## OCCASION

This publication has been made available to the public on the occasion of the 50th anniversary of the United Nations Industrial Development Organisation.

## DISCLAIMER



## FAIR USE POLICY



## CONTACT

Please contact publications@unido.org for further information concerning UNIDO publications.

For more information about UNIDO, please visit us at www.unido.org

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
Vienna International Centre, P.O. Box 300, 1400 Vienna, Austria
Tel: (+43-1) 26026-0 · www.unido.org · unido@unido.org

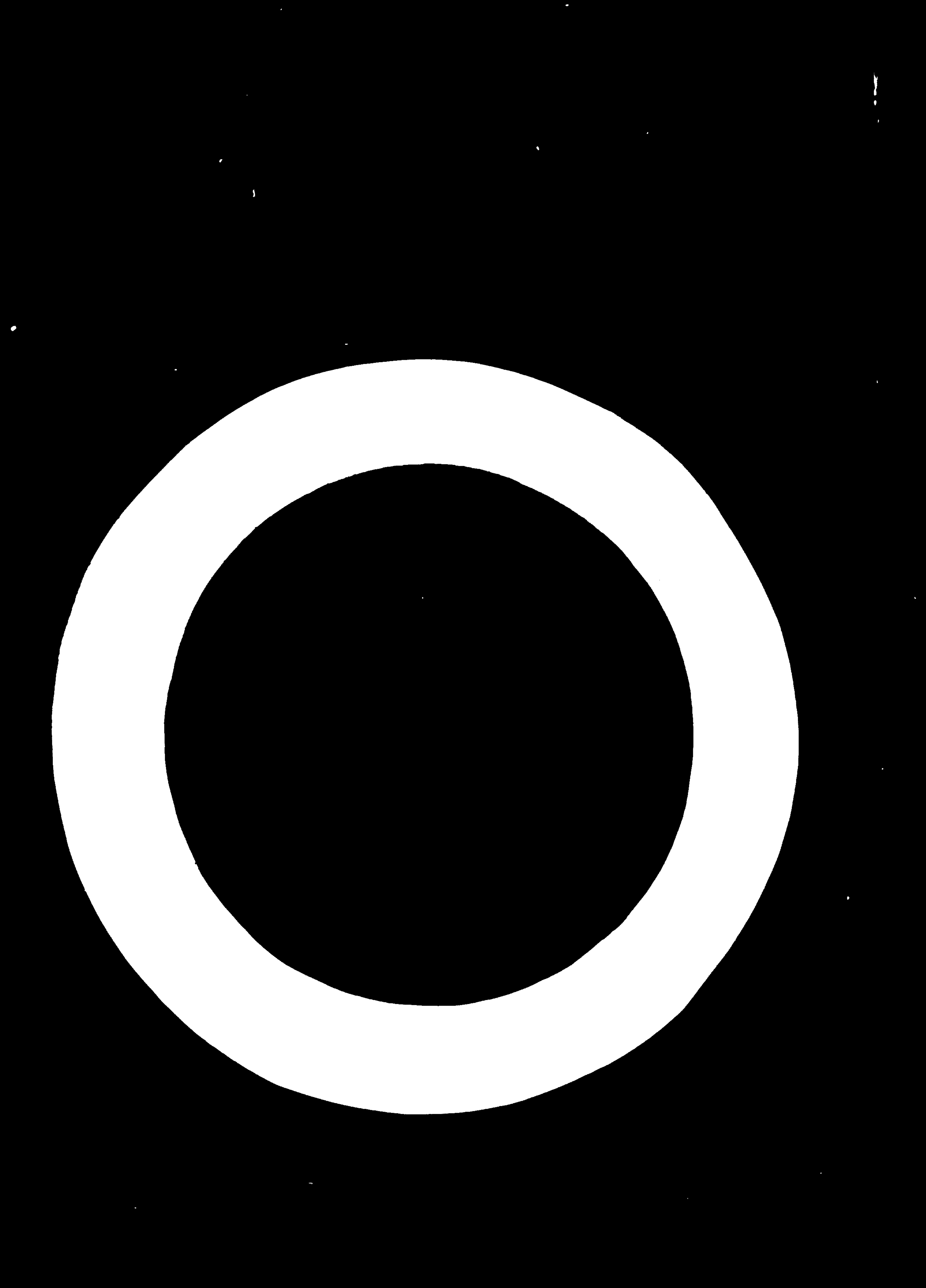
UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
VIENNA

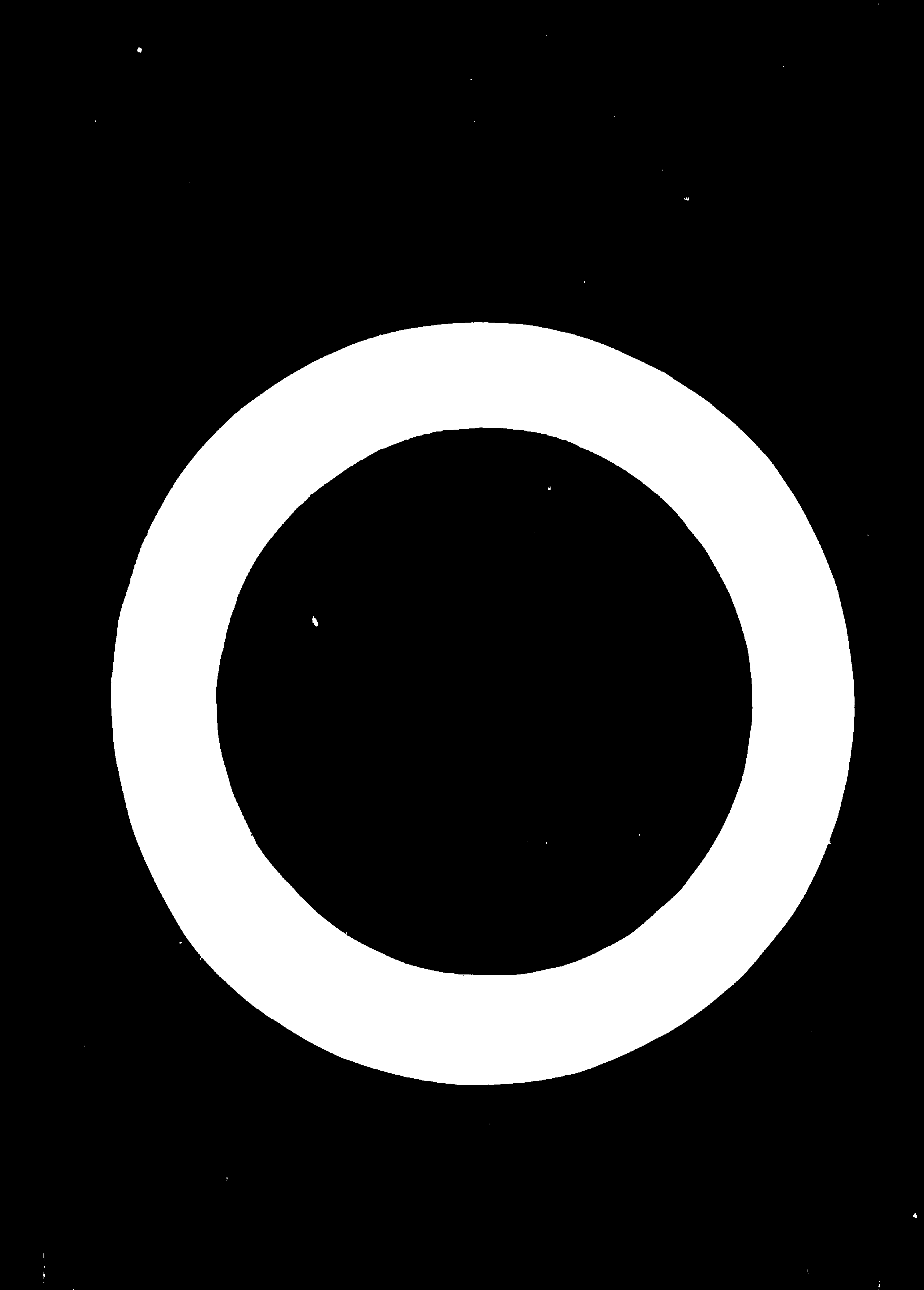
# Development of Metalworking Industries in Developing Countries

*Reports presented at the United Nations Interregional Symposium, Moscow 7 September—6 October 1966*

Sales No.: E.69.II.B.2
ID/6

UNITED NATIONS
New York, 1969





D01181

# 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 press 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 materia' can be dissolved readily after the casting has cooled, so that the production of complex internal forms is greatl 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 toolholders 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 latne 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 produeed 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.

74. 10. 17