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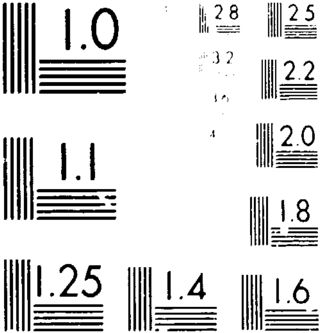
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TECHNOLOGICAL PERSPECTIVES IN MACHINE TOOL INDUSTRY WITH SPECIAL REFERENCE TO MICRO-ELECTRONICS APPLICATIONS*

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*/ Extracts from draft study commissioned by the Technology Programme of UNIDO: "Technological Perspectives in Machine Tool Industry and Their Implications for Developing Countries".
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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, which include micro-electronics as well as machine tools, 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 contains those chapters of the draft report on machine tools which have a bearing on micro-electronics applications. 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 paper is made available to spotlight the micro-electronics advances in the machine tool industry and in production engineering, 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.

CHAPTER I

MACHINE TOOL CONTROL SYSTEMS

INTRODUCTION: In the industrially advanced world, a spectacular state of a new art of manufacturing is emerging. This is based on the changing nature of information stream that runs a manufacturing enterprise. In the past, humans were both the translators and transmitters of information. The operator was the ultimate interface between the design intent as incorporated in the machine drawing or instructions and the functioning of the machine tool. The human used mental and physical abilities to control machine tool.

However, computers are increasingly becoming the translators and transmitters of information and, numerical control (NC) is perhaps the most representative of the kind of control that plugs into a data stream with minimum of human intervention. Historically, numerical control certainly 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 and with elements of semi-conductor technology. In other words, the building blocks of modern electronics hold the key to control technology. There are some basic aspects of machine tool controls which are important to the user and manufacturer alike. They are: (i) Operation & programming; (ii) Operation safety; (iii) Cost ; (iv) Flexibility and extendability; and (v) Integration and standardisation.

A numerically controlled machine tool is a machine which grinds, drills, turns and/or cuts according to pre-determined 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 in the past decade, they have become significantly more clever, compact and cheap. Thanks in part to 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. But now 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, rendered possible by the phenomenal growth in semi-conductor technology and digital science, is being guided to make it an invaluable tool of production, with all the attendant care towards reliability and cost.

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 positions, spindle feeds and rotational directions as well as a host of other functions, like control of coolant pump and so on.

But in the last ten years, NC has undergone phenomenal changes. The transistors have given way to integrated circuits. The advances in computer technology have helped to 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, inter-active computer graphics, adaptive control, micro computer code, servo mechanisms, human engineering and on line diagnostics have been added to those of the mundane aspects of process planning, interchangeability, maintenence, cutting tools, chatter and surface finish.

CNC System: The architecture of CNC system is entirely different from a conventional hardwired system. The concept of CNC is akin to the digital computer concept. Any digital computer has 3 major parts: the Central Processing Unit (CPU) does the arithmetic and logic operations; the Memory stores the data to be processed; and the Control Instructions and the Peripherals actually form the link between the computer and the outside world. For the CNC, the machine and various other equipment to be controlled form the peripherals.

The major constituents of CNC system are the computer and the executive programmes, data handling, machine axes controls, controls pertaining to machines magnetics etc.

All functions for controlling the operations of NC machine tools are synthesised by the logic designer by evolving a combination of logic modules consisting of gates, flip-flops, counters, shift resistors etc., along with the necessary peripheral devices.

Different approaches using the same type of logical elements as the basic hardware, can be employed to obtain the same end results. This gives rise to a non-standard system design, requiring for each system a large variety of spares. This leads to a large inventory. It was therefore realised that efforts had to be made for standardising the system design of the hardware. The evolution of large scale integrated circuit technology (LSI) brought NC system designs closer to this achievement. The design was done around a computer, capable of meeting the requirements of any machine. The computers used in such NC systems are either minicomputers or micro-processor based computers with a standardized hardware architecture. Other peripheral devices are kept unchanged , but the corresponding interface circuits are modified to cope with the new type of hardware. The requirements of each individual machine tool are met by software programme called the "Executive Programme" which is a part of the control. It contains the command logic which determines how the control is to perform its functions such as operating the tape reader, translating the programme tape, and sequencing the machine tool. In other words, the controller's own logic is actually a computer programme instead of specialised electronic circuits. The actual hardware remains standard and fixed with the different design approaches. But any software, once developed successfully, needs no maintenence. Hence, standardized/ system design is achieved with a minimum of maintenence requirements.

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

The number of printed circuit boards are reduced and the same control may be used for a 3-axis machine or a 5-axis Machining Centre. This reduces the inventory of spares for single or several CNC units, even if different machines are involved. Software, once developed successfully, needs no maintenence. Personnel training is reduced because only one system is to be maintained and serviced. De-bugging of any malfunctioning of the system is much easier in the computerised system because of diagnositc programmes. Even a less skilled person having a basic knowledge of operation can isolate a problem down to a sub-system or the card level.

Computerised control systems offer more flexibility since modification of the software programme is simpler, quicker and cheaper than in the case of hardware of a conventional NC system. This facilitates the inclusion of additional features by augmenting the software in standard building blocks. Though it may involve a marginal hardware modification it is less costly to make a CNC system compatible with any shop's unique problems and practices. Newly developed options can also be added after installation to upgrade the equipment. This facility eliminates the danger of premature obsoloscence although rapid progress in electronics indicates machine tool controls to become obsolete in 3 to 5 years. Part programmes are stored in the computer memory and then made available for machining. This feature is particularly helpful in repetitive production. Execution of short blocks is not limited by the reader speed because the access time for the data stored in the memory buffer is negligible.

A new part programme can be actively generated or an existing part programme can be modified inside the computer's memory. This facility simplifies changes in geometry, feed, speed and optimisation during tryout. Consequently, the time for tape proving and debugging is reduced, thus considerably enhancing production time.

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

CNC capabilities: 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, optimises machining conditions and achieves consistent surface finish and accuracy.

To reduce the machine set up time, and to compensate for tool wear, the offset data can be stored in the memory and called at any appropriate time. Use of thumb wheel switches for storing data as in hardwired controllers, is eliminated. Virtually, an unlimited number of offset 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.

The present trend is to use programmeable machine interface where a machine interface ladder network can be programmed in software. This has helped the machine tool builder to eliminate considerable number of relays, contactors and timers that are used in machine electrics and magnetics. Changes in the interface do not require corresponding hardware changes. The ladder network can be displaced on CRT. This feature is an extremely valuable tool in debugging the machine interface programme, enahncing the reliability of the system. Since a great deal of hardware is in CNC systems, diagnostics is a very important tool to trouble-shoot the faults that are developed in the course of operation in hardware circuits of the systems. Since computer used in a CNC system has the ability to perform different tasks under different programmes, a proper programme can be written to make the computer work like a circuit tester instead of a NC controller, thereby providing a dianostic programme.

<u>MDI Controller</u>: The latest trend in simplified CNC control of individual machines, has led to the micro-processor based Manual Data Input (MDI) type of control system. MDI controls go beyond the

digital readouts (DRO), by adding slide drives - but they do not stop there as advancing micro-electronic technology puts new skills at the machinist's fingertips. Among the aliases for MDI controls, are such terms as "tapeless NC", "memory NC" and "operator programme NC". These terms are every bit as valid as MDI. Many MDI controls can be converted into classic NC systems by plugging in an optional tape reader, and most present day NC systems incorporate programme editing features that make them fully capable of accepting manually input part programmes.

Most of the wellknown NC machine builders like the Cincinnati Milacron, Kearney & Trecker, Warner & Swasey, Allen Bradly, General Numeric, Fanuc and others have brought out this type of CNC system. In the MDI system, the 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 the part drawing. Since this does not make use of the punchd tape, the tape reader which is normally a source of trouble is totally eliminated. If required, the part programmes located in the system memory are transferred to a magnetic cassette for permanent storage. General Numeric provides a plug-in cartridge having Random Access Memory (RAM) with a nickel cadmium cell. Editing facility is also provided to make any part changes in the programme. MDI systems are lower in price and smaller in size than conventional CNC system. The only limitation of the MDI at present is that the controls are made for machines of upto only 3 axes. These controls are ideal for adaptation in machine tools, built in the developing countries like in India, Brazil, South Korea and Taiwan.

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, according to the definition of Electronics Industries Association , is "a system connecting a set of numerically controlled machines to a common memory for part programme or machine programme storage with a provision for on-demand distribution of data to machines". The DNC system has provision for collection, display or editing of part programme, operator instructions or data related to the numerical control process. Though the concept of Direct Numerical is not new, it is yet to spread widely in manufacturing sector. There are also many short-comings of these systems which have to be debugged. However, the main reason for the DNC not becoming so popular, is the initial high cost of investment. Another reason is that a universal DNC system is not yet created with a wide range of application. The utilisation of DNC system for maximum productivity is yet to be proved.

DNC level I and level II are the two schemes of DNC systems that are in use now. White-Sunstrand and Allen Bradly offer a DNC mini-computer that stores all machine data post-processed for a specific machine on a master disc file. The mini-computer sends the machine data on a real time basis to each NC machine interfaced to it. In this case, there is no 'stand-alone' NC system for the NC machine. There is a limitation on the number of NC machines interfaced to one minicomputer, as the computer works on real time basis. One major disadvantage of this system is that, if there is a malfunction in the mini-computer, then all the NC machines connected to this computer will be down. To overcome this drawback, a standby minicomputer is used which can take over in the event of malfunctioning in the DNC minicomputer. The other remedy is to DNC level II, where each NC machine has its own stand-alone CNC system. These individual CNC systems receive data from the DNC minicomputer. Here, even if the DNC mini-computer fails, the machines can be operated with the help of their independent CNC systems. If these individual CNC systemsare provided with floppy disc data storage, then a considerable amount of data can be transferred from the DNC mini-computer to these systems.

DNC offers several operative advantages. The tape reader, which is usually most downtime prone component of a machine control unit is by-passed. Secondly, a programme in a computer storage is much easier to access for use in operation; for revision or editing or for quick and easy interaction between the programmer and the machine tool. The same computer that directs the operation of a machine tool can also 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 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 systems-knowhow but the initial cost is still very high and needs software support of very high calibre.

<u>Recent trends in NC/Machine Tools:</u> The use of general purpose minicomputer as a part of a system and the use of software as applicable to the minicomputer is now being discontinued. Control systems built with microprocessors and with dedicated software constitute the architecture of CNC system.

Microprocessors are currently used in two configurations: in bit-slice architecture to construct a microcomputer which in all respects fulfils the function of a minicomputer and for microprogramming. The designer of a CNC system is thus offered the flexibility to formulate his own macro instruction sets. Hence it is now possible for many of the NC systems builders to change over from the minicomputer version to the microcomputer version without changing the system software. Westinghouse, Bendix, Standard and general automation, Fanucs, Siemens have changed over to microprocessor based systems keeping the same software that was developed for their minicomputer systems. This has proved very economical as no additional investment is required on software development.

The second configuration of microprocessor - based CNC system is to use three 16-bit microcompressors and to assign certain tasks to each microprocessor, viz, one for part calculation, one for axes drive and one for 1/0 interface. Similarly Allen Bradly 7100 CNC uses three 16-bit microprocessors, one each for axis drive, front panel interface and central processing unit (CPU). In this architecture, as the tasks are divided among the microprocessor, the CPU co-ordinates these tasks between the microprocessors.

In the earlier CNC systems, magnetic-core memory was used as the main memory of the system. This, provided a non-volatile memory but was more expensive and also temperature sensitive. Hence, this is now replaced by semi-conductor memories, like the Random Access Memory (RAM). Since these are volatile, a battery back-up is provided to retain the information in the memory in case of main power failure. Also these RAMs are now available in 16-bits configuration, in a single chip. Other types of memory chips like the Read Only Memory (ROM), Programme Read Only Memory (PROM), Erasable and Programmable Memory (EPROM) are used to store the management and control information. These are non-volatile memories. The latest trend is to store the system executive software in PROMs. Formerly, this software was on punched tape and was loaded through the tape reader into the main memory, but quite often this information in the memory was lost due to electrical disturbances in the workshop environment, or a power failure. A CNC system like the VET uses a floppy disc for storing an executive software. This is non-volatile and has proved very useful.

NC Perspectives: The advent of the computer and electronics has made possible NC machine tools which have drastically changed the technology. Further improvements in controls are foreseen, such as, to increase their capability, their memory to allow more functions to be monitored and/or controlled. Rapid progressive electronics causes machine tool controls to become obsolete in 3-5 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 have been replacing hardwire NC. PCs (programmeable controllers) are replacing hardwired relay logic. Computer reliability has been remarkable, and controls have helped to increase machine up-time 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 (CPU), the use of more computers is foreseeable as (i) supervisory computers in the DNC or machining system comprising several machine tools; (ii) as an aid to optimisation and shop performance, small hand-held computer or microprocessor and/or small personal computer; and (iii) as a tie-in of machine tools to a computer-assisted comprehensive operations-control system in the company.

Some of the directions for improving the machine tool control units are: 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 maintenence personnel; novel schemes of error compensation; additional diagnostics; devices to reduce set up efforts and time, such as tool-set stations or feelers probes placed in the tool holder with automatic adjustment for toolwear or fixture positions; on the machine inspection of geometry or surfaces with automatic correction; record keeping of machine utilisation or cutting tool life; self-healing or self-repair after diagnosing a certain failure, such as broken drill; and ability to modify programme on the shop floor or recording the events of the last minute or two prior to a failure.

Standardisation of interfaces or language/ data communications is an important concern, as are terminology and methodology for maintenece. Strong efforts are being made to evolve set of 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 three dimensional modelling of parts, and clearer communication between the devices and the operator are being further intensely investigated.

Verification of input data prior to running a programme 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 having been pursued for about 15 years, have found acceptance only in a limited application. Improvements in understanding the cutting processes, the variation of cutting conditions and more reliable sensors are needed to be developed. Good sensors for toolwear, tool breakage and 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 sensors, techniques for identifying intermittent errors and diagnosing more of the mechanical failure through signature analysis or other techniques. Novel diagnostic approaches are also needed such as those that can predict a failure and permit 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 (CAD) the use of this graphic display will be extended to the NC Systems, resulting in the interactive graphic CNC system.

General Numeric has already brought out their "Ultimate TG" microprocessor CNC, for turning machines with facilities for automatic programming and interactive graphic display. Here, the CRT can display the appearance of the finished part, the programmed tool part, the actual position value, the system parameters, programme data, tool offsets and diagnostics. Paging facility is provided for seeing long programmes on the CRT display.

Automatic programming will be another feature in CNC to attract 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 work piece, the codes for the tools used, the offsets, feeds, speeds and some simple instructions through the keyboard. The built-in software does the necessary computation, calculates the arc centre and programmes itself.

In the field of diagnostics for maintenence of CNC systems, remote diagnostics will be commonly employed in future. Numeric Easy Automatic Telephone (NEAT) service of Giddings & Lewis and

Diagnostic Communication Systems (DCS) of Kearney & Trecker are two such remote diagnostic facilities presently offered to NC users in the U.S.A. Remote diagnostics involve the use of a phone to transfer digital information between the CNC system under trouble-shooting, and the central computer used for diagnostics at the manufacturers premises. The central computer is able to make a multitude of analysis, checks on both the control unit and the machine elements, thus rapidly pin pointing solutions to malfunctions and also spotting potential sources of failure. This system acts as an expert on the shopfloor, talking the same language as the equipment and eliminating communication problems, delays in problems solving, and saving expenses by the travelling field service engineers. This facility can also be extended to other countries by using the satellite communication link.

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.

Electronic control, for example, will change the concept of a stand-alone machine and will allow machine to function as a part of a system. The machine cycle will be altered either by remote command or by some conditions sensed at 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 utilisation.

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

Knowledge of software design and system integration then 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 systems integrator should understand and determine how all the elements work in relation to the other.

At present, there is no general consensus on what the responsibilities of the system integrator should be, or whether it is even a necessary function. Its value will have to be determined, however, before complex systems can be developed and implemented.

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

Fujitsu Fanuc's latest brain to come on to the market is its system 6. Introduced in 1979, the System 6 incorporates large custom-integrated circuits and the latest techniques in electronics such as high speed microprocessors and bubble memories, making it a more reliable and more economical version of the model it replaces. 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 earlier system 5. Fanuc is now developing a system 9 which will reduce the number of parts still further through the use of "very large scale integrated circuits" (VISL) Research in this is being done, in co-operation with Siemens of West Germany. Production was originally planned for the latter part of the decade but may now start earlier as Nippon Electric Co., has recently announced that it can mass produce VISLs.

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.

CHAPTER II

CAD - 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 design procedures. A fairly typical design method is as follows :
(a) Functional specification; (b) preliminary rough design; (c) estimation and design analysis ; (d) final design; (e) detail design; and (f) drafting. In the modern state of development, computers are being widely used in the engineering design. This has led to the development of a new discipline known as 'Computer Aided Design' - CAD.

Conceptual Design: The first two aspects of design, viz., functional specifications and preliminary rough design, can be considered as conceptual part of the design process. This is essentially a creative activity. It depends upon the ingenuity, innovative qualities and the 'feel' of a desiger, based on his experience and creative ability. Computers have considerable limitations as aids to conceptual designing. Nevertheless, many of the computer methods are valuable to expedite the design process. Computer retrieval of design information is one of them. The designer spends a considerable part of his time to search for information from catalogues, standards, research papers, old designs etc. Computer managed data banks are available in certain fields to cater to the designer's needs. The designer can have access to such data bank through multi-access channels even from a remote place through computer terminals and telephone net-work. Industry's own in-house information retrieval system, based on a mini-computer is also viable in computer-aided design.

Estimation and design analysis: Next to the conceptual stage, is the stage of estimation and design analysis. This stage uses the computer to the maximum extent. Calculation of forces, deflections, stresses, or variations of a proposed design can be performed to a high degree of accuracy by the computer. Estimation of cost is also done very quickly and accurately by a computer.

At this stage, the recycling of information is done to alter the rough design and to reanalyse and re-estimate to arrive at cost effective and optimum design. If a computer is not available at this stage, the designer usually remains satisfied with one or two trials and waits for the performance report of his design after the prototype is manufactured and tested.

Availability of multi-axes and time-sharing computers and intelligent peripherals like visual display, graphics terminals have made things easier. The multi-access and time-sharing facility allows the user to communicate directly with a distant computer, send data or instructions via a visual display graphics terminal, and immediately receive back the output on the terminal screen in graphical form. If the designer is not satisfied with the output, then he can change some of the input parameters either through the key board or in the form of graphical input by using a light pen on the graphic screen and ask the computer for re-processing. The cycle can be repeated till the required result is achieved. By this method, the user and the computer can work inter-actively, modifying and improving the design and correcting errors without having to wait for the print out. This development in computer technology and graphics constitutes an essential part of the CAD approach.

Computer Aided Drafting: Once the design parameters and shapes are established through conceptual and analysis phases, the next step is the production of engineering drawings which is mainly a drafting job.

Development of automated drafting machines; (both drum and flat bed type) have made drafting easier. Once the various design data are available with the computer in the form of coordinates, these data can be transformed into an analogue drawing by driving the drafting machines as computer peripherals. Computer softwares are available to deal with two-dimensional and three-dimensional views, utomatic dimensioning of part drawings and assembly drawings.

CHAPTER III

TECHNOLOGICAL TRENDS IN PRODUCTION ENGINEERING

As mentioned earlier in the Report, development of production technology depends directly and uniquely on the development of modern machine tools, cutting tools and machine tool controls. With spectacular and innovative developments taking place in all these entities, one should naturally 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 the micro electronics to develop software systems which combine the benefits of all these newer developments in evolving highly productive systems of manufacture. Computer technology, micro processors and minicomputers have become the prime agents of the spectacular changes taking place in production engineering. Control of machine tools and manufacturing processes by computer, is the present day trend. Computer monitoring or control of plant operation is the most significant trend in the metalworking industry. Computers are being used to solve scientific and engineering problems related to product design and production engineering. They are being used in manufacturing, planning to stimulate the flow of parts and assemblies, eliminating bottle-necks in advance. They are being used to control inventories of raw materials, parts and assemblies and to monitor production operations - controlling them completely in some cases. Scheduling is being computer controlled, the objective being to keep machines and production lines as fully loaded as possible in order to receive maximum return on the company's investment and facilities.

Probably the biggest advantage of computers in metalworking plants is their ability to keep track of what is going on, on a real time basis. Alerted by computers, management is able to make decisions when they are needed and when the trouble occurs. The managers are able to study metalworking operations in their plants in greater detail to find where process improvements - better flows of parts and materials between machines and tools, better allocation of manpower and brain-power will pay off. Many routine management decisions are being made by computers freeing management from some of the day to day boredom of life in metal-working industry and giving them time for longer term strategic planning that is so very necessary for the success of metalworking business.

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, the machine tool based production technology is getting strongly integrated with computer.

Robots have been on the industrial scene since early 1960s. But the first models were 'hulking brutes'. The new breeds are sylph-like and are far brainier, thanks to today's micro electronic technology. They are nimble jacks-of-all trades. A typical model can be fitted with a variety of hands, mechanical "grippers" to pick up parts and are being provided with scanning eyes to pick and transfer and load whatever is desired by the programme engineer.

The unmanned factory of the future is shaping up fastly on computer, much quicker than previously estimated.

Manufacturing saw its first revolution in the latter half of this century with the advent of NC. It can be termed a revolution because it freed manufacturing engineers from their total dependence on the skilled machinist to obtain parts of acceptable specification and held out potential for complete control of the machining operation by the methods engineer. Manufacturing is now on the threshold of second revolution. The computer promises to give management complete control over the whole manufacturing operation, from design to despatch. "Computer aided design" (CAD) and computer aided manufacture (CAM) are terms which symbolise engineers' attempts at transferring all of the routine functions in manufacturing operations to the electronic computer, vesting in it a limited supervisory control and using its data processing capabilities to optimise the manufacturing operations. Electronic control of manufacturing operations is advancing as rapidly as development of software - always the bottleneck in such cases - will permit.

Three major factors have combined in the last decade to advance manufacturing to its present stage. They are: increasing cost and shortage of skilled labour; higher productivity and automation (including NC) of new machines offered by machine tool builders; and the availability of reliable low cost computers in the last five years.

Skilled labour is going scarcer and wage rates are ruling high. There is a gradual shift of the labour force away from the manufacturing into service industries in countries like U.S.A., Japan, Germany, U.K., Belgium and Sweden. This trend may strengthen as working weeks shorten and leisure and entertainment service attract more and more people.

There is an increasing demand for variety to meet changing and varied customers' tastes. Average lot size have decreased in recent years, even in traditionally mass producing industries like automobile. Today, people rarely talk about mass production; they talk about high volume. The former implies millions of identical parts while the latter means production at the same high <u>rates</u> but with the ability to adjust to customer preferences. To meet higher performance standards, and safety and ecological regulations, manufacturing tolerances are becoming finer. Economical methods of working to higher accuracies are becoming more popular.

The need to economise on material consumption is a major consideration in the manufacturing processes. Additionally, large number of new materials, generally of high strength and performance are evolved to meet product requirements.

The overall effect of these factors has been to demand from manufacturing operations, full optimisation of all the three resources - men, materials and machines. "Optimisation technology" in manufacturing is engaging the attention of top managements.

Computer in Manufacturing: Currently, emphasis is on linked 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. Future computer aided manufacturing (CAM) 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 hierarchial computer systems. The next logical progression will be linked multiple systems of this type with automated assembly and these could possibly be the forerunner of an unmanned factory.

DNC - Direct Numerical Control of NC machines from a central computer - has taken a back seat whilst recent attentions have been focussed on a "systems" approach to batch manufacturing, namely "Flexible Manufacturing Systems" (FMS) and Unmanned Manufacturing Systems (UMS). All the integrated CAM systems are aimed at batch manufacturing, have a high level of material handling and have integrated control systems. Hence they can be considered as an extension of the DNC systems with the inclusion of management information systems, work transport and possibly tooling transport systems.

In Japan, America, several of the East European countries and several of the West European countries, commerical DNC installations and integrated work transport systems have been introduced. The Japanese Project on the Automated Factory is an indication of their lead in batch manufacturing.

Integrated Manufacturing: 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, relative to each other. The chief benefits of so doing are: reduction in lost time caused by inter-stage movement of the components being made; improved machine tool utilisation; reduction in manpower; reduction of work in progress; and greater flexibility of component batching and loading.

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

However, the main concern has been with the application of this type of manufacture to small batch production, which constitutes a significant proportion 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 integrating manufacturing system could be "the mass production of one-ofs".

Integrated manufacturing systems of some form for machining components, have been in commercial use for about 22 years in the industrialised countries and existed in experimental form for some years before that. Early systems included, manually operated standard machine tools, fed by automatic means from a common source, as well as a limited number of machining centres coupled by palletised loading and unloading.

The real breakthrough, however, was dependent on the design of reliable comparatively low cost control systems, which became available in the late 1960s. From this point on, it was possible to design systems which would achieve a sufficiently long meantime between breakdown to make them economically attractive - always assuming that the standard of the mechanical functions was of an equal order.

Production could now be accurately planned through a complex system of machining operations, and the manual content was reduced largely to that of inspection of piece-parts and tooling to maintain the standards of accuracy and finish demanded by the specification of the component. The machine controlled environment on and off the shopfloor could yield efficiencies not previously considered attainable in this type of production.

Because of the high operating efficiencies leading to greater tool cutting time, a group of 8 machines can be equated to 100 conventional machines in output, especially on small batches upto 50 parts. The average number of machines in a system varies between 5 and 9 machining centres, though the greatest number recorded in one system is 70 in the United States at the Sunstrand Corporation. With high operating efficiencies (in some cases over 90%) the output from a single system can be as high as 4,000 pieces a month on a three-shift basis, thus giving to the batch production of small quantities, the volume outputs of mass production equipment.

Computer Aided Manufacture:(CAM): A computer aided manufacturing system (CAM) is a closed loop regulating system whose primary input dimensions are demand (requirements) and product idea (creativity) and whose primary output dimensions are finished components (finish-assembled, tested and ready for use). It represents a combination of software and hardware consisting of the methodology of production, production planning, production control as well as the choice of production aids including machine tools. It can be realised by systems engineering methods and it 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 and it constitutes the basis and guiding factor for the development and application of computers for integrated production. This is generally called the computer aided manufacture.

In other words, Computer Aided Manufacture (CAM) is a conglomerate concept where the ability of the computer is used at every stage of manucturing by evolving a cellular structure. Though this type of manufactureing may appear akin to the transferline concept, CAM has flexibility unlike transferlines, to alter the type of product, and also 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 a flexibility is achieved because of the monitoring and control exercised by central computer.

The availability of DNC and computer controlled installations are having a major impact on the manufacturing philosophy as a whole. 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 realised that the best benefits of computer control are only obtained in a kind of group tech-nology 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, material management, budgetry control, reporting etc., 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 hierarchial line of computers at different levels. Information and feedback from various cells go back to the central large computer, which possesses powerful software, capable of dynamically programming the whole operataion of the optimum utilisation of all resources. The addition of automatic warehouses, assembly, test and despatch systems is also proceeding partially, leading to the capability of automated unmanned manufacturing.

It is important to note that computer controlled manufacturing systems exist even today at various levels of development. An excellent example is Fujitsu Fanuc's Hino facility which uses computers and NC to automatic production of NC systems and NC drilling machines.

The motive force behind this strong and all pervasive trend of computer aided manufacturing system in modern factories, is a combination of long range economical and social factors. These factors have exerted an enormous influence on modern concepts of industrial production. It is important to correctly understand these factors so that the technological development is properly steered and the resultant technological developments are purposefully applied.

Economic factors: The decisive long range economic factor which governs the structure of industrialised nations, is the constant need to reduce cost of production, to achieve higher real growth. It is also known that the processing industry today constitutes the most important segment of production in industrially advanced countries. While the processing industries account for one third of the Gross National Product, the service sector accounts for almost half of the GNP in industrialised nations. It is true that the service sector is important for a good standard of living and for a better quality of life. But it does not create any wealth. This obviously leads one to conclude that the processing and manufacturing industry produces about two thirds of the wealth of an industrialised nation. The remaining growth can be attributed to primary products like agriculture, sericulture, mining etc.

Ther service sector producing no wealth, depends entirely on the sectors producing wealth. Thus the higher living standards, improved quality of life, better employment opportunities and general welfare of a country depend directly on the cost factors of producing wealth. Since the manufacturing/processing industry creates almost two thirds of the real growth in the industrialised countries, any reduction obtained in the cost of production can be of utmost significance. It is recognised now that the 'computer aided manufacture' offers more avenues of reducing production costs than all the other known techniques. Therefore, all industrialised countries, want to develop and apply computer aided manufacture as soon as possible. This again implies world-wide development of modern machine toolsand an intense concentration of computer optimised automated production systems.

Social Factor: The most important long range social factor influencing the manufacturing industry is the trend towards a post-industrial society. The attitude of the workers towards their working mehtods are fast undergoing changes. They will show an increasing disinclination towards the existing nature of work in factories. There is an unmistakable trend that more and more workers in the industrialised countries are preferring jobs in the service sector. For example, in the United States of America, in the course of industrial development, the proportion of workers in agriculture fell from 90 percent in 1870 to only 4 percent in 1976. Correspondingly, there was an increase in the number of those employed in industry in the 19th century. However, in the last few years, the percentage of workers in the industrial sector fell from 30 percent in 1947 to 24.6 percent in 1970 and it stood at only 21.7 percent in 1978. A study conducted by Rand Corporation has estimated that by 2000 only about 2 percent of the workforce will be employed in the industry. But Prof. Bell is a little more reserved in as far as, he estimates it at 10 percent . However, in all the industrialised countries, lack of industrial workers will be more acute in the coming years.

This workforce migration adds directly and puts social pressure on the manufacturing and processing industry of the industrialised countries which has to produce more and remain productive, irrespective of the fact that its workforce is preferring slowly but steadily the more attractive milieu of the service sector. This pressure on the manufacturing industry can be mitigated by computer integrated production systems.

Technological Evolution: As a consequence of the long range economic and social factors influencing the industry, a number of national plans have been drawn at present in the industrialised nations to accord priority for the development and application of computer aided manufacturing systems and computer optimised and automated machine tool systems. The governments, the universities and the industrial establishments are working in a team to promote this. Eventhough the realisation of fully computer integrated production systems is the long range plan, there is a clear awareness that the change from the present industrial methods, know-how and machines require an evolutionary process to reach the ultimate goal. The applied strategy, therefore, consists of developing and applying individual, practical and economic steps in the form of short term research, development and application programmes having the following two main principal characteristics :

(i) The step should result in adequate gains to justify its adoption and to produce profits on the invested capital to finance the next steps of R&D investigations;

(ii) Each step should be a link in the chain to achieve the final goal of fully computer automated optimised and integrated production.

Among the various programmes under execution in the highly industrialised countries; the following seem to find maximum attention:

(i) Creation of software modules by developing individual software modules which can be coupled with one another quickly at a later time to produce a complete software programme suitable for various production application. Such investigations are making tremendous progress in U.S.S.R., Czechoslovakia, and other COMECON countries and as well as in Federal Republic of Germany, Norway, and Japan. The U.S. Airforce is fostering a programme called the ICAM (Integrated Computer aided Manufacturing) and the Computer Aided Manufacturing International, U.S.A., is busy with several programmes for the development of software for integrated production.

(ii) Development and application of part family production & production cell: are a prerequisite for the application of hierarchial computer systems and for the development of flexible production systems. In Holland, West Germany, Norway, U.K. and COMECON countries, intensive work is going on in this direction.

(iii) Rapid progress has been achieved in the development and application of comprehensive computer controlled operations of machine tools and computer monitoring of production processes by employing numerical controls, computer-integrated controls, direct numerical controls and hierarchial computer systems in Japan, U.S.A., West Germany, Norway, Sweden, U.S.S.R., Bulgaria and Hungary.

(iv) Investigations on the development and application of computer controlled industrial robots for automatic manipulation of work pieces and tools, operation of machine tools and production aids of various types, are progressing in Japan, U.S.A., West Germany, Norway, Sweden, U.S.S.R., Bulgaria and Hungary.

(v) Rapid progress has been achieved in the development and application of computer controlled flexible production systems evolved on the concept of automatic production cells in countries like Japan and G.D.R. Recently, West Germany, U.S.S.R. Bulgaria, Czechoslovakia, Hungary, Norway, the United States of America and the U.K. are working in this field.

Flexible Machining Systems(FMS): There is no generally agreed-upon definition for what have come to be called, "Flexible Manufacturing Systems" (FMS) but there is no denying that within the last 5 to 7 years, a more responsive yet automated way of addressing the needs of manufacturing has evolved. This new method relies on three distinguishing chracteristics: (a) potentially independent NC machine tools; (b) a transport mechanism; and (c) an overall method of control that co-ordinates the function of both machine tools and conveyor system so as to achieve flexibility.

Within the broad scope, there are any number of individual approaches towards striking a balance between high output on the one hand, and great flexibility with concomitant reduction in output volume, on the other.

The main purpose of flexibile 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 microprocessor-based computer. The various functions of the individual cells are:

(i) supply of blanks, tools, guages, 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 workpiece, 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.

Each cell basically caters to a particular machining process like turning, milling etc., The different cells are connected by transport devices into a 'flexible manufacturing system' and the co-ordination of the simultaneous activity of all the cells is accomplished by the process computer hierarchy so that from raw material to the 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, boring etc., as a part of one individuaal cell. In this case, the material handling functions are reduced. An existing stand-by robot or an integrated robot performs the workpiece handling and the function of handling the measurement device.

Maximum utilisation of 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 strategy for utilisation of installed capacity, reduction of idle time and also to take care of the thermal effects of component accuracy.

Several manufacturing cells linked by a transport system, additional handling devices and an automated storage and a retrieval system for workpiece, tools etc., can lead to the concept of an automated factory. The ultimate optimisation is envisaged by a hierarchial set up, wherein all cells at a ligher level, are controlled by a centralised computer (DNC) and all production groups are linked to a minicomputer, providing a basis for the complete on-line optimisation of material flow, scheduling, routing and full automation of production.

Computer integrated flexible manufacturing systems are thus gaining increasing acceptance and importance in batch production. Of the 52 approximately flexible manufacturing systems developed upto 1979, about 40 have been put into operation, mainly in Federal Republic of Germany, Japan and the U.S.A., nearly 70 percent of them being for prismatic components.

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

Development is also proceeding with the automation of metalforming machines using mini-computers and microprocessors. Programmable turret punches, auto controlled guillotines and shears, and manipulative equipment are in use. Robot developments applied to metalforming operations will enable a considerable degree of automation in this class of piece-part manufacture. It is now possible to construct metalforming 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 fabricated piece-parts whether forged, welded, sintered or similarly processed, is being automated with the use of robots;

and major developments are taking place in Japan, Italy, U.S.A. and in the U.K.

The automation of assembly operations remains problematical, except for flow line manufacture. But again, robotic and computer developments will have a considerable impact on these operations in the immediate future.

Czechoslovakia and Poland are the biggest machine tool builders in the COMECON countries outside USSR and GDR, and both are actively developing flexible manufacturing systems (FMS). The main reason is that batch production constitutes a large proportion of engineering component manufacture in both these countries and both are short of skilled labour.

Flexible manufacturing system development in Czechoslovakia has concentrated on "prismatic" and latterly, flat milled and bored components. Poland has developed a number of flexible turning systems, though recently has begun work on flexible milling and boring system.

Most Czech FMS developments have been angled towards its machine tool industries, whereas Polish systems have been designed for general engineering such as the production of shaft-like components for the electrical motor, earthmoving, coal mining and commercial industries.

Czechoslovakia has progressed as far as developing distributed numerical control systems (DNC), pallet exchange and transport systems, a novel stacking-crane fed box pallet system, and automatic tool/raw material/work-in-progress stores

Group Technology: One of the methods of solving the problem of conflict between productivity and flexibility in the computer integrated flexible manufacturing system is Groupt Technology (G.T.). G.T. 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 rationalisation of components, it also helps to establish better co-ordination between the production wing & the other functions like design, methods, sales engineering etc., The fact that more than 80 per cent of the engineering industries of the world are engaged in medium and small batch production should lend the concept of group technology a new significance.

The traditionally laid out production lines on the basis of functions viz., turning family, drilling and boring family etc., led to a lot of production delays because of inherent limitations in production control. A group technology based production system organises 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 GT system, virtually function as small factories within the main factory. This assures reduction in through-put time, work in progress, inventory, setting time, work handling, jigs and

and fixtures etc. This concept improves design rationalisation, job satisfaction and production control. NC shops are at present major areas where group technology is employed. But with a shift from hardwired NC to software based controls like CNC, much of the essence of group technology will trickle down to the software.

Computer control and inspection of machine tools: The evolution taking place now in the direction of computer control and inspection of machine tools, constitutes the most progressive field of development of modern machine tools. It is aimed at exploiting the enormous potential of NC through computer based control, the DNC and the hierarchical computer system. This potential is ever increasing in its scope by the advances which are being continuously made in the field of computer technology.

The application trend is more and more towards minicomputers at the work spot. Because of the linkages between the work stations, the trend is towards a decentralised computer which in a way, is a partial separation between the data processing and control function. This is especially true of computer-based control of machine tools. The far reaching development of coupling computer with the machine is facilitating versatile control possibilities offered by the computer technology. The computer has thus become most modern device for error diagnosis and correction on modern machine tools. This has enabled a new approach to the supervision of machine tools because it is now possible to automatically detect the various errors and malfunctions, both in the electronic and mechanical systems. Thus the possibilities offered by computer technology not only provide the basic testing method during the trial run of the newly developed machine, but also enable to automatically find out the existing error and the potential sources of manfunctioning, even in the normal working range of machine tools. While detecting even the initial signs of an error or a malfunction, the computer immediately flashes out a signal to the operating personnel, and thanks to the diagnostic abilities of the computer, the maintence personnel immediately receive intimation on the cause and methods of correcting the disturbance.

The new capabilities of the computer are finding immediate application in modern machine tool. The future trend will be towards the development of methods which facilitate automatic correction of malfunctions. Given this possibility, the computer as soon as it detects conditions leading to an error, will alter machine parameters in such a manner that the error will not actually take place. In the case of malfunction, 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 into the science of measurement. Developments in inspection and guaging 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.

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

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

Integration of different devices is being done into 'measuring centres', especially in post-process inspection equipment. Application of minicomputers and output devices such as plotters, printers and CRT displays are developed for 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 0.01μm whereas 5 years ago, there was a practical limit of resolution of 1 [illegible] using guage blocks.

Progress in measuring techniques has been so rapid that the resolution and accuracy of guaging have reached limits governed 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, requirements of automatic assembly, longer final product life, legislation to reduce noise levels, needs of related technology like IC fabrication etc.,

The developments of compact rugged and reliable electronic probes has made possible in-process guaging on transfer-lines and other automatic manufacturing systems. Systems are now being developed to use this capability in the adaptive mode to correct job or tool setting to achieve the required size. Automatic guaging systems are also applied on equipment used for automated assembly. There is no doubt that the future will see more such applications in industries like electronics, instrumentation, electric motors, precision mechanics, cameras and bearings. 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 guaging requirements on a wide variety of parts and incorporate devices to load, transfer, index and unload parts and segregate them into acceptable and rejedted lots.

<u>Assembly</u>: Assembly with its high labour content, is an area holding 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 U.S.A. automated assembly has been applied only to sub-assemblies like rear-differential axle, breakdrum etc. 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 process. Automobile engine assembly is one area which has seen the application of such concepts with the process being controlled and monitored by computer.

Future design of automatic assembly equipment will incorporate guaging also. This will have an impact specially on electronic industries. Mechanical assembly is now trying to use such systems in situations where parts may get jammed together or deformed during assembly without the knowledge of the operator.

Controls for assembly machines have also seen much development. Programmable controllers are commanding many assembly machines surpassing even computers and hardwired controls in a number of applications.

Fasteners have seen much progress in recent years. New bolts, screws, nuts and rivets make assemblies easier, faster, cheaper and adaptable to automation. Newest in such concept is a system which sets bolts under a kind of adaptive control that shuts down the fastner driving tool when a preset torque + rotational angle combination is reached.

Industrial adhesives are taking over many areas now served by mechanical fastners. Developments are in progress to quote the adhesives automatically and hold the assembly in a fixture for a regulated time before releasing it. Techniques of adhesive bonding, originally developed for aerospace applications, will cause a revolution in mechanical assembly, if applied properly.

Material Handling: Material handling systems are increasingly being integrated with operations in the plant. These systems employ driverless trucks, conveyers, monorails, sorters and stock pilers in material handling.

Storage systems are employing taller stacks because of increased cost of floor space. To combat stock pilferage, increased use of driverless order pickers operating within the locked room are under development.

Computers are obvious tools for application in material handling systems. It is reported that over 100 U.S. material handling systems are operating under computer control. Foundries will be a major target for automated computer-controlled material handling systems in the years ahead.

CHAPTER IV

AUTOMATION AND FUTURE TRENDS IN MACHINE TOOL INDUSTRY

ROBOTS

Robots have been on the industrial scene since the early 1960s, but the first models were big affairs designed mainly for difficult and hazardous jobs. Tedious, laborious, repetitive and hazardous jobs in manufacturing industry were the areas where the robots were applied hitherto.

Thanks to today's micro electronic technology, they 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 are the latest of automation - a programmable or flexible variety. As distinct from the automatic mechanism, a robot has generally multiple degree of freedom, rotary and linear which can be actuated individually and simultaneously to approximate closely the physical motions of a human-being, performing the same tasks. Robots have been developed which stimulate closely the variety of movements possible with the human upper torso, shoulder, arm, elbow, wrist & hand.

Whilst the earliest robots were controlled by programmes set with limit switches, modern robots are programmed by minicomputer , temporarily attached to it. 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.

Compared with the previously built robots, the new robots are nimble jacks-of-all trades. A typical model can be fitted with variety of hands, mechanical "gripper" and enabled to pick up parts and pass them along a spray head that converts it into a painter or an arc that turns it into a welder. Such robots load and unload parts from furnaces, stamping presses and conveyors, and a few of them perform their jobs while driving conveyors. They also quench red hot parts, lubricate dies in stamping-machines, drill holes, insert screws and grind parts. Robots are involved in inspection of finished products. At Texas Instruments, for example, dozens of computer-controlled small robot arms with TV camera eyes, spot pocket calculators moving down a conveyor belt, pick them up and place them in an automatic electronic inspection station. Most wonderful of all, robots are starting to assemble components in factories. Over the next 12 months, General Motors will install 10 PUMAs (an acronym for 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 put the windshield washers together. PUMA is in the vanguard of an array of small and relatively in-expensive robots that are taking over more and more jobs that were previously performed by humans.

Robots are presently applied in diverse tasks which include loading and unloading machine tools and presses, removing parts from die casting machines, material handling and transfer, especially in foundry and forge, painting and even in simple assembly operations. The automobile industry in the U.S.A. use robots extensively in welding line.

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 feeling feedback.

It is important to note that prototype robots with rudimentary sensory feedback are already functioning in some countries. However, a general application of such advanced robots in industry will depend on the cost of such units and the ease with which they can be programmed.

The application of TV and holographic techniques are having a major impact on the major development of robots capable of seeing and recognising 3-dimensional objects, especially when the objects are presented to the robot in a random orientation. This device can retrieve a freely hanging carbon brush (randomly oriented) and place it in an assembly machine for insertion in fractional horsepower motor. Robots equipped with "sight" and "feel" sensors will certainly find widerapplication in automated assembly systems of the future.

Advanced projects have been concieved not only for adapting the comercially available robots for various production processes, but also develop them further for the present as well as for future requirements of computer aided manufacturing systems. Some of these projects are meant to ascertain the software and the hardware requirements of individual robot stations for future application in an integrated production cell and later, in an integrated sheet metal working centre consisting of several cells.

Two key developments have brought about the industrial robots to life. One was, technological - the development in the mid-60s of the micro processor, a computer so small that it can be fitted into a silicon chip, no bigger than a pea. As the computer shrank in size and cost, it suddenly became practical as the brains to run a robot. The second development was wage inflation. Two decades ago, in the U.S. a typical assembly line robot cost about $ 25,000; that plus all operating costs over its eight year lifetime, amounted to roughly $ 4.50 an hour, slightly more than the average worker's wages and fringe benefits, then prevalent.

Today, that typical robot costs $40,000 (they range from $ 7,500 to $ 150,000) and it can still be paid for, and operated at about $ 5 an hour. However, the U.S. worker often costs today $ 15 to $ 20 an hour. The robot revolution is just beginning but it is already moving fast.

The Japanese are resolutely pressing forward in the field of robotics. In January 1981, Fujitsu Fanuc would have opened a new $ 38 million plant in which robots will work 24 hours a day to produce more robots (100 a month). It may be that Japan will end up being the one who makes the modules and parts that go into veryone else's robots.

Today, roughly 10,000 robots are in operation in Japan as against 3,000 in the United States, 850 in West Germany, about 600 in Sweden and 500 in Italy. Though for various reasons Japanese lead in employing robots in their manufacturing industry, all, including the U.S.A., Japan and other European nations are equally determined to exploit robotic technology. For instance, automobile manufacturers in the U.S.A. are the biggest users of robots in the industry. Genral Motors (GM), is in the lead with 270 robots installed followed by Ford Motor Co. with 236, Chryslers 100 and American Motors 10. The robots are widely used in welding, with painting as close second.

PUMA

PUMA will take over a number of jobs at GM including fairly complex ones that involve putting things together. At a Delco Products plant in Rochester, New York, PUMA will be instructed to reach out, pluck a tiny electric armature out of a furnace in which the temperature is running at 230° C, attach a commutator-ring to the armature, put on some resinous material, & replace the armature in the furnace for curing.

Computer programme is the key to turning robots into assemblers. More advanced robots, such as Puma can be told what to do by typing the instructions on a computer keyboard in a "language" that includes about 100 English words, such as 'here', 'move' and so on. Eventually, robot enthusiasts say that the evolution of robot language will make it possible to give robots spoken or typed commands such as "assemble the carburettor".

This is no pipe dream. At SRI International, U.S.A., to cite one instance, robots have already been taught to obey one-sentence spoken-commands, relating to portions of an assembly job.

Industrial robotics is a technology in which the U.S. is in the forefront of innovation. Robots have been more extensively used in Japan possibly because the need has been more urgent in a labour-short country like Japan. But the newest and most sophisticated American robots can perform more chores than their overseas cousins. The U.S. now leads the world in the pursuit of further advances. Evenso, when the various strengths and weaknesses of all countries, including the U.S.A., Japan and the European nations are balanced out, basically, they are all about even in robotic technology. What matters however is, what happens from hereon.

Unmanned Machine 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

U.S.A., Japan and other industrialised 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 and early 1990 that can substantially boost machine tool through-put, assure strict adherence to hard-to-meet quality control standards, minimise inprocess inventories and guarantee production rates by eliminating the last major machining variable. This 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 specially true when one considers the fact that the computer network required to operate such system barely exists on paper right now. But it <u>is</u> the next step down the road to the unmanned factory in the future, and the concept is beginning to gain acceptance in many areas of manufacturing.

The difficulty of finding qualified workers in the highly industrialised countries, is not the only factor leading manufacturers to look at unmanned machining systems. The government's new regulations regarding quality control, rising demand for higher product efficiency - and the closer tolerances and improved repeatability that higher efficiencies entail - and the continuing need to slash product costs to maintain competitiveness in an increasingly competitive world market, are all factors that manufacturers are taking into account as they develop capital spending strategies for 1980s. With rising capital costs, its fuller utilisation has become most important. Skilled workers all over the world, particularly in the highly industrialised countries, besides becoming prohibitively costly, are not willing to work in unearthly hours of the night shifts and also accept continuous overtime. Hence in order to utilise the plant, and machining right round the clock to recover the high costs of machining in today's price level and write-off the investments in this regard before the facility becomes obsolete, unmanned night shift operation of machine shop has become an accepted feature in the highly industrialised countries.

It is not surprising that Swedish companies are among the first to put the unmanned machining centers, into production. High labour costs and trade unions' willingness to accept automation are key factors. The unmanned machining centres (UMCs) delivered by Kearney & Trecker U.S.A. to ASEA, the electical equipment manufacturers and to Bofors, the famous armament makers are in operation in Sweden. In this system, Milwaukee-Matic machining centres are automatically fed, palletised, passed via carousel magazine. The UMC system is aimed at increasing the number of machines that a worker can handle, reducing inventory, and speeding production throughout.

Any country that develops the capacity to run its factories around the clock (in all three shifts), seven days per week, with only a few human workers will have tremendous advantage economically.

Unmanned manufacturing and assembly operations in industry have been viewed with somewhat dismay by social scientists all over the world, particularly by the developing countries, who have been one of the important sources, providing imigrant labour to the industries in the developed countries. However there are two views: One is, that large number of economically active labour, both domestic and alien (hailing from poor developing countries), would lose their jobs through greater degree of automation in industry. But the other view point, which is equally strong, is that automation like use of industrial robots to do dirty work has mooted alarms of loss of jobs and in a way, kept the labour unions, mostly at bay. Welding cars and spraying paint are stupefying jobs, and besides, they are ideally done at temperatures higher than a worker can stand. For instance, in one of the Westinghouse factories in the U.S.A., as many as 25,000 workers may lose their jobs due to attrition and there is no way to replace them all. People joining labour force in industrialised countries do not want the dirty jobs. The main task is to train people for the skilled jobs, that are in demand in today's labour market. "New jobs have always come from new technologies". One reason why Japan has been able to shift so extensively to robots is that the Japanese corporations have a tradition of caring for their employees' health & life and they do not want them to work on dirty jobs or on hazardous occupations.

But as robots take over more and more jobs - and they can do more pleasant and interesting jobs as well as the dull and dirty ones - the labour unions' acquiescence may change. After all, the rate of unemployment is already increasing due to high inflation, in all the Western industrialised countries and retraining programme of all the workers including those retrenched by high degree of automation may not be possible. Furthermore, retraining will not be possible because there could be no jobs for workers to be retrained for.

Factory workers and their unions in industrialised countries are not today so much worried about automation. For one thing, automation frankly has not reached that situation as yet. But as more and more industrial jobs are taken over from humans by automation, there may be some problems from the organised labour, social scientists and governments of the countries. Already, there are a few rumblings. Russ Cook, The United Auto Workers (U.A.W.) District Committee man at GM's Buick plant in Flint says "if we do not get smarter and start combating the machines, we will be cannibalising ourselves and competing against one another for jobs".

Automation, leading to unmanned factories, is technologically feasible in industry, yet its effect on humans could become insoluble social problems. The concept of unmanned factories may therefore progress haltingly, though the scope for unmanned operations under certain special circumstances will increase in the developed countries.

Perspectives - Future Vistas: Developments in machine tool designs have come up at a rapid pace in the last 10 - 15 years. These developments have been in response to the increased demands made of manufacturing technology through the influence of factors such as scarcity and shortage of skilled labour, need for flexible manufacturing lines, production of larger variety of goods in smaller lots, higher part accuracies and wider range of stock materials to be worked. The most important single aim throughout has been to design machine tools to achieve higher productivity.

Developments in machine tools will continue to be influenced with added emphasis on meeting specific governmental and social regulations affecting the working environment.

The accent on increased productivity will continue. As machines become more sophisticated and costs climb, productivity increase will be measured in "real" terms and the machine tool builders will be frequently called upon to demonstrate them and other economic gains to the user.

Design of machines and controls will place emphasis on high reliability in operation. Downtime on versatile highly productive machines becomes very expensive. For a small shop it can spell financial disaster. Builders should study the users difficulties and the machine downtime data so that the design can be changed to improve reliability.

Factors that reduce the usefulness of machines involve not only machine downtime due to failure but time lost in set up, operators absence, unavailability of material stock, tooling problems etc., Better monitoring and sensing techniques will allow users to measure utilisation precisely. Quick, easy and reliable servicing will become a major factor in evaluating future designs. Advances in electronics and electrical systems will have a major influence on the configuration and design concepts of future machine tools.

Machine tools of the future will have higher accuracies to meet the requirements of increased precision on components. Regulations on noise levels will be enforced on future metalworking equipments. This factor is likely to force designers to evolve new alternatives to present methods and will have a major influence on machine tool designs. Safety of operators will contribute to machine design concepts in no small measure. Since regulations will be enforced on existing as well as new machines, employers are likely to incur considerable costs on equipping the already installed machines with mandatory safety equipment. Ecology is another consideration. Pollution is another factor which all have to be reckoned in the future technological developments in metalworking machine tools.

Machine tools of the future will be required to work wider range of materials including harder and stronger ones. Optimisation of cutting conditions will therefore be very important in years ahead. The need to catch up with automation is likely to revolutionise all aspects of machine tool technology.

Machine tool versatility will replace some traditional metalworking skills and reduce labour demands, but will also increase the need for new skills. The traditional machine skills and knowledge will be replaced by skills in programming, development of software, and electrical and electronic maintenece systems.

As machines become more productive and downtime more expensive, all aspects of operator, from attention, to job knowledge will become more important. Machine operations requiring minimal input will reduce the demand for skilled labour, held by such development as adaptive control, surface sensing and automatic cycle adjustments, and performing monitoring.

Keeping highly productive machines running will require top maintenece skills and alert machine builders will enhance these skills by providing machines with built-in diagnostics and documentation capabilities.

In general, the technological outlook is one of the continued improvement in machine tool productivity and versatility and of reduced requirements of operators skills. There is, however, one area, in which little work is being done but in which developments are necessary if these other goals are to be achieved. That area is the control of metalcutting chips. Many of the situations requiring operator action in metalcutting operations, relate to chips in unwanted or unpredicted places causing tool breakage, misalignment, malfunction of chip handling equipment etc.

What is ahead in the field of production technology and machine tool development ? This can be estimated perhaps with the help of few technological forecasts. Very recently, the Society of Manufacturing Enginners, U.S.A., made three forecasts on the future of production technology based on Delphi technique. These forecasts concern machining, production systems and assembly. These predictions provide useful answer to the question. Out of the 133 queries in the preliminary round, 99 or 74 percent were pertaining directly to the subject of 'computer aided manufacture'. Selected forecasts given below provide an excellent insight into the direction and time span of future developments in this most important technology of metalworking.

Around 1985: Assembling jobs will be integrated with the other production routines making use of computer aided manufacturing systems. At least 25 percent of the firms representing a cross section of the industry in the advanced countries, will apply. software systems for automation and optimisation of various stages of production planning, e.g., machining sequence, selection of suitable machine tools, clamping devices, sequence of operations, tool selection and optimal cutting conditions.

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

Around 1990: The advanced development of sensors will facilitate robots to attain human capabilities in the final assembly sequences. Computer aided design (CAD) techniques will be employed for the design of 50 percent of the newly designed production aids.

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

Around 2000: Based on these forecasts, it is preseumed that even before the end of this century, many changes in machine tools and production technology will take place around a computer, viz., computer aided design and fully integrated computer aided manufacture and automatic assembly uding extensively modern robots.

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