21

TRANSFER MACHINING

21.1 INTRODUCTION

The widespread increase in the quantity of production requiring a multiplicity of operation such as, milling, facing, boring, drilling, etc., has led to the development of a method of manufacture known as transfer machine. A transfer machine consists of several machining heads, or units fastened together by conveying units, the whole constituting one large automatic installation. In short, a transfer device is a combination of individual machine tools sequentially arranged and integrated with interlocked controls and a transferring device to form an automatic machine. The term *transfer* refers to the transfer of the job from machining station to the next as it proceeds through the machining processes involved. Components are loaded at one end and completed workpieces leave the transfer line at the other end.

Application of transfer machining leads to increase in productivity, and reduces the number of machine tools and floor space by 30 to 50 per cent. Transfer machining also leads to better quality and reduced manufacturing cost. On the other hand, initial cost of such devices is very high. It also requires better quality blanks and skilled personnel. Prominent among industries using transfer machining is the car and vehicle industry, where large-scale production of cylinder blocks and heads, gearbox, etc., justifies the capital outlay associated with this form of manufacture.

21.2 CLASSIFICATION OF TRANSFER MACHINES

There are three chief arrangements for transfer machining. These are the (1) in-line machine, (2) rotary indexing table machine, and the (3) drum machine.

In-line transfer machine : This consists of a straight central bed into the sides of which the machining heads are dowelled and bolted at convenient fixed pitch. A plan view of the arrangement is shown in Fig.21.1. The central bed could be built up along a straight line of any length. If the floor space does not permit to accommodate a very long straight bed, the bed could be built up to some other configuration, such as U, L, or a square shape instead of a straight line. The parts to be machined are conveyed along a track on the bed either with or without the use of a holding fixture, called pallet. In the *pallet system*, after the operations are completed, the pallets are returned back to the starting point by the use of a conveyor placed either over, under or around the transfer machine. The work may be loaded manually or automatically on to the machine, and it is transferred from station to station while being clamped in pallets or holding fixtures. In other words the work is clamped in a holding fixture and is moved throughout the entire operation on the same fixture. The work can be presented to the machining head in any desired position by using turntables or turn-over devices at the appropriate points on the bed.

The *pallet type transfer machine* is more accurate than the plain type due to the fact that pallets can be built with very close tolerances. The work once clamped will not be removed from the very good along the whole process.

In *plain type transfer machines*, the work moves in an unclamped condition from station to station. At the machine stations, fixed or disappearing type dowel locaters and hydraulically actuated fixed clamps hold the work. In other words, the fixtures are fixed and only the workpiece moves throughout the stations. The plain types are used when the workpieces are held in identical positions at each machining station and when it is not necessary to change over from one part to another frequently. Also they are used for workpieces of rather regular shape. In both pallet and plain type transfer machines, the cutting tools may be presented to the work at any desired position or angle and they can go back to their initial position immediately after the machining operation, such as drilling, tapping, reaming, etc. are completed. An automatic lubricating system releases the required quantity of lubricant to the moving parts at pre-set time intervals. Provisions for removing large quantities of swarf and supplying coolants are all made mostly automatically. Besides, there is arrangement for

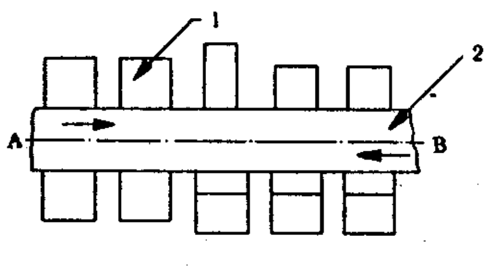


Figure 21.1 In line transfer machine
A. Unloading end, B. Loading end, 1. Machining head, 2. Central bed.

automatic safety devices so that if one is not functioning correctly no one will function.

The number of stations employed is limited only by the efficiency of the total machine, the power and accuracy of the drive mechanism and structural considerations. Usually the in-line transfer devices are selected when the number of station exceeds 24.

Rotary indexing table machine : Where the space does not allow work to be conveyed in straight line, it may be more convenient to transfer the work around a circular line. This principle leads to the use of a rotary system in which the workpieces are located on a circular table and are indexed around each successive machining station which are spaced as in-line transfer machine. The plan view of a rotary arrangement is given in Fig.21.2.

The main and central feature of the rotary machine is the circular table top supported on high-quality bearing system at its centre for rotating about a vertical axis, with driving arrangements for its indexing, and accurate locations that ensure the alignments between the cutting stations and their respective workpieces. There is also arrangement for supporting the rim of the table against the force of the machining operations to prevent deflection and also to eliminate vibration and chatter.

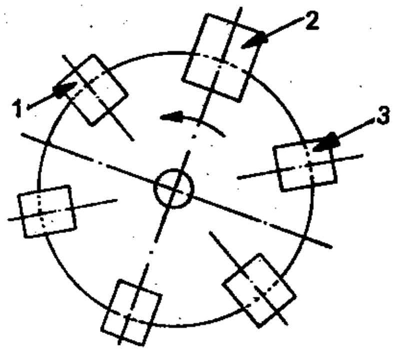


Figure 21.2 Rotary indexing table transfer machine
1, 3. Matching stations, 2. Loading and unloading stations.

Much of what was said about in-line transfer machines regarding machining heads, workpiece location, swarf and coolant control, etc. is true here, but rotary transfer machine will usually be smaller in size. This is because there must be a limit to the size of a table which can be held and rotated in a central base that will be sufficiently rigid to maintain the load and accuracy required.

For the maximum number of machining stations of which it is capable, say eight, a rotary machine is simpler than a line transfer machine of comparable capacity. The round table with its central pivot and indexing arrangements can be replaced easily, whereas it is difficult to replace the built-up central bed of the line machine with its complicated pallet and transfer system. On the rotary machine, one fixture for each station and a spare or extra for loading and unloading station are sufficient.

Rotary transfer lines may be successfully installed for the complete automatic assembly of a product where no metal removal is involved. Instead of machining heads radially disposed around the table, there are presses for peening over rivets, nut running heads for assembling nuts to screws, electric brazing heads for assembly, etc.

Drum machine : This type of transfer machine is similar in conception but different in configuration to the rotary table type as described above. In the drum method, the work fixture are fastened to the outside surface or periphery of a drum rather similar to a big wheel. The table which is replaced by the drum is mounted upon trunions such that the drum rotates about a horizontal axis.

This arrangement enables the workpieces to move or transfer around a circular path to work stations radially positioned around the path at equal distances. This method has the limitation that most of the machining must be done horizontally from the sides as, except for two or three stations, it is difficult to arrange for a radial (vertical) approach to the workpieces.

In Fig.21.3, it is seen that the lower station remains always idle as it is practically impossible to arrange a machining head to operate in the limited space under the drum. However, much of what was said in rotary table machine is true of drum machine except that this type of machine has limited working capacity because of the limited space available in the system.

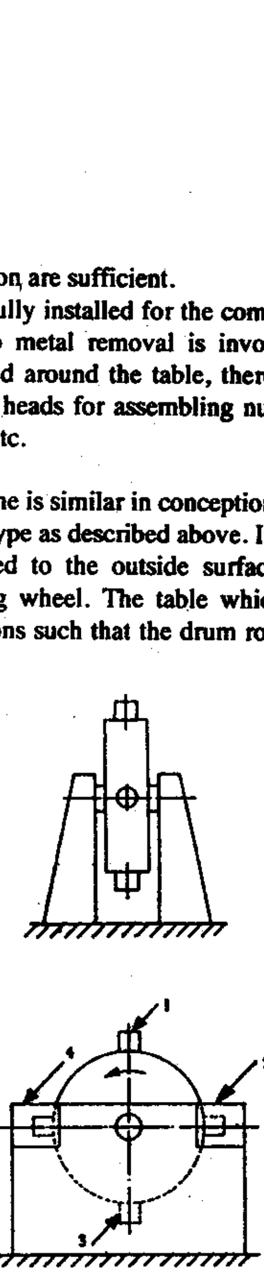


Figure 21.3 Drum transfer machine

1. Loading and unloading stations, 2., 4. Machining station, 3. Idle station.

21.3 MAIN PARTS OF A TRANSFER MACHINE

The parts which constitute a transfer machine are :

1. Bed (transfer track)
2. Machining head
3. Transfer mechanism

Bed : This constitutes the fundamental unit in the construction of the machine. The bed may be a single unit of cast or fabricated construction. But with longer machines it may be built up of several such units. The bed is generally straight although in some cases it may be made of a U, square, circular, curved forward or backward or of any other shape to suit particular condition. The upper surface of the bed has sideways for guiding and supporting the workpieces or holding fixtures (pallet) upon which the workpiece is clamped and located. There is also arrangement for transferring the workpiece along to each of the machining heads that are mounted on one or both sides of the bed. The arrangement includes chain conveyor, a longitudinal sliding shaft, and a 'walking beam'. The upper position of the bed also incorporated means for clamping and locating the workpiece at each station before cutting begins. Generally, roll-overs are also provided on the bed for rotating the workpieces through 90 or 180° during their passage through the line from station to station, if required. For fully automatic installation, use for pneumatically operated shuttle may be made for transferring the work from one position to another.

Underneath the bed there is a conveyor for carrying away the swarf and channel for receiving the cutting lubricants. Also below the surface of the bed and through the side extensions opposite the machine stations means are provided to return the empty fixtures back along the machine to the loading point after unloading.

Besides, there are other various basic units attached to the bed for the purpose of accommodating the machining units.

Machining heads : The machining heads are often made up of unit cutting heads, such as drilling, milling, etc., the spindles of which are usually driven from a self-contained motor. This is carried on an intermediate base slideways on its upper surface, and the lower, flat base of this is bolted to the flat surface of the wing base or column of the structural unit. This intermediate base of the cutting unit incorporates feeding arrangements to move the cutting unit forward on its slides for the purpose of traversing the cut. The heads can be mechanically or hydraulically traversed along the slideways while the cutting tools work upon the component. Using mechanical means, a cam or leadscrew can provide the medium through which the head is transversed. On modern machines the electrically controlled, hydraulically operated unit head is preferred.

The provision of feed units and machining head for rotary machines follows the same general principles as that have been described in connection with the line transfer machines.

Transfer mechanism : The transferring of the workpieces accurately from station to station can be done in many different ways. In the case of rotary and drum transfer machines it is a function of the indexing mechanism. On in -line machines various mechanical devices have been used.

The most common types of mechanical devices include :

1. Pawl type.
2. Walking beam.
3. Rotary transfer mechanism.

Pawl type : This is a very simple and inexpensive type of transfer mechanism in which the workpieces move from one machining station to the next. A single transfer, either round or rectangular in cross-section, has a series of pivoted fingers or pawls attached, to it. These fingers are either spring loaded or weighted so as to latch against the rear end of the workpieces as shown in Fig.21.4. Thus a forward stroke of the bar transfer the parts. The fingers rotate upward and slide along the upper surface of the parts during the return stroke causing the bar to move in the backward direction. The pawl type mechanism is suitable for parts or workpieces having good sliding surfaces.

Walking beam : This type of transfer mechanism provides positive movement of parts from station to station without sliding. It is, therefore, used to move workpieces of soft metals which would be subjected to too much wear if they are allowed to slide along guideways or rails on the surface of the bed.

In this type of mechanism two cylinders are used. One raises and lowers the transfer bar and workpieces while the other reciprocates the bar. This is schematically shown in Fig.21.5. When the cylinder *B* lifts the transfer bar and the workpieces, the cylinder *A* retracts pulling the transfer bar that slides on the wheels attached to the end of the cylinder rod. The cylinder *P* then goes down lowering the transfer bar and leaving the workpieces in an advanced position. At this time, cylinder *A* advances returning the transfer bar to its original position.

Rotary transfer mechanism : The type of transfer mechanism is used where parts are to be trapped. The mechanism used generally include :

1. Rotating bar mechanism.
2. Rack and pinion.
3. Ratchet and Pawl.
4. Geneva mechanism.

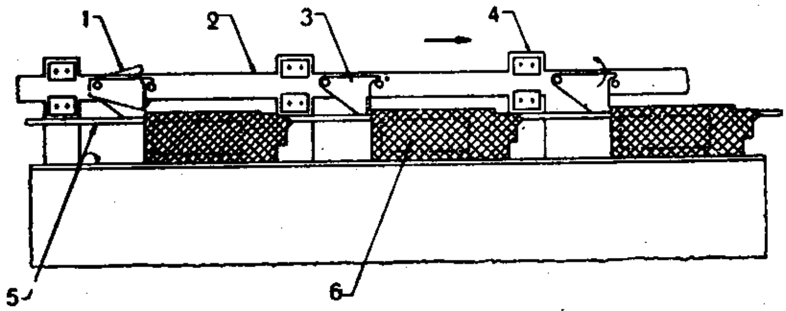


Figure 21.4 Pawl type transfer mechanism
1. Pivoted finger, 2. Transfer bar, 3. Bar support, 5. Guide rails, 6. Work (part)

The rotating bar has fingers attached to it and it rotates by the use of a hydraulic cylinder the bar. This rotating bar with fingers are used for parts with narrow sections. It has the advantage that the part can be trapped to avoid overtravel. Rack and pinion is a simple mechanism and is widely used to index a circular table at various angular positions and corresponding to workstation locations. However it is not suitable where high speed is required. Ratchet and pawl mechanism is unreliable and is prone to jam occasionally. The Geneva mechanism uses a continuously rotating driver to index the table. Fig.21.6 shows the Geneva mechanism.

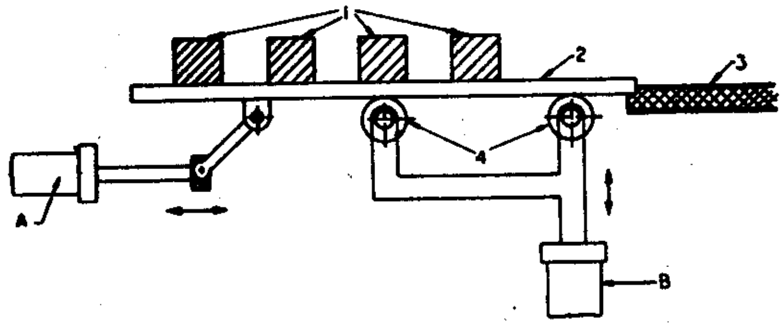


Figure 21.5 Walking beam transfer mechanism
A, B. Cylinders, 1. Work or part, 2. transfer bars, 3. Fixed rails, 4. Wheels

Besides the mechanical devices described above, there are hydraulic and pneumatic arrangements for transferring the work from station to station. The advantage of hydraulic power is that it lends itself to automatic control, and operate not only transfer devices but loading devices, machining heads, clamping devices, etc.

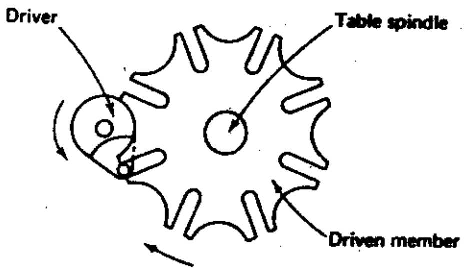


Figure 21.6 Geneva mechanism

21.4. AUXILIARY EQUIPMENT

The parts or units so far been described constitute the back bone of a transfer machine. To equip it for work many additional equipment are incorporated in it. The chief of these include :

Electrical control system : It initiates and controls the movement of the work along the bed, and clamp, unclamp and locate the work at each machining station. It also controls driving and feeding of the cutting heads and the depth of cutting. It provides facilities on the console for regulating the cycle of events, and gives information of what is taking place with the visual signals and as to when a fault occurs with the aid of danger signals. It is, therefore, by the sophistication of electrical control that advancement in the methods of production is made possible by transfer machining.

Work holding devices : In the pallet system, the job in its fixture is supported on a pallet which slides on the bed sideways. In the non-pallet system, the work slides directly on the bed. In some cases, particularly when the work is regular in design and possesses a flat surface, means are available to provide a suitable fixture with provision for clamping and locating the work at machining station. In the pallet system a conveyor is also used for the pallet to come back from the unloading to the loading station.

A common locating method is to use holes in the underside of the component or its supporting agent and arrange for plungers to draw the component into the exact position for registering in these holes. Clamping is usually operated by compressed air or hydraulically, and locating by suitable means.

Control and disposal of swarf : A huge amount of swarf is produced due to the high rate of production. Therefore, some means must be provided for regular removal of the swarf while the machine is in operation. To reomve swarf from the machine a conveyor system is used. It is a common practice to provide a gap in the ways so that swarf falls into the conveyor placed below the bed and the sliding ways remain clean. Since conveyor system alone does not take care of the clogging problems on the work itself, the chips are removed from the work by a blowing system using compressed air. However, to direct the chips to fall in the conveyor, the bed is provided with sides which slope inward like a hopper.

Sequence of operation : This is initially determined from the machining requirements for which the machine is designed and arranged. The various operations that may be performed by transfer machining include drilling, tapping, reaming, counter-boring, milling, etc. Their synchronization is important. Therefore, all the components must be moved to the next machining station simultaneously, location and clamping of the work must be done automatically as soon as the work comes to a machining head ; the head must come to descend and begins to cut as soon as it comes in contact with the work. In fact, no operation must start until the lob is indexed and clamped, and the component must not be released until the tool have completed their cut and withdrawn.

21.5 ADVANTAGES AND DISADVANTAGES

The chief *advantages* in favour of its use include the following :

1. Greater output is obtained in comparatively lesser lost.
2. Heavy components and components of extremely awkward size and shape can be handled.
3. Large number of operators are not required.
4. Considerable floor shape is saved by closed grouping of machines.
5. The life of cutting toll may be considerably enhanced. This reduces cost of replacement and time for resetting.
6. Greater accuracy is obtained as the work is clamped in fixture throughout .
7. Lesser time is required for a complete production because the machine is fully automatic.

The *disadvantages* which limit the use of this machine include :

1. Initial cost is very high .
2. Electrical control system is very complex .
3. A break down of one machine means stoppage of the whole line
4. Limited only to high production jobs .
5. Reshuffling and overhauling cost is very high

REVIEW QUESTIONS

1. What is a transfer machine ? List its advantages in high volume manufacturing.
2. What are the classifications of transfer machines ?
3. Describe the structure and operations of an in-line transfer machine.
4. What is the difference in construction of drum type transfer machine with rotary indexing table transfer machine ?
5. Describe the main parts of a transfer machine.
6. Describe a machinical device that transfer workpieces in a transfer machine.
7. Outline advantages and disadvantages of using transfer machine in manufacturing.

22

PROCESS PLANNINGS AND COST EVALUATION

22.1 INTRODUCTION

Process planning is the procedure used to develop a detailed list of manufacturing operations required for the production of a part or a product. It is the linkage between product design and product manufacturing. Process planning establishes an efficient sequence of operations, select proper equipment and tooling, and specifies their operations in such a manner that the product will meet all requirements stipulated in the specification. At the same time, the process will be performed at minimum cost and maximum productivity.(Please refer Fig. 22.1)

Basically there are two ways process plans can be generated. They are :

1. Manual Process Planning and
2. Computer-Aided Processes Planning

22.2 REQUIREMENTS FOR PROCESS PLANNING

A reasonably good process plan must satisfy the following requirements :

1. A brief description of the job to be manufactured which clearly and comprehensively defines its service function.
2. Specifications and standards that stipulate the service function.
3. Working drawings of the job with complete specification.
4. Drawing of the blank.
5. Data on the quantity of parts to be manufactured in a period.
6. Total quantity of spare parts required for each unit.
7. Equipment data that includes specifications and capacity data of machine tools, and other available equipment, the data concerning the arrangement and loading of equipment in the shop.
8. Conditions under which production engineering and manufacturing are to be organized and accomplished, i.e., whether a new or existing plants, available equipment in the plant, possibility of obtaining new equipment, etc.
9. Location of the plant.
10. Availability of manpower to staff the plant.

11. Date of starting the work and date of delivery.

22.3 STEPS IN PROCESS PLANING

The purpose of process planning is to determine and describe the *best process* needed to produce a part. In order to accomplish these objectives, the following steps may be followed :

1. To become acquainted with the service function of the part.
2. To study and critically analyse the manufacturing specifications and various standards, e.g., accuracy, output, efficiency, etc., that define the service function.
3. To become acquainted with the annual output of the product.
4. To study and critically analyse the working drawings to see whether it is feasible in all respect to produce the part, and to reveal and correct any mistakes in the drawings.
5. To determine what parts to be manufactured and what parts to be purchased with their complete identification and required quantity.
6. To prepare a list of raw materials of right quality and quantity to be purchased from outside giving their shape, size and special property.
7. To select the most economical process for obtaining the blanks, and to determine the quantities to be produced for the purpose of costing.
8. To determine the most economical process for manufacturing the parts, keeping in view the current production commitments, delivery date, quantity to be produced, and the quality standard.
9. To determine the best sequence of operation to be performed on each part in a particular process.
10. To select the machine tools that will perform the operations with required accuracies.
11. To select any other accessories and equipment like jigs, fixtures, dies, gauges, etc., that may be required to give higher production rate.
12. To lay out the equipment and workplaces, calculate machine loads and make necessary corrections in the process.
13. To revise the process to correct all mistakes and shortcomings that were discovered when the process was realized in actual production.
14. To determine the stages of inspection, inspection procedure and limit gauges required for different stages of manufacture to inspect accurately and at a faster rate.
15. To determine the set-up time and standard time for each operation and fix up the rate of payments.
16. To determine the kind of labour for successful execution of the job.
17. To determine the estimated cost of the product to see whether or not that will complete in the sales market.

It is worthwhile to mention that process planning is a dynamic process, and the planners are required to analyze the production procedure to simplify the processing taking into account of the technological changes in manufacturing.

Some of the aforesaid steps in process planning which require further explanation are stated below in a greater detail.

Manufacturing specifications : The chief document in which manufacturing specifications are listed is the detail drawing. The drawing specifies :

1. Dimensions and machining accuracy with permissible deviation from the proper geometrical form.
2. Accuracy in the coordination of various surface with permissible deviation.
3. Places subject to heat treatment and type of heat treatment required.
4. Surface quality.
5. Machining method required to obtain the specified surface finish if necessary.
6. Places of protective coating with the type and thickness of this coating.
7. Locating place for measurement of dimensions on finished part.
8. Special inspection procedure, such as x-rays, hydraulic tests, when required.

Lastly the specifications should be coordinated with the machining process and inspection to the maximum possible extent. If required, slight change or alterations may be made to make the planning successful.

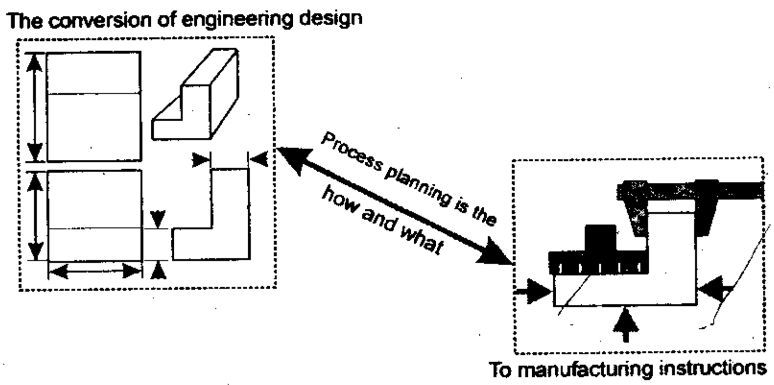


Figure 22.1 Process planning system

Determination of the blank : Process planning actually starts with the selection of blanks. The blank size and specifications of the finished part are interrelated and they determine the general outline of the machining and finishing operations.

The accuracy of the blank, which depends on its method of manufacture, and the specifications for the finished machine part determine the general outline of the machining process and its subdivisions into roughing, semifinishing, and finishing operations.

Selection of machine tools : The selection of machine tools is largely determined by the choice of the method or process of machining a part. In other words, principles which govern machining processes should be the basis of selection of machine tools. Even though it is difficult to formulate a definite rule for selecting the machine tool for any type of machining, the following factors must be considered in selecting a machine tool for a particular operation :

1. Size, shape and material of the workpiece.
2. Accuracy and surface finish required.
3. Required output and production capacity of the machine tool.
4. Power of the machine tool to know whether it is sufficient for performing the operation or not.
5. Performance of the operation to know whether it is economical or not.
6. Ease and convenience in operating the machine tool

Availability charts : The availability chart is a list of machine tools arranged according to their classes (i.e., classified list) e.g., engine lathes, turret lathes, automatics and the like, giving their identification and model number, location, general condition, tooling available, cutting speeds and feeds, etc. However, in the case of new machine tools, cutting speeds and feeds are obtained from catalogue available with them. This availability chart is necessity in selecting machine tools for a new product in an existing plant.

Machine load charts shows which machine is remaining idle and which one is loaded. Accordingly, the process planner will select the particular machine tool which may be used to perform the machining operation. Process planner is not so much concerned with machine load chart as the production planner is.

Capability charts : The capability chart may be defined as a chart which shows the ability of a machine tool of doing the work, The capability chart shows how much of its rated capacity a machine tool can perform its function satisfactorily. A machine tool, like any other machine, do not remain in the same condition as purchased due to wear and tear in use, and they loose their accuracy in the long run. The capability chart which shows the present condition of the machine is guide to the process planner in making his choice of the proper machines.

22.4 PLANNING THE OPERATIONS SEQUENCE

Determining the best sequence of operations is an important step in the realization of a product that is designed for production. Both product cost and product quality are closely related to operation sequence. A different sequence of operations performed will result in different operational times, different transportation time to the work centre, different tooling in view of different locating and clamping surfaces.

If a new plant is set up for a product, the process planner has much more freedom in determining the sequence of operation that may be best suited for the purpose. In the case of an existing plant the operation sequence for a new product is to be determined on the basis of available equipment and loading condition of the equipment. In the latter case the process planner must be provided with the following information :

1. List of available machines.
2. List of available general purpose tooling.
3. Capability of equipment.
4. Machine load charts.
5. Standard data.

However, in any case, there are certain fundamental principles which must be followed in planning the optimum operation sequence. These are :

1. First the datum surfaces should be selected with due attention. The selection of datum influences all subsequent machining operations and inspections. A surface which is to remain unmachined should be selected as the first setting-up datum surface only in the case of first machining operation. In the subsequent operations only machined surfaces may serve as setting-up datum.
2. Surfaces, whose machining will not reduce the rigidity of the work to any appreciable extent, should be machined earlier in the sequence.
3. Internal operations are performed in advance of external operations. This is not a rule that need always to be observed. The principal reason for performing internal operations. This is not a rule need always be observed. The principal reason for performing internal operations early is that internal surfaces are less likely to be damaged in material handling and subsequent processes so their surfaces can be completed more early in sequence. Another reason is that internal surfaces

frequently provide a better means of holding the work and thus help ensure concentricity between inside and outside diameters.

4. The operation in the sequence should begin with removing the largest layer of metal. Removing thick layers by heavy cuts will reveal internal defects in the raw materials (usually castings or forgings) much more readily than light cuts. The workpiece is also relieved of internal stresses which eliminate the danger of warping in subsequent operations. The large cutting and clamping forces that may be associated with heavy cut affect the accuracy of finished surfaces of another part of the same workpiece and call for those machines which are intended for roughing operations. Furthermore, heavy cuts involving coarse or rough finishes are usually faster with less-expensive workmen than fine finishes.
5. Operations, in which an increased number of rejects is to be expected due to revealing of defects as stated above, should be performed as near as possible to the beginning of the machine sequence. It is always advantageous to find out that work is being performed on the defective material as soon as possible with the least investment in secondary processes.
6. Finishing operations should be performed at the end of the operation sequence to reduce danger of damaging finished surfaces, of changing their dimensions and coordination in reference to other surfaces of the part.
7. Roughing and finishing operations should be done on separate machines so that accuracy of machines intended for finishing is not disturbed by heavy loads in roughing works.
8. Inspection stages should be introduced (a) after roughing, (b) before operations which are to be performed in other shops and departments, (c) before laborious and important operation (for example, before preparing datum surfaces) and after them, and (d) after the last machining operation,
9. The sequence of machining operations should be coordinated with heat treating operations which are of vital importance in the manufacture of machine part. Deformation of the workplace after heat treatment will require an increase in the machining allowances for subsequent operations for necessary correction in the geometric form of the part by machining.
10. Material handling is a necessity of any productive activity since it applies to the movement of raw materials, parts in process, finished goods, packing materials, and disposal of scraps. Thus operations sequence and material handling are closely linked. This is a lucrative area for possible cost reduction and takes a big slice of the

manufacturing cost. Therefore, modern trend is to mechanize the handling system wherever practicable.

11. Waiting of materials in the stores as well as in process should be avoided as far as possible as it involves different cost parameters associated with them. As far as possible they are therefore located adjacent to point of use for minimum cost involved.

The operation sequence is not rigid. It varies from product to product and even in the same product. There is always some scope for improvement and it should be continuously reviewed for developing better methods, increasing productivity and reducing costs.

22.5 PROCESS PLANNING SHEET

Process planning sheet is a detail record where all information relating to different operations needed to manufacture a part are listed in tabular form. This is also known as analysis sheet, instruction sheet, operation sheet or process design sheet. An example of a process sheet is given in Table 22.1.

The description of the operations and their elements indicated in the process sheet should give extremely concise but comprehensive information on what is to be done and why. The data should clearly indicate how and with what the job is to be done and, if possible, the time expenditure it will require.

The form of such sheets may vary for different production conditions. The character of a process sheet will depend mainly on the scale of production and the degree of importance of the product being manufactured. Furthermore, different types of sheets are used in manufacturing concepts which are already in operation and in organizations designing new plants.

In the majority of cases, however, the following information are listed in process sheets :

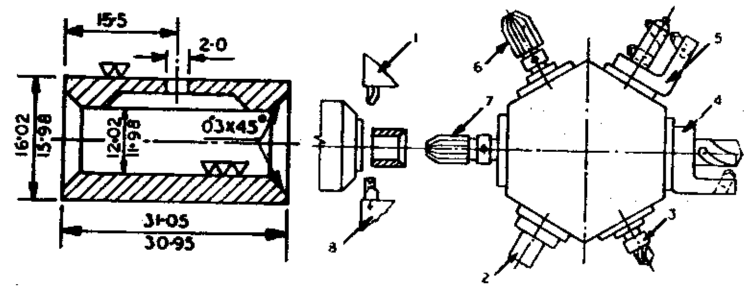
1. Information concerning the workpiece which includes name, drawing, and service function, if possible.
2. Information concerning the blank which includes material, size of stock when used as a blank, character etc.
3. Descriptions and numbers of operations and those of their elements.
4. Information concerning the manufacturing equipment such as machine tools, auxiliary equipment, attachments and accessories, etc.
5. Data on jigs, fixtures and tools such as description, sizes or code numbers.
6. Elements of standard time such as setting time, handling time and

machining time, etc.

7. Job rating of the worker for each operation.

Table 22.1 A Simplified Route Sheet

XYZ COPMANY		ROUTING SHEET		Product no.			Page of
				Part no.			
				Part name			
Material		Blank		Number of part per unit		Lot size	
Op. no.	Number of operation	Equipment	Jig or fixture	Tool	Gauge	Standard hours	Remarks
				Planner		Approved	
				Date		Date	
				Issue no.		Issue date	
Alteration no.		Approved	Date				



(a) (b)

Figure 22.2 Typical turret layout for a bush bearing

In planning manufacturing processes for machining operations frequently operation sketches are drawn for various operation as shown in Fig.22.2. The surfaces that are to be machined are indicated on the sketch together with dimensions giving tolerance desired.

22.6 AN EXAMPLE OF OPERATION SEQUENCE

Table 22.2 Operation sequence and process sheet for a bush bearing

Part name : Bush bearing | *Material : M.S. bar*
Drawing No. : Fig 22.2(a) | *Size : 20 mm dia. (available stock size)*

Sl. No.	Sequence of operation	M/c shop	Tools, gauges, etc.	Time analysis
		Turret Lathe		
*1.	Face end 2 mm deep	Position 1 (Rear slide)	Bar ending tool	Time for set up, handling, machining, tear down for each operation, and lost time allowance for entire operation are all recorded.
2.	Feed out bar to stop	Position 2	Bar stop	
3.	Stop for drilling	Position 3	Centre drill	
4.	Drill hole 10 mm ϕ, and rough turn to 16.5 mm ϕ × 36 mm	Position 4	drill 10 mm ϕ, (standard size), rough turning tool	
5.	Finish turn to 16.10 mm ϕ, bore 11.5 ϕ×36 mm and chamfer 0.3 × 45°	Position 5	Finish turning tool, chamfering tool, an boring tool.	
6.	Rough ream 11.8 mm ϕ × 36 mm	Position 6	Reaming tool (rough)	
7.	Finish ream 12.0 mm ϕ × 36 mm	Position 7	Reaming tool (finish)	
8.	Cut off to 31 mm length	Position 8	Parting off tool	
9.	Chamfer other end 0.3 × 45°	Upright drill	Chamfering drill	
10.	Drill oil hole	Upright drill	Drill 2 mm (standard size)	
11.	Cut oil grooves	Special m/c	Groove cutter	
12.	Grind to 16 mm ϕ	Cylindrical grinder	Finish grinding wheel	
13.	Inspect	Inspection deptt.	Limit gauges	

* In machining bush bearings from bar stock, the location datum surfaces being the external surface and faced end which bears against a stop, the facing is first done.

22.7 DISADVANTAGES OF MANUAL PROCESS PLANNING

Manual process planning (MPP) has many disadvantages. They are :

1. MPPs are largely subjective.
2. The quality of process plan is directly related to the skill and experience of the planner.
3. Incorporation of process changes is extremely difficult.

4. Technological changes or changes of batch sizes requires the change in process plan. MPPs are slow to respond.
5. It is difficult to check if the process plan is consistent and optimized. When it is not optimised it will specify excessive tooling and material requirement.
6. It is tiresome to search manually the process plans of similar parts from the large amount of documentation of the company.

22.8 COMPUTER AIDED PROCESS PLANNING

Computer-Aided Process Planning (CAPP) has become the most critical link to integrated CAD/CAM systems. CAPP is the application of computers to assist the human process planner to execute the process planning function. CAPP not also reduces the time and effort required to prepare consistent process plans, but only creates an automated interface between Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) to achieve complete integration within the manufacturing system.

The input of this process is a CAD-model of the workpiece to be created and the result of this process is a detailed process plan from which the workpiece can be created/manufactured.

A complete CAPP system would include[1] :

1. Design input.
2. Material selection.
3. Process selection and sequencing.
4. Machine and tool selection.
5. Intermediate surface determination.
6. Fixture selection.
7. Machining parameter selection.
8. Cost/time estimation.
9. Plan preparation.
10. NC tape image generation.

Two basic approaches to automated process planning are :

1. Variant, and
2. Generative

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[1] Wang Hsu-Pin and Li Jian-Kang, 1991, Computer-Aided Process Planning, Elsevier, Amsterdam.

22.8.1 Variant Method : Variant process planning explores the similarities among components (parts) and searches through a data base to retrieve the *standard process plan* for the part family in which the component belongs. The plan is them retrieved and modified to create a suitable plan for the new part.

In the variant approach, the process plan is generated in two operational stages. They are :

1. Preparatory stage and 2. Production stage.

In the preparatory stage the existing components are coded, classified and grouped into part families. The classification and coding offers a relative easy way to identify similarity among parts. Part families can thereafter be formed by clustering together similar parts. Various codification schemes are established; MICLASS, DCLASS, OPITZ, CODE are some of the classification schemes. After part families are formed, each family is assigned a standard plan. A standard plan consists of a set of machining processes, which represents the common set of processes to make the parts. The reader may read the concept of Group Technology (GT) in chapter 23 as a reference for the part family formation.

In the production stage the incoming component is coded based on its geometric feature or the processing requirements. The same codification scheme used in the preparatory stage, is also utilised here. The resultant code is them used as a basis on which the part is assigned to a part family. If the coding system is efficiently utilised, the part should be similar to the other parts belonging to its family. A process plan for the new part can be obtained by modifying the standard (of the part family in which new part belongs) plan retrieved from the data base.

22.8.2 Generative Method : Generative Computer-Aided Process Planning (GCAPP) synthesizes manufacturing information in order to create a process plan for a new component (part). Decision logics and optimisation methods are encoded in the system itself resulting in minimum or no human interaction in process planning.

A generative system produces a complete process plan from the engineering drawing or a CAD file.

The three areas of a GCAPP systems are[2] :

1. Component definition in terms of CAD file. It contains part features and part specification.

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[2] Chryssolouris G, 1992, Manufacturing Systems, Theory and Practice, Springer-Verlag, NY

2. Identification, capture and representation of the *knowledge of the process planner*. This takes into consideration the reasoning of the decisions made by the process planner about process selection, sequencing etc.
3. Compatibility of planner's logic

In GCAPP, design specifications are entered in the system. The decision logic recognizes stock material and machining features of the part. It further determines optimal sequences of operations along with the optimal fixture types and locations.

Disadvantages of GCAPP : The following disadvantages are observed in the GCAPP systems.

1. Limited use till to date. The required information (such as tolerances) are not usually available in the CAD model.
2. A lot of knowledge must be added to the system to make it capable of handling all the different types of parts that are fed.
3. Because of the great degree of complexity of the algorithms and enormous calculation effort, some systems specialize in developing plans for specific types of geometries. A few systems go as far as checking the manufacturability of a part and suggesting changes in the design, if necessary.

22.9 COST EVALUATION

A process design is not complete until one have a good idea of the cost required to manufacture the product. Generally the lowest- cost design will be successful in a free market place. So an understanding of the elements that make up the cost is vital.

Elements of costs : The constitutions of a product or cost elements can broadly be grouped into (1) *recurring costs* or manufacturing cost or operating costs and (2) *non-recurring costs.* They may again be classified as *direct costs*, *indirect costs* while capital costs come under non-recurring costs. They may again be classified as direct costs, indirect costs, and capital costs. Recurring costs include all direct and indirect costs while capital costs come under non-requiring costs.

Direct costs are the costs of those factors which can be directly attributed to the manufacturing of a specific product. These include costs of material and labour. *Material cost* is the cost of that material which goes into finished product and includes all wastes which has been has been cut away from the original stock. *Labour cost varies* form machine to machine and is usually calculated by multiplying the time required for an operation by labour rate. Thus, the time to set up and perform an operation must be estimated to find out its labour cost.

Indirect costs are the costs of those factors which can only be indirectly attributed to the manufacture of a specific product. They are sometimes called *overheads or on costs.* Overhead costs are commonly calculated by multiplying the operation time by an overhead rate. Such a rate is obtained by dividing the total indirect costs applicable to a manufacturing unit for a period of time (say a month or week) by the total number of hours of direct labour in the same period.

Capital costs are one-time costs or nonrecurring costs which include depreciable facilities such as plant, building or manufacturing equipment and tools, and non-depreciated capital costs, such as land. Capital costs are determined by distributing the major machine and tool costs on an hourly basis or among the piece produced.

The total cost of a product is the direct cost of manufacturing the product plus any indirect costs attributed to the manufacturing of the product.

In order for the process engineer to use cost data as a tool to help analyse manufacturing problem, costs may be more conveniently grouped as fixed costs and variable costs.

Fixed costs include preparation costs such as of tooling ,setting up, etc., and also the interest and depreciation costs which are independent of the quantity of the product manufactured.

Variable costs are those costs which vary as the quantity of product made varies. This includes the direct labour and material costs, and also that part of the indirect costs which will vary as production varies.

The total cost of a product can also be seen to be fixed cost plus variable cost.

Cost structure : The elements of cost can be combined to give the following types of cost:

1. *Prime cost.* Prime cost or direct cost is given as :
   Prime cost = Direct material + Direct labour + direct expenses.
2. *Factory cost.* Factory cost or works cost is given as :
   Factory cost = Prime cost + Factory expenses.
3. *Manufacturing cost.* This is given as :
   Manufacturing cost = Factory cost + Administrative expenses.
4. *Total cost :* Total cost is given as :
   Total cost = Manufacturing cost + Selling and distributing expenses.
5. *Selling price.* Selling price is given as :
   Selling price = Total cost + Profit.

22.10 STANDARD COSTS

In cost accounting actual or recorded costs or standard or predetermined costs are used. The nomenclature *actual cost* is misleading. Usually average labour rates are used rather then the actual ones and arbitrary allocations are made for use of capital equipment and for general and administrative costs. Also actual costs are compiled long after the job in completed. This approach is chiefly aimed at financial accountability than cost control.

Standard costs are based on the proposition that there is certain amount of material in a part and a given amount of labour goes into the part's manufacture. In a given period of time costs tend to vary around some average cost per unit or per hour. Through the use of standard costs, guesswork is reduced and a standard that measures performance is established. Each part and assembly has a standard cost card on which is recorded the standard material, labour, and overhead costs, and the total cost.

The system of standard costs consists of two parts : (1) a base standard and (2) a current standard. The *base standard* is determined infrequently, e.g., once a year, and the *current standard* represents the later cost. The difference between the two is the *cost variance.*

22.11 ESTIMATING LABOUR COSTS

All direct and in direct costs excluding labour costs are determined by the accounts department of the plant. Process planners are mostly concerned with labour costs which are directly related to the process of manufacturing. However, the total time required by workers to perform an operation may be divided into following classes :

1. ***Set-up time :*** This is the time required to set up elements to prepare for the operation. The elements include: time to study the blue print or to do any paper work, time to get tools from tool-room, time to install the tools on the machine. Set-up time is performed usually once for each lot of parts. If 20 min are required for a set-up time must be charged against each piece. The time for each or the elements is taken from standard tables usually available with the estimators.
2. ***Man or handling time :*** This is the time the operator spends loading and unloading the work, manipulating the machine and tools, and making measurements during each of the operation.
3. ***Machine time :*** This is the time during each cycle of the operation that

the machine is working or the tools are cutting.

4. ***Tear down time :*** This is the time required to remove the tools from the machine and to clean the tools and the machine after the last part of the lot or batch is machined. This occurs only once in a lot.
5. ***Down or lost time :*** This is the unavoidable time lost by the operator due to breakdowns, waiting for the tools and materials.

The time to perform an operation also includes time for personal needs, time to change and resharpen tools, etc. which are taken to be about 20 per cent of the sum of all other times. Besides, there are inspection or checking times which vary from instrument to instrument.

Each operation on a particular type of machine tool is divided into a number of small elements. These elements can be standardized, measured and then recorded. This is mostly done under Time and Motion study. Standard data is also available for various times. Machining times are calculated with the help of formulae for each machining operation which takes into account the feeds, speeds, depth of cut and tool travel plus tool approach.

Machining time : All machining times can be calculated with the basic formula :

$$T_m = \frac{L}{S_m}$$

where T_m = Cutting time in minutes.
L = Total tool travel in mm.
S_m = Feed of tool in mm/min.

It has already been stated that the total tool travel includes *approach distance* and *over travel.*

Now $S_m = S_r \times n$
where S_r = feed/revolution of work or cutter
and n = r.p.m. of work or cutter $= \frac{1000 \times v}{\pi d}$
where v = Cutting speed in metre/min of work or cutter.
and d = diameter in mm of work or cutter

Therefore, $$T_m = \frac{L}{S_r \times n}$$

Calculation of machining time for each operation and their feed, speed and depth of cut have been given in each chapter or they may be available in hand books.

22.12 METHODS OF COSTING

The method used to develop cost evaluation fall into three categories: methods engineering, cost by analogy, and statistical analysis of historical data.

In the methods engineering approach, that is usually followed, the separate elements of work are identified in great detail and summed into the total cost per part. A typical, but simplified example, is the production of a simple fitting from a steel forging. This is shown in Table 22.3.

TABLE 22.3 ESTIMATING COST OF A PART

Operations	*Material*	*Labour*	*Overhead*	*Total*
Steel forging	37.00			37.00
Set up on million m/c		0.20	0.80	1.00
Mill edges		0.65	2.60	3.25
Set up on drill press		0.35	1.56	1.91
Drill & holes		0.90	4.05	4.95
Clean and paint		0.30	0.90	1.20
	37.00	2.40	9.91	**Rs. 49.31**

Material cost, 75 per cent ; direct labour, 5 per cent ; overhead, 20 per cent.

REVIEW QUESTIONS

1. Why process planning is considered essential in any manufacturing industry ? Explain.
2. Outline the steps in process planning.
3. Briefly discuss the requirement of process planning.
4. What types of data and information are required to plan a manufacturing process ?
5. What do you understand by manufacturing specifications ? Explain.
6. What are the factors on which a machine tool is selected in carrying out an operation ?
7. How the operations sequence is determined ? Why do you feel that one set of machine sequence may be better than another ?
8. What types of information a process planner may need to fix the operations sequence for manufacturing a product ?
9. What is a process sheet ? What is its utility ? Why it is a must for planning of production.
10. What are the disadvantages of manual process planning? Discuss.
11. Discuss in brief the methods of computer-aided process planning?
12. What is standard cost ? Where it is useful ? Explain.
13. How labour cost is estimated ? Also outline the break - up of total machine time of manufacturing a component.

23

CAD, CAM AND CIM

23.1 INTRODUCTION

Computer is a tool to increase productivity in many aspects of our life. The areas where computers are being utilized currently can be classified into (1) Business applications, (2) Scientific applications and (3) Engineering applications. Engineering applications include Computer Aided Design (CAD) and Computer Aided manufacturing (CAM). Computer Aided Process Planning is the glue that attaches CAD and CAM.

CAD is the direct integration of computer hardware and software to execute design, design retrieval, geometric modelling, engineering analysis and automatic drafting.

CAM is the use of computer hardware and software to carryout actual manufacturing planning and production of the part. The most important elements of CAM are :

1. CNC manufacturing and programming techniques.
2. Computer - controlled robotics applications.
3. Flexible manufacturing systems (FMS).
4. Computer - aided inspection (CAI) techniques.
5. Computer - aided testing.

Computer - Integrated Manufacturing (CIM) is a management philosophy which rationalizes and co-ordinates all the functions of design and manufacturing using computer, communication and manufacturing technologies.

CIM considers all functions starting from product definition, raw material acquisitions to the dispatching of the final product. Thus it takes into account all functions of CAD and CAM.

23.2 COMPUTER SYSTEM

A simple digital computer system consists of various functional components. The various physical components are termed as *hardware*.

Softwares consisting of programs and instructions are used to control the working of a computer.

Hardware : Fig.23.1 shows the schematic diagram of a digital computer system. These components are input devices, output devices, arithmetic and logical unit (ALU), main memory unit, auxiliary memory unit and control unit.

Input devices : Input devices are used to enter data or information into a computer. Keyboard, magnetic disk drives, tape drives are some of the input devices used in computers.

Output devices : Output devices are used to let information out of a computer. Video display unit of a computer, mass storage devices (disk drives, etc.), printers, plotters and scanners are some of the output devices.

Arithmetic and logical unit (ALU) : ALU consists of a single and exhaustive electronic circuit capable of performing any desired arithmetic or logical operation. The design of such circuit is based on the concept of binary algebra. In binary system '0's and '1's can represent any number.

Control unit : The internal control mechanism of a computer co-ordinates and synchronizes all the activities of the computer system and as such this unit can be called as *supervisor* in a computer system. This unit monitors the feeding of data in and out of the system. It checks also if the data is correctly transmitted from one component to the other components of the system. The ALU and control unit together is termed as *central processing unit* (CPU) of the computers.

Main memory unit : Main memory unit stores the coded program instructions and the data in binary form. Main memory unit also holds intermediate results and the answers before they are printed or transferred to output devices.

Auxiliary memory : Auxiliary memory also known as *secondary memory* is used in computers. To store the information which is not currently needed. The auxiliary storage of a computer usually has a much larger capacity than the main memory. This auxiliary memory can not communicate with any other units of the computer directly but can be accessed through the main memory unit. The cost of storing information in the secondary memory is much lower and data remains intact even if the auxiliary memory is not operative. However the time to access the information in auxiliary memory is much higher.

Software : Computer software includes languages, operating system, utility software, and application software.

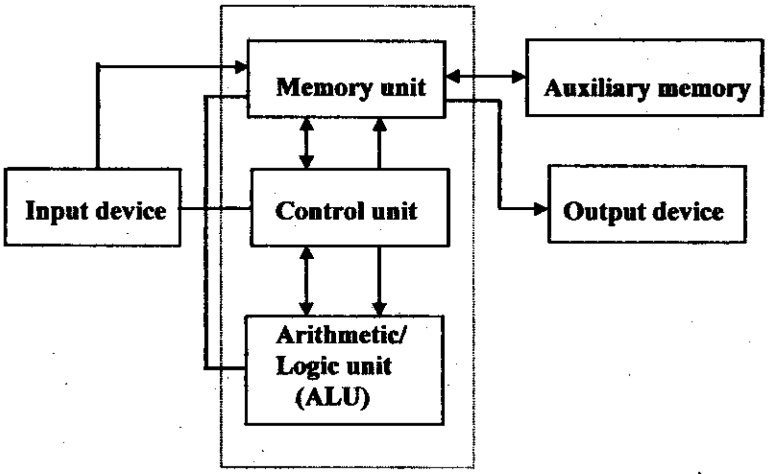

Figure 23.1 Schematic diagram of a digital computer system

Languages : Computers understand some specially developed languages for them so that they may communicate with outside world. These computer languages again can be divided in two categories : low level languages and high level languages.

Low level languages : Low level languages known as *machine language* is understood by computer system. This category bears very little resemblance with English words. A single computer understands not all machine languages. In fact the particular CPU chip used in a computer determines which machine language it accepts. For example the machine language used by IBM personal computer is not same with the machine language used in Apple computer. The machine languages are number systems and as such these are very difficult to learn and hard to use. It takes hundreds of lines on machine language instructions to perform even for a simple programming job.

High level languages : High level languages are general purpose application oriented programming languages. They are English like and contain some familiar phrases and terms of English language. They are translated to machine language with the help of a system program known as *compiler*. Some of the high level languages are BASIC, FORTRAN, ALGOL, PASCAL, C etc.

Operating system : Operating system consists of a set of system program that collectively simplify the operation of a computer most efficiently. Major user - benefits of an efficient operating system include the facility to carry out relatively complex tasks by typing in computer keyboard simple one or two command words. Various popular operating systems are available. MS-DOS used in IBM Personal Computer is very popular. Unix s also becoming popular for computer having higher processing power.

Utility programs : A utility program is written to accomplish routine jobs that allow the operator (a) to use his computer to communicate with other system and (b) to check if various components of the computer system are operating properly or not. Some diagnostic utility programs even identify which chip in the computer hardware needs to be replaced in a sick computer.

Application programs : An application program is a set of instructions that is designed to perform specified desired task. Game programs, educational programs, business system programs are all application program. These programs can be written in high level languages or in machine languages.

23.3 COMPUTER AIDED DESIGN

Good engineering design is the foundation of product reliability and maintainability. Functional considerations during design must take into account, weight, strength, thermal properties, kinematics, and dynamics. Not only functionality of a product is considered, the economics of using the product also should be addressed to. CAD takes into account all the parameters to make a design successful.

In the present usage CAD means a design process using sophisticated computer graphics, backed up with computer software packages to aid analysis and costing associated with the design work. CAD can be effectively used in the five phases of the design processes:

1. Geometric modelling.
2. Engineering analysis.
3. Design review
4. Evaluation.
5. Automated drafting and presentation.

The benefits of CAD are given hereunder:

1. Faster rate of producing drawings.
2. Greater accuracy of drawings.
3. Neater drawing.
4. No repetition of drawings.
5. Special draughting techniques not available in conventional draughting.
6. Quicker design calculations and analysis with a given input or change in input.
7. Integration of design with other disciplines.

The CAD computers can be of various types. They are classified into four types : micro, mini, main frames and super computers. Micros are presently - used personal computers. Workstations, a form of mini-computers, mostly used for CAD work, are more powerful and reliable than micros. Mainframes are multi-user, having many hard discs and are very fast machines. There are many CAD packages., Among them *AutoCAD* (from Auto Desk, Inc) is widely used as a design and drafting package implemented on PC and mini-computers. *Coreldraw* is another useful, easy to draw software package. High level languages used for science and engineering applications are also capable to represent drawings in a limited way.

23.4 INPUT AND OUTPUT DEVICES FOR CAD-WORK

Various input devices are required to facilitate CAD work. They include Light pen, Joystick, mouse, trackball, tablet, keyboard etc. Two of the input devices are described in brief hereunder.

Light pen contains a photo-detector at its tip and detects the light emitted from the screen. Through a timing circuit it can determine the X-Y screen co-ordinates. A light pen can be utilized as a drawing pen directly on the screen. However it is not much used presently.

Mouse is a small hand-operated device, which is moved over a flat surface. When it moves the distance traveled is inputed to computer system in terms of X, Y co-ordinates, which is the relative, positional information. Mechanical and optical are the two variations of mouse type. A cable connects the mouse with the computer and is known as tail.

There are various output devices. They are cathode ray tube (CRT), liquid crystal display (LCD), laser printers, inkjet printers, dot- matrix printers, and plotters.

Cathode ray tube (CRT) or ***visual display unit*** (VDU) is the most common display unit. The sensitivity is expressed in pixels. A high-resolution screen will have 1000×1000 to 2000×3000 pixels, and can be used for CAD-work. A ***liquid crystal display unit*** uses an organic liquid, having a high degree of modular order to change the polarization of light.

Laser printers use electrostatic fields to transfer toner to the paper. The unit contains a rotating drum which is coated with selenium based photosensitive material. Light (LASER) falling on the drum changes electrostatic charge over the drums. As the drum passes through the toner reservoir, the charged areas attract toner powder. Through a toner transferring mechanism the toner is subsequently transferred to the paper and a hot fusing roller melts the toner at 260°C and fixes the toner on paper. Presently the laser printers are having 600×600 dpi resolutions.

Dot matrix printers are impact printers using movable needle to form the dot marks. Here each character is divided in a matrix of dots and each time, the needles print one vertical line of dots for a character, and then the print head is moved horizontally for the next column of the character till the complete character is printed. The cycle is repeated till a complete line is printed. The paper position is initialized to the next line.

Pen plotters are used mainly to produce drawings. There are three inputs to the plotters; an X-coordinate, an Y-coordinate and a pen variable. The pen variable makes the pen to touch the paper to draw or keep it in a non-drawing position. Sophisticated plotters may have multiple pens for color plotting. The sensitivity is around 0.12 mm.

23.5 GEOMETRIC MODELLING

A geometric modelling system supports the creation, storage and manipulation of the description of the geometry of physical objects. There are different geometric representation schemes. They are broadly classified as : (1) Wireframe model and (2) solid models.

1. **Wireframe model:** In this model the user enters 3-D vertices of a component. Joining the vertices creates a 3-D object called wire frame. This representation contains only points and line. A wireframe drawing of a solid object is not often clear.

2. Solid modelling: This is basically a volume oriented representation scheme using a 'building block' approach to create 3-D geometric models. Many methods exist. They are:

1. Pure primitive instancing (PPI).
2. Spatial occupancy enumeration (SOE).
3. Cell decomposition (CD).
4. Sweeping (S).
5. Constructive solid geometry (CSG).
6. Boundary representation (BREP).

23.6 COMPUTER - AIDED MANUFACTURING (CAM)

CAM can be divided in two parts. They are :

1. Manufacturing planning.
2. Manufacturing control.

CAM application of manufacturing planning contains

1. Cost estimation.
2. Computer - aided process planning.
3. Computerized machinability data systems.
4. Computer assisted NC part programming.
5. Computer aided production and inventory planning.

CAM applications of manufacturing control include

1. Shop floor control.
2. Quality control and testing
3. Shop floor information processing.

Historically the work in this field started with the development of NC machines for producing complex components. The next step was the development of high level programming tool, known as computer-aided part programming like APT where the tasks of coordinate calculations and tape preparation were automated to generate the necessary control system codes for machining.

Use of *robot* in manufacturing is another landmark for CAM. Robot is a programmable, multifunction device, designed to move and manipulate materials, parts, tools etc. utilized in many CAM applications.

Benefits of CAM can be listed as given hereunder:

1. Higher production rate with lower work force.
2. Less likelihood of human error.
3. Increase in manufacturing efficiency.
4. Repeatability of production processes via storage of data.
5. Analysis of deficiency to take correct measures.
6. Better production control.

Flexible Manufacturing System (FMS): FMS is another important CAM application. FMS system is characterized by the following components:

1. Two or more work stations with computer controlled machine tool (normally machining centre)
2. An automated materials handling system for moving the work-in-process (WIP).
3. Mechanism for transferring WIP between the machine tools and materials handling system.
4. Storage by an automated storage and retrieval system (AS/RS) of WIP and tooling.
5. Central computer control of the entire process.

In FMS, the term flexibility means that the machine is able to process a variety of components without having to adjust machine set-ups or tool changing.

Application characteristics of FMS relative to other system are shown in Fig.23.2.

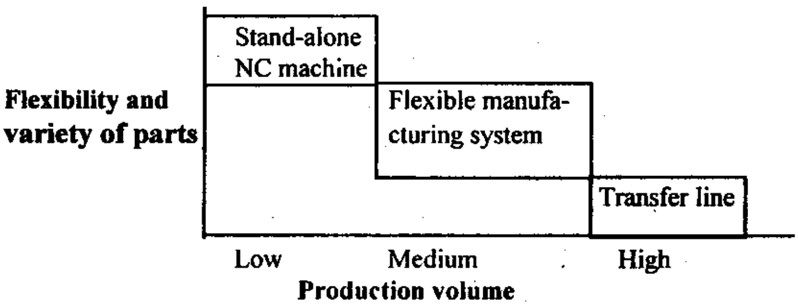

Figure 23.2 Production volume versus manufacturing system

Industrial Robot: An industrial robot[i] is officially defined by ISO as an *automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes*. The field of industrial robotics may be more practically defined as the study, design and use of robot systems for manufacturing (a top-level definition relying on the prior definition of *robot*) Typical applications of industrial robots include welding, painting, ironing, assembly, pick and place, palletizing, product inspection, and testing, all accomplished with high endurance, speed, and precision. The following terms are to be understood for knowing the topic:

Articulated robot

An articulated robot is one which uses rotary joints to access its work space. Usually the joints are arranged in a "chain", so that one joint supports another further in the chain.

SCARA robot

The SCARA acronym stands for Selective Compliant Assembly Robot Arm or Selective Compliant Articulated Robot Arm. In general, traditional SCARA's are 4-axis robot arms, i.e., they can move to any X-Y-Z coordinate within their work envelope. There is a fourth axis of motion which is the wrist rotate (Theta-Z)..Figure 23.3 shows some common types of industrial robots.

Cartesian coordinate robot

A Cartesian coordinate robot is an industrial robot whose three principal axes of control are linear (i.e. they move in a straight line rather than rotate) and are at right angles to each other.

Continuous path

A control scheme whereby the inputs or commands specify every point along a desired path of motion. The path is controlled by the coordinated motion of the manipulator joints.

Degrees of freedom (DOF)

The number of independent motions in which the end effectors can move, defined by the number of axes of motion of the manipulator.

Gripper

A device for grasping or holding, attached to the free end of the last manipulator link; also called the robot's hand or end-effector.

Payload

The maximum payload is the amount of weight carried by the robot manipulator at reduced speed while maintaining rated precision. Nominal

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[i] http://en.wikipedia.org/wiki/Industrial_robot

payload is measured at maximum speed while maintaining rated precision. These ratings are highly dependent on the size and shape of the payload.

Reach

The maximum horizontal distance from the center of the robot base to the end of its wrist.

Accuracy

The difference between the point that a robot is trying to achieve and the actual resultant position.

Repeatability

The ability of a system or mechanism to repeat the same motion or achieve the same points when presented with the same control signals. The cycle-to-cycle error of a system when trying to perform a specific task

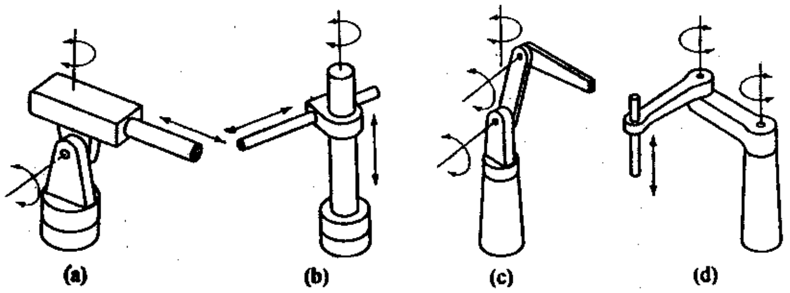


Figure 23.3 Four common robots: (a) polar (b) cylindrical (c) jointed arm ,and (d) SCARA

Virtual manufacturing system: Virtual manufacturing is a key concept that summarizes computerized manufacturing activities dealing with models and simulations instead of objects and their operations in the real world. Virtual manufacturing supports assessment of manufacturability of a new design and provides accurate estimates for processing times, cycle times and costs as well as product quality.

Virtual prototyping: Virtual prototyping is a method that helps to visualize and test CAD models on a computer before they are physically created. Thus before actually producing the product consumers reaction can suitably be understood about the designed product. The design can subsequently be modified or amended. The functionality of the product also can be appropriately judged by fixing a few measurable parameters Simulation study can be conducted on its performance. Many pre-production activities like design visulalisation, product functionality checking, modification in design /

testing for optimization can be carried out subsequently. Recent developments in computer graphics and simulation have provided more tools to the electronic prototyping. It is now very much feasible to take the 3-D model data and produce the product as a virtual prototype instead of a real one and testing may be conducted to analyze geometry, functionality and manufacturebility of the designed products. Recent advances in the information technology may give the feeling of testing the prototype of real world by any persons by providing him head sets and data gloves so that he may have a feeling of actual experiencing the product in virtual world. The user may thus gauge how the product will perform and behave in an intended environment. The procedure contains the following steps.

1. Product representation and model generation
2. Human computer interaction.
3. Manufacturing simulation to see the performance evaluation of the product

23.7 COMPUTER - INTEGRATED MANUFACTURING (CIM)

The CIM concept accounts for all of the firm's operations related to production functions. An integrated central computer assists, augments and automates all the business operations. Fig.23.4 shows the scope of CIM.

Major business function and positions of each function along with interrelationships are shown in Fig.23.5

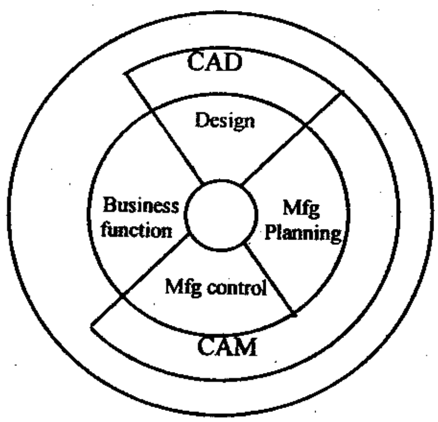
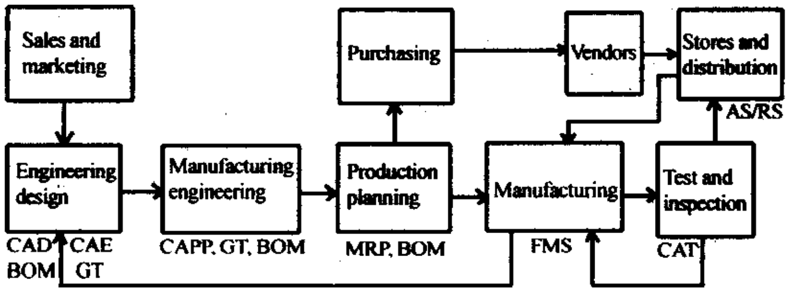


Figure 23.4 Scope of CIM

Potential benefits of CIM are:

1. Improved customer service
2. Improved quality.
3. Reduce inventory level.
4. Lower total costs.
5. Increase productivity.
6. Lower in WIP inventory.
7. High through-put.



Legends :

AS/RS	:	Automated storage / retrieval system.
BOM	:	Bill of materials.
CAD	:	Computer - aided design.
CAE	:	Computer - aided engineering.
CAPP	:	Computer - aided processing planning.
CAT	:	Computer - aided testing.
GT	:	Group technology.
MRP	:	Materials requirement planning.

Figure 23.5 Major elements of manufacturing and scope of CIM

Materials Requirement Planning (MRP) : Material requirement planning (MRP) is a computer based inventory and production schedule system that considers all that go into completing an order for large job shop situations where many products are manufactured in periodic lots via several processing steps. In fact MRP can be described as a subsystem of manufacturing planning and control system where concept of dependent-part demand is utilized.

Materials requirement planning usually harnesses the computer to perform thousands if simple calculations in transforming a master schedule of end products into parts requirement and is based on the fact that most manufactured products are made by some hierarchical structure of subassemblies and component parts. These subassemblies may be further broken down into their end component parts. Thus the number of component parts of a particular type depends on the number of end-products required to be manufactured.

Bill of Materials (BOM) : BOM is an input file that gives the listing of all raw materials and parts, necessary to manufacture one unit of a product. BOM also defines identification code of items, and the level of hierarchy of the product structure. A typical bill of material record contains the following data:

1. Project code, which identifies end items with the project where it is used.
2. Item code , which identifies the product.
3. Item description.
4. Unit of measurement.
5. Quantity, the number of components used for one unit of the end product.

Group Technology (GT) : Group technology is an important technique in the planning of manufacture that allows the advantages of product line organization to be obtained in what otherwise would be jobbing or batch manufacture. This technique identifies the sameness of parts, equipment or processes. Machines are grouped according to the routing required for a family of parts rather than by their functions.

By using this technique, production planning and control functions are also simplified as the group of machines can be treated as one work centre, thereby decreasing the number of work centres and simplifying the routing of parts. Waiting time is reduced significantly and work centre utilization in improved.

Group technology offers its greatest benefits when it is extended to all phases of production and production preparation including drafting and part programming for NC machine.

The generally accepted benefits of group technology are :

1. Reduction in setting up times and cost.
2. Reduction in material handling costs.
3. Reduction in inventory cost and thus reduction of lot size.
4. Reduction in throughput time.
5. Reduction in work-in-progress.
6. Reduction in planning cost and simplifying the documentation and administration of the process planning function.

This technique, along with good general management practices, therefore, has a large contribution towards improving productivity in general and reducing inventory cost in particular.

Agile Manufacturing[1] : Agile manufacturing is an emerging concept in industry that aims at achieving responsiveness and flexibility of producing any component according to the market needs at the quickest possible time. It is the science of a business system that integrates management, technology and workforce in a most cost effective manner. Agile manufacturing is a system characterized by its ability to allow rapid response to continuously changing customers requirements and market needs. It must be accomplished without compromising quality or increasing the cost. Any firm cannot be fat and agile at the same time. Before a firm can get agile, it has to get lean in all aspects such as lean product development, lean manufacturing, lean vendor arrangements, lean staff etc.

A lean organization has the benefit of speed; reduction in approval cycles and the decision maker is closer to the fact finder, resulting the faster and usually better decisions. Any organization that has nor mastered lean manufacturing should not expect to have too much success in pursuing agility.

REVIEW QUESTIONS

1. Define CAD, CAM and CIM. Why they are considered as important in manufacturing ?
2. Outline the relationships among CAD, CAM and CIM.
3. Describe in brief the function of a digital computer with the help of a block diagram.
4. Outline the scope of hardware and software of computer systems.
5. Name a few input - output devices of CAD system. Describe two input and two output devices.
6. List the phases of CAD process.
7. List the benefits of CAD.
8. What do you understand by geometric modelling ? Classify and describe the types.
9. Outline benefits of CAM applications.
10. State the characteristics of FMS.
11. Write short notes on : (1) MRP, (2) BOM, (3) GT, (4) Rapid prototyping.

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[1] Surender Kumar, Agile Manufacturing Technology for Rural, Small and Medium Scale Industries, Proceedings: National Conference on "Manufacturing Challenges in 21st Century", Jan, 2000.

24

RAPID PROTOTYPING

24.1 INTRODUCTION

Rapid prototyping (RP) is the most common name given to a host of related technologies that are used to fabricate physical objects directly from CAD data sources. These methods are unique in that they add and bond materials in layers to form objects. Such systems are also known by the names of *additive fabrication, three dimensional printing, solid freeform fabrication (SFF)* and *layered manufacturing*. Today's additive technologies offer advantages in many applications compared to classical subtractive fabrication methods such as milling or turning.

The capabilities of Rapid prototyping techniques can be listed as shown below:

1. Substantially reduce product development time, through rapid creation of 3D models.
2. Improve communication (visualization) within multidisciplinary design teams.
3. Address issues of increased flexibility & small batch sizes, while remaining competitive (rapid manufacture).

24.2 BASIC PRINCIPLES OF RAPID PROTOTYPING

The Basic Process

Although several rapid prototyping techniques exist, all employ the same basic five-step process. Figure 24.1 shows the conceptual representation of a RP technique. The steps are listed hereunder:

1. Create a CAD model of the design
2. Convert the CAD model to STL format
3. Slice the STL file into thin cross-sectional layers
4. Construct the model through layer by layer
5. Clean and finish the model

1. Create a CAD model of the design:
First, the object to be built is modeled using a Computer-Aided Design (CAD) software package. Solid modelers, such as Pro/ENGINEER, tend to

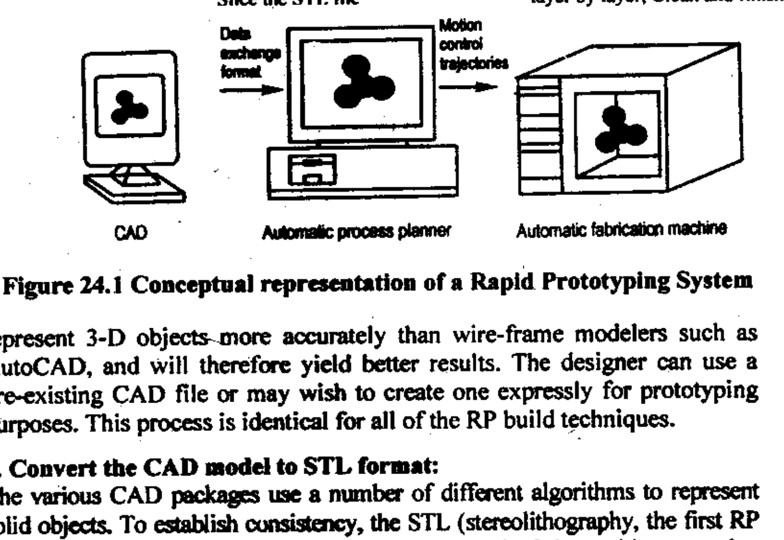

Figure 24.1 Conceptual representation of a Rapid Prototyping System

represent 3-D objects more accurately than wire-frame modelers such as AutoCAD, and will therefore yield better results. The designer can use a pre-existing CAD file or may wish to create one expressly for prototyping purposes. This process is identical for all of the RP build techniques.

2. Convert the CAD model to STL format:
The various CAD packages use a number of different algorithms to represent solid objects. To establish consistency, the STL (stereolithography, the first RP technique) format has been adopted as the standard of the rapid prototyping industry. The second step, therefore, is to convert the CAD file into STL format. This format represents a three-dimensional surface as an assembly of planar triangles, "like the facets of a cut jewel.". The file contains the coordinates of the vertices and the direction of the outward normal of each triangle. Because STL files use planar elements, they cannot represent curved surfaces exactly. Increasing the number of triangles improves the approximation, but at the cost of bigger file size. Large, complicated files require more time to preprocess and build, so the designer must balance accuracy with manageability to produce a useful STL file. Since the .stl format is universal, this process is identical for all of the RP build techniques.

3. Slice the STL file into thin cross-sectional layers:
In the third step, a pre-processing program prepares the STL file to be built. Several programs are available, and most allow the user to adjust the size, location and orientation of the model. Build orientation is important for several reasons. First, properties of rapid prototypes vary from one coordinate direction to another. For example, prototypes are usually weaker and less accurate in the z (vertical) direction than in the x-y plane. In addition, part orientation partially determines the amount of time required to

build the model. Placing the shortest dimension in the z direction reduces the number of layers, thereby shortening build time. The pre-processing software slices the STL model into a number of layers from 0.01 mm to 0.7 mm thick, depending on the build technique.

4. Construct the model through layer by layer:
The fourth step is the actual construction of the part. Using one of several techniques (described in the next section) RP machines build one layer at a time from polymers, paper, or powdered metal. Most machines are fairly autonomous, needing little human intervention.

5. Clean and finish the model:
The final step is post-processing. This involves removing the prototype from the machine and detaching any supports. Some photosensitive materials need to be fully cured before use. Prototypes may also require minor cleaning and surface treatment. Sanding, sealing, and/or painting the model will improve its appearance and durability.

24.3 RAPID PROTOTYPING TECHNOLOGIES

Various RP techniques are developed. They can be classified in three main categories[1], depending on the form of the starting material in the RP process: (1) liquid based (2) solid based, and (3) powdered based.

24.3.1 LIQUID BASED RAPID PROTOTYPING TECHNOLOGIES

In this category, three RP methods will be discussed:(1) stereolithography (2) solid ground curing, and droplet deposition manufacturing.

Stereolithography
Stereolithography (SL) was commercially introduced by 3D systems Inc. (Valencia, CA) in the late 1987 based upon a patented process originally developed by Mr. Charles Hull. Since this was the first RP technique, various system are presently available commercially to industries. In this process, a laser beam builds parts by photochemically curing liquid plastic. A laser beam is focused on the top layer of a photo-curable polymer resin contained in a vat. The beam is moved and positioned at a point in a layer using a set of mirrors. The beam cross-hatches the area contained within the boundary of a particular layer. As one layer is solidified, the platform holding the layer is lowered down (from 0.076mm to 0.50mm) and a new layer is formed. The beam then forms another layer and the process is repeated. Each layer consists of its own area shape as per the STL file created. Once the model is built, it is cured in an oven. Figure 24.2 illustrates the basic components of SL process. Several photopolymer resins from various vendors (Ciba-Geigy, DuPont, Allied Signal) are available for

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[1] Groover M.P.,Fundamentals of Modern Manufacturing,John Wiley & Sons,N.Y,Second Edition

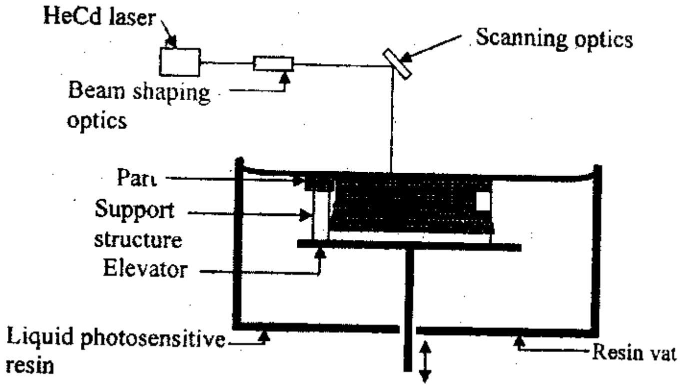

Figure 24.2 Schematic Diagram of Stereolithography

use with various stereolithography systems. Appropriate resins now exist to use stereolithography parts in machining and investment casting applications.

Considerable development efforts have been undertaken to provide dimensional stability of the part. The other drawback of the process in ' initial stage of development was in terms of generation of toxic gases. This defect has now been eliminated. The process is expensive in terms of both initial cost as well as the running cost. The time taken to build a part ranges from one hour to several hours depending the size and complexity of the part. There are five materials currently available for the SLA. All are acrylates(non-reusable thermosets). Accuracy of the prototype ranges from 0.1% to 0.5% of overall dimension from small to large parts. Currently this method has been seen to be the most accurate RP technology

Solid Ground Curing

Cubital Limited has developed this RP system. In this process, a layer of liquid polymer resin is cured by ultraviolet light. This is accomplished by exposing the layer in a flash or flood manner. The boundary and area for exposure is generated by developing a glass mask plate by electrostatic deposition of black toner powder outside the boundary. All voids in a layer are fitted with wax followed by milling to provide a flat support for the next layer. When all layers are complete, the prototype part is washed away to remove the water-soluble wax. Cubital photopolymer resin is completely cured during fabrication of each layer

Droplet Deposition manufacturing

Using this technology, the metal droplets can be generated flexibly and controlled precisely. Net-form manufacturing of components or ingots based on precisely controlled metal droplets is gaining industrial interest due to the promise of improved component quality resulting from rapid solidification processing and the economic benefits associated with a structural component in one integrated operation

24.3.2 SOLID BASED RAPID PROTOTYPING TECHNOLOGIES

In this category, two RP methods will be discussed:(1) laminated object manufacturing, and (2) fused deposition modeling.

Laminated Object Manufacturing

The laminated object manufacturing (LOM) process from Helisys, Inc. (Torrance, CA) uses solid sheet materials, most typically bleached

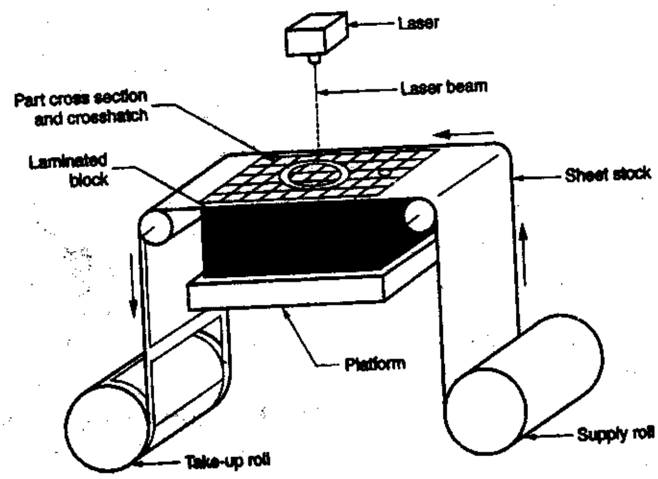

Figure 24.3 Schematic Diagram of Laminated Object Manufacturing

"butcher" paper, to create prototype parts. In this process, the LOM machine automatically positions a thin sheet of material from a roll onto an elevator platform. A CO_2 laser is then used to cut the sheet, using a computer controlled x-y plotter system and mirrors to direct the laser beam. The cuts are representations of the cross section obtained from the STL file. The machine bonds fresh sheet to previous sheet using a heated roller, which causes the sheets with precoated heat sensitive adhesive to fuse. Again, the layer is laser cut using slice data and the process repeats until the part is complete. Unwanted pieces are separated and removed from the part. The prototype parts resulting from the LOM process look and feel like wood. The general operation of LOM process is illustrated in Figure 24.3.

The process is simple and there is no phase change of starting material during its use. The strength of the part in the plane of the sheet remains intact. However, the dimensional as well as the surface quality is poor and the parts tend to absorb moisture unless properly treated.

Fused Deposition Modeling

Fused deposition modeling (FDM) is the name of the technology used by commercial RP systems from Stratasys, Inc. (Minneapolis, MN). The Stratasys systems are primarily targeted for product development teams for use during the conceptual design stage. The system utilizes simple operation. Inert materials and lack of fumes make the FDM process quite compatible with an office environment. In this process, a model is built using a thin filament of thermoplastic polymer. The filament is heated and passed through a nozzle. The movement of the nozzle forms of a layer which is solidified. The platform is lowered and the process is repeated. For overhanging features, a separate nozzle head deposits the support material. Once the model is built, the support material can be easily broken off from the part. This process is inherently slow during layer deposition. However, no post curing is required in this process. Compared to other processes, FDM has relatively lower initial cost and easy operation. The running cost is also low. The surface in this case may need some finishing operations. Figure 24.4 illustrates the general concept of the FDM process.

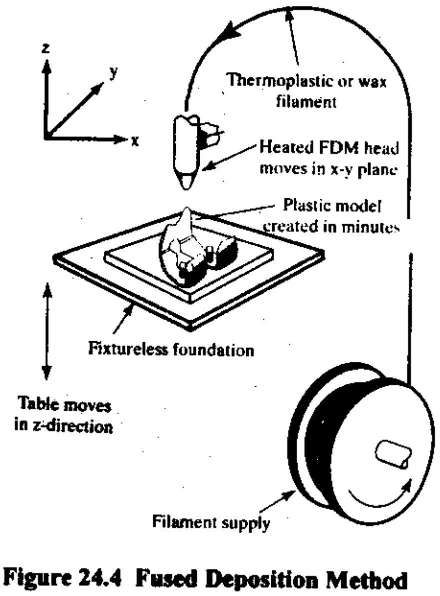

Figure 24.4 Fused Deposition Method

Prototype part materials for FDM process are currently limited to low temperature materials, including investment casting wax, machinable wax and plastic polymers. The plastic materials exhibit nylon like properties. Material changeover for Stratasys system is relatively quick and simple, with little or no material waste.

24.3.3 POWDER BASED RAPID PROTOTYPING TECHNOLOGIES

In this category, three RP methods will be discussed:(1) selective laser sintering (2) three dimensional printing, and,(3) laser engineered net shaping

Selective Laser Sintering

The selective laser sintering (SLS) system from DTM Corporation (Austin, Texas) builds parts layer by layer using a laser to bond powdered material into the desired part shape. In this process, a layer of thermoplastic powder is spread out. Then, using a high power laser beam, the portion needed for a model is melted and cooled. A roller then spreads the next layer and the process is repeated. The unsintered powder serves the function of supports for overhanging features. Recently, the process has been extended to produce ceramic and metallic parts. The process requires sintering in a furnace for complete bonding. This process is simple. The range of materials is broad. The visible limitation is that the parts are porous and are therefore useful for only specific applications.

Three Dimensional Printing

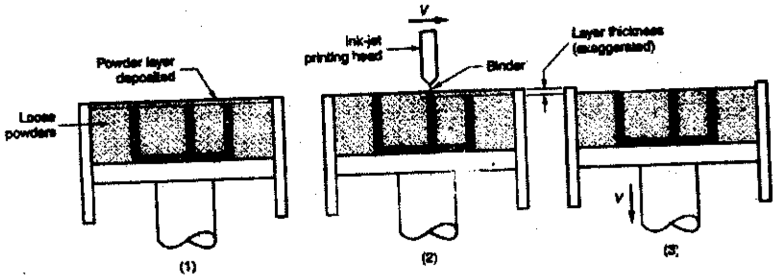

Figure 24.5 Three Dimensional Printing

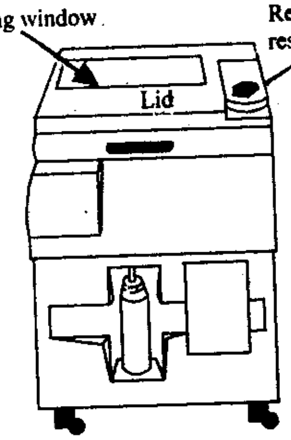

Figure 24.6 Three dimensional Printer

The Massachusetts Institute of Technology (MIT) has developed a prototyping system for creation of ceramic parts that uses the jetting mechanism similar to that used in ink jet printers.

In this process, a three dimensional object is fabricated by selectively applying binder to thin layers of powder, causing particles of powder to stick together. Each layer is formed by generating a thin coating of powder and then applying binder to it with the ink-jet like mechanism. Layers are formed sequentially and adhere to one another to generate the three dimensional object. Unwanted droplets of binder are skimmed before reaching the powder by electrically charging them at the nozzle and then deflecting them from the stream by applying a potential to the electrodes located below the nozzle. After all layers are formed, the unbonded powder is removed and the part is fired in an oven to cure and strengthen.

This process can be used to fabricate parts in a wide variety of materials, including ceramic, metal, metal-ceramic composite and polymers. The limitation is inadequate surface finish and porosity. The schematic diagram of the process is shown in Figure 24.5. Figure 24.6 shows a simplified diagram of three-dimensional printer.

Laser Engineered Net Shaping[2]

The strength of these technologies lies in the ability to fabricate fully dense metal parts with good metallurgical properties at reasonable speeds. A high power laser is used to melt metal powder supplied coaxially to the focus of the laser beam through a deposition head. A variety of materials can be used such as stainless steel, copper, aluminum etc. Of particular interest are reactive materials such as titanium. Most systems use powder feedstock. Objects fabricated are near net shape, but generally will require finish machining. They are fully dense with good grain structure, and have properties similar to, or even better than the intrinsic materials. Initial applications are concentrated on the fabrication and repair of injection molding tools and the fabrication of large titanium and other exotic metal parts for aerospace applications.

24.4 RAPID TOOLING

Rapid tooling (RT in short) is a technology that adopts rapid prototyping techniques and applies them to tool and die making. RT is becoming an increasing attractive alternative to conventional tool making. The move from conventional machining methods for making the tools to rapid tooling is more a leap than a step, similar to moving to computer aided design (CAD) from drafting. Rapid tooling methodology is classified as direct or indirect process. In the indirect method of RT, a pattern is created by the RP process and it is used to form the tool. For example, one can make the pattern using the stereolithography process. This is followed by making the tool using the investment casting process. The other type of RT methods produces the tools directly. For example, using the selective laser sintering process, one can make a green mold by printing a binder onto a metal powder. This mold is sintered and infiltrated with a low melting metal so as to get the tool in its finished form.

Rapid tooling can be used in many manufacturing processes. For plastic parts, RT can be used in conjunction with the following manufacturing processes: injection and compression moulding, vacuum casting, vacuum forming, glass reinforced plastic lay-up, blow moulding, extrusion etc. For

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[2] http://home.att.net/~castleisland/

metallic parts, RT can be used in conjunction with following manufacturing processes: sand casting (patterns, matchplates, coreboxes), investment casting using wax patterns, sheet metal forming, die casting, hot and cold forging etc. For ceramic parts, RT can be used in conjunction with slip casting, isostatic forming and powder compaction in presses.

Generally most RT applications have involved soft tooling. But there will be a gradual shift to hard tooling in the next few years. Hard tooling is often referred to that made from hardened tool steels. Materials with lower hardness are considered 'soft', e.g. silicones, rubber, epoxies, low melting point alloys, zinc alloys, aluminum, etc. Soft tools are required for small-lot size production.

24.5 LIMITATIONS OF RAPID PROTOTYPING

Rapid prototyping systems can't yet produce parts in a wide range of product, at a fast rate. Nevertheless, an increasing number of applications are taking advantage of additive fabrication and now incorporate parts that are directly made by RP processes. Today, typically these requirements are for low-volume items with complex geometries used in high value added applications such as medicine or aerospace. As materials and technologies have improved, and as the capabilities have become more widely understood, direct manufacturing has become a fast growing area in RP.

To address a wider range of applications sooner, RP is also often used as the starting point for making conventional fabrication processes faster, cheaper and better. Rapid prototyping is used in two ways to accomplish this: Molds may be directly fabricated by an RP system, or RP-generated parts can be used as patterns for fabricating a mold through so-called *indirect* or *secondary processes*.

24.6 PRACTICAL APPLICATIONS OF RAPID PROTOTYPING

Rapid prototyping is used to model new products at a very fast rate. Jacob[3] has identified the following applications of Rapid Prototyping.

1. Visualizations
2. Verification
3. Iteration
4. Optimization
5. Fabrication

Visualization

In blue prints and CAD Models, the visualisers have some difficulties to correctly identifying some of the features of the product. This is true specifically when the product contains blind holes, complex interior passage ways and compound curve surfaces, etc. Rapid prototyping can detect all the

[3] Jacobs P.F., Rapid Prototyping and Manufacturing,McGraw-Hill,Inc.,1992

features as the prototype of the final product is available for inspection and appropriate decision making.

Verification

Manufacturing engineers and mangers can check up the characteristics such as strain, operational temperature fatigue etc. on fully functional prototype. Thus the product can be verified before it goes to a fully manufacturing cycle.

Iteration

Once the prototype is made the designer can perform tests on it within the physical limit of the prototype. For example fluid dynamic flow test can be made on a prototype, cured photopolymer material. If a problem is detected during the test the geometry can be modified in the model, a new RP can be built and the same test can be made for its use.

Optimization

Design optimization can improve the situation further. RP technology allows the design to alter the design without any problem. Having achieved an acceptable design through RP Iteration, the designer has the opportunity to attend to optimize the design by changing various parameters of the product and to test, which is the best one.

Fabrication

Once an optimized prototype has been developed by the using any of the methods of RP technologies, it is important to fabricate a functional test model (FTM). Because this model has not yet been fabricated or tested, it is not known if it will pass the functional test requirements. RP can be used to perform functional test on the FTM. If the test result is satisfactory, tools and pre manufacturing activities start.

REVIEW QUESTIONS

1. Define Rapid Prototyping.
2. What are the basic principles of RP?
3. Describe basic operations of RP.
4. What are the three types of starting materials in RP?
5. What other manufacturing aspects may distinguish the RP Technologies?
6. What is the most widely used RP Technology?
7. Describe the RP Technology called Stereolithography.
8. Describe the RP Technology called Three Dimensional printing.
9. What is the starting material in Droplet Deposition Manufacturing?

25

FLEXIBLE MANUFACTURING SYSTEMS

25.1 INTRODUCTION

A flexible manufacturing system is a highly automated group technology (GT) machine cell, consisting of a group of processing workstations, interconnected by an automated material handling and storage system, and controlled by a distributed computer. A concise description of FMS has already been described in page 684 in this book.

FMS is made up of hardware and software elements[1]. Hardware elements are visible and tangible such as CNC machine tools. Software elements are invisible and intangible such as NC programs. FMS is one, that can be adapted rapidly to manufacture varieties of components at different volumes.[2] The flexibility is built up in such a manner that the system may be capable of reacting in case the design or volume of production of the component changes, whether predicted or unpredicted.

Although the early FMSs have been in operation now for more than 10 years, the use of such system is still a new and unknown experience for many companies and certainly for up-coming generation of engineers. FMS is limited to companies involved in batch production or job shop environments. Normally, batch producers have two kinds of equipment from which to choose: dedicated machinery or un-automated general-purpose tools. Dedicated machinery results in cost savings but lacks flexibility. General purpose machines such as lathes, milling machines, or drill presses are all costly, and may not reach to their full capacities. FMS provides the batch manufacturer with an important option: one that can make batch manufacturing just as efficient and productive as mass production using the

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[1] http://www.slideshare.net/LeicesterColTechEngCentre/flexible-manufacturing-systems-v2-090310

[2] http://www.technologystudent.com/prddes1/flexbl1.html

concept of GT cell formation (please refer Hajra Choudhury.[3] for GT system.).

25.2 TYPES OF AUTOMATION

Three types of automation in production can be mentioned: (1) fixed automation, (2) programmable automation, and (3) flexible automation.

Fixed automation, also known as "hard automation," refers to an automated production facility in which the sequence of processing operations is fixed by the equipment configuration. Programmable automation is a form of automation for producing products in batches. The products are made in batch quantities ranging from several dozen to several thousand units at a time. For each new batch, the production equipment must be reprogrammed and changed over to accommodate new product style. Flexible automation, system is capable of changing over from one job to the next with little lost time between jobs. The typical features of flexible automation are (1) high investment for custom-engineered system, (2) continuous production of variable mixes of products, (3) medium production rates, and (4) flexibility to deal with product variety. Fig. 25.1 shows the relationship of various automation system in terms of product varieties and volumes. Fig. 25.2 shows application area of different manufacturing systems.

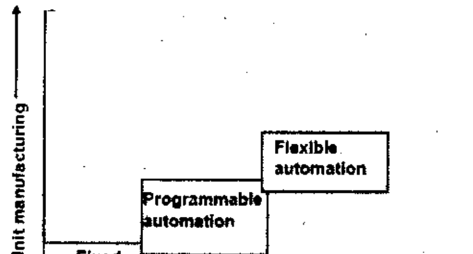

Figure 25.1 Types of various automation systems

25.3 FLEXIBILITY EXAMINED

Flexibility in manufacturing indicates the ability to deal with slightly or greatly mixed parts. It allows variation in parts assembly and process sequence, production volume and design of certain product for manufacturing

[3] Hajra Choudhury S K. et al.(2009). Elements of Workshop Technology, Vol: I. pp7-10

The term flexibility also can be expressed in different ways as given hereunder:

1) Basic flexibilities,
2) System flexibilities, and
3) Aggregate flexibilities

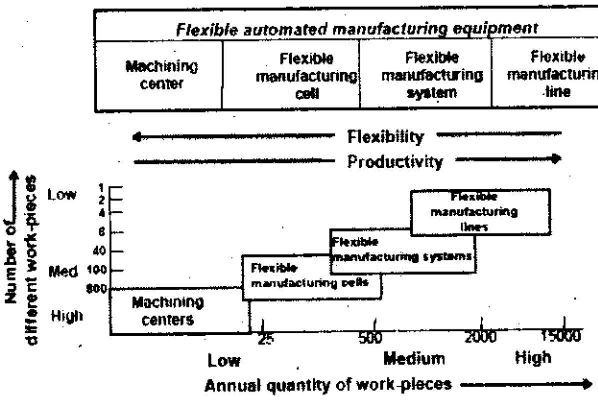

Figure 25.2. Application area of different manufacturing systems

Basic flexibilities

This is used for machine, materials handling and operations.

Machine flexibility - the ease with which a machine can process various operations

Material handling flexibility - a measure of the ease with which different part types can be transported and properly positioned at the various machine tools in a system

Operation flexibility - a measure of the ease with which alternative operation sequences can be used for processing a part type

System flexibilities

The following types of system flexibilities are considered:

Volume flexibility - a measure of a system's capability to be operated profitably at different volumes of the existing part types

Expansion flexibility - the ability to build a system and expand it incrementally

Routing flexibility - a measure of the alternative paths that a part can effectively follow through a system for a given process plan

Process flexibility - a measure of the volume of the set of part types that a system can produce without incurring any setup

Product flexibility - the volume of the set of part types that can be manufactured in a system with minor setup

Aggregate flexibilities

Aggregate flexibilities can be of the following types:

Program flexibility - the ability of a system to run for reasonably long periods without external intervention

Production flexibility - the volume of the set of part types that a system can produce without major investment in capital equipment

Market flexibility - the ability of a system to efficiently adapt to changing market conditions

25.4 FLEXIBLE MANUFACTURING EQUIPMENT

Flexible Manufacturing Systems (FMS) mainly consists of three sub-systems, namely:

1. Fabrication
2. Machining and
3. Assembly

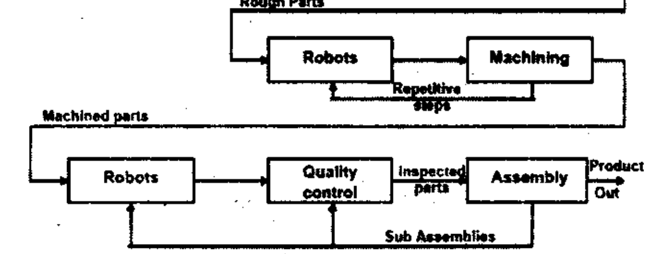

Figure 25.3 Main structure of FMS

The main structure of an FMS and flow of production in metal working industries are indicated in Fig. 25.3. In FMS, an efficient transportation system is very important in order to mount the components and allow them to be routed between different machines/workstations. Transportation systems can be built up by a circular conveyer system or by a stacker crane without any use of robotic trucks or arms. Industrial robots, on the contrary, are capable of supporting a very good transport system for performing a large variety of handling functions in FMS. The role of a supervisory computer to link industrial robots and various subsystems of FMS ensure satisfactory performance in producing a wide range of production volumes. Industrial robots with their sophisticated control and re-programmability function provide at the same time, consistency and flexibility in the existing automated manufacturing systems.

An FMS can be divided into the following classes:

- Flexible manufacturing module (FMM)
- Flexible manufacturing cell (FMC)
- Flexible manufacturing group (FMG)
- Flexible fabrication-machining-assembly system (FFMAS)

Flexible manufacturing equipment is used to automate machining of work pieces of different varieties. NC machines consist of column, workable and tool storage. NC machines may contain various automated functions like tool and work-piece handling and buffering, use of multiple tools, facilities for inspection and measurement in the machine during operations etc. Flexible machining equipment contains the variants of NC machines with different capabilities of loading and unloading components and transfer of components if needed along with inspection and measurement functions. Individual machines also can be interfaced together. When such functions are integrated, it is possible to distinguish among different manufacturing technologies such as machining centers, machining cells, flexible manufacturing system and flexible manufacturing lines. Kindly refer Fig. 23.2 which illustrates these concepts to flexibility and productivity with different manufacturing technologies. These are machining centers, flexible manufacturing cells, flexible manufacturing system and flexible machining lines.

Machining centers

Numerically controlled (NC) machine centers use several different types of cutting tools to machine a part or a collection of parts. The tools are stored in a magazine, from which they are taken automatically for use in the order determined by the manufacturing process. The time taken for tool change (please refer Fig.25.4) is unproductive and therefore should be minimized. The manufacturing method is batch production, and batch changes usually imply manual retooling in NCs. However in machining centers have automated tool changes.

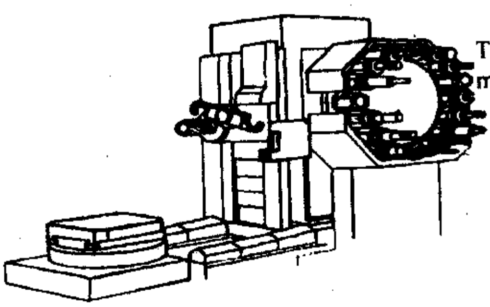

Figure 25.4 Tool changing in FMS

Int J Adv Manuf. Technol. (2004) 24: 567-572, Optimal tool magazine operation, Niemi, E

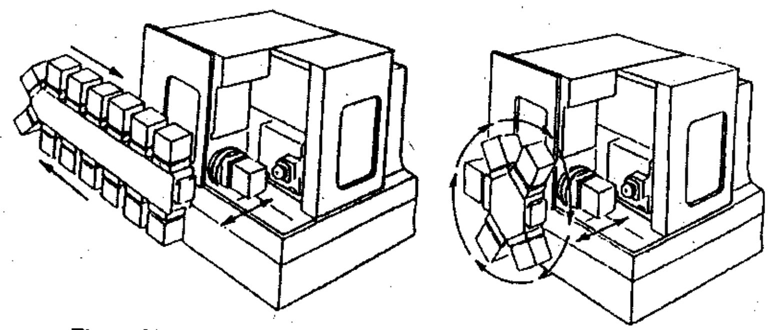

Figure 25.5 **Machining centre incorporating work piece changes**

Clamping of work-pieces are carried on manually on the machines. Fig. 25.5 shows the diagram of one machining centre incorporating work piece changes. With an extended facility, this machining centre can be a part of FMC.

Flexible manufacturing module

In flexible manufacturing module (FMM), automation is effected by a single robot. Fig. 25.6 indicates an FMM where a robot is loading a single NC machine unit picking up parts from the component buffer.

In FMM a single robot interacts with a single NC machine and FMM is the simplest form of FMS. Whenever production rate is low and the number of different producible parts is high, FMM offers a better solution.

Functions of Flexible manufacturing systems

The FMS is a configuration of computer-managed numerical work stations where materials are automatically handled and machine loaded. Please refer Fig.25.3 for understanding structure of FMS and also understanding flow of production.

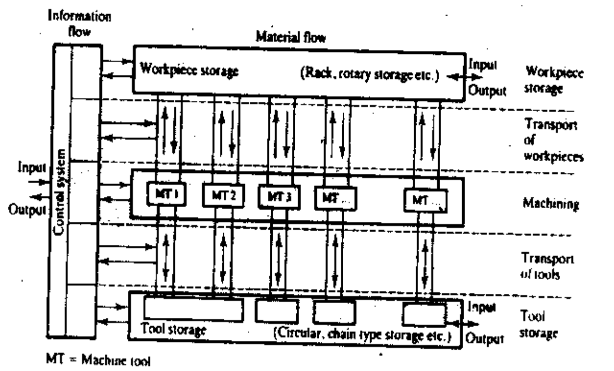

Figure 25.6 Functions of a Flexible Manufacturing System

The flexible manufacturing system is principally used in mid-volume (200 to 30.000 parts per year) mid-variety (5 to 155 part types) production. The functions of the FMS are shown in a Fig. 25.6.

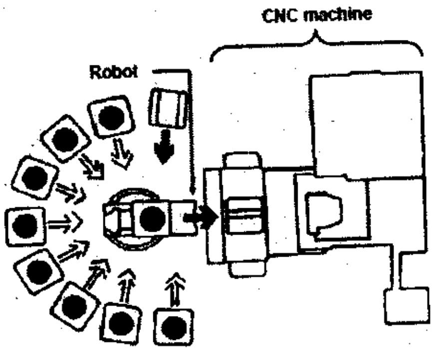

Figure 25.7 Structure of a Flexible Manufacturing Module (FMM)

Flexible machining cells

A flexible manufacturing cell (FMC) consists of two or more CNC machines, a computer and a robot for material handling. The cell computer (typically a programmable logic controller) is interfaced with the microprocessors of the robot and the CNCs. The functions of the cell controller include work load balancing, part scheduling, and material flow control. The supervision and coordination among the various operations in a manufacturing cell is also performed by the cell computer. The software includes features permitting the handling of machine breakdown, tool breakage and other special situations. In many applications, the cell robot also performs tool changing and housekeeping functions such as chip removal, staging of tools in the tool changer, and inspection of tools for breakage or expressive wear. Figure 25.7 shows the structure of a flexible machining cell in which a machining centre and a lathe are linked together by a system for transporting materials. The figure also shows the machine oriented control level containing the NC and robot controls. This level is supervised by a dedicated controller.

Flexible manufacturing group

A flexible manufacturing group (FMG) consists of several flexible manufacturing modules (FMMs) and FMCs of the same kind. Automated guided vehicle provides the materials handling arrangements for different types of products and processes. All the system components of this category are under central computer control.

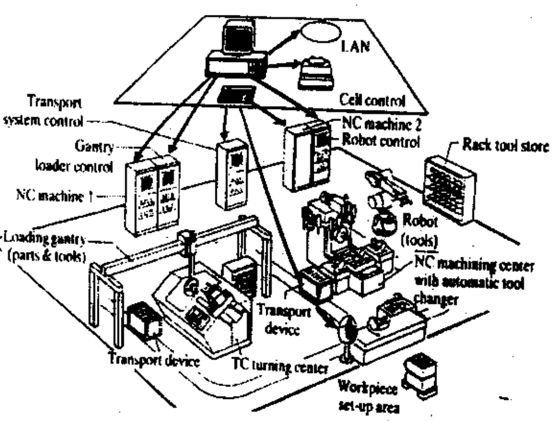

Figure 25.8 Structure of a flexible manufacturing cell
Source: Rambold U., et al. (1996). Computer Integrated Manufacturing and Engineering, Addison Wesley Publishing Company, New York

Flexible fabrication machining assembly system

A Flexible fabrication machining assembly system(FFMAS) consists of flexible manufacturing modules of different kinds of manufacturing processes namely , fabrication, machining and assembly. AGVSs play an important part in FFMASs. Fig. 25.9 shows a structure of FFMAS.

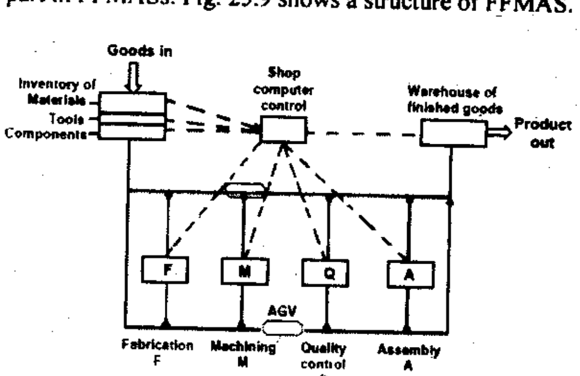

Figure 25.9 Structure of FFMAS

25.5 IMPORTANT ITEMS OF FMS

Some important items/components of flexible manufacturing system are indicated as follows:

1. Inspection equipment
2. Chip removal system
3. In process storage inventories
4. Material handling system
5. Pallets and fixtures

Inspection equipment :
Monitoring the quality of operation in a FMS is usually done through:
1. Coordinate measuring machine
2. Probing machine center

Chip removal system :
Chips are the piece of metals, which have been removed from work piece. Two methods of removing these from work area are
1. Chip conveyor to the collection box
2. In- floor flume system with a centralized collection area.

In process storage inventories:
Due to lack of perfect information, some buffering is needed between the handling system and machine. The buffering of parts is called in process inventories.

Material handling system:
The primary purpose of work handling equipments was to transfer pallet and work piece between the loading and unloading. These include a variety of conventional materials transport equipment. The materials handling function in an FMS is often shared between two systems: (1) a primary handling system and (2)a secondary handling system.

TABLE 25.1 MATERIAL HANDLING FOR THE FIVE FMS LAYOUTS

Layout Configuration	Typical Material Handling System
In-line layout	In-line transfer system Conveyor system Rail guided vehicle system
Loop layout	Conveyor system In-floor towline carts
Ladder layout	Conveyor system Automated guided vehicle system Rail guided vehicle system
Open field layout	Automated guided vehicle system In-floor towline carts
Robot-centered layout	Industrial robots

The primary handling system establishes the basic layout of the FMS and is utilized for movement of work pieces between stations of the system.

The table[4] 25.1 shows material handling equipment typically used as the primary handling system of five different types of FMS layouts. Figures 25.10 and 25.11 show in-line one directional flow and FMS loop layout with secondary part handling system at each station.

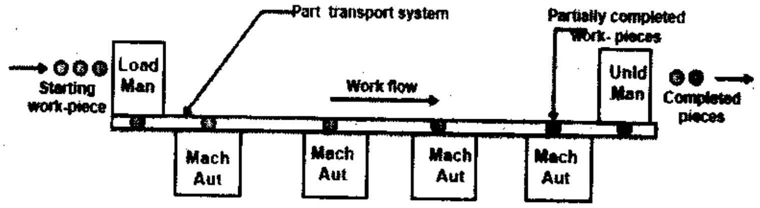

Figure 25.10 In-line one directional flow

Automated guided vehicles

AGVs in FMS are used to transport an object from one point (say A) to another point(say B). AGVs navigate manufacturing areas with sensors. There are two main sensors AGVs use for navigation, a wired and a wireless sensor. Lower cost versions of AGVs are often called Automated Guided Carts (AGCs) and are usually guided by magnetic tape. AGCs are available in a variety of models and can be used to move products on an assembly line, and deliver loads to and from stretch wrappers and roller conveyors.

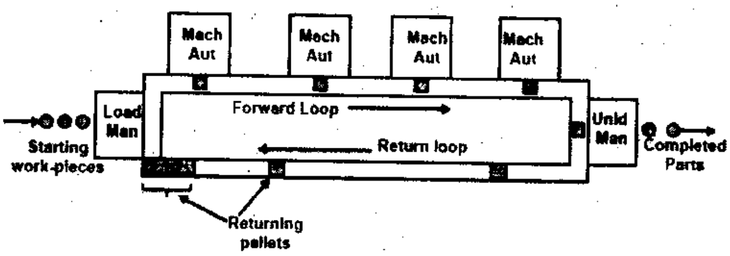

Figure 25.11 FMS rectangular layout with re-circulation of pallets

Robot

Robot is an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes. Robots play an important role in FM systems. With the three major qualities that robots have: efficiency, quality, and flexibility, make robots prime components for a FMS.

[4]Groover M.P, Automation, Production Systems, and Computer-Integrated Manufacturing, Pearson Education,2008

Conveyors

A conveyor system is a common piece of mechanical handling equipment that moves work-pieces from one location to another. Conveyors are especially useful in applications involving the transportation of heavy or bulky materials. Conveyor systems allow quick and efficient transportation for a wide variety of materials, which make them very popular in the material handling and packaging industries. A roller conveyor is used when the produce have to be of adequate size and shape so that they cannot fall between the moving rollers. If the product being conveyed is of varying size, the belt conveyor system is generally used as an alternative option.

Pallet and fixtures:

The functional component which allows for integration of machines, material handling and in process materials/storage is to use palletized parts. The palletized part is a steel disk with slots on surface. These slots are used to fasten the fixture to the pallet.

Programmable Logic Controller

Any FM system contains a computer witch controls different NC machines, and robotic arms. Each of these equipment can be programmed to do a number of different tasks. The computer in this system can be programmable logic controller (PLC). The PLC has several functions. It communicates with the other machines and monitors what is being process. The PLC determines when a part is done in a machine and when it needs to be moved form one area to another. The PLC will issue all the commands that are involved in the process. PLCs are armored for severe conditions (such as dust, moisture, heat, cold) and have the facility for extensive input/output (I/O) arrangements. These connect the PLC to sensors and actuators. PLCs read limit switches, analog process variables (such as temperature and pressure), and the positions of complex positioning systems. Some use machine vision. On the actuator side, PLCs operate electric motors, pneumatic or hydraulic cylinders, magnetic relays, solenoids, or analog outputs. The input/output arrangements may be built into a simple PLC, or the PLC may have external I/O modules attached to a computer network that plugs into the PLC[5].

25.5 ADVANTAGES AND DISADVANTAGES OF FMS

FMS is implemented in many manufacturing and assembly industries. However FMS has its own advantages and disadvantages. These are listed below.

Advantages

[5] http://en.wikipedia.org/wiki/Programmable_logic_controller

1. Less waste
2. Fewer workstations
3. Quicker changes of tools, dies, and machinery
4. Reduced downtime
5. Better control over quality
6. Reduced labor
7. More efficient use of machinery
8. Work-in-process inventory reduced
9. Increased capacity
10. Increased production flexibility

Disadvantages

1. Limited ability to adapt to changes in product or product mix
   Substantial pre-planning activity
2. Expensive
3. Technological problems of exact component positioning and precise timing necessary to process a component
4. Sophisticated manufacturing systems

REVIEW QUESTIONS

1. Define flexible manufacturing system. Why it is important in the present scenario of lean type of manufacturing?
2. Discuss of different types of automation. Illustrate with the help of a diagram to show the relationships of different types of automation system.
3. What do you understand by flexibility? What are different classes of flexibilities? List them.
4. Why the flexibility is desired in automation system?
5. What are the various flexible manufacturing equipment? List them and briefly describe.
6. Describe flexible manufacturing module.
7. What is FMC? What way it is different from FMG? Discuss.
8. What is a machining centre? Explain how it is so important in FMS.
9. Identify different components of FMS. Describe them in brief.
10. What is an AGVS? Why it is important? What are its functions?
11. What are the advantages and disadvantages of FMS? Describe.