1.a

Automation has been classified into three types

1. Fixed (or) Rigid Automation
2. Programmable Automation
3. Flexible Automation

1. Fixed Automation (OR) Rigid Automation

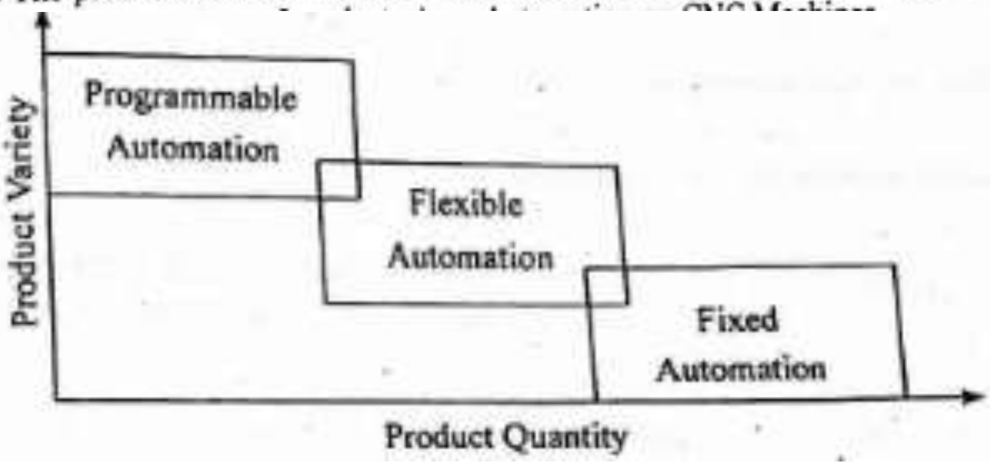
As the name suggests, in this automation the sequence of operations are fixed, and easier to perform. Fixed automation is used when the volume of production is high, and product variety is low. This kind of automation is mostly suitable for Mass Production. Here the equipment is specially designed to produce a particular product. If the product changes the same equipment cannot be used. Fixed automation has very high production rates. Overall investment is less in case of fixed automation when compared to other types of automation. **Ex:** Oil refineries, chemical processing, Assembly lines special purpose machines

2. Programmable Automation

In this type of Automation Sequences of operations can be interchanged. The sequence of operations are controlled by program of instructions. If the product is changed only program of instructions are changed but not the equipment. Programmable automation is used when production volume is low. This kind of automation is more suitable for Batch production. The product variety will be high in this automation compared to fixed automation If the product changes, the same equipment can be used with minimal changes. Ex: NC Machines, Industrial Robots.

3. Flexible Automation

It is an extension of programmable automation. A flexible automation system is capable of producing a large variety of parts with virtually no time lost for change over from one part style to the next. It covers the advantages of both fixed and programmable automation. The production rates are medium in flexible automation. The entire system



1.B

Production Rate $R_p = 1/T_p$

Batch production:

Batch time, $T_b = T_{su} + QT_c$

Average production time per work unit, $T_p = T_b/Q$

Production rate, $R_p = 1/T_p$

T_{su} Setup time; Q Batch quantity.

Job shop production:

For $Q = 1$, $T_p = T_{su} + T_c$

For quantity high production:

$R_p = R_c = 60/T_p$ since $T_{su}/Q \rightarrow 0$

Production Capacity

- The maximum rate of output that a production facility (or production line, or group of machines) is able to produce under a given set of assumed operating conditions.
- When referring to a plant or factory, the term *plant capacity* is used.
- Assumed operating conditions refer to:
  - Number of shifts per day
  - Number of hours per shift
  - Employment levels
- **PC = n S_wH, R_p**, where,

n - production machines in the plant and they all produce the same part or product; **S_w**- number of shifts per period (shifts/week); - hours / shift; **R_p** – hourly production rate of each work center (output units / hr)

Utilization

- Proportion of time that a productive resource (e.g., a production machine) is used relative to the time available. OR
- Amount of output of a production facility relative to its capacity.
- **U = Q/PC,** where, Q – actual quantity produced by a facility during a given time period (pc/week); PC – production capacity for the same period (pc/week).
- Utilization can be assessed for the entire plant / any other productive resources(i.e., labor).
- Usually expressed in %.

Availability (A)

- A common measure of reliability of an equipment (or proportion uptime of the equipment)

$$A = \frac{MTBF - MTTR}{MTBF}$$

where *MTBF* = mean time between failures, and

MTTR = mean time to repair

Manufacturing Lead Time (MLT):

- The total time required to process a given part or product through the plant, including any time for delays, material handling, queues before machines, etc.

$$MLT = n_o (T_{su} + QT_c + T_{no}) \text{ where}$$

- MLT = manufacturing lead time
- n_o = number of operations
- T_{su} = setup time
- Q = batch quantity
- T_c = cycle time per part, and
- T_{no} = non-operation time

Work - in - Process(WIP):

- The quantity of parts or products currently located in the factory that either are being processed or are between processing operations.

$$WIP = R_{pph} (MLT), \text{ where}$$

- WIP = work-in-process, pc
- R_{pph} = hourly plant production rate, pc/hr;
- MLT = manufacturing lead time, hr

2.a

2.6 TYPES OF FLOW LINE CONFIGURATIONS (DEC 2012, DEC2011)

Automated flow lines can be configured to move different types of work parts to suit different types of processing operations. The different types of Automated flow line configurations are:

(a) Linear (or) In - line Configuration

(b) Segmented In - line Configuration

- L - Type configuration
- U - Type configuration
- Rectangular configuration.

(c) Rotary configuration.

(a) Linear (or) In - Line Configuration

In - Line Configuration is the most common and simple type of configuration. This type of configuration consists of sequence of workstations in a straight line arrangement. In line configurations are used for machining large work pieces. More number of operations can be performed on the work parts and can accommodate larger number of workstations. Storage buffers and inspection stations can be incorporated in between the lines. One disadvantage of this type of configuration is that it requires more floor space.

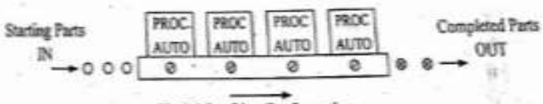


Fig 2.5 In - Line Configuration

(b) Segmented In - Line configuration

Segmented In - line configuration is a combination of two or more in - line configurations. These In - line transfer lines will be perpendicular to each other. By incorporating such type of configuration, factory floor space can be reduced. Segmented in - line configurations can accommodate more number of workstations, and can process larger work pieces. Inspection stations and storage buffers can be incorporated in between the workstations.

- There are three types of segmented in - line configurations.
  - L - Type configuration
  - U - Type configuration
  - Rectangular type configuration

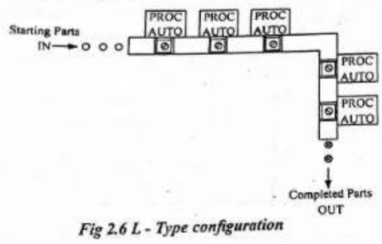


Fig 2.6 L - Type configuration

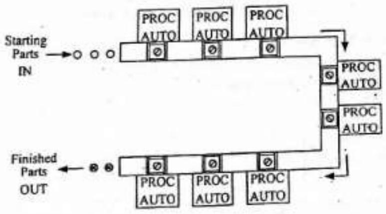


Fig 2.7 U - Type configuration

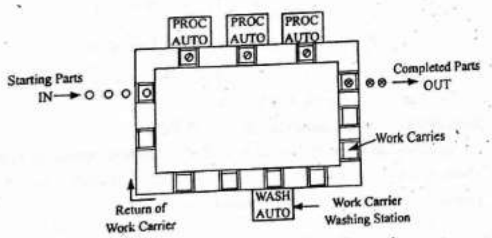


Fig 2.8 Rectangular layout type configuration

2.b

$T_c = 1.4$ min

$T_d = 6$ min

$P = 0.004$

Upper bound approach :

- Frequency of breakdowns

$$F = np$$
$$= 16 \times 0.004$$
$$F = 0.064$$

- Production time,

$$T_p = T_c + F\,T_d$$
$$= 1.4 + 0.064 \times 6$$
$$= 1.784 \text{ min / pc}$$

- Production rate,

$$R_p = \frac{1}{T_p} = 0.56 \text{pc / min}$$

$$R_p = 33.63 \text{ pc/hour.}$$

- Line efficiency,

$$E = \frac{T_c}{T_p} = \frac{1.4}{1.784} = 78.47\%$$

Lower bound approach :

- Frequency of break downs:

$$F = 1 - (1 - p)^n$$
$$= 1 - (1 - 0.004)^{16}$$
$$F = 0.062$$

- Production time,

$$T = T_c + F.T_d$$
$$= 1.4 + 0.062 \times 6$$
$$= 1.772 \text{ min / pc}$$

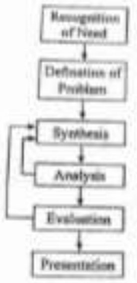
- Production rate,

$$R_p = \frac{1-F}{T_p} = \frac{1-0.062}{1.772}$$
$$= 0.529 \text{ pc/min}$$
$$= 31.76 \text{ pc/hour.}$$

- Line efficiency,

$$E = \frac{Tc}{Tp} \times 100 = \frac{1.4}{1.784} \times 100 = 79\%$$

3.a



Analysis :

In this phase, a prototype model is analysed by giving different boundary conditions and constraints, subjecting the model to different temperatures and loads to perform feasibility study. If the product fails at this stage, once again the design is reverted back to the synthesis phase.

Evaluation :

The end products of the analysis phase is compared with the definition phase. If there requires any changes, then the design is one again reverted back to synthesis phase.

Presentation :

This includes documentation of the design by means of drawings, material specifications, Bill of materials, Views, tolerances etc.

3.3 COMPUTER AIDED DESIGN PROCESS

The various design related tasks which are performed by a modern computer. Aided design system can be grouped into four functional areas.

1. Geometric Modeling
2. Engineering Analysis
3. Design review and evaluation
4. Automated drafting

Geometric modeling corresponds to synthesis phase. Engineering analysis corresponds to analysis. Design review and evaluation corresponds to evaluation phase. Automated drafting corresponds to presentation phase.

3.3.1 Geometric Modeling

It is concerned with computer compatible mathematical description of the geometry. These drawings are created in a computer and also computerized model can be developed instead of a prototype model. Here,the designer constructs the graphical image of the object on the screen by giving three types of commands to the computer.

I type of commands : Generates basic geometric elements such as points, lines and circles.

II type of commands : Used for scaling, rotation and other transformation.

III type of commands : Used to join various elements to get desired shape.

There are different ways of representing the objects in geometric modeling.

1. Wireframe modeling
2. Surface Modeling
3. Solid modeling

1. Wireframe Modeling :

Basic representation form. It is easier to create, but complex to understand. It consists of only points, lines and curves.

Here, the geometry is represented in the form of surfaces, But the object will not have any mass or volume.

3. Solid Modeling :

This is the most advanced method of geometric modeling. Here, the objects will occupy volume.

During the geometric modeling process, computer converts the commands into mathematical models, stores it in computer data files and displays it as an image on the CRT. There are different software which are capable of performing geometric modeling like, ProlE, CATIA, Solid Edge Uni Graphics, Solid Works.

3.3.2 Engineering Analysis

The analysis involve stress-strain calculations, heat - transfer computations, fluid flow analysis etc. Different types of analysis can be performed on a geometric model, like structural analysis, Thermal analysis, Electro - Magnetic analysis, computational fluid-dynamics etc.

There are mainly two different types of analysis

1. Analysis of mass properties
2. Finite element analysis

Analysis of mass properties provides different properties of a solid model like surface area, weight, volume, center of gravity, moment of inertia etc.

For planar surfaces we can find out perimeter, area and inertia properties.

Finite element analysis is the most powerful analysis of a CAD system. In this type of analysis the model is divided into a large number of finite elements. Then these small elements are analyzed for different properties and thus by analyzing these elements, the behaviour of the entire object can be accessed.

There are different analysis packages available in the market. They are,

Ansys, Nastran, COSMOS, Fluent, Hyper Mesh, Star - CD, ...

3.3.3 Design Review and Evaluation

- Checking the accuracy of the design can be easily accomplished by using computers.
- Semiautomatic dimensioning and tolerance will help the user reducing the possibility of dimensioning errors.
- A procedure called layering, is often used to compare similar type of images with each other and helps to find out the defects.
- Interference checking helps to find out if any parts are intersecting with each other in a assembly model.
- Kinematics is one of the most interesting evaluation factor which provides capability to animate the motions of simple designed mechanisms. Commercial software are available to perform kinematics like ADAMS(Automatic Dynamic Analysis of Mechanical Systems).

3.3.4 Automated Drafting

This involves creation of hard - copy drawings of the models from the solid model in a CAD database. Automated drafting helps to generate different orthographic and sectional views directly from a solid mode.

The dimensioning and tolerances including cross hatching is automatically provided to the models. It also takes care of various design standards in the drawing such as thick lines, thin lines, hidden lines, center lines.

The part list can be automatically generated in a CAD system. By using automated drafting, the productivity of a system can be increased rapidly.

3.5 COMPUTER GRAPHICS

CAD/CAM has more potential to increase productively. These CAD/CAM software provides engineers with tools needed to perform this technical jobs efficiently. Similar to hardware, CAD/CAM software has developed steadily since the development of ICG in 1960's.

The graphics software is the collection of programs that includes programs to generate images on the CRT screen, to manipulate the images, and to accomplish various types of interaction between the user and the system. In addition to the graphics software, there may be additional programs for implementing certain specialized functions relation to CAD/CAM. These include design analysis programs (e.g., Finite element analysis and Kinematic simulation) and manufacturing planning programs (e.g. automated process planning and numerical control part programming)

3.b

3.11 2-D TRANSFORMATIONS

X and Y co-ordinates are required to specify a point in a two dimensional co-ordinate system. These co-ordinates can be represented in matrix form as

$$P=\begin{bmatrix}X\\Y\end{bmatrix}$$

Similar matrix representation can be used to specify line connecting between two co-ordinates (x_1,y_1) and (x_2,y_2)

The notation would be

$$L=\begin{bmatrix}x_1 & y_1\\x_2 & y_2\end{bmatrix}_{2\times2} \qquad L=\begin{bmatrix}x_1 & x_2\\y_1 & y_2\end{bmatrix}$$

Using matrix algebra , 2D transformations can be performed on the line or point.

3.11.1 Translation :

Translation involves moving the element to one location to other. Translation of a point (x,y) to a new position (x',y') is given by

$$x' = x + dx \text{ and } y' = y + dy$$

where,

x', y' = Co – ordinates after translation

x, y = Co – ordinates of the point before translation

dx, dy = Movement of the point in x and y direction respectively

In matrix form, translation is represented by

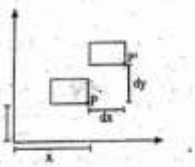
$$\begin{bmatrix}x'\\y'\end{bmatrix}=\begin{bmatrix}x\\y\end{bmatrix}+\begin{bmatrix}m\\n\end{bmatrix}$$

$$\Rightarrow[p']=[p]+[T]$$

where $[p']=\begin{bmatrix}x'\\y'\end{bmatrix}$

$$[p]=\begin{bmatrix}x\\y\end{bmatrix}$$

$$[T]=\begin{bmatrix}dx\\dy\end{bmatrix}=\text{Translation matrix}$$



3.11.2 Rotation

In such type of transformation, the co-ordinate points associated with the geometry are rotated about a point (origin) in two dimensional x - y plane. Rotation of the point takes place around z - axis.

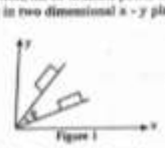


Figure 1

Consider a point 'p' attached to the axis OAB as shown in figure 1. At this stage the co-ordinates of the points w.r.t x and y axis be P_x and P_y.

$$\therefore P=\begin{bmatrix}P_x\\P_y\end{bmatrix}$$

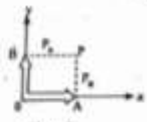


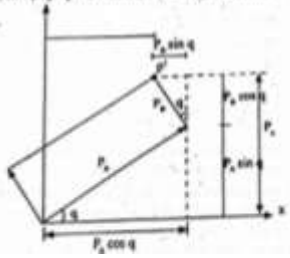
Figure 2

Original point before rotation

$P_A = P_x$

$P_B = P_y$

Let the point 'P' rotates around z -axis angle 'q' such that the axis system OAB attached to the point 'P' also rotates by 'q' in counter clock wise direction.



3.13 Concatenation of transformations

The previous single transformations can be combined as a sequence of transformations. This is called concatenation, and the combined transformations are called concatenated transformations. The objective of concatenation is to accomplish a series transformations to achieve a single transformation.

Example:

Rotation of the element about an arbitrary point in the element

The sequence of transformations would be:

- Translation to the origin,
- Then rotation about the origin,
- Then translation back to the original location.

Magnifying the element but maintaining the location of one of its points in the same location.

The sequence of transformations would be:

- The element would be scaled (magnified)
- Translation to locate the desired point.

8. Determine the position of the point (3,1) after scaling by a factor of 2 and rotated by 45°.

$$\begin{bmatrix}x'\\y'\end{bmatrix}=\begin{bmatrix}S_x & 0\\0 & S_y\end{bmatrix}\begin{bmatrix}x\\y\end{bmatrix}$$

$$\begin{bmatrix}x'\\y'\end{bmatrix}=\begin{bmatrix}2 & 0\\0 & 2\end{bmatrix}\begin{bmatrix}3\\1\end{bmatrix}$$

$$\begin{bmatrix}x'\\y'\end{bmatrix}=\begin{bmatrix}6\\2\end{bmatrix}$$

Next, the rotation can be performed.

$$\begin{bmatrix}x''\\y''\end{bmatrix}=[R]\begin{bmatrix}x'\\y'\end{bmatrix}$$

$$\begin{bmatrix}x''\\y''\end{bmatrix}=\begin{bmatrix}\cos\theta & -\sin\theta\\\sin\theta & \cos\theta\end{bmatrix}\begin{bmatrix}x'\\y'\end{bmatrix}$$

$$\begin{bmatrix}x''\\y''\end{bmatrix}=\begin{bmatrix}\cos 45 & -\sin 45\\\sin 45 & \cos 45\end{bmatrix}\begin{bmatrix}6\\2\end{bmatrix}$$

$$\begin{bmatrix}x''\\y''\end{bmatrix}=\begin{bmatrix}0.7071 & -0.7071\\0.7071 & 0.7071\end{bmatrix}\begin{bmatrix}6\\2\end{bmatrix}$$

$$\begin{bmatrix}x''\\y''\end{bmatrix}=\begin{bmatrix}2.828\\5.657\end{bmatrix}$$

The same result can be accomplished by concatenating the two separate transformation matrices. The product of the two matrices would be

$$SR=\begin{bmatrix}S_x & 0\\0 & S_y\end{bmatrix}\begin{bmatrix}\cos\theta & -\sin\theta\\\sin\theta & \cos\theta\end{bmatrix}$$

$$SR=\begin{bmatrix}2 & 0\\0 & 2\end{bmatrix}\begin{bmatrix}0.7071 & -0.7071\\0.7071 & 0.7071\end{bmatrix}$$

$$=\begin{bmatrix}1.414 & -1.414\\1.414 & 1.414\end{bmatrix}$$

Now applying this concatenated transformation matrix to the original point, we have

$$\begin{bmatrix}x''\\y''\end{bmatrix}=[SR]\begin{bmatrix}x\\y\end{bmatrix}$$

$$\begin{bmatrix}x''\\y''\end{bmatrix}=\begin{bmatrix}1.414 & -1.414\\1.414 & 1.414\end{bmatrix}\begin{bmatrix}3\\1\end{bmatrix}$$

$$\begin{bmatrix}x''\\y''\end{bmatrix}=\begin{bmatrix}2.828\\5.657\end{bmatrix}$$

4.a

4.5 COMPUTER AIDED PROCESS PLANNING (CAPP)

Manual process planning, as discussed at the starting of this chapter, includes the creation of all paper work necessary to direct the flow of raw materials and parts through production and assembly. The process planner determines the sequence and machines that will transform the raw material into finished part. Process planning is challenging, since it involves selecting the best plan out of several possible ways for manufacturing a component.

Automating the task of manual process planning is called as computer Aided process planning. As the process planning is the link between the design and manufacturing, CAPP is the link between CAD and CAM. Now-a-days the shop trained people who are familiar with the details of machining and other process are gradually retiring and these people will be unavailable in future to do process planning. An alternative way of accomplishing this function is required and CAPP systems are providing this alternative.

Approaches to CAPP *(Dec 2012, June 2012)*

There are two basic approaches to Computer Aided Process Planning

1. Variant Computer Aided Process Planning (OR) Retrieval CAPP system.
2. Generative type Computer Aided Process Planning.

sheet".

4.7 GENERATIVE CAPP SYSTEM

Unlike Variant approach, the generative approach does not require assistance from the user to generate a process plan. It usually accepts geometrical and manufacturing data of the part , and utilizes computerized searches and decision logics to develop the part process plan automatically.

Generative process planning systems do not require (or) store predefined master process plans. Instead, the system automatically generates a unique plan for a part. The generalized system in Figure 4.5 illustrates the generative CAPP operation.

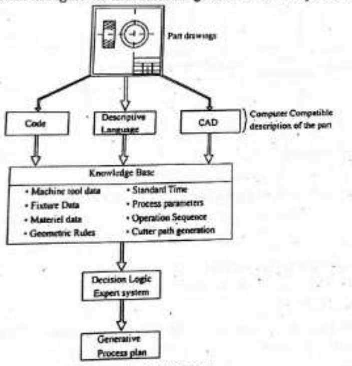


Fig. 4.5 Generative CAPP System

In generative CAPP system, the entire process is carried out without human assistance and the process of generating such process plan is termed to be a part of expert system.

To generate a process plan for a new component, the following procedure is used

- The part drawing is received from the design department
- The design specifications which are present in the part drawing is to be converted

(c) CAD

- In each technique, the complete design specification for the part is converted into a format compatible with the system.
- The technical knowledge of manufacturing and the logical data required for process planning is captured in the computer which is called as knowledge data base.
- The Generative CAPP system uses this knowledge data base to determine different operations to be performed on the part.
- Generative approach uses Decision Logic systems such as expert system to select proper data required to manufacture the given part from the knowledge data base and generates a process plan in the form of "Route sheet".

4.8 COMMERCIALLY AVAILABLE CAPP SOFTWARE'S

CAPP software's captures the knowledge and experience that has been developed on the shop floor, creates detailed process plans with accurate time standards and then communicates this information to material requirement planning (MRP) and Enterprise requirements planning (ERP) databases.

One of the commercially available retrieval CAPP system is "Multi CAPP" from Organization for Industrial Research (OIR). It is an online computer system that permits the user to create new plans(or) retrieve and edit existing process plans.

"METCAPP", developed by Institute of Advanced Manufacturing sciences in Cincinnati, Ohio, is one of the most successful Commercial CAPP software's used for machining operations. METCAPP uses cutting speeds and feeds from the industry standard machining data handbook, which makes accurate cut time and cost calculations possible. METCAPP uses solid part models to extract design features.

"GENPLAN", developed by Lockheed. Georgia co., is an example of generative type CAPP software.

4.9 BENEFITS OF CAPP

Some of the advantages of Computer Aided process planning include the following:

1. Process plans are Created rapidly and Consistently
2. Standard process plans are developed which tend to result in lower manufacturing costs and higher product quality.
3. The systematic approach and the availability of standard process plans in the data files permit more work to be accomplished by the process planners there by increasing the productivity of process planners.

4.b

4.11 MATERIAL REQUIREMENT PLANNING (MRP (OR) MRP - I)

For a manufacturing company to produce the parts to meet the demand, the availability of sufficient production capacity must be coordinated with the availability of raw materials and purchased items from which the end items are to be produced.

One approach to manage the availability of raw materials and purchased items is to keep a high stock of all the items that might be needed to produce the end items. However this approach is costly due to the excessive inventory of Components, fabricated parts and sub assemblies.

An alternative approach to manage this situation is to plan for procurement or manufacture of the specific components that will be required to produce the required quantities of end products as per the production schedule indicated by the Master Production Schedule (MPS). This technique is known as Material Requirement Planning (MRP)

Definition: *"MRP is a computer based information system for ordering and scheduling of raw materials and other components used to produce end products".*

MRP is a computer based system in which the given master production schedule is converted into the required amounts of raw materials, parts and sub – assemblies, needed to produce the end product in each time period.

4.15 INPUTS TO MRP SYSTEM

MRP must operate on the data contained in several files.

These files serves as input to MRP processors.

They are :

1. Master Production schedule (MPS).
2. Bill of Materials file (or) product structure file
3. Inventory status file.

4.15.1 Master Production Schedule (MPS)

- The MPS specifies what end products are to be produced and when.
- The production quantities of a major product line is converted into a specific schedule of individual products and is known as Master production schedule.
- MPS is based on the demand of products and the company production capacity.
- MPS is the key input which drives the MRP.
- The general format of MPS for a product line is shown in fig 4.8
- MPS uses weeks or months as time periods and these time periods are called as "Time buckets".

End Item	Week			
	1	2	3	4
Product, P_1	100	120	140	160
Product, P_2		80	90	100
Product, P_3		40		60

Fig 4.8 MPS of products P 1, P 2 and P 3 for one month (4 Weeks)

4.15.2. Bill of Materials file

- The MRP obtains information about the components needed to make an end product from Bill-of-Materials (BOM) file.
- BOM file is also called as product structure file.
- BOM file lists the raw materials and components for the end products listed in Master Production schedule.
- A Bill of material not only lists all the required parts but also is structured to reflect the sequence of steps required to produce the end product.
- The BOM has a series of levels, each of which represents a stage in the manufacture of the end product.
- The product structure for an assembled product is as shown in fig 6.9.

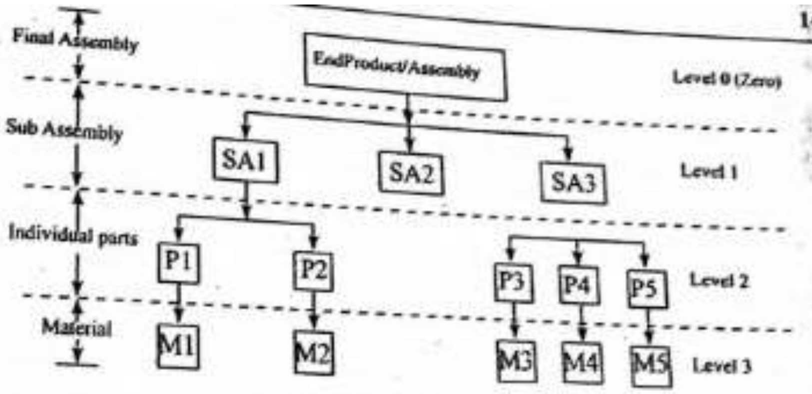


Fig. 4.9 (a) Product Structure Chart

Parts Number	Parts Name	Quantity	Description (Material Type, Dimensions, etc)	Cost

The highest level (or) Zero-Level of the B.O.M represents the final assembly or er product. The next lower level might represent the sub assemblies that are combined make the final assembly. The next lower level might represent the parts needed to ma the sub assemblies and the bottom most level might represent the raw materials fr which the parts are made.

4.15.3. Inventory status file

The inventory status file gives complete and up-to-date information on the on-h quantities, gross requirements, scheduled receipts and planned order releases for the i

It also includes other information such as lot sizes, Lead times, safety stock levels scrap allowances etc.

This file contains important information such as what items should be ordere when the orders should be released.

The inventory status file keeps the data about the projected use and receipts o item and determines the amount of inventory that will be available in each time bu

The inventory file must be kept upto date taking into consideration the daily inv transactions such as receipts, scrapped materials, Order releases and planned ord

If the projected available inventory is not sufficient to meet the requirement in a the MRP program will recommend that the item be ordered.

There will be three types of data in a Inventory status file.

(a) Item master data : This data provides the information about individual parts. This data includes Part Number, Manufacturing lead time, Quantity of parts.

(b) Inventory status : This gives a time phased record about the current inventory level as well as estimates any future changes to the inventory.

(c) Subsidiary data : This data provides the information about purchase orders, scrap(or) rejects, Engineering design changes and so on.

The MRP processor operates on the data contained in Master production Schedule, Bill-of-materials file and Inventory status file.

The MPS specifies period by period list of final product required.

The BOM file specifies what materials and components are needed for each part.

The Inventory status file specifies the data on current and future inventory status of each product, component and material.

4.16 OUTPUTS FROM MRP SYSTEM

The outputs provided by the MRP system are

1. Planned order release, which is a plan of the quantity of each material to be ordered in each time period.

   The order may be a purchase order which gives the authority to purchase raw materials (or) parts from outside vendors (or) Work orders which gives the authority to produce the parts in the factory.

2. Changes in the planned orders which represents the modification of previous planned orders.
3. Performance reports regarding how well the system is operating, Inventory turnovers, costs, raw material usage and so on.
4. Planning reports such as inventory forecasts, purchase commitment reports, etc.,
5. Cancellation reports

4.17 PROBLEMS IN USING MRP

1. Preparation of MPS must be realistic and must provide adequate lead time
2. Maintaining accurate BOM files.
3. Incorrect stock (Inventory) status.
4. Unrealistic lead times.
5. Improper and untimely information flow among various related departments.
6. Substantial education and training at all levels.
7. Continuous monitoring of progress against schedule.
8. The entire system is expensive

9. Bill of materials, product structure chart and inventory status files must be computerized.
10. MRP is suited only for dependent demand and not for independent demand.
11. MRP is best suited for assembly operations.

4.18 CAPACITY PLANNING

Definition: "Capacity planning is concerned in determining labour and equipment resources that are required to meet the current Master production schedule as well as long term future production needs of the firm".

Capacity planning helps to identify the limitations of the available production resources so that an unrealistic master schedule is not planned.

Capacity planning can be accomplished in two stages as represented in figure 4.18

1. When the master production schedule has been established.
2. When MRP computations are done.

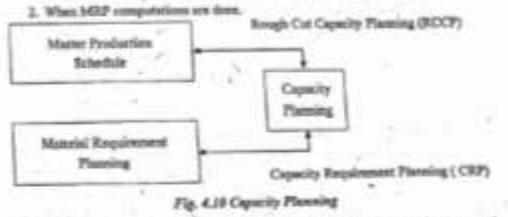


Fig. 4.18 Capacity Planning

Soon after the master production schedule has been established, a rough cut capacity planning is made to check the feasibility of MPS. After MRP computation has been performed, capacity calculations are made and is called as capacity requirement planning (CRP).

CRP determines whether there is sufficient production capacity in the individual departments and work cells to complete the specific parts and assemblies as scheduled by MRP.

If the schedule is not compatible, adjustments are made either in plant capacity or in master production schedule.

The different types of capacity adjustments made when the schedule is not compatible are divided into two types.

1. Short term adjustments.
2. Long term adjustments.

5.a

5.2 GROUP TECHNOLOGY

Group technology is a manufacturing philosophy which can be used to group parts based on the similarities in design or manufacturing process so as to reduce the overall manufacturing cost. Parts having similar characteristics in design (or) in manufacturing are grouped into part families.

Part family is the collection of parts that are similar either because of geometric size and shape or because of similar processing steps required to manufacture.

There are two types of part families

5.8 BENEFITS OF FMS

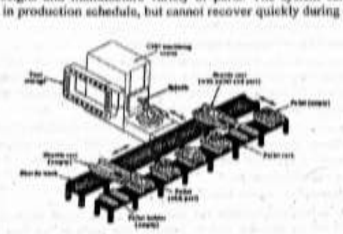
1. Increased machine utilization.

   Implementing FMS reduces setup time and tool handling time by employing automatic pallet changers at workstations and automatic tool changers at machines, thereby increasing machine utilization.

2. Greater response to changes.

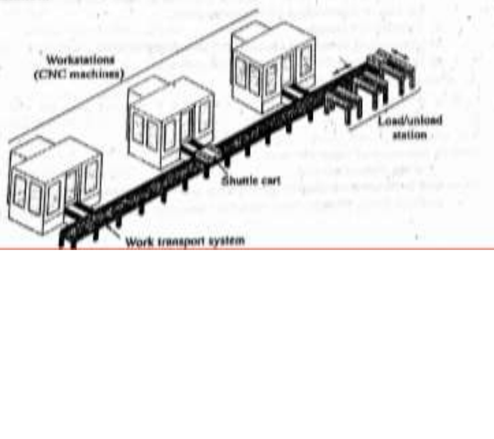
   FMS can quickly accommodate changes in part design, introduction of new parts, changes in production schedule, machine breakdowns and cutting tool failures.

the product changes, the entire batch has to be changed. During flexible mode, the machine will be able to produce components with various design features. The processing is sequential and not simultaneous. Such systems are capable accepting new product designs and manufacture variety of parts. The system can readily accept changes in production schedule, but cannot recover quickly during machine breakdown.



b. Flexible Manufacturing Cell (FMC)

It entails two or three processing workstations along with a material handling system with a limited parts storage capacity. The material handling system is linked to a load / unload station. It is a simultaneous production system. FMCs can recover during machine breakdowns and continue production as there are more than one workstation.



c. Flexible Manufacturing System (FMS)

It has four or more processing stations interconnected with material handling system and controlled by a distributed computer system. It also includes non-processing work stations that support production like pallet washing stations, co-ordinate measuring machines.

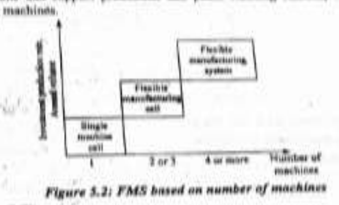


Figure 5.2: FMS based on number of machines

2. Level of Flexibility

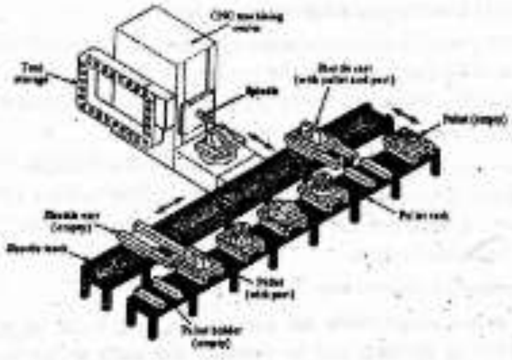
a. Dedicated FMS

It produces a limited variety of parts. The design of the all the parts to be manufactured will be similar. Specialized process can be used to make the operations more efficient as the design is known in advance and hence it is also referred as special manufacturing system. The machines are designed for the specific process thus increasing the productivity. Transfer lines are used when the sequence of processing is identical for all parts processed.

b. Random order FMS

Random order FMS is able to handle large part families and substantial variations in part configurations. New part designs can be introduced into such system. Random order FMS allows changes in the production schedule. Random order FMS is more flexible compared to dedicated FMS but will a low production rates due to large part variations and changes in the sequence of the process. General purpose machines are used to deal with the variations in product and is capable of processing parts in various sequences (random-order). A more sophisticated computer control system is required for this FMS type.

the product changes, the entire batch has to be changed. During flexible mode, the machine will be able to produce components with various design features. The processing is sequential and not simultaneous. Such systems are capable accepting new product designs and manufacture variety of parts. The system can readily accept changes in production schedule, but cannot recover quickly during machine breakdown.



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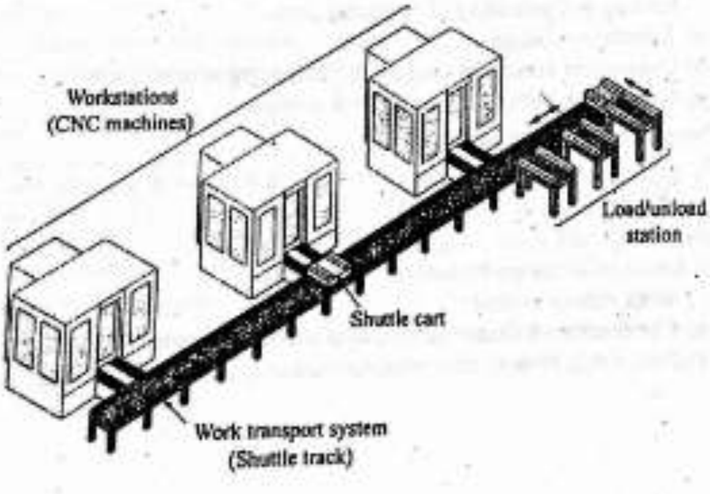
It entails two or three processing workstations along with a material handling system with a limited parts storage capacity. The material handling system is linked to a load / unload station. It is a simultaneous production system. FMCs can recover during machine breakdowns and continue production as there are more than one workstation.



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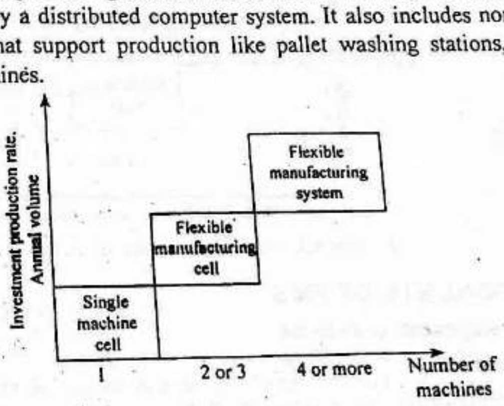


5.b

5.11 AUTOMATED STORAGE AND RETRIEVAL SYSTEMS (AS/RS)

The function of a material storage system is to store materials for a period of time and to permit access to those materials when required. Different categories of materials require different storage methods and controls. Many production plants use manual methods for storing and retrieving items. Automated methods are available to improve the efficiency of the storage function. Many conventional storage systems are available such as rack systems, shelves, and bins, bulk storage and draw storage. These storage equipment requires a human worker to access the items in storage. The storage system itself is static. Mechanized and automated storage systems are used to reduce or eliminate the amount of human intervention required to operate the system.

"An automated storage and retrieval system (AS/RS) can be defined as a storage system that performs storage and retrieval operations with speed and accuracy under a defined degree of automation."

5.11.1 Advantages of AS/RS

- Increases storage capacity
- Reduce factory floor space used for storing
- Improves security and reduce pilferage
- Reduce labor cost
- Increase labor productivity in storage function
- Improve safety in the storage function
- Improved control over inventories

5.11.2 AS/RS COMPONENTS AND TERMINOLOGY

An AS/RS consists of one or more storage aisles (passages) that are serviced by a storage/retrieval (S/R) machine. The materials are held in storage racks of aisles. The S/R machines are used to deliver and retrieve materials in and out of inventory. There are one or more input/output stations in each AS/RS aisle for delivering the material into the storage system or moving it out of the system. In AS/RS terminology, the input/output stations are called pickup-and-deposit (P&D) stations.

5.11.3 Types of AS/RS Systems

Several important categories of AS/RS can be distinguished based on certain features and applications. The following are the principle types:

Unit Load AS/RS

The unit load AS/RS is used to store and retrieve the loads that are palletized or stored in standard-sized containers. The system is computer controlled. The S/R machines are automated and designed to handle the unit load containers by employing mechanical clamps, vacuum cups or a magnet-based mechanisms.

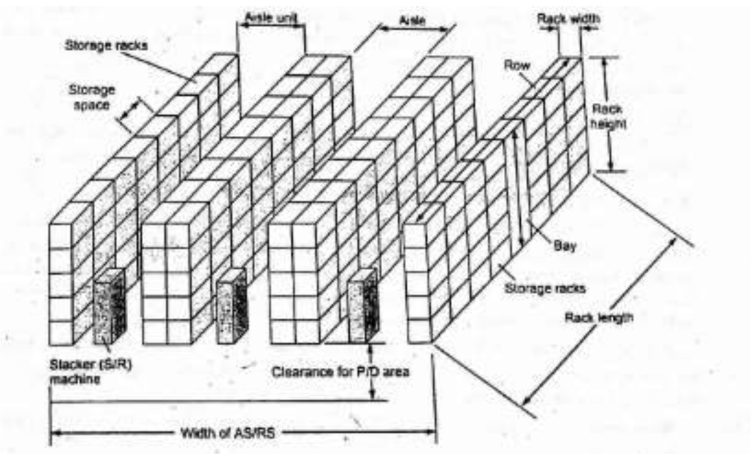


Figure 5.4. Structure of AS/RS systems.

Mini Load AS/RS

This system is designed to handle small loads such as individual parts, tools and supplies that are contained in bins or drawers in the storage system. Such a system is applicable where the availability of space is limited and volume is low. A mini load AS/RS is generally smaller than a unit load AS/RS.

Deep-lane AS/RS

This is a high-density unit load storage system that is appropriate for storing large quantities of stock. The items are stored in multi deep storage with up to 10 items in a single rack, one load behind the next.

Man-on-board AS/RS

In this system, human operator rides on the carriage of the S/R machine to pick up individual items from a bin or drawer. The system permits individual items to be picked directly at their storage locations. The operator can select the items and place them in a module. It is then carried by the S/R machine to the end of the aisle or to a conveyor to reach its destination.

6.a

$\therefore T_p = \frac{1}{R_p} = \frac{1}{1} = 1$ min/unit

$E = 95\% = 0.95$

$T_r = 3\text{sec} = \frac{3}{60} = 0.05$ min

W.T.T, $E \Rightarrow \frac{T_c}{T_p} = T_c = T_p \times E$

$\therefore T_c = 1 \times 0.95 = 0.95$ min

Processing time,

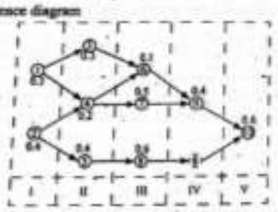
$T_s = T_c - T_r$

$T_s = 0.95 - 0.05$

$T_s = 0.9$min

Killbridge and Westers Method

Step1: Precedence diagram



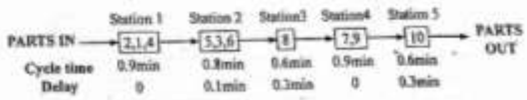
Step 2: List out the elements along column wise and according to the element times in the particular column.

Work element	Column	T_e (min)	Preceded by
2	I	0.4	-
1	I	0.3	-
5	II	0.4	2
3	II	0.3	1
4	II	0.2	1,2
8	III, IV	0.6	5
7	III	0.5	4
6	III	0.1	3,4
9	IV	0.4	6,7
10	V	0.6	8,10

Steps 3: Work elements assigned to the stations according to killbridge and western method

Workelement	Column	T_e	Precedence	Station	Total Station time
2	I	0.4	-	1	0.9
1	I	0.3	-		
4	II	0.2	1,2		
5	II	0.4	2	2	0.8
3	II	0.3	1		
6	II	0.1	3,4		
8	III, IV	0.6	5	3	0.6
7	III	0.5	4	4	0.9
9	IV	0.4	6,7		
10	V	0.6	8,10	5	0.6

Step 4: Computing Balance efficiency and balance delay



Balance Delay

$$D_b = \frac{nT_s - T_{wc}}{nT_s}$$

$n = 5$ (from Kilbridge and Westers method).

$$\therefore D_b = \frac{5 \times 0.9 - 3.8}{5 \times 0.9} = 0.1555 \approx 15.55\%$$

Balance efficiency

$E = 1 - D_b$

$E_b = 1 - 0.1555$

$E_b = 0.8444 \therefore 84.44\%$

6.b

$\therefore\ T_p = \frac{1}{R_p} = \frac{1}{1} = 1\text{min/unit}$

$E = 95\% = 0.95$

$T_r = 3\text{sec} = \frac{3}{60} = 0.05\text{min}$

W.T.T, $E \Rightarrow \frac{T_c}{T_p} = T_c = T_p \times E$

$\therefore T_c = 1 \times 0.95 = 0.95\text{min}$

Processing time,

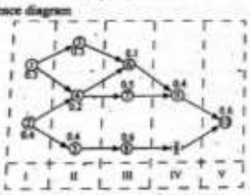
$T_s = T_c - T_r$

$T_s = 0.95 - 0.05$

$T_s = 0.9\text{min}$

Kilbridge and Westers Method

Step1: Precedence diagram



Step 2: List out the elements along column wise and according to the element times in the particular column.

Work element	Column	T_e (min)	Preceded by
2	I	0.4	-
1	I	0.3	-
5	II	0.4	2
3	II	0.3	1
4	II	0.2	1,2
8	III, IV	0.6	5
7	III	0.5	4
6	III	0.1	3,4
9	IV	0.4	6,7
10	V	0.6	8,10

Steps 3: Work elements assigned to the stations according to kilbridge and western method

Workelement	Column	T_e	Precedence	Station	Total Station time
2 1 4	I I II	0.4 0.3 0.2	- - 1,2	1	0.9
5 3 6	II II II	0.4 0.3 0.1	2 1 3,4	2	0.8
8	III, IV	0.6	5	3	0.6
7 9	III IV	0.5 0.4	4 6,7	4	0.9
10	V	0.6	8,10	5	0.6

Step 4: Computing Balance efficiency and balance delay

	Station 1	Station 2	Station3	Station4	Station 5	
PARTS IN →	2,1,4	5,3,6	8	7,9	10	→ PARTS OUT
Cycle time	0.9min	0.8min	0.6min	0.9min	0.6min	
Delay	0	0.1min	0.3min	0	0.3min	

Balance Delay

$$D_b = \frac{nT_s - T_{wc}}{nT_s}$$

$n = 5$ (from Kilbridge and Westers method).

$$\therefore\ D_b = \frac{5\times0.9 - 3.8}{5\times0.9} = 0.1555 \approx 15.55\%$$

Balance efficiency

$E = 1 - D_b$

$E_b = 1 - 0.1555$

$E_b = 0.8444\ \therefore\ 84.44\%$

Activate
Go to Setti

7.a

... can be eliminated by automatic gauging system.

7.9 ADVANTAGES OF CNC MACHINES *(DEC 2012, DEC 2010)*

Some of the advantages of CNC machine tools are briefly discussed below.

(1)Setup time reduction

In many cases, the setup time for a CNC machine can be reduced. It is important to realize that setup is a manual operation, greatly dependent on the performance of CNC operator, the type of fixturing and general practices of the machine shop. The design of CNC machines consists of modular fixturing, standard tooling, fixed locators, automatic tool changers, pallets and other advanced features which makes the setup time more efficient than a comparable setup of a conventional machine.

(2)Reduced lead time

The time required to manufacture a component on the CNC machine is very less compared to other conventional machines.

(3)Accuracy and repeatability

The high degree of accuracy and repeatability of modern CNC machines has been the single major benefit to many users. This particular factors allows high quality of parts to be produced consistently time after time.

(4)Longer tool life :

Tools can be used at optimum speeds and feeds because these functions are controlled by the part program. Programmed speeds and feeds can be overridden by the operator if difficulty in manufacturing is encountered.

(5)Elimination of special jigs and fixtures :

Standard locating fixtures are often not used on CNC machines, and cost of special Jigs and fixtures is frequently eliminated. The capital cost of jig storage facilities is also reduced.

(6)Flexibility in changes of component design :

The modification (or) changes in component design can be readily accommodated by reprogramming and altering the concerned instructions.

7.10 DISADVANTAGES OF CNC MACHINES *(DEC 2012, DEC 2010)*

As with every system, the CNC system too have certain disadvantages which are given below.

1. Higher investment cost.
2. Higher maintenance cost.
3. Requires highly skilled CNC personnel.
4. Tools on CNC machines do not cut metal faster than conventional machines.
5. CNC machines does not eliminate the need for expensive tools.

However, the advantages of CNC systems outweigh the disadvantages considerably and the CNC machines have been widely accepted by the industry.

... MACHINING CENTERS

7.b

```
N010 G21    G98
N020 G28    U0     W0
N030 M06    T0404
N040 G97    G98    M03   S1200
N050 G00    X21    Z2
(Box turning cycle)
N060 G90    X20    Z-10  F60
N070 X19
N080 X18
N090 X17
N100 X16
N110 X15
N120 X14
N130 X13
N140 X12
N150 X11
N160 X10
N170 G00    X21    Z-10
N180 G90    X20    Z-20
N190 X19
N200 X18
N210 X17
N220 X16
N230 X14
N240 G00    X21    Z-20
```

8.a

8.5 ROBOT JOINTS

The members of a Robotic manipulator are called as Links. The Links are connected together by joints. The relative motion between the links are mainly due to joints.

Depending on the relative motion between the two adj accent Links, Joints are classified into four types :

1. Prismatic joints 2. Rotational joints
3. Twist joints 4. Revolute joints

1. Prismatic joints : If the relative motion between two links of a joint is linear then that particular type of joint is called as Prismatic joint. Here two links are joined such that they can slide with respect each other. There are two types of prismatic joints

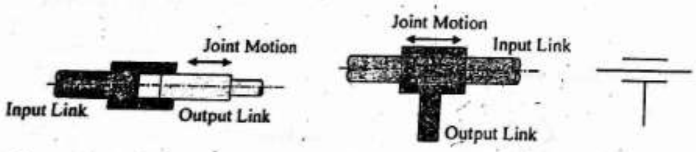
(a) Linear joints

(b) Orthogonal joints.

Linear type prismatic joints are denoted by 'L.

Orthogonal type prismatic joints are denoted by 'O'.

A schematic representation of linear and orthogonal type prismatic joints is show in in the figure 8.3.

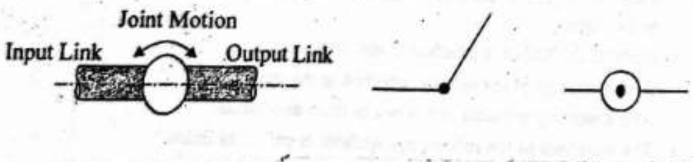


Linear typePrismatic joint **Orthogonal type prismatic joint**

Fig. 8.3 Prismatic joints.

2. Rotational joint : If the relative motion between two links of a joint is rotary then the joint is called as a Rotational joint.

Rotational joints are denoted by " R".

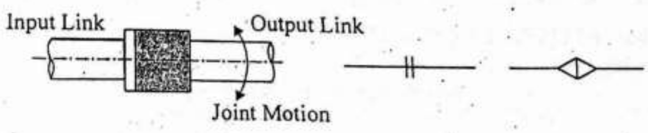


Symbolic representation

Fig. 8.4 shows a rotational joint along with its symbolic representation.

3. Twist joint : If the two links are in a straight line and if there is a twisting motion between the two links, then the joint is called as Twist joint.

Twist joints are indicated by Letter ' T'

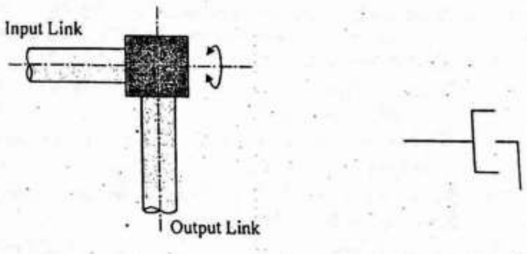


Symbolic representation

Fig 8.5 shows a Twist joint along with its symbolic representation

4. Revolute joint : If the two links are perpendicular to each other and if one link revolves around another link, then the joint is called as "Revolute joint".

Revolute joints are indicated by "V".



Revolute joint **Symbolic Representation**

Fig. 8.6 shows a Revolute joint along with its symbolic representation

8.b

8.7 ROBOT CONFIGURATION *(DEC 2012, JUNE 2012)*

Robot configuration specifies the possible movements provided by different robots. The majority of present commercially available robots possess one of these four basic configurations.

1. Polar Configuration.
2. Cylindrical Configuration.
3. Cartesian co-ordinate configuration.
4. Jointed arm Configuration.

8.7.1. Polar Configuration (T-R-L Configuration):

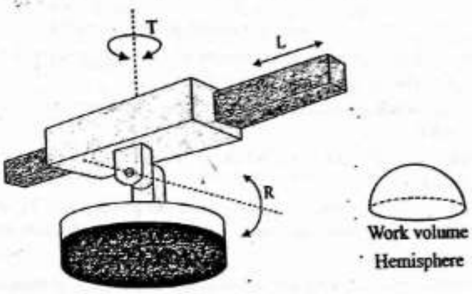


Fig 8.7 Polar co-ordinate configuration

- Polar configuration uses a telescopic arm that can be raised or lowered about a horizontal joint.
- This robot consists of one Linear prismatic joint (L), a Rotational joint (R) and a Twist joint (T), and hence is also called as T-R-L configuration.
- These joints provide the robot with the capacity to move its arm in a spherical space and hence this robot is sometimes called as spherical co-ordinate robot.
- The workspace within which the polar configuration robot moves its arm will be spherical in shape.
- Most of the commercially available robots possess polar configuration
- **Example:** UNIMATE 2000 Series, MAKER 110.

8.7.2. Cylindrical Co-ordinate Configuration (T-L-O Configuration)

[illegible]

8.7.3. Cartesian co-ordinate Configuration (L-O-O Configuration)

[illegible]

8.7.4. Jointed Arm Configuration (T-R-R Configuration)

[illegible]

9.a

MANUFACTURING

Additive manufacturing has been deemed as one of the most promising technology attracting many industrial applications. Additive manufacturing has a very high potential for directly shaping of complex parts from 3D computer-aided design (CAD) database or 3D scanning system database. Additive manufacturing make a part by depositing the materials layer by layer instead of removing unwanted as in conventional manufacturing. Today additive manufacturing processes have been developed for producing all kinds of parts with different materials

Definition: As per International committee F42 for Additive Manufacturing Technologies, ASTM, "*Additive Manufacturing (AM) refers to a process by which digital 3D design data is used to build up a component in layers by depositing material.*

Advantages

1. One key benefit of using AM is the ability to easily fabricate complex shapes.
2. Additive manufacturing also offers the freedom to design partsand innovate.
3. Another important benefit is the ability to fabricate parts without expensive tooling or long lead times.
4. Cost savings are associated with less production labour, material waste and energy consumption, as well as increased on-demand manufacturing.
5. Because only the material that is needed is used, there is very little (if any) material wasted.
6. A relatively small amount of electricity is required to produce parts especially when compared to more traditional manufacturing thus supporting green manufacturing.
7. This technology is particularly advantageous in low-to-moderate volume markets
8. Elimination of production steps: Even complexobjects will be manufactured in one process step
9. AM enables weight reduction viatopological optimization
10. Potential elimination of tooling: Direct production possible without costly and time-consuming tooling

Disadvantages

1. Slow build rates: Many printers lay down material at a speed of one to five cubic inches per hour
2. Extensive knowledge of material design and the additive manufacturing machine itself is required to make quality parts.
3. The surface finish and dimensional accuracy is low compared to other manufacturing methods.
4. Discontinuous production process: Parts can only be printed one at a time.
5. Limited component size/small build volume
6. Poor mechanical properties: Layering and multiple interfaces can cause defects in the product.

9.b

9.6.1. Photo polymerization

Photo polymerization process is also called as Stereolithography (SLA) process which is widely recognized as the first 3D printing process and was first commercialized. It works based on the principle that photo polymer resins when react with UV or laser light, cures to form a solid part. A photo polymer resin is a light activated resin that changes its properties when exposed to light.

Photo polymerization uses liquid photopolymer resin, out of which the model is constructed layer by layer.An ultraviolet (UV) light is used to cure or harden the resin where required, whilst a platform moves the object being made downwards after each new layer is cured.As the process uses liquid to form objects, there is no structural support from the material during the build phase. In this case, support structures will often need to be added. During the process, UV light is directed across the surface of the resin with the use of motor controlled mirrors. When the resin comes in contact with the light, it cures or hardens.Figure 9.7 clearly demonstrates photo polymerization process.

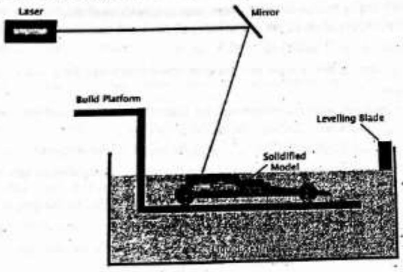


Fig 9.7. Photo Polymerization Process

Process Steps

1. The photopolymer resin is held in a vat (a large container) with a movable platform.
2. UV light (or) laser beam is directed across the surface of the resin. The light source can be moved in x and y axis according to the 3D data supplied to the machine.
3. Upon interaction of the light beam with the resin, the resin hardens precisely where the laser hits the surface.
4. Once the layer is completed, the platform lowers down in z - axis, by a distance equal to layer thickness and the subsequent layer is traced out by the laser.
5. The process continues until the entire object is completed.
6. The build platform is raised and the object is removed for subsequent post processing.

The process is generally accepted as being one of the most accurate 3D printing process with excellent surface finish.

Advantages

1. High level of accuracy and good finish
2. Relatively quick process
3. Large build areas and large model weights can be accommodated.

Disadvantages

1. Relatively expensive
2. Post processing requires more time
3. Requires support structures
4. Post curing of parts is required.

9.6.2 Material jetting process

Material jetting creates objects similar to a two dimensional ink jet printer. Material jetting machines utilize inkjet print heads to dispense melted photopolymers over a specific area. Material is deposited from a nozzle which moves horizontally (X-Y axis) across the platform. The print head then cures (solidifies) the photopolymer via a UV light. After a layer has been deposited and cured the build platform drops down by one layer thickness and the process is repeated to build up a 3D part.

Different materials can be used in the process and the material can be changed during the build stage. Material is jetted on the platform in the form of droplets, which are directed on the surface using deflection plates. The system allows a high level of droplet control and positioning. Droplets which are not used are recycled back into the printing system.

Polymers and waxes are commonly used materials, due to their viscous nature and ability to form drops. The process is demonstrated in figure 9.8

Process Steps

1. The print head is positioned above build platform.
2. Droplets of material are deposited from the print head on the surface.
3. Droplets of material solidify and make up the first layer.
4. On further material deposition, layers are built up on top of the previous layers.
5. Layers are allowed to cool and are cured by passing UV light
6. Post processing involves removal of support material can be removed using sodium hydroxide solution or water jet.

Advantages:

1. Low wastage of material
2. High accuracy of deposition of droplets
3. The process allows multiple materials and colors under one process

Disadvantages:

1. Support material is often required
2. A high accuracy can be achieved but materials are limited to polymers, plastics and waxes.
3. Parts produced have poor mechanical properties and are typically very brittle
4. Material jetting is one of the most expensive methods of 3D printing relative to the other technologies. This is due to the high cost of the material

10 .a

9.4.1. Slicing of 3D models

One of the key challenges in additive manufacturing processes is to slice 3D CAD models. Many software's are available for slicing the 3D CAD models. During slicing, software algorithms converts digital 3D models into printing instructions for AM system to create an object. During the process of slicing, 3D model is cut into horizontal layers based on the thickness of each layer and calculates how much material is required to build the product and the time to build the product. All of this information is then bundled up into a G-Code file. Slicer parameters such as layer height, shell thickness, fill density, print speed do impact the quality of the product.

Fig 9.4. Slicing of 3D model

10 .b

9.6.6 Sheet lamination

Sheet lamination is a process in which solid physical model is made by stacking layers of sheet. The sheet is supplied from the spool as shown in Figure 9.12. The AM machine consists of sheets supplied from material spool, a build platform and cutting mechanism. The sheets are bonded either by an adhesives or by welding in case of metals.Based on the type of build material, sheet lamination process has two variants, Laminated Object Manufacturing (LOM) and Ultrasonic Additive Manufacturing (UAM)

Laminated object manufacturing (LOM) is the first additive manufacturing technique and uses paper as material and adhesive. Laminated objects are often used for aesthetic and visual models and are not suitable for structural use. The process is inexpensive, as well as a relatively simple when compared to UAM. The material is cross hatched by the cutting mechanism for easy extraction of part from the surrounding sheets.

The Ultrasonic Additive Manufacturing (UAM) process uses sheets of metal, which are bound together using ultrasonic welding instead of an adhesive. Build materials employed in UAM includes Aluminum, Copper, Stainless steel and Titanium. The process can bond different materials and requires relatively little energy, as the metal is not melted. The process does require additional CNC machining of the unbound metal. Unlike LOM, the metal cannot be easily removed by hand and unwanted material must be removed by machining.LOM process employs two different types of procedures (a) bond-then-form, (b) form-then-bond. In the former, the laminates are bonded together and then cut and in the later the stacked laminates are cut and then bonded together.The process of sheet lamination using LOM is shown in Figure 9.12

Process Steps

1. During the process, the sheet along with adhesive is positioned in place on the build platform.
2. Laser is employed to cut the required shape from the sheet to from a first layer of the product.
3. On further rotation of the spool, second layer of material is positioned on the top of the first layer.
4. The material is bonded in place, over the previous layer, using the adhesive and heated roller.
5. The required shape is then cut from the layer, by laser.
6. The next layer is added and the process continues until the required thickness is obtained.
7. The build is removed and post processing is carried out to extractthe part from the surrounding sheet material.

Advantages:

1. The process is faster and economical.
2. Strength of the arts depends on the type of bonding between the sheet laminates.
3. The LOM process does not induce residual stresses in the finished product

Disadvantages:

1. Finishes can vary depending on paper or plastic material but may require post processing to achieve desired effect
2. Limited material use
3. Bonding of sheet laminates require further research.

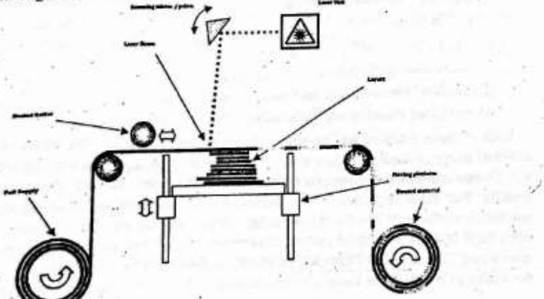


Fig 9.12. Sheet lamination process - LOM

9.6.7 Directed energy deposition (DED)

Directed energy deposition (DED) processes enable the creation of parts by melting material as it is being deposited. Although this basic approach can work for polymers, ceramics, and metal matrix composites, it is predominantly used for metal powders. Thus, this technology is often referred to as "metal deposition" technology. The process is widely used for repair and maintain structural parts rather than fabrication of the components. The DED process depositsmolten metal powders or thin metal wires on the components. The energy is focused into a narrow region of the components (a beam) to heat the metal that is being deposited. Laser or electron beam or plasma arc is used as energy source.

Many variants of DED process are available based on the type of energy used, type of filler material; type of motion. The variants include Laser Engineered Net Shaping (LENS), Directed Light Fabrication (DLF), Direct Metal Deposition (DMD), 3D laser cladding, Laser based metal deposition (LBMD) and Laser free forming (LFF).

DED equipment consists of a deposition head which is an integration of energy source, powder nozzle or wire feeding mechanism, inert gas tubing and in some cases, sensors. The deposition is controlled by the relative movement between the deposition head and the build platform. 3- 4- or 5- axis systems are used to control the movement. The working principle of DED process is shown in figure 9.13. DED process is widely used for repairing and maintaining structural parts. During the process the energy source (Laser or Electron beam) generates a small metal pool on which the powder is injected. The powder is melted as it inters the pool and solidifies as the beam moves away. In certain situations the powder is melted before deposition. Rapid cooling takes place due to small molten pool (typically 0.25 – 1mm in diameter and 0.1 to 0.5 mm in depth) and large thermal gradients from the surroundings. After each layer is formed the deposition head moves away from the platform or the component by one layer thickness.

Process Steps

1. Deposition head is mounted on the 4 or 5 axis arm moves around the fixed object.
2. Material is deposited from the nozzle onto existing surfaces of the object.
3. Material is either provided in wire or powder form.
4. Material is melted using a laser, electron beam or plasma arc upon deposition.
5. Further material is added layer by layer as it solidifies, repairing or creating new material features on the existing object.

Advantages

1. The process is capable of producing denser parts.
2. The process allows directional solidification which enhances microstructural features of the components.
3. DED process is utilized effectively for repairing and refurbishing components like turbine blades, crank shaft, bearings.