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TECHNOLOGY TRENDS SERIES NO. 10

Technological trends in machine tools and their implications for developing countries*

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* The views expressed in this document are those of the author and do not necessarily reflect the views of the Secretariat of UNIDO. This document has not been edited.

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I. INTRODUCTION:

Few, if any, products and services of modern civilization would exist if it were not for machine tools. However, inspite of its basic importance, the machine tool industry has represented only a small part of the total industrial output of the world. The entire world output of machine tools is in fact smaller than the output of many individual corporations in the United States of America.

The ability of the machine tool industry to produce a variety of machine tools necessary for industrialization has a major impact on the economic and industrial progress of a country. Many developing countries have lagged behind in establishing their own capital goods, machine tools, consumer durables, and other engineering industries. A few developing countries like the People's Republic of China, the Republic of Korea, Taiwan, Yugoslavia, India, Mexico and Argentina have, however, a sizeable capital goods industry and a large machine tool industrial base, which has given them a big advantage over other developing countries. They are now able to substitute local production for imports of many types of capital and consumer goods and some have even reached a stage of development which enables them to export a variety of their industrial products, including machine tools.

II. OBJECTIVES OF THE STUDY

Steadily increasing and exacting demand for improving performance, reducing costs and enhancing generally the over-all productivity of the metal working industries of the industrialised countries, has led to the development of innovative designs of intricate and sophisticated types of machine tools. The activity and technical standards of the machine tool industry have therefore become an accurate index of the economic efficiency and productivity of manufacturing industry.

In view of such rapid and innovative changes in the design and technology of machine tools, developing countries should thoroughly investigate the question of obsolescence in machine tools before acquiring foreign designs and technical and economic co-operation with other countries. The objective of this study is to briefly make a realistic forecast of machine tool technology upto the end of the century. This could help the developing countries to establish their own machine tool industry on a more sustaining basis, avoiding designs and technology, ill-suited to their needs and/or likely to become obsolete in the near future.

III. WORLD MACHINE TOOL INDUSTRY (Brief Review)

According to the latest global survey (Feb. 1989) conducted by the American Machinist, the production of machine tools - both metal cutting and metal forming - in the year 1988 from 36 machine tool producing countries is estimated at $ 38 billion. This is 15 per cent more than the production in 1987. The growth in production is more or less steady during the last two years. It was 14.5 per cent in the year 1987.

Japan maintains its number one position for the seventh year in succession as the largest producer of machine tools. It increased its production by 35 per cent which accounted for 22.7 per cent of the global production. Japan is followed by the Federal Republic of Germany, Union of Soviet Socialist Republics, Italy and the United States in the order of production. Italy overtook the United States in production in 1988. These five countries together produced 66 per cent of the total output. People's Republic of China improved its position from 17th place in 1987 to tenth in 1988, increasing its production by 15.8 per cent which is more than the world average. The share of metal-forming machine tools in the total output remained steady at 24 per cent.

The Union of Soviet Socialist Republics continues to lead as the largest consumer of machine tools with a total of $ 6 billion, a share of nearly 16 per cent of the world output. The Union of Soviet Socialist Republics is closely followed by Japan which has moved from fourth to second position with a consumption of $ 5.7 billion. The United States and the Federal Republic of Germany occupy third and fourth positions with a more or less equal consumption of $ 3.85 billion. The People's Republic of China has more than doubled its consumption of machine tools from $ 449 million in 1987 to $ 1151 million in 1988.

It is generally true that larger producers of machine tools are also the larger buyers of machine tools. With the exception of Japan, countries like the Union of Soviet Socialist Republics, United States, Federal Republic of Germany and Italy imported machine tools to the extent of 31%, 52%, 30% and 32% of their consumption respectively. Japan, however, imported only 7% of its consumption.

On the export front, among the top producers Federal Republic of Germany maintained its lead in exports with 60% of its production having been exported in the year 1988. This is an improvement by 3% over the previous year. Italy is second, exporting 47% of its production. Japan and the United States take third and fourth place with 39% and 25% exports. Japan's exports fell from 47% in 1987 to 39% in 1988, partly due to the appreciation in the yen value. The Union of Soviet Socialist Republics, however, exported only 8% of its production.

The following table gives the details of production, consumption, imports and exports of machine tools for the year 1988 in respect of the 36 countries covered in the survey by American Machinist.

World Machine Tool Statistics - 1989 (estimated)
(millions of US dollars)

S.No.	Country	Production	Consumption	Imports	Exports
1	Japan	8643.3	5686.8	404.0	3360.5
2	FRG	6833.3	3843.7	1138.9	4128.5
3	Soviet Union	4500.0	5990.0	1850.0	360.0
4.	Italy	2803.6	2181.5	706.7	1328.8
5	United States	2440.0	3850.0	2012.0	602.2
6	Switzerland	1913.6	690.2	403.2	1626.6
7	GDR	1457.0	443.6	285.0	1298.4
8	United Kingdom	1349.3	1420.4	737.8	666.7
9	France	805.8	1376.6	906.5	335.7
10	People's Republic of China	731.6	1151.6	550.0	130.0
11.	Taiwan	695.2	589.9	316.3	421.6
12	Spain	673.6	726.8	302.9	249.7
13	Yugoslavia	671.7	398.1	171.9	445.5
14	Rumania	657.5	621.4	126.9	163.0
15	Rep. of Korea	597.1	1109.1	560.0	48.0
16	Czechoslavakia	450.0	170.0	95.0	375.0
17	Brazil	448.9	453.0	40.0	35.9
18	Poland	320.0	420.0	200.0	100.0
19	Canada	290.2	944.7	748.6	94.1
20	Sweden	280.9	414.4	345.3	211.8
21	India	272.0	383.0	145.0	34.0
22	Hungary	241.5	156.3	105.8	191.0
23	Belgium	190.0	220.0	345.0	315.0
24	Austria	155.0	161.0	175.0	169.0
25	Bulgaria	150.0	400.0	350.0	100.0
26	Israel	135.0	175.0	155.0	115.0
27	Denmark	80.2	129.2	111.4	62.4
28	Australia	50.0	185.0	140.0	5.0
29	Netherlands	45.5	209.8	343.6	179.5
30	Finland	42.7	114.1	111.3	39.9
31	Argentina	38.1	50.2	38.4	26.3
32	Singapore	37.0	97.0	150.0	90.0
33	Portugal	19.2	43.6	34.0	9.6
34	Mexico	18.0	255.5	240.0	2.5
35	South Africa	9.7	97.5	88.0	0.2
36	Hong Kong	1.5	75.0	80.0	6.5
	Total	38047.4	35233.1	14513.7	17328.0

Source: American Machinist - February 1989

IV. TECHNOLOGY TRENDS IN MACHINE TOOLS:

The present study is designed to be practical. No attempt has been made to forecast technological trends in machine tools, using mathematical models like the 'Project Delphi', though it may be interesting to compare our projections with the forecast made in 1970 by Eugene Merchant, author of the Project Delphi.

Because machine tools are the most important means of industrial production, the development of production technology depends directly and uniquely on the development of machine tools. In this study of the latest developments in machine tool technology, therefore, the vital link between modern machine tools and development of production technology will be considered.

The great changes taking place in metal-working may be attributed to the rapid developments in machine tool design and technology control systems and production engineering Developments relating to, inter alia, new materials, cutting tools and a new generation of drives are not only influencing the concept of machining, but also adding a new dimension to the mothodology of machine tool designs.

New norms of production organization such as the concept of fully or partially integrated flexible manufacturing systems, are emerging. At present, by far the most important form of technology is computer-aided manufacture (CAM).

It has already proved its ability to improve production possibilities more than all the known forms of production techniques put together. For this reason, machine tool-based production technology is becoming increasingly integrated with computerization.

MACHINE TOOL DESIGN:

Structure: The principal design parameters of the machine-tool structure are: stiffness-to-weight ratio, natural frequency and damping from the standpoint of dynamics, dimensional stability and the long-term stability influencing the retention of accuracy of alignments. The search for cheaper alternatives to cast iron has spurred research in the use of welded structures, concrete and even granite.

Guideways and bearing surfaces: New design concepts are now being tried to ensure the longevity of machine accuracy, to reduce periodic maintenance and provide for easily replaceable guideway elements that do not require costly and time-consuming scraping. Recent innovations in guideway technology have resulted in the development of glued-on and fixed-on guides.

Glued-on guides are built with hardened or nitrided steel stripes of 10-12 mm thickness which are bonded on the properly prepared base structure by using bonding agents like epoxy resins.

The fixed-on guides are designed with case-hardened or nitrided steel guides which are bolted or dowelled on to the precision-milled, ground or hand-scraped locating surface of the welded or cast-iron machine bed or base. This is likely to be the basic design approach for the guideways and bearing surfaces of machine tools in the future.

The cost of such guideways is much less than even the conventional precision-milled or hand-scraped guideways. They facilitate easy replacement of worn-out guides, considerably reducing the down time of the machine. The mating part may be of cast iron or any self-lubricating or tribologically compatible material.

Spindle Systems: The thermal energy dissipated in the machine spindle-head during operation leads to considerable thermal dilation which causes spindle drift and spindle droop. These thermal problems can be overcome by controlling and stabilizing the operating temperatures of the spindle head and by keeping it cool through refrigeration. The cooling is done in such a way that a temperature of 20° to 25°C is maintained.

Drift and droop compensation is very important in the case of boring and jig-boring machines. The modern trend is to compensate the boring spindle assembly in such a manner that whatever the projection of the spindle, the tool position does not drift or droop. Such compensation is now possible with hydrostatic bearing systems and with pressure feedback in respect of a built-in reference.

Feed Drives: Automatic and NC machines now demand high acceleration or deceleration and a steady state of operations of the feed drive systems. The innovations in semiconductor technology, serve-drives, electrohydraulic systems and high-energy magnetic materials have led to the development of a new breed of feed drives. Electrohydraulic and total electronic serve-drives dominate and field at present, although the electrohydraulic versions are being phased out because of their low response time, actuation delay and associated problems of noise, heat and cost. Modern CNC and EDM machines are fully equipped with electronic serve-drives.

The present generation of high-performance drives incorporate one of the following:

DC permanent-magnet direct-drive torque motors;
DC permanent-magnet servo-motors; electric and electrohydraulic stepper motors; AC variable-frequency motors; brushless DC motors; and wound field DC motors.

The DC permanent-magnet systems are the most commonly used because of the attainable band-width and good performance at low speeds with added benefits of less heat, noise and low cost.

Even in Japan, where electrohydraulic stepper motors haver hitherto been widely used, because of the simplicity of electronic control, permanent magnet DC motors are slowly replacing them.

The permanent torque motors are a special brand of DC control motors. They have a pancake form and develop high torque at low speeds without becoming overheated. The permanent magnetic field does not allow heat dissipation while the motor is on stand-by. Because of these characteristics, they can be directly coupled to the load, offering a very high coupling drive stiffness and even zero backlash with careful macharical design. These torque motors are highly reliable and durable.

Mechanical Drive Elements: Along with the direct drive DC servos and torque motors, the most commonly used mechanical drive elements are recirculating anti-friction screws and nuts. However, the hydrostatistically lubricated nut and lead-screw systems have recently found increased application in the machine tool field because of lower rumble. higher stiffness and low friction. Although the hyrostat[illegible] nut and screw systems are more expensive, they provide higher reliability when used in the servo-drive system along with DC torque motors and grating transducers.

Accuracy of Design : The design of modern machine tools is aimed towards a high accuracy of the machined components. In this context, not only the (already mentioned) aspects of stiffness of structures, suitable assembly configurations, required stiffness and reliability of drives, sensitivity of slide motions and thermal stability should be achieved, but also an integrated approach should be adopted for the design of the machine and controls.

In view of the enhanced performance requirements of modern machine tools, the design should satisfy a dual purpose. A machine tool has to be able to accurately machine a component and even take over the added function of inspecting the machined job. Hence the incorporation of a number of measuring devices and systems on the machine tool. Among these, the most commonly used are the inductive scale. absolute digital or incremental-type shaft encoders and laser interferometers associated with digital read-outs.

Although the vast majority of servo-positioning aids, used in NC and CNC machines are the indirect type of transducers such as shaft encoders, the direct types such as inductive scales and moire fringe gratings are finding increased use because of their higher precision. In a new instrument developed in the United Kingdom, the interpolation of moire fringes from optical gratings is obtained by a scanned photodiode array which makes possible a very fine resolution from a transmission grating with 100 lines per millimetre. This resolution is close to that obtained by laser interferometry, but at a fraction of the cost.

Modular construction : A distinct trend towards the modular construction of machine tools is already evident. This trend is strengthened by the need of the metal-working industry to machine a wide range of parts in small and large batches, with an ability to change over quickly from one part to another. This can be done best by a system which allows various configurations of machining systems to be built up from a range of standard modules rather than by the use of inflexible machine parts.

Considerable success has been achieved in using modular units for building grinders for high-volume production, but a wider application of the concept to embrace lathes, milling machines, drilling machines etc., has yet to be established. However, as more industries turn to group technology, it is expected that machine tool builders will increasingly adopt this concept of machine building.

Other technical factors encouraging modular construction include the move towards higher speed and power, variable spindle drives, inter-changeable tool turrets and direct-drive feed units. The first three factors have led NC lathe designs to a concept where the drive motor, gear box and spindle units are separated to limit thermal problems and isolate sources of vibration. The same considerations are seen in modular grinder designs.

Builders of machine tools also stand to gain by adopting a modular design concept. Short lead times, flexibility in final machine configuration, low inventory and larger batch quantities lead to savings of cost and time in machine-tool building. The builder can offer machining systems tailored to meet customers' needs with a possibility of adding more modules when required. All these considerations are prompting a move towards modular design of machining systems.

Computer-aided design: Engineering design involves the use of scientific principles, technical information and imaginative manufacturing instructions to make an engineering product from engineering drawings. Every industry and engineering company evolves its own particular design methods and procedures. A fairly typical design method is as follows: functional specification; preliminary rough design: cost estimates and design analysis; final design; detail design; and drafting. In the modern state of development, computers are being widely used in engineering design. This has led to the development of a new discipline known as computer-aided design.

High-speed Machining: Expected improvements in cutting-tool materials allow an increase in the limits of material removal rate, in maximum speed (5,000-6000 rev/min) and feed by an average factor of about 2, and in power by a factor of almost 4. This requires specific efforts in the development of faster and more powerful machine tools in all categories and extensive research and development efforts in spindles, bearings, drives, tailstocks and structures. Work on these aspects is being carried out in the laboratories, research institutes and machine-tool industries in developed countries.

It is estimated that in 1979 the cost of metal removal in the United States exceeded $ 60 billion. If special techniques like high-speed machining could reduce that expenditure by 1 per cent, the savings obtained would be considerable. Given the amount of money spent on metal removal in all the countries, even a marginal saving obtained by a high-speed machining could release a large amount for new investments.

Ergonomics, noise and safety : Even though technology is progressing towards unmanned machine operations and unmanned factories, there is nevertheless concern for the health and safety of the industrial labour-force. Recent years have witnessed a great emphasis on ergonomics, safety and noise consideration in machine-tool design. It is aimed at providing operators with pleasant working environments, both from physical and aesthetic points of view. This is seen as an important method of retaining skilled labour in manufacturing and preventing its migration to other areas such as service industries. Recent recommendations on acceptable shop noise levels and mandatory safety regulations point to an increasing obligation of the machine-tool builders to meet even more stringent regulations in future.

Proper ergonomic (operator-machine relationship) design is important especially on manually operated machines. Easy indentification of controls, low operating forces, logical grouping and pleasing colour schemes are the major considerations. New concepts are emerging to design a lathe which can be comfortably operated by a seated person, thereby stressing the importance attached to the operator's comfort in the design of modern equipment. With the increasing international trade in machine tools, the trend towards visual communication between human beings and machines through symbols is increasing. Recent work in evolving an internationally recognised code of symbols even for NC and other electronic control systems is a positive proof of this trend.

Present recommendations limit the level of noise to which an operator is exposed to 90 decibels over an eight-hour shift. Machine-tool designers therefore, have to design machines with noise levels of 85 decibels or less. So far, efforts have been directed towards containment and not noise reduction. New designs are striving to reduce the absolute noise levels of machine tools to 80 decibels. This is expected to have a major impact on machine-tool design. Hydraulic and gear drives and pneumatic systems are giving way to quieter, smoother, electrical drives and electronic controls. Non-metallic panels for guards, covers, trays, access doors etc., are used to reduce noise radiation from sheet metal surfaces. Drive paths are made short and stiff with a minimum number of transmitting elements and controlled clearance throughout.

Operator safety is an important aspect of machine-tool design and construction. While regulations are more stringent for metal-forming equipment, metal-cutting machine tools are also subjected to mandatory safety regulations both in the case of simple manually operated machines and NC and similar advanced machine tools. Guards and seals to protect the operator from chips, coolants and other hazards have already reached a point where there are often limiting factors in quick loading and unloading. This is especially true of grinding machines designed for abrasive machining. These conditions point to new machine configurations in the years ahead.

Future machines may evolve along lines where the guarding is distributed between the machines and the operator rather than being confined to the machines totally. Possible solutions lie in partial curtailment of the working zone, allowing quick and easy access while the operator is placed in an enclosed control station. The use of closed-circuit television can become popular as a visual link between the operator and the machining zone, with remotely operated systems for scanning the work, gauging and inspection when required. Doubtless such methods will be applied only where the machine and production situations lend themselves to reasonably long operation without operator intervention.

Another solution that is likely to be used is to substitute robots for loading and unloading operations while the operator is sufficiently removed from the machine to avoid hazardous conditions. Such concepts are bound to appear on future machine tools since safety considerations will not be allowed to impair the productivity of the machine.

Energy management in metal-working : About 1 hp (750W) of power is needed at the spindle of a machine tool to produce mild steel or cast iron chips at a rate of 16 cm^3/min. in milling, drilling or turning. The power required is more in some other alloys and less in materials that could be machined more easily. In other words, it takes about 12 Wh to turn out a pile containing 16 cm^3 of chips. This in itself does not appear very expensive, but it should be remembered that the energy required concerns only the material cut from the workplace, and does not include the energy fed to the spindle drive to overcome mechanical losses of gears and bearings and also the electrical losses within the spindle drive motor.

The adoption of a manufacturing philosophy that boosts productivity, whether computer-based or not, also leads to a higher level of energy efficiency. The choice of cutting tools that increases metal removal rates or ensures longer tool edge life or reduces the machine down time for tool changing also facilitates and increases both productivity and energy efficiency. The modern trends towards higher productivity in machine tools is basically meant to enhance the energy efficiency.

The price of industrial energy is about triple what it was in 1967. Energy costs are increasing at a rate of approximately 15 per cent a year and economists are not forecasting a slowing down of this rate even if the current rate of inflation is brought under control. Perhaps the most important factor in machine use, however, is reliability in terms of machine performance and uptime.

Design is often a creative compromise of conflicting requirement. Clover design can increase the output, reduce down time and enhance universality, or the flexibility to handle different workpieces and materials. Considerable research is being carried out on easier chip disposal, improved systems of automated workpiece loading and unloading, safety, ergonomics, energy conservation, faster tool and workpiece clamping, and cutting with more than one tool simultaneously.

MACHINE-TOOL CONTROL SYSTEMS :

A spectacular new art of manufacturing, based on the changing nature of the information stream that runs a manufacturing enterprise, is emerging in developed countries. In the past, human beings were both the translators and transmitters of information. The operator was the ultimate inter-face between the design intent as incorporated in the machine drawing or instructions and the functioning of the machine tool. Human beings used mental and physical abilities to control the machine tool.

However, computers are increasingly becoming the translators and transmitters of information, and numerical control is perhaps the most representative example of the kind of control that plugs into a data stream with the minimum of human intervention. Historically, numerical control has been the most significant development of the electronic revolution as it affects manufacturing engineering.

The possibility to store information at a low cost and to compute and regulate on the basis of stored information has considerably automated the production cycle. Storage, computation and machine regulation is done according to the principle of digital technology, that is by employing a large quantity of evaluated symbols with elements of semiconductor technology. In other words, the building blocks of modern electronics hold the key to control technology. The following basic aspects of machine-tool controls are important to the user and manufacturer alike: operation and programming; operation safety; cost; flexibility and extendability; and integration and standardization.

A numerically controlled machine tool is a machine which grinds, drills, turns and cuts according to a predetermined programme. Its work cycle is recorded on perforated cards or tapes or on magnetic tapes. Commercial production of NC machine tools began in the United States as long ago as 1952. Their application was limited, but during the past decade they have become significantly more sophisticated, compact and cheap, partly because of the silicon chip and the associated micro-electronic technology.

Though initially numerical controls were built to prove their efficacy in machine control, many of the above factors associated with the new art of manufacture were not considered. Today numerical control is no longer an engineering curiosity. It has come to occupy an important place in the very concept of production engineering. The development of NC, rendered possible by the remarkable growth in semiconductor technology and digital science, is designed to make it an invaluable tool of production, due attention being paid to its reliability and cost.

A decade ago, numerical control was a means of automatically controlling machine movements with the help of coded numerical instructions. These instructions were contained in a punched tape. The coded tape was the heart of NC, with the responsibility for controlling the sequence of machining operations, machine positions, spindle feeds and rotational directions, as well as many other functions like control of the coolant pump. But, in the last ten years, NC has changed considerably. Transistors have given way to integrated circuits. Advances in computer technology have helped to replace all logical hardware. Decision circuits have been superseded by executive software in the form of minicomputers. The NC guided and controlled by computer has given birth to computer numerical control (CNC) which is the heart of the modern machining centre. Part programming, inter-active computer graphics, adaptive control, micro-computer codes, servo-mechanisms, human engineering and on-line diagnostics have been added to the establishment aspects of process planning.

The computer and the properly designed software have made increased sophistication of CNC control possible. In conventional NC, this increase in sophistication necessitates more hardware with a consequent rise in costs.

All the machine axis irregularities may be measured and inserted in the control software so that in subsequent programmed operations the absolute accuracy of movement is maintained. It is thus possible to produce a part which is even more accurate than the machine itself. This feature facilitates programming, optimizes machining conditions and achieves consistent surface finish and accuracy.

To reduce the machine set-up time and compensate for tool wear, the offset date can be stored in the memory and called at any appropriate time. Use of thumb-wheel switches for storing data as in hard-wired controllers is eliminated. Virtually an unlimited amount of offset information can be provided.

In the case of tool breakage, the machining operation can be stopped and the tool changed without destroying the programmed data.

The present trend is to use a programmable machine interface where a machine interface ladder network can be programmed in software. This has helped the machine-tool builder to eliminate a considerable number of relays, contactors and magnetics. Changes in the interface do not require corresponding hardware changes. The ladder network can be displayed on a cathode ray tube (CRT). This feature is an extremely valuable tool in debugging the machine interface program, enhancing the reliability of the system. Since a great deal of hardware is in CNC systems, diagnostics is a very important tool for correcting the faults that appear in the course of operation in the hardware circuits of the systems. Since a computer used in a CNC system has the ability to perform different tasks under different programs, a proper program can be written to make the computer work like a circuit tester instead of an NC Controller, thereby providing a diagnostic program.

The use of a general-purpose minicomputer and related software as part of control systems is being discontinued. Control systems built with microprocessors and dedicated software are the basic constituents of the CNC system.

The development of computer technology has made possible the introduction of NC machine tools which themselves had drastically changed the technology. Further improvements in controls are foreseen, such as those designed to increase their capability and their memory to allow more functions to be monitored and controlled. Rapid progressive electronics causes machine tool controls to become obsolete in three to five years. There will be new, complex, high-performance controls as well as simpler low-cost versions suitable for less complex parts and versions compatible with manufacturing systems.

Computers have proved themselves in stand-alone machine-tool controls. CNC Units are replacing hard-wire NC, and programmable controllers are replacing hard-wired relay logic. Computer reliability has been remarkable, and controls have helped to increase machine uptime and the time needed to correct failures. A modular control design that allows for add-on capability with additional functions can improve flexibility and reduce costs. In addition to the central processing unit, the use of more computers is expected, with functions such as the following:

supervisory computers in the DNC or machining system comprising several machine tools; an aid to optimization and shop performance, in the form of a small hand-held computer or micro-processor or a small personal computer; and a tie-in of machine tools to a computer-assisted comprehensive operations-control system in the company.

Some of the methods of improving machine-tool control units include the following:

use of integral adaptive controls; features to assist or speed up accuracy measurement of the machine tool; using the computer and display already embedded in the machine tool for training of operators or maintenance personnel; novel schemes of error compensation; additional diagnostics; devices to reduce set-up efforts and time, such as tool-set stations or feeler probes placed in the tool holder with automatic adjustment for tool wear or fixture positions; on-the-machine inspection of geometry or surfaces with automatic correction; keeping record of machine utilization or cutting-tool life; self-healing or self-repair after diagnosing a certain failure such as a broken drill; and development of the ability to modify a program on the shop-floor or record the events of the last minute or two prior to a failure.

Standardization of interface or language and data communications is an important concern, like terminology and maintenance methodology. Strong efforts are being made to evolve a set of standards.

Interactive graphics, a powerful emerging technology, is playing an increasing role by providing visual displays for monitoring and command or control at each step in the manufacturing process, from design to cutter motion and interaction and the complete manufacturing systems. Improvements through three-dimensional modelling of parts and clearer communication between the devices and the operator are under-going further intensive investigation.

Verification of input data prior to running a program on a machine can be very cost-effective in batch production of complex parts. The spin-off benefit is to prevent production machine tools from being used extensively for tape checking.

Adaptive controls, although studies for about 15 years, have found only limited applications. Improvements in understanding the cutting processes, the variation of cutting conditions and more reliable sensors need to be developed. Good sensors for tool wear and breakage, geometric dimensions or contours, preferably of the non-contact type, and demonstrations of specific complete adaptive control systems have not yet been perfected.

There is a need to develop more and better sensors. techniques for identifying intermittent errors and diagnosing more of the mechanical failures through signature analysis or other techniques. Novel diagnostic approaches are also needed, such as those making it possible to predict a failure and permitting orderly shut downs of operations rather than unscheduled emergency stops.

Future NC systems will be microprocessor-based and provided with computer graphic display. With computer-aided design the use of this graphic display will be extended to the NC systems, resulting in the interactive graphic CNC system. One firm has already brought out a microprocessor CNC for turning machines with automatic programming and interactive graphic display. In this system the cathode ray tube (CRT) can display the appearance of the finished part, the programmed tool part, the actual position value, the system parameters, program data, tool offsets and diagnostics. A paging facility is provided for viewing long programs on the cathode ray tube display.

Automatic programming is another feature of CNC to attract users of NC machines. The post-processor is built into the software of the system. The operator need only enter the basic dimensions of the workpiece, the codes for the tools used, the offsets, feeds, speeds and some simple instructions through the key-board. The built-in software does the necessary computation, calculates the arc centre and programs itself.

In the field of diagnostics for maintenance of CNC systems, remote diagnostics will be commonly employed in future.

Two such remote diagnostic facilities are currently offered to NC users in the United States. Remote diagnostics involve the use of a telephone to transfer digital information between a malfunctioning CNC system and the central computer used for diagnostics on the premises of the manufacturers. The central computer is able to make a multitude of analysis and checks on both the control unit and the machine elements, thus rapidly pin-pointing solutions to malfunctions and also spotting potential sources of failure. The system acts as an expert on the shop-floor, talking the same language as the equipment, eliminating communication problems and delays in problem-solving, and saving expenses by the travelling field service engineers. This facility can also be extended to other countries by using a satellite communications link.

Electronics from the most sophisticated computer to the circuitry in a simple drive of a sensor have introduced versatility to manufacturing technology. Advances in electronics are expected to increase cost-effective production.

Electronic control, for example, will change the concept of a stand-alone machine and allow the machine to function as part of a system. The machine cycle will be altered either by remote command or by conditions sensed on the machine, such as a process variable or the position of a surface.

Machine performance will be monitored by electronic sensing devices. The information thus obtained will be useful for diagnostic analysis as well as for management decision making on machine utilization.

To be useful, however, machine feedback will have to be communicated to someone besides the machine operator, and so control at the machine will involve the additional responsibility of a communications terminal. Electronic technology, such as the data transmission and line protocol, will help create an information flow that will make the machine an integral part of the manufacturing system.

Knowledge of software design and system integration will then become necessary in manufacturing plants. A good software designer, for example, will be able to maximise hardware utility and create flexible systems that others can repair and alter. A systems integrator should understand and determine how all the elements work in relation to each other.

Producing NC tapes through voice command is already a reality. A speed processor that converts a programmer's analog voice signal into the digital language of the computer permits part programs to be generated by vocalizing the data.

A system introduced in 1979 incorporates large custom-integrated circuits and the latest techniques in electronics such as high-speed microprecessors and bubble memories. It is capable of operating a robot, thus eliminating the need for a separate NC system for the robot, and it uses only about half the parts of the system it replaces. Another system which will reduce the number of parts still further through the use of very large-scale integrated circuits is being developed.

Soon microprocessors will start replacing wheels, gears and mechanical relays in a variety of control applications, because it is more efficient to move electrons around than mechanical parts.

Machine Design : More sophistication is now built into machine tools to machine a part in a single set-up. Simple two-axis lathes have given way to four-axis lathes and turning centres. Similarly, four-axis and five-axis machining centres are replacing three-axis milling machines. Automatic tool changers with large tool magazines and chains to store upto 70 tools or more are a standard feature of the modern machining centre. The contouring table is now used as the fourth axis of a machining centre instead of an indexing table. Pallets are to reduce workpiece set-up time.

Turret lathes are now the most common NC machines. The present trend is to have a single combination turret which can hold tools for both internal and external diameter turning. However, much care is required in planning the tool layout and to ensure that there is no interference between the tools and the chuck while machining the internal and external diameters. Production centres are available on which all basic machining operations like turning, boring, drilling and milling can be done in one set-up. A spindle can also be indexed and moved up and down to do many milling jobs.

Control systems are now being built as an integral part of the machine tool itself. Builders of CNC systems now offer control systems in the form of different modules, so that machine-tool builders can buy only the modules required and accommodate them in their machine structure. By this modular concept, it is possible to eliminate bulk stand-alone enclosures, to amplify machine electrics and to avoid having long interface cables. This concept has cut down the cost of NC machines.

V. NON-TRADITIONAL MACHINING METHODS :

The increasing use of difficult-to-machine materials, such as hastelloy, nitralloy, vespalloy, nimonics, carbides, stainless steels and heat-resisting steels in the aerospace, nuclear and communications engineering industries and for the manufacture of military hardware, has spurred the development of non-traditional machining methods. Conventional machining processes have become inadequate to machine these materials according to rigid quality standards and economic production requirements. In addition, the machining of such materials into complex shapes is difficult, time-consuming and sometimes impossible.

Non-traditional machining techniques have overcome some of the machining difficulties. The non-traditional methods are classified according to the nature of the energy employed in machining, namely thermal and electrothermal, chemical and electrochemical and mechanical.

In the thermal and electrothermal methods, the thermal energy is employed to melt and vaporize tiny bits of work materials by concentratinv the heat energy on a small area of the workpiece. By continued repetition of this process, the required shape is machined. These methods include electron-discharge machining (EDM), laser-beam machining (LBM), plasma-arc machining (PAM), electron-beam machining (EBM) and ion-beam machining (IBM).

The chemical and electrochemical machining methods involve a controlled itching or anodic dissolution of the workpiece material in contact with a chemical solution. These processes include chemical machining (milling and blanking), electrochemical grinding, honing and deburring.

In the mechanical methods of non-traditional machining, material is primarily removed by a mechanical erosion of the workpiece material. The mechanical methods include ultrasonic machining (USM), abrasive-jet machining (AJM) and water-jet machining (WJM).

Non-traditional machining processes are applied to all metals and alloys. This is in contrast to the conventional machining processes which vary in their application depending upon the strength and the hardness of the material. Among the non-traditional processes themselves, there is a good degree of variation in respect of their application on different work materials.

The application of non-traditional machining processes is also influenced by the shape and size of the workpiece to be produced, including holes, through holes and cavities, pocketing, surfacing, through cutting etc,.

The other parameters of comparison between conventional and non-traditional machining, on the one hand, and among the non-traditional machining methods, on the other, are with regard to material removal rates, the power consumed and the accuracy and surface finish that can be achieved.

Non-traditional machining processes cannot at present completely replace conventional machining methods of metalworking. They also do not offer the best solution for all applications. They should only be viewed as complementing conventional metalworking methods. The suitability of any of the non-traditional machining process for a specific application should be judged from the standpoint of increased reliability of the process, better assurance of quality and the ability to machine work-pieces which cannot be machined easily by any conventional methods.

VI. METAL-FORMING MACHINE TOOLS :

Until the third quarter of the twentieth century, metal-cutting has dominated over metal-forming in the metalworking industries. The share of production of metal-forming machines as a percentage or world machine-tool production was barely 10 per cent during the 1940s and 1950s. However, the present concern to conserve materials, the rising cost of energy and the need to explore new routes of production have given metal-forming considerable significance. Metal-forming machines such as mechanical and hydraulic presses (single-column open-back inclinable types, heavy-duty, straight and double-column types and forged types), press brakes, shears and guillotine machines represented more than 20 per cent of total world machine-tool production during 1979, and since then, have remained steady at 24 per cent (1988). However, there are signs that this share will rise to 30 per cent by the end of the century.

The plastic deformation of metals take place in two ways : by bulk deformation and by incremental deformation. Until 1960 metal-forming machines, mainly conventional forges and presses, were built to accommodate workpieces formed by the bulk deformation process. However, incremental deformation processes are currently finding wider application. These are to a certain extent non-traditional forming methods. They include helical rolling, ring rolling, spinning and flow-forming. These non-traditional methods and other high-speed forming techniques such as fine blanking and NC punching, powder metallurgy are partly responsible for a discernible shift from cutting to forming.

High-speed Forming : A great deal of interest is now being shown in various methods of forming metal at very high speeds. Considerable development efforts on a wide variety of processes have resulted in some high-speed forming techniques which have become important in industry by replacing conventional methods.

Development engineers in the United States have designed and built a stamped-steel automotive exhaust manifold that weighs 60 per cent less than its cast-iron counter-part. Weight reduction, hence energy-saving, was the main objective, but faster engine warm-up and noise reduction are additional benefits. Many automobile manufacturers are closely following developments in stamped engine components.

Internal combustion engines will never be stamped out like wheel covers, but in eight to ten years from now most of their components could be products of press-working shops. Moreover, the exhaust manifolds and piping ahead of the catalytic converter could consist of stampings even sooner.

The automobile industry uses a great many presses which are continuously being improved in design. Their greater capacity (1,500-5,000 tonnes), suitable also for deep-draw metal-forming operations, gives greater production and higher quality of pressed components such as bodies. doors, panels and bumper stamping for cars and trucks with advanced designs of safety accessories. However, more sophisticated application of forming presses is seen in the aircraft, space and armament industries. In the production of military hardware, new technologies are being used in the assembly line of transfer presses to produce cartridge cases of higher calibres.

Cold-forging : The cold-forging of steel has attracted attention as a method of improving the utilization of material in the manufacture of engineering components. Although the process is still not regarded as a means of producing components difficult to make by other methods, cold-forging is now receiving much more attention as a result of the rising cost of material and the low recovery price of swarf. In cold-forging, usually the starting billet is progressively changed in shape until the final form is achieved. This involves different deformation processes combined in an arbitrary sequence. The basic sub-processes involved are extrusion, upsetting or heading, drawing, ironing, swaging, expanding, threading and form-rolling.

Fine-blanking presses : A part made by the blanking process is essentially . finished part. A triple-action sturdily built press exerts forces on equally sturdy specially designed tooling and, with precision unattainable on conventional presses, shears a part with smooth-edge contours from stock as thick as 20mm. The part may be pierced, counter sunk, bent or coined. It may become flatter. Offsets may be formed in it without loss of demensional accuracy. Most important, many, if not all, secondary operations that may have been required to produce it by previous conventional methods are by-passed. The real advantage of fine blanking is the time and money it saves.

Innovations in punching by numerical control : Flat metal was first punched using NC in 1955. This innovation had far-reaching consequences, leading to major changes in machinery for producing holes and contoured cuts in sheet metal plates and structural steel members. It also affected the operation of companies that bought such equipment, boosting their manufacturing efficiency.

Everyone, including manufacturers of controls, tooling and auxiliaries, benefitted from the adoption of NC by the metal-punching industry, just as builders and users of metal-cutting machinery have reaped the fruits of NC since its introduction. The widespread acceptance of this type of punch press control stimulated new press designs and improvement on earlier designs. In recent years, it has led to hybrid machines that not only punch but also cut by plasma arc or laser beam and even perform such functions as milling.

On most sheet metal and plate machines, however, NC not only governs the X and Y-axis positioning of the workpiece and actuation of the punch, but also selects the correct tooling at the right moment in the punching programme on presses with automatic tool changers. These machines represent a new generation of metalworking machines.

Powder-metal technology : The powder metal (PM) method of forming finished to almost-finished components is gaining popularity in the manufacturing industry. More and more parts in the instrument, aerospace and automotive industries are exploiting this technique. PM carbide tools, high-speed cutting tools, low-cost PM-brass and liquid phase sintering are some of its applications. Test results on aluminium PM parts compacted by means of shock waves have proved successful, and parts which could not be made in one piece with conventional PM - compacting techniques are being injection-moulded. These and other innovative techniques in PM and injection moulding could be employed to produce many difficult-to-machine complex parts.

Non-traditional forming processes : Instead of the brute force used in bulk deformation techniques, the incremental deformeation techniques, employ force purposefully and skillfully. These non-traditional forming presses are helical rolling, ring rolling, spinning, flow-forming and rotary forging. Of these processes, rotary forging, spinning and flow-forming are now the most popular ones.

Future of Forming : Metal-forming is bound to attract greater attention in the future because of the growing concern to conserve material and restrict energy input to optimum levels. Forming is increasingly preferred because it not only makes a more prudent use of material, but also has in-built possibilities of better control over material properties.

The future of forming is bright because it allows reductions in machining sequences which are otherwise inevitable in metal-cutting. The newly developed high-precision die-casting and forging techniques, precision-blanking and sheet metal-working methods and advances made in powder metallurgy, fine-blanking, NC and CNC punching, investment castings and cold extrusion, and explosive, electrohydraulic, electromagnetic, compressed-gas, water-hammer and fuel-combustion forming are offering production managers more economical routes of production. Even though tooling costs of metal-forming machines are high at present, future research efforts may bring them down, particularly through the use of CNC in the manufacture of dies and tooling.

VII. TECHNOLOGICAL TRENDS IN PRODUCTION ENGINEERING

The following three major factors have combined in the last decade to advance manufacturing technology to its present stage: the increasing cost and shortage of skilled labour; the higher productivity and automation of new machines (including CNC) offered by machine-tool builders; and the availability of reliable low-cost computers.

Average lot size has decreased in recent years, even in traditional mass production industries such as the automobile industry. Today, the emphasis is on high volume rather than mass production. The latter implies millions of identical parts while the former means production at the same high rates but with the ability to adapt to customer preferences. To meet higher performance standards and safety and ecological regulations, manufacturing tolerances are becoming finer. All these factors have enhanced the importance of optimization technology in manufacturing, which in turn has led to innovative types of machine tools and machining systems.

Computers in manufacturing : Computer monitoring or control of plant operation is the most significant trend in the metalworking industry. Computers are used to solve scientific and engineering problems related to product design and production engineering, ensure the flow of parts and assemblies, control inventories and monitor production operations. Scheduling is computer-controlled, the objective being to keep machines and production lines as fully loaded as possible in order to receive maximum return on company investment and facilities.

Probably the biggest advantage of computers in metalworking plants is their ability to keep track of what happens on a real-time basis. Alerted by computers, management is able to make decisions when they are needed and whn trouble occurs. The managers are able to study metalworking operations in their plant in great detail to find where process improvements (e.g. better flows of parts and materials between machine and tools, better allocation of manpower and brainpower) will pay off.

Computer-aided design and manufacture are making it possible to transfer all the routine functions in manufacturing operations to the electronic computer vesting in it a limited supervisory control and using its data-processing capabilities to optimize the manufacturing operations. Electronic control of manufacturing operations is advancing as rapidly as development of software will permit.

Emphasis is currently on linked machines, integrated systems and Computer-Aided Manufacture (CAM). The stand-alone CNC machine and groups of CNC machines are now widely used for batch manufacturing. Future CAM systems will probably be formed by linking first one and then several CNC machines with automatic work handling or robotics with overall control by means of hierarchical computer systems. The next logical progression will be linked multiple systems of this type with automated assembly, which could possibly be the forerunner of an unmanned factory.

Direct numerical control of NC machines from a central computer has played a less prominent role while recent attention has been focused on a systems approach to batch manufacturing, namely Flexible Manufacturing Systems (FMS) and unmanned manufacturing systems. All the integrated CAM systems are aimed at batch manufacturing, have a high level of materials handling and have integrated control systems. Hence they can be considered an extension of DNC systems with the inclusion of management information systems, work transport and possibly tooling transport systems.

<u>Integrated Manufacturing</u> : An integrated manufacturing system is one that combines a number of hitherto separate manufacturing processes so that they can be controlled by a single source. The chief benefits are as follows :

reduction in lost time caused by inter-stage movement of the components being made; improved machine tool utilization; reduction in manpower; reduction of work in progress; and greater flexibility of component batching and loading.

At present, the majority of systems developed have concentrated on the machining processes involved and, in particular, the manufacture of prismatic parts. A truly complete integrated manufacturing system would require the same degree of co-ordination and control to be applied to other major operational areas, that is, production of rational parts, fabrication and assembly.

However, the main concern has been with the application of this type of manufacture to small batch production, which represents a significant proportion of manufacturing output in almost all countries. It has been estimated that the different in cost between mass production and small batch production of the same components can be as much as 30 to 1, and an appropriate expression of the cost target for integrating manufacturing systems could be the mass production of one-offs.

Production could now be accurately planned through a complex system of machining operations, and the manual content has been reduced largely to that of inspection of parts and tooling to maintain the standards of accuracy and finish demanded by the specification of the component. Because of the high operating efficiencies leading to greater tool-cutting time, a group of eight machines can be equated to 100 conventional machines in output, especially on small batches up to 50 parts. The average number of machines in a system varies between five and nine machining centres, though in the United States 70 have been included in one system.

<u>Computer-aided Manufacture (CAM)</u> : A CAM system is a closed-loop regulating system, the primary input dimensions of which are demand (requirements) and product idea (creativity), and the primary output dimensions of which are finished components (finish-assembled, tested and ready for use). It represents a combination of software and hardware involving production methodology, planning and control, and the choice of production aids including machine tools. It can be realised by systems engineering methods and offers a possibility of total automation through flexible and adaptive means. The most important aid to achieve this goal is the computer. This is the basic concept guiding the development and application of computers for integrated production.

In other words, CAM is a conglomerate concept where the ability of the computer is used at every stage of manufacture by evolving a cellular structure. Though this type of manufacturing may appear related to the transfer-line concept, CAM has the flexibility, unlike transfer-lines, to alter the type of product and the product flow sequence from machine to machine. The alteration of product flow sequence is done in such a manner as to keep the idle time of any machine to the minimum. Such flexibility is achieved because of the monitoring and control exercised by the central computer.

The flexibility offered by new hardware and software is encouraging a shift from fixed-programme mass production facilities to variable-programme automation. It is now realized that the best benefits of computer control are only obtained in a kind of group technology where the machines are linked by automatic transfer systems and the computer keeps a continuous track on a variety of components as they go through the manufacturing cell.

The DNC computer is now extended to handle management functions within the manufacturing cell such as scheduling, inventory, materials management, budgetary control and reporting. The integration of a number of such manufacturing cells into a single manufacturing facility through a central computer will complete the cycle, giving rise to the integrated manufacturing system. Such systems are required to have a hierarchical line of computers at different levels. Information and feedback from various cells, back to the central large computer, which possesses software capable of programming the whole operation for the optimum utilization of resources. The addition of automatic warehouses, assembly, test and dispatch systems is also proceeding, leading to the possibility of automated unmanned manufacturing.

Flexible machining systems (FMC) : Flexible manufacturing systems have three distinguishing characteristics: potentially independent CNC machine tools; a transport mechanism; and an overall method of control that coordinates the function of both machine tools and the conveyor system so as to achieve flexibility. The main purpose of such systems is to integrate the various functions in the same machine tool to form a flexible manufacturing cell that is a module of flexible manufacturing systems.

Each flexible manufacturing cell is an autonomous module, the functions of which are supervised and controlled by a microprocessor-based computer. The various functions of the individual cells are as follows : supply of blanks, tools, gauges and devices; use of clamping devices for identification selection, transport, orientation, loading, positioning, clamping, declamping, interlock supervision and other step-by-step operations; automatic execution of operations such as measurement of the workpiece, adjustment of clamping device, material handling and positioning, and automatic monitoring by sensors of interlocks, lubrication failure, tool breakage and other malfunctions.

Each cell basically caters to a paticular machining process like turning and milling. The different cells are connected by transport devices into flexible manufacturing system, and the coordination of the simultaneous activity of all the cells is accomplished by the process computer hierarchy so that from raw material to end-product the complete production process is automated.

An alternative concept of a flexible machining system envisages a manufacturing cell which performs various machining processes like turning, milling and boring as a part of one individual cell. In this case, the material-handling functions are reduced. An existing stand-by robot or integrated robot handles the workpiece and the measurement device.

Maximum utilization of the cutting capability of the machine tool is ensured by an adaptive control. Suitable sensors to monitor process parameters are incorporated in the manufacturing system. The CNC system integrates the whole control strateg for utilization of installed capacity, reduction of idle time and monitoring the thermal effcts on component accuracy.

Several manufacturing cells linked by a transport system, additional handling devices and an automated storage and retrieval system for the workpiece, tools etc., can lead to the concept of an automated factory. The most advanced stage of optimization would involve a hierarchical organisation in which all cells at a higher level are controlled by centralized DNC-type computer and all production groups are linked to a mini-computer, providing a basis for complete on-line optimization of material flow, scheduling, routing, and full automation of production.

Flexible manufacturing systems based on group technology or cell production principles using CNC machines and gauging equipment are now being installed with robot handling devices and palletized conveyor supply units to machine families of parts.

Development is also proceeding with the automation of metal-forming machines using mini-computers and micro-processors. Pogrammable turret punches, auto-controlled guillotines and shears, and manipulative equipment are in use. Robot developments applied to metal-forming operations will enable a considerable degree of automation in this class of piece-part manufacture. It is now possible to construct metal-forming production cells with the aid of robots that will blank, pierce and bend a family of components using a common stock material.

The manufacture of piece-parts, whether forged, welded, sintered or similarly processed, is being automated with the use of robots. The automation of assembly operations remains problematical, except for flow-line manufacture. But robotic and computer developments will have considerable impact on these operations in the immediate future.

Group Technology : One of the methods of solving the problem of conflict between productivity and flexibility in the computer-integrated flexible manufacturing system is group technology, which is a progressive management concept employed in an engineering industry within the framework of an integrated manufacturing system. The application of group technology in a purposeful manner can result in economic benefits of mass production even in large and medium batch production. In addition to streamlining production through the rationalization of components, it also helps to establish better co-ordination between the production wing and other functions like design, methods and sales engineering. The fact that more than 80 per cent of the engineering industries of the world are engaged in medium and small batch production should give the concept of group technology a new significance.

Traditionally laid-out production lines based on functions such as turning, drilling and boring, lead to many production delays because of inherent limitations in production control. A group technology-based production system organizes the production facilities in self-contained and self-regulating groups, each of which undertakes complete manufacture of a family of components with similar configurations and manufacturing characteristics. The different cells of the group technology system virtually function as small factories within the main factory. This assures reduction in throughput time, work in progress, inventory, setting time, work handling, jigs and fixtures etc.,. This concept improves design rationalization, job satisfaction and production control. NC shops are at present major areas where group technology is employed. But with a shift from hard-wired NC to software-based control like CNC, much of the essence of group technology will trickle down to the software.

Computer control and inspection of machine tools :

The evolution currently taking place in the direction of computer control and inspection of machine tools represents the most progressive field of development of modern machine tools. It is aimed at exploiting the enormous potential of NC throgh CNC, DNC and the hierarchical computer system. This potential is steadily increasing in scope as a result of the advance continuously being made in the field of computer technology.

More and more mini-computers are being used in the work-place. Because of the linkage between the work stations, the trend is toward a decentralized computer, which allows a partial separation between data processing and the control function. This is especially true of computer control of machine tools. The computer has thus become the most modern device for error diagnosis and correction on modern machine tools.

The future trend will be towards the development of methods which facilitate automatic correction of malfunctions. The computer, as soon as it detects conditions that may lead to an error, will alter machine parameters in such a manner that the error will not actually take place. In case of malfunctioning, the computer will send a command for the replacement of the defective electrical or mechanical module. Thus it is now possible to operate machine tools without operating personnel.

Metrology and Inspection : Metrology is going through a revolution brought about by the integration of electronics with the science of measurement. Developments in inspection and gauging equipment are aimed at matching the high production rates of modern machine tools and meeting the requirements of finer measuring resolution and higher accuracy. A large degree of automation is also being built into these systems for compatibility with automated manufacturing systems.

Major trends in gauging and inspection equipment point towards an increase in speed and accuracy of measurements. Systems using opto-electronics and electrical contact to replace electromechanical probes have been specially developed and there is a clear trend towards remote sensing of size, using lasers and similar devices.

A complete shift to digital display of information in most measuring equipment, including such devices as hand-held micrometers, is now evident.

Different devices are being integrated with measuring centres, especially in post-process inspection equipment. Applications of mini-computers and output devices such as plotters, printers and cathode ray tube (CRT) displays have been developed to enable inspection equipment to achieve rapid and accurate processing and presentation of metrological information.

An increase of two orders of magnitude in accuracy has been obtained in the resolution of measurement. With the advent of the job-shop laser, it is now possible to measure distances down to 0.01 micron.

Progress in measuring techniques has been so rapid that the resolution and accuracy of gauging have reached limits governed by the inherent instability of the machine and workpiece system. The stress on machine design to achieve higher final part accuracies is now greater. The drive towards even higher part accuracies continues, justified on the grounds of lower rejections, requirements of automatic assembly, longer final product life, legislation to reduce noise levels and the needs of related technology such as integrated circuits.

The development of compact and reliable electronic probes has made possible in-process gauging on transfer lines and other automatic manufacturing systems. Systems are being developed to use this capability in the adaptive mode to correct job or tool setting to achieve the required size. Automatic gauging systems are also applied on equipment used for automated assembly. Modular automatic inspection systems have already been developed to fit automated production lines ranging from automobile to bearing manufacture. these modules can be combined to suit gauging requirements on a wide variety of parts and to incorporate devices to load, transfer, index and unload parts and segregate them into acceptable and rejected lots.

Assembly and materials handling: Assembly, with its high labour content, is an area holding potential for profitable automation. Mass production industries in developed market economies have made considerable progress in this direction.

So far, automated assembly has been applied only to subassemblies. Even in the automobile industry, automated assembly has been applied only to subassemblies like the rear-differential axle and brake-drum. There is, however, a continuing search for methods to extend automatic assembly to whole products. Modern systems integrate assembly, inspection and testing into one automatic proces. Automobile engine assembly is one area that has seen the application of such concepts with the process being controlled and monitored by computer.

Future design of automatic assembly equipment will also incorporate gauging, which will have a special impact on the electronics industries. Attempts are being made to use such systems in mechanical assembly when parts become jammed together or deformed without the knowledge of the operator.

Controls for assembly machines have also experienced considerable development. Programmable controllers are commanding many assembly machines, surpassing even computers and hard-wired controls in a number of applications.

Substantial progress has been made in recent years in the development of fasteners. New types of bolts, screws, nuts and rivets make assemblies easier, faster, cheaper and adaptable to automation.

The newest concept is a system which sets bolts under a kind of adaptive control that shuts down the fastener driving tool when a preset torque-rot tional angle combination is reached.

Industrial adhesives are taking over many areas now served by mechanical fasteners. Techniques of adhesive bonding, originally developed for aerospace applications, may produce revolutionary changes in mechanical assembly.

Materials-handling systems are being integrated increasingly with operations in the plant. Computers are obvious tools for application in such systems. Foundries will be a major target for automated computer-controlled materials-handling systems in the years ahead.

VIII. AUTOMATION AND FUTURE TRENDS IN PRODUCTION TECHNOLOGY

Robots : Robots have been on the industrial scene since the early 1960s, but the first models were large and designed mainly for tedious, difficult and hazardous tasks.

Thanks to modern micro-electronics technology, robots have computers that enable them to learn a succession of tasks and versatility that promises to render obsolete a good deal of what is currently thought of as automation. Robots in fact represent the latest advance in automation, whether programmable or flexible. As distinct from the automatic mechanism, a robot generally has a multiple degree of rotary and linear freedom that can be actuated individually and simultaneously to give a close approximation to the physical motions of a human being performing the same tasks.

Whereas the earliest robots were controlled by programmes set with limit switches, modern robots are programmed by a minicomputer to which they are temporarily attached. Robots have been developed which can be automatically programmed or taught a sequence of movements by a human operator who guides the robot through the sequence.

Robots are at present applied in a wide range of tasks, including loading and unloading machine tools and presses, removing parts from die-casting machines, the handling and transfer of materials, especially in foundry and forge, welding, painting and simple assembly operations.

Prototype robots with rudimentary sensory feedback are already functioning in some countries. The use of television and holographic techniques is having a major impact on the development of robots capable of seeing and recognizing three-dimensional objects, especially when the objects are presented to the robot in a random orientation.

The computer program is the key to turning robots into assemblers. More advanced robots can be told what to do by typing the instruction on a computer keyboard in a language that includes about 100 English words. Eventually, the evolution of robot language will make it possible to give robots more complicated instructions.

Having effectively eliminated the need for skilled operators for most machining operations in the 1960s and 1970s, machine-tool builders in developed countries are trying to evolve reliable unmanned machining systems capable of substantially boosting machine-tool throughout, ensuring strict adherence to stringent quality control standards, minimizing in-process inventories and guaranteeing production rates.

Automation, leading to unmanned factories, is technologically feasible in industry, yet its effect on people could cause insoluble social problems. The widespread use of unmanned factories may therefore come about only gradually, although the scope for unmanned operations under certain circumstances will increase in developed countries.

IX THE TECHNOLOGY GAP AND ITS IMPLICATIONS ON DEVELOPING COUNTRIES

Technological Factors : The phenomenal progress taking place in the metal-working and machine-tool industries in developed countries may be attributed to the following :

the evolution of modern machine-tool mechanics and design, cutting-tool materials and tool-geometry, machine-tool controls, and manufacturing systems. By contrast, the newly industrializing countries have made insignificant progress in these areas, and the least developed countries, with little manufacturing industry, none at all. It appears almost impossible therefore for the developing countries to bridge this wide technological gap.

Machine tool mechanics and design :

In the field of machine-tool mechanics and design, developing countries lag far behind. The majority of the machine tools being produced in these countries mostly the general purpose machine tools - have been licensed from advanced countries. It is unlikely that the licensed designs would be the latest designs, since the latest designs are the main export items of developed countries, and licensors would be reluctant to transfer the designs and know-how to produce these machines elsewhere. Even if it were possible to obtain agreements for license manufacturing rights for some of the advanced designs of machine tools, the licensee would require considerable resources to invest in licence fees, royalties, production facilities and for extensive training of technical and production personnel in order to master the whole process of producing the sophisticated machine designs.

More important is the fact that in developing countries, a sufficiently large volume of demand cannot be expected for highly sophisticated machines. Advanced designs of machine tools, and machining systems are developed to meet specific demands of the machine-tool-using industries such as the aerospace, aircraft, automobile, armaments and engineering industries. However, it is encouraging to note that some of the newly industrializing countries like the People's Republic of China, the Republic of Korea, Taiwan, Singapore and India have taken up the production of CNC machine tools and machining centres to cater primarily to their national metal-working industries of the above categories.

Although computer-aided design is catching up in some of the newly industrializing countries, it is restricted to applications such as bed and column design calculations, gear drives and the main design of main spindles. Computers are mainly employed for checking the designs of machine elements and unit assemblies after the proto-types have been built on empirical designs. Facilities for such work are far too limited and may be available only at machine tool research institutes and universities teaching machine tool technology.

The experience of developed countries has been as follows :

Improvement in manufacturing systems takes place in the machine tools using industries through the availability of advanced and highly productive machine tools; and the advanced designs of machine tools are made available to the using industry if there is sufficient demand for them. Hence, the technological gap in the machine tool industry could narrow if modernization takes place in the production technology employed by the metalworking industry, which is the main customer for machine tools.

If their metal-working industries were given the correct incentive to upgrade their technologies and modernise their engineering methods and production technology, developing countries would in the course of time be able to narrow the technological gap in machine tool mechanics and designs. But taking into account the market situation, the resources available and, above all, the great technological advances taking place continuously in developed countries, the gap in machine tool technology between developed and developing countries will probably be difficult to bridge.

Machine Tool Controls : One of the major technological gaps between developed and developing countries is in the area of micro-electronics. There has been growth in the electronics industry in some developing countries, mainly to meet the requirements of entertainment, communications and armaments production. Though the use of computers for office purposes is comparatively well-established in some developing countries, the industrial application of modern computer technology lags behind that of industrially advanced countries.

Some of the machine-tool producing developing countries have introduced CNC machine tools, but the designs are out-dated compared to those of the developed countries.

The manual-data-input-type of control system is used in some developing countries on centre lathes, knee-type milling machines, drills etc.,. However, modern manual data inputs employed in developed countries are microprocessor-based, and such controls are gradually being introduced by some of the newly industrializing countries.

Manufacturing systems : The absence of the latest computer-integrated manufacturing systems in developing countries stems from their lack of progress in areas such as computer technology and advanced designs of sophisticated machine tools. Although the large-scale introduction of robots into the manufacturing systems of developing countries is not foreseen in the near future and may even be undesirable in view of the presence of a large unemployed labour force, robots could, to some extent, be employed for specific tasks that are usually impossible or undesirable for humans to perform. But without the strong support of computer science, this cannot be achieved.

Metal-forming : With regard to metal-forming presses, some developing countries are manufacturing conventional types of open-back-inclinable and parallel frame presses with hydraulic and mechanical drives and shears and press brakes. Heavy-duty hydraulic and mechanical types of conventional presses, mainly used in mass production industries, are being made in some developing countries, but the hydraulic aggregates and other accessories are still imported from developed countries.

As in the case of metal-cutting machine tools, the technology gap between developed and developing countries with regard to metal-forming presses is also widening each year. This is more apparent in the case of non-traditional forming methods such as helical and ring rolling, spinning and flow-forming. In developed countries, considerable research is focussed on the production of parts consisting of high-strength alloys formed into complicated shapes, for example, by means of powder metallurgy. In some newly industrializing countries, simple types of cold-forging, extrusion, fine blanking and NC punching presses are manufactured mostly under license from developed countries.

One of the main bottle-necks in metal-forming is the manufacture of complicated dies and tooling. For this, high-strength alloy steels must be machined on sophisticated machine tools such as CNC continuous-path vertical or horizontal machining centres. This is an area for future development.

Another piece of sophisticated equipment of the high speed metal-forming industry is the transfer line press for automatic and progressive operations on transfer line, both in forging and forming. Although some sheet-metal forming transfer line presses are manufactured in the newly industrializing countries, heavy-duty and progressive forge presses with NC controls are being imported.

Non-traditional machining : In the area of non-traditional machining systems, developing countries have made very little progress. One reason is that such metal-working processes have a relatively restricted field of application. Moreover, the development, and in particular the application, of many of the technologies has yet to be perfected even in developed countries.

A survey of developments taking place in this field in developing countries shows that only the following processes are employed in the metal-working industries in some newly industrializing countries :

electron-discharge machining, electrochemical machining and electron-beam machining. Of these, EDM and EBM welding have found greater usage than the others. In EDM, the wirecut process is becoming increasingly popular mainly in the production of high-precision die and press tooling, for instance, in the horological and instrument industries. EBM welding technology is receiving greater attention, particularly, in more advanced industries, such as the aircraft, aerospace and atomic energy industries.

Economic Implications : It is not possible for any country, whether developed or developing, to become completely self-sufficient in machine tools. It is also unnecessary and economically undesirable. The largest machine-tool producing developed countries with the exception of Japan, are themselves the biggest importers of machine tools. This type of interdependence, in which a country imports its own requirements of machine tools and yet specializes in producing certain types of machine tools, is a special feature of the global machine-tool industry. Some of the CMEA countries, which at first aimed at becoming completely self-sufficient, were eventually compelled to abardon the attempt and now import a large number of specialized machine tools from developed market economies. This was necessary in order to improve the quality standards of the products of their metalworking industry to compete in the world markets.

It is sometimes argued that production technology employing a comparatively large labour force could be as efficient as highly advanced labour-saving technology. However, labour productivity in developing countries is very poor compared with labour productivity, that is, added value per worker per annum, in developed countries. Productivity improvements are not entirely the result of a more industrious application by workers. Productivity improvements largely arise from the efficient use of material and capital resources. In modern industry, this is possible mainly through better management of resources employing improved and advanced technology.

The insufficient development of the machine-tool and manufacturing industries in developing countries is one of the main reasons for the latters' poor performance industrially and economically.

Over 80 per cent of the world manufacturing industry is in developed countries. Unless there is a massive transfer of modern technology from developed to developing countries, the latter will remain in a state of permanent economic weakness. On the other hand, such a transfer would enable third-world countries to develop their own technological capability and eventually produce a surplus of manufactured goods, machinery and engineering products which could compete on world export markets. With the export earnings they, in turn, could import their special requirements of machines and machine tools thus widening markets for the developed countries.

It has been estimated that in India alone, 10 million jobs must be created every year from now on, to the year 2000 to cope with population growth and the backlog of unemployment. With more than 850 million people, India has a gross national product, two fifths the size of that of the United Kingdom, which has only 60 million people. The same is true for the many developing countries of Africa and Asia. Part of the problem is that most developing countries depend heavily on agriculture, with more than half their products coming from this sector which employs at least two thirds of the labour force. The main object of the policy-makers and governments of developing countries should be to relieve agriculture of this heavy concentration of labour by introducing mechanization and to a large extent diverting labour to industries. This is only possible through rapid industrialization using modern tools and production technology.

Industrialization in developing countries has been very uneven. Some of the middle-income countries have made considerable advances in industry. Several of them have nearly one quarter of their workers in the manufacturing sector, which is as much as some developed countries have, at present. Other countries show little change. In many of the poorest countries, less than 5 per cent of the work-force is engaged in the manufacturing sector. It would be highly misleading to present developing countries as invariably poverty-stricken. Even among the low-income countries some progress has occured, and the newly industrializing countries have achieved remarkable growth rates. Republic of China, Argentina, Brazil, Republic of Korea, Taiwan, India and Mexico have an established industrial base which has increased rapidly in recent decades. Though economically, there appears to be no way for the developing world to match the industrialised countries, yet some of the newly industrializing countries are striving to improve their economies.

X. ECONOMIC AND TECHNICAL CO-OPERATION

To minimise the widening technological gap between the developed and developing countries in the area of machine tools, a possible approach appears to be technical and economic co-operation between the countries. Generally speaking, and this is also the case with machine tools, the scientific and technological achievements of the world's advanced countries could contribute to speeding up the developing countries' economic and industrial progress. This is one method by which developing countries raise the technological level of their economies and sharply reduce the time taken to advance to high, efficient mechanised and automated production which is the basis of modern economy.

How can this be done? From the national, economic standpoint should developing countries import ready-made technological innovations or should they develop their own scientific ideas and develop technological innovations on a national basis? Those seem to be the two extremes of a range of possible solutions. One must take into account the diversity of the developing countries and their disparate economic levels. It is important therefore, to formulate a general principle of approach to the solution of this problem, by the individual countries.

The machine-tool industry represents an area where economic and technical co-operation between the developed and developing countries on the one hand and among the developing countries themselves on the other, could be highly profitable to both groups. However, there are many practical hurdles in the process.

Any technology transfer has, of course, economic implications. Specific technologies, like machine-tool technology, could be acquired at reasonable costs and on acceptable terms and conditions. Since the cost of technology could be high, certain broad priorities should be established and a degree of selectivity applied. As the machine-tool industry is the basic industry for the development of any metalworking industry, in our opinion, it should enjoy high priority in the industrialization plans of a developing country.

The current deliberations in developing countries on appropriate technology are a sequel to some of the failures and pitfalls of indiscriminate purchase and the adoption of alien technology. The types of technology obtained from industrialised countries under 'aid' programmes or outright purchase with scarce foreign exchange, have not in some cases reflected the actual needs of these countries.

The transfer of technology from the industrialized nations to developing countries should not be an exercise of blind faith in technology but that of tested faith in human resourcefulness. This implies that a valid development strategy should be evolved not only from the technologies of the advanced countries but from alternative or adapted technology that should facilitate low capital investment, employment generation and production through decentralised means viz., among the industries and small, medium scale and ancillary sectors.

The choice of technology depends also on the stage of industrial development of a young nation. All developing countries have not attained a uniform level in their industrial and technological progress. One of the major obstacles preventing developing countries from adopting more appropriate designs and production technology is the scarcity of foreign exchange and sometimes even internal resources. As a result, some developing countries depend upon foreign credits and sometimes on 'tied' aids. Such a situation occasionallv raises an element of doubt regarding the relevance of the imported designs and technology to the local conditions and whether the donor countries have not been trying to pass on obsolete or inappropriate technology. Are the foreign partners prepared to modify their latest designs and production technology to suit the prevailing conditions of the recipients?

It is imperative that the choice of technology, as also that of the licensor, is exercised with great care and deliberation, particularly if foreign capital ownership is involved.

The following are some of the more commonly adopted types : joint arrangements for machine tools between licensee and licensor -

(i) Turnkey projects : One of the well-known and well understood modes of acquiring design and know-how, is to enter into an agreement on a turn-key basis. Most of the countries with low and very low levels of industrial status and inadequate infrastructural facilities and knowledge of machinery enter into this type of agreement.

But it is evident that the turnkey method is always costly and one usually pays more. It is also possible in this type of arrangement for the licensing firm to stipulate rigid conditions and that the turnkey arrangement does not provide any flexibility to the licensee, often even taking away the initiative and the enthusiasm of the local management. Therefore, this arrangement is advisable in the initial stages of development.

(ii) Licensing : The design and know-how of building a particular type of machine tool can be acquired by entering into a limited licence agreement. This would include, from the licensor, up-to-date drawings and specifications of the machine tool and components, details and specifications of raw materials required for manufacturing various components, operational schedules of all manufactured components with full details such as types of machines used, timings, details of tooling, heat treatment and plating etc., tool designs, assembly, testing and inspection details, maintenance manuals with a list of spare parts.

A licence agreement should also include the appointment of experts, stipulating the minimum man-months and the areas of expertise as well as the training of adequate numbers of the licencee's technicians and managers.

For such arrangements it is normal to provide a down payment to compensate the costs of development of design and know-how and/or pay royalty on the portion of the work executed by the licensee. This type of collaboration is suitable for countries with a fairly good experience in manufacturing industrial machinery and which enjoys extensive infrastructural facilities.

(iii) Selective collaborations : When a country develops its own expertise and has sufficient years of experience in manufacturing varieties of engineering products, it could normally resort to very limited and highly selective collaboration tie ups. Sometimes, all that is needed is to pay a lumpsum to acquire designs and drawings. Further assistance, if any, might include services of experts for a limited duration in vital areas, the training of licensee's personnel in limited numbers, in critical areas. There are also the possibilities of acquiring designs and drawings of machinery and equipment by paying only a certain percentage of royalty for specified periods.

In some instances, a developing country acquires designs and certain limited but vital technical assistance through foreign collaborations by placing large orders for a particular design of machine tool. When an order for a large number of advanced designs of machine tools has to be placed with a foreign firm, this opportunity is taken to negotiate the bulk order in exchange licensing the design for its progressive manufacture indigenously.

(iv) Production Sharing : Sometimes a firm from a developed country is interested in utilising manufacturing facilities in the developing country to take advantage of lower labour costs and increase the volume of its business. This leads to yet another type of collaboration between the developing and the developed countries. The licensing firm from the developed country could get its designs manufactured at the licensee's works in the developing country, either partly or even fully, and buy back from the latter such equipment at much lower prices and export the production to its well established markets abroad. Naturally, this arrangement benefits both partners.

(v) Joint development of designs : A unique arrangement is one whereby firms from developed countries collaborate with reputable firms in developing countries to jointly design a machine tool for the world market. Such an arrangement involves the designs, manufacture and approval of a prototype by both parties. Regular production of different parts of machines are so distributed that work-sharing results in a considerable overall cost-saving; as a consequence, the product could be more competitively priced for the world market.

(vi) Third-country collaboration : In this type of co-operation, the developed and the developing country join hands in a consortium to work in a third country. Here again, the sharing of the work load follows almost the same pattern as above, viz., each undertaking to perform that portion of the assignment which is possible and profitable. Third-country assignments, where a firm in the developed country collaborates with the firm in the less developed country to secure the business jointly in the developing markets of the world, are on the increase.

(vii) Joint-ventures : In this case both partners have a financial stake, so making it a popular type of arrangement. Expanding the business and markets could be an over-riding incentive for the technically more advanced partner. This arrangement is normally adopted in the high-tech product area, such as CNC machine tools, machining centres, FMS and other machining systems and highly specialised machine tools for the aircraft industry as well as for areas such as space, atomic energy, and power generation. Such arrangements are becoming more and more popular in newly industrialising countries like China, India, Mexico, the Republic of Korea, Taiwan and Singapore.