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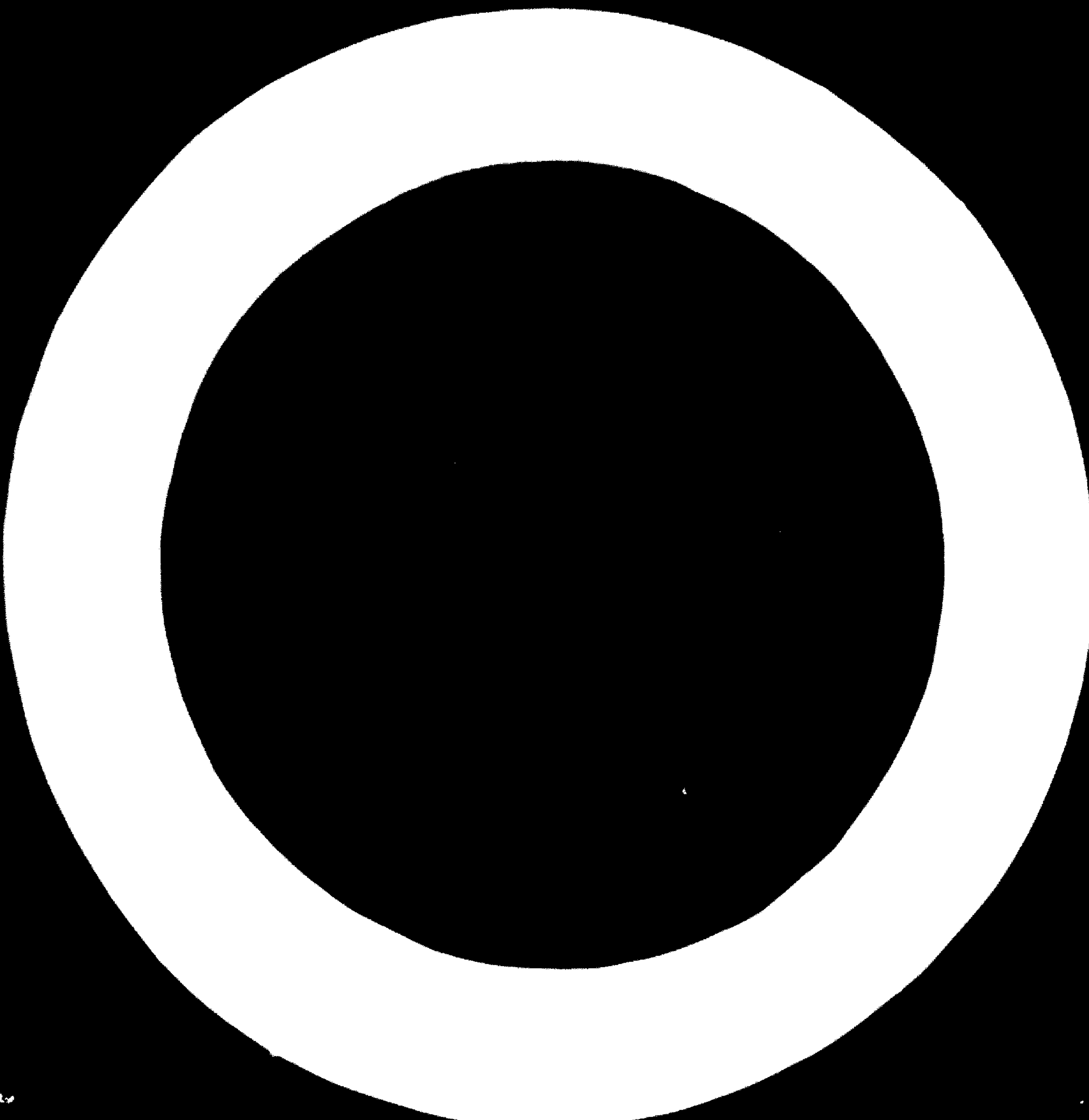

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SPECIAL CONSIDERATIONS OF MACHINERY DESIGN FOR INDUSTRIALLY DEVELOPING COUNTRIES

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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 essential 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 Europe and Japan.

It must be kept in mind that the current situation is entirely different and also that the political, cultural, climatic and economic backgrounds vary greatly from one country to another.

Another important point concerning the suitability of a machine tool or machine group must be considered when supporting manufacturing industries. In most cases, industries of developing countries do not export their products; these are destined to satisfy domestic demand only. Therefore, a generous development of manufacturing industries 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 chucks. The machines are operated by hand. The tool setting and the control of the operations call for highly qualified operators whose

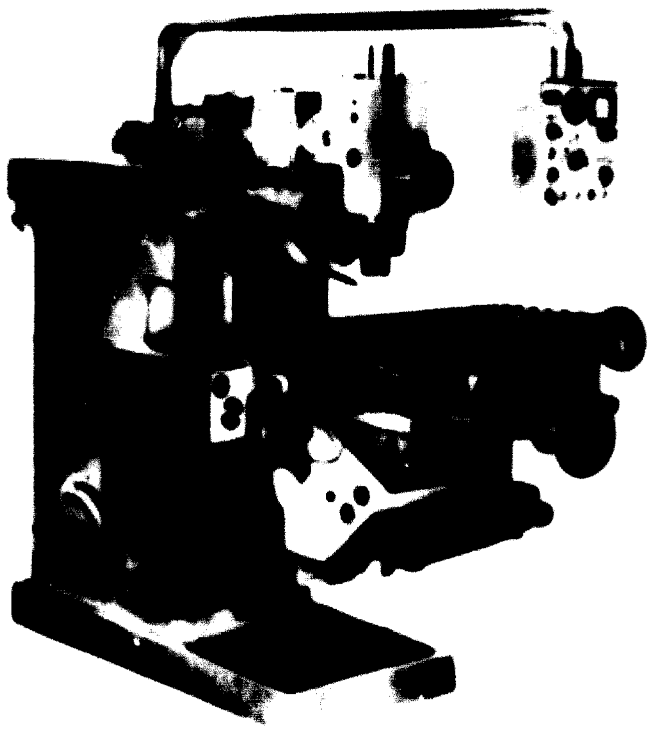

Figure 2

KNEE AND COLUMN TYPE OF UNIVERSAL MILLING MACHINE

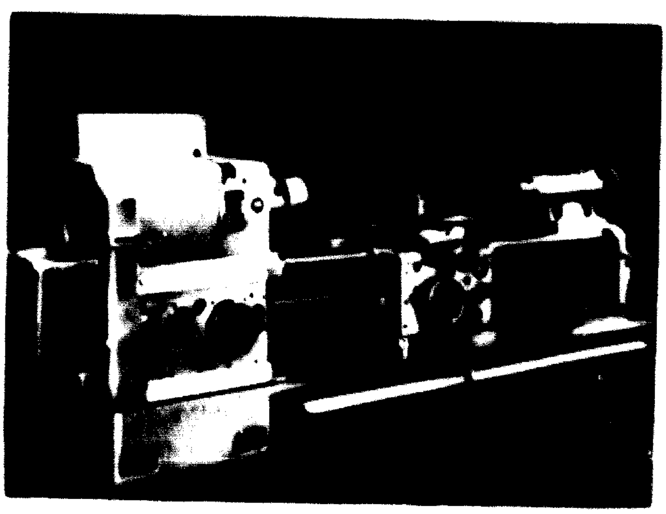

Figure 1

ENGINE LATHE

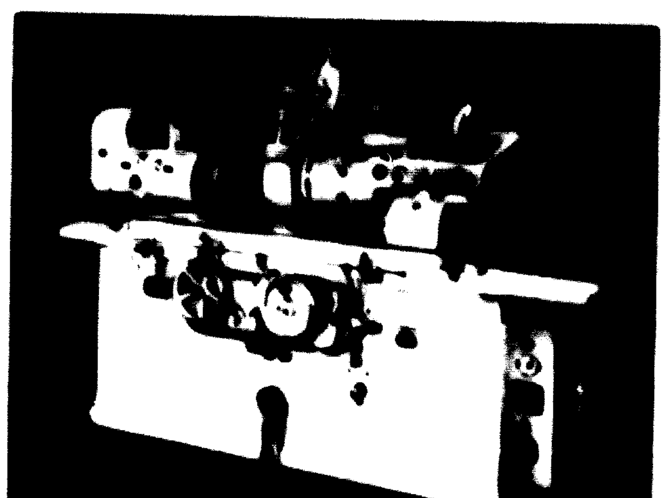

Figure 3

UNIVERSAL GRINDING MACHINE

skill 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 automatic accessories is not provided. The regular type of engine lathe is primarily designed for frequently changing 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 maintained by well-qualified workers, and such a skilled labour force will be available in only a few developing countries.

B. *Machines for batch production*

In industrialized nations the type of machine tool selected for the production of a certain workpiece will primarily depend upon the number and shape of the parts to be produced. Certain types of machines have been developed for the production of similar small batches. Such machines can be used for continuous production and, thereafter, can be set up for a new batch in a relatively short time. These machines are also manually 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

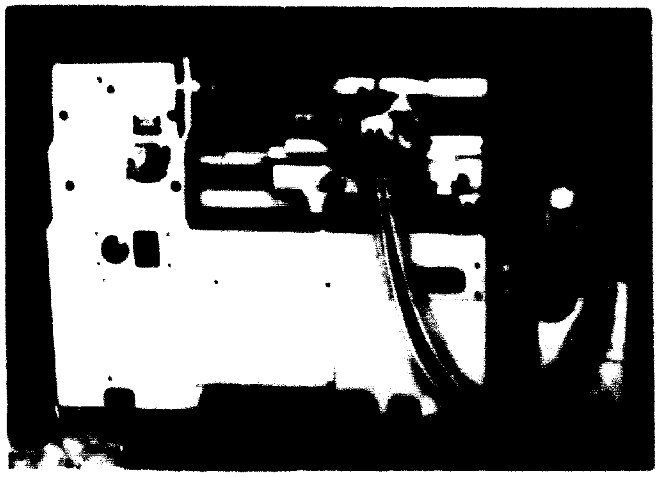

Figure 4

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

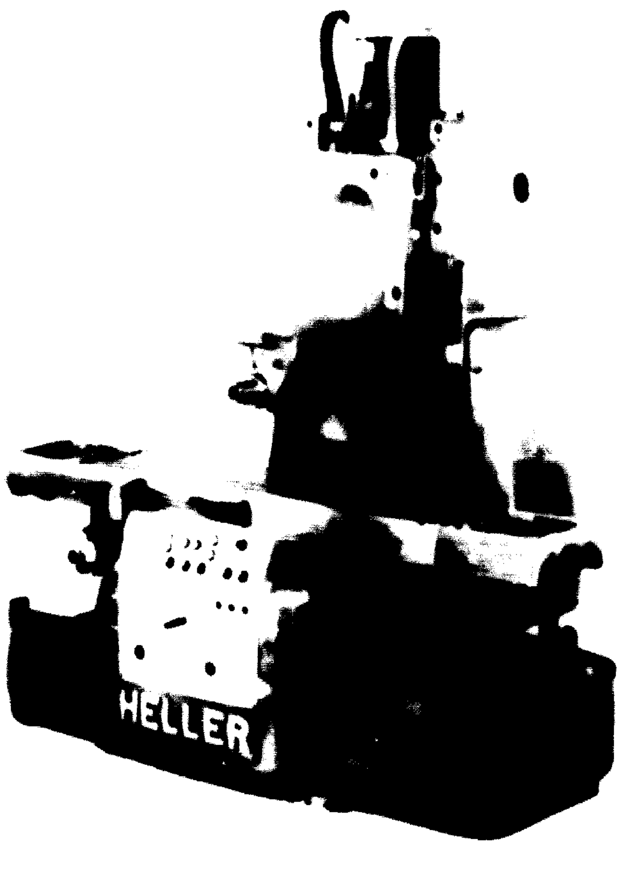

Figure 5

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.

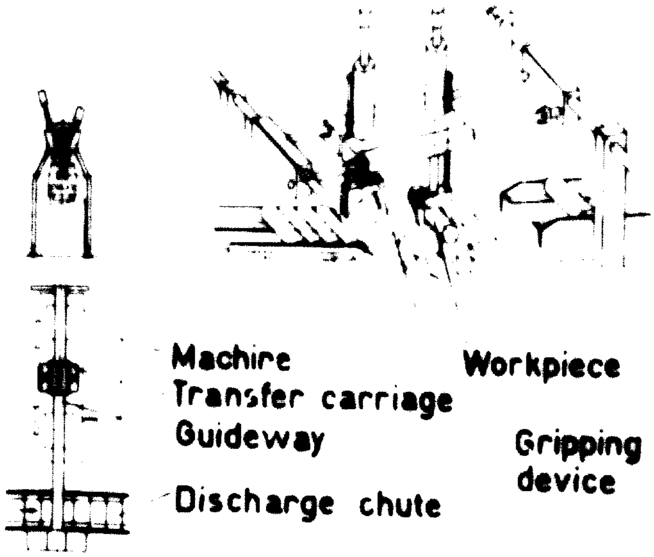

Figure 6

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 frequently designed as a turret. The technological sequence, including feeds, spindle rpm and depth of cut, can be pre-selected by means of cams, discs, curves or electrical contacts, to the effect that the operator no longer makes these decisions.

Due to its simple operation, quick adaptability to a new 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

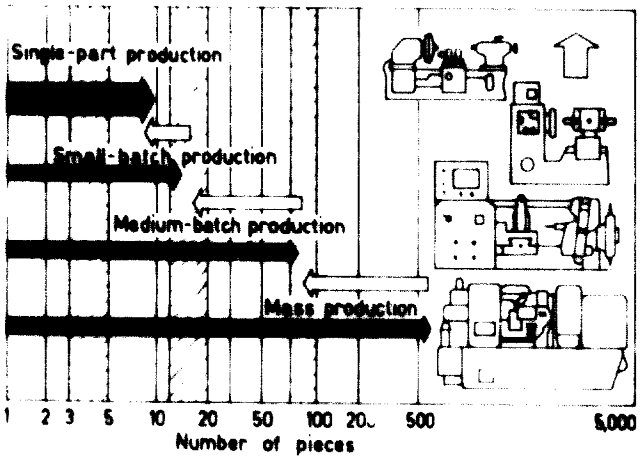

Figure 7

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 carriage with the cam selection of speeds and feeds according to the tool position and the wheel for hand feed and for engaging the automatic feed can be seen. Next to the turret pilot wheel is the board for the selection of the rpm commands. For large-batch production, such a machine can be equipped with a plug-board sequence control. By means of such an extended sequence control, this type of machine can become even more flexible, and the operator will be the more relieved of complicated interactions. However, special training of the 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.

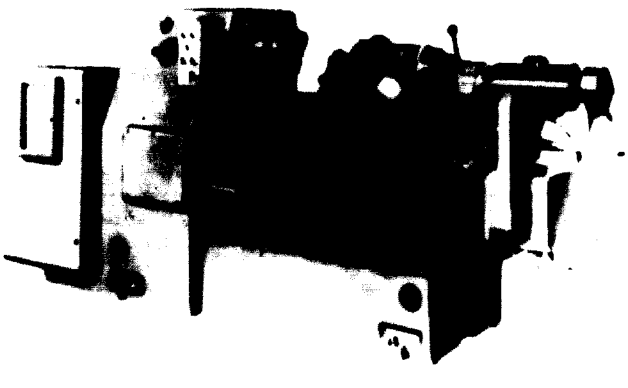

Figure 8

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

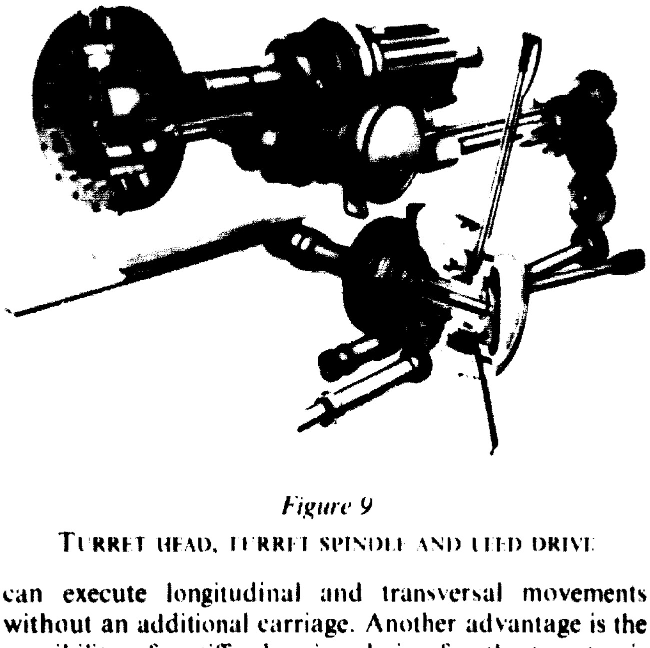

Figure 9

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.

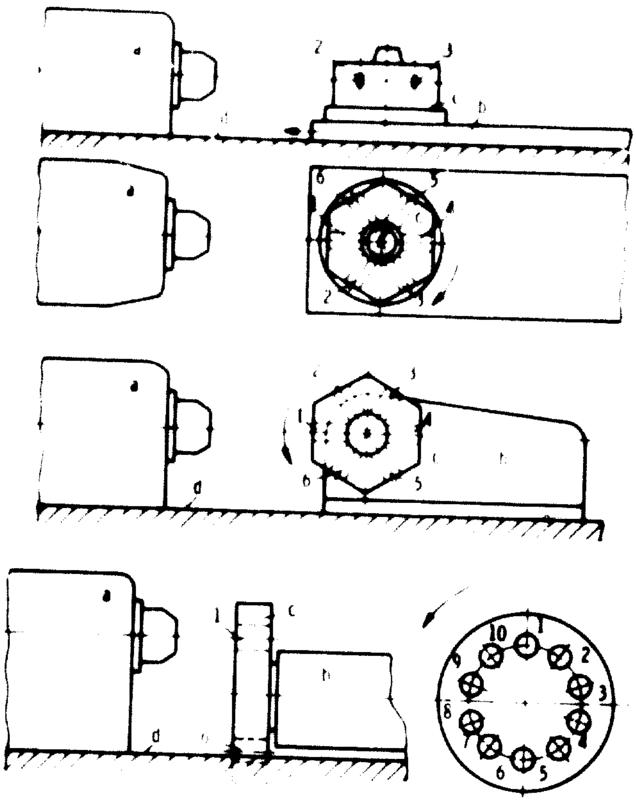

Figure 10

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 30 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

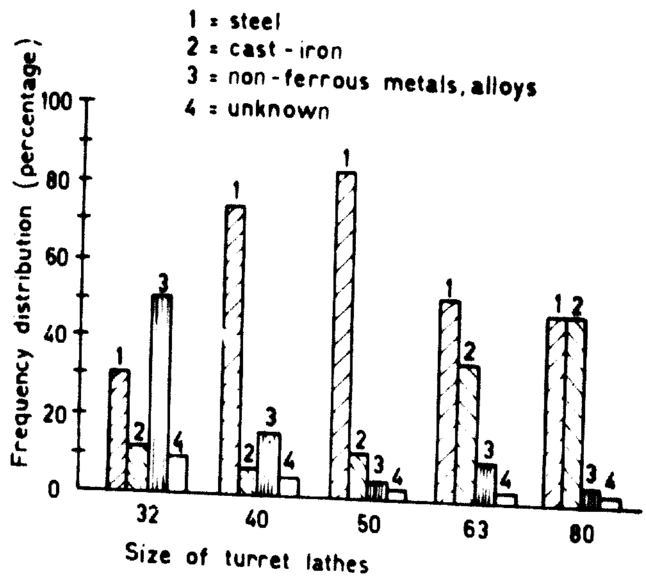

Figure 12

FREQUENCY DISTRIBUTION OF THE MACHINED MATERIALS FOR TURRET LATHES personnel and workpiece feeders, compared with an interlinked line (shown in the lower part of the picture) consisting of automatic machines and only one supervisor. While the machine line can produce a buffer storage and is very flexible in regard to its adaptation to a new production programme because of the loose arrangement of the individual machines, the transfer line operates in a fixed pace. Its adaptation to a new programme can be difficult.

As stated above, there are, in many developing countries, 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.

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.

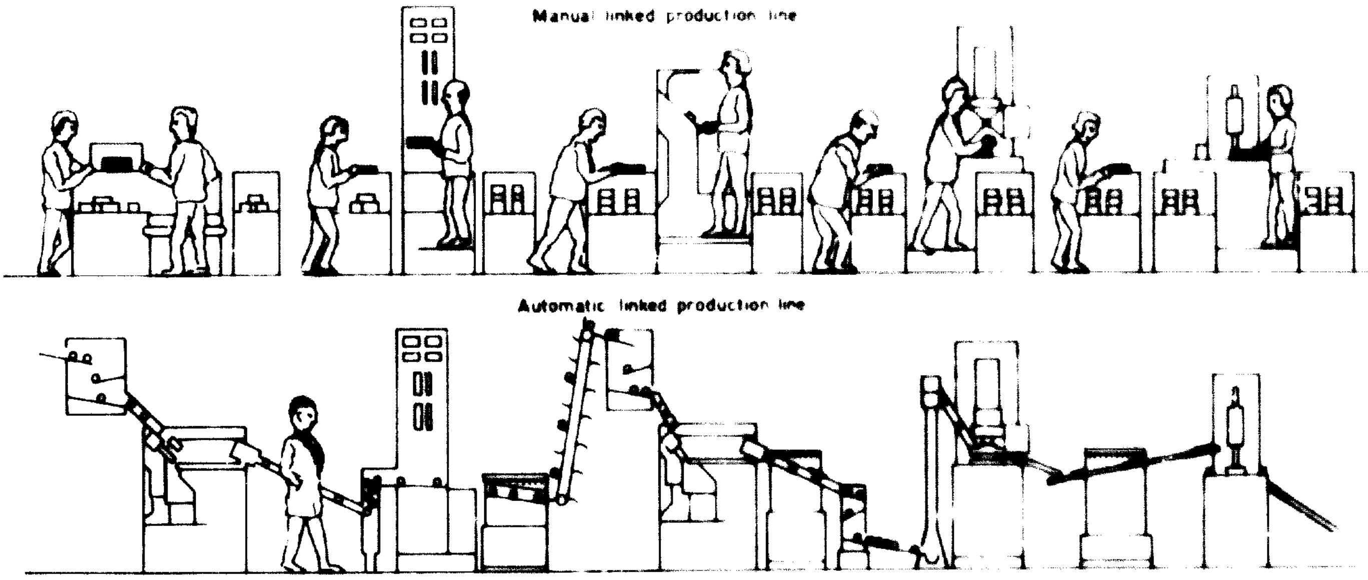

Figure 13

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 interactions. As batch sizes increased more and more, machine development tended towards liberating the work sequence from the presence of an operator and mechanizing it fully. The development of automatic machines began in the United States of America. The first machines of this type were built in 1871 by Porkhorts, and in 1880 by Pelzer.

The work process on automated machines necessitates

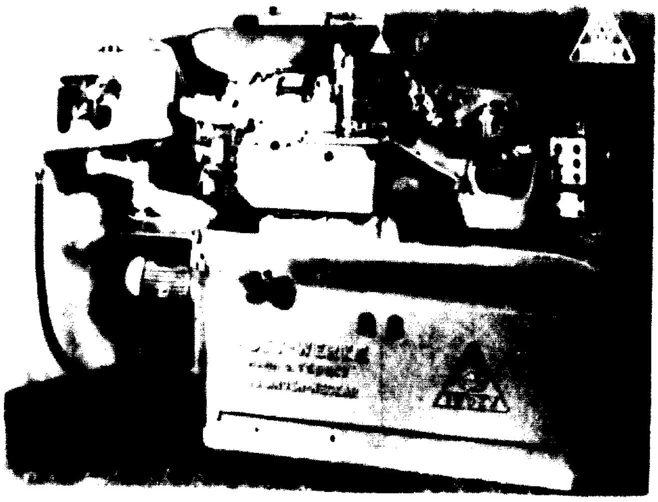

Figure 14

SINGLE-SPINDLE AUTOMATIC MACHINE, INDEX C 29 (F), WITH NEW PNEUMATIC HOLLOW CLAMPING-CHUCK

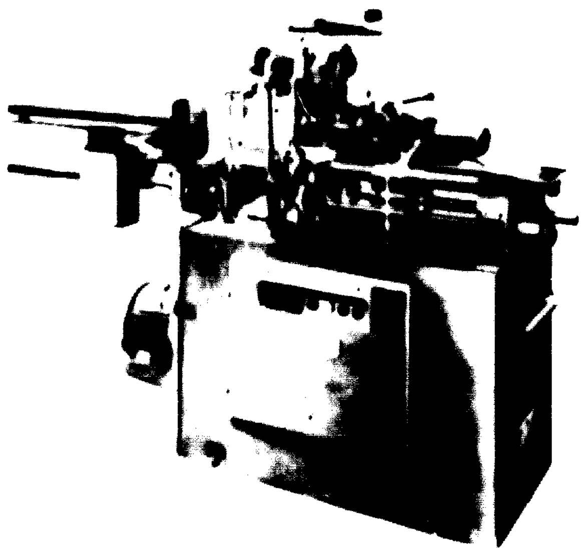

Figure 15

SINGLE-SPINDLE AUTOMATIC MACHINE

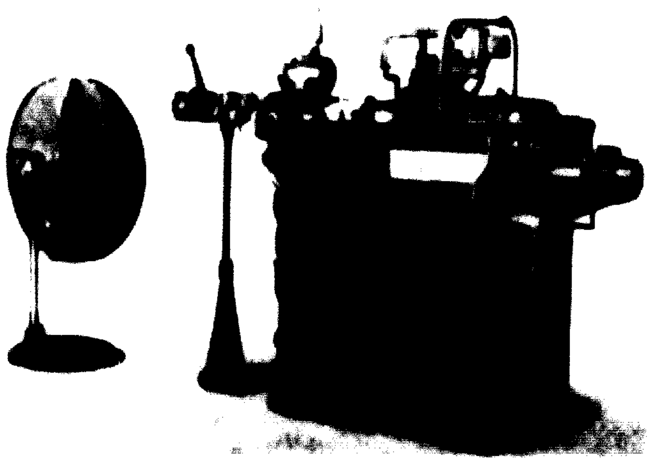

Figure 16

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

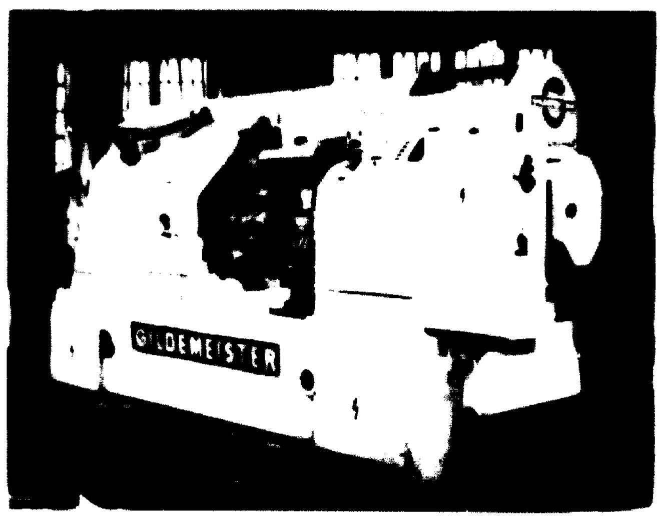

Figure 17

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 simultaneously. It is used for the production of mass-type parts, such as cast or die-forged parts, bar sections or cold-formed parts. Machining from bar stock is not possible. Rotating tool spindles bear the tools, which are frequently 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 live 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.

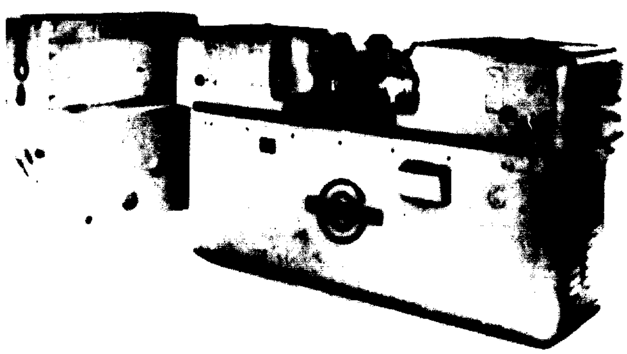

Figure 18

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 runs of the drive curves. The man at the machine cannot be expected to utilize the full potential of modern turning machines according to the knowledge of modern production technology. Furthermore, special experiences and designs for a specific production problem can be co-ordinated by a central department only. For example, comprehensive data about chip-forming operations for the numerous available materials will be collected in this department. In handbooks, one often finds only approximate values with wide tolerance ranges. The required special experience must include such fields as fixture design, chucking and clamping problems, special tool-holders, 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 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 downtimes. 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.

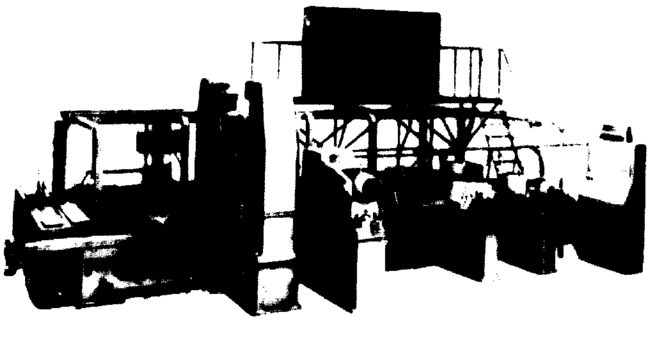

Figure 19

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.

Figure 24 represents the model of a transfer line composed of gear shapers. Here, the purpose is to generate automatically the helical teeth and the clutch gear ring

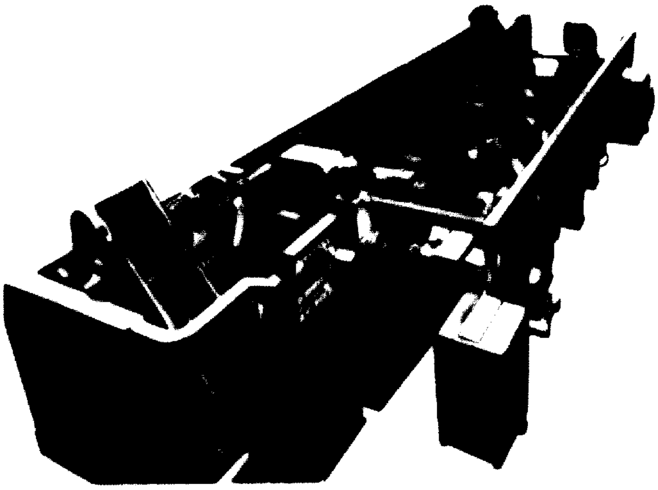

Figure 21

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

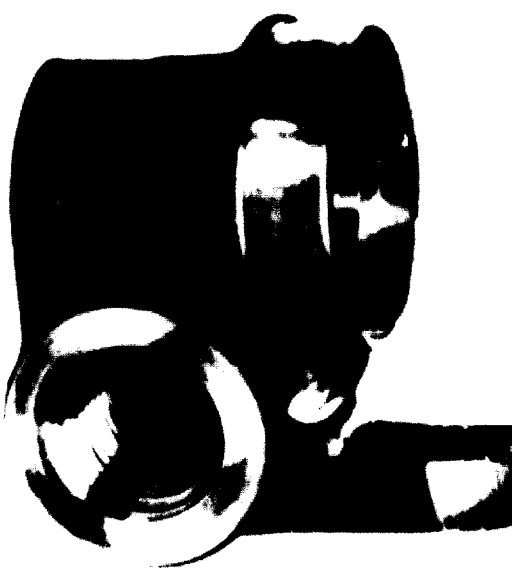

Figure 22

STEERING SWIVEL BUSH

within the same time. In this way, one part is completely geared every 2 minutes by this transfer line (see fig. 24). The raw parts are fed by means of a conveyor. It should be noted 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

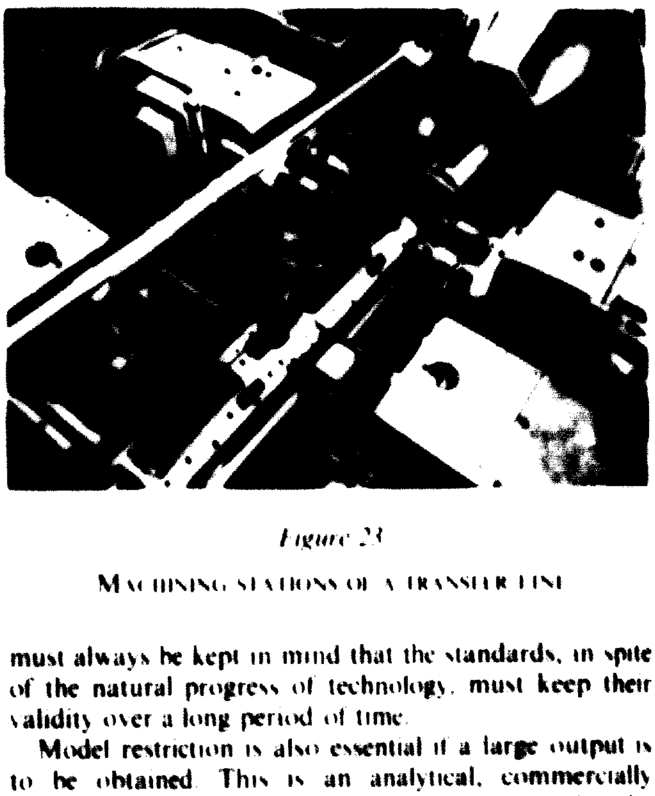

Figure 23

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.

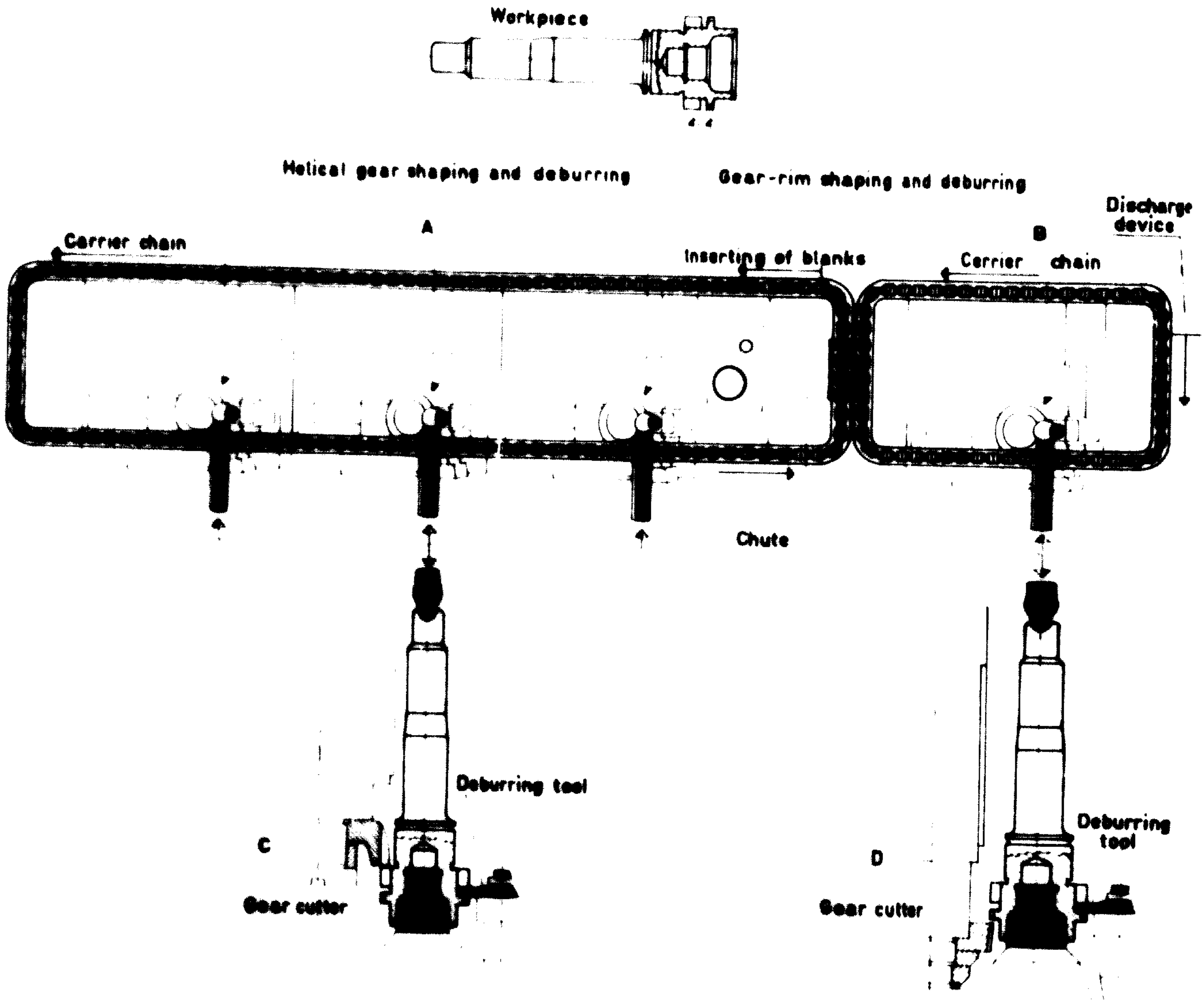

Figure 24

SCHEMATIC DRAWING OF A TRANSFER LINE

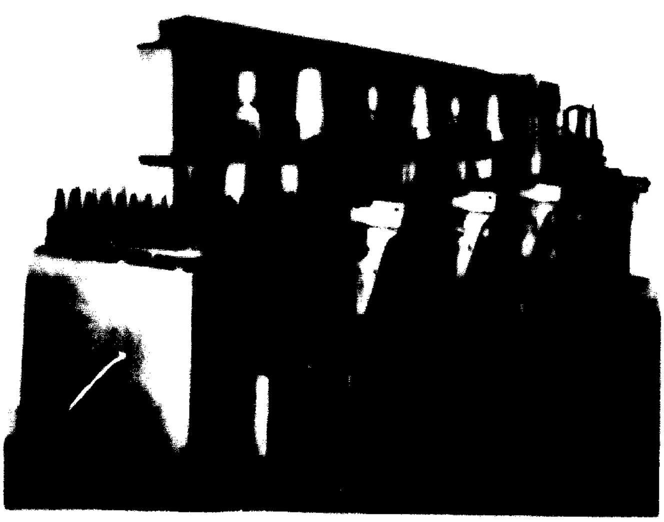

Figure 25

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 will suffice. Nevertheless, not every person is suited for the service of transfer lines. The selection, in regard to the operator's personal qualities, must be very careful since a transfer line represents a very considerable investment value. The operator must be absolutely reliable and alert over long periods of time without manual activity. This leads to high requirements in respect of the operator's ability to concentrate and his willingness to assume responsibility. In addition, the operator must be able to communicate his observations and perceptions clearly and distinctly. He must possess most of these capabilities from the very beginning since they can be taught 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 maintenance cannot be met by professional training of the personnel as either mechanics or electricians because the range of activities is much wider. A good maintenance team can only be formed by a further thorough training of the skilled workers in adjacent fields. For instance, a fully trained machine mechanic must also have basic knowledge of hydraulics, pneumatics, control engineering, electrical science etc. in order to detect faults quickly. Accordingly, an electrician must have a certain command of fields adjacent to his own profession. Then, in case of a breakdown, the man with the best knowledge and experience in the concerned field will be called upon to eliminate it. The many-sided maintenance problems of a transfer line can be solved only if the appropriate maintenance 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,

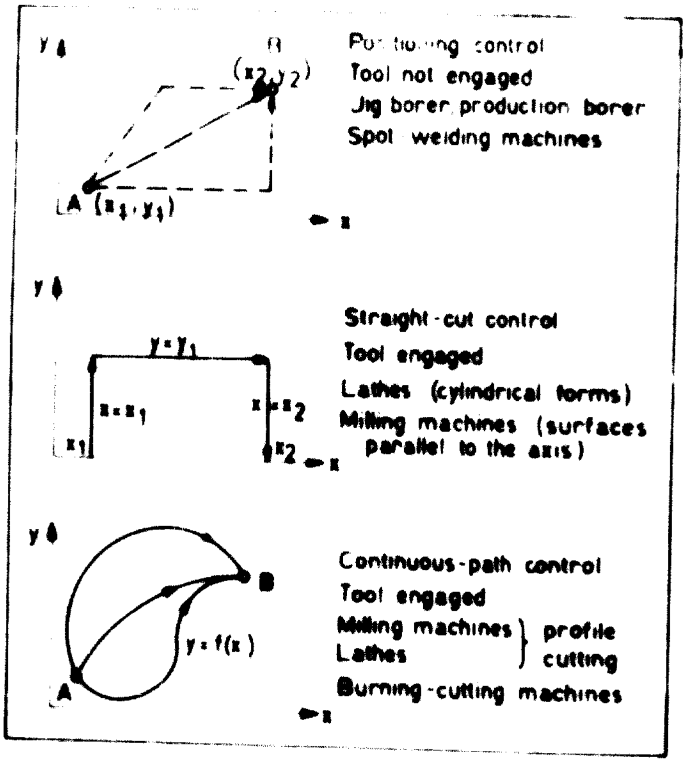

Figure 26

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 shortcomings, 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 rela-

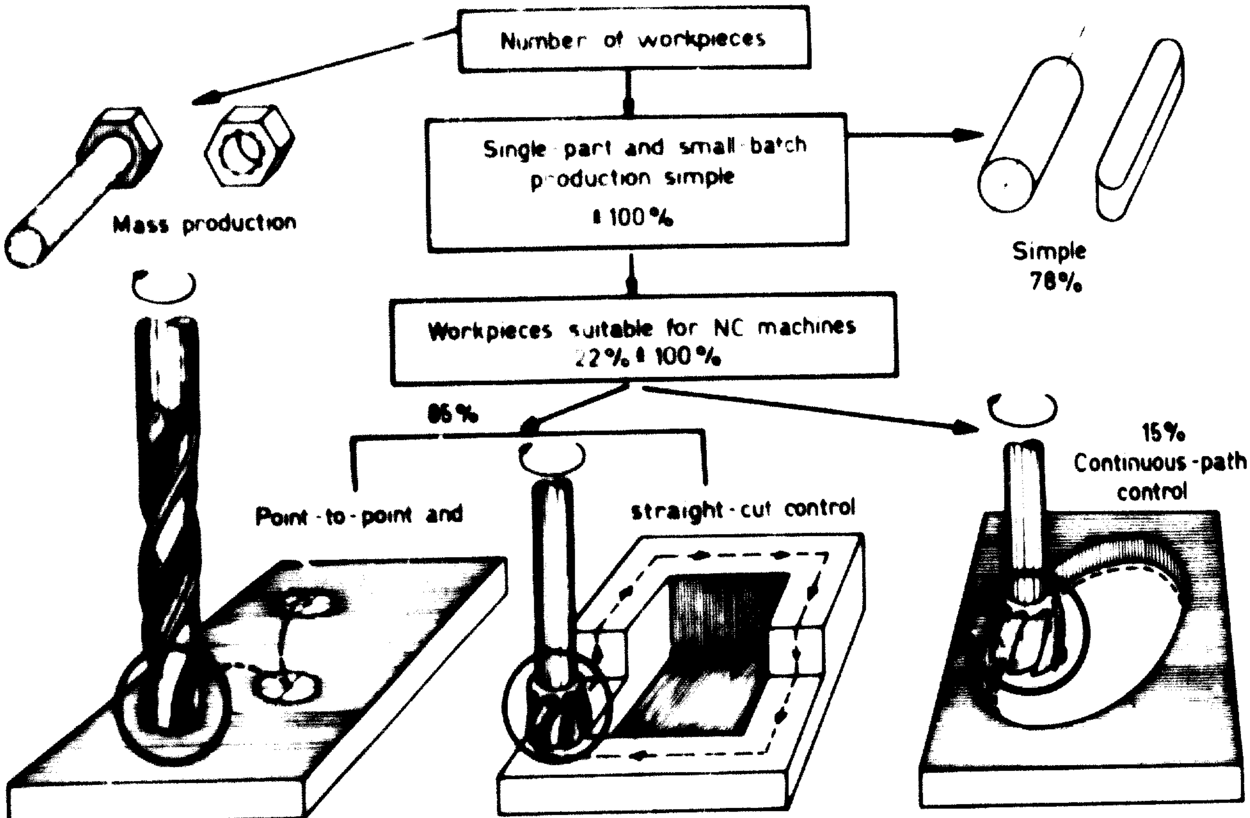

Figure 27

SCOPE OF APPLICATION FOR NUMERICALLY CONTROLLED MACHINE TOOLS AND PERCENTAGE DISTRIBUTION OF POINT-TO-POINT, STRAIGHT-CUT AND CONTINUOUS-PATH CONTROLS

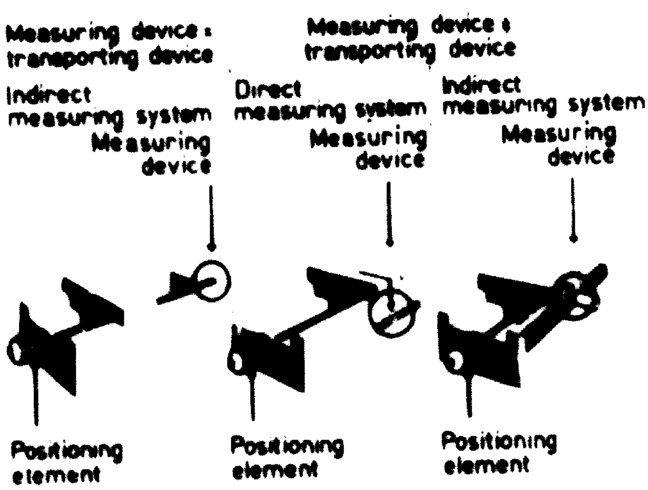

Figure 28

POSITION AND DISPLACEMENT MEASURING DEVICES

tively small batches will be predominant in developing countries. This is, indeed, the economic operational range of numerically controlled machines. For the selection of a suitable numerically controlled machine, the question of sturdiness, operational simplicity, reliability and easy maintenance must be thoroughly investigated.

If numerical control is introduced at all, point-to-point or two-dimensional control will be of the greatest interest for several reasons. As previously mentioned, a large percentage 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.

its profitable use even in small-batch production and the 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 abovementioned 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.

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