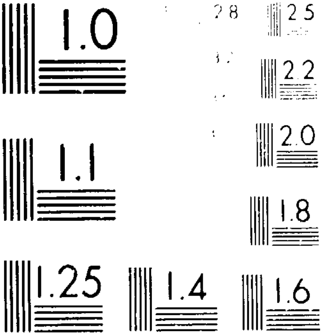
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Distr.
LIMITED
UNIDO/IS.226
5 May 1981
ENGLISH

UNITED NATIONS
INDUSTRIAL DEVELOPMENT ORGANIZATION

TECHNOLOGICAL PERSPECTIVES IN MACHINE TOOL INDUSTRY AND THEIR IMPLICATIONS FOR DEVELOPING COUNTRIES *

Summary **

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** Summary of draft study commissioned by the Technology Programme of UNIDO.

V.81-24716

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INTRODUCTION

Following the recommendations of the United Nations Conference on Science and Technology for Development, the Technology Programme of UNIDO has commissioned several studies on the future technological perspectives in selected industrial sectors and their implications for developing countries. These studies are intended to be of use to policymakers in developing countries in formulating industrial and technological policies and in building up technological capabilities.

The following paper is a summary of a draft report prepared for the Technology Programme on future technological perspectives in the machine tool industry. The report is in three volumes and covers a review of the world machine tool industry in the context of developed and developing countries and the technological trends in machine tool design and manufacture as well as production engineering. An attempt is made to assess the implications of these trends for the developing countries. The report will eventually be published under the Development and Transfer of Technology Series of UNIDO.

The summary is made available to present the future technological perspectives in the machine tool industry in brief and also to serve as a basis for discussion and comments which could be taken into consideration in finalizing the full draft report and in evolving a further programme of activities as appropriate.

WORLD MACHINE TOOL INDUSTRY

For industrial and economic development and technological self-reliance, the developing countries should consider establishing their engineering and capital goods industries, machine tool being one of the vital and basic industries. The machine tool industry is the main foundation of modern industrialisation. The industry's ability to produce multifarious types of machine tools necessary for industrialisation, is a vital factor affecting the industrial and economic progress of any nation.

In spite of such important considerations, many developing countries have lagged behind in establishing their capital goods industry in general and machine tool industry in particular. Some of the developing countries like Argentina, Brazil, China, India, Mexico, Portugal, South Korea and Taiwan have sizeable capital goods industry and a large machine tool base. This has given them a great advantage over other developing countries as they are today in a position to substitute imports of many items of consumer durables, consumer goods, capital machinery and many other engineering items.

Estimated production of world machine tool industry during 1979 was $ 22.7 billion. Of the 33 major machine tool producing countries of the world, 22 advanced countries accounted for 92 per cent of the total production; exported 93 per cent of the world's exports and consumed 75 per cent of the world production of machine tools during 1979. As against this performance, developing countries who have fairly well established machine tool industry like China, Brazil, Yugoslavia, Taiwan, Korea, India, Argentina, Singapore, Mexico and Portugal (ranked according to their machine tool production), produced only 6.37 per cent of the total world production of machine tools, exported 3.5 per cent of the world's machine tools exports and consumed only 9 per cent of the world production of machine tools during the corresponding year, viz., 1979. It is further estimated that the machine tool production in the developed countries would exceed $ 25 and $ 35 billion by 1990 and 2000 respectively.

Detailed survey of the current status of the machine tool industry in the first top 11 leading industrialised nations (vide Part I - Chapter IV), indicates that these countries have been able to continuously improve their industrial performance through development of new designs of machine tools and innovative production technology with computer as the main backbone. Their spectacular advancement in the micro-electronics and computer technology have revolutionised their machine tool industry, which in turn has provided their metalworking industry with highly productive machine tools and computer aided manufacturing systems. The result has been, an equally impressive growth of the metalworking and capital goods industry in the developed nations, who have built over the past three decades or so, technological strength and capabilities which cannot be surpassed by the rest of the world. Consequently, they have reaped enormous economic gains and material prosperity.

A brief study of the machine tool industry in some of the newly industrialising developing countries (vide Part I - Chapter V), who have farily well established machine tool industry and a well-founded industrial base, throws up the fact that these countries have been able to build their machine tool industry on modern lines because of the impetus and assistance that they have received from their respective country's governments. As amply indicated in the Case Study of the Indian Machine Tool Industry (vide Part I - Chapter VI), most of these developing countries have obtained their designs and know-how and production technology from the developed countries in building up their machine tool industry and are today in a position to meet over 70 per cent of their own requirements of machine tools - mainly of the general purpose types. Some of them also export their machine tools and in spite of keen competition in the world markets, not only among themselves but also from the developed countries, they have been able to make a break-through. However, due to their technological backwardness particularly in computer applications and knowledge of micro-electronics technology, their development in machine tool industry and metalworking capital goods industry has lagged behind so much, that over the past decade, the progress seems to be poor and almost stagnant in comparison with what is taking place in the highly industrialised countries in the field of machine tools and production technology. The technology gap has widened considerably and there is a serious doubt if this gap could ever be narrowed.

TECHNOLOGICAL PERSPECTIVES IN MACHINE TOOL INDUSTRY - DEVELOPED COUNTRIES

The enormous changes that are taking place in the developed nations in the realm of metalworking can be attributed to the fast tempo of developments in machine tool designs and technology, control engineering and production concepts. The production technology of machining is developing fast to answer the incessant demand from their manufacturing sector. Developments pertaining among others, to new materials, cutting tools, new generation of drives and innovative manufacturing systems are not only influencing the very concept of machining but they are adding a new dimension to the very methodology of machine tool designs.

Machining efficiency is the crucial requirement of machine tools. Research on maximum obtainable reduction in machining time and the maximum achievable accuracy and surface finish in machining is going on all over the industrialised countries. But emphasis at present is on the possible reduction that can be obtained in operation time, preparation time and in various non-machining times. Many new technologies covering the fields of machine rigidity, drives and controls have now helped considerably to reduce the non-cutting time and also to slash down the preparation time, specially with the development of new electronic controls and positioning devices. It is the bid for reducing the operation time that has led to the search for better tools, better designs of machine tools having high speeds and power.

<u>DESIGNS</u>: The design of modern machine tools consists of the fusion of several technologies. The design of structure, drive, control and the very design methodology demand a close interaction of mechanical, electrical and electronic engineers, besides metallurgists and others from host of specialised disciplines. The design of machine tool

structure is witnessing a quiet revolution. The requirement of high rigidity, light weight and good damping characteristics, are forcing designers to evolve new designs using alternate materials and new configurations. The present approach is towards tructures, using combinations of metals and non-metals to ensure proper thermal stability, static and dynamic stiffness and favourable wear and noise characteristics.

There is no instant transformation into an era of chatterless machine tools with high material removal rates, ultra precision and 100 per cent uptime. Rather, there are sign-posts pointing to the path that might be taken in improving the capabilities of metalcutting machines. This in itself is an important contribution to the state of the art of machining. Spectacular advances in the capabilities of today's cutting tools could double cutting speeds for both roughing and finishing and could double feed rates in cutting. Taken together, these offer potential time reductions of 50 to 70 per cent and a further reduction of perhaps 50 per cent is possible if roughing and finishing can be combined into single-pass-machining, at increased depths of cut. Depending on the application, such savings could increase overall output by 15 to 300 per cent.

Each of the above possibilities, however, adds to the challenge of machine tool design - roughing at high speeds, faster feed mechanism, larger torques and forces, significantly greater horsepower, and much increased static and dynamic stiffness. The latest trends bear a testimony to the integrated approach to the design of every major element of machine tool; the design trends in structures, guideways and bearing surfaces, spindle systems, feed drives, accuracy aspects in design and computer aided designs, are all contributing to the extremely high degree of sophistication and technological refinement and modernisation built into the machine tools, designed and produced in the industrialised countries.

The philosophy of manufacturing is showing a shift from mass production to large volume production with built-in flexibility for quick change-over from one component spectrum to the other. The user industries are demanding finer part accuracies, tolerances and assembly requisites to meet the demand for high accuracies of end-products.

The urgent need of the metalworking sector for multi-function machines to reduce production time and to assure high accuracies of machined components is responsible for the birth of versatile "machining centre". The concern of the manufacturing sector to humanise the working environment is forcing designers to view ergonomics as an essential component of machine tool design. The need to conserve materials is dictating a shift from cutting to forming. The threatening energy crisis is forcing keener attention towards energy management in metalworking. All these challenges are changing the very foundation of design and manufacture of machine tools.

The development of new cutting tool materials is compelling designers to conceive drives of higher speeds and higher reliability. Noise considerations are restricting the use of gear drives at high speeds. SCR Controlled DC motors are being developed to obtain finer steps. Bearing systems are witnessing many changes and specially the requirements of high speeds, increased stiffness, high accuracy and reduced noise are favouring the application of hydrostatic bearing on a much wider scale.

Design is often a creative compromise of conflicting requirements. A clever design of machine tool can increase the output, reduce the downtime and enhance the versatility. Considerable research is being carried out in areas of easier chip disposal, improved system of automated workpiece loading and unloading, energy conservation, faster tool and workpiece clamping and cutting with more than one tool simultaneously.

CUTTING TOOLS: The metalcutting industry in the industrialised countries is constantly searching for better tools, tool materials and methods which will yield high productivity, in an era of heavy emphasis on NC machines which are sophisticated and reasonably high horse-powered equipment, capable of removing metal efficiently, provided the cutting process itself is efficient in control and predictable.

High speed steels were unsurpassed till the introduction of cast-cobalt-based alloys. Cast-alloyw have properties, intermediate between high speed steels and cemented carbides. The first major breakthrough in the development of tool materials came in with the advent of cemented carbide for metalcutting. Initially, straight tungsten carbide with cobalt as the bonding material formed the basic constituent of this tool material which was well suited for machining of short chipping material like cast iron. Shortage of tungsten has led to the development of many non-tungsten cutting tool materials. Among them, most promising are the titanium carbide and titanium nitride tool materials. The bonding materials used are nickel and molibdinium. These tools have greater solubility in nickel and molibdinium than tungsten carbide, in cobalt. The potential for major development in tungsten-carbide cutting material depends primarily on the availability of cobalt. The supply of this essential material is controlled by some governments and a cut-off would hinder the developmental efforts in tungsten-carbide tools.

In the case of conventional cemented carbide grades, a compromise has been sought between the wear resistance and toughness. In principle, increased wear-resistance also means reduced level of toughness and vice versa. Therefore, the emphasis in the development of cemented carbides is on improving the wear resistance while retaining adequate toughness. This has lead to the development of coated-carbides in which microscopic layer of wear-resistance material (titanium carbide, titanium nitride) is chemically coated over carbide surface to attain a single grade of carbide having the property of both hard-wear resistance and toughness.

New tool materials like ceramics are available in the industrialised countries for cutting tough materials at high speeds and at higher temperature as compared to other tool materials. However, the relatively low transfer-rupture strength of ceramics is a serious limitation which has been restricting their wide application and only to uninterrupted cuts. Diamonds of various forms are used in many industrial applications, such as grinding wheels, dressing tools, drawing dies, hones, lapping compounds, cold drills etc., As a cutting tool, diamond is mainly used for machining non-ferrous metals like aluminium, brass, copper, bronze and other bearing materials, non-metallic materials like epoxi-resin, hard rubber, glass and precious metals like gold, silver and platinum. In light alloy pistons, nearly all surfaces are diamond turned and bored specially where high silica content is involved. New tool materials like UCON and cubin-boron-nitride are finding greater application in the industrialised countries. UCON cuts very cool and it has an excellent thermal shock resistance, high hardness and toughness. Next to diamond, cubic-boron-nitride (CBN) is the hardest substance known. CBN is successfully used as a grinding wheel on high speed steel tools providing good surface finish, precision and high output and also on titanium, stainless steel and stellites. With this tool material, it is possible to grind hardened steel, leadscrews, splines, threads and ball and roller bearing parts. Because CBN cuts cool, grinding defects such as burrs and thermal shocks are not produced. They are also used for grinding the slideways of cast iron beds and housing type components.

Designs and geometry of cutting tools is undergoing rapid changes. Various chip breaker designs and configurations have been conceived to obtain effective chip control. A new land geometry was first evolved by Kennametal of U.S.A. In this design, the chip leaves the rake-face very quickly, thus reducing the chip-tool contact length and transferring very little heat to the insert. Yet another design of tool chip-breaker is the wave-shaped insert design.

The inherent disadvantages of inducting throw-away inserts right on the NC machine tools, have prompted Messrs. Kennametal of U.S.A. to design the 'Kenturn' tooling system. This system provides rapid changing of qualified tooling, with tool holders held in place by a ball-lock mechanism. Qualified tool holders are another asset in the tool design, especially while using automatic or copying or NC machine. An important factor is the positioning of the cutting edge in both X and Y axes. Qualified tool holders meet this exacting requirement.

Eventhough modern machine tools are cutting much faster, there are still limitations to increasing speed. Tool life deteriorates drastically with speed, because of the significant increase in abrasion and temperature on the flank, rake-face and nose radius of the insert. By understanding the inter-relationships between speed, feed and depth of cut, productivity increase and tool life can be balanced. In the quest for higher metal removal, better tool life and productivity gains, the search for better tool design will continue for a long time and this trend is well discernible in highly industrialised countries.

MACHINE TOOL CONTROL SYSTEMS: Historically, Numerical Control (NC) of machine tools, certainly has been the most significant development in the industrialised nations so far as it affects the metalworking manufacture. 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, computacion and machine regulation are done according to the principles of digital technology, that is, by employing a large quantity of evaluated symbols and with elements of semi-conductor technology. The numerical control is no more an engineering curiosity. It has come to occupy an important place in the very concept of production engineering. The development of NC is rendered possible by the phenomenal growth in semiconductor technology and digital science is being guided to make it an invaluable tool of production with all the attendant care towards reliability and cost.

Punched Tape & Magnetic Tape - NC: A decade ago, numerical control was a means of controlling automatically machine movements with the help of coded numerical instructions. These instructions were contained in a punched tape. The coded tape was the heart of the NC and it was responsible to control the sequence of machining operations, machine position, spindle feeds, speeds and rotational directions as well as a host of other functions.

Computer Numerical Control - CNC: But in the last 10 years, NC has undergone phenomenal changes. The most outstanding feature of the development of machine tool industry and manufacturing technology in metalworking industry in the industrialised nations is the micro-electronic and the computer technology. This in part is due to the silicon chip and the associated science of micro-electronics. The transistors have given way to integrated circuits. The advances in computer technology has helped replace all logical hardware. Decision circuits are replaced by executive software in the form of minicomputers. The NC guided and controlled by computer has given birth to the "Computer Numerical Control" (CNC), which is the heart of modern machining centres. Part programming, interactive computer graphics, adaptive controls, micro-computer code and on-line diagnostics have been added.

Today, production engineers have at their disposal machine tools having electronic controls with unimaginable facilities of the micro-electronics to develop software systems which combine the benefits of all the newer developments in machine tool designs, cutting tool materials and so on, in evolving high productive systems of manufacture. Computer has become the prime agent of the spectacular changes taking place in the production engineering and control of machine tools; and manufacturing processes monitored by computer, is the present day trend.

The evolution of large scale integrated circuit technology (LSI) brought NC system designs closer to the achievement of standardising the system design. The design was done around a computer, capable of meeting the requirements of any machine. Computers used in such NC systems are either minicomputers or micro-processor based computer with standardised hardware architecture. Other peripheral devices are kept unchanged but the corresponding interface circuits are modified to cope with the new types of hardware.

A computerised controller needs lesser number of electronic components and fewer circuit inter-connections. The tape reader which is a most vulnerable equipment in workshop environment is removed from on-line operations during machining, thus leading to improved reliability.

Computerised control systems thus offer more flexibility since modification of the software programme is simpler, quicker and cheaper than in the case of hardware of conventional NC systems. This facilitates the inclusion of additional features by augmenting the software in standard building blocks. A new part programme can be actively generated or an existing part programme can be modified inside the computer's memory.

This facility simplifies the change in geometry, feed, speed and optimisation during try out. Consequently, the time for tape proving and debugging is reduced, thus considerably enhancing production time.

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

CNC capabilities: All 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.

To reduce machine set up time and to compensate for tool wear, the off-set data can be stored in the memory and called back at any appropriate time. Use of thumb wheel switches for storing data as in the hardwire controller is eliminated. Virtually, an unlimited number of off-set information can be provided. In the case of tool breakage, the machining operation can be stopped and the tool can be changed without destroying the programmed data.

MDI Controller: The latest trend in simplified CNC control of individual machine has lead to the micro-processor based 'manual data input' (MDI), type of control systems. In the MDI system, operator has a choice of either making the programme by machining the first part manually, to automatically record the machine slide and tool movements, or use the keyboard for input of work cycle commands from a programme sheet on the basis of part drawing. If required, the part programmes located in the system memory are transferred to magnetic cassettes for permanent storage. The only limitation of the MDI at present, is that the controls can be made for machines upto only 3 axes.

Direct Numerical Control (DNC): Direct Numerical Control (DNC), is an extension of the CNC concept. In DNC, a central computer controls simultaneously a number of NC or CNC machines. DNC offers several operative advantages. The tape reader which is usually most downtime prone component of a machine control unit is bypassed. Secondly, a programme in a computer storage is much easier to access for use in operation for revision or re-editing or for quick and easy interaction between the programmer and the machine tool, The same computer that directs the operation of machine tool can be used for auxiliary purposes such as downtime recording, performance tabulation, real-time machine status and other operational items of interest to the management. An advance design of DNC unit can also be utilised to sense operating conditions and also to make modifications in programmed instructions. DNC does require programmers and supervisors having a thorough knowledge to exercise full and optimum control. DNC systems can be extremely effective when combined with first rate system know-how, but the initial cost is still very high and needs software support of a very high calibre.

NC Perspectives: The use of general purpose minicomputer as a part of a system and the use of software as applicable to minicomputer is now being discontinued. Control systems built with microprocessors and with dedicated software constitute the architecture of the new CNC systems.

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

The advent of the computer and electronics has made possible NC machine tools which have drastically changed the technology. Further improvements in controls in developed countries are foreseen such as to increase their capability - their memory to allow more functions to be monitored and/or controlled. There will be new complex, high performance controls as well as simpler low cost versions suitable for less complex parts and intermediate versions, compatible with manufacturing systems.

Standardisation of interface or language/ data communications is an important concern, as are terminology and methodology for maintenance. Research efforts are being made to evolve a set of these standards. Interactive graphics, a powerful emerging technology, has an increasing key role in providing visual displays for monitoring and command/control at each step in the manufacturing process - from design to cutter motion and interaction to complete manufacturing systems. Improvements through 3-dimensional modelling of parts in colours and clearer communciation between devices and the operators are being further intensely investigated.

Ada ive controls, although having been pursued for about 15 years, have found acceptance only in limited applications. Improvements in understanding the cutting processes, the variation of cutting conditions and more reliable sensors are needed to be developed. Good sensors for tool breakage, geometric dimensions or contours, preferably of the non-contact type, and demonstrations of specific complete adaptive control systems, are yet to be perfected.

There is a need to develop more and better sensor techniques for identifying intermittent errors and diagnosing more of the mechanical failures through signature analysis or other techniques.

Future NC systems will be microprocessor-based and provided with computer graphic display. With computer aided design, CAD, the use of this graphic display will be extended to the NC systems resulting in the interactive graphic CNC systems.

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

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

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

Knowledge of software design and system integration will 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 system integrator should understand and determine how all elements work in relation to others.

Producing NC tapes through voice command is already a reality. A speech processor that converts a programmer's analogue voice signal into the digital language of the computer, permits part programmes to be generated by vocalising the data.

Control systems are being developed which will reduce a number of parts still further through the use of very large scale integrated circuits, viz., VLSI. Soon micro-computers 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.

NON-CONVENTIONAL MACHINING METHODS: The increasing use of difficult-to-machine materials such as hastalloy, nitralloy, vespalloy, nimonics, carbides, stainless steels, heat resisting steels etc., in the aerospace, nuclear and communication industries and for the manufacture of military hardware, have all spurred the development of non-traditional manufacturing methods. The conventional machining processes have become inadequate to machine some of these materials from the standpoint of rigid quality standards and economic production. Besides, machining of these materials into complex shapes is difficult, time consuming and sometimes impossible.

Non-traditional machining techniques have overcome some of these difficulties. These could be classified according to the nature of the energy employed in machining: (i) Thermal and electro-thermal; (ii) Chemical and electro-chemical; and, (iii) Mechanical.

In the thermal and electro-thermal methods are included the electrical discharge machining (EDM), laser beam machining (LBM), plasma arc machining (PAM), electron beam machining (EBM) and ion beam machining (IBM).

The chemical and electro-chemical machining methods are : chemical machining (CHM), electro-chemical machining (ECM), electro-chemical grinding (ECG), electro-chemical honing (ECH) and electro-chemical deburring (ECD).

The mechanical methods of non-traditional machining include, ultrasonic machining (USM), abrasive jet machining (AJM) and water jet machining (WJM).

Non-traiditional machining processes find application over all metals and alloys. This is in contrast to the conventional machining processes which vary in their application, depending upon strength and hardness of materials.

The application of non-traditional machining processes is also influenced by the workpiece shape and size to be produced, viz., holes, through-holes, through-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, power consumed, 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 solutions on all occasions. They should therefore be viewed as complementing the conventional metalworking methods. The suitability of any of the non-traditional machining processes for any specific application should be judged from the stand point of increased reliability of process, better quality assurance and the ability to machine workpieces which cannot be easily machined by any conventional methods.

METALFORMING MACHINES: Right down the third quarter of this century, metalcutting has dominated over metalforming in metalworking industries. However, the concern to conserve materials, rising cost of energy and the need to explore new routes of production have given metalforming lot of significance. Metalforming machines like mechanical and hydraulic presses, single column open back inclinable types, heavy duty parallel frame presses, forge presses, press brakes, shears, guillotine machines and non-traditional forming presses constituted more than 25 per cent of the total world production of machine tools during 1979. Signs are, that this share will go up further by the end of the century.

Plastic deformation of metal takes place in two ways; by bulk deformation and by incremental deformation. Metalforming machines commonly seen are those of the conventional types, heavy duty and light duty hydraulic and mechanical presses, conventional forge presses and so on. Non-traditional forming presses include helical rolling, ring rolling, spinning and flow forming. These non-traditional methods and other high speed forming techniques like die casting, fine blanking, NC punching and powder metallurgy (PM technology) are responsible for the discernible shift from cutting to forming.

The development of new high strength alloys combined with the need to produce parts of more complicated forms has increased problems associated with forming on conventional presses. Many manufacturers would prefer to form parts rather than use the often wasteful cutting methods, but high capital cost of conventional forming machines and dies and tooling has precluded the use for all but high and very high mass production purposes.

Automobile industry is one of the main customers for heavy duty high speed presses, although agricultural machinery manufacturers including lawn and garden equipment manufacturers are some other principal customers. In the highly sophisticated line, aerospace industry is another pace setter of designs of metalforming machines. The U.S. aerospace industry will soon fabricate much of its sheetmetal components with the help of forming presses, controlled by computers.

U.S. Steel Corporation's development engineers have designed and built a stamped steel automotive exhaust manifold that weighs 60 per cent less than the cast iron counterpart. Many automobile manufacturers are similarly interested and keep close watch on the development in stamped engine components.

In eight to ten years from now, it is estimated that many of the internal combustion engines' components could be products of press-working shops.

Cold forging of steel has been considered as a method of improving material utilisation in the manufacture of engineering components. Though this process is still not considered as a principal route to produce components difficult to make by other methods, yet in view of the rising cost of materials, low recovery price of the scrap, cold forging is now receiving a lot more attention.

Extrusion is a versatile manufacturing process in which the cross sectional area of the billet is reduced during deformation. Symmetrical products which are varients of basic shapes like rods, tubes and cans are readily made, using extrusion process.

In mass production of fastners, heading or upsetting method of metalforming is commonly seen.

Ironing is yet another metalforming process which has been extensively used to produce stepped shafts for electric motors and tubular components of large length-diameter ratios.

Fine blanking press is another revolutionary method of producing very precise press components. The ingenuity of fine blanking press builders and tool makers has produced parts with precise contours and flatness. In fine blanking, the press is almost an accessory to the tooling, tooling being the key element in the process of producing clean cut parts, through the entire thickness of stock with no distortion except for a slight turnover at the tool-entry edge and a small easily-removed burr at the exit edge. The dimensional accuracy of the fine blanked parts depends on the quality of the tooling ahd thickness, strength and quality of the stock as well as on the parts size and configuration. In general, by contrast, tolerances are far more finer than in conventional press-working.

Punching using numerical controls (NC), has benefited everyone in the metalworking industry including manufacturers of controls, toolings and auxiliaries. The widespread acceptance of this type of punch press control system has also stimulated new press designs and improvement on earlier designs. In the recent years, it has spawned hybrid machines that not only punch, but also cut by plasma arc or laser beam and even perform such functions as milling. Furthermore, computerised numerical controls (CNC), entered the metal punching field early in 1972 and provided even greater benefits. The strongest advantage of NC punching equipment is the adaptability of its workpiece positioning mechanisms to that kind of control. Moreover, the beam lines that fabricate structural shapes as well as flats use NC for X axis motion and punch actuation, and some use it for tool shifting as well. On most sheetmetal and plate machines, however, NC not only governs 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.

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.

The future of metalforming is bright, because it affords reduction in machining sequences which is otherwise inevitable in metalcutting. The newly developed high precision die casting & forging techniques, precision blanking & sheetmetal working methods and advances made in powder metallurgy (PM technology), fine blanking, NC & CNC punching, investment castings, cold extrusion, explosive forming, electro hydraulic forming, electro magnetic forming, compressed air gas forming, water hammer forming and fuel combustion forming, are offering production managers more economical routes of production. Eventhough the tooling costs of metalforming machines are pretty high at present, future research efforts may bring down the costs particularly using NC and CNC in the manufacture of dies and tooling.

PRODUCTION TECHNOLOGY: Development of production technology depends directly and uniquely on the development of modern machine tools, cutting tools and machine tool controls. With innovative developments taking place in all these entities, one should expect equally if not more spectacular progress and development in the manufacturing methods in the metalworking industry. Today, production engineers have at their disposal, machine tools, cutting tools and unimaginable facilities of micro-electronics to develop software systems which combine the benefits of all these newer developments in evolving high productive systems of manufacture. Computers, with microprocessors and minicomputers have become the prime agents of the spectacular changes taking place in production engineering.

By far the most important form of modern production technology is the "computer aided manufacture" - CAM. It has already proved its higher ability to considerably improve production possibilities than all the other known forms of production techniques put together. It is due to this reason that machine tool based production technology is getting strongly integrated with computers. Currently, emphasis is on link machines, integrated systems and computer aided manufacture. The stand-alone NC machine and groups of NC machines are now widely accepted methods for batch manufacturing. Further computer aided manufacturing systems will probably be formed by linking first one and then several CNC machines with automatic work handling and/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 and these could possibly be the forerunners of an "unmanned factory".

'Integrated manufacturing system' is one that combines a number of hitherto separate manufacturing processes so that they can be controlled by a single source relative to each other. The chief benefits of doing so, are, reduction in lost time caused by inter-stage movement of components being made, improved machine tool utilisation, reduction of work-in-process and greater flexibility of component batching and loading.

However, the main concern has been with the application of this type of manufacture to small batch production, which constitutes generally a significant proprotion of manufacturing output in almost all countries. It has been estimated that the difference 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 cost target for integrated manufacturing system could be the "mass-production of the one-offs".

Flexibile Machining Systems: The main purpose of "flexible machining systems" is to integrate the various functions in the same machine tool to form a flexible manufacturing cell which is a module of a flexible manufacturing system. Each flexible manufacturing cell is an autonomous module whose functions are supervised and controlled by micro processor based computer. Various functions of the individual cells could be: (i) Supply of blanks, tools, gauges, and devices; (ii) Clamping devices which include identification, selection, transport orientation, loading, positioning, clamping, declamping, interlock, supervision and such other step by step operations. (iii) All operations like measurement of workpieces, adjustment of clamping devices, material handling/positioning are accomplished automatically. (iv) All interlocks, lubrication failure and such other malfunctions like tool breakages etc., are automatically monitored by sensors.

Computer integrated flexible manufacturing systems are thus gaining increasing acceptance and importance in batch production.

Flexible manufacturing systems based on group technology or cell production principles using NC machines and gauging equipments are now being installed with robot handling devices and palletised conveyors supply units, to machine families of parts.

Metrology and Inspection: Metrology is going through a revolution brought about by integration of electronics into the science of measurement. Developments in inspection and gauging equipment are aimed at matching the high production rates of modern machine tools and to meet 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.

Progress in measuring techniques has been so rapid that the resolution of gauging has reached limits governed only by the inherent instability of the machine 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, requirement of automated assembly, longer final product life, legislation to reduce noise levels, needs of related techhology like IC fabrication, etc.,

Assembly: Assembly with its high labour content is an area holding the greatest potential for profitable automation. Mass production industries in the West have made considerable progress in this direction. So far, automated assembly has been applied only to sub-assemblies. Even in the automobile industry, considered highly automated in the United States of America, automated assembly has been applied only to sub-assemblies like rear/differential axle, breakdrum etc., There is however, a continuous search for methods to extend automatic assembly to whole products.

AUTOMATION IN PRODUCTION TECHNOLOGY: The computer technology has enabled robots to learn succession of tasks and versatility that promises to render obsolete a good deal of what is currently thought of as automation. Robots are in fact the latest of automation - a programmable or a flexible variety. Robots have been developed which stimulate closely the variety of movements possible with the human upper torso, shoulder, arm, elbow, wrist and hand. Robots have been developed which can automatically be programmed or taught a sequence of movements by human operator who guides the robots through the sequence. Developments are taking place with the use of addition of a device to give "sight" and to give "feel" to robots. By imparting intelligence to robots, they can be made to take tactical decisions in carrying out the assigned tasks by using "vision" and feel feedback.

The application of TV and holographic techniques are having a major impact on the large scale developments of robots capable of seeing and recognising 3-dimensional objects, especially when the objects are presented to the robots in a random orientation. Robots equipped with 'sight' and 'feel' sensors will certainly find wider application in automated assembly systems of the future.

Most wonderful of all, robots are starting to assemble components in factories. Over the next 12 months, General Motors will instal 10 PUMAS (Programmable Universal Machine for Assembly) which, among other things, will partly assemble armatures for electric motors, screw small electric bulbs into instrument panel and help to put the windshield washers together. PUMA is in the vanguard of an array of small and relatively inexpensive robots that are taking over more and more jobs that were previously performed by humans. Advanced projects have been conceived not only for adapting the commercially available robots for various production processes, but also develop them further for the present as well as for the future requirements of computer aided manufacturing systems.

Unmanned Machining Work - Unmanned Factories: Having effectively eliminated the need for skilled operators for most machining operations in the 1960s and 1970s, machine tool builders in the advanced countries are now turning their hands towards eliminating the need for operators altogether in 1980s. The goal appears to be reliable unmanned machining systems for the 1980s as early as 1990s that can substantially boost machine tool through-put, assure strict adherence to hard to meet quality control standards, minimise in-process inventories and guarantee production rates by eliminating the last major machining variable. That is not the unmanned factory, not yet anyway !

In the industrialised countries, hard as it is to train and keep skilled workers these days, current economics still do not justify the high cost of developing and building an unmanned manufacturing facility. This is especially true when one considers the fact that the computer network required to operate such system barely exists on paper, right now. But it is the next step down the road to unmanned factory of the future and the concept is beginning to gain acceptance in many areas of manufacturing.

However, unmanned manufacturing and assembly operations leading to unmanned factories in industry have been viewed with somewhat great dismay by social scientists all over the world, particularly by the developing countries who have been one of the important sources of providing labour to the industries in the highly industrialised countries.

PERSPECTIVES: Selected forecasts given below provide an excellent insight into the direction and time span of future developments in the most important technology of metalworking.

1. Around 1985: Assembling jobs will be integrated with the other production routines, making use of computer aided manufacturing systems. At least 25 per cent of the firms representing a cross-section of the industries in advanced countries will apply software systems for automation and optimiaation of various stages of production.

2. Around 1987: About 15 per cent of the total machine tool production will not consist of single purpose machines but will constitute component blocks of flexible production systems where the manipulation of work pieces between individual work stations will be done automatically and controlled by a central computer.

3. Around 1990: The advance development of sensors will facilitate robots to attain human capabilities in the final assembly sequences. Computer aided design, CAD, techniques will be employed for designing of 50 per cent of the newly designed production aids.

4. Around 1995: Almost 50 per cent of the direct work in the final assembly of automobiles will be achieved by programmable automation and robots.

5. Around 2000: Based on these forecasts, it is presumed that even before the end of this century, many charges in machine tool and production technology will take place around computer, viz., Computer Aided Designs and fully integrated computer aided manufacture, flexible, manufacturing systems, automatic assembly using extensively modern robots.

IMPLICATIONS OF TECHNOLOGICAL DEVELOPMENTS IN MACHINE TOOL INDUSTRY FOR DEVELOPING COUNTRIES:

It is quite evident that in the industrially advanced nations, there have been tremendous developments in the machine tool industry and consequently in the production technology employed in the metalworking industry particularly over the past three decades. Most spectacular are the foreseeable future trends in development in these countries, which could carry the industry to a logical stage of a very high degree of automation/sophistication. It appears therefore impossible for the developing countries to bridge this technology gap. Such unbridgeable technology gap could create a large economic imbalance and great disparity in social standards and living conditions between the North and the South. This technological backwardness in machine tool production and the metalworking industry could be to some extent improved if the developing countries make determined efforts to push their respective country's programme of industrial development in general and production of capital goods including machine tools in particular, in line with some of the latest advances in technological developments which are taking place in this field in the industrialised nations.

Technology gap and its implications: Among the developing world, some of the newly industrialising countries like China, Brazil, Argentina, Taiwan, South Korea, India, Singapore, Mexico and Portugal, have a well established machine tool industry.. In the last three decades some of them have been able to make significant progress in their respective machine tool industry mainly through acquiring designs and manufacturing technology from the transnational corporations. Besides, these countries have simultaneously strived to build their own capabilities in developing original designs of machine tools, mostly of the general purpose types. As a result, most of them are today self-sufficient in their needs for general purpose machine tools. Also, some advance types of machines like special purpose machines, some types of transferlines, single and multi-spindle automatics, certain types of gear cutting machines, horizontal and vertical boring mills, commonly needed designs of grinding machines of cylindrical, internal and universal types and so on, are also being produced in these countries. The inherent strength of their machine tool industry is further proved by the fact that the newly industrialising developing countries have made a breakthrough in exporting a range of general purpose machine tools to the world markets, not only competing amongst themselves but also facing stiff competition from the developed countries. As the industrially advanced countries give up manufacturing many types of general purpose machines in preference to the advance designs due to the relatively high labour content in the former type of machine tools, the developing countries are likely to expand their exports, provided they build high quality, modern machine tools needed in the markets of the industrialised countries and those of less developed developing countries of Asia and Africa.

Notwithstanding such satisfactory progress achieved by the developing countries in the machine tool industry, yet, the vast technological developments which are taking place in the machine tool and metalworking industries in the developed countries, have created an enormous technological gap between the developing world and the advanced nations. Among other aspects, the technological gap seems to be more pronounced in: (i) designs of machine tools, (ii) machine tool controls,

(iii) cutting tool materials and tool geometry, and (iv) manufacturing systems.

Machine Tool Mechanics & Designs: In the machine tool mechanics and designs, developing countries lag far behind. Many of the new design concepts have no relevance in the developing countries. The art of high and very high speed machining is yet to be learnt and mastered in these countries. The incentive for evolving new designs of advanced machine tools is dependent on the production technology employed by the main machine tool using industry, viz., metalworking and other engineering industries. Advancement in machine tool design per se has no advantage unless these are needed in the capital goods and other metalworking industries. Hence it is very necessary to update the manufacturing methods employed in the metalworking industries on the pattern of the industrialised countries so that there is sufficient incentive and demand for developing more modern designs of machine tools particularly the NC (numerically controlled) machines, machining centres etc., It is also the experience of the developed world that improvements in production technology of the metalworking industry takes place if advanced types of machine tools are produced in the country, which could increase the production and improve the quality and bring competitiveness by reduction in cost of the end products of the metalworking industry. In actual practice however, both these things happen viz., improvement in manufacturing systems take place in the machine tool using industry through the ready availability of advanced and high productive machine tools like NC machine tools, machining centres and so on.

In sum, attempts in evolving original designs of advanced machine tools have just begun in these countries recently, particularly in the field of special purpose machines and transferlines. New concepts in machine tool designs suitable for NC (CNC & DNC) and high precision work are just being thought of in some of the developing countries.

Cutting Tools: Some of the world well-known transnational companies manufacturing cutting tools like Krupps-Widia of West Germany and Sandvik of Sweden, have their factories or joint ventures in some of the developing countries. Hence, they are in a position to provide advance types of cutting tools like sintered carbide tools, tungsten carbide, coated carbide, throw-away tips like 'T-max' for use in conjunction with some of the more advanced machine tools (many imported) used in industries like aircraft, automobile and other metalworking and engineering industries. However, ceramic tools, special tools needed for tool changers for the machining centre and high precision diamond tools are still being imported since their demand is very much restricted.

Extensive use of high speed steel tools for steel bar work and machining of steel castings and the use of carbide tools for machining only cast iron components is still a common feature of the metalworking industries in the developing countries. Due to various reasons, mainly on account of the absence of competition in the domestic market for capital goods and other products and in some cases on account of protected market and insufficient export trade, there appears to be less compulsion on the part of the developing countries to exploit the full potential of such advanced type of cutting tools. This is partly due also to the non-availability of very high speed machine tools capable of exploiting the use of advanced range of cutting tools.

Machine Tool Controls: One of the most glaring technological gap between the developed countries and the developing countries is in the area of computer technology and micro-electronics. There has been some growth in electronic industry in some of the developing countries but it is mainly to meet the requirements of the consumer/entertainment electronic sector and to some extent, communication and defence sectors. Though the use of computers for office purposes is satisfactorily established in some of the developing countries, however, industrial application of modern computer technology is almost absent in these countries.

Some of the machine tool producing developing countries have started producing NC machine tools but the controls belong to older generation where coded tape is the heart of the NC. But in the last 10 years in the industrially advanced countries, NC has undergone phenomenal changes. The NC guided and controlled by computer. viz., CNC is the heart of NC machines like machining centres extensively produced in the industrialised countries. Though we do see some imported CNC machining centres in use in some of the developing countries, these come with the executive programmes developed by the manufacturers in the form of standardised system designs. Knowledge of software design and system integration is necessary in all the new production/manufacturing systems. A good software designer will be able to maximise hardware utility and create flexible systems which others can repair and even alter. Such personnel are rare to find in the developing countries and this in itself is a great hurdle for the further development of computer control of machine tools in the developing countries.

We do see extensive use of DROs (digital read-outs) in some of the developing countries like Taiwan, Brazil, South Korea, Singapore and India. Further, 'manual data input' controls (MDI) are also seen in use in some of the developing countries but these belong to the older generation.

The modern MDIs developed and employed extensively in the industrialised countries are microprocessor-based types, which eliminate the tape reader which is normally the source of trouble. Although there is a great scope for such types of MDI controls in the developing countries, yet these are not produced by them at present. In addition, the greatest hindrance to the extensive use of micro-processor based MDI controls is the inadequacy of programmers.

Non-traditional Machining: In the area of non-traditional machining systems, the progress made by the developing countries is negligible. For one thing, these exotic metalworking processes have relatively restricted field of applications. Also, apart from some, the development of many of the technologies is yet to be stabilised in respect of many applications, even in the highly industrialised countries. Hence one cannot expect the developing countries to take to such special machining processes whose developmental costs are high and cost-benefits doubtful.

Among the various non-traditional machining techniques, EDM and EBM welding have found greater use than others in the developing countries. In EDM, the wirecut process is getting to become more popular mainly in the production of high precision dies and press tooling. EBM welding technology is also receiving greater attention particularly in the more advanced industries like aircraft, atomic energy and space. However, apart from very simple EDM and ECM machines, the rest of the machines using machining techniques like LBM, PAM, IBM, CHM, ECM etc., are being imported by the developing countries wherever needed.

Metalforming Machine Tools: The technology gap between the industrialised and the developing nations in the field of metalforming presses is widening year by year. This is more discernible in the area of non-traditional forming methods such as helical rolling, ring rolling, spinning and flow forming. In the developed nations, considerable R&D is being carried out in producing parts of high strength alloys of complicated shapes by forming with high speed equipment. Developing countries are backward in the production of cold forging presses and extrusion presses.

One of the main bottlenecks in metalforming is the manufacture of complicated dies and tooling. For this it is necessary to use high strength alloy steels as raw material to be machined on sophisticated computer controlled machine tools. Another sophisticated equipment of the high speed metalforming industry is the transferline presses for automatic and progressive operations on transferline, both in forging and in forming. Although some sheetmetal forming transferline presses are manufactured in the industrialising developing countries, heavy duty and progressive type forge presses are still being imported. In the area of fine blanking and punching presses, developing countries are yet to reach the degree of sophistications of the developed countries.

Manufacturing Systems and Production Technology: Although during the last three decades in some of the industrialising developing countries, there has been some progress achieved in the area of production engineering, yet, for the last decade or so, the progress has been almost stagnant in the production technology mainly because they have no strong base and support of the computer technology. The aggregate effect of the backwardness of the developing countries in the areas like computer technology, advanced designs of machine tools like machining centres controlled by CNC or even DNC, development of software for minicomputers, microprocessors and highly advanced types of cutting tools that usually go with sophisticated types of machine tools, has resulted in almost total absence of computer integrated manufacturing systems like the computer aided manufacture, CAM and flexible machining systems. Consequently, the productivity of the metalworking industry in the developing countries is poor and levels of production in some of the key industries is a pittance in comparison to the norms of the developed world.

Economic implications: Economic progress and development depend very largely on improvements in the overall productivity - efficient use of resources, manpower, material and capital. In so far as it applies to machine tool technology, it is evident that economic prosperity depends on the productivity of the machine tools used in the manufacturing industry. Hence to improve the economic health of the developing nations, it is necessary to improve the productivity of the metalworking and capital goods industry. And since machine tools and production technology are fundamental for the improvement in productivity for the manufacturing and engineering industries, these, viz., machine tools and production technology have to be productive and advanced.

Labour intensive technology per se cannot be universal remedy and its applicability to all kinds of economic activities is not advisable. It is argued that production technology employing comparatively large labour force could be as efficient as highly advanced and labour saving technology. This is a fallacious statement and cannot be applicable under all circumstances.

Furthermore, improvement in output (added value) per worker per annum - which is what the universally accepted measurement of productivity is - does not come entirely from the labour side, because workers are working harder and better. It is to be emphatically stated that the improvements in productivity come largely from non-labour factors - through efficient use of material and capital resources, besides manpower. This, in the modern industry is possible mainly through better management of resources employing improved and advanced technology. Backwardness in machine tool and manufacturing industry of the developing countries is one of the reasons for poor industrial growth and resultant poorer growth of national economy.