be considered during the practical co-ordination of design assignments for the machine-tool works.

When considering the issues concerning the possibility of development of national branches of the metalworking industry and of the machine-tool branch, in particular, it is necessary to envisage the creation of foundries, the manufacture of forgings and the provision of electrical equipment, bearings and other completing products.

The establishment of facilities to fabricate grinding machines for general purposes is closely connected with the necessity of creating a national industry for the production of abrasive materials.

No machine-tool production is available in the metalworking branches of industry being set up in the developing countries. The available stock of metalworking machines mainly comprises cutting and measuring tools, and even simple auxiliary technological-process equipment is imported from abroad.

Since the planned development of metalworking industries is impossible without tool production in the country, it is considered extremely advisable to provide for the design and construction in these countries of tool-making plants for fabricating cutting and measuring tools, lathe chuckings, all types of cutters, keys, jaw vices, files, centres and other running auxiliary tools.

For the composite development of metalworking industries, it is necessary to provide uncomplicated forging and press equipment—mechanical presses with pressures up to 100 tons, punch presses, plate shears and hammers with weight of drop parts up to 100 kg—as well as woodworking equipment in countries which are rich in forests and woods.

According to the experts' opinion, the distribution of the required tools by specific gravity of machine tools is characterized by the following percentage:

a) Cutting tools, 40 per cent;
b) Chuckings, jibs and grips, 22 per cent;
c) Gauges and other measuring tools, 8 per cent;
d) Other tools, 30 per cent.

The requirements for such tools are closely connected with the stock of operating metalworking machine tools. To provide the unique technological processes used in metalworking industries it will be necessary to purchase tools.

At the current time, the matter of great importance is the extension of the economic co-operation of the Soviet Union with the developing countries by means of strengthening the trade relations and rendering to them the economic and technical assistance needed in consolidating their economies and creating national industries, establishing scientific research and design offices, as well as in training specialists and skilled workers.

Annex

Various types of metalworking machines produced in the Union of Soviet Socialist Republics

Sl. No. — *Description of machine tools and brief specifications*

Turning lathes

1. Screw-cutting lathe: diameter of workpiece, 250 mm; distance between centres, 500 mm
2. Screw-cutting lathe: diameter of workpiece, 320 mm; distance between centres, 710 mm
3. Screw-cutting lathe: diameter of workpiece, 400 mm; distance between centres, 710, 1,000 and 1,400 mm
4. Screw-cutting lathe: diameter of workpiece, 500 mm; distance between centres, 1,000, 1,400, 2,000 mm
5. Screw-cutting lathe: diameter of workpiece, 400 mm; distance between centres, 900, 1,400 mm
6. Screw-cutting lathe: diameter of workpiece, 630 mm; distance between centres, 1,400, 2,800 mm
7. Compound engine lathe: diameter of workpiece, 450 mm; distance between centres, 1,100 mm
8. Single-upright turning and boring lathe: maximum diameter of workpiece, 1,250 mm; maximum height, 1,000 mm

Automatic single-spindle bar turret lathes

9. Automatic single-spindle bar turret lathe: maximum diameter of bar, 12 mm
10. Automatic single-spindle bar turret lathe: maximum diameter of bar, 18 mm
11. Automatic single-spindle bar turret lathe: maximum diameter of bar, 24 mm
12. Automatic single-spindle bar turret lathe: maximum diameter of bar, 40 mm
13. Bar turret lathe with lateral axis of rotation of turret: maximum diameter of bar, 25 mm
14. Turret lathe: maximum diameter of bar, 25 mm
15. Turret lathe with longitudinal axis of rotation of turret: maximum diameter of bar, 25 mm
16. Turret lathe: maximum diameter of bar, 40 mm
17. Chucking turret lathe with lateral axis of rotation of turret: diameter of workpiece, 500 mm

Upright drilling machines

18. Universal single-spindle upright drilling machine: maximum diameter of drilling, 18 mm
19. Universal single-spindle upright drilling machine: maximum diameter of drilling, 25 mm
20. Universal single-spindle upright drilling machine; two models; maximum diameter of drilling, 35 mm
21. Universal single-spindle upright drilling machine: two models; maximum diameter of drilling, 50 mm
22. Universal single-spindle upright drilling machine: maximum diameter of drilling, 75 mm

Radial drilling machines

23. Radial drilling machine: maximum diameter of drilling, 25 mm
24. Radial drilling machine: two models; maximum diameter of drilling, 35 mm
25. Radial drilling machine: maximum diameter of drilling, 55 mm

Boring machines

26. Boring machine with steady front-rest, turn-table and chucking with radial carriage: diameter of spindle, 80 mm; table size, 800 × 1,000 mm

Jig-boring machines

27. Single-upright fine-boring machine: table working surface, 280 × 560 mm

Plain-grinding machines

28. Universal plain grinding machine: maximum diameter of workpiece, 100 mm; maximum length, 150 mm
29. Universal plain grinding machine: maximum diameter of workpiece, 140 mm; length, 250 mm
30. Universal plain grinding machine: maximum diameter of workpiece, 200 mm; length, 500 mm
31. Universal plain grinding machine: maximum diameter of workpiece, 280 mm; length, 700, 1,400 mm

Sl. No.	Description of machine tools and brief specifications

Plain-grinding machines

32. Universal plain grinding machine: maximum diameter of workpiece, 400 mm; length, 1,000, 2,000 mm
33. Universal plain grinding machine: maximum diameter of workpiece, 140 mm; length, 500 mm
34. Universal plain grinding machine: diameter of workpiece, 200 mm; length, 700 mm
35. Universal plain grinding machine: diameter of workpiece, 280 mm; length, 1,000 mm
36. Universal plain grinding machine: diameter of workpiece, 400 mm; length, 1,400, 2,000, 2,800 mm
37. Camshaft grinding machine: working diameter, 120 mm; length, 1,250 mm
38. Crankshaft and crankpin grinding machine: working diameter, 560 mm; length, 1,600 mm

Internal grinding machines

39. Universal internal grinding machine: diameter of hole, 50 mm
40. Universal internal grinding machine: diameter of hole, 1,000 mm
41. Universal internal grinding machine: diameter of hole, 200 mm
42. Universal internal grinding machine: diameter of hole, 400 mm

Flat-surface grinding machines

43. Flat-surface grinding machine of high accuracy with compound rectangular table and horizontal spindle: table size, 200 × 630 mm
44. Flat-surface grinding machine of higher accuracy with rectangular table and horizontal spindle: table size, 320 × 1,000 mm
45. Flat-surface grinding machine with rectangular table and vertical spindle: table size, 320 × 300 mm
46. Flat-surface grinding machine of higher accuracy with round table and horizontal spindle: diameter of table, 400 mm
47. Flat-surface grinding machine with travelling round table and vertical spindle: diameter of table, 800 mm

Sharpening and rough-grinding machines

48. Sharpening and grinding machine: double-sided; diameter of wheel, 300 mm

Honing machines

49. Upright honing machine: diameter of honing, 165 mm; stroke, 500 mm

Sharpeners and grinders

50. Sharpener: diameter of workpiece, 100 mm; length, 250 mm
51. Sharpener: diameter of workpiece, 250 mm; length, 630 mm
52. Cutter grinder of higher accuracy: height, 25 mm
53. Semi-automatic drill grinder: diameter of drill, 12–80 mm

Gear-cutting machines

54. Semi-automatic gear-milling machine of higher accuracy: diameter of wheel machined, 50 mm; module, 1 mm
55. Semi-automatic gear-milling machine of higher accuracy: diameter of wheel machined, 80 mm; module, 1 mm
56. Gear-milling machine: diameter of wheel machined, 200 mm; module, 3 mm
57. Gear-milling machine: diameter of wheel machined, 320 mm; module, 6 mm
58. Gear-milling machine of higher accuracy: diameter of wheel machined, 500 mm; module, 6 mm
59. Gear-milling machine: diameter of wheel machined, 800 mm; module, 6 mm
60. Vertical gear-shaping machine: diameter of wheel machined, 80 mm; module, 1 mm
61. Vertical gear-shaping machine: diamteer of wheel machined, 200 mm; module, 4 mm
62. Vertical gear-shaping machine: diameter of wheel machined, 500 mm; module, 6 mm
63. Semi-automatic vertical gear-shaping machine: diameter of wheel machined, 800 mm; module, 12 mm
64. Semi-automatic spline-surface milling machine: diameter, 150 mm; module, 6 mm; length of workpiece, 700, 1,500, 2,000 mm
65. Semi-automatic gear-shaving machine: diameter of wheel, 125 mm; module, 1.5 mm
66. Semi-automatic gear-shaving machine: diameter of wheel, 320 mm; module, 6 mm
67. Semi-automatic gear-tooth chamfering machine with vertical axis of workpiece: diameter of wheel, 320 mm; module, 6 mm

Milling machines

68. Bracket plain milling machine: table size, 200 × 800 mm
69. Bracket plain milling machine: table size, 250 × 100 mm
70. Bracket plain milling machine: table size, 320 × 1,250 mm
71. Bracket plain milling machine: table size, 400 × 1,600 mm
72. Bracket vertical milling machine: 200 × 800 mm
73. Bracket vertical milling machine: table size, 250 × 1,000 mm
74. Bracket vertical milling machine with turning spindle head: table size, 320 × 1,250 mm
75. Bracket vertical milling machine with turning spindle head: table size, 320 × 1,250 mm; module, 2

Sl. No.	Description of machine tools and brief specifications

Milling machine

76. Bracket vertical milling machine with turning spindle head: table size, 400 × 1,600 mm
77. Vertical milling machine without bracket: table size, 630 × 1,600 mm
78. Bracket plain milling machine with turn-table (universal): table size, 200 × 800 mm
79. Bracket plain milling machine with turn-table (universal): table size, 250 × 1,000 mm
80. Bracket plain milling machine with turn-table (universal): table size, 400 × 1,600 mm
81. General-purpose tool milling machine: table size, 200 × 630 mm
82. General-purpose milling machine with turning head: table size, 200 × 800 mm
83. General-purpose milling machine with turning head: table size, 250 × 1,000 mm
84. General-purpose milling machine with turning head: table size, 320 × 1,250 mm
85. General-purpose milling machine with turning head: table size, 400 × 1,600 mm
86. Single-upright horizontal plano-milling machine: table size, 500 × 1,000 mm
87. Single-upright horizontal plano-milling machine with bracket cross-piece with vertical and horizontal spindle: table size, 630 × 2,000 mm
88. Single-upright horizontal plano-milling machine with bracket cross-piece with vertical and horizontal spindle: table size, 800 × 3,000 mm
89. Single-upright horizontal plano-milling machine with bracket cross-piece with vertical and horizontal spindle: table size, 1,000 × 4,000 mm
90. Horizontal plano-milling double-upright machine with two horizontal spindles: table size, 500 × 1,600 mm
91. Horizontal plano-milling double-upright machine with vertical and two horizontal spindles: table size, 630 × 2,000 mm
92. Horizontal plano-milling double-upright machine with vertical and two horizontal spindles: table size, 800 × 3,000 mm
93. Two-dimensional pantograph engraving machine: table size, 200 × 320 mm
94. Three-dimensional pantograph engraving machine: table size, 200 × 320 mm

Shaping and planing machines

95. Open-side planer: table size, 900 × 3,000 mm
96. Open-side planer: table size, 1,120 × 4,000 mm
97. Double-column planer: table size, 900 × 3,000 mm
98. Double-column planer: table size, 1,120 × 4,000 mm
99. Power-operated shaping machine: table size, 200 × 200 mm
100. Power-operated shaping machine: table size, 280 × 320 mm
101. Power-operated shaping machine: table size, 360 × 500 mm
102. Power-operated shaping machine: table size, 450 × 700 mm

Slotting machines

103. Power-operated slotting machine: ram travel, 100 mm
104. Power-operated slotting machine: ram travel, 200 mm
105. Die-shaping machine: piston stroke, 100 mm

Bolt-threading and nut-tapping machines

106. Semi-automatic bolt-threading machine: maximum pitch diameter, M40
107. Fully automatic nut-tapping machine with hook top (twin-spindle): pitch diameter, M12
108. Fully automatic nut-tapping machine with hook top (twin-spindle): pitch diameter, M16
109. Fully automatic nut-tapping machine with hook top (twin-spindle): pitch diameter, M24

Cutting-off machines

110. Hack-sawing machine: maximum diameter of sawing, 250 mm
111. Band cutting-off machine: saw diameter, 250 mm
112. Semi-automatic cutting-off machine: saw diameter, 240–710 mm

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