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DEPARTMENT OF MECHANICAL ENGINEERING

LECTURE NOTES

COMPUTER INTEGRATED MANUFACTURING
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VI Semester
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COURSE COORDINATOR

Dr. K. M. SATHISH KUMAR
Professor and Head

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Chapter 1

Introduction to CIM and Automation

Computer Integrated Manufacturing (CIM) encompasses the entire range of product development and manufacturing activities with all the functions being carried out with the help of dedicated software packages. The data required for various functions are passed from one application software to another in a seamless manner. For example, the product data is created during design. This data has to be transferred from the modeling software to manufacturing software without any loss of data. CIM uses a common database wherever feasible and communication technologies to integrate design, manufacturing and associated business functions that combine the automated segments of a factory or a manufacturing facility. CIM reduces the human component of manufacturing and thereby relieves the process of its slow, expensive and error-prone component. CIM stands for a holistic and methodological approach to the activities of the manufacturing enterprise in order to achieve vast improvement in its performance.

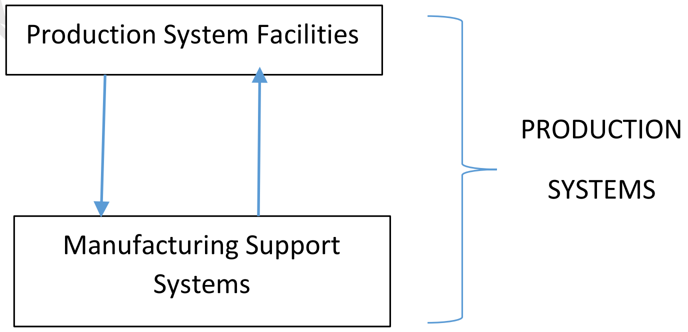
Automation is a dynamic technology that represents a continuous evolutionary process. It is the process of reducing the human labour by an automated machines.

Automation is a technology concerned with the application of Mechanical, Electrical, Electronic, Computer, Hydraulic and Pneumatic based system to operate and control production.

Production systems: A production system is a collection of People, Equipment and Procedures organised to perform the manufacturing operations of a company.

It is divided into the following 2 categories:

1. Production system facilities
2. Manufacturing support systems



The facilities of the production system consists of the factory, the equipment in the factory and the way the equipment is organized.

The manufacturing support system is the set of procedures used by the company to manage production and to solve the technical & logistics problems encountered in the process.

Production System Facilities:

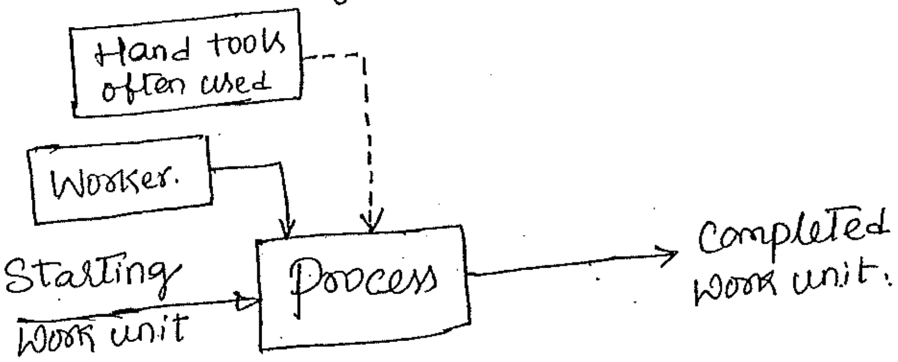
The facilities in the production system are the factory, production machines and tooling, material handling equipment, inspection equipment and computer systems that control the manufacturing operations. Facilities also include the plant Layout, which refers to the way the equipment is physically arranged in the factory.

The equipment is usually organized into logical groupings and these equipment arrangements and the workers who operate them are referred as Manufacturing Systems in the factory. The manufacturing systems come in direct physical contact with the parts. They 'touch the product'.

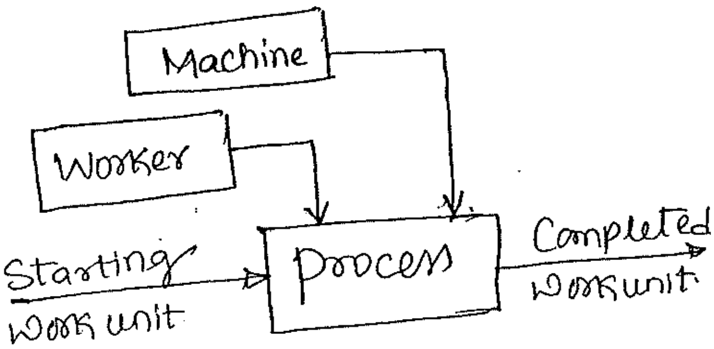
In Terms of the human participation in the processes performed by the manufacturing systems, three basic categories can be distinguished :

i) Manual Work Systems.
ii) Worker - Machine Systems.
iii) Automated Systems.

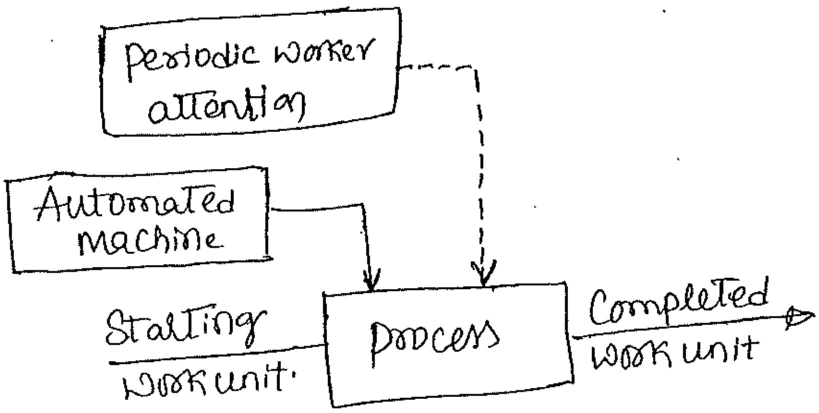
] Classification Based on the Human participation in the facility.



i) Manual work system.



ii) Worker - Machine system



iii) Automated System.

A manual work system consists of one or more workers performing one or more tasks without the aid of powered tools. Material handling is performed manually. production Tasks require the use of hand tools.

Examples include

* A machinist using a file to round the edges of rectangular part.
* A quality control inspector using a micrometer for measurement purposes.
* A material handling worker moving the parts.
* A team of workers doing the assembly.

In a worker-machine system, a human worker operates powered equipment like machine tools. This is the commonly used manufacturing systems. worker-machine systems include combinations of one or more workers and one or more equipments.

Examples include:

* A Machinist operating a Lathe.
* A fitter and robot working together in a work-cell.
* A crew of members operating the machines.

An automated ~~machine~~ system is one in which a process is performed by a machine without the direct participation of a human worker. Automation is implemented using a program of instructions. Power is required to drive the process and to operate the program and to control the system. Here, there will be a two levels of automation : Semi-automated and Fully automated. A Semi-automated machine performs a portion of the work cycle under some form of program control and human worker attends to the machine for the remainder of the cycle for loading/unloading operations. A fully automated machine has the capacity to operate for extended periods of time with no human attention.

(2)

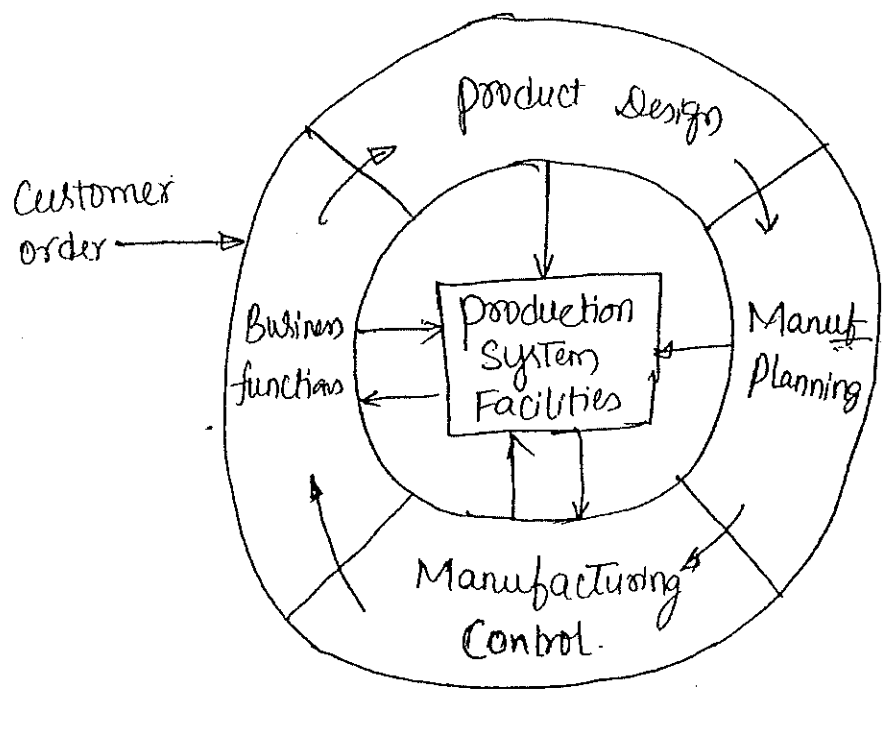
PTO →

Manufacturing Support Systems: This is the set of procedures used by the company to manage production and to solve the technical & logistics problems encountered. This system mainly involves design of process and equipment, plan & control the prodn orders and satisfying product quality requirement. These functions are accomplished by manufacturing support systems. These support systems do not directly contact the product, but they plan & control its progress through the factory.

This involves a cycle of information processing activities. They include;

i) Business Functions iii) Manufacturing planning

ii) Product Design iv) Manufacturing control.



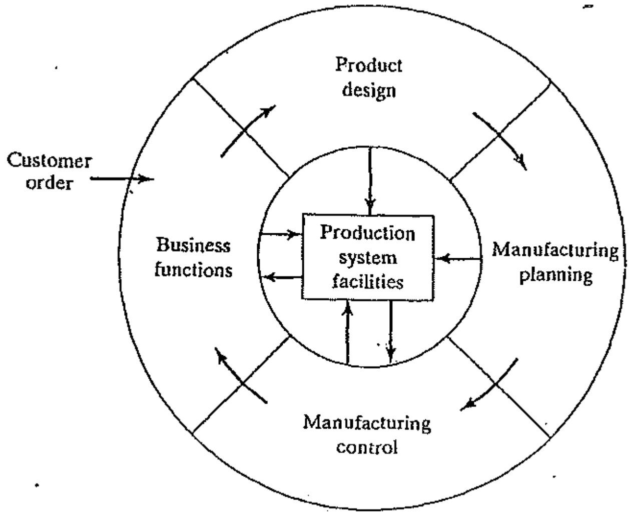


Figure 1.3 The information-processing cycle in a typical manufacturing firm.

Most of these support systems do not directly contact the product, but they plan and control its progress through the factory.

Manufacturing support involves a cycle of information-processing activities, as illustrated in Figure 1.3. The production system facilities described in Section 1.1.1 are pictured in the center of the figure. The information-processing cycle can be described as consisting of four functions: (1) business functions, (2) product design, (3) manufacturing planning, and (4) manufacturing control.

Business Functions. The business functions are the principal means of communicating with the customer. They are, therefore, the beginning and the end of the information-processing cycle. Included in this category are sales and marketing, sales forecasting, order entry, cost accounting, and customer billing.

The order to produce a product typically originates from the customer and proceeds into the company through the sales and marketing department of the firm. The production order will be in one of the following forms: (1) an order to manufacture an item to the customer's specifications, (2) a customer order to buy one or more of the manufacturer's proprietary products, or (3) an internal company order based on a forecast of future demand for a proprietary product.

Product Design. If the product is to be manufactured to customer design, the design will have been provided by the customer. The manufacturer's product design department will not be involved. If the product is to be produced to customer specifications, the manufacturer's product design department may be contracted to do the design work for the product as well as to manufacture it.

If the product is proprietary, the manufacturing firm is responsible for its development and design. The cycle of events that initiates a new product design often originates in the sales and marketing department; the information flow is indicated in Figure 1.3. The departments of the firm that are organized to accomplish product design might include research and development, design engineering, and perhaps a prototype shop.

Manufacturing Planning. The information and documentation that constitute the product design flows into the manufacturing planning function. The information-processing activities in manufacturing planning include process planning, master scheduling, requirements planning, and capacity planning.

Process planning consists of determining the sequence of individual processing and assembly operations needed to produce the part. The manufacturing engineering and industrial engineering departments are responsible for planning the processes and related technical details. Manufacturing planning includes logistics issues, commonly known as production planning. The authorization to produce the product must be translated into the master production schedule. The *master production schedule* is a listing of the products to be made, the dates on which they are to be delivered, and the quantities of each. Months are traditionally used to specify deliveries in the master schedule. Based on this schedule, the individual components and subassemblies that make up each product must be planned. Raw materials must be purchased or requisitioned from storage, purchased parts must be ordered from suppliers, and all of these items must be planned so that they are available when needed. This entire task is called *material requirements planning*. In addition, the master schedule must not list more quantities of products than the factory is capable of producing each month with its given number of machines and manpower. A function called *capacity planning* is concerned with planning the manpower and machine resources of the firm.

Manufacturing Control. Manufacturing control is concerned with managing and controlling the physical operations in the factory to implement the manufacturing plans. The flow of information is from planning to control as indicated in Figure 1.3. Information also flows back and forth between manufacturing control and the factory operations. Included in the manufacturing control function are shop floor control, inventory control, and quality control.

Shop floor control deals with the problem of monitoring the progress of the product as it is being processed, assembled, moved, and inspected in the factory. Shop floor control is concerned with inventory in the sense that the materials being processed in the factory are work-in-process inventory. Thus, shop floor control and inventory control overlap to some extent.

Inventory control attempts to strike a proper balance between the risk of too little inventory (with possible stock-outs of materials) and the carrying cost of too much inventory. It deals with such issues as deciding the right quantities of materials to order and when to reorder a given item when stock is low.

The function of *quality control* is to ensure that the quality of the product and its components meet the standards specified by the product designer. To accomplish its mission, quality control depends on inspection activities performed in the factory at various times during the manufacture of the product. Also, raw materials and component parts from outside sources are sometimes inspected when they are received, and final inspection and testing of the finished product is performed to ensure functional quality and appearance. Quality control also includes data collection and problem-solving approaches to address process problems related to quality. Examples of these approaches are statistical process control (SPC) and Six Sigma.

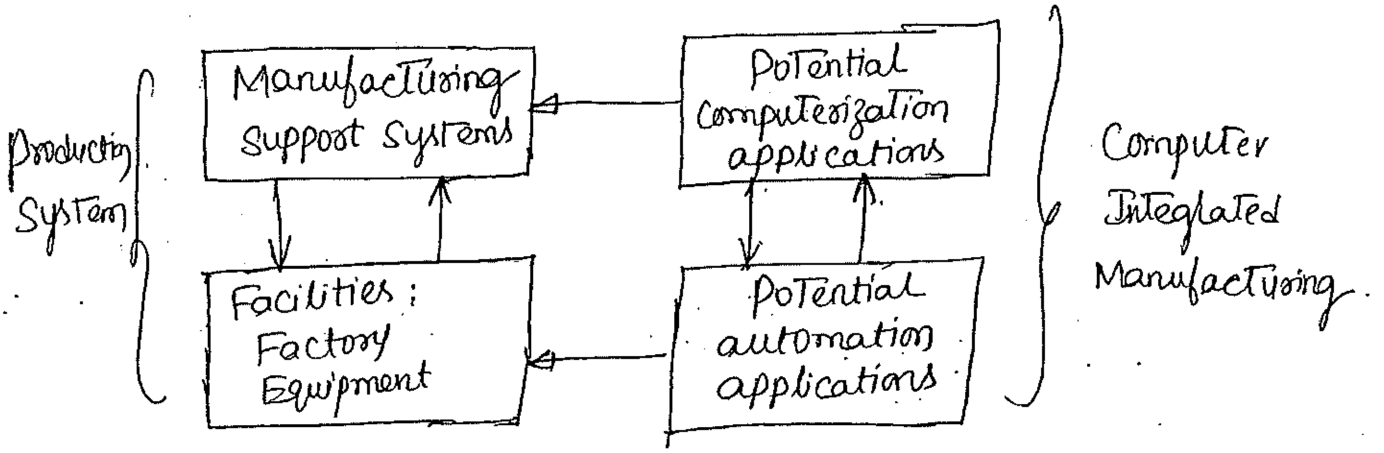
Automation in Production systems:

The Automated elements of the production system can be seperated into two categories:

i) Automation of the manufacturing systems in the factory

ii) Computerization of the manufacturing support systems.

These two categories are shown as below:



The Term computer Integrated manufacturing is used to indicate the Extensive use of computers in production systems.

Automated Manufacturing Systems:

Automated manufacturing systems operate in the factory on the physical product. They perform operations such as processing, assembly, inspection and material handling. They are called automated because they perform their operations with a reduced level of human participation. Examples of automated manufacturing systems include:

* Automated machine tools that process parts.
* Automated Flow lines that perform series of operations.
* Automated assembly systems.
* Automatic Material handling and Storage systems.
* Automatic inspection systems.

Automated manufacturing systems can be classified in to three basic types : [Types of Automation]

1) Fixed Automation
2) programmable Automation
3) Flexible Automation

Fixed Automation: Fixed Automation is a system in which the sequence of processing (or assembly) operations is fixed by the equipment configuration. Each operation in the sequence is usually simple. It is the integration and co-ordination of many such operations into one piece of equipment that makes the systems complex. Features of fixed automation includes:

* High initial investment for custom engineered equipments
* High production rates.
* Relative inflexibility of the equipment to accomodate product variety.

The economic justification for fixed automation is found in products that are produced in very large quantities and high production rates. Examples includes Transferlines and automated assembly machines.

Programmable Automation ; In programmable automation, the production equipment is designed with the capability to change the sequence of operations to accomodate diffelent product configurations. The operation sequence is controlled by a program, which is a set of instructions. New programs can be prepared and entered in to the equipment to produce new products.

Some of the features are:

* High investment in general purpose equipment
* Lower production rates than fixed automation
* Flexibility to deal with variations and changes in product configuration
* High suitability for batch production.

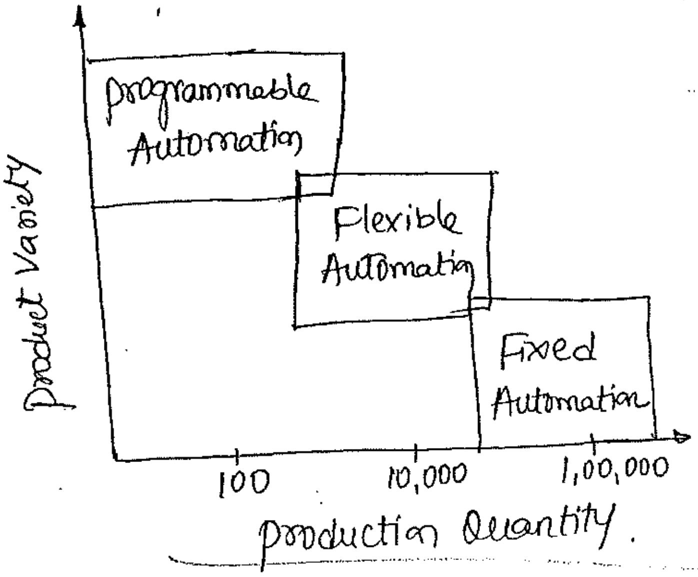
programmable automation system are used in low and medium volume production. The parts or products are typically made in batches. To produce each new batch of a different product, the system must be reprogrammed with the set of machine instructions that corresponds to the new product. The physical setup, tools, fixtures and settings must be changed. This changeover procedure takes time. Examples include NC machine tools, industrial robots and PLC's.

Flexible Automation: Flexible Automation is an extension of programmable automation. A flexible automated system is capable of producing a variety of parts with virtually no time lost for changeovers from one part style to the next. There is no lost production time while reprogramming the system and altering the physical setup. Hence the system can produce various mixes of products. The features includes

* High investment
* Continuous prodn. of variable mixtures of products.
* medium prodn rates
* Flexibility to deal with product design variations.

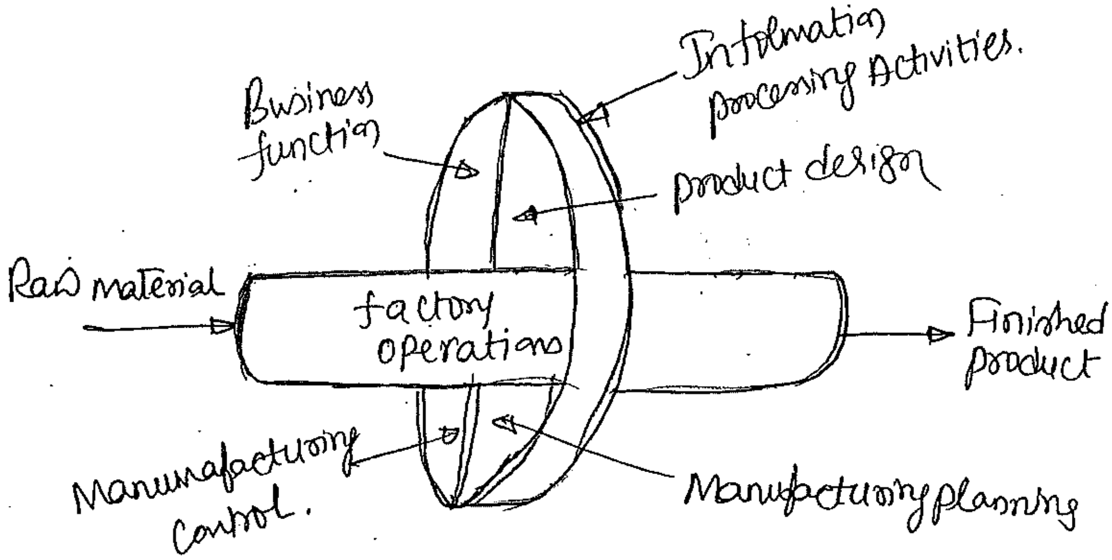
Ex: Flexible manufacturing systems.

The relative positions of three types of automation for different production quantity & product variety is shown below:



Computerized Manufacturing Support Systems:

Automation of the manufacturing support systems is aimed at reducing the amount of manual and clerical effort in product design, manufacturing planning & control and the business functions of the firm. All modern manufacturing support systems are implemented using computers. Computer technology is used to implement automation of the manufacturing systems. The term Computer Integrated Manufacturing (CIM) denotes the pervasive use of computer system to design the products, plan the production, control the operations and perform the various information processing functions. True CIM involves ~~the computer~~ integrating all of these functions in one system that operates throught the enterprise. Others Terms are used to identity the specific elements of the CIM system. This includes CAD, CAM, CAE, CAQC, CAPP etc. The Computer Integrated manufacturing involves the information processing activities that provide the data & Knowledge required to successfully produce the product. The Automation & CIM models are shown below:



Reasons for Automation: The various reasons used to justify automation are:

* TO increase labor productivity
* TO reduce labor cost
* TO mitigate the Effects of labor shortages.
* TO reduce or eleminate the routine manual & Clerical Tasks.
* TO improve worker safety
* TO improve product quality

* TO reduce Manufacturing Lead Time.
* TO accomplish processes that cannot be done manually.
* TO avoid the high cost of not automation.
* TO have intangible benefits like Improved quality, better labor relations, Improved Company image, Job satisfaction.

Computer Integrated Manufacturing:

Computer Integrated Manufacturing (CIM) encompasses the entire range of product development and manufacturing activities with all the functions being carried out with the help of dedicated software packages.

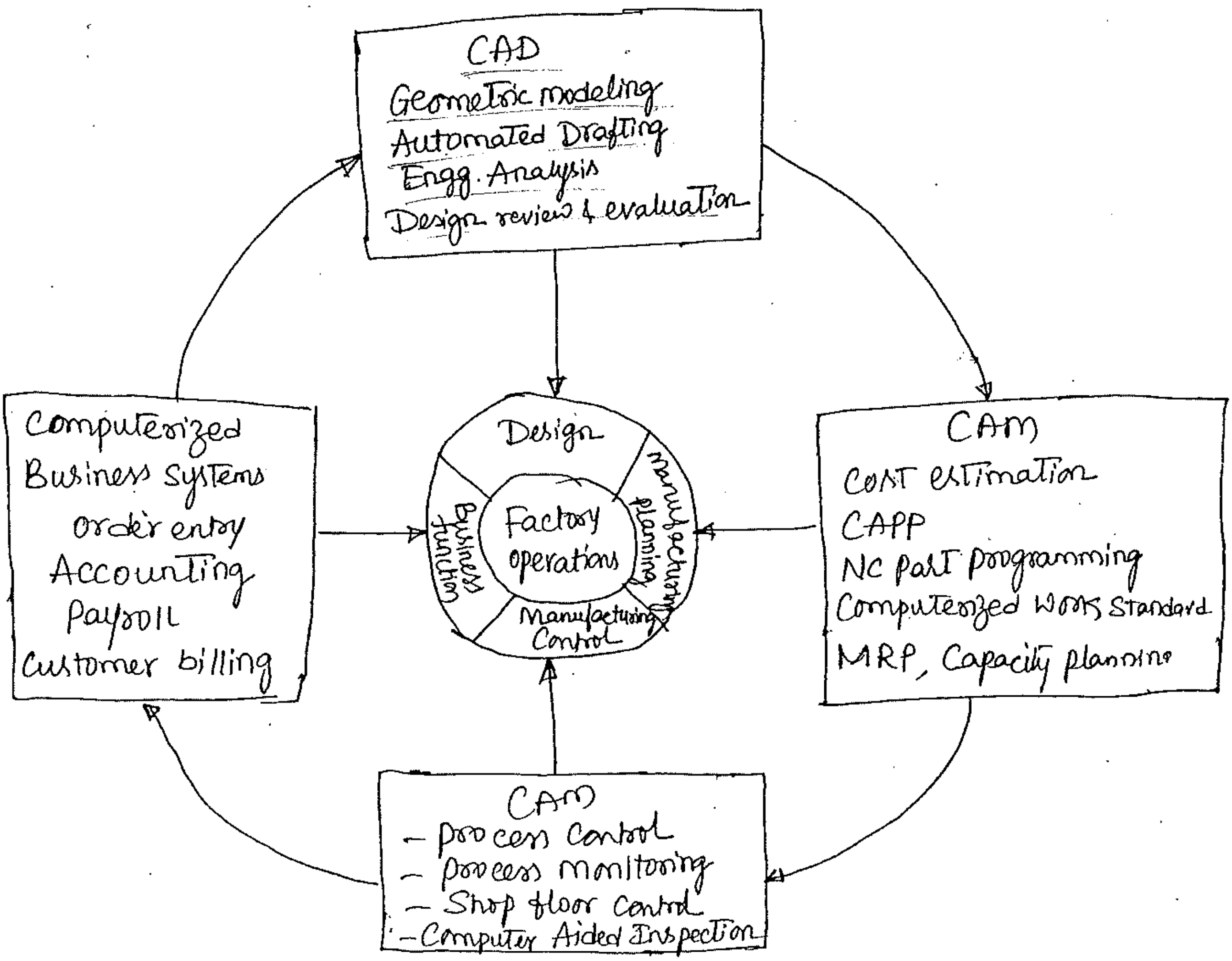
CIM is considered a natural evolution of the Technology of CAD/CAM which by itself evolved by the integration of CAD and CAM.

CIM is generally considered as a management and manufacturing strategy. It is nothing but use of Computer Technology to integrate or combine together the product design, production, marketing and delivery of a product into a totally integrated system.

As per CASA/SME ('Computer and Automation Systems Association' division of 'Society of Manufacturing Engineers', CIM is defind as:

"CIM is the integration of the total manufacturing enterprise through the use of integrated systems and data communications coupled with new managerial philosophies that improve organizational and personnel efficiency".

Computerized Elements of CIM System:



Computerized elements of CIM is as shown in fig. The Elements consists of the various computerized function of manufacturing support systems. The functions of manufacturing support systems ie Business function, product Design, Manufacturing planning & Manufacturing control activities will be undertaken with the help of computer systems. Mainly the computerized Elements of CIM involves Computer Aided Design (CAD), Computer Aided Engineering (CAE), Computer Aided Manufacturing (CAM), Computer Aided Process planning (CAPP), Computer Aided Production planning & Control (CAPP&C), Enterprise Resource Planning (ERP), Computer Aided Quality control (CAQC) to name a few.

Advantages (or Benefits of CIM):

- Improves short run responsiveness.
- Reduces inventory
- Increases machine utilisation
- Higher profits
- Less direct labor involvement
- Reduced scrap & Reworks.
- Higher employee morale
- Safer working environment
- Improved customer image
- Increased job satisfaction
- Reduced MLT.

Production Concepts & Mathematical Models & Matrices:

A number of production concepts are quantitative & requires a quantitative approach to measure them. The various matrices are indicated below;

Manufacturing Lead Time: (MLT).

"Manufacturing Lead Time is the total time required to process a given part or product through the plant."

In the competitive business environment, the ability of a manufacturing firm to deliver a product to the customer in the shortest possible time wins the order. This time is referred to as Manufacturing Lead Time.

The components of MLT is as shown below:

We know that, production consists of a series of individual steps: processing & Assembly operations.

- Between the operations are material handling, storage, inspection & other non-productive activities.
- Therefore divide the activities in production into two main categories; operations & Non-operations element.
- An operation on a product takes place when it is at the production machine.
- The non-operations elements are the handling, storage, inspection & other sources of delay.

Let T_o : Operation time at a given machine

T_{no} : Non-operation Time associated with the same m/c

n_m : No of machines (operations) through which the product must be routed inorder to be completely processed.

- Assuming a batch production situation, there are 'Q' units of the product in a batch.
- A setup procedure is generally required to prepare each machine for the particular product.
- This setup usually includes arranging the workplace & installing the tooling & fixturing required for the product. Let this setup time be denoted as T_{su}.

Given these terms, MLT is defined as the Total time required to process a given product.

ie

$$MLT = \sum_{i=1}^{n_m} T_{su_i} + Q T_{o_i} + T_{no_i} \quad \text{---} (1)$$

Where 'i' indicates the operations sequence in the processing ie $i = 1, 2, 3 \ldots n_m$.

Let us assume that all operations Time, Setup Time & non-operations times are Equal. ∴ The above Equation simplifies to

$$\boxed{MLT = n_m(T_{su} + Q \cdot T_o + T_{no})} \quad \text{———— (2)}$$

This Equation can be adopted for jobshop production & mass production situation by adjusting the parameter values. For a job shop production, the batch size is 1 ie Q = 1, Hence above Equn becomes

$$\boxed{MLT = n_m(T_{su} + T_o + T_{no})}$$

For Mass production, the 'Q' term in equn ② is very large & dominates the other terms.

In the case of Quantity type mass production in which large number of units are made on a single machine, the MLT becomes the operation time for the machine after the setup has been completed & production begins.

For flow-type mass prodn, the entire production line is setup in advance. Also, the non-operation time between the processing steps consists only the time to transfer the product from one machine to the next machine.

If the workstations are integrated so that the parts are being processed simultaneously at each station, the station with the longest operation Time will determine the MLT value.

Hence $$MLT = n_m \left(\text{Transfer Time} + \text{Longest } T_o \right)$$

Here n_m represents the number of seperate workstations on the production line.

Production Rate: The prodn rate (R_p) for an individual process (or) assembly operations is usually Expressed as an hourly rate (eg: units of product per hour)

Let us consider T_o as the operations time & T_{su} as the setup time at any given machine.

Considering for the Batch production;

The Total batch time for the machine.

$$\frac{\text{Batch time}}{\text{Machine}} = T_{su} + Q \cdot T_o$$

If the value 'Q' represents the desired quantity to be produced & if there is a scrap rate of an amount 'q' the quantity started through the process must be $\frac{Q}{1-q}$.

∴ The above Equn becomes,

$$\frac{\text{Batch time}}{\text{Machine}} = T_{su} + \frac{Q \cdot T_o}{(1-q)}$$

Dividing the batch time by the quantity in the batch yields "Average production time per unit of product" for the given machine ie

$$T_p = \frac{\text{Batch time / machine}}{Q}$$

∴ The average production rate for the machine is the reciprocal of the production time

ie $$R_p = \frac{1}{T_p}$$

For job shop production, Quantity $Q = 1$

∴ The production time per unit is $T_p = T_{su} + T_o$

∴ R_p for job shop production is $R_p = \frac{1}{T_p} = \frac{1}{T_{su} + T_o}$

For Quantity type mass production, the production rate Equals the cycle time of the machine ie the reciprocal of the operation time after the production has started and the Effects of setup are neglected. $R_p = \frac{1}{T_p} = \frac{1}{T_o}$

For flow line mass production, the production time approximates to the cycle time of the production line, neglecting the setup time. The problem in the production lines is the interdependence among workstations on the line. If one workstation breaks down, the entire line must often be stopped. The bottleneck station is sometimes used to refer to this workstation.

Therefore, cycle time of the production line is the sum of the longest operation time and the time to transfer the workunits between stations.

$$\therefore T_c = \text{Longest operation time} + \text{Transfer time}$$

$$\therefore R_p = \frac{1}{T_c} = \frac{1}{\text{Longest } T_o + \text{Transfer Time}}$$

Components of the Operation Time:

The operation time is the time an individual workpart spends on a machine but not all of this time is productive. Operation time for a given machining operation is composed of three elements:

i) The Actual machining time T_m

ii) The workpiece handling time T_h

iii) Tool handling time per workpiece T_{th}.

Hence, operation Time $\boxed{T_0 = T_m + T_h + T_{th}}$

The tool handling time represents

i) All the time spent in changing tools when they wearout

ii) Changing from one tool to the next for successive operations performed on a Turret lathe.

iii) Changing between the drill bit & Tap in a drill & Tap sequence performed at one drill press.

∴ T_{th} is the Average time per workpiece for any & all of these tool handling activities.

Capacity (or) Plant Capacity:

It is defined as the maximum rate of output that a plant is able to produce under a given set of assumed operating conditions. It is closely related to production rate. The assumed operating conditions refer to the following:

i) The number of Shifts per day (one, two or three)

ii) The number of days in the week (or Months) that the plant operates.

iii) Employment Level

iv) Whether or not overtime is included.

Capacity for a production plant is usually measured in terms of the types of output produced by the plant.

Eg: Tons of steel for a steel plant.

Number of Cars produced for an Automobile industry.

Barrels of oil for an oil refinery.

Let PC = plant capacity of a given workcenter (or) group of workcenters.

Capacity will be measured as the number of good units produced per week.

W = Number of workcenters. A workcenter in a production system in the plant typically consists of one worker & one machine.

R_p = Average production rate produced by 'W' work-centers in units/hr

H = Total number of hrs/shift each workcenter operates.

Sw = Number of shifts/week

The above parameters can be used to calculate the production capacity as follows:

$$PC = W\,S_w\,H\,R_p.$$

W	S_w	H	R_p
No. of Workcenter	No. of Shifts per week	Hours per shift	units per Hour

The unit of PC is units/week.

If each workunit is routed through n_o operations with each operation requiring a new setup on either a same or other machine, then the plant capacity equation becomes

$$PC = \frac{W\,S_w\,H\,R_p}{n_o}$$

Where n_o = Number of distinct operations (Machines) through which the workunits are routed.

The above eqn indicates the operating parameters that affect plant capacity. The plant capacity can be appropriately adjusted as per the plans below:

Short Term plans to increase or decrease plant Capacity are:

i) Change the number of Shifts per week (S_w) : Make Saturday shifts authorized to Temporarily increase the Capacity.

ii) Change the number of hours worked per shift (H) : OverTime on Each regular shift might be authorized to increase the Capacity.

Intermediate or Long Term plans

i) Increase the number of workcenters 'W' in the shop: This might be done by using equipment that was formerly not in use & hiring new workers. Over the long Term new machines may be acquired.

ii) Increase the production rate R_p by making Improve-ments in methods (or) process methodology.

iii) Reduce the number of operations (n_o) required per workunit by using Combined operations (or) Simulta-neous operations.

Utilization & Availability:

Utilization refers to the amount of output of a production facility relative to its capacity. Let 'U' represents utilization. We have,

$$U = \frac{\text{output}}{\text{Capacity}}$$

This term can be applied to an entire plant, a single machine or any other productive resources.

It is also defined as the proportion of time that the facility is operating relative to the time available under the definition of capacity. It is usually expressed as percentage.

Availability: The term availability is used as a measure of reliability of equipment. Availability is defined using two reliability terms, Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR). Here MTBF indicates the average length of time between breakdowns of the equipment. MTTR indicates the average time required to service the equipment & place it back into operation when a breakdown occurs.

$$\text{Availability (A)} = \frac{MTBF - MTTR}{MTBF}$$

It is also Expressed as a percentage.

Work-In-Process (WIP):

Work in process is the amount of product currently located in the factory that is either being processed or is between processing operations.

WIP is an inventory that is in the state of being Transformed from rawmaterial to finished product. A measure of WIP is given by:

$$\boxed{WIP = \frac{PC.U}{SW.H} \cdot MLT}$$

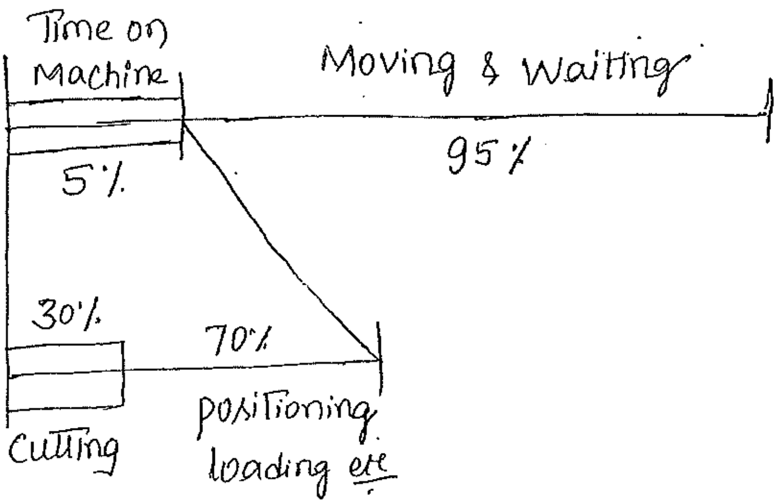
$$\frac{\text{units/wk}}{\text{Shifts/wk} * \text{Hrs/shift}} * \text{Hr} = \text{units/hr} * \text{hr.}$$

WIP represents the number of units in the process.

The above Equation states that the level of WIP will be Equal to the rate at which parts flows through the factory multiplied by the length of Time the parts spent in the factory.

WIP represents an investment by the firm, but that cannot be Turned into profit untill the processing is completed. Many manufacturing companies sustain major costs because work remains in-process in the factory too long. The units for $\frac{PC \cdot U}{SwH}$ (eg: parts per hr.) must be consistent with the units of MLT (eg: hr.).

Eugene Merchant, an advocate & spokesman for the manufacturing industry observed that materials in the factory spend more time waiting or being moved than in processing. His observation is illustrated as shown:



About 95% of the time of a workpart is spent either moving or waiting. Only 5% of the time is spent on the machine tool. Of this 5%, less than 30% of the time at the machine (1.5% of the total time of the part) is time during which actual cutting is taking place. The remaining 70% (ie 3.5% of the total time of the part) is required for loading, unloading, positioning & other causes of non processing time.

Two measures that can be used to assess the magnitude of the WIP are WIP ratio & TIP ratio.

<u>WIP Ratio:</u> The WIP ratio provides an indication of the amount of inventory in process relative to the work actually being processed.

It is the total quantity of a given part in the plant divided by the quantity of the same part that is being processed.

WIP ratio can be obtained by dividing the WIP level by the number of machines currently engaged in processing parts.

The divisor ie the number of machines processing can be calculated as:

$$\text{Number of machines processing} = W U \frac{Q T_o}{T_{su} + Q \cdot T_o}$$

Where W = Number of available workcenters.

U = Plant utilization

Q = Batch Quantity

T_o = Operation time

T_{su} = Setup time.

$$\therefore \text{ WIP ratio} = \frac{\text{WIP}}{\text{Number of machines processing}}$$

The ideal WIP ratio is 1 : 1 which implies that all parts in the plant are being processed.

TIP Ratio: The TIP ratio measures the time that the product spends in the plant relative to its actual processing time. It is determined as the total Manufacturing Lead Time for a part divided by the sum of the individual operations times for the part.

$$\text{TIP ratio} = \frac{MLT}{n_m T_o}$$

The ideal TIP ratio is 1 : 1

Comments on the Production concepts:

Manufacturing Lead time determines how long it will take to deliver a product to the customer. Here the ability of the firm to deliver the product to the customer in the shortest possible time is important.

High production rates are important objective in automation. These objective can be achieved by reducing workpiece handling time (T_h), processing time (T_m), tool handling time (T_{th}) & setup time (T_{su}).

Another objective of automation is to increase the plant capacity without the need for drastic change in employment levels.

Utilization provides a measure of how well the production resources are being used given that they are available. If the utilization is low, the facility is not being operated nearly to its capacity. If the utilization is higher, it may mean that the facility is being used fully.

Availability gives an indication of how well the maintenance personnel are servicing & maintaining the equipment in the plant. If it is 100% it means that the equipment is reliable & maintenance personnel are doing a good job.

WIP is an important issue in manufacturing. Many firms are attempting to reduce the high cost of WIP and one of the approaches that is being used is to automate the operation.

Finally, WIP ratio & TIP ratio should be kept as low as possible as the ideal ratio's being 1:1.

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AUTOMATED PRODUCTION LINES.

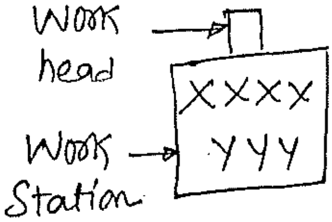
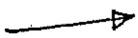
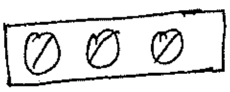
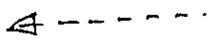
Dr. K.M. SATHISH
BMSIT&M.

Introduction: Some of the products have to be manufactured in large quantities as the demand is larger. Such large quantities of production may be Termed as High volume production. High volume production is same as mass production using various types of processes and operations. This system is used for products that requires multiple processing operations. Each processing operation is performed at a workstation, and the stations are physically integrated by means of mechanized transport system to form an Automated production Line. These lines are commonly referred as Automated Flow Line (or) Transfer Line (or) Transfer Machines.

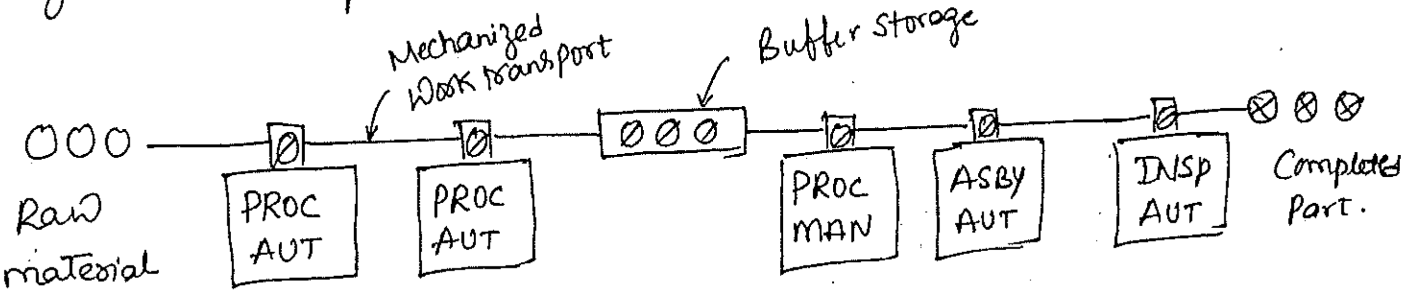
Automated Flow Line: An automated flow line consists of multiple workstations that are automated and linked together by a work handling system that transfers parts from one station to the next. A raw workpart enters one end of the line, and the processing steps are performed sequentially as the part progresses forward. The line may include inspection stations. Also, manual stations may also be located.

Each station performs a different operations, so all the operations are required to complete one work. Automated flow lines require a significant capital investment.

The following are the Symbols used to represent an Automated flow line:

Symbol	Description
	Workstation May be represented as XXXX and YYY. It indicates type of workstation. XXXX may be; PROC: Processing station ASBY: Assembly station INSP: Inspection Station WASH: Wash station. YYY May be; AUT: Automated Station MAN: Manual Station
	Material Handling System
	Raw Material
	Semi finished part
	Finished part
	Buffer storage
	Information flow / Data flow (feedback).

General configuration of Automated flow line with the symbols is represented as below;



Objectives of Automated flow Lines: Are as follows;

- TO reduce labor costs
- TO increase production rate
- TO reduce Work-In-Process.
- TO minimize distance moved between the operations.
- TO Achieve specialization of operations.
- TO achieve integration of operations.

Applications of Automated flow line (When to use?).

Automated flow line is recommended under the following conditions:

- Stable product design
- High rate of production
- High rate of demand for the product.
- Low amount of direct labor.
- When the products are generally heavy
- When Multiple operations needs to be performed.

System Configurations of Automated Flow Lines:

(Arrangements of Automated Flow Lines)

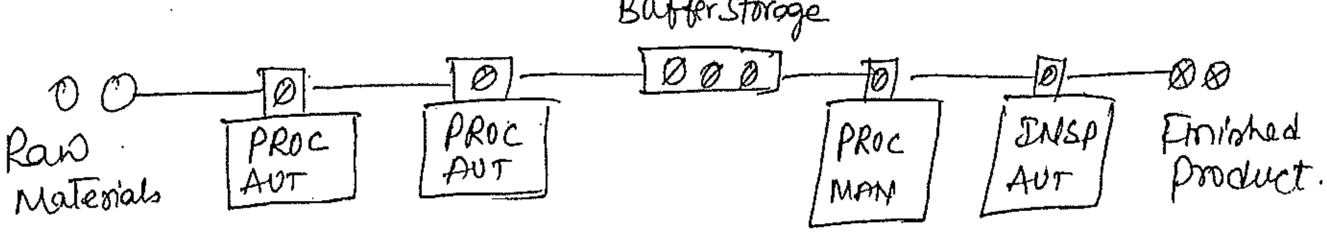
The various configuration of automated flow lines are categorized/classified into;

i) In-line configuration
ii) Segmented In-line configuration
iii) Rotary type configuration.

The above said configurations/Arrangements of automated flow lines are adopted depending on;

* Availability of Space
* Number of workstations required.
* Number of operations to be performed.
* Rate of production
* Accomodation of Buffer storage.
* Size of the workparts.

In-line configuration:



In line configuration consists of sequence of stations in a straight line arrangement as shown in fig. All the workstations will be arranged in the straight line manner.

This is the most commonly used configuration. This is common for machining larger workpieces such as automotive engine blocks, engine heads etc. This is also recommended when larger number of operations is required to be processed on the workpart. In-line system can also accomodate storage buffer along the path. One of the major disadvantage is that it requires a larger space to accomodate many workstations along the line.

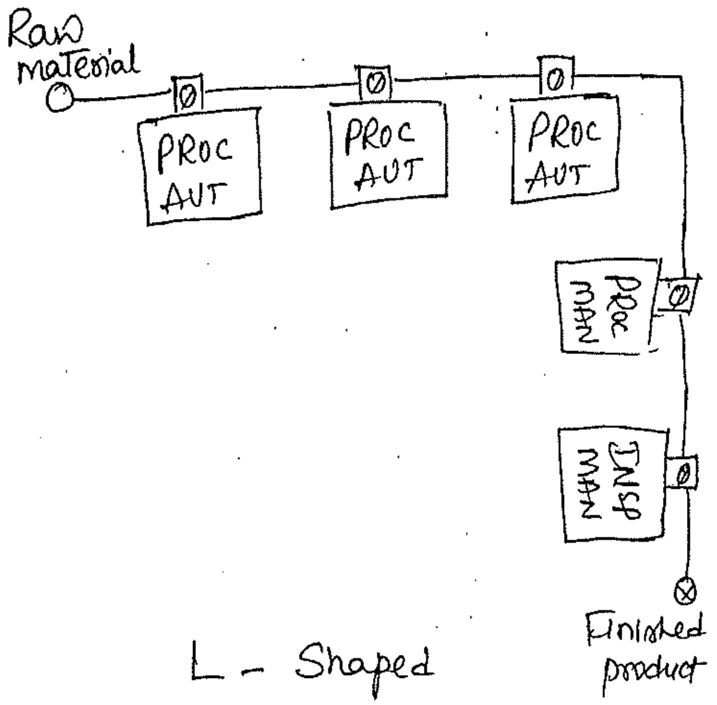
Segmented- In line Configuration:

The segmented in-line configuration consists of two or more straight line transfer sections where the segments are usually perpendicular to each other. Fig below shows the the various types of the segmented In-line configulation like L-Shaped, U-Shaped and Rectangular type.

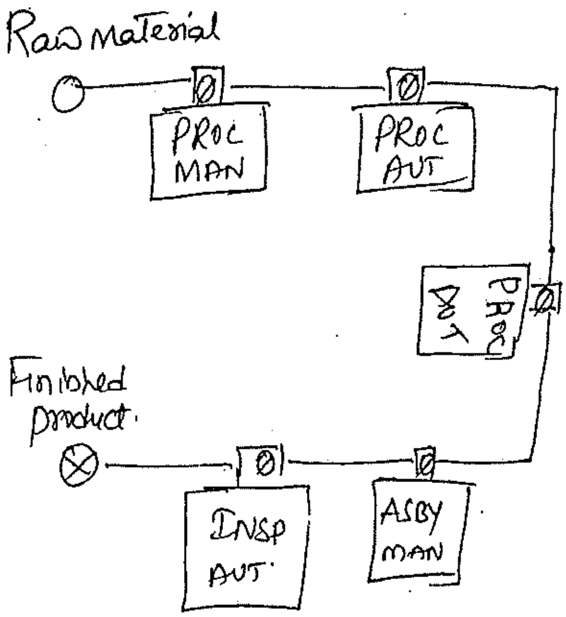
The reasons for segmented In-line configulation is:

i) Available floor space may limit the length of the line

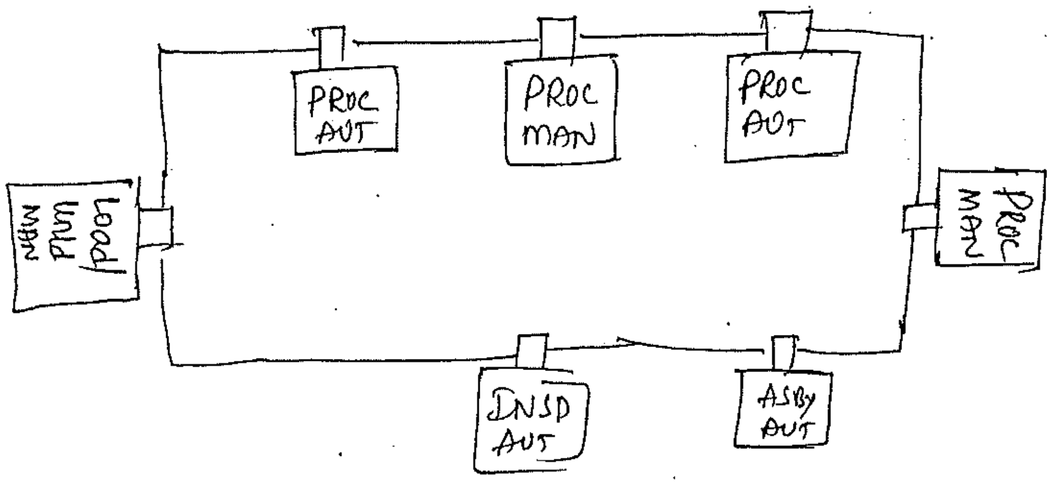
ii) A workpiece in a segmented in-line configuration may be reoriented to present different surfaces for machining.



L - Shaped



U - Shaped.



Rectangular shaped.

L - Shaped configuration has the advantage of orientation for a product in the process and also the length of space required is comparatively less when compared to In-line configuration.

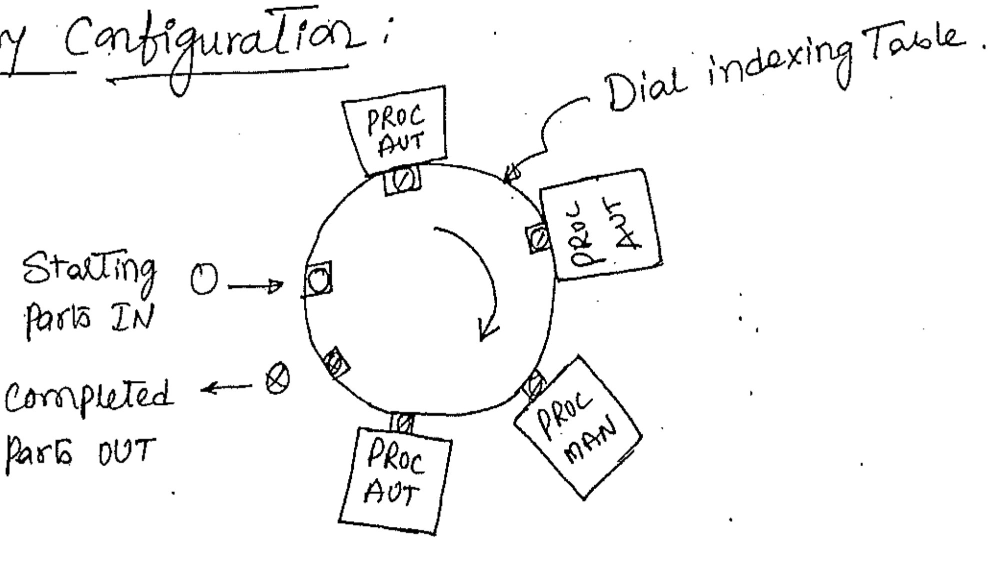
U - Shaped configuration is characterized by two orientation when compared to in-line and the total space to accommodate the entire process is also comparative lesser for the same product.

Rectangular configuration is an improvement on U-shaped configuration. Also, the space required is much less when compared to In-line, L and U configurations. Notable advantage is that only one operator is necessary for loading & unloading resulting in reduction of labor.

NOTE: In line | Segmented In-line configuration is adopted when,
* The no of operations on the product is more.
* Size of the product is large
* Availability of large space.
* Availability of buffer storage.

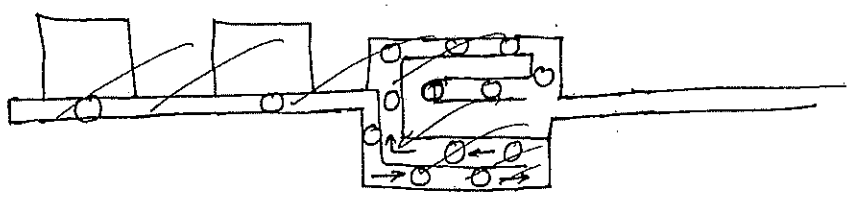
Rotary configuration in ~~contract~~ contrast to the above, used when,
* The number of operations required on the product is less.
* Smaller size of the product.
* Limitation on the available space.
* Limitation of the buffer storage.

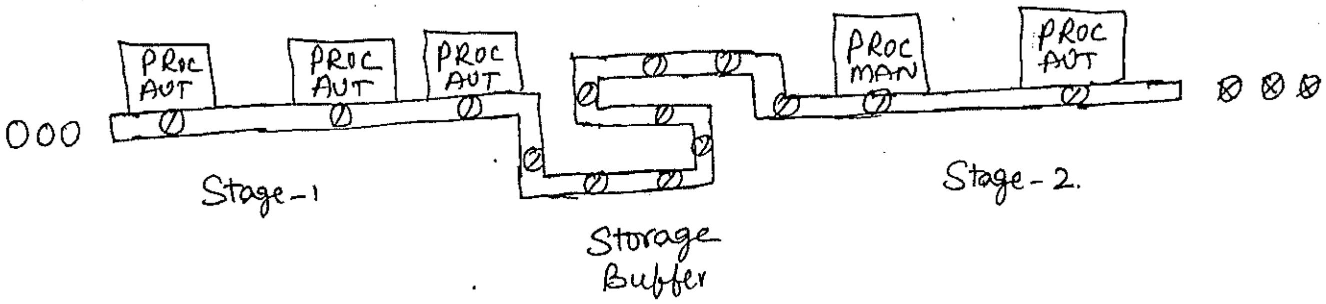
Rotary Configuration:



In the rotary configuration, the workparts are attached to fixtures around the periphery of a circular worktable and the table is indexed to present the parts to workstations for processing. The worktable is often referred to as a dial and the equipment is called a dial indexing machine (or) Indexing machine.

Buffer storage:





A Buffer storage is a location in the production line where parts can be collected and temporarily stored before proceeding to subsequent workstations. The storage buffers can be manually operated or automated. When it is automated, a storage buffer consists of a mechanism to accept parts from the upstream workstation, a place to store the parts, and a mechanism to supply parts to the downstream station. A key parameter of a storage buffer is its storage capacity, that is the number of workparts it is capable of holding.

The principal reasons for the use of buffer storage is to reduce the effect of individual breakdowns in the line. When a breakdown occurs at the individual stations, production must be stopped.

The following are the common reasons for line stoppages;

- Tool failures or tool adjustments at individual stations
- Scheduled tool changes.
- Defective workparts or components at assembly stations.
- Any electrical malfunction.
- Mechanical failure of transfer mechanism systems.

When a breakdown occurs on an automated flow line, the purpose of buffer storage is to allow a portion of the line to continue operating. The remaining portion of the line is stopped for repair.

A buffer storage divides the line into two stages. If the breakdown of any workstation cause first stage of the line to stop, then the second stage will continue to operate as long as the supply of parts in the buffer zone lasts. Similarly, If the second stage has to be shut down, the first stage will continue to operate as long as there is a place in the buffer storage to store the parts.

Reasons for use of Buffer Storage in flow Lines;

i) TO reduce the Effect of station breakdown - Storage buffers permit one stage to operate continuously.

ii) TO provide a bank of parts to supply the line - Parts can be collected into a storage unit and can be automatically fed to a downstream stations.

iii) TO allow for curing time or other required delay - A curing or setting Time is required for some processes like painting or adhesive applications. The storage buffer is designed to provide sufficient time for curing.

iv) TO smooth out cycle Time variations :- If any of manual stations are present in a line, this point is relevant as the cycle time will vary from one operator to another on the manual stations.

The Disadvantages of the buffer storage are Increased floor space, Higher work-in-process inventory, more material handling equipment and greater complexity of the line.

Control of the Production Line: Controlling an automated production line is a complex process because of the number of sequential and simultaneous activities that occur during the operations.

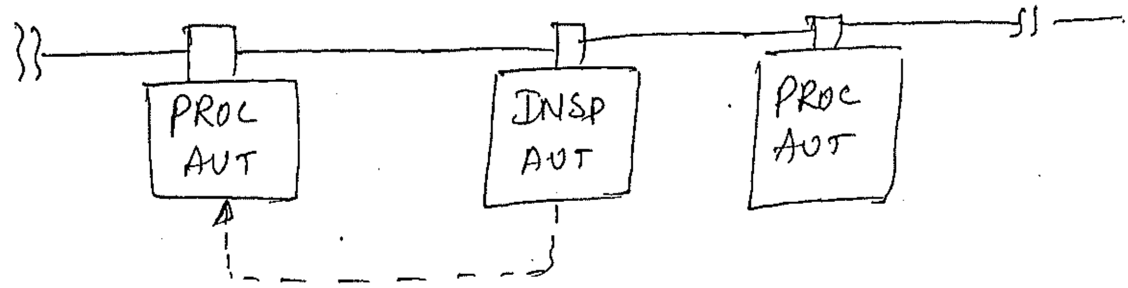
Following are the basic control functions that can be considered to control the operations of production line:

i) Sequence control – Operational requirement
ii) Safety monitoring – Safety requirement.
iii) Quality control – Quality requirement.

The purpose of sequence control is to co-ordinate the sequence of actions of the transfer system and workstations. The various activities of the production line must be carried out with split-second timing and accuracy. On a transfer line, the parts must be released from their current workstations, transported, located and clamped into position at their respective next workstations. All these operations to be sequentially monitored.

The safety monitoring ensures that the production line does not operate in an unsafe manner. Safety applies to both the workers and the machines. Sensors may be incorporated to monitor the tool status, breake of the tool etc.

In quality control functions, quality attributes of the workparts are monitored. The purpose is to detect and possibly reject defective workunits produced on the line. The inspection devices will be incorporated into the flow line. It is possible to extend the quality monitoring to incorporate a control loop into the flow line as shown in fig below:



Information feedback regarding Quality of the workpart.

An inspection station will be used to monitor the quality characteristics of the part and to feed back information to the preceeding ~~[illegible]~~ workstation so that adjustments in the process could be made.

Two additional alternative control strategies or Auxillary control functions present. They are

a) ~~Instantaneous Control~~

a) Instantaneous control

b) Memory control.

Instantaneous control mode stops the line immediately when a defect or malfunction is detected. This is relatively simple, inexpensive, easiest to implement & reliable. Diagnostic features can be added to aid in identifying the location and cause of the problem so that repairs can be made instantly.

In contrast to ~~instaneous~~ instantaneous control, memory control is designed to keep the line running. If the problem is associated with a particular work unit ie a defective part is detected, memory control prevents subsequent stations from processing the particular unit as it moves towards the end of the line. When the part reaches the last station, it is seperated from the rest of the good parts produced.

Fundamentals of Automated Assembly Systems:

The Term automated assembly refers to the use of mechanized and automated devices to perform the various assembly Tasks in an assembly line. Most automated assembly systems are designed to perform a fixed sequence of assembly steps on a specific product. Automated assembly Technology should be considered when the following conditions exist:

* High product demand.
* Stable product design.
* A limited number of components in the assembly
* product designed for automated assembly.

An automated assembly system performs a sequence of automated assembly operations to combine multiple components into a single entity. The single entity can be a final product or a sub assembly in a larger product. A typical automated assembly system consists of the following subsystems:

i) one or more workstations at which the assembly is done.
ii) Parts feeding devices that deliver the individual components to the workstations.
iii) A workhandling system.

Configurations (or Classifications or Types) of Automated Assembly Systems:

Automated assembly systems can be classified according to physical configuration. They are

i) In-line assembly machine.

ii) Dial type assembly machine.

iii) Carousel assembly system

iv) Single station assembly machine.

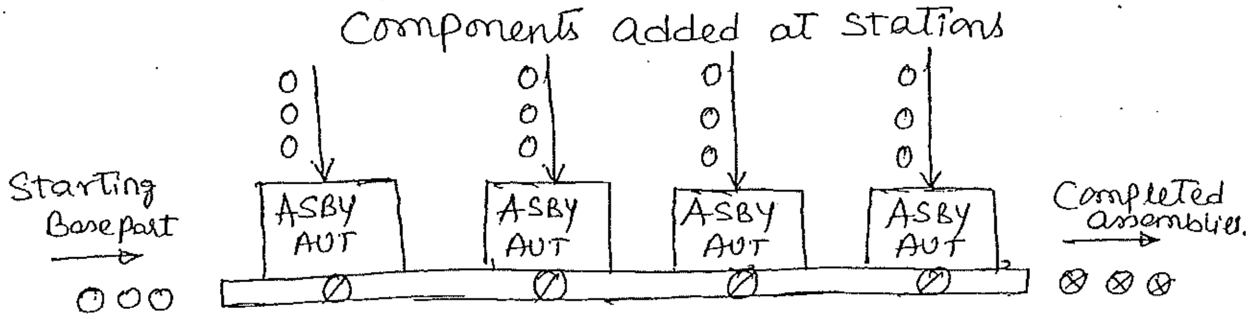


Fig: In-line Type

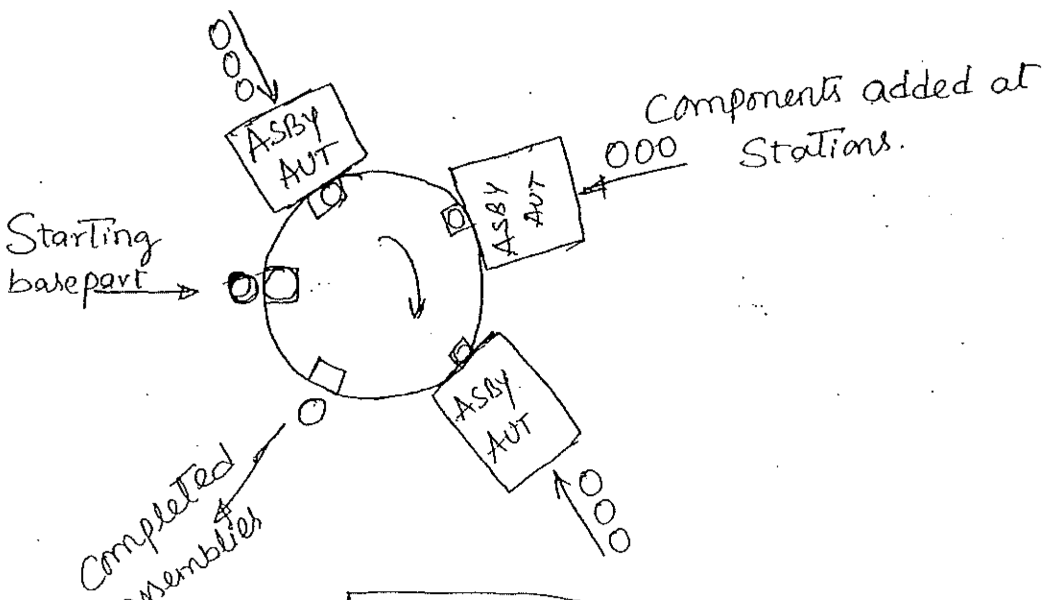


Fig: Dial Type

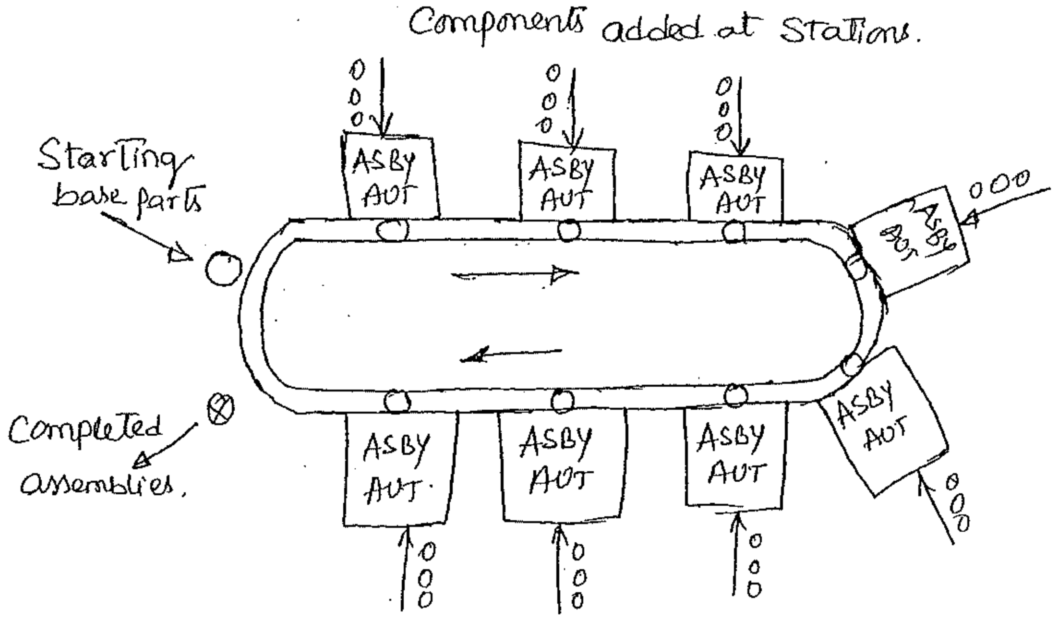


Fig: Carousel Type

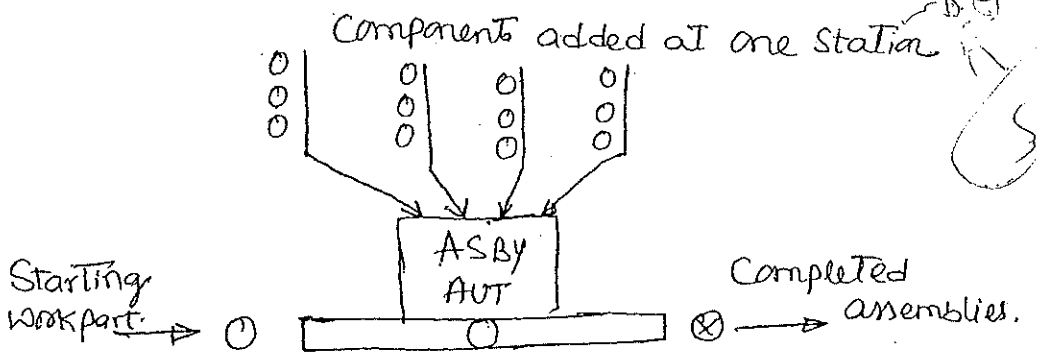


Fig: Single Station Type

The in-line assembly machine is a series of automatic workstations located along an in-line transfer system. Here the base part is launched on to the first workstation. In each workstations, the components will get added up to make the final assembly.

In Dial-Type machine, base parts are loaded on to fixtures attached to the circular dial. Components are added to the base part at the various workstations located around the periphery of the dial. This is common in beverage bottling & canning plants.

The Carousel assembly system represents a hybrid between the circular work flow of the dial type assembly machine and the straight work flow of the in-line system.

In the single-station assembly machine, assembly operations are performed on a base part at a single location. The operating cycle involves the placement of base part, the addition of components and finally the removal of the completed assembly from the station.

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Unit - 6

Computerized Manufacturing Planning System

CONTENTS : Computerized Manufacturing Planning System : Introduction, Computer Aided Process Planning, Retrieval types of process planning, Generative type of process planning, Material requirement planning, Fundamental concepts of MRP Inputs to MRP, Capacity planning.

6.1 INTRODUCTION

The product design is the plan for the product, and its components and subassemblies. To convert the product design into a physical entity, a manufacturing plan is needed. The activity of developing such a plan is called **PROCESS PLANNING**. It is the link between product design and manufacturing.

Process planning involves determination of the sequence of processing and assembly operations that must be performed to develop the product. Process planning is concerned with the engineering and technological issues of how to make the product and its parts. The scope and variety of processes that can be planned are generally limited by the available processing equipment and the technological capability of the plant.

Process planning is usually accomplished by manufacturing engineers. The process planner must be familiar with all the manufacturing processes available in the plant and be able to interpret engineering drawings. The logical steps and decisions incorporated during process planning stage are as follows :

(1) Interpretation of design drawings : The part or product design must be analyzed (i.e., materials, dimensions, tolerances, surface finish etc) at the start of the process planning.

(2) Processes and sequence : The process planner must select which processes are required and their sequences. A brief description of the processing steps must be prepared.

(3) Equipment selection : In general, process planners must develop plans that utilize existing equipment in the plant.

(4) Tools, dies, jigs and fixtures : The process planner must decide what tooling is required for each processing step, which includes dies, jigs and fixtures in addition to cutting tool.

(5) Work standards : Work measurement techniques are used to set time standards for each operation.

(6) Cutting tools and cutting conditions : These must be specified for each machining operation very clearly.

Process planning for parts : For individual parts, the processing sequence is documented on a form called **"Route sheet"** (operation sheet). A typical route sheet format and the general contents includes the following information.

(1) All operations to be performed on the workpart listed in the order in which they should be performed.

(2) A brief description of each operation indicating the processing steps to be performed.

(3) The specific machines on which the work is to be done.

(4) Any special tooling, jigs and fixtures required.

(5) Setup time and standard time required to complete the operation.

It is called as a route sheet because the processing sequence defines the route that the part must follow in the factory so as to finish the product manufacturing.

Routing :

Routing is a series of actions to be performed to achieve a particular goal. In a manufacturing or production unit routing defines the exact process by which a product is to be manufactured or a service is to be delivered. That is routing will spell the most efficient and economical way to perform a function. In manufacturing sector routings are prepared keeping in mind, the number of employees' available, type/s of machinery/equipment available, their capacity and run time etc.

Route sheet :

Route sheet is a hardcopy document which has the information and data inputs and a step wise listing of all processes and transaction performed in minute detail. It is a form containing the details of manufacturing processes of a part. It provides the exact location of the various processes of the part. In addition to this it also provides the sequence or order of involvement of various departments in the production of that part. It also contains details such as date and time log in/out, point of contact remarks etc..A typical route sheet format is as shown in Table 6.1.

Table 6.1 : A typical Route Sheet Format

Sl.No.	Symbols	Task Number	Description of the task	Time taken for the task	Machinery/ Equipment Required

6.2 COMPUTER AIDED PROCESS PLANNING (CAPP)

Computer Aided Process Planning is a means of implementing process planning function by computer. The CAPP represents the link between design and manufacturing. There is a much interest by a manufacturing firm in automating the task of process planning. The subsequent result in Computer Aided Process Planning. The shop-trained people who are familiar with the details of machining and other processes are gradually retiring and these people will be unavailable in the future to do process planning. An alternative way of accomplishing this function is needed and CAPP systems are providing this alternative.

Computer Aided Process Planning systems are designed around two approaches.

(1) Retrieval CAPP system.

(2) Generative CAPP system.

6.3 RETRIEVAL CAPP SYSTEM

Retrieval type CAPP system also called variant CAPP systems. It is based on the principles of group technology and parts classification & coding. In this approach, similar parts are identified and grouped together to take advantage of their similarities in manufacturing and design. Similar parts are arranged in to a part family. Parts classification and coding results in a code number that uniquely identifies the part's characteristics.

In this type of a CAPP, a standard process plan is stored in computer files for each part code number. The standard route sheets are based on current part routings in use in the factory or an ideal plan that is prepared for each family.

The general procedure of a retrieval type CAPP system is as shown in the fig. 6.1.

The user begins by deriving the GT code number for the component for which the process plan is to be determined. With this code number, a search is made in the part family file to determine if a standard route sheet exists for the given part code. If the file contains a process plan for the part, it is retrieved and displayed for the user. The standard process plan is examined to determine whether any modifications are necessary. The user edit the standard plan accordingly. Because of this capability of alternation to the existing process plan, retrieval system is also called **"Variant System"**.

If an exact match cannot be found between the code number of the new part, the user may search the computer file for the presence of a similar or related code number for which a standard route sheet exist. Now either by editing an existing process plan or by starting from scratch, the user can write the route sheet for the new part. This route sheet becomes the standard process plan for the new part code number.

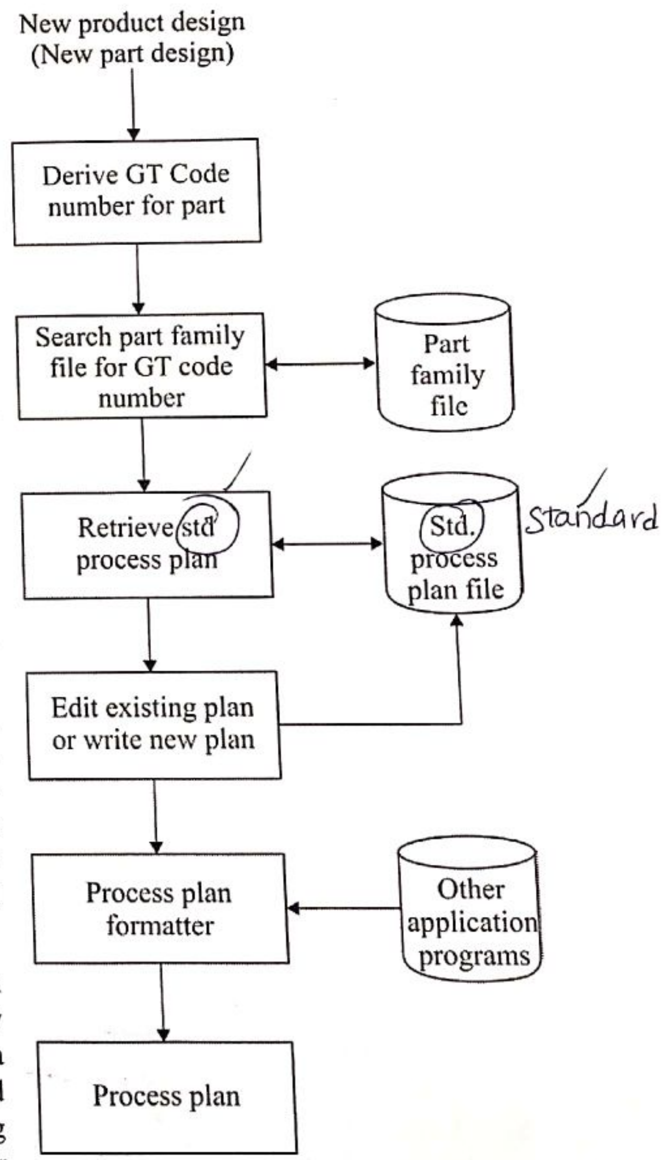


Fig. 6.1 : Retrieval type CAPP system

The process planning session concludes with the process plan formatter prints out the route sheet. The formatter may call other application programs like, To determine machining conditions for the various machine tools. To calculate the standard time for operations etc. One of the commercially available retrieval CAPP system is MultiCAPP from Organisation of Industrial Research.

6.4 GENERATIVE TYPE CAPP SYSTEM

Generative type CAPP involves the use of the computer to create an individual process plan from scratch automatically and without human assistance. Instead of retrieving and editing an existing plan contained in a computer database, a generative system creates the process plan based on logical procedures similar to the human process planner. In a fully generative CAPP system, the process sequence is planned without human assistance and without a set of predefined standard plans. The general procedure of Generative type CAPP system is shown in fig. 6.2.

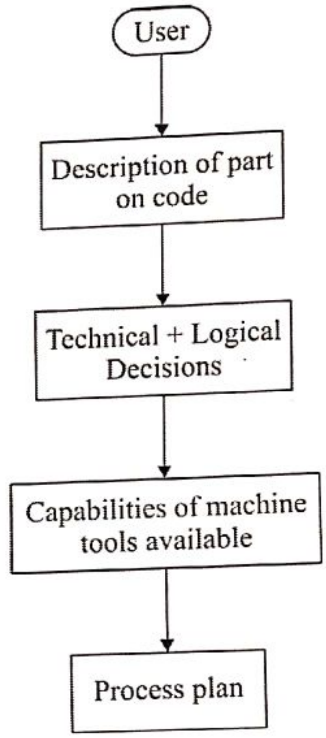


Fig. 6.2 : Generative type CAPP system

Designing a generative CAPP system is a part of the expert system and branch of artificial intelligence. An expert system is a computer program that is capable of solving complex problems that normally requires a human being with more experience and education.

There are several parameters required in a fully generative process planning system. The most important of them are :

The technical knowledge of manufacturing and the logic used by the successful process planners must be obtained and coded into a computer program. In an expert system applied to process planning, the knowledge and the logic of the human process planners is incorporated into a "Knowledge Base". The generative CAPP system will then use this knowledge base to solve a process planning problems.

The second parameter in the important list is a computer compatible description of the part to be produced. The description contains all of the pertinent data and informations needed to plan the process sequence. The possible ways of providing this information is given by :

(i) The geometric model of the part developed on a CADD system.

(ii) The GT code number of the part which defines the part features.

The third is the capability to apply the process knowledge and the logic contained in the knowledge base to a given part. The CAPP system uses its knowledge base to solve a specific problem of writing a process planning. This problem solving procedure is referred as "Inference Engine". By using the knowledge base and inference engine, a generative CAPP system synthesizes a new process plan from scratch for each new part.

Benefits of CAPP

(1) **Process rationalization and standardization :** Automated process planning leads to more logical and consistent process plans. Standard plans tend to result in lower manufacturing costs and higher product quality.

(2) **Increased productivity of process planners :** The systematic approach and the availability of standard process plans permit more work to be accomplished by the process planners.

(3) **Reduced lead time for process planning :** Process planners working with the CAPP system can provide route sheets in a shorter lead time compared to manual process planning operation.

(4) **Improved legibility :** Computer prepared route sheets are legible and easier to read and understand.-

(5) **Incorporation of other application programs :** The CAPP programs can be interfaced with other application programs like cost estimation, work standards, estimating machining conditions etc.

6.5 COMPUTER INTEGRATED PRODUCTION PLANNING SYSTEMS

The principle functions (or activities) involved in a production planning systems are given in fig. 6.5.

6.3

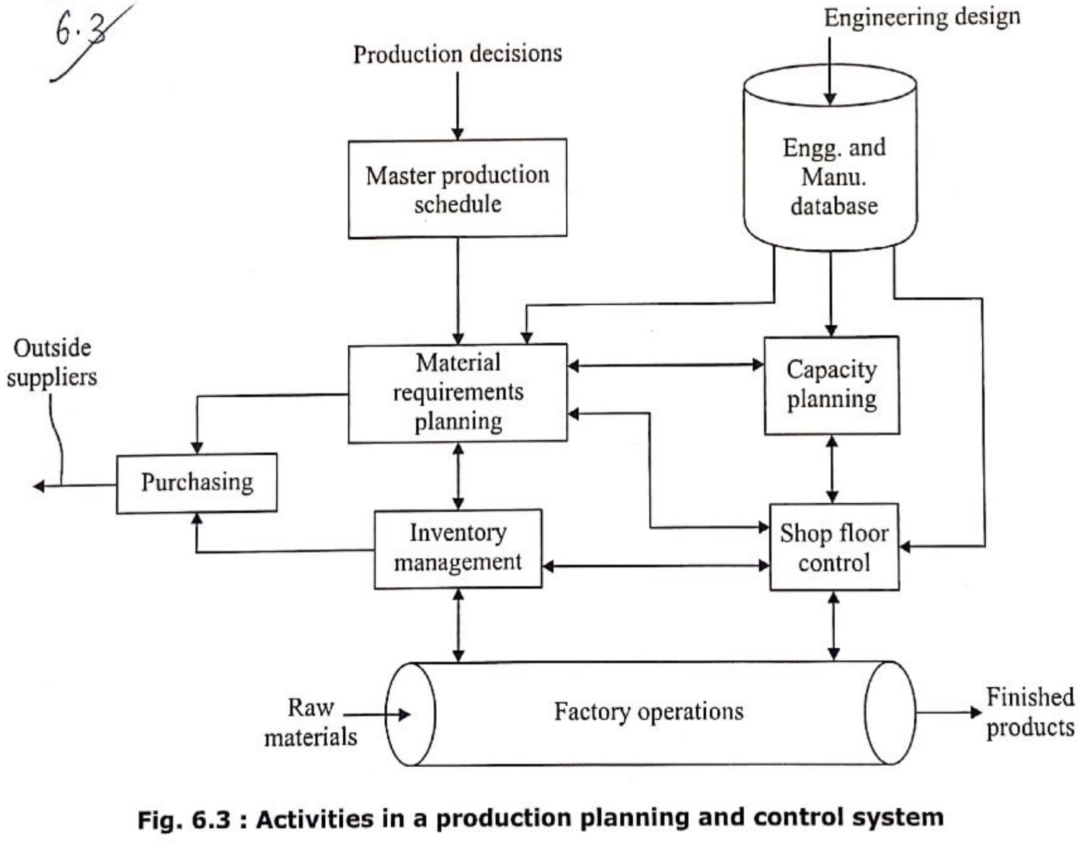


Fig. 6.3 : Activities in a production planning and control system

(1) **Master production schedule :** Master production schedule is a listing of the products to be manufactured, when they are to be delivered and in what quantities. It is developed from customer orders and forecasts of future demand. The master schedule represents the plan of the production for the firm which serves as an input to the material requirement planning function.

(2) **Material Requirement Planning (MRP) :** This is a procedure used for determining when to order raw materials and components for assembled products.

(3) **Capacity planning :** Capacity planning is concerned with the planning of production resources like labor and equipment needed to meet the master schedule.

In addition to the above functions, there are other functions which interface with the production planning functions. They are :

(i) **Engineering and Manufacturing database :** This database contains the engineering data required to make the components. The engineering data includes the product design, material specifications, bill of materials, process plan etc. This data base is utilized to perform the planning calculations for MRP and capacity planning.

(ii) **Inventory Management :** This is concerned with investment on raw materials, work-in-process, finished goods, factory supplies. This should be as low as possible without disrupting the production operations.

(iii) **Purchasing :** Purchasing department places the orders that are specified by the MRP and inventory management. Qualifying vendors are included to achieve this function.

(iv) **Shop floor control :** It is concerned with monitoring the progress of orders in the factory and reporting the status of each order to management so that effective control can be exercised.

6.6 MATERIAL REQUIREMENTS PLANNING

Material Requirement Planning (MRP) is a computational technique that converts the master schedule into a detailed schedule for the raw materials and components used in the end product. The detailed schedule identifies the quantities of each raw material and components required. It also indicates when each item must be ordered and delivered so as to meet the master schedule.

MRP is a method of inventory control. It is an effective tool for minimizing unnecessary inventory investment. MRP is also useful in production scheduling and purchasing of materials. The master schedule provides the overall production plan for the final products in terms of units to be produced. Each of the product may contain hundreds of individual components. These components are produced from raw materials, some of which are common among the components. The components are assembled into simple subassemblies and these subassemblies are put together into a main assembly. Each step in the manufacturing and assembly sequence takes time. All these factors must be considered during MRP calculations.

6.7 FUNDAMENTAL CONCEPTS OF MRP

MRP is based on the following concepts :

(1) Independent demand versus Dependent demand.

(2) Lead Times.

(3) Commonly used items.

Independent demand means that demand for a product is **not directly related** to demand for other items. End products and spare parts are examples of independent demand. **Independent demand patterns must usually be forecasted**. Dependent demand means that demand for the item is related directly to the demand for some other product. The components, raw materials and subassemblies are the items subjected to dependent demand.

The demand for the company's end product can be forecasted. But the raw materials and component parts should not be forecasted. Once the delivery schedule for end products is established, the requirements for components and raw materials can be calculated directly.

MRP is the appropriate technique for determining quantities of dependent demand items. These items constitute the inventory of manufacturing i.e., raw materials, work-in-process, component parts and subassemblies. Thus, MRP is a powerful technique in the planning and control of manufacturing inventories.

The lead time for a job is the time required to complete the job from start to finish. There are two types of lead times in MRP. **Ordering lead time** and **manufacturing lead time.**

An ordering lead time is the time required from the initiation of the purchase requisition to the receipt of the item from the vendor. If the item is a raw material that is stocked by the vendor, the ordering lead time is shorter. If the item is fabricated, the lead time may be larger. The manufacturing lead time is the total time required to complete the job considering operation time, Non-operation time and setup time.

Commonly used items are raw materials and components that are used on more than one product. MRP collects these common use items from different products to effect economies during ordering the raw materials.

6.8 INPUTS TO MRP SYSTEM

For the MRP to function properly, it must operate on data contained in several files. These files serve as inputs to the MRP system and they are

(1) Master production schedule file.

(2) Bill Of Materials (BOM) file.

(3) Inventory record file.

Fig. 6.4 illustrates the flow of data into the MRP system and its conversion into useful output reports.

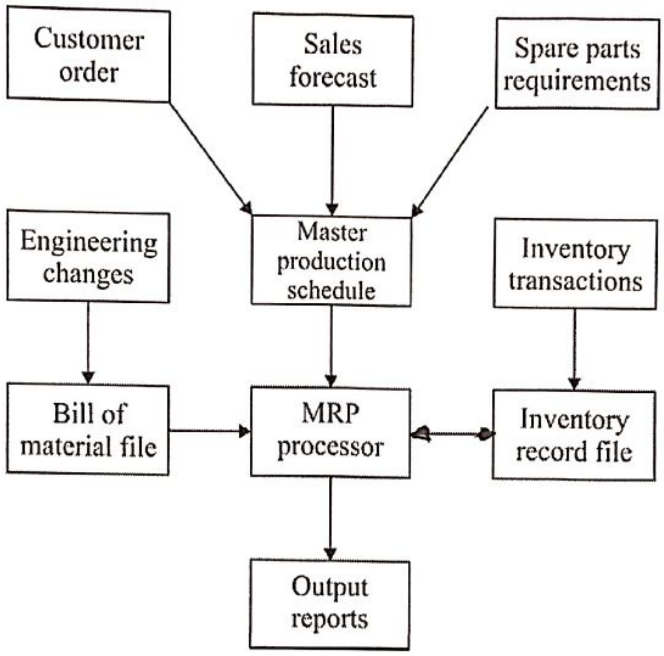


Fig. 6.4 : Structure of MRP system

The master production schedule is a listing of what end products are to be produced, how many of each product to be produced and when they are to be delivered. The master schedule must be based on an accurate estimation of demand and a realistic assessment of its production capacity.

Product demand that makes up the master schedule can be separated into three categories. The first consists of guaranteed customer orders for specific products. These orders usually includes a delivery date promised to the customer. The second category is forecasted demand. The forecast may constitute the major portion of the master schedule. The third category is the demand for individual component parts. These are spare parts and are stocked in the companys spare parts department.

The Bill Of Materials (BOM) file is used to compute the raw material and component requirements for end products listed in the master schedule. It provides information about the product structure by listing the component parts and subassemblies that make up each product. The structure of an assembled product can be pictured as shown in figure 6.5

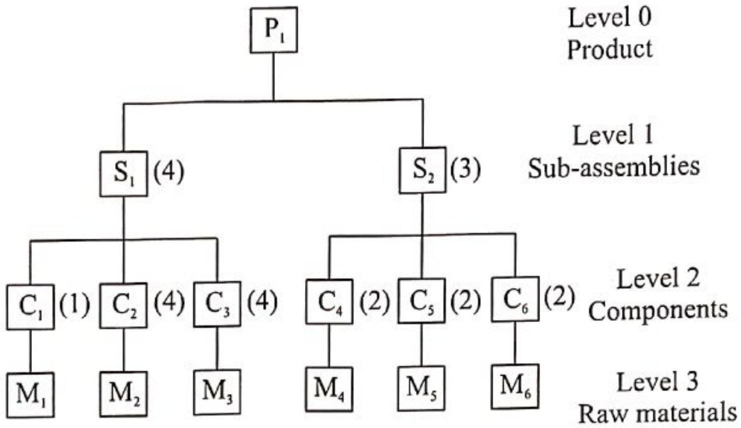


Fig. 6.5 : Bill of Material structure for a single product

This is relatively a simple product in which a group of individual components make up two subassemblies which inturn make up the product. The product structure is in the form of pyramid, with lower levels feeding into the levels above. The items at each successively higher level are called the parents of the items in the level directly below i.e., subassembly S_1 is the parent of component C_1, C_2 and C_3. The product structure also specifies how many of each item are included in its parent. This is shown in the paranthesis. Explanation of the above structure is provided below.

To produce one product P, 4 items of S_1 (hence [(S_1)4)] and 3 items of S_2 [i.e. (S_2)3] are required.

One item of S_1 requires one item of C_1, [C_1(1)], 4 items of C_2 and 4 items of C_3.

The raw materials required to produce one part C_1 is M_1, part C_2 is M_2 and part C_3 is M_3 respectively.

Similar explanation holds good for item $\mathbf{S_2}$.

The inventory record file is referred to as the **item master file** in a computerized inventory system. The data contained in the inventory record file are divided into three segments.

(a) Item Master Data : This provides the items identification (part number) and the other data about the part such as order quality and lead time.

(b) Inventory status : This gives a time phased record of inventory status. In MRP, it is important to know not only the current level of inventory but also the future changes that may occur against the inventory.

(c) Subsidiary data : It provides data such as purchase orders, scrap or rejects and engineering changes.

The MRP processor operates on the data contained in the Master Production Schedule (MPS), the Bill of Materials file and the inventory record file.

WORKING Of MRP:

The MPS provides a period-by-period list of final products required. The BOM defines what materials and components are needed for each product. The inventory record file contains information on the current and future inventory status of each component. The MRP processor computes how many of each component and raw material are needed each period by "exploding" the end product requirements into successively lower level in the product structure.

6.9 MRP OUTPUT REPORTS

The MRP program generates a variety of outputs which can be used in planning and managing plant operations. The output include

(i) Planned order releases provide the authority to place orders as planned by MRP system.

(ii) Report of planned order releases in future periods.

(iii) Rescheduling notices, indicating changes in due dates.

(iv) Cancellation notices, indicating the reasons.

(v) Report on inventory status.

(vi) Performance reports of various types, costs, actual v/s planned lead times etc.

(vii) Exception reports showing deviations from the schedule.

(viii) Inventory forecasts indicating projected inventory levels.

6.10 MRP BENEFITS

The benefits from a well-designed MRP system is

(i) Reduction in inventory.

(ii) Quicker response to changes in demand.

(iii) Reduced setup and product changeover costs.

(iv) Better machine utilization.

(v) Improved capacity to respond to changes in the master schedule.

(vi) As an aid in developing the master schedule.

6.11 CAPACITY PLANNING

Capacity planning is concerned with determining what labor and equipment capacity is required to meet the master production schedule as well as long term future production needs of the company. Capacity planning also serves to identify the limitations of the production resources so that an unrealistic master schedule is not planned.

Capacity planning is typically accomplished in two stages. When MPS is established and when the MRP computations are done. Fig. 6.6 shows the concept of capacity planning.

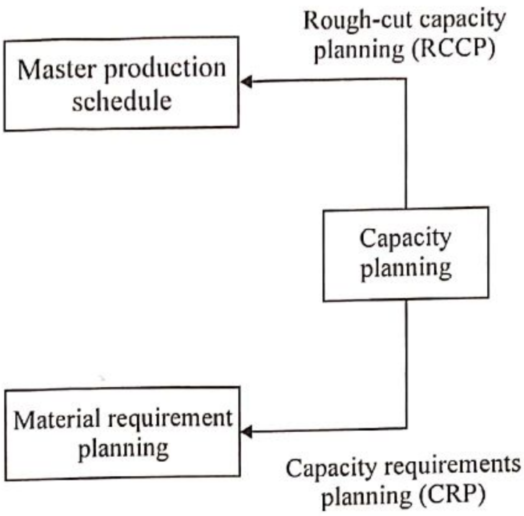


Fig. 6.6 Concept of Capacity Planning

In the MPS stage, a **Rough-Cut Capacity Planning (RCCP)** calculation is made to assess the feasibility of the master schedule. Such a calculation indicates whether there is a significant violation of production capacity in the MPS. A second capacity calculation is made at the time the MRP schedule is prepared called the **Capacity Requirements Planning (CRP)**. This determines whether there is sufficient production capacity in the individual department to complete the specific parts, that have been scheduled by MRP. If the schedule is not compatible with capacity, adjustments must be made either in plant capacity or in the MPS.

Capacity adjustments can be divided into short term and long term adjustments. Short term capacity adjustments include the following :

(i) **Employment levels :** Employment in the plant can be increased or decreased in response to changes in capacity requirements.

(ii) **Temporary workers :** Increase in employment level can also be made by using temporary workers.

(iii) **Number of work shifts :** The number of shifts worked per production period can be increased or decreased.

(iv) **Labor hours :** The number of labor hours per shift can be increased or decreased through the use of overtime or reduced hours.

(v) **Inventory stockpiling :** This might be used to maintain steady employment levels during slow demand periods.

(vi) **Order backlogs :** Deliveries of the product to the customer could be delayed during busy periods when production resources are insufficient to keep up with demand.

(vii) **Subcontracting :** This involves the letting of jobs to other shops during busy periods.

Capacity planning adjustments for the long term include possible changes in production capacity that generally require long lead times. These adjustments include

(i) New equipment investments : This involves investing in more machines to meet increased future production requirements or investing in new types of machines to match future changes in product design.

(ii) New plant construction : It represents a significant increase in production capacity for the firm.

(iii) Purchase of existing plants from other companies.

Exercise

1. Define Process planning. List and explain the logical steps involved in it.
2. Define CAPP. Discuss the benefits of CAPP.
3. With a neat diagram explain the Retrieval type CAPP system.
4. With a neat diagram explain the Generative type CAPP system.
5. With a block diagram explain the principal functions involved in a production planning system.
6. Explain the importance of MRP.
7. With a block diagram explain the fundamental concepts of MRP.
8. With a block diagram explain the inputs to the MRP system.
9. List the MRP output reports and benefits of MRP.
10. Define Capacity Planning. How capacity planning can be accomplished?
11. What are the short term and long term adjustments needed to meet the capacity. Explain.

Computerized Manufacture Planning and Control System

****This study material is in addition to the pdf material (PART I) which was shared****

Dr. K. M. Sathish Kumar
Professor and Head, Dept. of ME, BMSIT&M

Production Planning and Control Systems:

Production planning and control (PPC) is concerned with the logistics problems that are encountered in manufacturing, that is, managing the details of what and how many products to produce and when, and obtaining the raw materials, parts, and resources to produce those products. PPC solves these logistics problems by managing information. Computers are essential for processing the tremendous amounts of data involved to define the products and the means to produce them, and for reconciling these technical details with the desired production schedule. In a very real sense, PPC is the integrator in computer-integrated manufacturing.

Production planning consists of:

1. Deciding which products to make, in what quantities, and when they should be completed
2. Scheduling the delivery and/or production of the parts and products
3. Planning the manpower and equipment resources needed to accomplish the production plan.

Production control consists of determining whether the necessary resources to implement the production plan have been provided, and if not, attempting to take corrective action to address the deficiencies. As its name suggests, production control includes various systems and techniques for controlling production and inventory in the factory.

Typical activities of PPC System:

Activities in production planning:

Aggregate production planning: This involves planning the production output levels for major product lines produced by the firm. These plans must be coordinated among various functions in the firm, including product design, production, marketing, and sales.

Master production planning: The aggregate production plan must be converted into a master production schedule (MPS) which is a specific plan of the quantities to be produced of individual models within each product line.

Material requirements planning (MRP): MRP is a planning technique, usually implemented by computer, that translates the MPS of end products into a detailed schedule for the raw materials and parts used in those end products.

Capacity planning: This is concerned with determining the labour and equipment resources needed to achieve the master schedule.

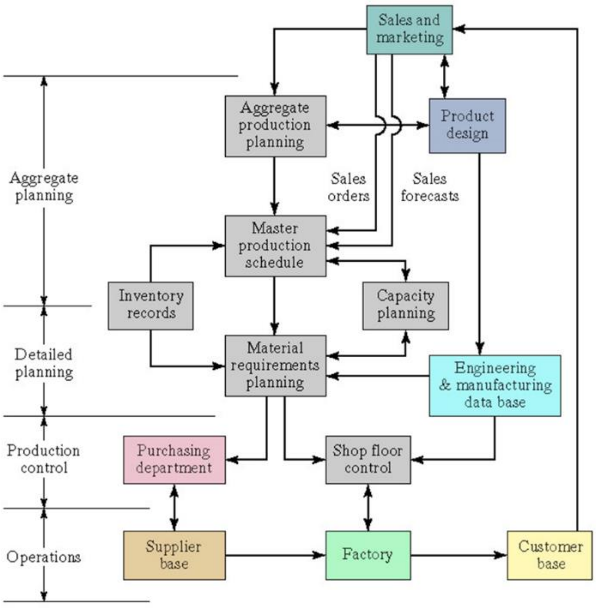
Activities in production control:

Shop floor control: It compares the progress and status of production orders in the factory to the production plans.

Inventory control: It includes a variety of techniques for managing the inventory of a firm.

Manufacturing resource planning: Also known as MRP II, it combines MRP and Capacity planning as well as shop floor control and other functions related to PPC.

Just in time Production systems: It refers to a discipline in which materials and parts are delivered to the stations just prior to their usage.



Computer integrated production management system:

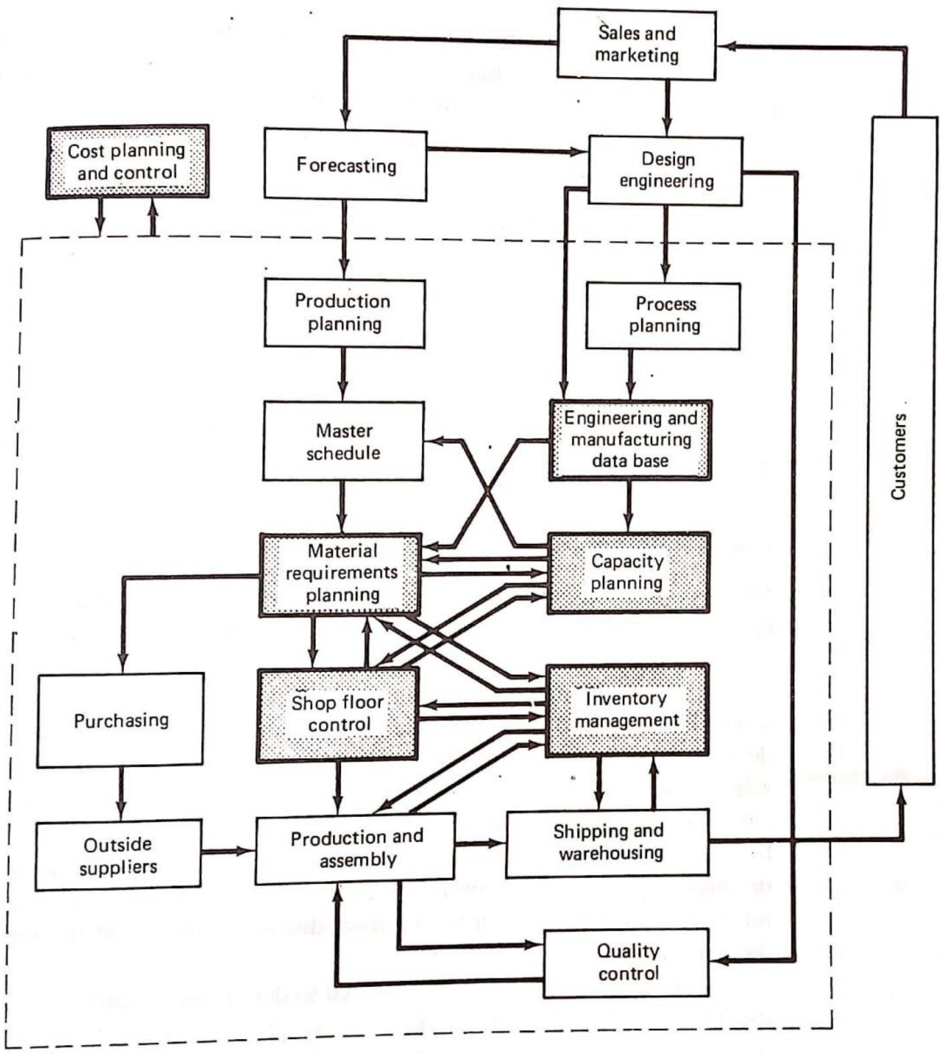


FIGURE 14.2 Cycle of activities in a computer-integrated production management system.

Shop floor control:

Shop floor control (SFC) is the set of activities in production control that are concerned with releasing production orders to the factory, monitoring and controlling the progress of the orders through the various work centers, and acquiring current information on the status of the orders.

A typical SFC system consists of three phases:

1. Order release
2. Order scheduling
3. Order progress

The three phases and their connections to other functions in the production management system are pictured in below Figure.

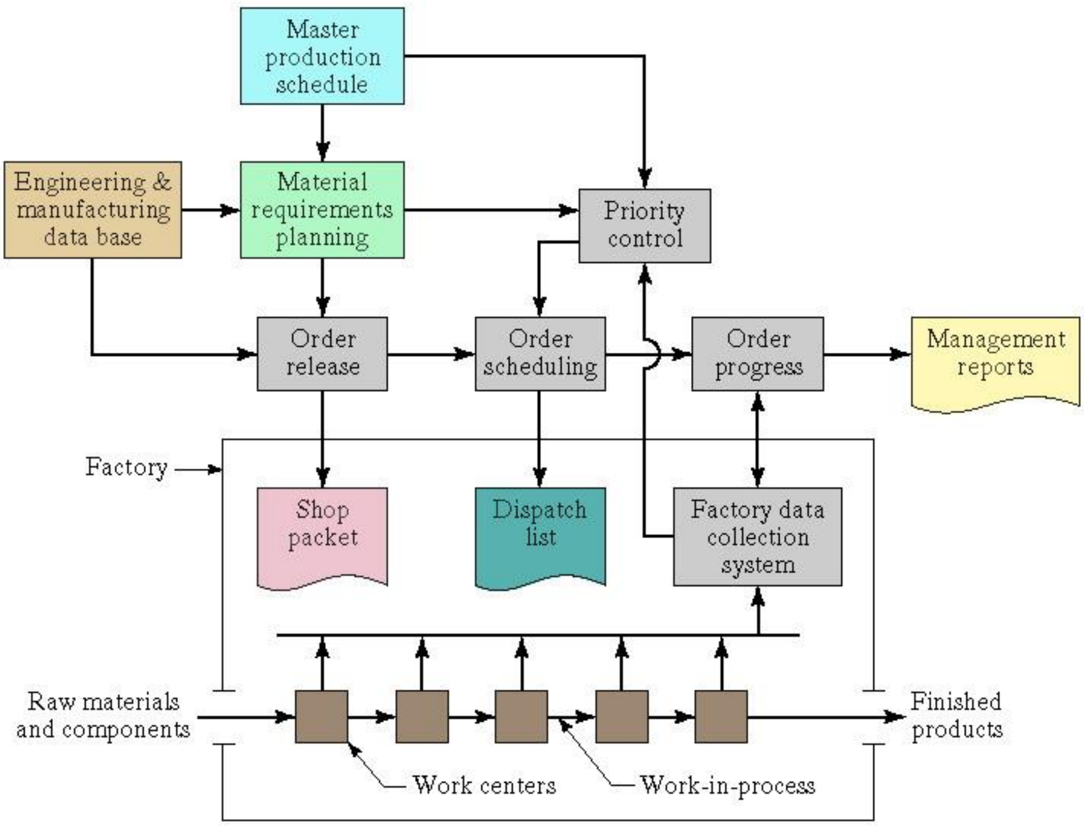


Fig: Three phases in a shop floor control system

In modern implementations of shop floor control, these phases are executed by a combination of computer and human resources, with a growing proportion accomplished by computer automated methods.

Order Release:

The order release phase of shop floor control provides the documentation needed to process a production order through the factory. The collection of documents is sometimes called the shop packet. It typically includes (1) the route sheet, which documents the process plan for the item to be produced, (2) material requisitions to draw the necessary raw materials from inventory, (3) job cards or other means to report direct labour time devoted to the order and to indicate progress of the order through the factory, (4) move tickets to authorize the material handling personnel to transport parts between work centres in the factory if this kind of authorization is required, and (5) the parts list, if required for assembly jobs.

In the operation of a conventional factory, which relies heavily on manual labor, these are paper documents that move with the production order and are used to track its progress through the shop. In a modern factory, automated identification and data capture technologies are used to monitor the status of production orders.

The order release phase is driven by two inputs, as indicated in Figure 25.9. The first is the authorization to produce that derives from the master schedule. This authorization proceeds through MRP, which generates work orders with scheduling information. The second input to the order release phase is the engineering and manufacturing database that provides the product structure and process plans needed to prepare the various documents that accompany the order through the shop.

Order Scheduling:

The order scheduling phase follows directly from the order release phase and assigns the production orders to the various work centers in the plant. In effect, order scheduling executes the dispatching function in PPC. The order scheduling phase prepares a dispatch list that indicates which production orders should be accomplished at the various work centers. It also provides information about relative priorities of the different jobs, for example, by showing due dates for each job. In shop floor control, the dispatch list guides the shop foreman in making work assignments and allocating resources to different jobs to comply with the master schedule.

The order scheduling phase in shop floor control is intended to solve two problems in production control: (1) Machine loading and (2) Job sequencing.

To schedule a given set of production orders or jobs in the factory, the orders must first be assigned to work centers. Allocating orders to work centers is referred to as machine loading. The term shop loading is also used, which refers to the loading of all machines in the plant. Since the total number of production orders usually exceeds the number of work centers, each work center will have a queue of orders waiting to be processed. The remaining question is: In what sequence should these jobs be processed? Answering this question is the problem in job sequencing, which involves determining the sequence in which the jobs will be processed through a given work center. To determine this sequence, priorities are established among the jobs in the queue, and the jobs are processed in the order of their relative priorities. Priority control is a term used in production control to denote the function that maintains the appropriate priority levels for the various production orders in the shop.

Order Progress:

The order progress phase in shop floor control monitors the status of the various orders in the plant, work-in-process, and other measures that indicate the progress of production. The function of the order progress phase is to provide information that is useful in managing the factory. The information presented to production management is often summarized in the form of reports, such as the following:

Work order status reports: These reports indicate the status of production orders. Typical information in the report includes the current work center where each order is located, processing hours remaining before completion of each order, whether each job is on time or behind schedule, and the priority level of each order.

Progress reports: A progress report is used to report performance of the shop during a certain time period (e.g., a week or month in the master schedule). It provides information on how many orders were completed during the period, how many orders should have been completed during the period but were not, and so forth.

Exception reports: An exception report identifies deviations from the production schedule (e.g., overdue jobs) and similar nonconformities. These reports are useful to production management in making decisions about allocation of resources, authorization of overtime hours, and other capacity issues, and in identifying problem areas in the plant that adversely affect achieving the master production schedule.

Computer Aided Quality Control (CAQC):

Quality in manufacturing context can be defined as the degree to which a product or its components conform to certain standards that have been specified by the designer. The design standard generally relates to the materials, dimensions and tolerances, appearance, performance, reliability, and any other measurable characteristics of the product.

The use of the computers for quality control of the product is called as the **Computer Aided Quality Control or CAQC.**

The two major parts of quality control are inspection and testing, which are traditionally performed manually with the help of gages, measuring devices and the testing apparatus.

Inspection is normally used to examine whether a product conforms to the design standards specified for it. For a mechanical component, this would be probably concerned with the dimensions, surface texture and tolerances specified for the part. Non-conforming goods result in scrap, rework, and the loss of customer goodwill.

The common situations that warrant inspection are:

- Incoming materials (raw materials, standard items, subcontracted parts)
- Stage inspection during manufacturing (e.g., when the parts are moved from one production section to another)
- At the completion of processing of the parts
- Before shipping the final assembled product to the customer.

Testing is a significant stage of work in product development to prove the capability of the product. Testing is normally associated with the functional aspect of item, and is often directed at the final product rather than its components. Testing consists of the appraisal of the performance of the final product under actual or simulated conditions. If the product successfully passes the tests, it is deemed suitable for use. Testing ascertains the quality of performance of the product.

Various categories of tests used for final product evaluation are listed below:

- ❖ Functional tests under normal or simulated operating conditions
- ❖ Fatigue or wear tests to determine the product’s life function until failure
- ❖ Overload tests to determine the level of safety factor built into the product
- ❖ Environmental testing to determine how well the product will perform under different environments (e.g. humidity, temperature, vibration).

Role of Computers in Quality Control (QC):

The two major parts of computer aided quality control are computer aided inspection (CAI) and computer aided testing (CAT). CAI and CAT are performed by using the latest computer automation and sensor technology. CAI and CAT are the standalone systems and without them the full potential of CAQC cannot be achieved.

OBJECTIVES OF CAQC:

The objectives of Computer-Aided Quality Control are to:

i. Improve product quality

ii. Increase productivity in the inspection process

iii. Increase productivity

iv. Reduce lead-time

v. Reduce wastage due to scrap/rework

The strategy for achieving these objectives is basically to automate the inspection process through the application of computers combined with sensor technology. Where technically possible and economically feasible, inspection should be done on a 100% basis rather sampling.

Advantages of CAQC:

- **100% testing and inspection:** With Computer aided inspection and computer aided testing, inspection and testing will typically be done on a 100% basis rather by the sampling procedures normally used in traditional QC. This eliminates any problem in assembly later and therefore is important in CIM.
- Inspection is integrated into the manufacturing process. This will help to reduce the lead-time to complete the parts.
- An important feature of QC in a CIM environment is that the CAD/CAM database will be used to develop inspection plan.
- The use of non-contact sensors is recommended for computer aided inspection and CIM. With contact inspection devices, the part must be stopped and often repositioned to allow the inspection device to be applied properly. These activities take time. With non-contact sensing devices, the parts can be inspected while in operation. The inspection can thus be completed in a fraction of a second.
- Computerized feedback control system: The data collected by the non-contact sensors is sent as the feedback to the computerized control systems. These systems would carry out the analysis of the data including statistical trend analysis. This helps in identifying the problem going on in the manufacturing line and find appropriate solution to it.

Inspection: Inspection refers to the activity of examining the product, its components, subassemblies to determine whether they conform to the design specifications. Classified as

1. Inspection for variables: In which one or more quality characteristics of interest are measured using an appropriate measuring instrument or sensor.
2. Inspection for attributes: In which the part or product is inspected to determine whether it conforms to the accepted quality standard. The determination is sometimes based simply on the judgment of the inspector. Inspection by attributes can also involve counting the number of defects in a product.

Inspection Procedure: A typical inspection procedure performed on an individual item, such as a part, subassembly, or final product, consists of the following steps

1. Presentation: The item is presented for examination.
2. Examination: The item is examined for one or more nonconforming features. In inspection for variables, examination consists of measuring a dimension or other attribute of the part or product. In inspection for attributes, it involves gaging one or more dimensions or searching the item for flaws.
3. Decision: Based on the examination, a decision is made whether the item satisfies the defined quality standards. The simplest case involves a binary decision, in which the item is deemed either acceptable or unacceptable. In more complicated cases, the decision may involve grading the item into one of more than two possible quality categories, such as grade A, grade B, and unacceptable.
4. Action: The decision should result in some action, such as accepting or rejecting the item, or sorting the item into the most appropriate quality grade. It may also be desirable to take action to correct the manufacturing process to minimize the future occurrence of defects.

Inspection Accuracy: Errors sometimes occur in the inspection procedure during the examination and decision steps. Items of good quality are incorrectly classified as not conforming to specifications, and nonconforming items are mistakenly classified as conforming. These two kinds of mistakes are called Type I and Type II errors. A Type I error occurs when an item of good quality is incorrectly classified as being defective. It is a “false alarm.” A Type II error is when an item of poor quality is erroneously classified as being good. It is a “miss.” The term inspection accuracy refers to the capability of the inspection process to avoid these types of errors. Inspection accuracy is high when few or no errors are made. These error types are portrayed graphically in Table below

		Product is Good	Product is Defective
Outcome	Inspector Accepts Product	OK	Type II error – “Miss” Consumer’s risk
	Inspector Rejects Product	Type I error – “False alarm” Producer’s risk	OK

Automated Inspection: An alternative to manual inspection is automated inspection. Automation of the inspection procedure will almost reduce inspection time per piece.

Automated inspection is defined as the automation of one or more steps involved in the inspection procedure. Automated or semi-automated inspection can be implemented by:

1. Automated presentation of parts by an automatic handling system with manual examination and decision steps.
2. Automated examination and decision making with manual presentation.
3. Examination and decisions are performed automatically.

Inspection techniques: Inspection techniques can be divided into two broad categories:

1. contact and
2. Noncontact.

In contact inspection, physical contact is made between the object and the measuring or gaging instrument, whereas in noncontact inspection no physical contact is made.

Contact Inspection Techniques: Contact inspection involves the use of a mechanical probe or other device that makes contact with the object being inspected. The purpose of the probe is to measure or gage the object in some way. By its nature, contact inspection is often concerned with some physical dimension of the part. Accordingly, these techniques are widely used in the manufacturing industries, in particular in the production of metal parts (machining, stamping, and other metalworking processes). Contact inspection is also used in electrical circuit testing. The principal contact inspection technologies are the following:

- ❖ Conventional measuring and gaging instruments
- ❖ Coordinate measuring machines (CMMs) and related techniques to measure mechanical dimensions
- ❖ Stylus-type surface texture measuring machines to measure surface characteristics such as roughness and waviness
- ❖ Electrical contact probes for testing integrated circuits and printed circuit boards.

Noncontact Inspection Technologies: Noncontact inspection methods utilize a sensor located at a certain distance from the object to measure or gage the desired features. The noncontact inspection technologies can be classified into two categories: optical and nonoptical. Optical inspection technologies use light to accomplish the measurement or gaging cycle. The most important optical technology is machine vision; Nonoptical inspection technologies utilize energy forms other than light to perform the inspection; these other energies include various electrical fields, radiation (other than light), and ultrasonics.

Noncontact inspection offers certain advantages over contact inspection, including the following:

- They avoid damage to the part surface that might result from contact inspection.
- Inspection cycle times are inherently faster. Contact inspection procedures require the contacting probe to be positioned against the part, which takes time. Most of the noncontact methods use a stationary probe that does not need repositioning for each part.
- Noncontact methods can often be accomplished on the production line without the need for any additional handling of the parts, whereas contact inspection usually requires special handling and positioning of the parts.
- It is more feasible to conduct 100% automated inspection, since noncontact methods have faster cycle times and reduced need for special handling.

Coordinate Measuring Machines:

Coordinate metrology is concerned with measuring the actual shape and dimensions of an object and comparing these results with the desired shape and dimensions, as might be specified on a part drawing. In this sense, coordinate metrology consists of the evaluation of the location, orientation, dimensions, and geometry of the part or object.

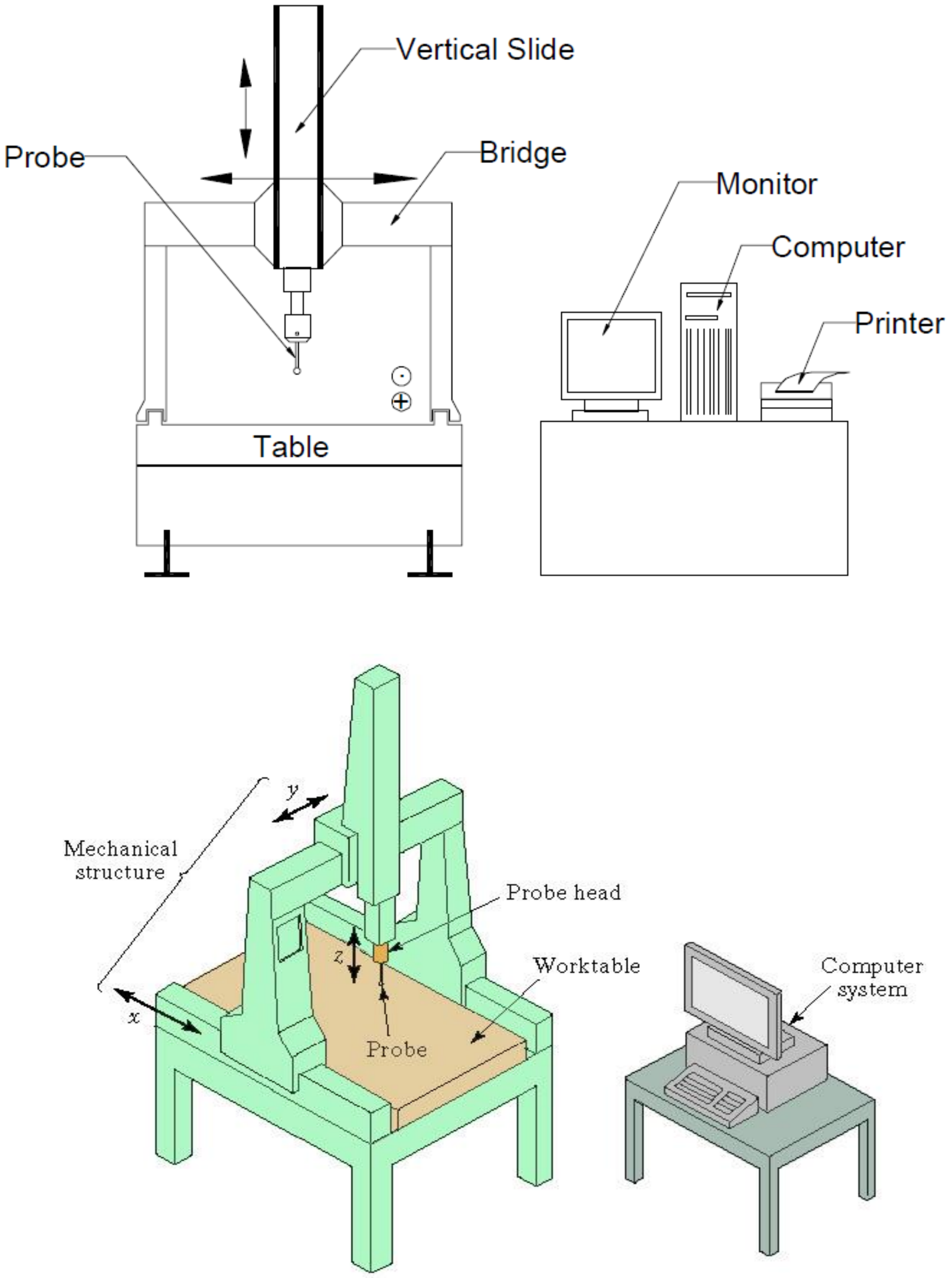
A coordinate measuring machine (CMM) is an electromechanical system designed to perform coordinate metrology. It has a contact probe that can be positioned in three dimensions relative to the surfaces of a work part. The x, y, and z coordinates of the probe can be accurately and precisely recorded to obtain dimensional data about the part geometry.

To accomplish measurements in three-dimensional space, the basic CMM consists of the following components:

- ❖ Probe head and probe to contact the work part surfaces
- ❖ Mechanical structure that provides motion of the probe in three Cartesian axes and displacement transducers to measure the coordinate values of each axis.

In addition, many CMMs include the following:

- ❖ Drive system and control unit to move each of the three axes
- ❖ Digital computer system with application software.



Coordinate Measuring Machine (CMM)

CMM Construction: In the construction of a CMM, the probe is fastened to a mechanical structure that allows movement of the probe relative to the part. The part is usually located on a worktable that is connected to the structure. The two basic components of the CMM are its probe and its mechanical structure.

Probe: The contact probe indicates when contact has been made with the part surface during measurement. The tip of the probe is usually a ruby ball. Ruby is a form of corundum (aluminum oxide), whose desirable properties in this application include high hardness for wear resistance and low density for minimum inertia. Probes can have either a single tip, as in Fig (a) or multiple tips as in Fig (b).

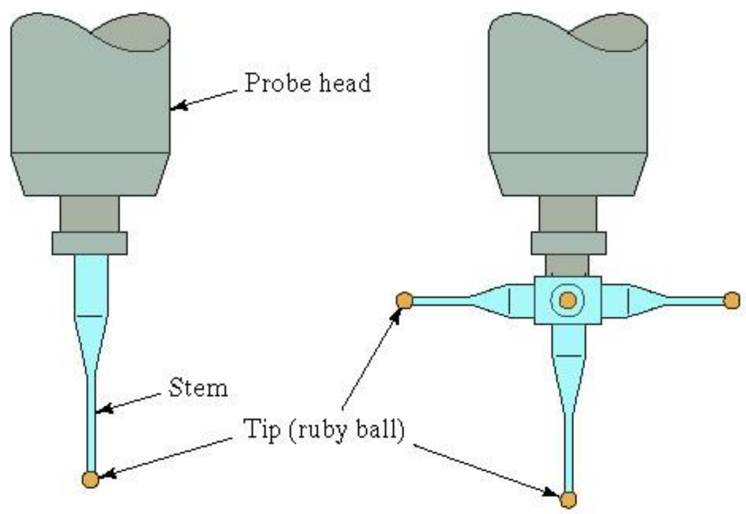


Fig (a) Single tip Fig (b) Multiple tip

Most probes today are touch-trigger probes, which actuate when the probe makes contact with the part surface. Commercially available touch-trigger probes utilize any of various triggering mechanisms, including the following:

(1) A highly sensitive electrical contact switch that emits a signal when the tip of the probe is deflected from its neutral position

(2) A contact switch that permits actuation only when electrical contact is established between the probe and the (metallic) part surface

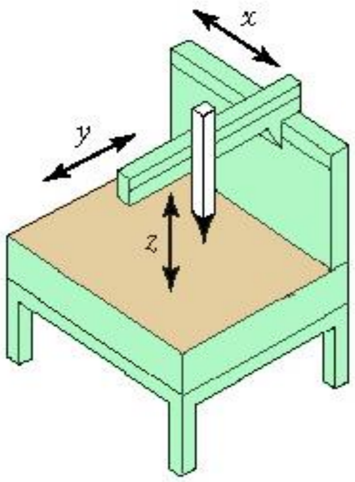
(3) A piezoelectric sensor that generates a signal based on tension or compression loading of the probe.

Immediately after contact is made between the probe and the surface of the object, the coordinate positions of the probe are accurately measured by displacement transducers associated with each of the three linear axes and recorded by the CMM controller. After the probe has been separated from the contact surface, it returns to its neutral position.

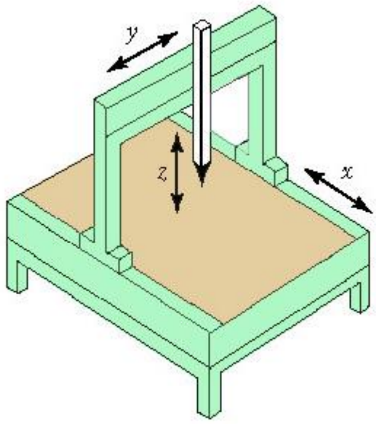
Mechanical Structure: There are various physical configurations for achieving the motion of the probe, each with advantages and disadvantages. Nearly all CMMs have a mechanical structure that fits into one of the following six types, illustrated in Figure:

Six common types of CMM mechanical structures are:

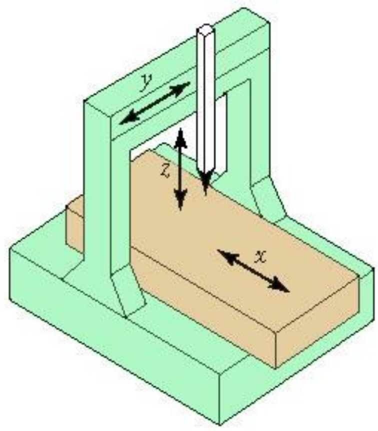
1. Cantilever
2. Moving bridge
3. Fixed bridge
4. Horizontal arm
5. Gantry
6. Column



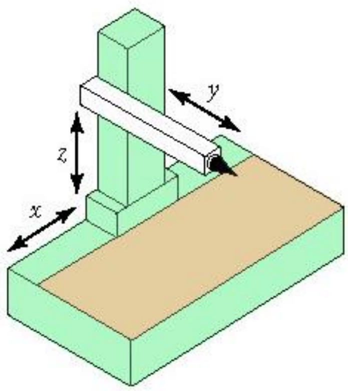
Cantilever



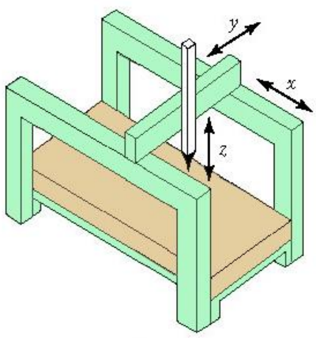
Moving bridge



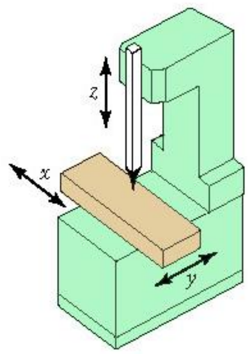
Fixed bridge



Horizontal arm



Gantry



Column

Cantilever: In the cantilever configuration, the probe is attached to a vertical quill that moves in the z-axis direction relative to a horizontal arm that overhangs a fixed worktable. The quill can also be moved along the length of the arm to achieve y-axis motion, and the arm can be moved relative to the worktable to achieve x-axis motion. The advantages of this construction are (1) convenient access to the worktable, (2) high throughput—the rate at which parts can be mounted and measured on the CMM, (3) capacity to measure large work parts (on large CMMs), and (4) relatively small floor space requirements. The disadvantage is lower rigidity than most other CMM structures.

Moving bridge: In the moving bridge design, the probe is mounted on a bridge that is translated relative to a stationary table on which is positioned the part to be measured. This provides a more rigid structure than the cantilever design. However, one of the problems encountered with the moving bridge design is called yawing (also known as walking), in which the two legs of the bridge move at slightly different speeds, resulting in twisting of the bridge. This phenomenon degrades the accuracy of the measurements. The moving bridge design is widely used in industry. It is well suited to the size range of parts commonly encountered in production machine shops.

Fixed bridge: In this configuration, the bridge is attached to the CMM bed, and the worktable is moved in the x-direction beneath the bridge. This construction eliminates the possibility of yawing, hence increasing rigidity and accuracy. However, throughput is adversely affected because of the additional energy needed to move the heavy worktable with the part mounted on it.

Horizontal arm: The horizontal arm configuration consists of a cantilevered horizontal arm mounted to a vertical column. The arm moves vertically and in and out to achieve y-axis and z-axis motions. To achieve x-axis motion, either the column is moved horizontally past the worktable (called the moving ram design), or the worktable is moved past the column (called the moving table design). The moving ram design is illustrated in Figure.

Gantry: This construction is generally intended for inspecting large objects. The probe quill (z-axis) moves relative to the horizontal arm extending between the two rails of the gantry. The workspace in a large gantry-type CMM can be as great as 25 m (82 ft) in the x-direction, by 8 m (26 ft) in the y-direction, and by 6 m (20 ft) in the z-direction.

Column: This configuration is similar to the construction of a machine tool. The x- and y-axis movements are achieved by moving the worktable, while the probe quill is moved vertically along a rigid column to achieve z-axis motion.

CMM Applications and Benefits:

The most common applications are off-line inspection and on-line/post-process inspection (Section 21.4.1). Machined components are frequently inspected using CMMs. One common application is to check the first part machined on a CNC machine tool. If the first part passes inspection, then the remaining parts produced in the batch are assumed to be identical to the first. Inspection of parts and assemblies on a CMM is generally accomplished using sampling techniques. One reason for this is the time required to perform the measurements.

Other CMM applications include audit inspection and calibration of gages and fixtures. Audit inspection refers to the inspection of incoming parts from a vendor to ensure that the vendor's quality control systems are reliable. This is usually done on a sampling basis. In effect, this application is the same as post-process inspection. Gage and fixture calibration involves the measurement of various gages, fixtures, and other tooling to validate their continued use.

The advantages of using CMMs over manual inspection methods are the following:

- Reduced inspection cycle time: Because of the automated techniques included in the operation of a CMM, inspection procedures are faster and labor productivity is improved. Reduced inspection cycle time translates into higher throughput.
- Flexibility: A CMM is a general-purpose machine that can be used to inspect a variety of different part configurations with minimal changeover time.
- Reduced operator errors: Automating the inspection procedure reduces human errors in measurements and setups.
- Greater inherent accuracy and precision: A CMM is inherently more accurate and precise than the manual surface plate methods traditionally used for inspection.
- Avoidance of multiple setups: Traditional inspection techniques often require multiple setups to measure multiple part features and dimensions. In general, all

measurements can be made in a single setup on a CMM, thereby increasing throughput and measurement accuracy.

Machine Vision:

Machine vision consists of the acquisition of image data, followed by the processing and interpretation of these data by computer for some industrial application. Machine vision is a growing technology, with its principal applications in automated inspection and robot guidance. Vision systems are classified as being either 2-D or 3-D.

The operation of a machine vision system can be divided into the following three functions:

1. Image acquisition and digitization
2. Image processing and analysis
3. interpretation.

These functions and their relationships are illustrated schematically in Figure

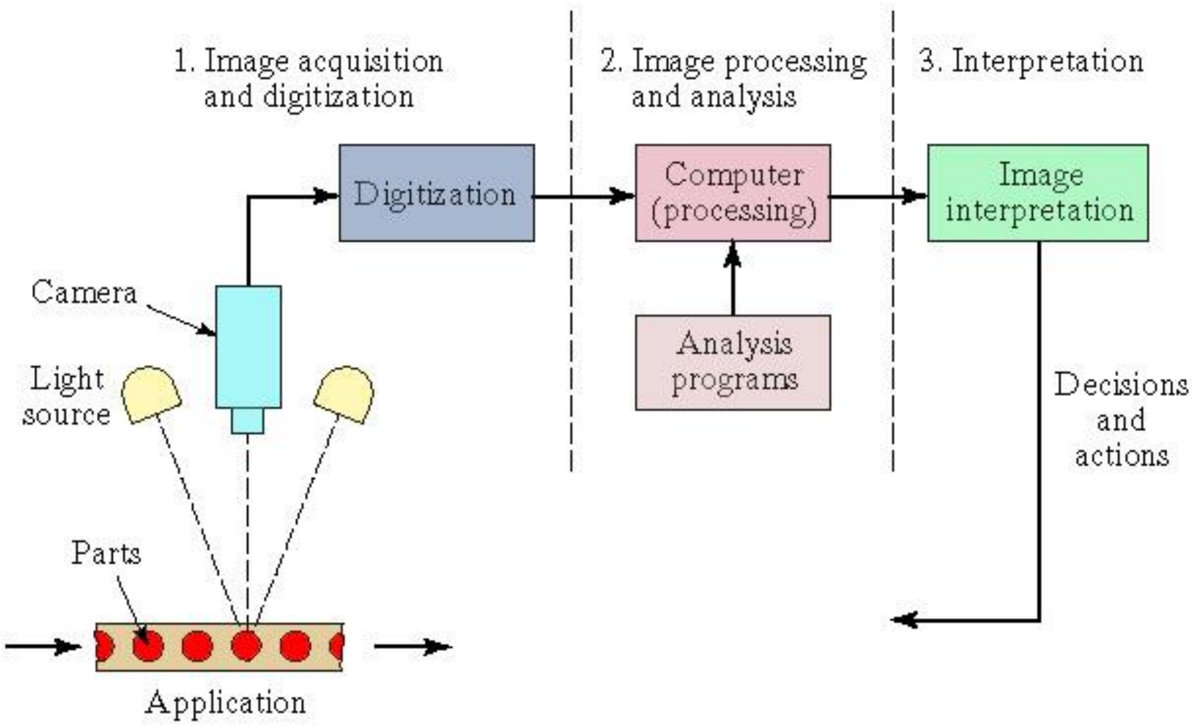


Image acquisition and digitization: Image acquisition and digitization is accomplished using a digital camera and a digitizing system to store the image data for subsequent analysis. The camera is focused on the subject of interest, and an image is obtained by dividing the viewing area into a matrix of discrete picture elements (called pixels), in which each element has a value that is proportional to the light intensity of that portion of the scene. The intensity value for each pixel is converted into its equivalent digital value by an ADC.

Image Processing and Analysis: The second function in the operation of a machine vision system is image processing and analysis. The amount of data that must be processed is significant. The data for each frame must be analyzed within the time required to complete one scan. A number of techniques have been developed for analysing the image data in a machine vision system. One category of techniques in image processing and analysis, called segmentation, is intended to define and separate regions of interest within the image. Two of the common segmentation techniques are thresholding and edge detection.

Thresholding involves the conversion of each pixel intensity level into a binary value, representing either white or black. This is done by comparing the intensity value of each pixel with a defined threshold value. If the pixel value is greater than the threshold, it is given the binary bit value of white, say 1; if less than the defined threshold, then it is given the bit value of black, say 0. Reducing the image to binary form by means of thresholding usually simplifies the subsequent problem of defining and identifying objects in the image. Edge detection is concerned with determining the location of boundaries between an object and its surroundings in an image. This is accomplished by identifying the contrast in light intensity that exists between adjacent pixels at the borders of the object.

Interpretation: For any given application, the image must be interpreted based on the extracted features. The interpretation function is usually concerned with recognizing the object, a task called object recognition or pattern recognition. The objective in this task is to identify the object in the image by comparing it with predefined models or standard values. Two commonly used interpretation techniques are template matching and feature weighting. Template matching refers to various methods that attempt to compare one or more features of an image with the corresponding features of a model or template stored in computer memory. The most basic template matching technique is one in which the image is compared, pixel by pixel, with a corresponding computer model. Feature weighting is a technique in which several features (e.g., area, length, and perimeter) are combined into a single measure by assigning a weight to each feature according to its relative importance in identifying the object. The score of the object in the image is compared with the score of an ideal object residing in computer memory to achieve proper identification.

Machine Vision Applications: The reason for interpreting the image is to accomplish some application. Machine vision applications in manufacturing divide into three categories: (1) inspection, (2) identification, and (3) visual guidance and control.

Inspection: By far, quality control inspection is the biggest category. Machine vision installations in industry perform a variety of automated inspection tasks, most of which are either on-line/in-process or on-line/post-process. Typical industrial inspection tasks include the following:

- Dimensional measurement: These applications involve determining the size of certain dimensional features of parts or products usually moving at relatively high speeds on a moving conveyor. The machine vision system must compare the features (dimensions) with the corresponding features of a computer-stored model and determine the size value.
- Dimensional gaging: This is similar to the preceding except that a gaging function rather than a measurement is performed.
- Verification of the presence of components: This is done in an assembled product such as a printed circuit board assembly.
- Verification of hole location and number of holes: Operationally, this task is similar to dimensional measurement and verification of components.
- Detection of surface flaws and defects: Flaws and defects on the surface of a part or material often reveal themselves as a change in reflected light. The vision system can identify the deviation from an ideal model of the surface.
- Detection of flaws in a printed label: The defect can be in the form of a poorly located label or poorly printed text, numbering, or graphics on the label.

Part identification applications use a vision system to recognize and perhaps distinguish parts or other objects so that some action can be taken. The applications include part sorting, counting different types of parts flowing past along a conveyor, and inventory monitoring. Part identification can usually be accomplished by 2-D vision systems.

Visual guidance and control involves applications in which a vision system is teamed with a robot or similar machine to control the movement of the machine. The term vision guided robotic (VGR) system is used in connection with this technology. Examples of VGR applications include seam tracking in continuous arc welding, part positioning and/or reorientation, picking parts from moving conveyors or stationary bins, collision avoidance, machining operations, and assembly tasks.

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BMS Institute of Technology and Management

Bengaluru 64

Department of Mechanical Engineering

Course Name: Computer Integrated Manufacturing (17ME62)

FLEXIBLE MANUFACTURING SYSTEMS (FMS)

(Module 3)

Course Coordinator

Dr. K.M. Sathish Kumar

Professor & Head

Department of Mechanical Engineering

FLEXIBLE MANUFACTURING SYSTEM

"A Flexible Manufacturing System (FMS) consists of a group of processing stations (usually CNC machine tools), interconnected by an automated material handling and storage system and controlled by an integrated computer system"

FMS is called flexible because it is capable of processing a variety of different part styles and quantities of production can be adjusted in response to changing demand patterns.

It is suited for mid variety and mid volume production range

- Flexible manufacturing system (FMS) is one of the machine cell types used to implement GT.
- FMS is the most automated and technologically sophisticated of the GT cells.
- An FMS typically involves ***multiple automated stations*** and is capable of ***variable routings*** among stations. Routing and storage are carried out by an ***automated material handling system***. Whole system is controlled by an ***integrated computer system***.
- FMS relies on GT principles. Thus,
  - An FMS is capable of producing a single part family or a limited range of part families.

What makes FMS flexible?

- What makes a system flexible?
  - Flexibility of a manufacturing system depends on the following questions:
    - Can the system machine different part configurations **in a mix rather than in batches**?
    - Does the system **permit changes in production schedule** and part mix?
    - Is the system **capable of continuing to operate even though one machine experiences a breakdown** (e.g. While repairs are being made on a broken machine, its work is temporarily assigned to the other machine)?
    - When new part designs are developed, can **NC part programs are written off-line** and then downloaded to the system for execution?
  - If the answers of all these questions are “yes”, then the system is flexible.

- Tests of Flexibility
  - To qualify as being flexible, a manufacturing system should satisfy the following criteria:
    - ***Part variety test*:** Can the system process different parts in a non-batch mode?
    - ***Schedule change test*:** Can the system accept changes in production schedule?
    - ***Error recovery test*:** Can the system respond to equipment malfunctions and breakdowns so that production is not completely disrupted?
    - ***New part test*:** Can the system accomodate introduction of new part designs?
  - The most important criteria are "**Part variety test**" and "**Schedule change test**". Others two can be implemented at various levels.

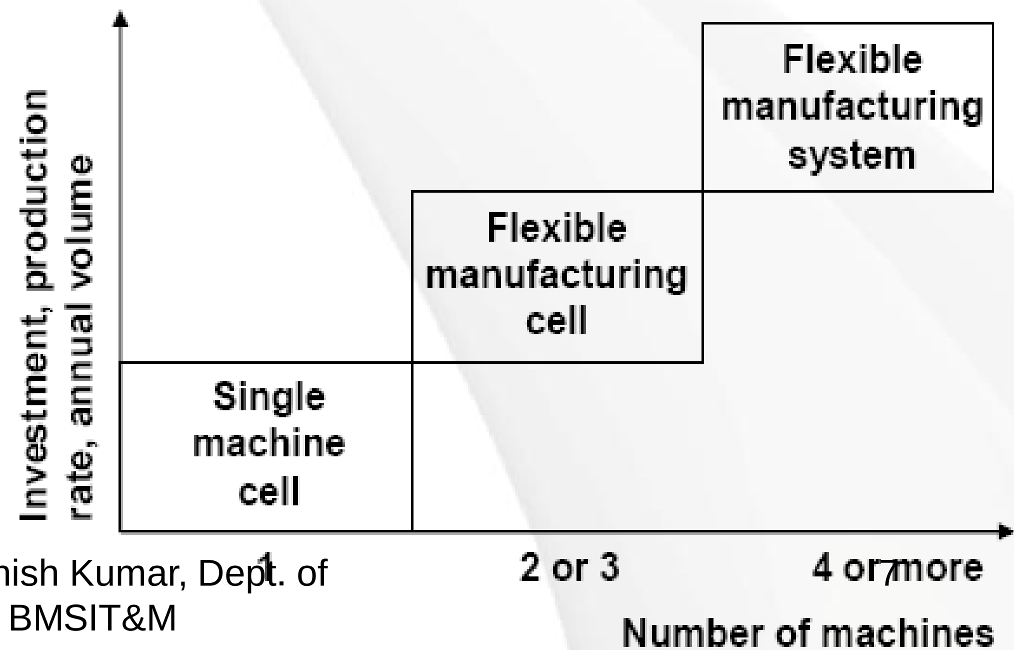
Types of Flexibility

- Machine flexibility
- Production flexibility
- Mix flexibility
- Product flexibility
- Routing flexibility
- Volume flexibility
- Expansion flexibility

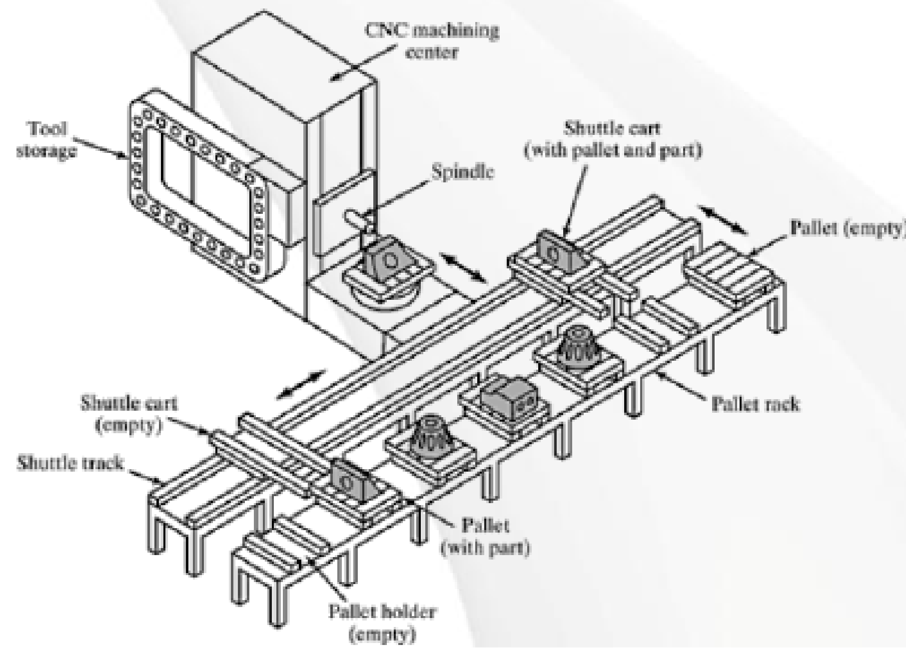
Types of FMS

- Types of FMS
  - Each FMS is designed for a specific application, that is a specific family of parts and processes Therefore, each FMS is custom engineered.

    → ***Each FMS is unique.***
  - Two ways to classify FMSs:
    - By the number of machines
    - By the level of flexibility
  - According to number of machines, flexible manufacturing systems are classified into three:
    - **Single machine cell**
    - **Flexible manufacturing cell**
    - **Flexible manufacturing system**



- Types of FMS – According to number of machines
  - **Single Machine Cell** (Type I A)
    - Consists one CNC machining center combined with parts storage system for unattended operation.
    - Completed parts are periodically unloaded from the parts storage unit, and raw workparts are loaded into it.
    - The system satisfies three of the four flexibility tests;
      - part variety test, schedule change test, and new part test.
    - The system fails error recovery test.
    - If the machine breaks down, production stops.



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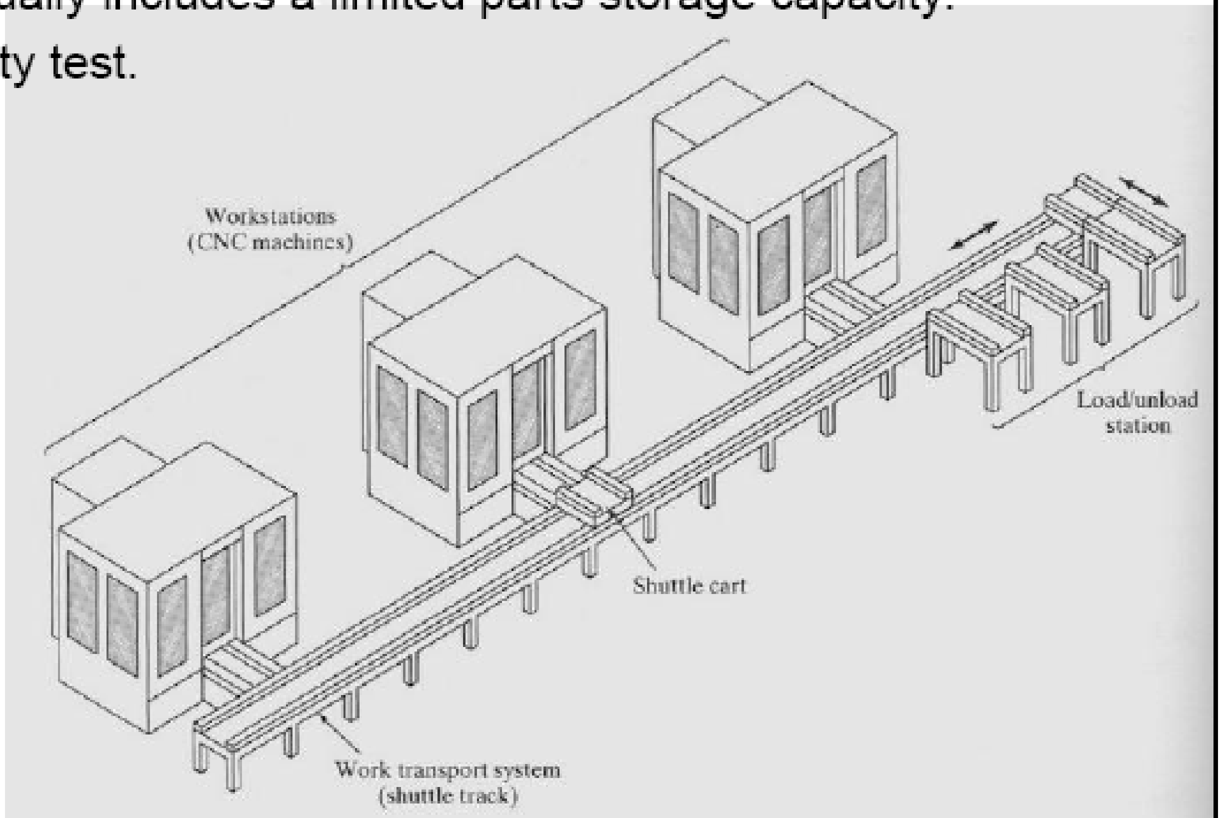
- Types of FMS – According to number of machines
  - **Flexible Manufacturing Cell (FMC)**
    - Consists of two or three processing workstations (typically CNC) plus a part handling system.
    - Part handling system is connected to a load/unload station.
    - The handling system usually includes a limited parts storage capacity.
    - Satisfies the four flexibility test.



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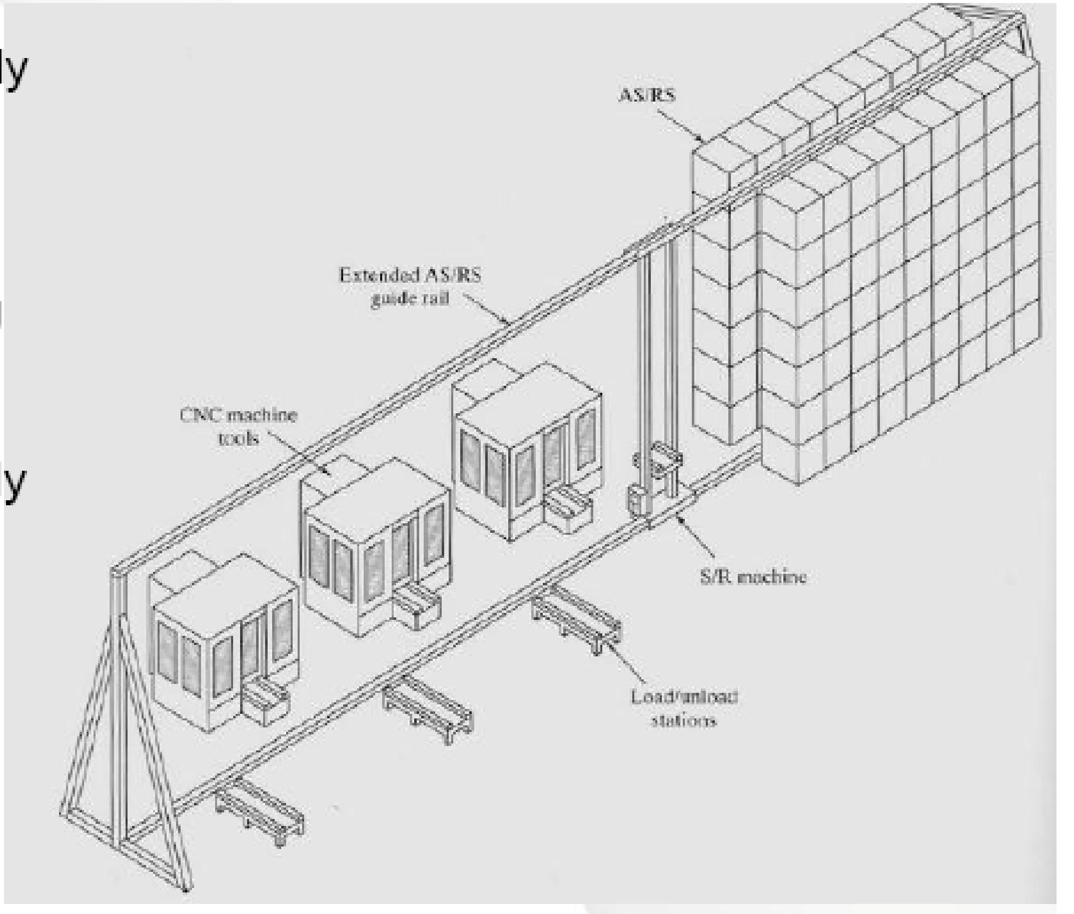
- Types of FMS – According to number of machines
  - Flexible Manufacturing System (FMS)

- Has four or more processing workstations connected mechanically by a common part handling system and electronically by a distributed computer system.

- Generally includes non-processing workstations (e.g. Coordinate measuring machine – CMM) that support production but do not directly participate in it.

- Computer control system is generally larger and more sophisticated, often including functions such as diagnostics and tool monitoring.



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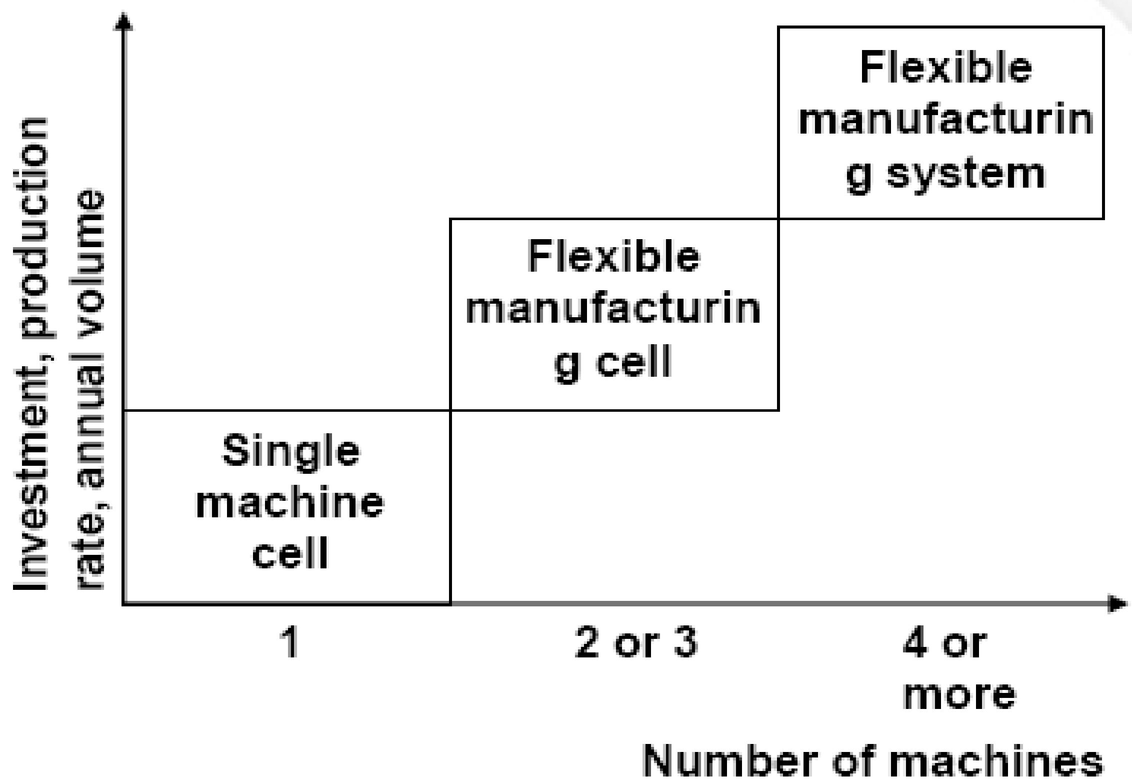
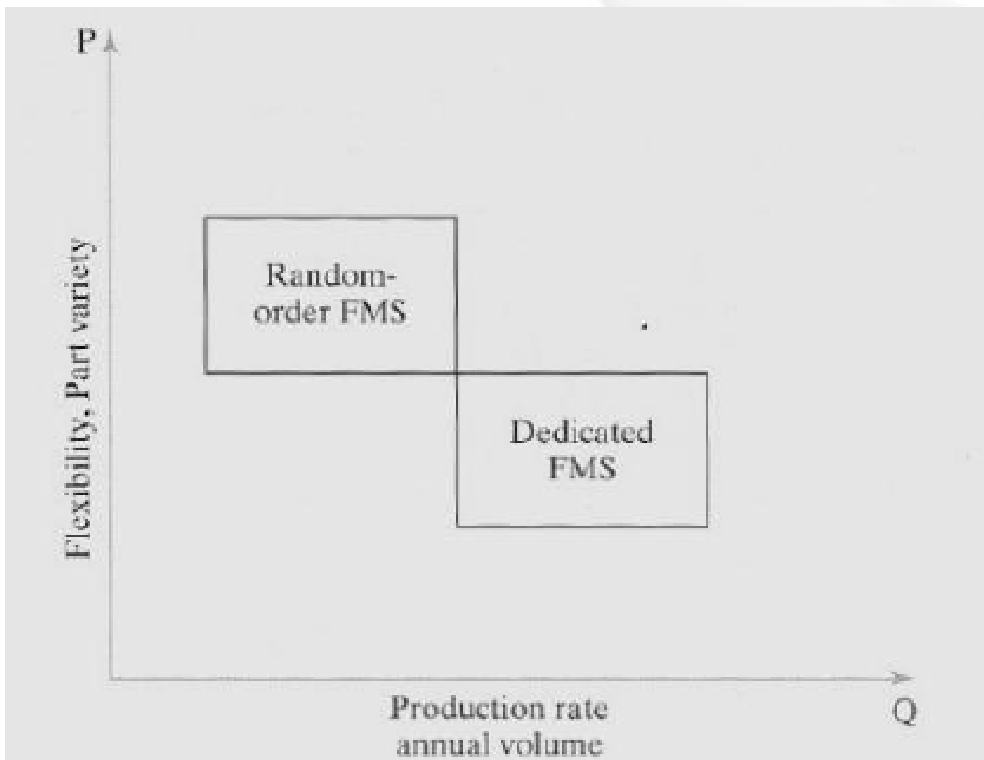

Investment, production rate, annual volume
Flexible manufacturing system
Flexible manufacturing cell
Single machine cell
1
2 or 3
4 or more
Number of machines

- Types of FMS
  - **According to level of flexibility**, flexible manufacturing systems are classified into two
    - **dedicated FMS**
    - **random-order FMS**



- Types of FMS - According to level of flexibility
  - **Dedicated FMS**
    - **A dedicated FMS is designed to produce a limited variety of part styles**,
    - The term "*special manufacturing system*" has also been used in reference to this FMS type"
    - Instead of using general purpose machines, the machines designed for specific processes are used, thus increasing the production rate of the system.
    - In some instances, the machine sequence may be identical for all parts processed and so a transfer line may be appropriate. Indeed, the term "*flexible transfer line*" is sometimes used for this case.

- Types of FMS - According to level of flexibility
  - **Random-order FMS**
    - **A random-order FMS is more appropriate when the part family is large.**
    - To accommodate these variations, the random-order FMS must be more flexible than the dedicated FMS.
    - It is equipped with general-purpose machines 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.

Components of FMS

- FMS Components
  - Workstations
  - Material handling and storage system
  - Computer control system
  - Workers

- Workstations
  - Not necessarily CNC machine tools!
  - According to the operation, following types can be observed
    - Load/Unload stations
    - Machining stations
    - Other processing stations
    - Assembly
    - Other stations and equipment

- Workstations
  - Load/Unload stations
    - Physical interface between the FMS and the rest of the factory
    - **Raw workparts enter the system at this point. and finished parts exit the system from here.**
    - Loading and unloading can be accomplished either manually or by automated handling systems.
    - The load/unload station should include a data entry unit and monitor for communication between the operator and the computer system.

- Workstations
  - Machining stations
    - **The most common applications of FMSs are machining operations.**
    - *CNC machining center* is the most common machining station used.
    - CNC machining centers have some features that make them compatible with the FMS.
      - Automatic tool changing systems
      - Tool storage systems
      - Use of palletized workparts
      - Number of axes (more axes mean more flexibility)
      - Automatic pallet changers

- Workstations
  - Other processing stations
    - The processing workstations consist of pressworking operations, such as punching, shearing, and certain bending and forming processes.
  - Assembly
    - Some FMSs are designed to perform assembly operations.
    - Industrial robots are often used as the automated workstations in these flexible assembly systems.
    - E.g. programmable component placement machines widely used in electronics assembly.

- Material handling and storage system
  - Functions of the handling system in an FMS:
    - Random, independent movement of work-parts between stations
    - Handle a variety of workpart configurations
    - Temporary storage
    - Convenient access for loading and unloading work-parts
    - Compatible with computer control
  - Functions of the handling equipment in an FMS:
    - Primary handling system: The system is responsible for moving workparts between stations
    - Secondary handling system: Located at the workstations to transfer the parts from the primary system to processing stations

- Material handling and storage system
  - FMS layout type and the material handling system are closely related.
  - Material handling equipment used in different 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 robot

- Material handling and storage system
  - In-line layout
    - Machines and the handling system are arranged in a straight line
    - There may be two different cases
      - Flow only in one direction (Type III A)
      - Flow in both directions

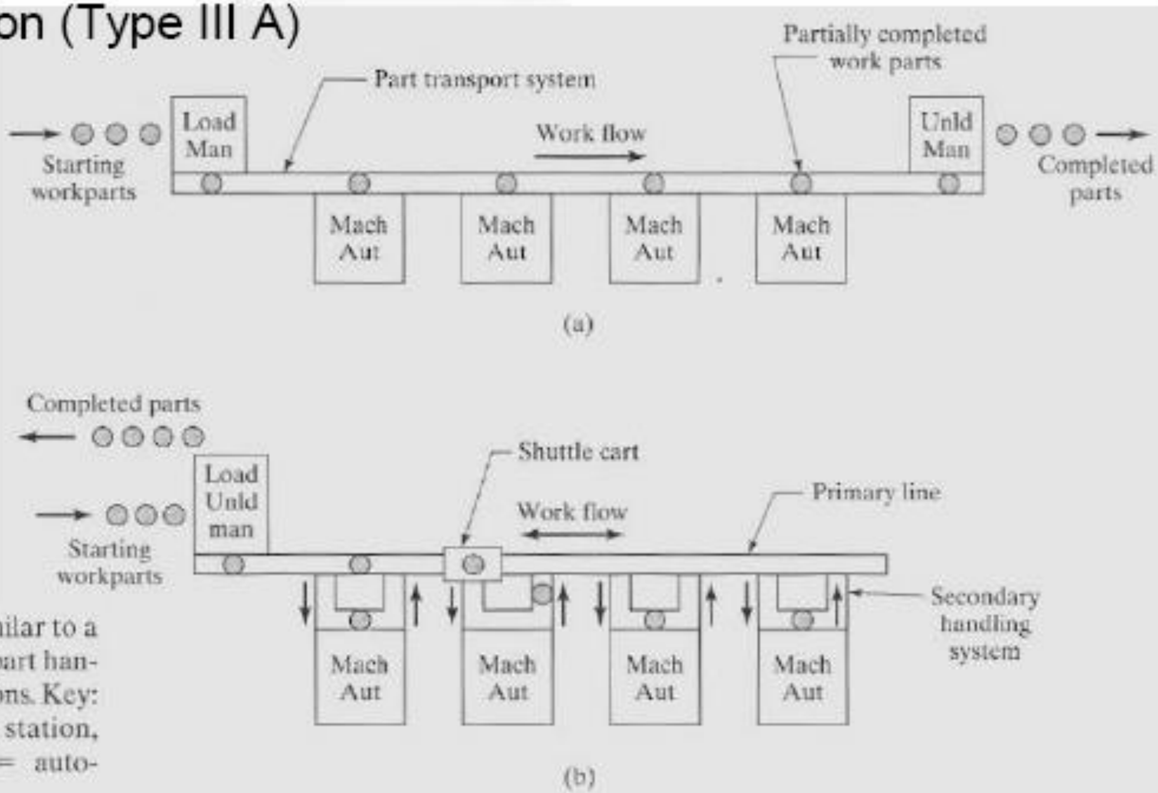
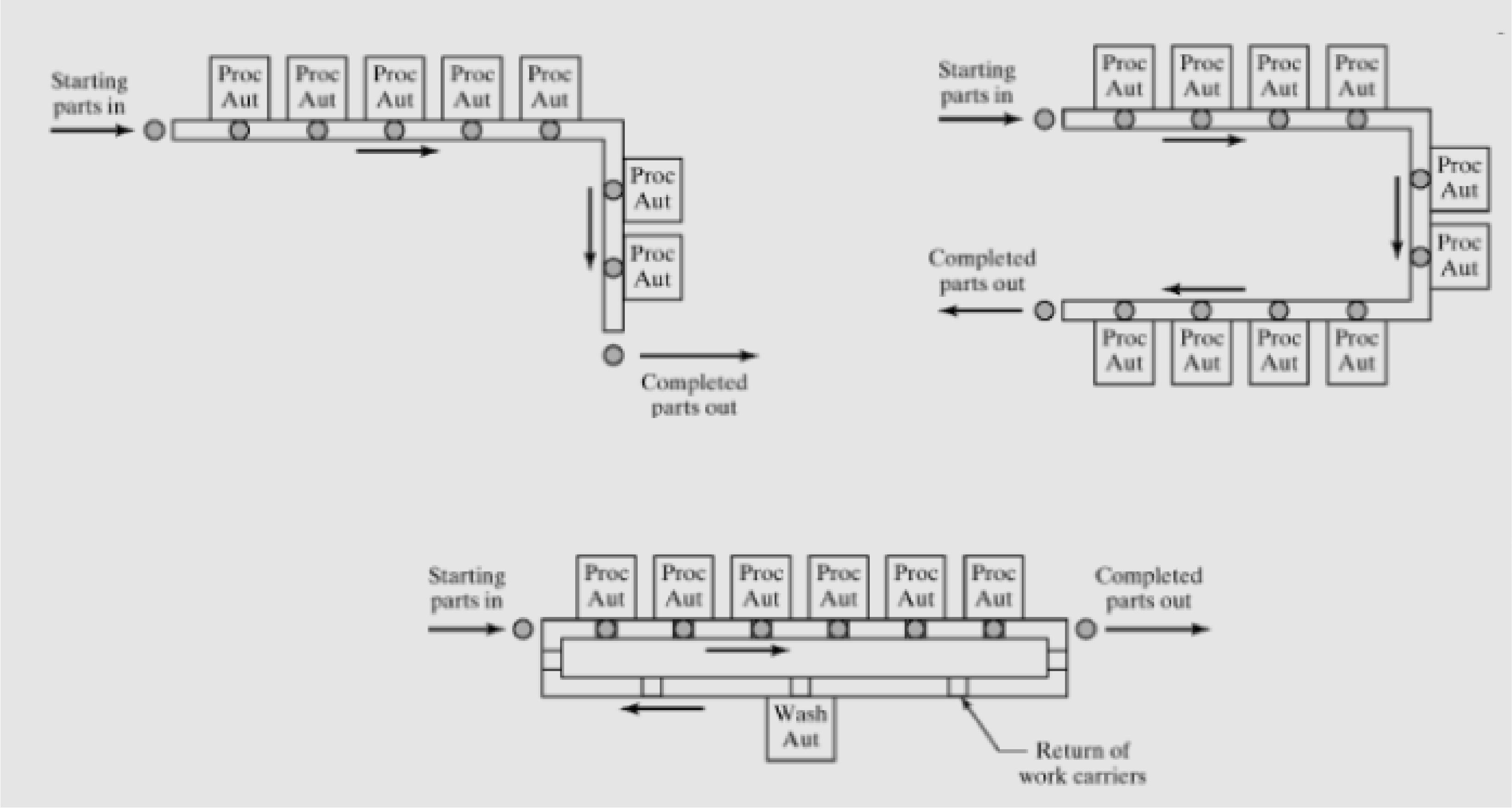
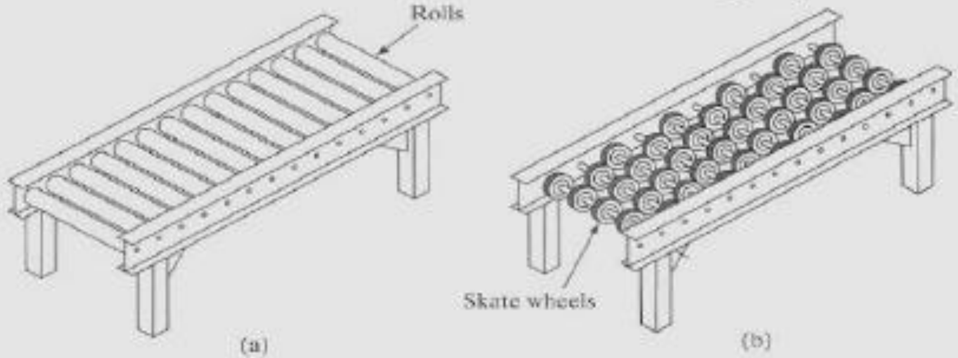


Figure 16.7 In-line FMS layouts: (a) one direction flow similar to a transfer line and (b) linear transfer system with secondary part handling system at each station to facilitate flow in two directions. Key: Load = parts loading station, UnLd = parts unloading station, Mach = machining station, Man = manual station, Aut = automated station.

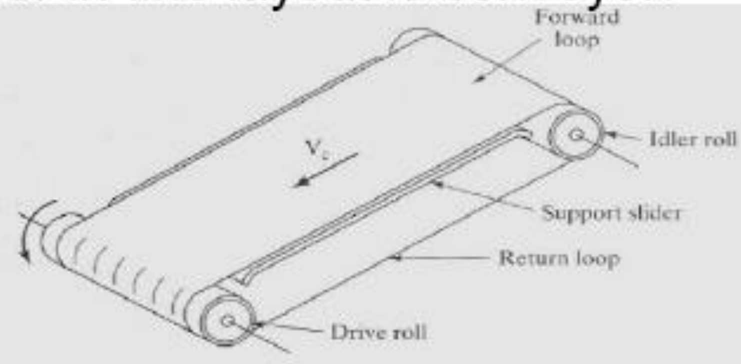
- Material handling and storage system
  - In-line layout
    - The line may be configured in segments (semented in-line layout)



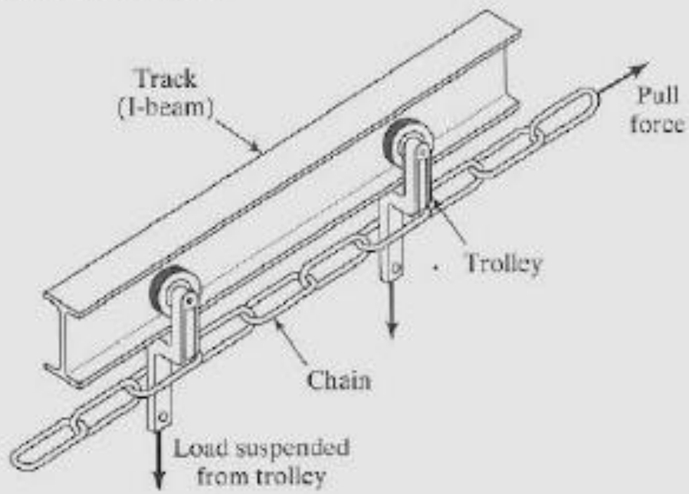
- Material handling and storage system
  - In-line layout
    - Common material handling system for in-line layout is conveyor.



(a) Roller conveyor and (b) skate wheel convevor.



Belt conveyor



Overhead trolley conveyor.

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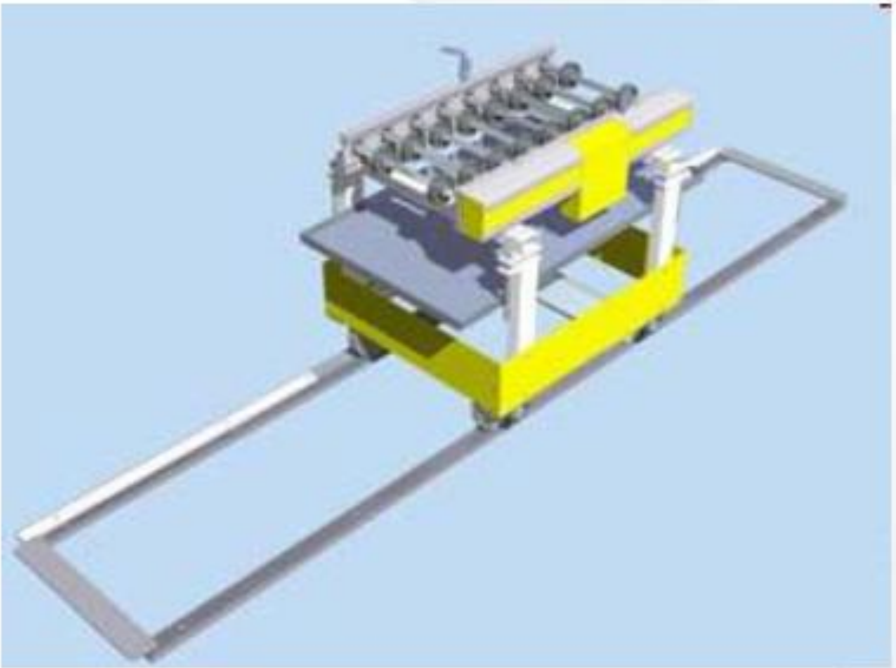
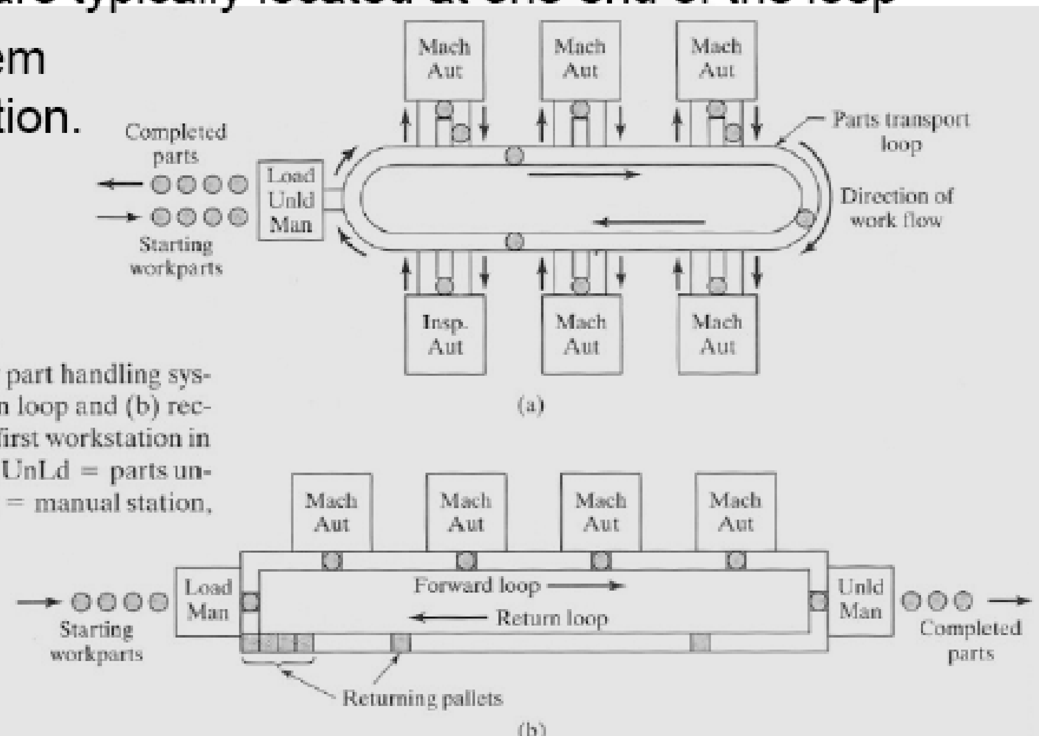
- Material handling and storage system
  - In-line layout
    - Rail guided vehicle systems are also used.



- Material handling and storage system
  - Loop layout
    - the workstations are organized in a loop that is served by a part handling system in the same shape, as shown below
    - Parts usually flow in one direction around the loop, with the capability to stop and be transferred to any station
    - The load/unload station(s) are typically located at one end of the loop
    - A secondary handling system is required at each workstation.



(a) FMS loop layout with secondary part handling system at each station to allow unobstructed flow on loop and (b) rectangular layout for recirculation of pallets to the first workstation in the sequence. Key: Load = parts loading station, UnLd = parts unloading station, Mach = machining station, Man = manual station, Aut = automated station.

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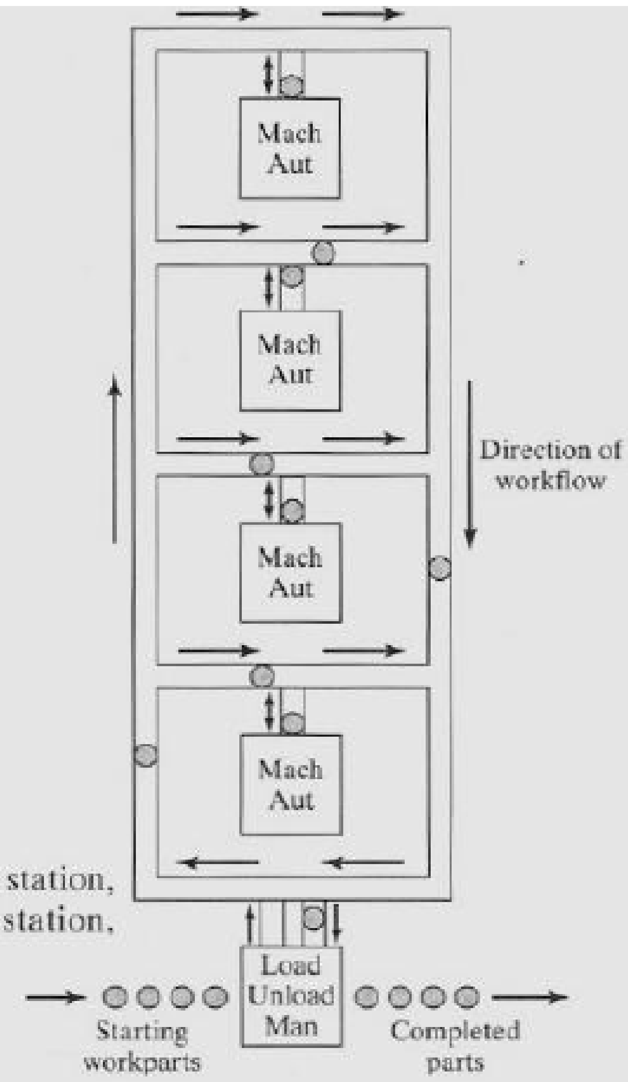
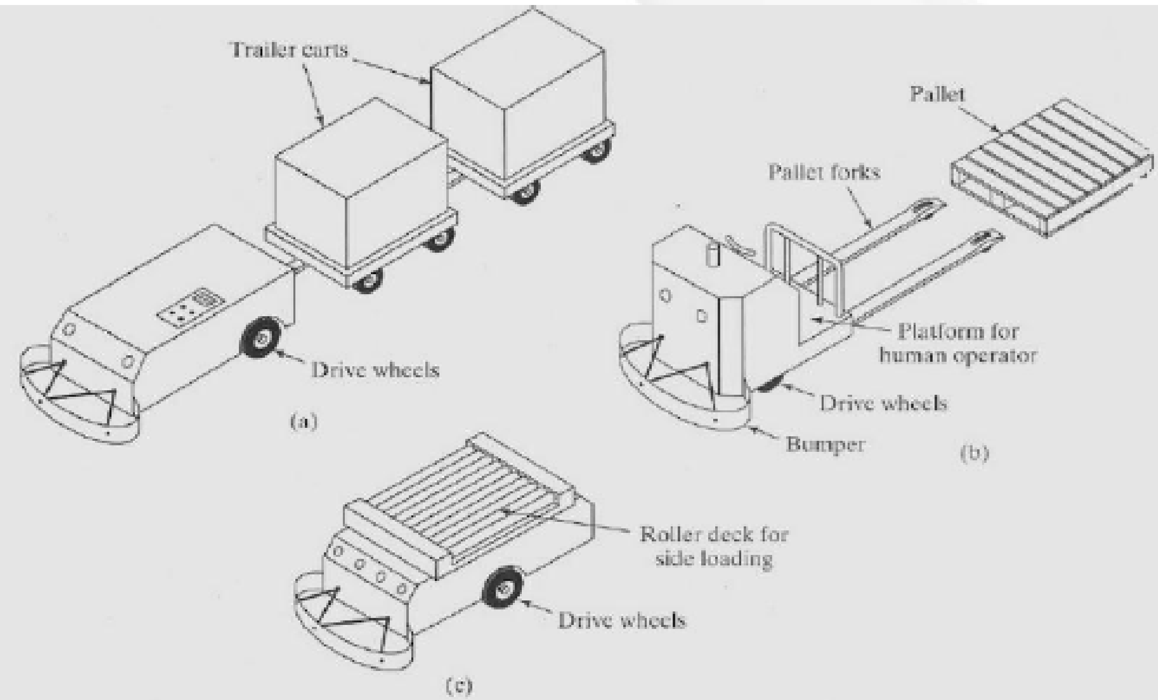
- Material handling and storage system
  - Ladder layout
    - Consists of a loop with rungs between the straight sections of the loop, on which workstations are located
    - The rungs increase the possible ways of getting from one machine to the next
    - Rungs obviate the need for a secondary handling system
    - Average travel distance is reduced thereby



FMS ladder layout. Key: Load = parts loading station, UnLd = parts unloading station, Mach = machining station, Man = manual station, Aut = automated station.

- Material handling and storage system
  - Ladder layout
    - Conveyors and rail guided vehicle systems are used also in ladder layout.
    - Automated guided vehicles (AGV) are also utilized in ladder layouts.



Three types of automated guided vehicles: (a) driverless automated guided train, (b) AGV pallet truck, and (c) unit load carrier.

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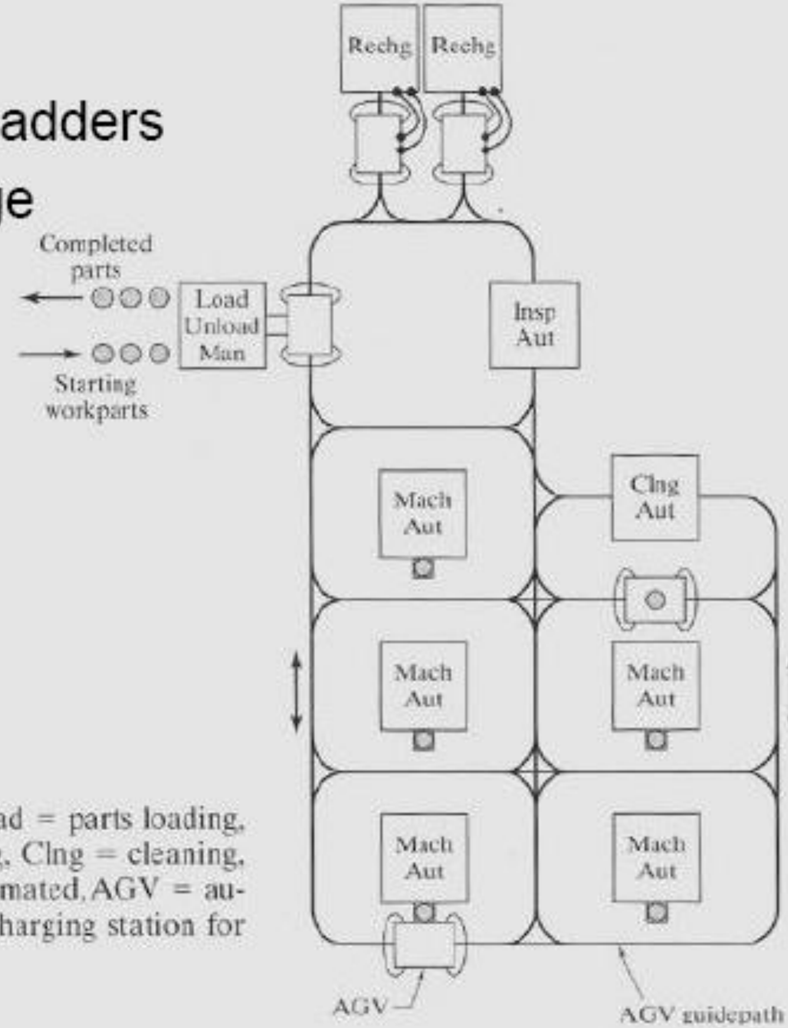
- Material handling and storage system
  - Open field layout
    - Consists of multiple loops and ladders
    - Suitable if the part family is large
    - Open field layouts utilize
      - AGVs and
      - In-floor towline carts



Open field FMS layout. Key: Load = parts loading, UnLd = parts unloading, Mach = machining, Clng = cleaning, Insp = inspection, Man = manual, Aut = automated, AGV = automated guided vehicle, Rechg = battery recharging station for AGVs.

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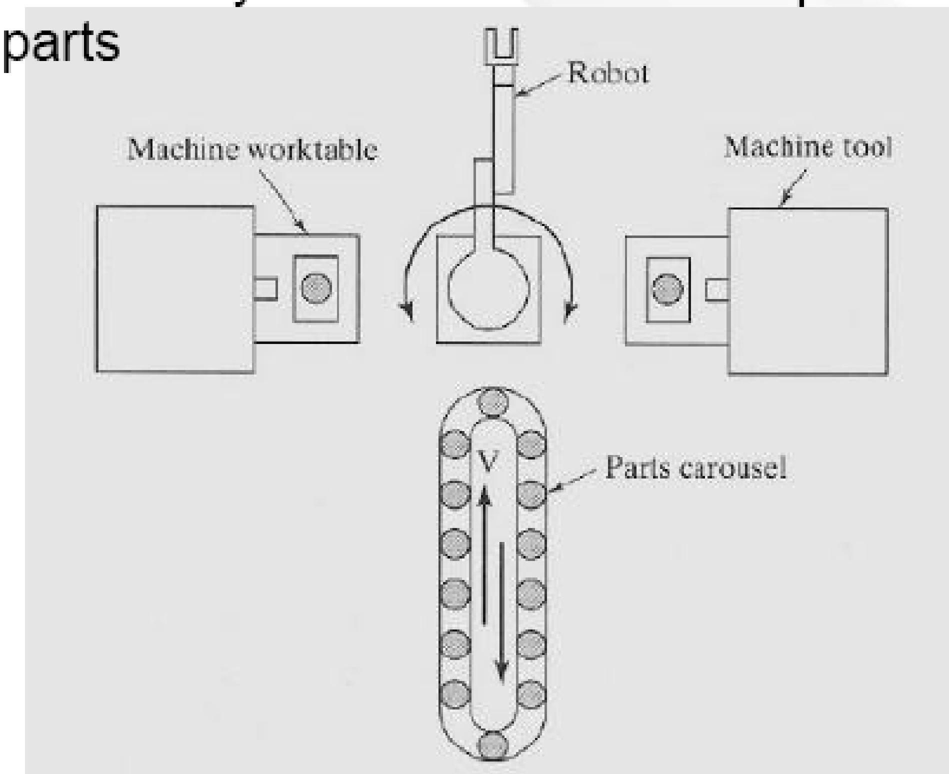
- Material handling and storage system
  - Robot centered layout
    - Uses one or more robots as the material handling system
    - Industrial robots can he equipped with grippers
    - robot-centered FMS layouts are often used to process cylindrical or disk-shaped parts



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Computer Control System:

A typical FMS computer system consists of a central computer and microcomputers controlling the individual machines and other components.

Functions of FMS computer control system can be grouped into following categories:

1. Workstation control
2. Distribution of control instructions to workstations
3. Production control
4. Traffic control
5. Shuttle control

7. Workpiece monitoring
8. Tool control
    - Tool location
    - Tool life monitoring
8. Performance monitoring and reporting
9. Diagnostics

Human Resources:

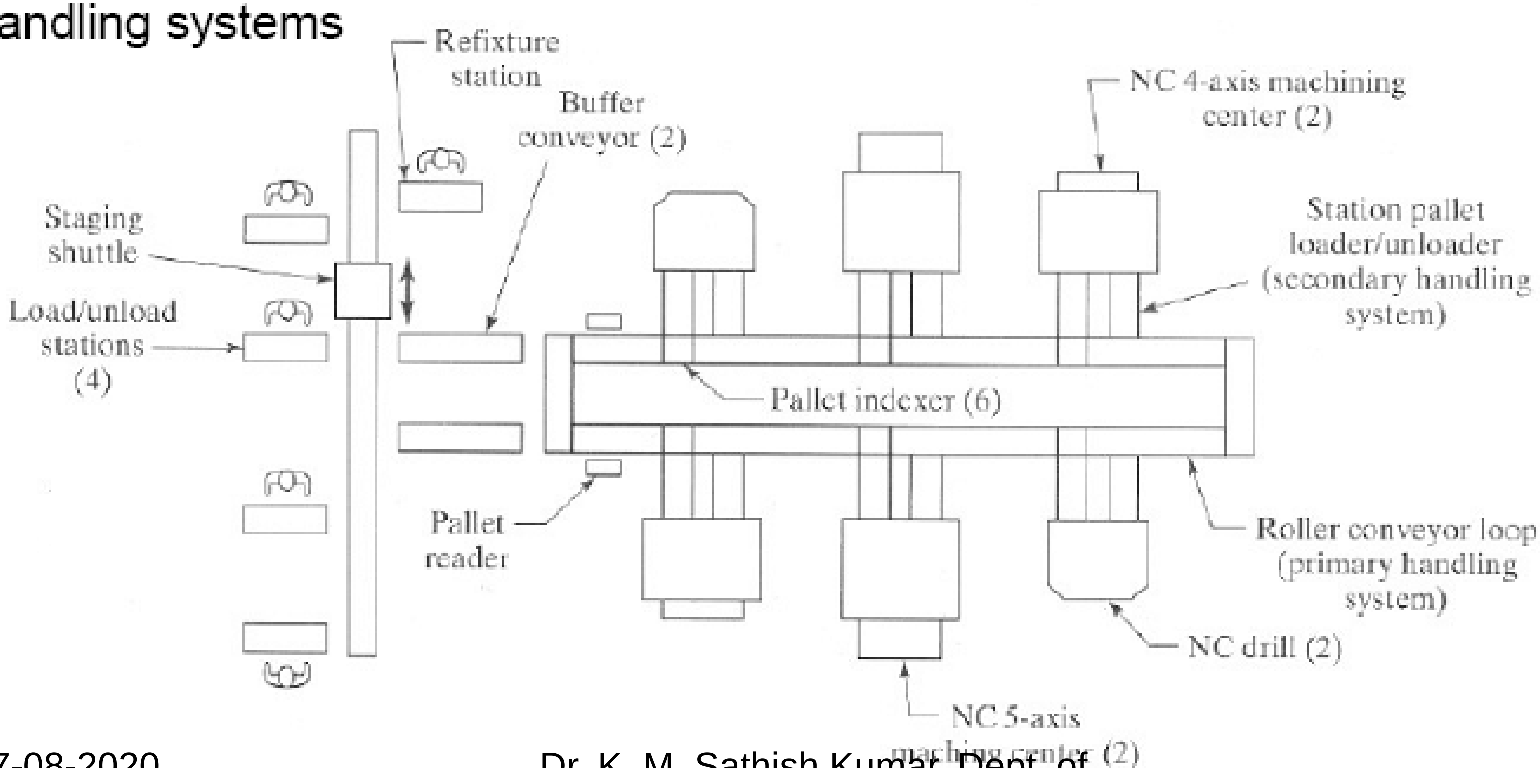
In FMS humans are required to manage the operations of the FMS. Functions typically performed by FMS includes

- Loading raw workparts into the system
- Unloading finished workparts from the system
- Changing and setting tools
- Equipment maintenance and repair
- NC part programming in a machining system
- Programming and operating the computer system
- Overall management of the system

FMS Applications

Layout of Ingersoll-Rand

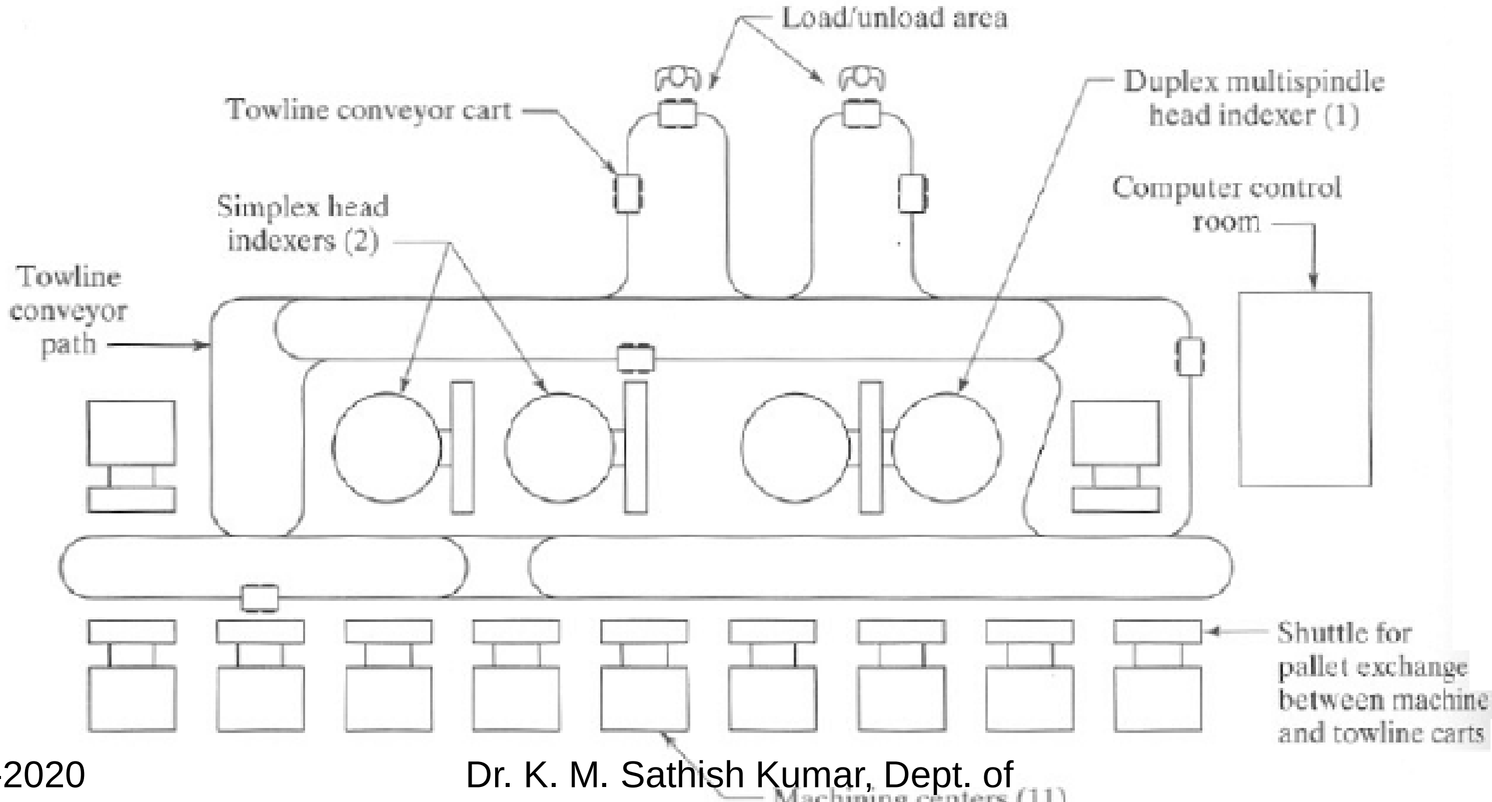
- installed in the late 1960s
- The parts begin as cast iron and aluminum castings and are machined into motor cases, hoist casings
- consists of two five-axis machining centers, two four-axis machining centers, and two four-axis drilling machines.
- powered roller conveyor system is used for the primary and secondary workpart handling systems



Layout of Ingersoll-Rand FMS in Roanoke, Virginia

FMS Applications
Layout of Avco-Lycomming

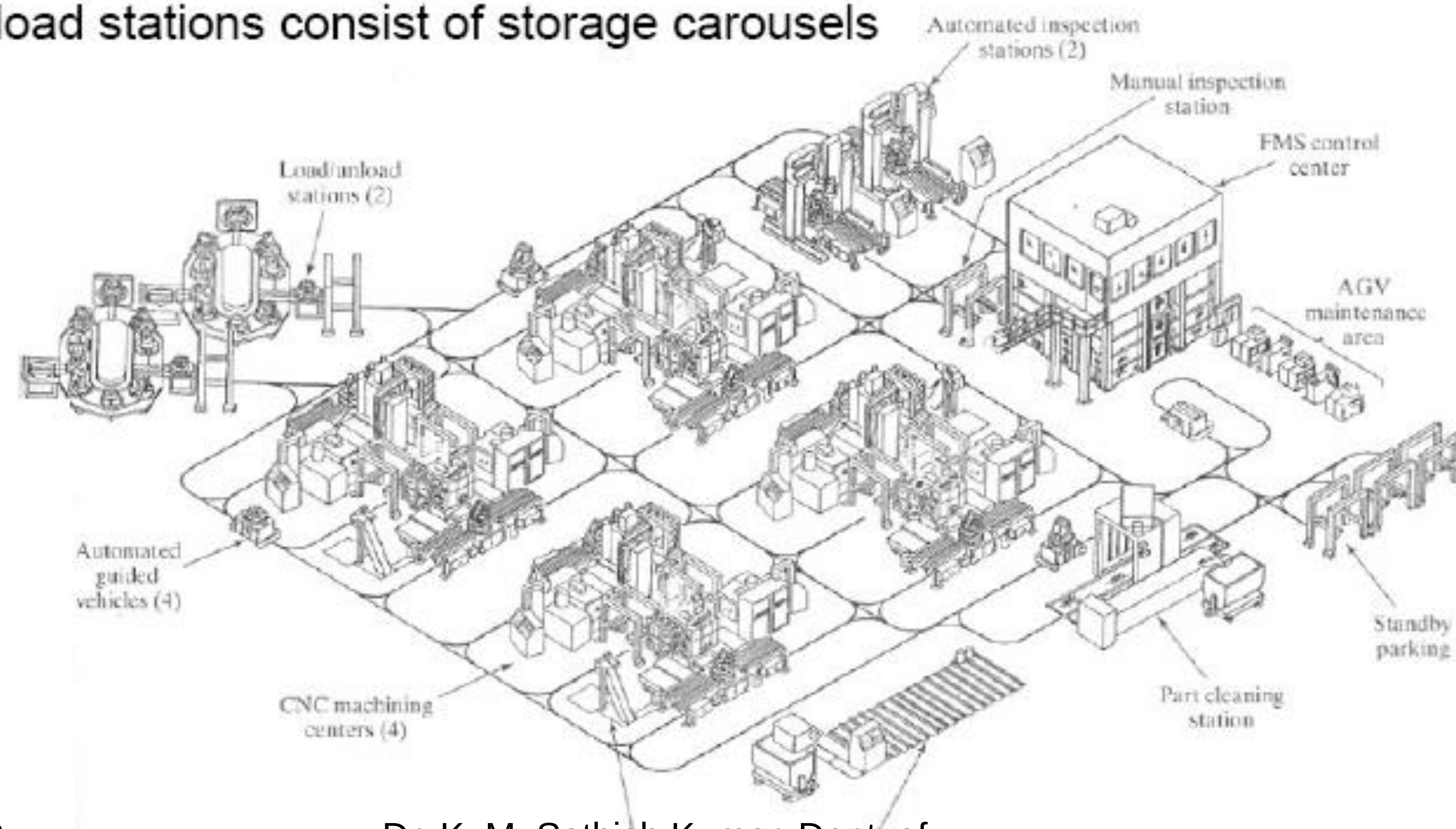
- to manufacture aluminum crankcase halves for aircraft engines
- an open field type
- The handling of workparts between machines is performed by an in-floor towline cart system with a total of 28 pallet carts
- The system contains 11 machining centers



FMS layout at Avco-Lycoming in Williamsport, Pennsylvania

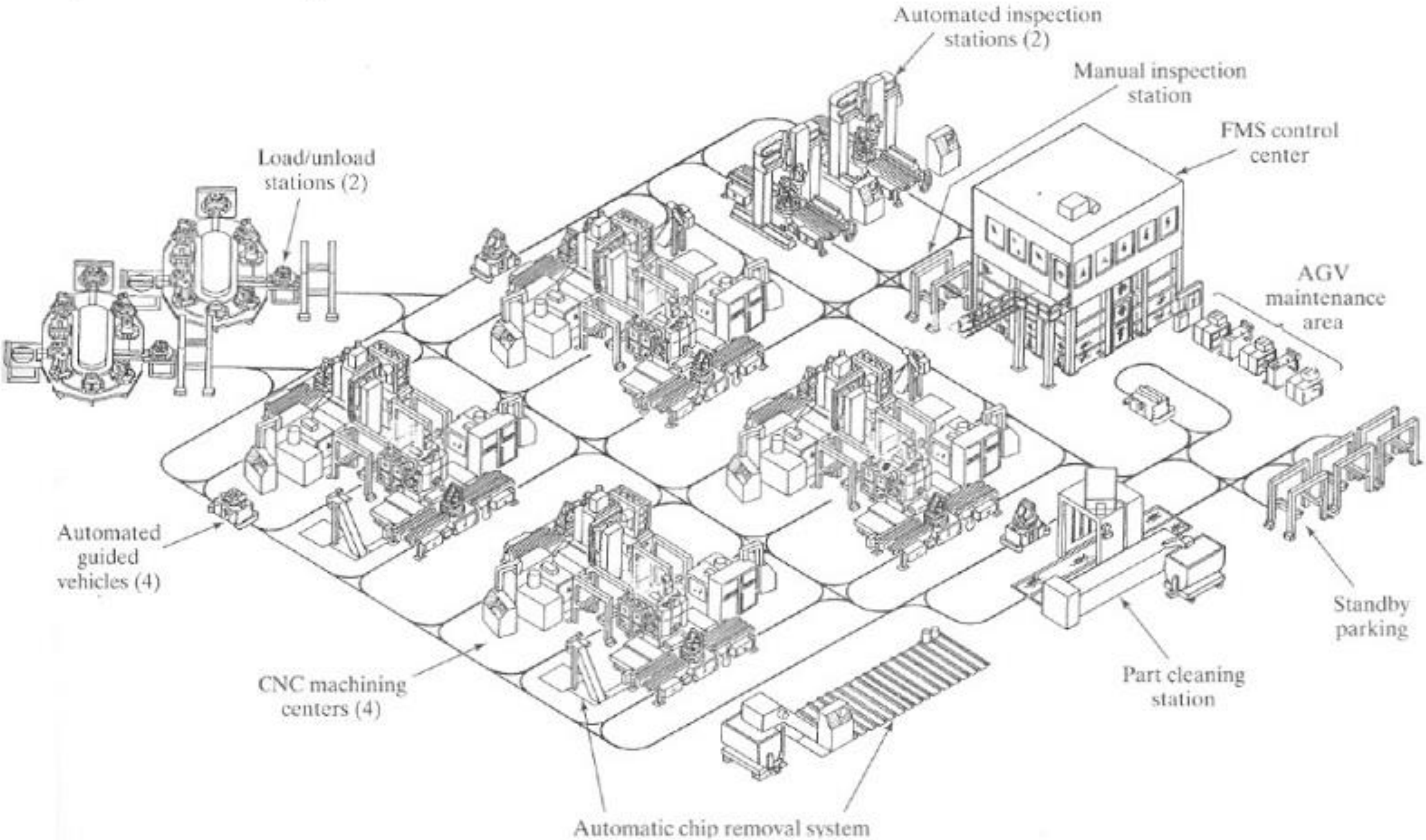
FMS Applications
Layout of Vought Aircraft

- used to machine approximately 600 different aircraft components.
- consists of eight CNC horizontal machining centers plus inspection modules
- Part handling is accomplished by an automated guided vehicle system using four vehicles
- load/unload stations consist of storage carousels



FMS at Vought Aircraft

FMS Applications
Layout of Vought Aircraft



FMS at Vought Aircraft

Benefits of FMS

- Benefits of FMS
  - The benefits that can be expected form an FMS include:
    - Higher machine utilization compared to a conventional machine shop due to:
      - Better work handling
      - Off-line setups
      - Improved scheduling
    - Fewer machines required
    - Reduction in factory floor space required
    - Reduced WIP due to continuous production rather than batch production
    - Lower MLT
    - Reduced direct labor requirements and higher labor productivity
    - Opportunity for unattended production
    - Greater flexibility in production scheduling

FMS Planning and Implementation issues

Implementation of FMS represents a major investment and commitment by the user company. This is divided into FMS planning & Design issues and FMS operational issues.

FMS Planning issues

- Part family considerations
- Processing requirements
- Physical characteristics of the workparts
- Production volume

FMS Design issues

- Types of workstations
- Variations in process routings and FMS layout
- Material Handling system
- Work in process and storage capacity
- Tooling
- Pallet fixtures

FMS Operational issues

- Scheduling and Dispatching
- Machine loading
- Part routing
- Part grouping
- Tool management
- Pallet and fixture allocation

Thank you

LINE BALANCING

Dr. K.M. SATHISH
BMSIT&M

Line Balancing is a method to arrange the individual processing & assembly operations at workstations so that the total time required at each workstation is approximately the same.

It is the process of distributing the operation time equally among all the workstations present in the line. By doing so, none of the workstations will become bottleneck station.

Terminologies used :

1) Minimum Rational Work Element : A minimum rational workelement is a smallest amount of work that has a specific limited objective such as drilling a hole, Tapping a hole, adding a component to the base part etc. A minimum rational work element cannot be subdivided any further without loosing practicality. For Example, drilling a hole in a part and subdividing this operation has no meaning.

The amount of Time required to process a perticular minimum rational work element is called work element time T_e.

ii) <u>Total Work Content</u> T_{wc}: It is defined as the summation of all the workelement time.

ie
$$T_{wc} = \sum_{K=1}^{n_e} T_{eK}$$

Where n_e = Number of workelements

T_{eK} = Time to perform workelement 'K'

where $K = 1, 2, 3 \ldots n_e$.

iii) <u>Workstation Process Time</u> T_{Si}: It is defined as the total time required to complete the processing of all the work elements assigned to a perticular workstation. Denoted by T_s

If n = Number of workstations in the line

n_e = Number of workelements present.

These 'n_e' number of workelements needs to be processed by using 'n' number of machines.

Then the total time of processing all the workelement must be equal to summation of the workstation process time.

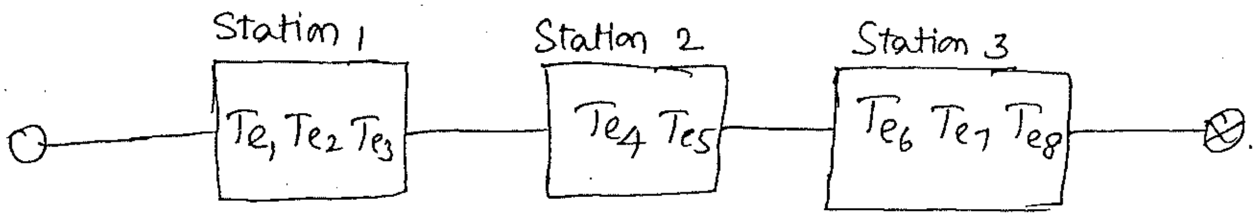
ie
$$\sum_{i=1}^{n} T_{Si} = \sum_{K=1}^{n_e} T_{eK}$$

<u>For ex:</u> Consider there were 8 minimum rational work elements present which needed to be processed on 3 number of workstations (ie $n_e = 8$ & $n = 3$)

Assume that 1, 2, 3 workelements to be processed on workstation No. 1

4 & 5 workelements on workstation 2

6, 7 & 8 workelements on workstation 3



$\therefore Ts_1 = Te_1 + Te_2 + Te_3 \quad Ts_2 = Te_4 + Te_5 \quad Ts_3 = Te_6 + Te_7 + Te_8$

ie $Ts_1 + Ts_2 + Ts_3 = Te_1 + Te_2 + \cdots + Te_8$.

ie $$\boxed{\sum_{i=1}^{3} Ts_i = \sum_{k=1}^{8} Te_k}$$

iv) Cycle Time T_c: It is the ideal or theoretical time required to complete a part in a flow line. It is the time interval between the parts coming off the line.

Cycle Time T_c is related to a) Efficiency 'E'
b) Workstation process Time T_s
c) Workelement Time T_e.

a) 'T_c' Related to E: The design value of T_c will be specified by the production rate requirement of the flow line & its efficiency. $T_c \leq \frac{E}{R_p}$ where E = Efficiency, R_p = Prodn rate.

we have $T_p = \frac{1}{R_p}$.

$\therefore$ $\boxed{T_c \leq T_p E}$

If E is 100%. then $T_c = T_p$.

For any values of $E < 100\%$. $\boxed{T_c < T_p}$

b) Tc related to Ts : The minimum value of T_c will be $\geq$ the maximum workstation time in the flow line.

ie $\boxed{T_c \geq \text{Max } T_{si}}$

c) Tc related to Te : The minimum value of T_c will be greater than or equal to the longest workelement time.

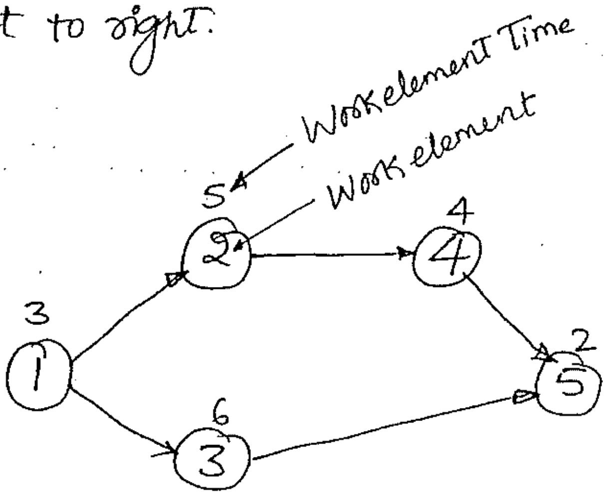
ie $\boxed{T_c \geq \text{max } T_{ek}}$

v) Precedence Constraints: Precedence constraints are refered to "Technological sequencing" requirement which indicates the order in which work elements has to be performed. precedence constraints are the restrictions on the order in which the work elements can be performed. Some elements must be done before others. For example, the hole must be drilled before the Tapping operation.

vi) **Precedence Diagram**: The graphical representation of the precedence constraints is refelled as precedence Diaglam. It is a network diaglam that indicates the sequence in which the work elements must be performed. Work elements ale symbolized by nodes, and the precedence requirements ale indicated by arrows connecting the nodes. The sequence proceeds from left to right.

Ex:

Work Element	Tek	Precedence
1	3	–
2	5	1
3	6	1
4	4	2
5	2	3, 4



Sample precedence diagram for the data in the Table

vii) **Balance Delay**: (d) In many situations it becomes difficult to distribute the workelement time equally among all the workstations. This results in imbalance of the flow line which results inturn in Balance Delay.

It is the value expressed in percentage used to represent the inefficiency of the line. It is given by

$$d = \frac{nT_c - T_{wc}}{nT_c}$$

Where n = No of Stations
T_c = Cycle Time
T_{wc} = Total Work = ΣT_{ek}.

Ex: Consider $n = 3$, $T_c = 4$ & $T_{wc} = 12$

Then $d = \frac{nT_c - T_{wc}}{nT_c} = \frac{3(4)-12}{3(4)} = 0\%$.

This indicates the line in perfectly balanced means all the station times are equal.

Assuming $T_{wc} = 10$ & all being same

$$d = \frac{3(4)-10}{3(4)} = 16.67\%$$

(This % of 'd' indicates inefficiency of the line due to the imbalance in allocation of workelements to the stations.)

(From the above Example we have $nT_c = 12$ and for any values of 'n' and 'T_c' whose multiple is 12, for all these cases perfect balance can be obtained) means 'n' and 'T_c' can be appropriately varied which should be equal to T_{wc} for perfect balance. (The combination may be $n = 2$ $T_c = 6$ (or) $n = 6$ $T_c = 2$ (or) $n = 4$ $T_c = 3$)

(The selection of 'n' & 'T_c' depends on the demand for the product. If the demand for the product is more, then choose more stations with less cycle time results in higher productivity (or) vice versa. ∴ For perpect balance $\boxed{nT_c = T_{wc}}$

To optimize the balance delay, the theoretical (or) ideal number of stations required to balance the line is given by;

Min $\boxed{n \geq \frac{T_{wc}}{T_c}}$ where 'n' is an integer)

Line Balancing Algorithms: The objective of line balancing is to distribute the total workload on the assembly-line as evenly as possible among the workers/ workstations. This objective can be expressed mathematically as;

Minimize $(nT_c - T_{wc})$ (or)

Minimize (Maximum $T_s - T_{si}$)

Subjected to

i) $\sum_{t} T_{ek} \le T_s$

ii) All precedence requirements are to be obeyed.

The following are the various Methods of Line Balancing (or) Algorithms of line Balancing;

1) Largest Candidate Rule (LCR) method.
2) Kilbridge & Wester's (K&W) method.
3) Ranked Positional Weight (RPW) method.
4) Computerized Line Balancing method.

These methods are heuristic, meaning Trial & Error method. There is no universally accepted method to balance the line.

Largest Candidate Rule Method : (LCR method)

In this method, the balancing is achieved based on the selection of the Largest Candidate which is nothing but the work element with largest work element Time T_{ek}. The preference to be given for the workelement which takes more time to complete the operation. The allotment of Largest Candidate work element to the station is based on;

i) Satisfaction of the precedence constraints.

ii) The summation of the T_{ek} values to the station should not exceed cycle time T_c.

Step-by-step procedure:

i) Draw the precedence diagram based on the constraints.

ii) Arrange all the workelements in the descending order of T_{ek} values. Larger T_{ek} workelement at the top (Table 1).

iii) Start assigning the workelements to the station: This is based on the selection of a feasible element. A feasible element is the one which satisfies the precedence constraint and the sum of all T_{ek} values allocated to the station should not exceed T_c.

iv) Above step is repeated till all the workelements assigned to the stations.

v) Determine the no of stations 'n' and determine balance delay.

(d) The step 'c' is continued until no further elements can be added to a workstation without exceeding T_c.

Repeat steps 'c' and 'd' until all the work elements are assigned to different station in the flow line. This is end of line balancing using LCR.

Numerical Examples on LCR method

1. A proposal has been submitted to replace a group of assembly workers. The following table gives work elements and its predecessor. Use largest candidate rule method to balance the line.

Element	T_{ek} (min)	Predecessor
1	1.0	-
2	0.5	-
3	0.8	1, 2
4	0.3	2
5	1.2	3
6	0.2	3, 4
7	0.5	4
8	1.5	5, 6, 7

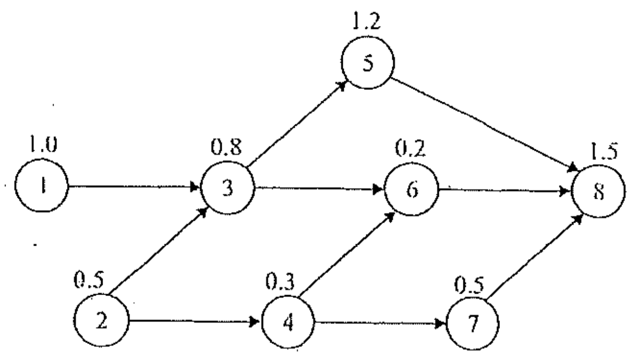
The demand rate for this job is 1600 units/week at the rate of 40 hrs/week

(i) Construct the precedence diagram.

(ii) Determine the number of stations required to balance the line.

(iii) Determine balance delay.

Soln. (i) Precedence diagram



(ii) LCR method :

Calculate T_c :

Given : Demand rate is 1600 units\wk at 40 hrs\week

$$\therefore \quad R_p = \frac{1600}{40}$$

$$= 40 \text{ units/hr}$$

$$= \frac{40}{60} \text{ units/min}$$

$$= \frac{2}{3} \text{ units/min}$$

$$\therefore \quad T_c = \frac{1}{R_p} = \frac{3}{2} = \boxed{1.5 \text{ min/unit}}$$

$$T_{wc} = \sum T_{ek} = \boxed{6 \text{ mins}}$$

Step 1 : Arrangement of T_{ek} in descending order.

Table 4.1

Work element	T_{ek}	Predecessor
S_5 (8)	1.5	5, 6, 7
S_3 (5)	1.2	3
S_1 (1)	1.0	-
S_2 (3)	0.8	1, 2
S_1 (2)	0.5	-
S_4 (7)	0.5	4
S_2 (4)	0.3	2
S_2 (6)	0.2	3, 4

It can be observed from table 4.1, except work element 1 & 2, all other work elements have got predecessors. Hence 1 and 2 can be allocated. In this case, element 1 has got largest T_{ek} between 1 and 2 and hence it has to be allocated first. The allottment of the second work element to the first workstation depends on sum of T_{ek} of 1 and 2 which should not be greater than T_i i.e., 1.5 min. $T_{e1} + T_{e2} = 1.0 + 0.5$ and hence can be allotted to first station.

Allotment of work elements to station 2 : The selection of elements here will be excluding the work elements 1 & 2 which is already allotted to station 1.

It can be observed from the remaining work element moving from top to bottom from table 1 elements 3 & 4 are feasible candidates since their corresponding predecessor elements 1 & 2 has

Dr. K. M. Sathish (1)
BMSIT&M.

Computer Numerical Control.

Introduction: Many of the achievements in CAD and CAM have a common origin in numerical control.

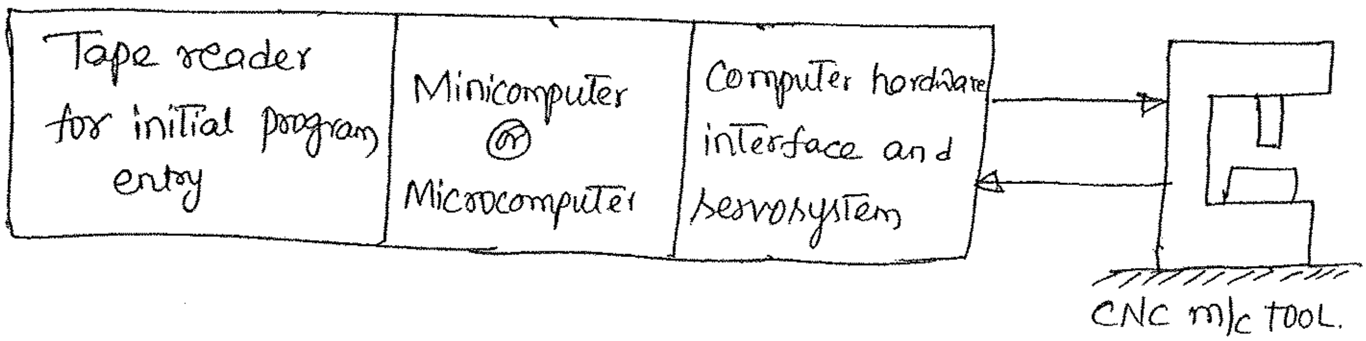
Numerical control can be defined as a form of programmable automation in which the process is controlled by numbers, letters and symbols. In NC, the numbers form a program of instructions designed for a particular workpart. The instructions to the NC machines are fed through an external medium using paper or magnetic tape. The magnetic tape is very fragile and to be discarded if any mistakes occur. NC machines are generally hardwired machines.

Introduction to Computer Numerical Control (CNC):

Computer Numerical Control is an NC system that utilizes a dedicated, stored program computer to perform all the basic NC functions.

CNC is defined as NC system whose machine control unit is based on a dedicated microcomputer rather than on a hard-wired controller. Here, the part program to produce the component is inputted and stored in the computer memory. CNC is often referred to by the Term "Soft-Wired" N/C.

Fig illustrates the general configuration of CNC.



Features of CNC System:

- Storage of more than one part program
- Various forms of program input
- program editing at the machine site
- Communication interface
- Information about machine utilization
- positioning features for setup.
- Use of Canned cycles.
- Diagnostics
- Proving the part program without actually running it on the machine.

7.3 ELEMENTS OF CNC (Components of CNC)

CNC system consists of basic three components as shown in Fig 7.1

1. A program of instructions
2. A machine control unit
3. Processing Equipment

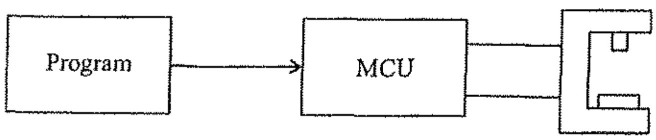


Fig. 7.1 : Elements of CNC System

The program of instructions is a detailed step-by-step commands that direct the actions of the processing equipment. Program of instructions is called a part program. In this the individual commands which refers to the position of a cutting tool relative to the worktable is present. Additional instructions like spindle speed, feed rate, cutting tool selection are also present. Earlier, the common medium is 1 inch wide punched tape. Now, the punched tape has been replaced by newer storage technologies.

In modern NC technology, the machine control unit consists of a microcomputer and related control hardware that stores the program of instructions and executing it by converting each command into mechanical actions of the machine tool. The hardware of MCU includes components to interface with the processing equipment and feedback control elements. The MCU also includes one or more reading devices for entering part program into memory. A MCU is a microcomputer, the term Computer Numerical Control (CNC) is used to distinguish conventional NC from CNC. Now, virtually all new MCU's are based on computer technology, hence NC and CNC are used synonymously.

The third component of CNC system in the processing equipment that performs useful work. It accomplishes the processing steps to transform the starting work piece into a completed part. Its operation is directed by the MCU, which in turn is driven by instructions contained in the part program.

7.4 CLASSIFICATION OF CNC SYSTEM

(i) Based on feedback control

(ii) Based on motion control system

(i) Based on **feedback control system**, CNC machines are classified as **open-loop** and **closed loop control system.**

Open - loop control system : Machine tool controls in which there is no provision to compare the actual position of the cutting tool or workpiece with the input command value are called open-loop systems. Fig. 7.2 shows the concept of open-loop control system.

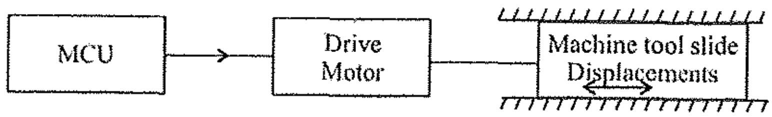


Fig. 7.2 : Open Loop Control System

In open-loop control system the actual displacement of the slide is not compared. Since these is no provision of feedback in the control system periodical adjustments are required to compensate for the changes due to various factors.

Closed loop control system : In a closed loop control system the actual output from the system ie actual displacement of the machine slide is compared with the input signal. The closed loop control systems are characterised by the presence of feedback devices in the system. In the closed loop control system, the displacement can be measured by using a measuring/ monitoring device which is used to determine the displacement of the slide. The feedback from the monitoring device in then compared with the input signal. Fig. 7.3 shows the concept of closed loop control system.

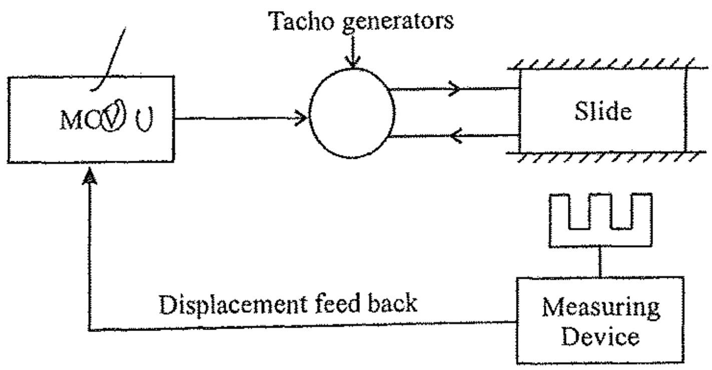


Fig. 7.3 : Closed Loop Control System

(ii) **Based on motion control system** :

(1) **Point - to - point**

(2) **Straight cut**

(3) **Contouring**

Point - to - point (PTP) is also called a positioning system

(1) **Point-to-point control system** : This is also called as positioning method. PTP control system in mainly used to move the machine spindle to a predefined location, while the spindle is moving from one location to another, no processing should takes place. Here, the tool moves rapidly to the location and actual machining operation will takes place at that location. Drilling in an example for PTP motion.

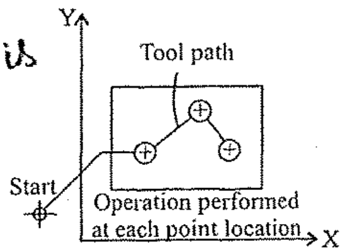
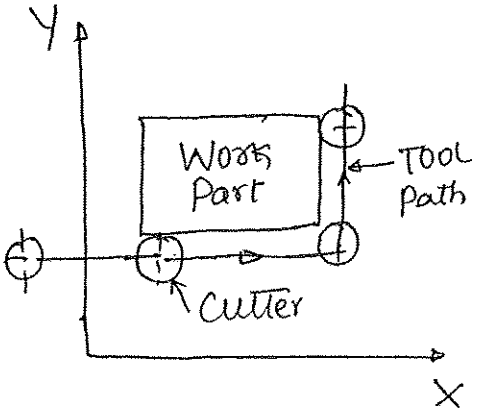
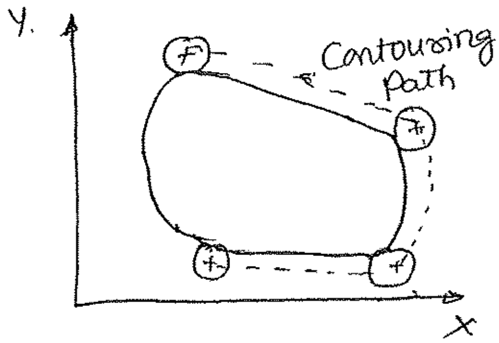


Fig 7.4 (a) : PTP Motion

(2) **Straight cut Motion:** It is an extension of PTP control system with the provision of machining along a straight line which is parallel to any of the axes. This is obtained by providing movement at controlled rate of feed along the axis of line of motion.



(3) **Contouring motion:**



It is a high Technology and most versatile system. The Contouring system generates a continuously controlled motion of the Tool and the workpiece along different co-ordinate axis. This control system enables the machining of profiles, contours and curved surface. Here the simultaneous control of x and y axis is required to move the tool along angle or along a curve.

iii) **Based on the Number of Axes:**

a) 2 Axes CNC machines (X & Z - Lathe) and
3 Axes CNC machines (X, Y, & Z - Milling).

b) 4 Axes CNC machines (X, Y, Z & A)
5 Axes CNC machines (X, Y, Z, A & B)

A & B are rotation about X & Y

iv) Based on the input power supply:

a) Electrical powered.
b) Hydraulic powered
c) Pneumatic powered
d) Hybrid powered (Combination of the above).

Advantages of CNC System:

- Higher flexibility.
- Increased productivity
- Consistent quality
- Reduced scrap rate
- Reliable operation
- Machining of Advanced materials.
- Reduced non-production Time.
- Reduced manpower
- Shorter cycle Time.
- Higher accuracy
- Increased operational safety
- Part program editing on the machine site.
- Supports Just in Time manufacturing.
- Automated material handling.

Disadvantages of CNC System:

- Higher investment
- Higher maintenance.
- Skilled labor requirement.

CNC programming: 2 Ways.

i) Manual part programming ii) Computer Assisted part programming.

Steps involved in the development of a part programme are as in Fig. 7.5

1. Process planning
2. Axes selection
3. Tool selection
4. Cutting process parameters planning
5. Job and tool setup planning
6. Machining path planning
7. Part program writing
8. Part program proving

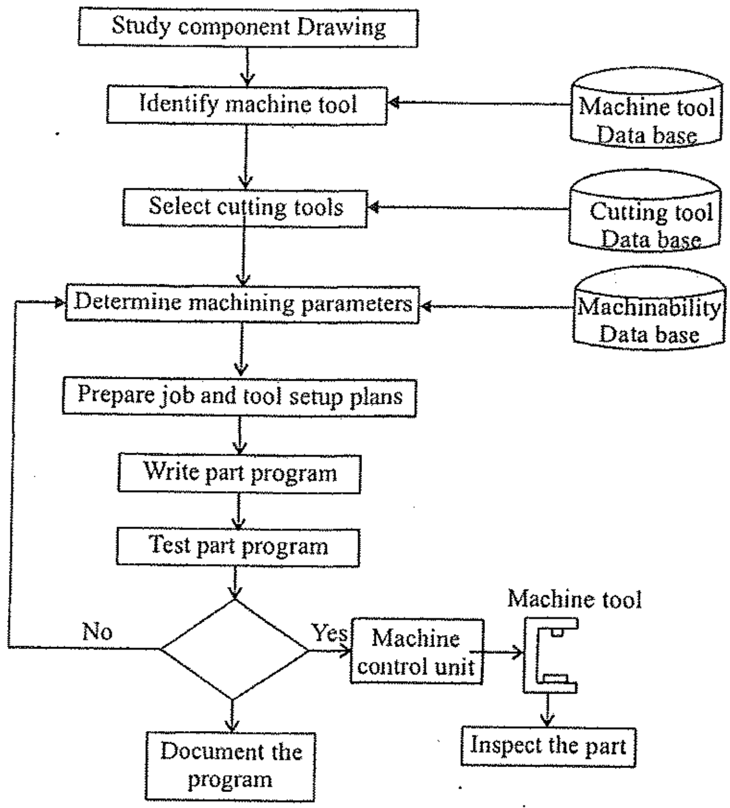
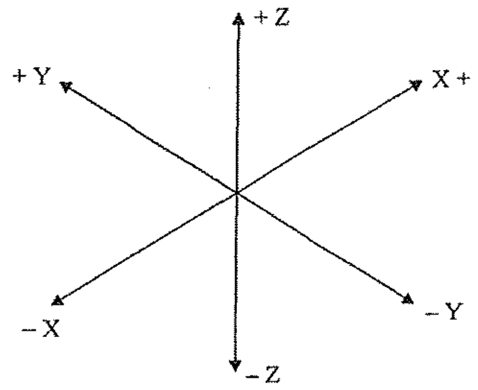


Fig. 7.5 : Steps involved in the development of a part program

7.8 CNC PART PROGRAMMING

Co-ordinate system for a CNC lathe : Machining of a work piece by NC program, a co-ordinate system is to be applied to the machine tools. As all machine tools have more than one slide, it is important that each slide is identified individually. There are three planes in which movement can taken place. Longitudinal, vertical and transverse. Each plane is assigned a letter and is referred to as an axis i.e., AXIS X, AXIS Y and AXIS Z.

In order to describe the location of any point on a two dimensional plane, first develop a co-ordinate system to define the direction and relative positions. This co-ordinate system is often called the **Cartesian Co-ordinate System**. It is often most useful in CNC machining to work in a three dimensional co-ordinate system. It is represent as given below :



CNC Lathe Cartesian Co-ordinate System

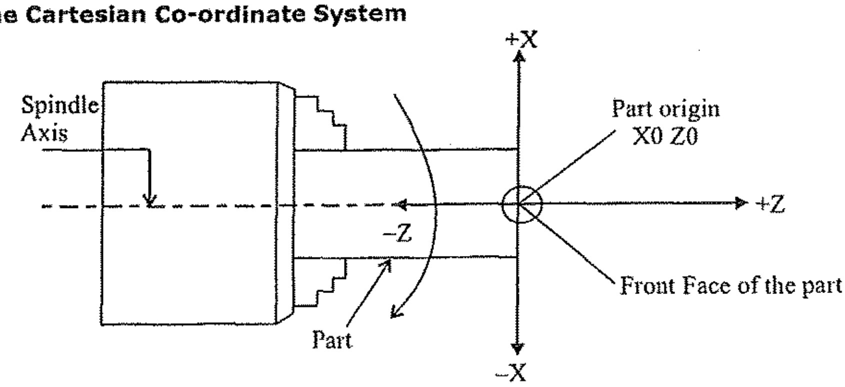


Fig. 7.6 : CNC Lathe Co-ordinate System

The cartesian co-ordinate system can be applied to CNC machine tools on a CNC Turing machine as shown in Fig. 7.6. The X-axis specifies the diameter co-ordinate movement and Z - axis specifies the Length co-ordinate movement. Another common application of CNC lathes is the U-axis and W-axis which also specifies the diameter co-ordinate movement (U-axis) and the length co-ordinate movement (w-axis)

7.9 NC CO-ORDINATE SYSTEMS

Two types of co-ordinate systems are used to define and control the position of the tool in relation to the workpiece. The co-ordinate system used are

1. Absolute co-ordinate system
2. Incremental co-ordinate system.

In the absolute co-ordinate system, the co-ordinates of a point is always referred with reference to the same datum point. The dimension lines run parallel to the co-ordinate axes and aways start at the reference point. This method is also called 'Reference Dimensioning'. A major advantage of using absolute system is that, it is very easy to check and correct a program written using this method.

In the incremental system, the co-ordinates of any point are calculated with reference to the previous point. The point at which the cutting tool is positioned is taken as datum point for calculating the co-ordinates of the next point to which the movements is to be made. It is difficult to check a part programme written in incremental dimension mode.

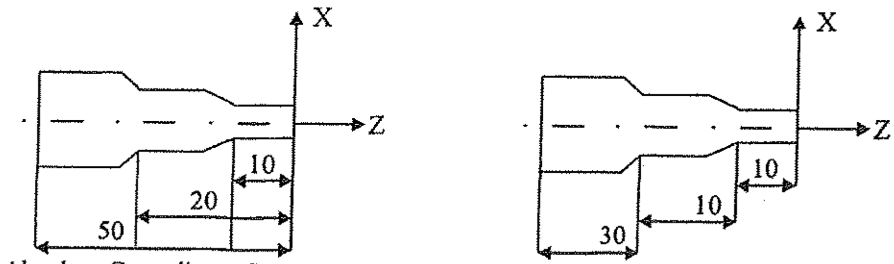


Fig. 7.7 : Absolute and Incremental coordinate system

NC Block

NC Block is a collection of NC words. NC word is a collection of address letter and a sequence number. It gives information about the movement of the tool in X, Y and Z co-ordinates. The tool to be used, spindle speed feed, etc.

A generalized NC block looks like this :

N – G – X – Y – Z – R – F – S – T – M

N → Sequence number

G → Preparatory Function

X,Y,Z → Co-ordinates along X, Y and Z axes.

R → Arc radius

F → Feed rate

S → Speed of the spindle

T → Tool function

M → Miscellaneous function

7.10 PART PROGRAM FORMATS

The order in which NC words appear in a block of instructions is called the format. There are three types of formats.

1. Fixed sequential format
2. Tab sequential format
3. Word address format.

In the fixed sequential format, instructions are always given in the same sequence. All instructions must be given in every block, including those instructions which remain unchanged from the preceding blocks. For example, if the co-ordinates values (ie X, Y or Z) remain constant from one block to next block these values have to be specified in the next block also.

N01 G00 X10 Y20 Z0 F60 S2000

N02 G01 X20 Y20 Z0 F60 S2000

In the Tab sequential format, instructions in a block are always given in the same sequence as in case of fixed block format and each word is separated by a TAB character. If the word remains same in the succeeding block, the word need not be repeated, but TAB is required to maintain the sequence of words.

N01 G00 X10 TAB Z0 TAB F60 S800

N02 G01 X20 TAB Z–10

In the word address format, each word is preceded and identified by its address letter. Example, X identifies the X - co-ordinate, F identifies the feed rate etc. If a word remains unchanged, it need not be repeated in the next block. This is the format adopted by most CNC machine control units.

N01 G00 X200 Y200 Z0

N02 G01 Z-10 F0.2 S2000

Sequence number N

Each block or line starts with a sequence number which identifies the block. The sequence number is usually a number preceded by a letter N.

Preparatory Functions G

Preparatory Functions are used to set the control for various machine movement such as linear movement, circular movement etc. Preparatory function prepares the controller to carry the instructions, that are to follow after 'G' letter. The commonly used G codes are

G00	Rapid traverse
G01	Linear Interpolation
G02	Circular interpolation clockwise
G03	Circular interpolation counterclockwise
G04	Dwell
G20	Inch units
G21	Metric units
G28	Automatic zero return
G32/G33	Thread cutting
G40	Tool nose radius cancel
G41	Tool nose radius compensation left
G42	Tool nose radius compensation right

G50	Maximum spindle speed setting
G70	Finishing cycle
G71	Rough turning cycle (stock removal cycle)
G72	Rough facing cycle (stock removal in Facing)
G73	Pattern repeating cycle
G74	Peck drilling on Z-axis / Face grooving
G75	Grooving Cycle
G76	Multiple thread cutting cycle
G94/ G98	Feed per minute
G95 / G99	Feed per revolution
G90	Absolute co-ordinate system
G91	Incremental co-ordinate system

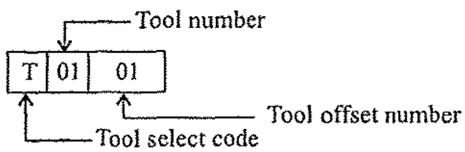
X, Y and Z are used to specify the co-ordinates along the respective axes.

R is the arc centre radius to be used in circular interpolation

F is the feed rate in mm/rev or mm/min

S is the spindle speed in rpm.

T is the tool function needed for machines which uses automatic tool changer (ATC). The T-word specifies which tool is to be used in the operation. The tool call always starts with a letter 'T' followed by a number as T00 to T99. Also with each tool code, the corresponding tool length offset is also specified with the help of two additional digits.



7.11 EXPLANATION OF COMMONLY USED G CODES

G00 POSITIONING IN RAPID

N_G00_X_Z_

The G00 command is a rapid tool move. A rapid tool move is used to move the tool linearly from position to position without cutting any material. When the tool being positioned at a point preparatory to a cutting motion, to save time it is moved along a straight line at Rapid traverse, at a fixed traverse rate which is pre-programmed into the machine's control system. Typical rapid traverse rates are 10 to 25 m/ min., but can be as high as 80 m/min.

(12)

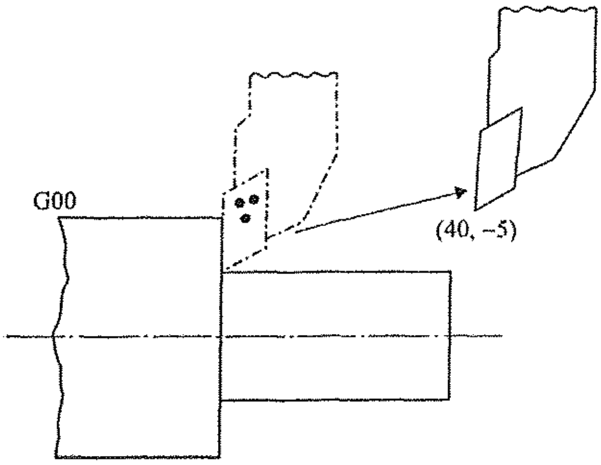


Fig. 7.8 : Positioning in Rapid

G01 LINEAR INTERPOLATION

N_G01 X_Z_F

The G01 command is mainly used for the linear removal of material from a workpiece. Any combination of the X or Z axes can be used. The machine tool will follow a linear trajectory from the current position to the target position. The tool moves along a straight line in one or two axis simultaneously at a programmed linear ~~speed.~~ feed.

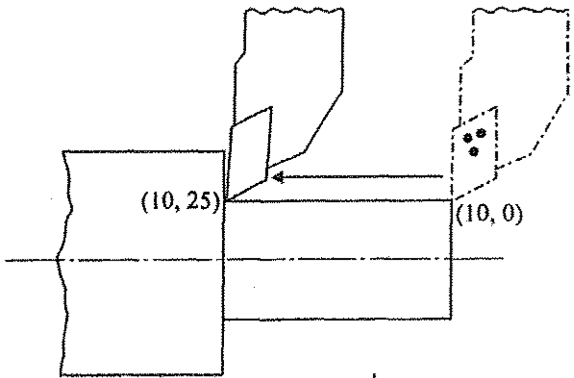


Fig. 7.9 ; Linear Interpolation

G02 CIRCULAR INTERPOLATION (CLOCKWISE)

N_G02 X_Z_R_F_ (R specifies the radius)

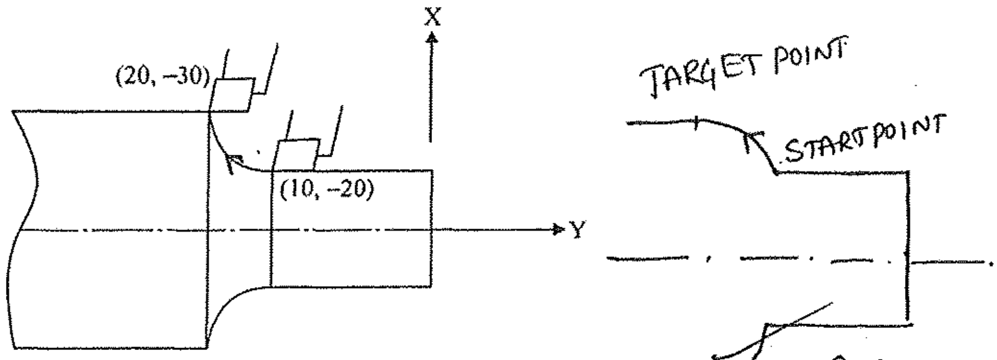
Circular Interpolation is defined by the G02 command. It executes all circular or radial cuts in a clockwise motion. The G02 command requires an endpoint for the move, the radius, and a feedrate.

(13)

G03 CIRCULAR INTERPOLATION (COUNTER-CLOCKWISE)

N_G03 X_Z_R_F_ (R specifies the radius)

The G03 command executes all radial cuts in a counterclockwise motion. It requires an end point for the move, then the radius, the distance from the startpoint to the centerpoint, and a feedrate.



G02 **Fig. 7.10 :** Circular Interpolation G03

G04 DWELL

N_G04 P_

The G04 command is a nonmodal dwell command that halts all axis movement for a specified time while the spindle continues revolving at the specified rpm. A dwell is sometimes used to allow for the clearance of chips during drilling operation.

G20 INCH UNITS

N_G20

The G20 command specifies the system to inch units. When a program is being run and the G20 command is encountered, all coordinates are given as inch units. This command is usually found at the beginning of a program.

G20 METRIC OR SI UNITS

N_G21

The G21 command specifies the system to metric units. When a program is being run and the G21 command is encountered, all coordinates are given as millimeter units. This command is usually found at the beginning of a program.

G28 AUTOMATIC RETURN TO REFERENCE POINT

N_G28 X_Z_

The G28 command is commonly used prior to an automatic tool change operation. It allows the existing tool to be positioned to the predefined reference point automatically via an intermediate position. This ensures that when the tool turret is engaged, it is properly aligned and clears the workspace.

- Retract Amount N- G74 R(e)
- Axial position of tool N- G74 X_ Z_ Q_ F_ (16)
- length of the Drill.

Q = peck Depth ~~[illegible]~~

F = Feed rate

G74 PEEK DRILLING CYCLE G74 Axial Drilling cycle (Peck Drilling cycle)

~~N_G74X0 Z_K_F_~~

The G74 command involves individual peck moves in each drilling operation. When this command is invoked, the tool positions itself as in a standard G81 drill cycle. The ~~K~~ Q value specifies the ~~peek~~ peck depth.

G75 GROOVING CYCLE

N_G75 R(e)

N_G75X_Z_P_Q_F_

The G75 command invokes an outside diameter groove cycle. This cycle involves the tool plunges into the workpiece from the outside of the workpiece parallel to the X axis. The X value is the final diameter. The Z value represents the final Z position. The R value specifies the retract after every plunge. The P and Q values specify the incremental movements in the X and Z axes, respectively. F in the feed value.

G76 THREADING CYCLE

The G76 command automatically performs all cutting operations required to achieve a thread. The G76 cycle code is used for the CNC lathe single point threading applications. This code allows the CNC programmer to enter the data required for a specified thread size and the controller will determine the number of thread passes and automatically position the tool. The G76 tool reduces the number of programming blocks required for a threading operation.

Format

G76 P☐☐☐ Q R

G76 X Z P Q F

Ex : G76 P031560 Q150 R0.015

P03 indicates Number of passes for finishing operations

15 indicate a Pull out angle (15° to 22°)

60 indicate Thread Angle

Q150 is the depth of cut for each pass in microns

R0.015 is the finishing allowance

5

G76 X9.854 Z-20 P1073 Q300 F1.75

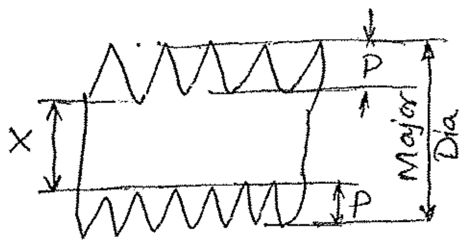
X9.854 is the Minor Diameter in mm for M12 X1.75 mm pitch

Z-20 is the length of the thread.

P1073 is the height of the thread in microns

Q300 is the Depth of cut for first pass in microns

F1.75 is the pitch of the thread.



P = 0.613 * pitch

X = Major Dia. − 2P

(17)

G90 Absolute Positioning

N_G90

The G90 command defaults the system to accept all coordinates as absolute coordinates These coordinates are measured from a fixed origin (X0, Y0, Z0) and expressed in terms of X,Y and Z distances.

G91 Incremental Positioning

N_G91

The G91 command defaults the system to accept all co-ordinates as incremental, or relative, coordinates. This command is found at the beginning of some programs to default the system to incremental coordinates. It is possible to switch between incremental and absolute coordinates at any time within a program (see the G90 command).

G98 Linear Feed Rate Per Time

N_G98

The G98 command sets the linear feedrate to units (inch or millimeter) per time (minutes). The setting depends on which type of unit is currently active.

G99 Feedrate per revolution

N_G99

The G99 command sets the feedrate to units (inch or millimeter) per revolution. The setting depends on which type of unit is currently active.

7.12 MISCELLANEOUS FUNCTION : (M-WORD)

It is used to perform certain miscellaneous or axillary functions which do not relate to the dimensional movement. The commonly used M-functions are

M00	Optional program stop automatic
M01	Optional program stop request
M02	Program end
M03	Spindle ON clockwise
M04	Spindle ON counter clock wise
M05	Spindle stop
M06	Tool change
M07	Mist coolant ON
M08	Flood coolant ON
M09	Coolant OFF
M30	End of program, Reset to start

(18)

7.13 PART PROGRAMMING FOR MILLING

Co-ordinate axes : In order to machine a workpiece on a CNC machining centres, we need to establish a co-ordinate system in relation to the workpiece to be machined. The common practice is to set the origin of the co-ordinate system on a corner of the workpiece so that the top of the workpiece forms an X – Y plane with the Z - coordinate of zero.

Milling machine or machining centre use all the three axis X, Y and Z.

Z axis denotes movements parallel to the spindle axis. The X - axis moves to the operator left and right which has a longest travel. The 'Y' axis moves towards and away from the operator. The 'Y' axis usually has the shortest travel.

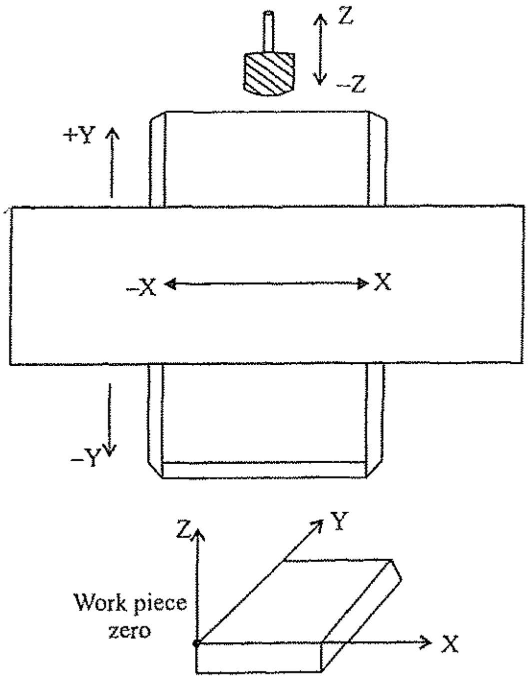
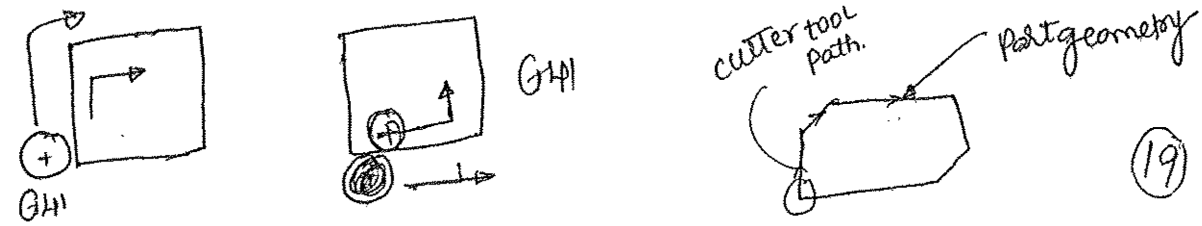


Fig. 7.11 : Co-ordinate axes for milling

Commonly used G codes :

G00	Rapid traverse	G94	Feed per minute
G01	Linear Traverse	G95	Feed per revolution
G02	Circular Interpolation CW	G98	Return to initial point in canned cycle
G03	Circular Interpolation CCW	G99	Return to 'R' point in canned cycle
G04	Dwell	G80	Canned cycle cancel
G40	Cutter radius compensation cancel	G81	Drilling cycle
G41	Cutter radius compensation left	G82	Drilling cycle with Dwell
G42	Cutter radius compensation right	G83	Peck drilling cycle / deepdrill
G43	Tool length compensation	G84	Tapping cycle
G49	Tool length compensation Cancel	G85	Reaming cycle
		G86	Boring cycle



(19)

Cutter Radius Compensation (CRC)

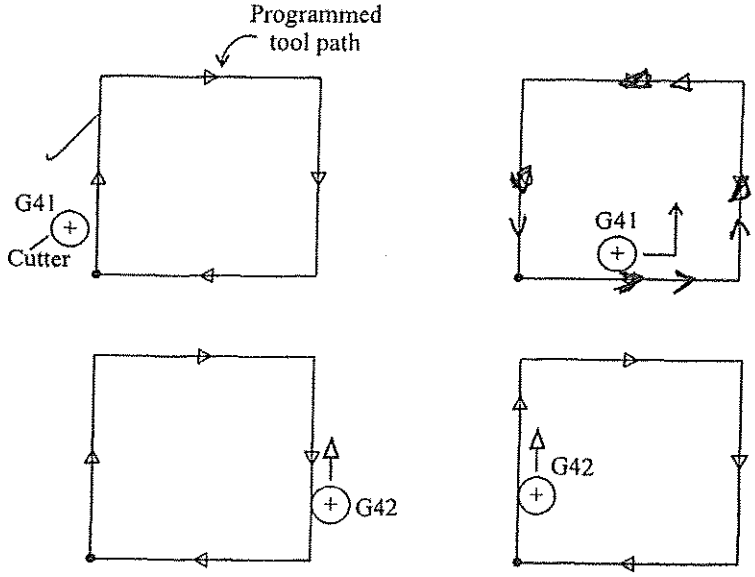


Fig. 7.12 : Concept of Cutter Radius Compensation

The typical application of cutter radius compensation is contour end milling. This cutter compensation can be calculated into the CNC program or the G41 and G42 codes can be used to compensate for the radius of the end mill. These codes once activated will command the CNC machine to compensate appropriately. The concept is as shown in Fig.7.12

The part programme is developed for cutter path with reference to the centre of the tool rather than the point on the periphery where the actual cutting talking place. At the time of writing a part program a cutter of suitable diameter is selected and programme is developed for centre line of the cutter. But when actual machining is done, if a cutter of smaller diameter is used, it will result in a larger workpiece and if a cutter with larger diameter is used it will result in a smaller workpiece. The part programme can be developed assuming the cutter radius as zero i.e. on the actual drawing dimensions of the component. The cutter path can then be shifted by using relavent G-code.

The difference in the programmed diameter of the cutter and the diameter of the actual cutter is accounted for by cutter radius compensation. The difference in the diameter of the cutter is entered into the control system. The control system will generate a new-cutter path. The new path will be separated from the programmed cutter path by difference in the radius of programmed cutter and the actual cutter. It is necessary to indicate whether compensation is to be made to the right or to the left of the tool when machining.

The following three G-codes are used

G41 - Compensation applied to shift the programmed cutter path to left

G42 - Compensation applied to shift the programmed cutter path to right

G40 - Cancel cutter radius compensation.

The direction in which the cutter path to be shifted is decided by looking in direction of cut. If the direction of cut is programmed in clockwise direction, compensation would be provided to shift the cutter path towards left of the programmed path (G41) and if the direction of cut is programmed counter clockwise, the compensation would be applied to shift the cutter path towards right from the programmed path (G42).

The cutter radius compensation in very useful as cutter of different diameters can be used without changing the program.

Tool Length Compensation : G43

The G43 tool length compensation code is used to shift the Z-axis by a specified length amount. The amount is the actual tool length measurement that the CNC operator is responsible for entering into the length offset memory when is stored in 'H' register. When the tool control reads the G43 code, it will shift the spindle i.e Z-axis by the amount stored in the memory. The G43 tool length compensation is used to shift the spindle and cutter in a negative direction towards the table and the workpiece. The concept of Tool length compensation is as shown in Fig 7.13

The machine is positioned to machine zero and then the tool length offset is set. The relationship between the actual length of the tool and its length offset value in shown in figure below.

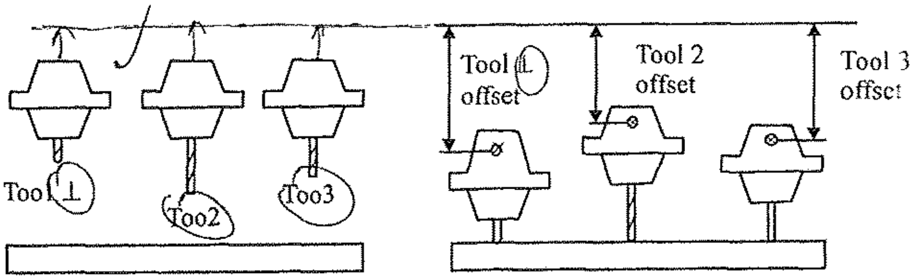


Fig. 7.13 : Concept of Tool Length Compensation

When the machine is in the machine zero, the resulting value of the registry will be 0.000". Next, each tool in inserted in the spindle and carefully jogged down to the surface of the part assuming that the part program uses the top surface as zero and the tool length offset is set.

When the tool is called in the program, the machine will move the z-axis the value of the tool length offset plus the value specified in the program. The typical tool length offset block is N01G43H01, means the G43 calls for a tool length offset, H01 is the ~~number~~ Value of the offset, which in found in register 1 of the tool length offset file. The tool length compensation allows tools of different lengths usage without altering the part program.

G49 Tool length compensation cancel : The G43 tool length compensation code is modal, and therefore it require G49 cancel code when the cutting is finished. This is required for every tool used in the CNC program.

7.15 CANNED CYCLES IN MILLING

G81 Drilling Cycle : G81 invokes a drill cycle at specified locations.

Format : N_G98/G99 G81 R_Z_F_

G98/G99 indicates return position code. If G98 is used the tool returns to the initial point in canned cycles. If G99 is used the tool returns to R point in canned cycle. G81 is the drilling cycle. Z is the final depth of the hole to be drilled at a feed rate of F.

G83 Deep hole Drilling cycle or Peck Drilling cycle : G83 involves individual peck modes in each drilling operation. When this command is invoked the tool positions itself as in the case of standard G81 drill cycle.

Format : N_G98/G99 G83 R_Z_Q_F_

G98/G99 means the same as that of G81.

R is the same height position.

Z is the total depth of the hole to be drilled.

Q is the peck depth means the amount of depth to be drilled in each peck.

F is the feed value.

G84 Tapping cycle : The tapping cycle will invoke a tapping operation as specified by the X and Y coordinate values. Tapping cycle will feed a tap to the bottom of the hole and the spindle reverses to remove the tap from the hole.

Format : N_G98/G99 G84 R_Z_F_

G98/G99, R, Z and F means the same as the drilling cycle format.

G85 Reaming cycle : The reaming cycle can be invoked either after completing G81 or G83 cycles.

Format : N_G98/G99 G85 R_Z_F_

G98/G99 indicates the return position codes.

G85 is the Reaming cycle,

R is safe height,

Z final depth of the hole to ream and

F the feed rate.

G86 Boring Cycle : As similar to G85, G86 boring cycle can be invoked after drilling cycle G81 or peck drilling cycle G83.

Format : N_G98/G99 G86 R_Z_F_

where G98/99 is written position code.

G86 Boring cycle,

R is safe height,

Z is the depth of the hole to bore,

F is the feed rate.

7.15 CNC PROGRAMMING FOR TURNING OPERATIONS

PROBLEM NO : 1 :

Write the manual part program for the part shown below.

Raw material size : Dia 75 mm
Length 110 mm

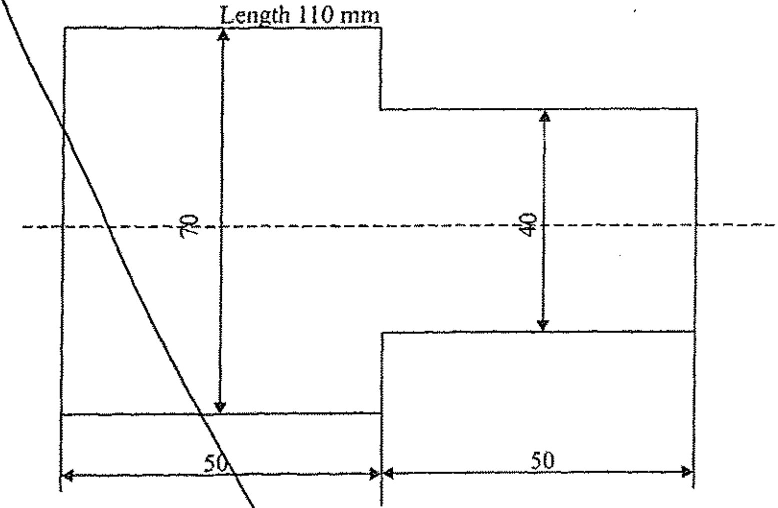


Fig. 7.14

01001 Programme Number

Billet Dia 75 length 110 start Z 3 Specification of Billet Size.

Sl. No.	Name of the operation	Tools used
1.	Rough face	01
2.	Rough Turn	01
3.	Finish Face	02
4.	Finish Turn	02

N01 G21 G99 Metric Unit, Feed in mm/rev.

N02 G28 U0 W0 Tool Present in home position

N03 M06 T0101 Tool change, selection of first tool

N04 M03 S1000 M08 Rough Facing Operation

N05 G00 X76 Z2 Rapidly Position the tool for operation

N06 G01 X- I F0.2 Spindle rotates clockwise, coolant ON

N07 G00 Z5 Retrieval

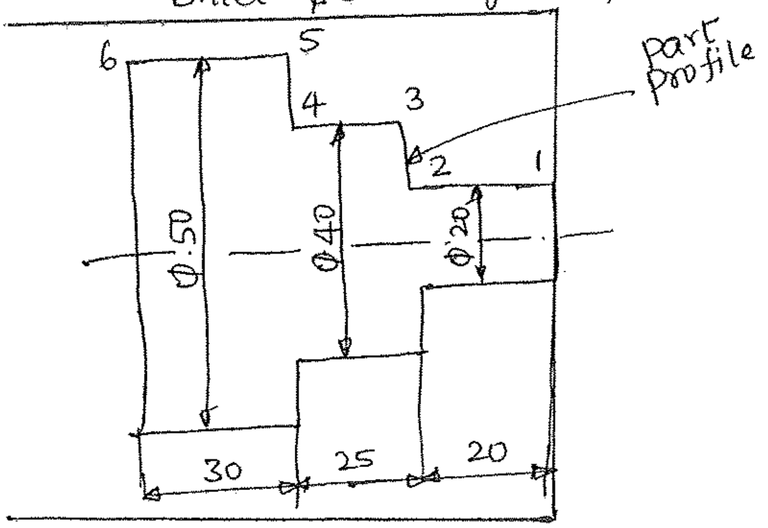
N08 G00 X73 Positioning

N09 G01 X73 Z-100 F0.2 First Rough Cut

CNC programming for Turning operations:

(1)

Billet Ø55, Length 150, Start Z0



O 01

Billet Ø55 L150 Start Z0

N05 G21 G90 G99 Metric unit, Absolute co-ordinates, feed mm/rev.

N10 G28 X0 Z0 sending the tool to home position

N15 M06 T0101 Tool change, Select TOOL NO 01 (Rough Turning).

N20 M03 S1500 M07 Spindle ON CW, Spindle speed, Coolant 'ON'

N25 G00 X56 Z1 Approach to Start rough Turning cycle

N30 G71 U0.5 R1 DOC in 0.5mm & Retract after cut in 1mm.

N35 G71 P40 Q65 U0.1 W0.1 F0.2 – Cycle Starts from N40 to N65. Leaves an allowance of 0.1 along X & Z directions

N40 G01 X20 Z0 – START of cycle (1)

N45 G01 X20 Z-20 – (2)

N50 G01 X40 Z-20 – (3)

N55 G01 X40 Z-45 – (4)

(N45–N55: Co-ordinates of Part profile)

N60 G01 X50 Z-45 - ⑤

N65 G01 X50 Z-75 - ⑥ END of cycle

N70 M05 M09 - Spindle STOP, Coolant OFF

N75 G28 X0 Z0 - Send tool to home position

N80 M06 T0202 TOOL Change, Select finishing tool.

N85 M03 S2500 M07 Spindle ON CW, Coolant ON

N90 G70 P40 Q65 F0.02 - finishing cycle from N40 to N65 with 0.02mm/rev feed value.

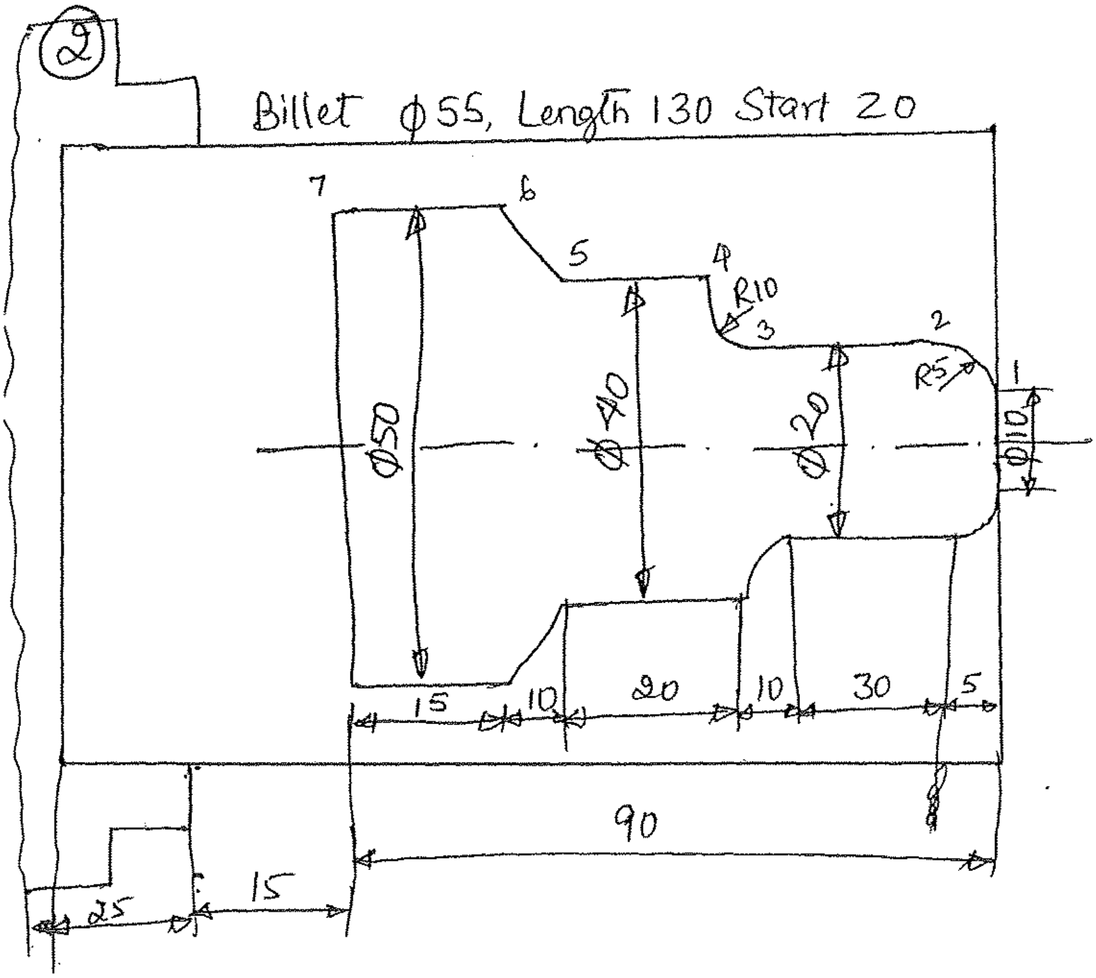
N95 M05 M09 Spindle stop, Coolant OFF

N100 G28 X0 Z0 Send tool to home position

N105 M30 program stop, reset to beginning.

(2)

Billet ϕ55, Length 130 Start Z0



O 02

Billet ϕ55 L130 Start Z0

N05 G21 G99

N10 G28 X0 Z0

N15 M06 T0101

N20 M03 S1500 M07

N25 G00 X56 Z1

N30 G71 U0.5 R2

N35 G71 P40 Q70 U0.1 W0.1 F0.2

N40 G01 X10 Z0 — (1) START

N45 G03 X20 Z-5 R5 — (2)

N50 G01 X20 Z-35 — (3)

N55 G02 X40 Z-45 R10 — (4)

N60 G01 X40 Z-65 — (5)

N65 G01 X50 Z-75 — (6)

N70 G01 X50 Z-90 — (7) END.

N75 M05 M09

N80 G28 X0 Z0

N85 M06 T0202

N90 M03 S2500 M07.

N95 G70 P40 Q70 F0.02

N100 M05 M09

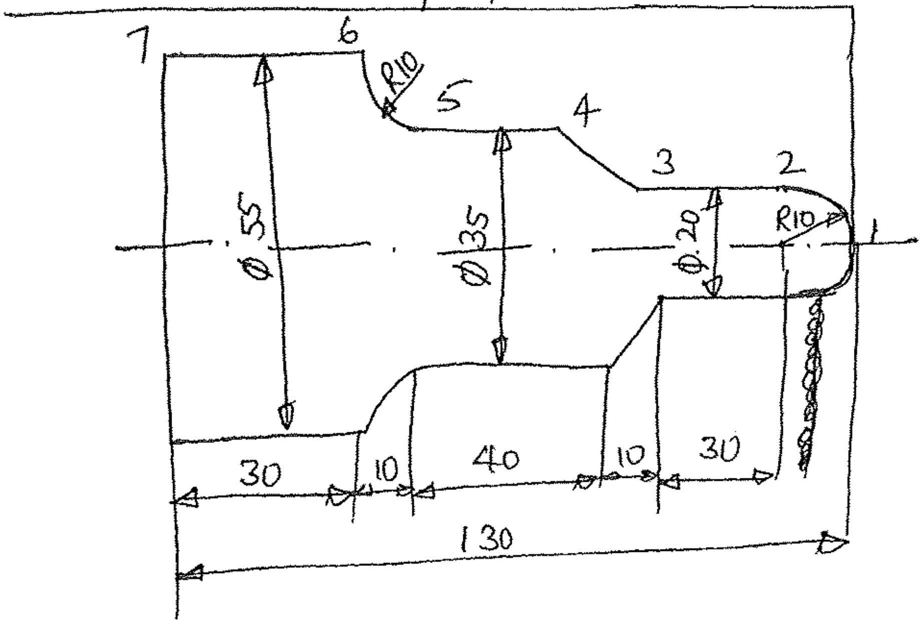
N105 G28 X0 Z0

N110 M30

(3)

(25)

Billet Ø60, L170 Start Z0



O 03

Billet Ø60, L170, Start Z0.

N05 G21 G90 G99

N10 G28 X0 Z0

N15 M06 T001

N20 M03 S2000 M07

N25 G00 X61 Z1

N30 G71 U0.3 R2

N35 G71 P40 Q70 U0.1 W0.1 F0.25

N40 G00 X0 Z0 — (1)

N45 G03 X20 Z-10 R10 — (2)

N50 G01 X20 Z-40 — (3)

N55 G01 X35 Z-50 — (4)

N60 G01 X35 Z-90 (5).

N65 G02 X55 Z-100 R10 (6).

N70 G01 X55 Z-130 (7).

N75 M05 M09

N80 G28 X0 Z0

N85 M03 S3000 M07

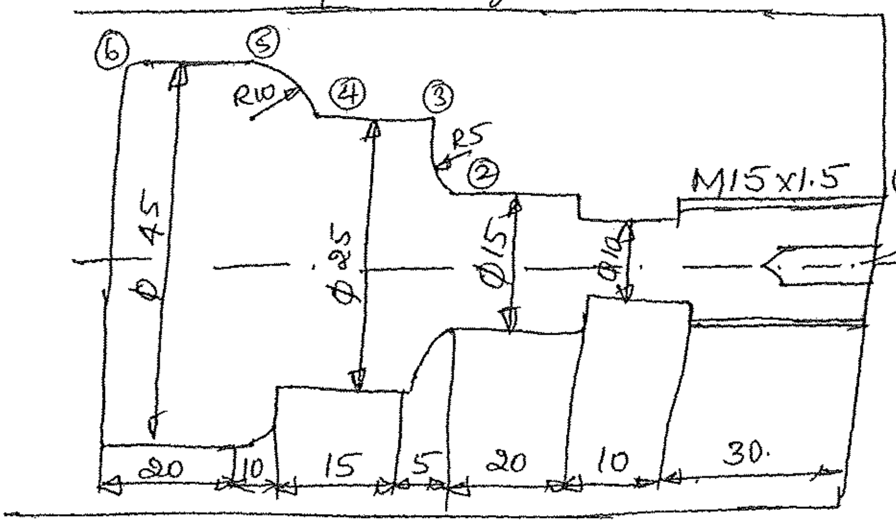
N90 G70 P40 Q70 F0.02

N95 M05 M09.

N100 G28 X0 Z0

N105 M30

(4) Billet ϕ50 Length 150 Stalt 20



Operations

1) Rough Turning
2) Finish Turning
3) Grooving
4) Threading
5) Drilling.

O 04.

Billet ϕ50, L150 Stalt Z0.

N05 G21 G99 G90

N10 G28 X0 Z0

N15 M06 T0101

N20 M03 S2000 M07

N25 G00 X51 Z1

N30 G71 U0.5 R1

N35 G71 P40 Q65 U0.1 W0.1 F0.3

N40 G01 X15 Z0 — ①

N45 G01 X15 Z-60 — ②.

N50 G02 X25 Z-65 R5 ③

N55 G01 X25 Z-80 ④.

N60 G03 X45 Z-90 R10 ⑤

N65 G01 X45 Z-110 — ⑥ END.

N70 M05 M09.

N75 G28 X0 Z0.

N80 M06 T0202

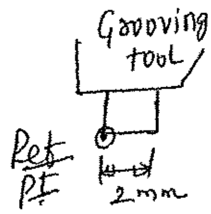
N85 M03 S3000 M07

N90 G70 P40 Q65 F0.02

N95 M05 M09

N100 G28 X0 Z0

N105 M06 T0303



N110 M03 S500 M07.

N115 G00 X16 Z-32

N120 G75 R2

N125 G75 X10 Z-40 P1000 Q1800 F0.2

N130 M05 M09.

N135 G28 X0 Z0.

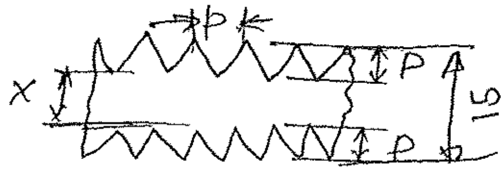
N140 M06 T0404.

N145 M03 S300 M07.

N150 G00 X15 Z1

N155 G76 P031560 Q500 F0.01

N160 G76 X13.161 Z-30 P919.5 Q400 F1.5 **



$P = 0.613 * p.$

$= 0.613 * 1.5$

$P = 0.9195$ mm

$P = 919.5$ micron

$X = 15 - 2(P).$

$X = 15 - 2 * 0.9195$

$X = 13.161$ mm

N165 M05 M09

N170 G28 X0 Z0

N175 M06 T0505

N180 M03 S400 M07

N185 G00 X0 Z1.

N190 G74 R2

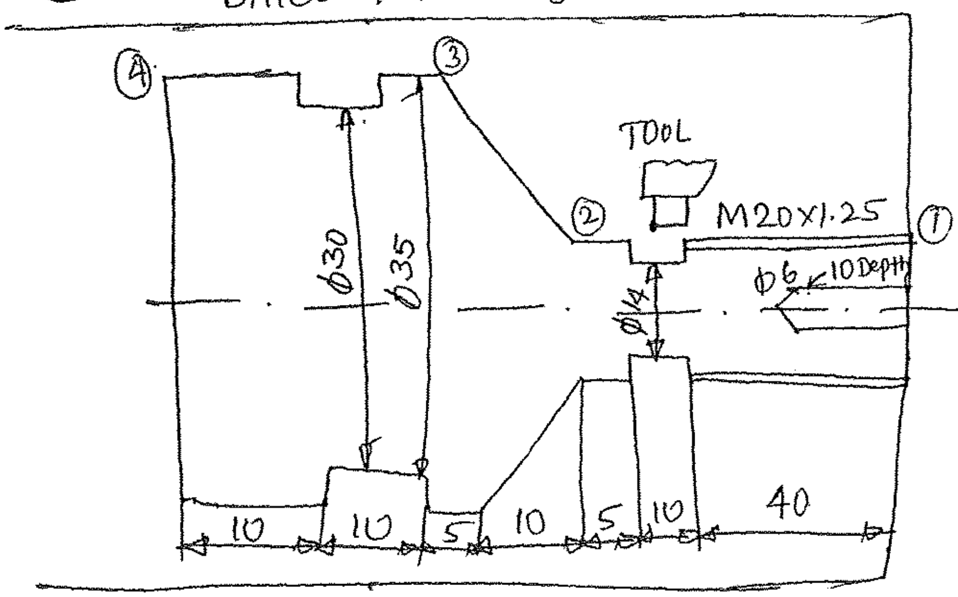
N195 G74 X0 Z-15 Q3 F0.2

N200 M05 M09.

N205 G28 X0 Z0.

N210 M30

(5) Billet ϕ40 Length 130 Start 20.



G71_T01 = Rough Turning

G70-T02 = Finish ––

G75_T03 = Grooving

G76-T04 = Threading

G74-T05 = Drilling

O05

Billet ϕ40 L 130 Stalt Z0.

N05 G21 G99

N10 G28 X0 Z0

N15 M06 T0101

N20 M03 S2000 M07

N25 G00 X41 Z1

N30 G71 U0.5 R2

N35 G71 P40 Q55 U0.1 W0.1 F0.3.

N40 G01 X20 Z0 — (1). START

N45 G01 X20 Z-55 — (2)

N50 G01 X35 Z-65 — (3)

N55 G01 X35 Z-90 — (4). END

N60 M05 M09.

N65 G28 X0 Z0

N70 M06 T0202

N75 M03 S3000 M07

N80 G70 P40 Q55 F0.03

N85 M05 M09

N90 G28 X0 Z0

N91 M06 T0303

N95 ~~G00~~ M03 S500 M07.

N100. G00 X21 Z-42

N105 G75 R2

N110 G75 X14 Z-50 P1000 Q1800 F0.2

.N115 M05 M09

N120 G28 X0 Z0

N125 M06 T0303

N130 M03 S500 M07.

N135 G00 X36 Z-72

N140 G75 R2

N145 G75 X30 Z-80 P1000 Q1800 F0.2

N150 M05 M09

N155 G28 X0 Z0 → N156 M06 T0404

N160 M03 S300 M07.

N165 G00 X20 Z1

N170 G76 P031560 Q500 R0.015

N175 G76 X18.468 Z-40 P766
Q400 F1.25

N180 M05 M09

N185 G28 X0 Z0

N190 M06 T0505

N195 M03 S400 M07.

N200 G00 X0 Z1

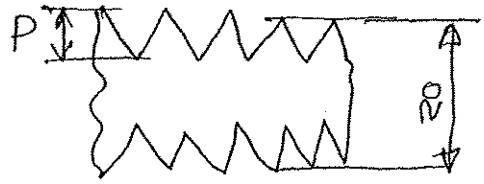
N205 G74 R2

N210 G74 X0 Z-10 Q2 F0.2

N215 M05 M09

N220 G28 X0 Z0

N225 M30



P = 0.613 * pitch
= 0.613 * 1.25
P = 0.766 mm
P = 766 microns

X = 20 − 2(P)
= 20 − 2 * 0.766
X = 18.468 mm

N60 G01 Z-82
N65 M05 M09
N70 G28 U0 W0
N75 M06 T0202
N80 M03 S2000 M08
N85 G70 P40 Q60 F20
N90 G28 U0 W0
N95 M06 T0303
N100 M03 S500 M08
N105 G00 X20 Z-34 — I grooving
N110 G75 R1
N115 G75 XI6 Z-38 P100 Q1000 FI5
N116 M05 M09
N117 G28 U0 W0
N118 M06 T0303
N119 M03 S500 M08
N120 G00 X40 ~~G-69~~ Z-69
N125 G75 R1
N130 G75 X36 Z-77 P100 Q1000 FI5
N135 M05 M09
N140 G28 U0 W0
N145 M06 T0404
N150 M03 S500 M08
N155 G00 X20 Z-2
N160 G76 P03I560 Q50 R0.015
N165 G76 X18.161 Z-32 P919.5 Q100 F1.5
N170 M05 M09
N175 G28 U0 W0
N180 M06 T0505
N185 M03 S1000 M09
N190 G00 X0 Z1

30

N195 G74 R2

N200 074 XO 2-10 Q50 F15

N210 G00 Z5

N215 M05 M09

N220 G28 U0 W0

N225 M30

N230 M30

7.16 CNC PROGRAMMING FOR MILLING OPERATIONS.

PROBLEM NO 1:

Write the part programming for the component shown in figure 7.23

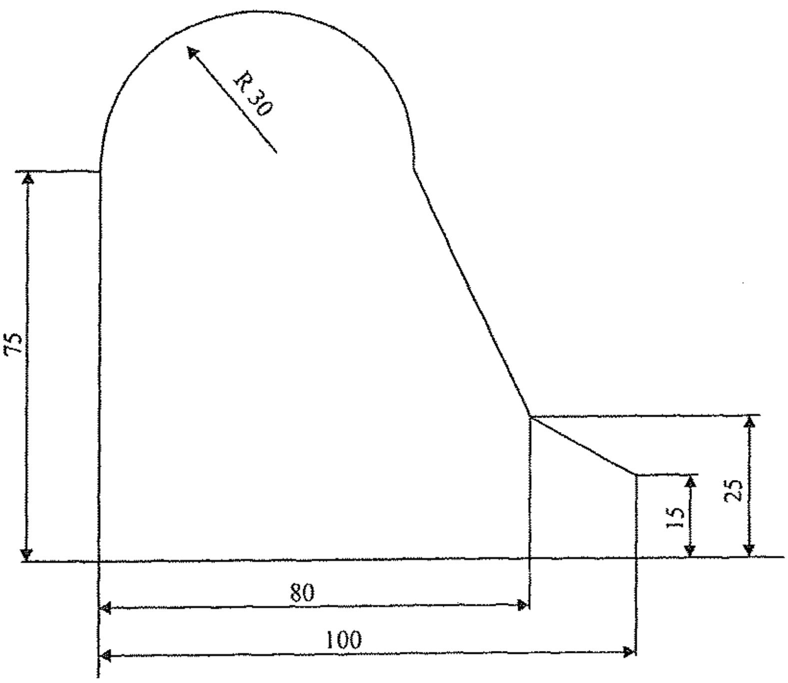


Fig. 7.23

O 01

BILLET X150 Y150 Z30

N01 G21 G94 G90

N02 G28 X0 Y0 Z0

N03 M06 T01

```
N04 G43 H01
N05 M03 S1500 M08
N06 G00 X-30 Y0 Z5
N07 G01 Z-5 F45
N08 G01 X190 Y0 F40
N09 G01 Y30
N08 G01 X-30
N09 G01 Y60
N10 G01 X190
N11 Y90
N12 G01 X-30
N13 G01 Y120
N14 G01 X190
N15 G01 Y150
N16 G01 X-30
N17 G00 Z5
N18 M05 M09
N19 G49
N20 G28 X0 Y0 Z0
N21 M06 T02
N22 G43 H02
N23 M03 S1000 M08
N24 G00 X0 Y0 Z5
N25 G00 X25 Y25 Z5
N26 G01 Z-10 F40
N27 G01 X25 Y100
N28 G02 X85 Y100 R30 F30
N29 G01 X105 Y50 F40
N30 G01 X125 Y40
N31 G01 Y25
N32 G01 X25 Y25
N33 G00 Z5
N34 M05 M09
```

N35 G49

N36 G28 X0 Y0 Z0

N37 M30

PROBLEM NO 2:

Write the part programming for the component shown in figure.7.24

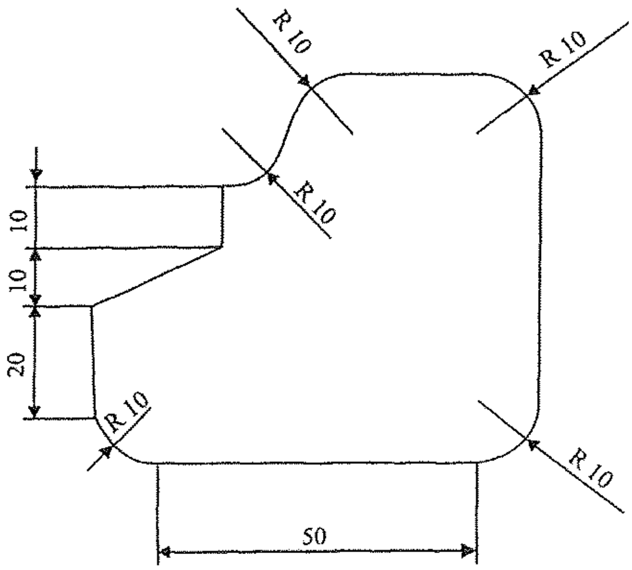


Fig. 7.24

002

BILLET 120 X 120 X 30 MM

N01 G21 G94

N02 G28 X0 Y0 Z0

N03 M06 T01

G43 H01

N04 M03 S1500 M08

N05 G00 X-25 Y0 Z5

N06 G01 Z-5 F40

N06 G01 X140 Y0

N07 G01 Y10

N08 G01 X-25

```
N09 G01 Y20
N10 G01 X140
N11 G01 Y50
N12 G01 X-25
N13 G01 Y80
N14 G01 X140
N15 G01 Y100
N16 G01 X-25
N17 G01 Y130
N18 G01 X140
N19 G00 Z5
N20 M05 M09
N21 G49
N22 G28 X0 Y0 Z0
N24 M06 T02
N25 G43 H2
N26 M03 S1500 M08
N27 G00 X0 Y0 Z5
N28 G01 X25 Y35 F35
N29 G01 Z-10 F40
N30 G01 Y55
N31 G01 X35 Y65
N32 G01 Y75
N33 G03 X45 Y85 R10 F35
N34 G02 X55 Y95 R10 F35
N35 G02 X85 F40
N36 G02 X95 Y85 R10 F35
N37 G01 Y35 F40
N38 G02 X85 Y25 R10 F35
N39 G01 X35
N40 G02 X25 Y35 R10 F35
```

(34)

N41 G00 Z5

N42 M05 M09

N43 G49

N44 G28 X0 Y0 Z0

N45 M30

PROBLEM NO 3:

Write the part programming for the component shown in figure 7.25

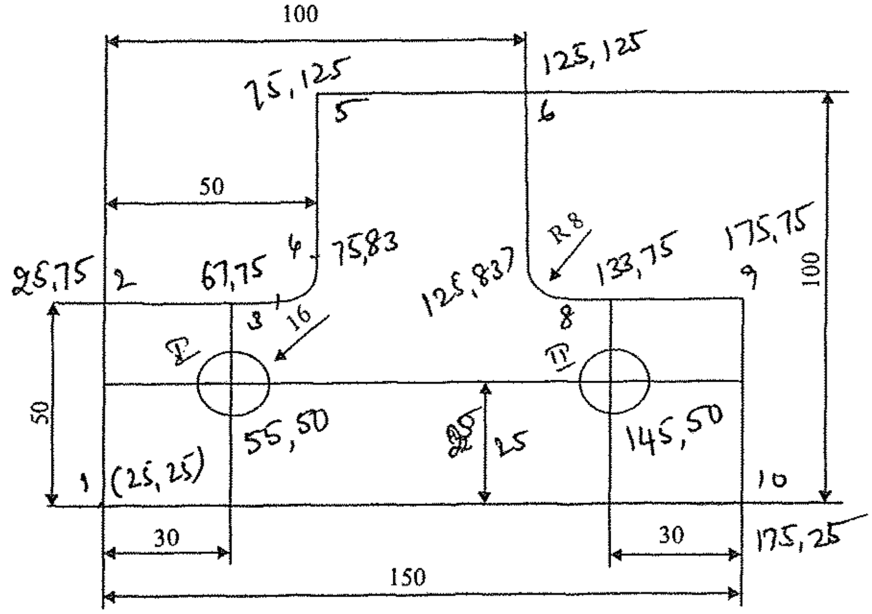


Fig. 7.25

O 03

BILLET 200 X 150 X 30 MM

N01 G21 G94 G17G90 — XY plane selection

N02 G28 X0 Y0 Z0

N03 M06 T01

N04 G43 H01

NOS M03 S1500 M08

N06 G00 X0 Y0 Z5

N07 G00 X25 Y25 – 1

35

N08 G01 Z-15 F40

N09 X25 Y75 – 2

N10 Gal X67 Y75 – 3 (G01)

N11 G03 X75 Y83 R8 F30 – 4

N12 G01 Y125 F40 – 5

N13 G01 X125 – 6

N14 G01 X125 Y83 – 7

N15 G03 X133 Y75 R8 F30 – 8

N16 G01 X175 – 9

N17 G01 Y25 – 10

N18 G01 X25 Y25 – 1

N19 G00 25 Z5

N20 M05 M09

N21 G49

N22 G28 X0 Y0 Z0

N23 M06 T02

N24 G43 H02 → M03 S500 M07

N25 G00 X55 Y50Z3 – Drilling I hole

N26 G01 Z-10

N27 G00 Z3

N28 G00 X145 Y50 – Drilling II hole

N29 G01 Z-10

N30 G00 Z3

N31 M05 M09

N32 G49

N33 G28 X0 Y0 Z0

N34 M30

PROBLEM NO 4:

Write the part programming for the component shown in figure 7.26

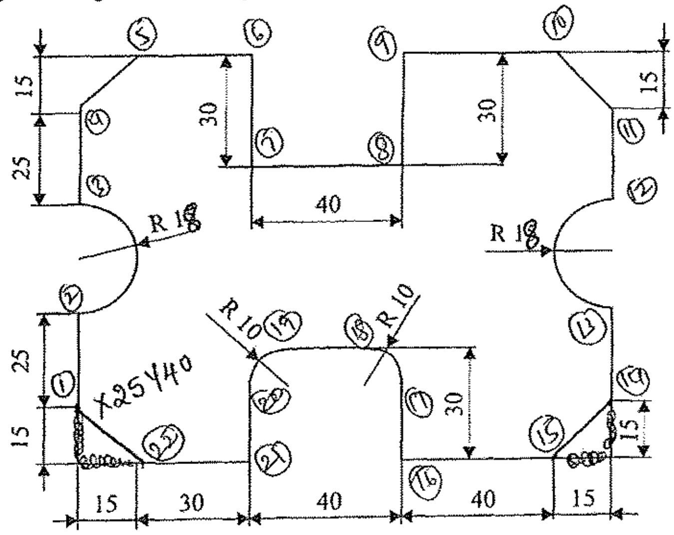


Fig. 7.26

O 04

BILLET 180 X 180 X 30 MM

N01 G21 G94 G90 G17
N02 G28 X0 Y0 Z0
N03 M06 T01
G43 H01
N04 M03 S1500 M08
N05 G00 X0 Y0 Z5
N06 G00 X25 Y40
G01 Z-20 F40
N07 G01 Y65 F40
N08 G03 Y101 R18 F30
N09 G01 Y126 F40
N10 G01 X40 Y141
N11 G01 X70
N12 Y111
N13 X110

```
N14 Y141
N15 X140 Y141
N16 G01 X155 Y126
N17 X155 Y101
N18 G03 X155 Y65 R18 F30
N19 G01 X155 Y40 F40
N20 G01 X140 Y25
N21 G01 X110 Y25
N22 G01 X110 Y47
N23 G03 X102 Y55 R8 F30
N24 G01 X78 Y55 F40
N25 G03 X70 Y47 R8 F30
N26 G01 X70 Y25 F40
N27 G01 X40 Y25
N28 G01 X25 Y40
N29 G00 Z5
N30 M05 M09
N31 G28 X0 Y0 Z0
N32 M30
```

PROBLEM NO 5:

Write the part programming for the component shown in figure 7.27

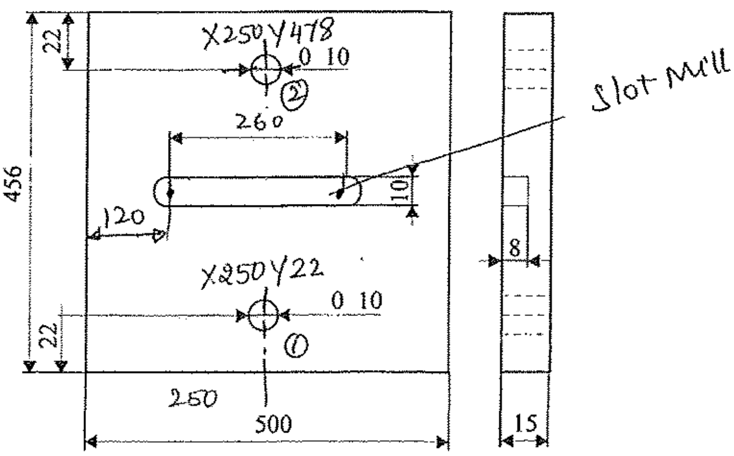


Fig. 7.27

38

005

BILLET 500 X 500 X 30 MM

N01 G90 G21 G94 G17

N02 G28 X0 Y0 Z0

N03 M06 T01 → Twist Drill

N04 G43 H01

N05 M03 S1200 M08

N06 G00 X250 Y22 Z5 – (1) Drilling

N07 G01 Z-15 F30

N08 G01 Z10 F40

N09 G01 X250 Y478 – (2) Drilling.

N10 G01 Z-15

N11 G01 Z10

N12 M05 M09

N13 G49

N14 G28 X0 Y0 Z0

N15 M06 T02 → Slot Mill Cutter

N16 G43 H02

N17 M03 S700 M08

N18 G00 X120 Y250 Z5

N19 G01 Z-8 F30

N20 G01 X380

N21 G01 Z5

N22 M05 M09

N23 G49

N24 G28 Z0

N25 G28 X0 Y0

N26 M30

PROBLEM NO 6:

Write the part programming for the component shown in figure 7.28

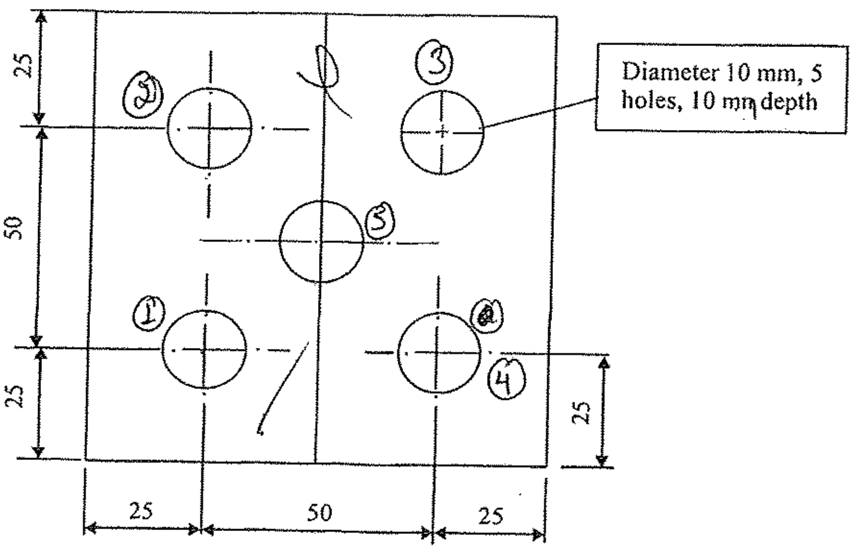


Fig. 7.28

O 06

BILLET 100 X 100 X 30 MM

CANNED CYCLES USED: G81 Drill Cycle & G85 Reaming cycle

```
N01 G21 G94 G90
N02 G28 X0 Y0 Z0
N03 M06 T01
N04 G43 H01
N05 M03 S1500 M08
N06 G00 X0 Y0 Z5
N07 G00 X25 Y25
N08 G99 G81 Z-10 R5 F100
N09 Y75
N10 X75
N11 Y25
N12 X50 Y50
N13 G80 M09 M05
N14 G28 X0 Y0 Z0
N15 M06 T02
N16 G43 H02
```

N17 M03 S750 M08
N18 G00 X25 Y25
N19 G99 G85 Z-10 R3 F75
N20 Y75
N21 X75
N22 Y25
N23 X50 Y50
N24 G80 M09 M05
N25 G28 X0 Y0 Z0
N26 M30

PROBLEM NO 7:

Write the part programming for the component shown in figure 7.29

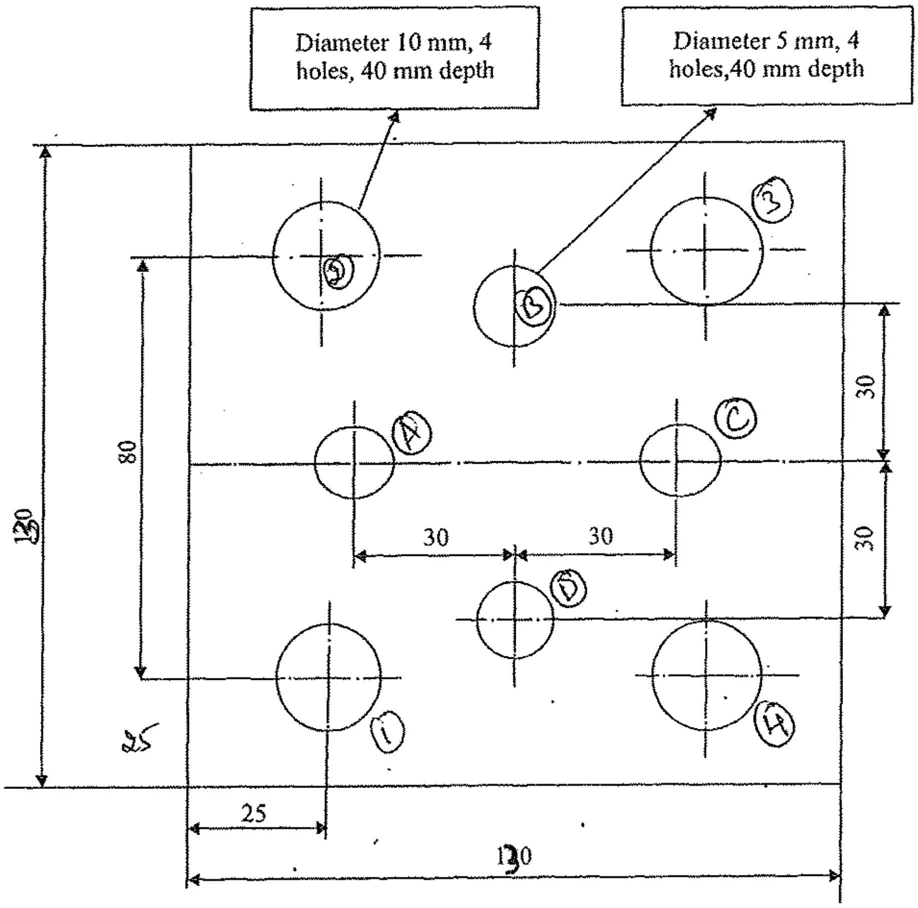


Fig. 7.29

(41)

007

BILLET 120 X 120 X 50 MM

CANNED CYCLES USED : G83

```
N01 G21 G94 G90
N02 G28 X0 Y0 Z0
N03 M06 T01
N04 G43 H1
N05 M03 S1500 M08
N06 G00 X0 Y0 Z5
N07 G00 X25 Y25 —(1)   peck depth
N08 G99 G83 Z-40 Q5 R5 F100
N09 Y105 —(2)
N10 X105 —(3)
N11 Y25 —(4)
N12 G80 M09 M05
N13 G28 X0 Y0 Z0
N14 M06 T02
N15 G43 H2
N16 M03 S1500 M08
N17 G00 X0 Y0 Z5
N18 G00 X30 Y65 —(A)
N19 G99 G83 Z-40 Q5 F100
N20 X60 Y95 —(B)
N21 X90 Y65 —(C)
N22 X60 Y35 —(D)
N23 G80 M09 M05
N24 G28. X0·Y0 Z0
N25 M30.
```

PROBLEM NO 8:

Write the part programming for the component shown in figure 7.30 to mill the profile to the depth of 10mm.

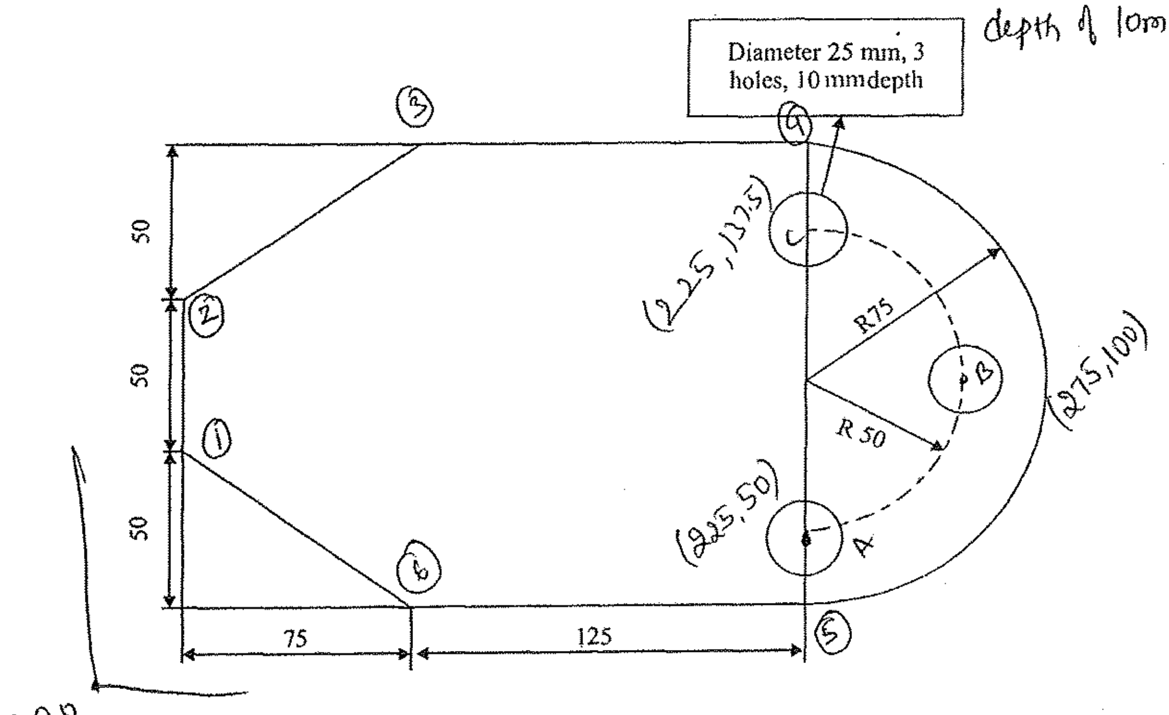


Fig. 7.30

O 08

BILLET 350 X 250 X 30 MM

CANNED CYCLES USED: G81 Drilling cycle & G86 Boring cycle

N01 G21 G94 G90

N02 G28 X0 Y0 Z0

N03 M06 T01

N04 G43 H01

N05 M03 S1500 M08

N06 G00 X0 Y0 Z10

N07 G01 X25 Y75 F100 — (1)

N08 G01 Z-IO

N09 G01 Y125 — (2)

G81
G83
G84
G85
G86

G81 & G85
Drill Ream
G83
G81 & G86

43


```
N10 X100 Y175  — (3)
N11 X225  — (4)
N12 G02 X225 Y25 R75 F70 — (5)
N13 G01 X100  — (6)
14 G01 X25 Y75 — (1)
15 G01 Z5
N16 M05 M09
N17 G28 X0 Y0 Z5
N18 M06 T02
G43 H02
N19 M03 S1000 M08
N20 G00 X225 Y50 Z5  — (A)
N2l G99 G8l Z-10 R5 F100  ——> Dolling
N22 G00 X275 Y100  — (B)
N23 X225 Y137.5  — (C)
N24 G80 M09 M05
N25 G28 X0 Y0 Z5
N26 M06 T03
G43 H03
N27 M03 S500 M08
N28 G00 X225 Y50 Z5
T29 G99 G86 R5 Z-10 F75
N30 G00 X275 Y100
N3l X225 Y137.5
N32 G80 M09 M05
33 G28 X0 Y0 Z5
N34 M30
N35 M30
```

(44)

Exercise

1. Define NC. How CNC came into existence.
2. List the features of CNC.
3. List the advantages & disadvantages of CNC.
4. Briefly explain the elements of CNC with a block diagram.
5. Explain the classification of CNC systems.
6. Briefly explain about machining centres. What is the importance of VMC, HMC, UMC & TMC.
7. Explain the importance of Automatic Tool Charger & Automatic Pallet Charger.
8. Explain CNC turning centres with the features.
9. Explain the co-ordinate system for lathe & milling machine.
10. Differentiate between absolute & incremental coordinate system.
11. Define NC block. Explain the components of it.
12. Explain various types of G codes & M codes.
13. Explain about cutter radius compensation & cutter length compensation.
14. Manual part progrmming exercises for CNC turning related operations.
15. Manual part programming exercises for CNC Milling related operations.

QP's Contents:

Module - IV

Unit - 8

ROBOTICS

Contents : Introduction Robot configuration, Robot motions, programming of Robots, end effectors, Robot sensors and Robot applications.

8.1 INTRODUCTION

Man is always thinking of developing all creations of God including himself. The very purpose of this thought is to replace whatever work or task he has to do is to be done by some other system. Manual work was replaced by machines and with a technological development superior machines were developed to produce high quantity, high quality at lower cost and also to carry out the tasks done by human beings. One such outcome of this is the development of a robot.

A robot is a near replica of a part of human being or whole human being to perform various types of tasks. As such there is no standard size and shape of a robot and any robots developed till now is as per the imagination of man. However, there are some essential characteristics that a robot must have to carry out various tasks and they are

(i) Sensing (ii) Movement (iii) Energy (iv) Intelligence

Sensing is necessary for a robot to be able to sense its surroundings.

Movement is necessary to move around its environment.

Energy is necessary for sensing and movement and

Intelligence is necessary to carryout all the above three characteristics or functions in a controlled, sequential and precise manner, and here comes the concept of programming. With the above concepts a robot can be defined as follows.

DEFINITIONS

1. A system containing sensors, control systems, manipulators, power supplies and software all working together with a proper co-ordination to perfom a task is called a Robot.
2. Integration of Mechanical Engineering, Electronics Engineering and Computer Science Engineering to create a system, then it is called Mechatronics. If mechatronics is used to create a robot then it is Robotics.
3. "A Robot is a programmable, multifunctional system designed to perform various tasks."
4. According to Webster's dictionary, Robot is a machine that looks like a human being and performs various complex activities, those performed by human being.
5. A device that automatically performs complicated and often repetitive tasks, without committing any mistake or error.

A robot in an industry is a general purpose programmable machine possessing some anthropomorphic i.e. human like characteristics. The most typical anthropomorphic characteristic of a robot is its arm. The arm together with the robot's capacity to be programmed make it ideally suited for variety of production tasks such as machine loading, spot welding, assembling etc.

The most essential or important feature of an industrial robot is its mechanical arm or manipulator.

8.2 BASIC STRUCTURE OF A ROBOT MANIPULATOR

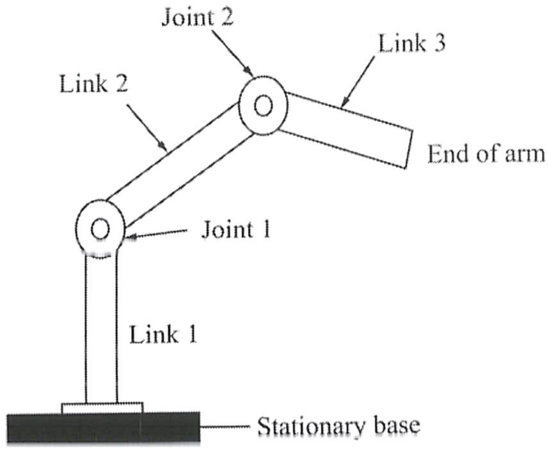


Fig 8.1. : Basic structure of a Robot manipulator

Fig. 8.1 shows the basic structure of an industrial robot. This consists of a stationary base with a link 1 mounted on it. Link 1 and Link 2 are connected by a Joint 1 and similary Link 2 and Link 3 connected by Joint 2. A Robot joint is similar to the joints in human arm which provides relative movement between the two links.

A robot generally consists of

(a) Mechanical structure
(b) Actuator
(c) Sensors
(d) Power source
(e) Controller
(f) Tooling
(g) Safety system
(h) Programming interface

(a) Mechanical Structure : Mechanical structure constitutes the major chunk of the robot weight and parts and this is the one which provides required stability and shape to the robot. Mechanical structure may be

- Industrial Robot Arm
- Frame structure specific to a robot.

In industrial robot, arm is the maximum type of mechanical structure used in which resembles a human arm, as the human arm is the one which carries out most of the tasks in industries. This consists of a series of links connected by joints as shown in Fig. 8.1.

The end of the arm carries a wrist to which is connected an end effector. Even the end effector is a link whereas wrist is a joint. The joints are rigid elements and the size and shape and material used depends on the purpose for which the robot has been designed to perform the task.

b. Actuators : As mentioned earlier, joints provides relative motion to the links and hence, joints have to be actuated or motion to be imparted to the joints. Different types of actuations are :

- Electric motor/electric actuators.
- Hydraulic actuator (oil hydraulics)
- Pneumatic actuator (air as the medium)

Electric Motors/Electric Actuators

The most common method used for actuation of joints is electric motors. Varieties of electric motors are available and the use of specific motor depends on the speed, torque necessary at the joint keeping in mind the weight of the links and other associated elements. Various types of electric motors available are AC motors, DC motors of high speed low torque, low speed and high torque and for robots sometimes stepper motors are used at joints for precise motion and control. These electric motors are built into the robot itself.

Hydraulic Actuators

Hydraulic actuators are also used in some robots when large power is required and in several types of robots for under water applications. Hydraulic actuators are used for heavy applications.

Pneumatic Actuators

Pneumatics are generally used for the end effector such as grippers, suction cups for grabbing parts to be moved and positioned at required locations. Pneumatics are used for light applications.

c. Sensors : Sensors are one of the most important components of any robot and it is these sensors which give life to the robot. There can't be a robot without a sensor. The main function of a sensor is to sense position, obstruction and also for controlling the speed.

d. Power Source: All the activities are performed only when there is power and without power the whole system is useless or just like any other dead structure. Various types of power sources used in robots are (i) battery for dedicated mobile robots, electric power for stationary robots and use of diesel and gasoline for large mobile robots. The type of power used depends on the purpose what robots needs to do.

e. Controller : Every robot requires a controller without which a robot cannot perform its intended task. Controller is like a brain of a robot, generally a computer. Controller is necessary to manipulate the following activities or actions of a robot. They are

- Controlling the motion of the manipulator.
- Calculating and storing of paths
- Receiving signals for various sensors.
- Sending commands in the form of signals to the actuators.

Generally the controlling activities of the robots are achieved using various types of microcontrollers.

f. Tooling : Ultimately it is the end effector which carries out the task for which the robot has been designed and built. End effector may be designed similar to human hand and this may carry

- scoop for sample collection
- brush for cleaning
- Surgery tools for surgery

depends on the task to be carried out by the end effector. The joints provides relative motion between the links and the type of joint used depends on the type of relative motion desired between the links, again depends on the configuration required for carrying out a specific task. Other specific tools such as gripper for moving parts, welding gun, drill gun, paint gun, portable grinder etc.

g. Safety System : Robot is a slave and it just carries out the order as per the instructions provided in the microcontroller and it is not able to think and act on its own. Safety system in the form of sensors to sense the environment and send the signals to the controller. The controller in turn directs the robot what action has to be carried out which is again controlling of manipulator, actuators and end effectors. Safety systems should be built in the robot to prevent damage to the human, the work area or the robot itself.

h. Programming interface :

All robots are integrated with electronic systems containing microcontroller and some other types of controllers. Programs are embedded into the microcontroller and as per the instructions (program) the robot acts. Most robots can be programmed using a special robot programming language or using standard languages such as **C** or **Java**.

Many of the industrial robots arms are taught with a small hand held device called teach pendant which stores the movement of robot through a sequence of points, which can be played back any number of times. Offline programming can also be done on the robot.

8.3 CLASSIFICATION OF JOINTS

It was mentioned earlier that in between two links there will be a joint and the function of the joint is to provide (impart) relative motion between the links. The name of the joint depends on the type of relative motion the joint provides to the two links that are connected to it.

Based on this we have two types of joints. They are

(a) Prismatic joint (linear joint)

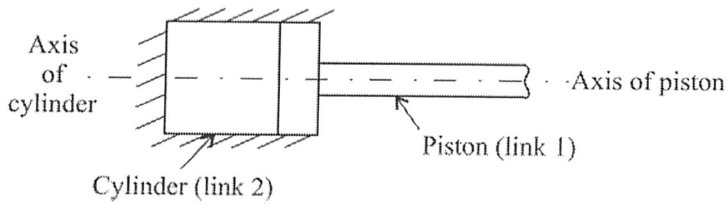
(b) Revolute Joint (Rotary joint)

(a) **Prismatic joint :** Prismatic joints provides linear motion between links. Based on the type of relative motion we have

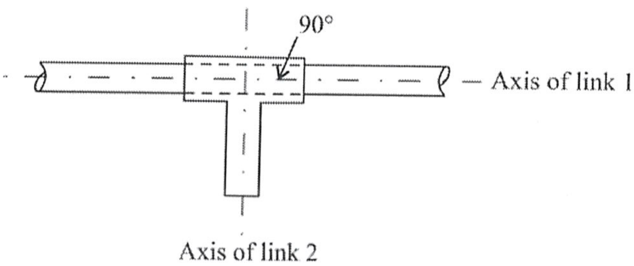
(i) Linear joint (L Joint)

(ii) Orthogonal joint (O Joint)

(i) **Linear joint (L Joint) :** In the case of **L joint** the relative motion imparted by the joint between the links connected to them is translational motion, the axes of the two links being collinear. Example piston and cylinder.



(ii) **Orthogonal joint (O Joint) :** In this case also the relative motion imparted by the joint is translational sliding, but the axes of the two links are perpendicular (ortho) to each other.



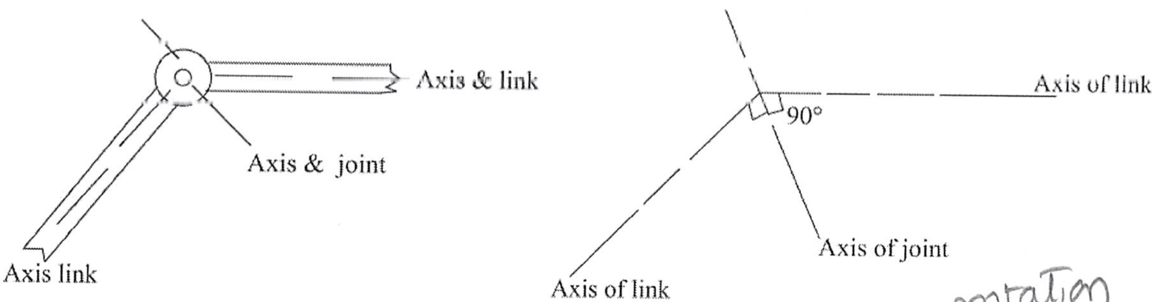
b) **Revolute joints :** Revolute joint is a rotary joint wherein the relative motion between the adjacent links is rotation about a fixed axis. There are three types of revolute joints based on the alignment of the axes of the links and the joint itself. They are

i) **R**otational joint (R joint)

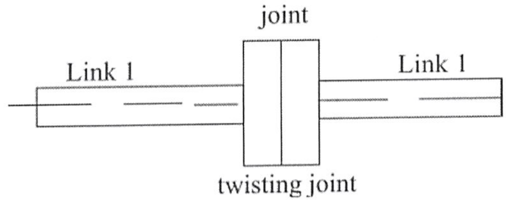
ii)**T**wisting joint (T joint)'

iii)Revolving joint (V-joint)

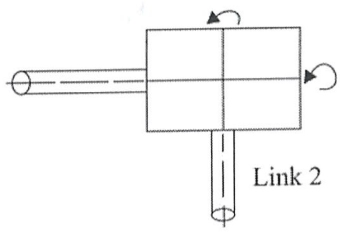
i) **Rotation joint (R joint) :** In a rotational joint the relative motion is a circular path and the axes of the links are perpendicular to the axis of the joint. In this case, the links change their orientation with respect to the axes of each other.



ii) **Twisting joint (T joint)** : T-joint is also a rotational joint where the roation of one link imparts twisting of the other and hence the name twisting joint



iii) **Revolving joint (V-joint) :** In this case, the axes of two links are always perpendicular to each other or angular and the axis of rotation of one link is abut the axis of the other. Since one link revolves about the other, hence the name revolving joint.



8.4 DEGREES OF FREEDOM (DOF)

The axis about which a link can move freely or can have free relative motion is called freedom of motion.

The number of freedom of motion a robot can have is called its **Degree of Motion (DOF)**. Here degrees means number.

Degrees of Freedom can also be defined as the number of joints that can be moved independently OR degrees of freedom are the axes around which the robot is free to move.

One actuator is necessary for each degree of freedom. Hence the degrees of freedom indicates the number of actuator or number of joint that can impart relative motion to the adjoining links connected to it.

To reach an arbitrary point in space, i.e. coordinate (x,y,z) a robot arm needs three degrees of freedom.

A robot manipulator may be broadly divided into two sections

- Arm assembly
- Wrist assembly

Arm assembly : Most robots are equipped with one hand and one arm of several articulated joints. Some of these joints swivel in smooth arcs imitating the behaviour of human shoulder, wrist and elbow. Generally arm assembly has three degrees of freedom and end of the arm can reach any point in space.

Wrist assembly : This assembly also requires three degrees of freedom to control the three motion arm, pitch and roll of the end effector.

8.5 ROBOT CONFIGURATIONS (MANIPULATOR CONFIGURATIONS)

Robot configuration is the combination of joints used in its construction i.e. different combination of revolute and prismatic joint leading to different manipulator configurations.

There are five types of configuration used in present day industrial manipulators. All of them contain three joints. They are

a) Cartesian (LOO)
b) Cylindrical (TLO)
c) Spherical (TRL)
d) Revolute or Articulated (TRR)
e) SCARA (Selection Compliance Assembly Robot Arm)

a) **Cartesian configuration :** Cartesian configuration is also called **Rectilinear or Rectangular configuration** as the joints allow only translational or linear relative motion between the adjacent links of the joint. A robot using such a configuration is called X-Y-Z robot. Any point in X, Y, Z coordinate system can be reached using this configuration and Notation : LOO : Linear, Orthogonal, Orthogonal

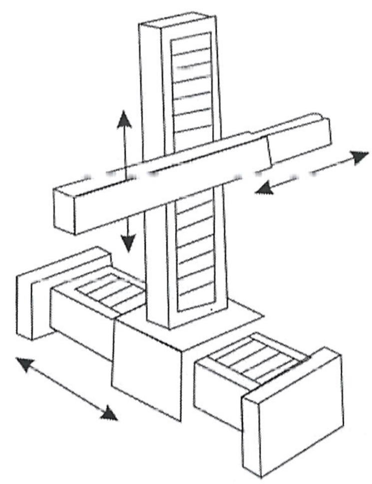


Fig. 8.2 Cartesian configuration

Fig. 8.2 illustrates a typical Cartesian configuration

Features :

i) Three prismatic joints are used
ii) The position is specified by X, Y and Z location.
iii) Easy to visualize motion
iv) Additional axes can be incorporated to the wrist action.
v) Easy to program motions.
vi) Adapted in gantry crane and CNC milling machines.

vii) Gantry type can handle heavy loads.

viii) Difficult to protect the sliding axes from contaminants such as dust and moisture as it is open.

b) **Cylindrical configuration :** This also has three degrees of freedom, two prismatic and one revolute. It moves linearly along X and Y axes and rotation about at its base i.e. Z-axis.

Notation : TLO – Twisting, Linear and Orthogonal.

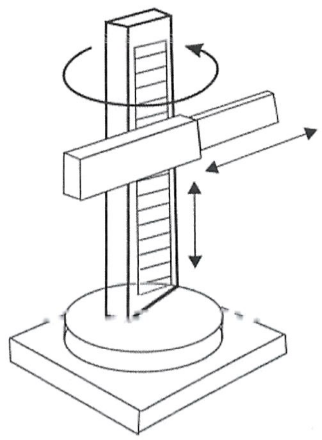


Fig. 8.3 : Cylindrical robot configuration

Fig. 8.3. typical cylindrical Robot configuration

Features :

i) Two prismatic and one revolute.

ii) Position is specified Y value (height) extension of arm X axis and angle of rotation of z-axis (θ)

iii) Recommended for pick and place operations such as machine loading and unloading.

iv) Not finding much application in the present scenario.

v) Restricted access above and below the robot.

This configuration consists of a vertical column (z-axis) relative to which an arm assembly is moved up and down. The arm can be moved away and towards the vertical axis z radially. The vertical axis itself is rotated about its own axis.

c) **Spherical configuration :** This configuration is also called polar coordinate configuration. It consists of linear joint (L) and a twisting joint (T relocate) and a rotation joint (R). Notation : LTR

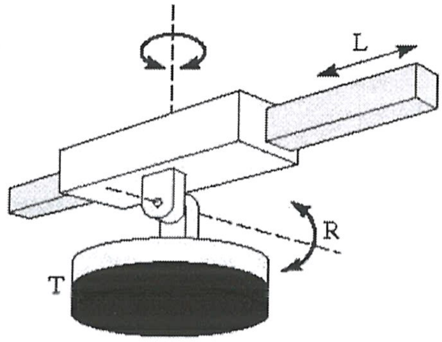


Fig. 8.4 : Spherical configuration

Features :

i) One prismatic axis and two revolute axes.

ii) Position is specified by base rotation and extension of arm and tilt angle.

iii) Rarely used in industries but common in automated cranes.

iv) Prismatic joint can be covered to prevent from dust and moisture.

A vertical column Z rotates about its own axes, and carries a prismatic joint which slides away and towards the column radially. End of the prismatic joint carries a revolute twisting joint which tilts about the axis of the prismatic joint.

d) **Revolute or Articulate configuration : (Notation TRR)**

The main feature of this configuration is that all the three joints are of revolute type.

Fig. 8.5 shows Revolute or articulate configuration

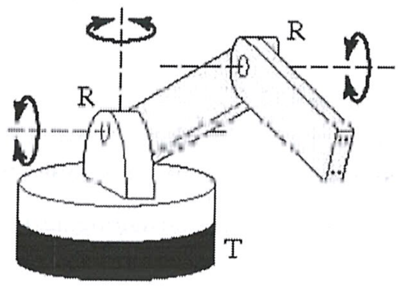


Fig. 8.5 : Revolute or Articulate configuration

This robot manipulator has the general configuration of a human arm. The joined arm consists of a vertical column that swivels about the base using a T joint. At the top of the column is a shoulder joint (R joint), whose about link connects to an elbow joint (R joint).

Features :

i) All the three are revolute joints.

ii) Position specified by the angle of rotation of each joint.

iii) Can reach above, below and around obstacles.

iv) Can reach a point with different orientation resulting in good flexibility but redundant.

v) Joints can be sealed easily.

vi) Difficult to calculate angular motion of the axis for a given top or end motion.

(e) SCARA (Selective ~~Assembly~~ Compliance Assembly Robot Arm) : (Notation VRO)

This configuration consists of one prismatic and two revolute, the important features being the relative motion of all the links at the joints are about vertical axes.

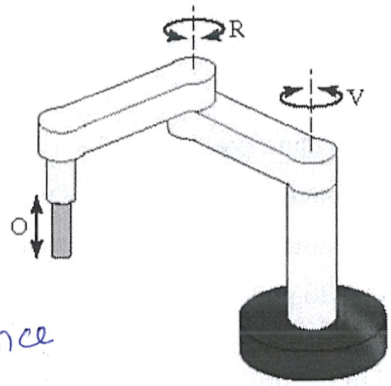


Fig. 8.6 : Basic concept of SCARA configuration.

SCARA stands for Selective Compliant Assembly Robot Arm. This configuration is similar to the jointed robot except that the shoulder and elbow rotational axes are vertical, which means that the arm is very rigid in the vertical direction, but complaint in the horizontal direction. Similar to jointed-arm robot except that vertical axes are used for shoulder and elbow joints to be compliant in horizontal direction for vertical insertion tasks

8.6 WORK VOLUME (Work Envelop)

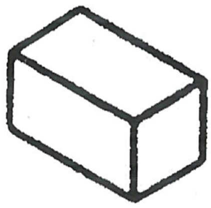
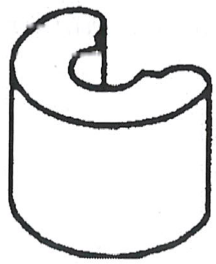
The volume a robot arm can reach is its work volume or work envelop or the collection of all the points in space that a particular manipulator can reach is called **work volume** or **work envelop**.

The knowledge of work volume is necessary for designing a robot which can reach all the required points.

WORK VOLUME FOR DIFFERENT ROBOT CONFIGURATIONS

Table 8 gives a concise idea about robot configuration and work volume.

Sl. No.	Configuration	Diagram of Work Volume

1.	Cartesian	
2.	Cylindrical	
3.	Spherical or Polar Coordinates	
4.	SCARA	

5.	Revolute or Articulate	

8.7 END EFFECTOR

Definition : End effector is a generic term which includes all the devices that can be mounted at the wrist. The type of end effect mounted depends on the specific to the task that has to be carried out by the end effector Table 8.1 shows a few tasks. and the corresponding end effector.

Table 8.1 : Task and corresponding End Effectors

Task	End effector
Painting	Spray Gun
Cleaning	Brush
Welding	Welding head
Grinding	Grinder
Pick and place	Vacuum cup or Gripper

In some applications, tooling is the most challenging aspect of design. The possibilities are limited only by the imagination and ingenuity of the application.

For basic jobs, off-the shelf components are preferred and for special jobs the end effector will be custom made.

a. CLASSIFICATION OF END EFFECTORS

For the purpose of organization, end effectors are broadly classified into two types. They are

i. Grippers

ii. Tools

i. Grippers : Grippers are the most commonly used end effectors and are generally object holding or grasping device, typically with two or more fingers or other gripping jaws that envelop around the object. Some jaws are shaped or contoured to fit around the outershape of the object and others are flat.

Many grippers use air (pneumatic) to open and close the gripper. Pneumatic is preferred as they are simple, clean, lightweight, small, inexpensive and actuate quickly.

Flat grippers use friction to hold objects and the gripping is calculated based on the co-efficient of friction and weight of the part.

There are varieties of grippers that have been developed and their classification depends on the method or mechanism adopted to hold or grasp the object. They are

- Mechanical grippers
- Vacuum or suction cups
- Magnetic grippers
- Dispensers

Fig. 8.7 shows Typical robot gripper

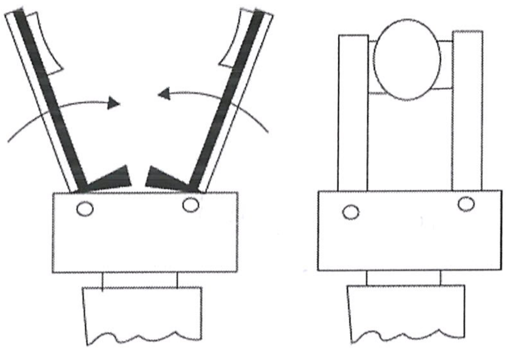


Fig. 8.7 : Typical Robot Gripper (Open & Closed Position)

Mechanical Grippers uses mechanical force (springs) to hold the object and the force to be exerted depends on the weight of the part, coefficient of friction between the part and the surface of the gripper material. This type of grippers are used for holding moderately heavy and bulky and robust parts.

Vacuum Cups : This uses suction force to hold or grasp the object. Vacuum cups are simple, inexpensive and generally used for pick and place of light, small, delicate parts. Highly reliable as few moving parts and the cups are flexible which takes the shape of the objects i.e. provide a good compliance. Generally found in food processing and packaging industries which calls for a very clean environment.

Magnetic Grippers : As the name itself indicates, its application is limited to handling of magnetic materials used for handling of heavy and irregular jobs. Generally for pick and place application, and the function-wise it is similar to vacuum cups.

Dispensers : Variety of dispensers are available that allow a robot to dispense material required during a process. The dispensed materials may be liquid, solid or gas and custom dispensers for specific applications. The dispensers used based on materials are

- Sealant dispenser
- Glue dispenser
- Gasket material dispensers
- Paint dispensers

- Air dispensers (for cleaning)
- Medicine dispensers

Tools : Tools are generally used to carry out certain operation and such tools are provided to the wrist of the robot as end effector. Typical tools generally used has end effectors in robots are

i) Welding tools

ii) Guns for painting, washing etc.

iii) Machine tools such as drilling, polishing etc. (for removal of materials)

iv) Assembly tools such as spanner, screw driver etc.

8.8 PROGRAMMING OF ROBOT END EFFECTOR

Robot has been defined as a reprogrammable multifunctional manipulator designed to carryout varieties of desired tasks with the help of its end effector.

Either it is programming of robots or end effector is is one and the same, as there is no meaning in programming of end effector only. When programming of robit it includes all the joints and links, and end effector also, since at the end it is the end effector which is to be positioned at the desired location with the help of the movements of all links associated with the robot, which finally carries the end effector.

Program in general is a set of instructions to carry out or perform certain manipulation of data in an orderly sequence as per the instructions in the program. This is the same case with a machine which includes robots also.

A program exclusively written for a robot to follow the instruction as per the program embedded in it is called a robot programming.

Robot programming is the defining of the desired motions through a set of instructions so that the robot may perform them without human intervention.

These programs are step by step instruction in proper sequence the robot has to perform to complete a desired or require work cycle of activities combined with peripheral actions which includes opening and closing of grippers, operating and stopping a deburring operation, and performing logical decision making. These instructions or commands are embedded or entered in the controller memory.

The instructions or commands contained in the robot program generally includes the following :

i. Path to be followed.

ii. Location of the end effector has to reach.

iii. Interpretation of sensor data

iv. Activating sequence of end effector.

v. Movements of parts from one point to another.

For limited sequence robots programming is accomplished by limit switches and mechanical stops to control the movements and end of activities. This is almost manual setting rather than programming.

Today almost all robots are controlled by digital computers with compatible storage device as their memory.

TYPES OF ROBOT PROGRAMMING

Basically there are three level or types of robot programming. They are

i. Joint level programming
ii. Robot level programming
iii. High level programming.

i) Joint level programming

This programming includes the programming of the basic actions or the movement of the individual joints of the robot arm. The movement to be controlled through programming being linear positions in the case of prismatic joints and joint angles in the case of revolute joints.

ii) Robot level programming

The programming in this case is considering robot as a single entity or unit, the basic actions being positions and orientations of the end effector to position itself at the desired or designed location and the frame of reference attached to it.

iii) High level programming

In this case the programming of the robot is done either considering the element of small units of activity or the task as a whole. Based on the above consideration, this programming type may further be subdivided into two types. They are

- Object-level programming
- Task-level programming.

In the case of object-level programming the basic actions are activitiers to be performed on the parts, or relationship that must be established between the parts.

This level of programming can better explained with an illustration.

FIG.

Pick up part - A

Place the part A in location 1

Pick up part B

Place it above part A in location 1

Pick up bolt 1

Insert bolt into the hole of Part A and Part B.

Pick up the nut

Place the nut in location 2

Rotate the nut into the threads of the bolt.

Thus an assembly is carried out with the help of an object level programming.

Task level programming

In this level programming the whole task is specified as the basic action to complete the task or subtask.

Methods of robot programming

All robot programming may be broadly classified into two methods. They are

i. On-line programming
ii. Off-line programming

On-line programming

It is called on-line programming because the programming is carried out with the physical presence or use of robot. The main feature of this method of programming is

- Requires access to the robot or use of robot to generate the program
- Program exists only in the memory of the robot control system.
- Teaching and guiding the robot through a sequence of motions that can then be executed.
- Often difficult to transfer documents, maintain and modify the program.

The different means of on-line programming are

i) Manual method
ii) Walk through method
iii) Lead through method

Manual method

Manual method is adopted for robots of low technology with short work cycle and a few number of activities to be carried out by the robot. Manual method is more like setting up a machine, rather than programming. This method involves setting mechanical stops, cams, microswitches, relays in the control unit of the robot to control the same.

Walk through method

This method is based on learning systems, demonstration system or instruction system. This is similar to a mother holding the hand of the child and practicing alphabet writing or teaching how to walk.

In this case initially, the programmer manually moves the robot's arm and end effector through the motion of sequences in the work cycle. Each movement or action is recorded in the memory of the robot for subsequent play back during production. The lead through method is easy and convenient.

This method of robot programming was initially popular, but has now almost disappeared.

However still finds its application in spray painting and welding robot. Applicable for small robots.

Disadvantages

- Exceedingly difficult to program for large robots.
- Any inaccuracies introduced into the program cannot be easily edited and in fact whole program has to be repeated.
- Difficult to program for circular, arc and complicated curvilinear trajectory
- External data from sensors is difficult to be incorporated.
- Difficult to synchronize with other machines or equipments in the workcell.
- Large amount of memory is necessary.

Lead through method

Also called Powered lead through programming. In this case teach pendant is used. A teach pendant is a small hand held device with many functional switches and dials used to control the robot's movements. These switches and dials will drive the robot in a number of coordinate systems to the desired locations. These locations are then stored with the names that can be used within the robot program. A typical teach pendant is shown in Fig.8.8

FIG. 0.0 A typical Teach Pendant

Advantages

- Simple to use especially where movements required are simple.
- No special programming skills or training necessary.
- Other conditions such as type of trajectory can be specified on robot movements.

Disdvantages

- Dangerous to work when motors are on.
- The robot will be idle during reprogramming (which may not be a setback when robots are used for same task for lifetime).

Off-line programming method

In this method programming is done without direct involvement of the robot. Programming is done on a system depending on the end task to be performed by the end effector of the robot. This method of programming is also termed as **remote programming**. Effectiveness of the program can be checked by simulation techniques and any changes required can be incorporated without testing on the robot.

Off-line methods have already been used for generating NC programs for milling machines using CAD systems.

Features or Advantages of off-line programming

- Programmes can be developed without the actual need or involvement of the robot.
- The sequence of actions and robot movements can be easily optimised or improved.
- Tested procedures and subroutines developed earlier can also be used.
- External sensors data can be incorporated but not easily.
- Existing CAD data can be incorporated.
- Programs can be easily maintained and modified.

Robot Programming Languages

Language is a communicative medium between two human beings or between two living beings. To communicate among machines which do not have life machine languages have been developed by man. As human beings have variety of languages between themselves for communication so also many machine languages have been developed.

The development of robot programming concepts is almost as old as the development of robot manipulator itself. Tremendous efforts have been made by international robotic community to develop user friendly and at the same time powerful programming languages.

Evolution has taken place from the control concepts on the hardware via point-to-point and simple motion level languages to motion oriented structured robot programming languages. Early 70's has seen the development of task-oriented programming languages such as IBM's AUTOPASS systems, RAPT from University of Edinburgh and LAMA system by MIT. Mid 70's saw the development of modern motion oriented programming languages.

Different programming languages of industrial robots having relatively similar structure and similar system of commands have been developed. Languages like VAL and AML are examples of early structured robot programming languages with sophisticated data structures incorporated in it.

In the recent past, plenty of programming languages have been developed and five commonly and basically used among them are

i. RAIL

ii. AML

iii. VAL

iv. AL

v. RPL

i. RAIL Robot Programming Languages

RAIL is a high-level robot programming language developed by **Automatix Inc**. in 1981 for arc-welding and inspection purpose. It is one of the best languages for controlling two major tasks such as ***manipulation*** and ***vision*** system. This language is based on Pascal. It is in fact designed and developed to control Cybervision, Autovision and Robovision.

Cybervision for assembly operations, Autovision for inspection process and Robovision for arc-welding process. RAIL languages includes three ***data types*** like **Paths**, **Points** and **Reference frames** for robot locations. This language also provides many other programming features.

Features of RAIL

- Offers welding commands and parameters.
- Contains approaching and departing commands.
- Includes commands for editing, sorting, displaying and loading programs.
- Allows robot to interface with external devices.
- Almost all other features of high-level languages.
- The control structures of RAIL and Pascal are very similar.

ii. AML (A Manufacturing Language)

This is also an high-level language based on subroutine developed by IBM for robot programming. This language is mainly used to manage ***RS/I Assembly Robot***, ***End-Effector active force feedback*** and Cartesian arm with hydraulic motor.

iii. VAL (Variable Assembly Language)

This Industrial Robot Language (IRL) is developed by Unimation company and mainly adopted by robots of the same company. This language is designed with simple syntax and hence capable of illustrating the robot functions very easily. Two major tasks are included in this language (a) programming instructions to manage robot functions and (b) use of monitor commands to execute user written programs.

iv. AL Robot Language – This languages is developed by Artificial Intelligence Lab at Stanford University and is the second generation language based on simultaneous Pascal. For programs developed using high-level code, it should be written in SAIL (Stanford Artificial Intelligence Language).

v. RPL – This was developed by SRI international. Improvements, checking and correction of control algorithms are very easily performed using this language and very easy to use.

Other Industrial Robot Languages (IRL) in use are Kuka Robot Language (KRL) by Kuka Company, RAPID by ABB, BAPS by Bosch, MRL and MELFA Basic by Movemaster Command etc. are

8.9 ROBOT MOTION :

Motion of the links is the main feature of any robot, immaterial of the type of configuration. The ultimate purpose of a robot is to perform desired task, with the help of its end effector. End effector is the end part of any robot. To perform the desired task the end effector has to be positioned at the required location with the help of motions of various joints and in turn links.-

Basically there are six types of motions and the combination of any of these six motions in sequence the desired position and orientation of the end effector can be achieved.

The six basic motions consists of three arms motions, three wrist motions. The three arm motions can be

i) Radial traverse

ii) Vertical traverse

iii) Rotational traverse.

Radial traverse : This motion involves the extension and retraction of the arm or the in and out relative motion.

Vertical traverse : In this case also the motion is linear and vertical i.e. up and down.

Rotational traverse : It is the movement of the arm assembly about a rotary axis such as left or right swivel of the robot's arm.

The other three motions that can be provided to the wrist of the manipulator are

a) Pitch

b) Yaw and

c) Roll

In all the above three types of wrist motions, the motion is again rotational about a rotary axis.

Pitch is the motion experienced by a link in a robot with reference to horizontal axis.

Yaw is the motion of a links in a robot with its reference to vertical axis.

Roll is the motion of a link also with the horizontal axis.

The above combination is experienced when a body moves in a fluid i.e. aircraft in space and ship or boat in water.

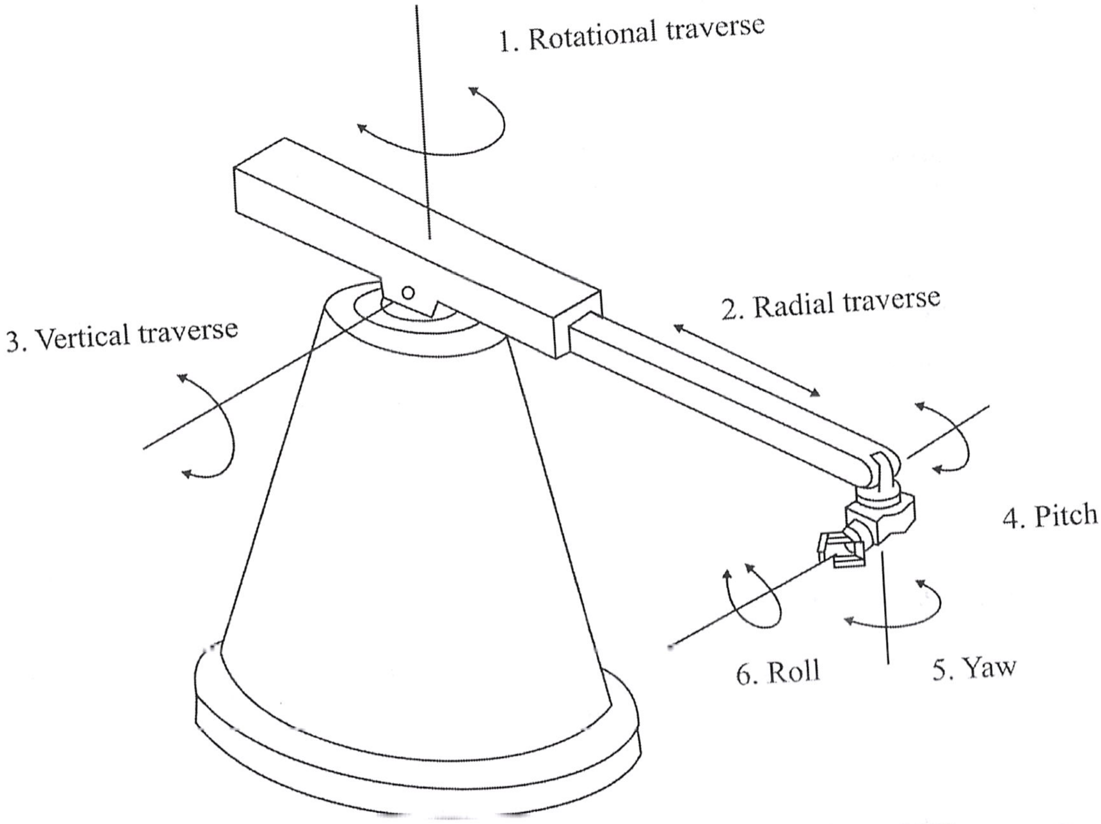


Fig. 8.9 : Six degrees of freedom of robotic system

8.10 ROBOT SENSORS

Sensors are devices capable of sensing or identifying a change in physical phenomenon and convert the change into some form of signals as output. Sensors are the eyes of robots and without sensors there is no robots.

Sensors are generally used in a robot with two purposes.

- to measure a physical phenomenon
- to observe a change in the environment or path

Sensors used in a robot based on the above purposes may be broadly classified into two types ;

- Internal sensor
- External sensor

i) Internal sensors

Internal sensors are generally used to measure a physical phenomenon where the changes can be felt by the surface or observed. These sensors are used to measure joint position, motion, torque, force etc.

ii) **External sensors** : These sensors are used external to the robot (of course mounted on the robot) and are used for measuring obstructions in the path of robot, absence of an object supposed to be there, distance from an object, relative position, absolute position (GPS), object's location (camera) , presence of an object etc.

Varieties of sensors are available in the market and selection and use of a particular type of sensor depends on what the robot has to detect or measure. The sensors discussed here is what is applicable or required in a robot.

Based on the purpose of sensors listed earlier, sensors commonly used in robots are broadly classified into four categories. They are

a) Tactile sensors

b) Proximity sensors

c) Vision sensors

d) Voice sensors

a) Tactile sensors : Human sense of touch is a marvelous phenomenon and scientist and engineers have a real challenge in developing robot fingers that can actually "feel" the difference between various textures, surfaces, shapes, whether is surface cold or hot etc.

In robots tactile sensors are used for two purposes, whether contact has been made between two surfaces or what force exits between the two surfaces in contact. This is very much essential in the grippers as it has to decide at the amount of force to be exerted to grip or hold an object. Based on the above two purposes tactile sensors are of two types. They are

- Touch sensors
- Force sensors

Touch sensors are used in robots just to find out whether contact has been made between two surfaces and if so what action is to be initiated. Limit switches, microswitches will serve the required purpose. Touch sensors can also be used for measuring dimensions of parts as in an inspection process. These sensors find their application in robots used for assembly and inspection operations. Strain gauging devices are generally employed in force sensors.

Force Sensors are used to measure the magnitude of the contact force.

b) Proximity sensors : Proximity is nearness of an object.This type of sensors are generally used in end effector to find whether the object is within the proximate range. Proximity sensors are specified by the range of distance the sensor could sense an object. Varieties of proximity sensors are available based on different principles of working such as optical, eddy current, inductive type etc and each having its own limitation in its application.

c) Vision sensor : One of the areas which is drawing lot of attention is the vision sensors. Vision sensors are nothing but cameras mounted on robot or into a fixed position so that the robot can have the complete vision of work volume or the work cell. Software enables the robot to sense the presence of an object, its location and orientation, and reorient the parts which are incorrectly oriented especially in assembly operation using image processing. Application of cameras has found in almost all fields such as traffic, offices, ATM's and airports etc.

d) Voice sensors : This is another area of interest in sensor research in general and robotic research in particular. Voice sensing is already exists in telephones and mobile phones, voice sensors are used in robots to sense the comands by the operator. (This idea or concept already exists in fables) In this case, the robot is equipped with a speech recognition system (voice processing) which analyse or compares the voice with that already stored in memory in the form of a set of stored word pattern. When a match is found between the input command and stored vocabulary, then the robot act according to the input command. This is much helpful and adopted for remote controlling of robots and where human cannot reach due to hazardous and dangerous environments, such as nuclear mines, gutters, underwater and space exploration.

8.11 ROBOT APPLICATIONS

1. Repetitive and monotonous tasks.
2. Harsh and dangerous environments.
3. Locations where human access is difficult, expensive or limited (air space, underwater, pipes)
4. Tasks require high repeatability.

TYPICAL INDUSTRIAL APPLICATIONS :

1. Material handling including part transfer, part loading and unloading.
2. Assembly shops (mechanical and electronic industries).
3. Welding, spray painting, grinding, deburring, polishing etc.
4. Machining, cutting.
5. Inspection and testing.

OTHER SPECIAL APPLICATIONS

1. Pipe inspection.
2. Planets, Ocean, exploration.
3. Cleaning of buildings, product delivery, assistance to surgery etc.

As mentioned earlier, a robot is just another machine or device controlled by human being directly or indirectly.

8.12 ADVANTAGES OF USING ROBOTS

1. Increased productivity.
2. Increased product consistency and quality.
3. Reduced Production cost (Economical production)
4. High level of repeatability, accuracy
5. Improved management control (scheduling, planning and monitoring)
6. Can work in hazardous environment such as nuclear environment, where it is unsafe for human beings.

7. Reduces workers injuries.
8. Reduces labour unrest.

DISADVANTAGES OF USING ROBOTS.

1. High initial cost.
2. Lack of decision making power by the robot.
3. Necessity of programming.

8.13 ROBOTS TERMINOLOGIES

The different terminology associated with robots are

a. Work volume or work space.
b. Work cell.
c. Resolution.
d. Precision
e. Repeatability
f. Speed
g. Payload

a. **Work volume** also called work envelope has already been discussed earlier.

b) Robot workcells : Industrial robots arms are often combined into one working space and such a working space is called **workcells**. A workcell typically has only one task and this single task may be welding a frame or adding a few components to an assembly of a larger product. Multiple work cells are used for a complete product.

Features

1. One or more robot arm.
2. Enclosed space – provides safety against noise, access, heat etc.
3. Adoption of safety systems.
4. Feeders and conveyors – for feeding parts
5. Task specific tooling

The most expensive concept and in fact cost of work cell is much higher than cost of robot arm.

c) Resolution : The smallest variation of any physical phenomena that can be sensed or measured is called **resolution**. The term resolution is commonly used for monitors, TV etc and generally we say high resolution for clarity of a picture or an output of a system. With reference to robot, resolution is the smallest variation in motion at the joint or wrist end that can be controlled by the robot i.e.robot controller.

d) Precision : Also called accuracy is the minimum variation in motion that can be achieved or it is the capacity of the robot to position the wrist closely to the given target point within its work volume. Closed to the given point higher will be the precision or the accuracy. Robots should be designed for high precision.

e) Repeatability : The ability of a robot to position itself to the same target point again and again i.e. more number of times, whenever the robot is to perform the same task again and again and of course, this is the purpose for which a robot is built or designed.

f) Speed : The maximum speed with which a robot can manipulate the end effector to reach the target point is called Speed of the robot.

g) Payload : The maximum mass or weight a robot can lift before it fails or loses its precision. It is possible to exceed the payload, still the robot being operative, but this is not advisable, as the life of the robot, designed for will decrease or in other words it will have a shorter life span. While designing a robot for its payload the acceleration of the different links and joints and also the weight of end effector is taken into consideration.

Exercise –

1. Define an industrial robot. Briefly explain with the diagram the configurations of a robot.
2. Explain the robot motions in detail.
3. Briefly explain the robot control systems in detail.
4. Write a note on end effectors.
5. Explain the various sensors used in a Robot.
6. List and explain the various applications of an industrial robot.
7. Explain about robot programming.
8. Explain about lead through type of programming.
9. Briefly explain robot programming languages.
10. What do you understand by off line programming?

* * * *

Robot Technology

***** This study material is in addition to the pdf material which was shared *******

Dr. K. M. Sathish Kumar
Professor and Head, Dept. of ME, BMSIT&M

Robot Drive System: The Robot drive systems are used to actuate robotic joints. The three types of drive systems that are generally used for industrial robots are:

- Hydraulic drive
- Electric drive
- Pneumatic drive

Hydraulic drive system: It gives a robot great speed and strength. Hence they are adopted for large industrial robots. This type of drives are preferred in environments in which the use of electric drive robots may cause fire hazards.

Disadvantages of a hydraulic robot:

- Occupy more floor space for ancillary equipment in addition to that required by the robot.
- There are problems such as leaks

Electric drive system: This provides a robot with less speed and strength. Electric drive systems are adopted for smaller robots. Robots supported by electric drive systems are more accurate, exhibit better repeatability and are cleaner to use. Electrically driven robots are the most commonly available. Electric drives are generally favoured in commercial applications, as they readily take advantage of the advances in electric motor technology made in recent years, and owing to their ready compatibility to computing systems. Electric motors constitute the main type of electric drive system. Variety of electric motors are available and the use of specific motor depends on the speed and torque necessitated at the joint. Various types of electric motors available are AC motors, DC motors, stepper motors and servo motors. Typically, servo-motors or steeper motors are used.

Pneumatic drive system: Generally used for smaller robots. Have fewer axes of movement. Carry out simple pick-and-place material-handling operations, such as picking up an object at one location and placing it at another location. These operations are generally simple and have short cycle times. Here pneumatic power can be used for sliding or rotational joints. Pneumatic robots are less expensive than electric or hydraulic robots.

Robot Control Systems:

The actuation of the individual joints must be controlled in a coordinated fashion for the manipulator to perform as desired. Micro-processor-based controllers are regularly used to perform this control action. Each joint has its own feedback control system and a supervisory controller coordinates the combined actuation of the joints according to the sequence of the robot programme. Controller is organised in a hierarchical fashion, as illustrated in Figure.

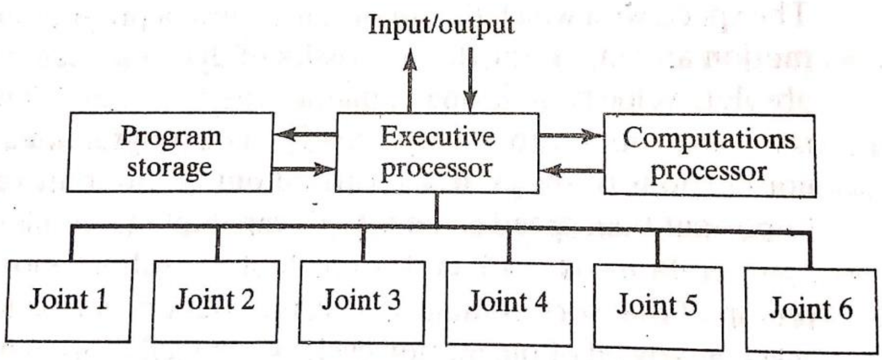


Figure 7.9 Hierarchical control structure of a robot microcomputer controller.

Robot control systems are classified into the following FOUR categories:

1. Limited sequence control
2. Playback with Point to Point control
3. Playback with continuous path control
4. Intelligent control

Limited Sequence Control: This is the most elementary control type. It is used for simple motion cycles, such as pick and place operations. It is implemented by fixing limits or mechanical stops for each joint and sequencing the actuation of joints to accomplish operation. Feedback loops may be used to inform the controller that the action has been performed, so that the programme can move to the next step. Many pneumatically driven robots are this type.

Playback with Point to Point Control: This method represents a more sophisticated form of control than limited sequence robots. Playback control means that the controller has a memory to record the sequence of motions in a given work cycle, as well as associated locations and other parameters and then plays back the work cycle during programme execution. It is this playback feature that gives the control type its name. In Point to Point (PTP) control, individual positions of the robot arm are recorded in the memory. These positions include both mechanical stops for each joint and the set of values that represent locations in the range of each joint. Feedback control is used to confirm that the individual joints achieve the specified locations in the programme.

Playback with Continuous Path Control: Continuous path robots have the same playback capability as the previous one. Continuous path control refers to a control system capable of continuous simultaneous control of two or more axes. Continuous path control has a Greater storage capacity—the number of locations that can be stored is greater than compared to point to point. Interpolation calculations may be used, especially linear and circular interpolations.

Intelligent Control: An intelligent robot is one that exhibits behaviour that makes it seem intelligent. Some of the characteristics that make a robot appear intelligent include the capacity to:

- Interact with its ambient surroundings
- Make decisions when things go wrong during the work cycle
- Communicate with humans
- Make computations during the work cycle
- Respond to advanced sensor inputs.

In addition, robots with intelligent control possess the playback capability for both PTP or Continuous path control. These features require a high level of computer control and an advanced programming language to input the decision-making logic and other 'intelligence' into the memory.

Accuracy and Repeatability: The capacity of the robot to position and orient the end of its wrist with accuracy and repeatability is an important control attribute in nearly all industrial applications. Some assembly applications require that objects be located with a precision of 0.05 mm. Other applications, such as spot welding, usually require accuracies of 0.5 to 1.0 mm.

There are several terms that must defined in the context of this discussion:

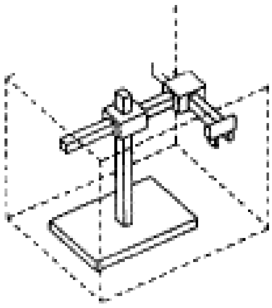
- Control resolution
- Accuracy
- Repeatability

Control resolution: The capability of the robot's controller and positioning system to divide the range of the joint into closely spaced points that can be identified by the controller. These points are called addressable points because they represent locations to which the robot joint can be moved by the controller.

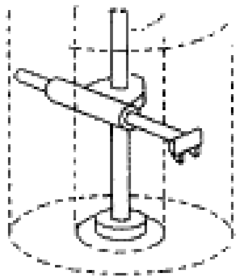
Accuracy: The robot's ability to position its end-of-wrist at a desired location in the work volume. "How close does the robot get to the desired point". This measures the distance between the specified position, and the actual position of the robot end effector.

Repeatability: How close will the robot be to the same position as the same move made before". A measure of the error or variability when repeatedly reaching for a single position. Repeatability is often smaller than accuracy

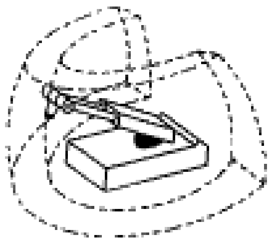
Work volume / Work space / Work envelope: The work volume or work envelope is the three-dimensional space in which the robot can manipulate the end of its wrist. A space on which a robot can move and operate its wrist end is called as a work volume. It is also referred as the work envelope and work space. Work volume is determined by the number and types of joints in the manipulator, the ranges of the various joints, and the physical size of the links. Its actual shape is dependent on the robot's configuration: Polar robotic configuration tends to produce a spherical (or near-spherical) work volume. Cylindrical configuration has a cylindrical work envelope. Cartesian co-ordinate robot produces a rectangular work volume.



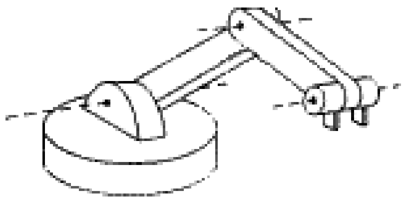
Rectangular Coordinate Robot



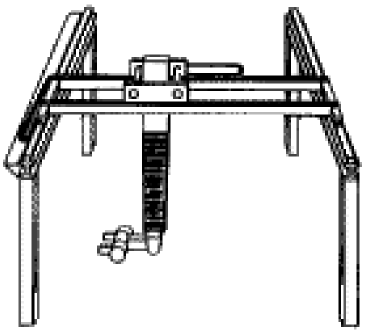
Cylindrical Coordinate Robot



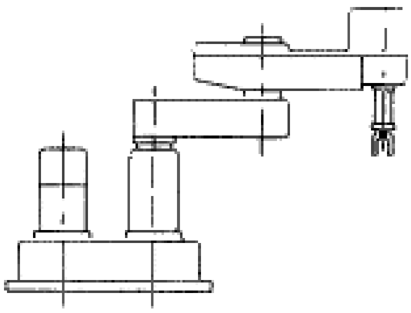
Sperical Coordinate Robot



Articulated Arm Robot



Gantry Robot



SCARA Robot

Payload: The maximum mass or weight a robot can able to lift. This depends on the acceleration of the various links and joints and also the weight of the end effector.

Speed: The maximum speed with which a robot cam manipulate the end effector to reach the target point is called speed of the robot.

Robot Programming:

A robot program is a path in space to be followed by the manipulator, combined with peripheral actions that support the work cycle. To programme a robot, specific commands are entered into the robot’s controller memory, and this action may be performed in a number of ways.

All robot programming may be broadly classified into TWO methods. They are:

I. On-line Programming
II. Off-line Programming

For industrial robots with digital computers as controllers three programming methods can be distinguished.

(a) Lead-through programming
(b) Computer-like robot programming languages
(c) Off-line programming.

In case of Lead through programming, Task is ‘taught’ to the robot by manually moving the manipulator through the required motion cycle and simultaneously entering the programme into the controller memory for playback. Two methods are used for teaching:

- Powered lead-through
- Manual lead-through.

Powered lead-through: It is commonly used as the programming method for playback robots with point-to-point control. It involves the use of a teach pendant (handheld control box) that has toggle switches and/or contact buttons for controlling the movement of the manipulator joints. Using the toggle switches or buttons, the programmer power drives the robot arm to the desired positions, in sequence, and records the positions into memory. During subsequent playback, the robot moves through the sequence of positions under its own power.

Manual lead-through: It is convenient for programming playback robots with continuous path control. This programming method requires the operator to physically grasp the end-of-arm or tool attached to the arm and manually move it through the motion sequence, recording the path into memory. Because the robot arm itself may have significant mass and would therefore he difficult to move, a special programming device often replaces the actual robot for the teach procedure. The programming device has the same joint configuration as the robot and it is equipped with a trigger handle (or other control switch), which is activated when the operator wishes to record motions into memory. The motions are recorded as a series of closely spaced points. During playback, the path is recreated by controlling the actual robot arm through the same sequence of points.

Robot Programming Languages: The use of textual programming languages became an appropriate programming method as digital computers took over the control function in robotics. These computer-like programming languages are really-online/off-fine methods of programming.

Commonly used Robot Programming Languages are:

- Motion programming
- AML (A Manufacturing Language)
- VAL (Variable Assembly Language)
- AL Robot Language (Artificial Lab)
- Kuka Robot Language by Kuka Company
- RAPID by ABB
- BAPS by Bosch

Off–line Programming: The trouble with online programming techniques is that the robot must be taken out of production for a certain length of time to accomplish the programming. Off-line programming permits the robot program to be prepared at a remote computer terminal and downloaded to the robot controller for execution. The advantage of true offline programming is that new programs can be prepared and downloaded to the robot without interrupting production.

Industrial Robot Applications:

The general characteristics of industrial work situations that tend to promote the substitution of robots for human labour are the following:

Hazardous work for humans: In situations where the work environment is unsafe, unhealthy, uncomfortable, or otherwise unpleasant for humans, robot application may be considered.

Repetitive work cycle: If the sequence of elements in the work cycle is the same, and the elements consist of relatively simple motions, robots usually perform the work with greater consistency and repeatability

Difficult handling for humans: If the task requires the use of heavy or difficult-to-handle parts or tools for humans, robots may be able to perform the operation more efficiently.

Multi-shift operation: A robot can replace two or three workers at a time in second or third shifts, thus they can provide a faster financial payback

Infrequent changeovers: Robot use is justified for long production runs where there are infrequent changeovers, as opposed to batch or job shop production where changeovers are more frequent.

Part position and orientation are established in the work cell: Robots generally don't have vision capabilities, which means parts must be precisely placed and oriented for successful robotic operations.

Industrial Robot Applications can be divided into:

- Material-handling Applications
- Processing Operations Applications
- Assembly and Inspection Applications

Material-handling applications: In material handling, robots move parts between various locations by means of a gripper type end effector. Two sub-divisions may be noted in material handling:

- Material transfer
- Machine loading and/or unloading.

Material transfer: The application involves Pick and place operations, Part re-orientation, Palletising, de-palletising, Stacking and Insertion operations

Machine loading and/or unloading: Here the **c**hief purpose is to transfer parts into or out- of a production machine. The three possible cases are:

- Machine loading: where the robot loads the machine only
- Machine unloading: where the robot unloads the machine only
- Machine loading and unloading—where the robot performs both actions.

Machine loading and/or unloading is used in the following processes: die casting, plastic moulding, metal machining operations, forging, press-working, and heat treating

Processing operations applications: In processing operations, the robot performs some processing actions such as grinding, milling, etc. on the work part. The end effector is equipped with the specialised tool required for the process. The tool is moved relative to the surface of the work part. Robot performs a processing procedure on the part. The robot is equipped with some type of process tooling as its end effector. Manipulates the tooling relative to the working part during the cycle.

Industrial robot applications in the processing operations include:

(1) Spot welding
(2) Continuous arc welding
(3) Spray painting
(4) Metal cutting and deburring operations
(5) Various machining operations like drilling, grinding, laser and waterjet cutting and riveting.
(6) Rotating and spindle operations
(7) Adhesives and sealant dispensing

Assembly and Inspection applications: The applications involve both material handling and the manipulation of a tool. They typically include components to build the product and to perform material handling operations. One of the well suited area for robotics assembly is the insertion of odd electronic components. Used for identifying flaws in raw materials and finished parts. Inspection probe can be attached to the wrist of the robot. (Worked as a Tool, a classification of End effector)

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ADDITIVE MANUFACTURING SYSTEMS

Dr. K. M. Sathish Kumar
Professor and HoD, Dept. of ME, BMSIT&M

Introduction:

The term Rapid Prototyping (or RP) is used in a variety of industries to describe a process for rapidly creating a system or part representation before final release or commercialization. In other words, the emphasis is on creating something quickly and that the output is a prototype or basis model from which further models and eventually the final product will be derived. In a product development context, the term rapid prototyping was used widely to describe technologies which created physical prototypes directly from digital data.

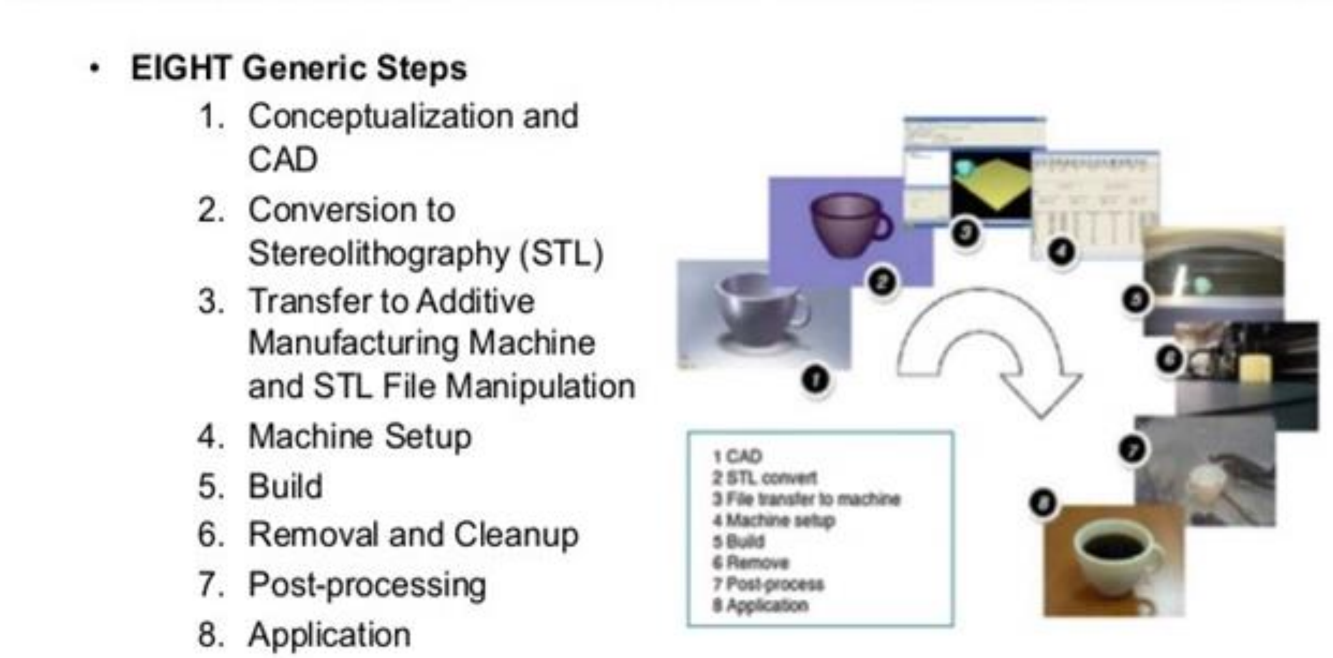
Users of RP technology have come to realize that this term is inadequate and does not effectively describe more recent applications of the technology. Improvements in the quality of the output from these machines have meant that there is a much closer link to the final product. Many parts are in fact now directly manufactured in these machines; so it is not possible for us to label them as “prototypes.” The term Rapid Prototyping also overlooks the basic principle of these technologies in that they all fabricate parts using an additive approach. A recently formed Technical Committee within ASTM International agreed that new terminology should be adopted. While this is still under debate, recently adopted ASTM consensus standards now use the term Additive Manufacturing.

Referred to in short as AM, the basic principle of this technology is that a model, initially generated using a three-dimensional Computer Aided Design (3D CAD) system, can be fabricated directly without the need for process planning.

Additive Manufacturing (AM) is defined as a process by which digital 3D design data is used to build up a component in layers by depositing material. Commonly known as “3D Printing”.

Basic Principles of Additive Manufacturing: (Steps of AM process)

AM involves 8 steps that move from the virtual CAD description to the physical resultant part



Step 1: CAD

All AM parts must start from a software model that fully describes the external geometry. This can involve the use of almost any professional CAD solid modeling software, but the output must be a 3D solid or surface representation. Reverse engineering equipment (e.g., laser scanning) can also be used to create this representation.

Step 2: Conversion to STL

Nearly every AM machine accepts the STL file format, which has become a de facto standard, and nearly every CAD system can output such a file format. This file describes the external closed surfaces of the original CAD model and forms the basis for calculation of the slices.

Step 3: Transfer to AM Machine and STL File Manipulation

The STL file describing the part must be transferred to the AM machine. Here, there may be some general manipulation of the file so that it is the correct size, position, and orientation for building.

Step 4: Machine Setup

The AM machine must be properly set up prior to the build process. Such settings would relate to the build parameters like the material constraints, energy source, layer thickness, timings, etc.

Step 5: Build

Building the part is mainly an automated process and the machine can largely carry on without supervision. Only superficial monitoring of the machine needs to take place at this time to ensure no errors have taken place like running out of material, power or software glitches, etc.

Step 6: Removal

Once the AM machine has completed the build, the parts must be removed. This may require interaction with the machine, which may have safety interlocks to ensure for example that the operating temperatures are sufficiently low or that there are no actively moving parts.

Step 7: Post processing

Once removed from the machine, parts may require an amount of additional cleaning up before they are ready for use. Parts may be weak at this stage or they may have supporting features that must be removed. This therefore often requires time and careful, experienced manual

Step 8: Application

Parts may now be ready to be used. However, they may also require additional treatment before they are acceptable for use. For example, they may require priming and painting to give an acceptable surface texture and finish. Treatments may be laborious and lengthy if the finishing requirements are very demanding.

Advantages of Additive Manufacturing Technologies:

Are as follows:

1. **Variety is free –** Changing a part is simple and can be made easily in the original CAD file and the new print can be taken easily.
2. **Complexity is free –** Printing of a complex part costs less than simple cubes of the same size. The less solid or more complex object, it can be fastly and cheaply made through additive manufacturing.
3. **No need for assembly –** Hinges and bicycle chains are some of the moving parts which can be printed in metal directly into the product and thus reduce the part numbers.
4. **Little-skill manufacturing –** Professionals take care of the complicated parts with specific parameters and high-tech applications, children in the elementary school have created their on figures by use of 3D printing processes.

5. **Few Constraints –** In the CAD software one can dream anything and design the same and create it with additive manufacturing.
6. **Various shades of materials –** In the CAD files, the engineers can program parts to have specific colors and printers can use materials of any color to print them.
7. **Lower energy consumption**: AM saves energy by eliminating production steps, using substantially less material, enabling reuse of by-products, and producing lighter products
8. **Less Waste**: Building objects up layer by layer, instead of traditional machining processes that cut away material can reduce material needs and costs by up to 90%. AM can also reduce the "cradle-to-gate" environmental footprints of component manufacturing through avoidance of the tools, dies, and materials scrap associated with CM processes. Additionally, AM reduces waste by lowering human error in production.
9. **Reduced time to market**: Items can be fabricated as soon as the 3-D digital description of the part has been created, eliminating the need for expensive and time-consuming part tooling and prototype fabrication.
10. **Innovation:** AM enables designs with novel geometries that would be difficult or impossible to achieve using CM processes, which can improve a component's engineering performance. Novel geometries enabled by AM technologies can also lead to performance and environmental benefits in a component's product application.
11. **Part Consolidation:** The ability to design products with fewer, more complex parts, rather than a large number of simpler parts – is the most important of these benefits. Reducing the number of parts in an assembly immediately cuts the overhead associated with documentation and production planning and control. Also, fewer parts mean less time and labor is required for assembling the product, again contributing to a reduction in overall manufacturing costs. The "footprint" of the assembly line may also become smaller, further cutting costs
12. **Lightweighting:** With the elimination of tooling and the ability to create complex shapes, AM enables the design of parts that can often be made to the same functional specifications as conventional parts, but with less material.
13. **Agility to manufacturing operations:** Additive techniques enable rapid response to markets and create new production options outside of factories, such as mobile units that can be placed near the source of local materials. Spare parts can be produced on demand, reducing or eliminating the need for stockpiles and complex supply chains.

Disadvantages of Additive Manufacturing Technologies:

1. **Production cost is high –** With the use of techniques other than additive manufacturing, parts can be made faster and hence the extra time can lead to higher costs. Besides, high-quality of additive manufacturing machines may cost high.
2. **Discontinuous production process –** To prevent economies of scale, parts can only be printed one at a time.
3. **Requires post-processing –** The surface finish and dimensional accuracy are of low quality than other manufacturing methods.
4. **Slow build rates –** Some of the printers lay down material at speed of one to five cubic inches per hour. Depending on the part needed the other manufacturing processes may be higher.
5. **Considerable effort in application design and setting process parameters –** Material design needs vast knowledge and additive manufacturing machine is needed to make quality parts.
6. **Poor mechanical properties –** Layering and multiple interfaces can cause defects in the product.
7. **Post-processing is needed –** Surface finish and dimensional accuracy may be of low quality than other manufacturing methods.

Applications of Additive Manufacturing Technologies:

- Automotive applications
- Aerospace applications
- Biomedical applications
- Consumer goods applications
- Space applications
- Health care applications
- Artistic Industry
- Architectural Industry

Additive Manufacturing Processes:

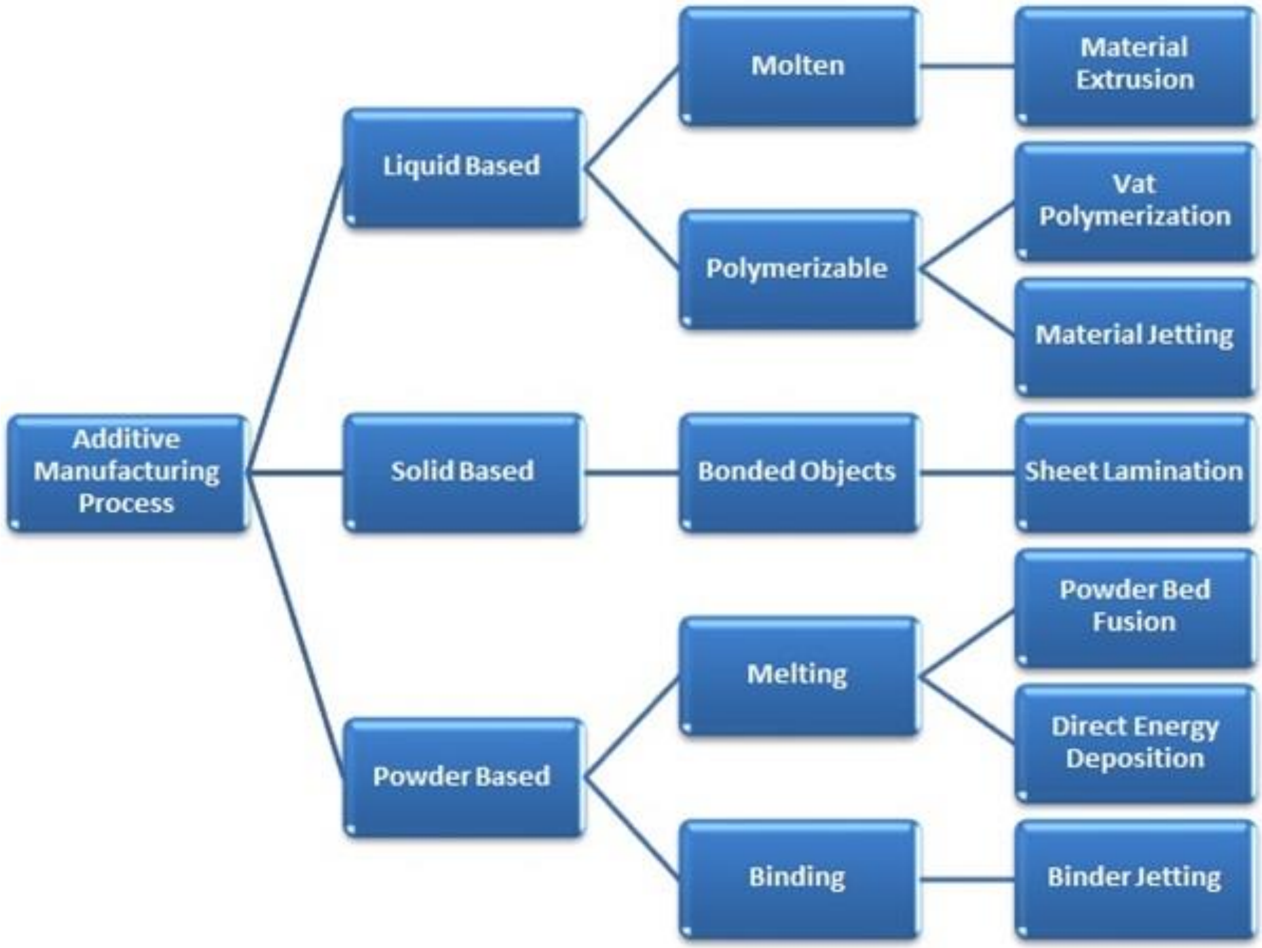
Additive manufacturing processes are classified into seven areas on the basis of

- Type of materials used
- Deposition technique, and
- The way the material is fused or solidified

These classifications have been developed by the ASTM International Technical Committee F42 on additive manufacturing technologies.

The seven major additive manufacturing processes classified as per ASTM F42 are:

1. Photopolymerization
2. Material jetting
3. Binder jetting
4. Material extrusion
5. Powder Bed Fusion
6. Sheet Lamination
7. Direct Energy Deposition



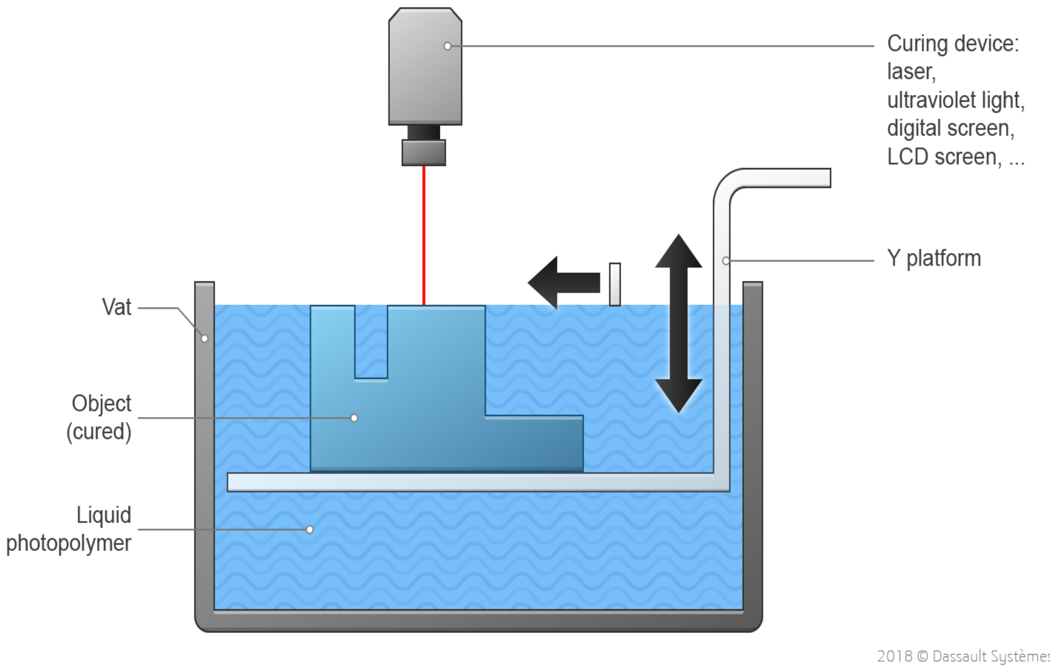
<u>Photopolymerisation:</u>

Photopolymerization processes make use of liquid, radiation curable resins, or photopolymers as their primary materials. Most photopolymers react to radiation in the ultraviolet (UV) range of wavelengths, but some visible light systems are used as well. Upon irradiation, these materials undergo a chemical reaction to become solid. This reaction is called photopolymerization. Related Additive manufacturing technology which uses Photopolymerization is **Steriolithography (SLA).**

Vat polymerisation uses a vat of 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., unlike powder based methods, where support is given from the unbound material.

In this case, support structures will often need to be added. Resins are cured using a process of photo polymerisation or UV light, where the light is directed across the surface of the resin with the use of motor controlled mirrors. Where the resin comes in contact with the light, it cures or hardens.



Photopolymerisation – Step by Step procedure

1. The build platform is lowered from the top of the resin vat downwards by the layer thickness.
2. A UV light cures the resin layer by layer. The platform continues to move downwards and additional layers are built on top of the previous.
3. Some machines use a blade which moves between layers in order to provide a smooth resin base to build the next layer on.
4. After completion, the vat is drained of resin and the object removed.

The SLA process has a high level of accuracy and good finish but often requires support structures and post curing for the part to be strong enough for structural use. The process of photo polymerisation can be achieved using a single laser and optics. Blades or recoating blades pass over previous layers to ensure that there are no defects in the resin for the construction of the next layer. The photo-polymerisation process and support material may have likely caused defects such as air gaps, which need to be filled with resin in order to achieve a high quality model. Typical layer thickness for the process is 0.025 – 0.5mm.

Advantages:

- High level of accuracy and good finish
- Relatively quick process
- Typically large build areas: objet 1000: 1000 x 800 x 500 and max model weight of 200 kg

Disadvantages:

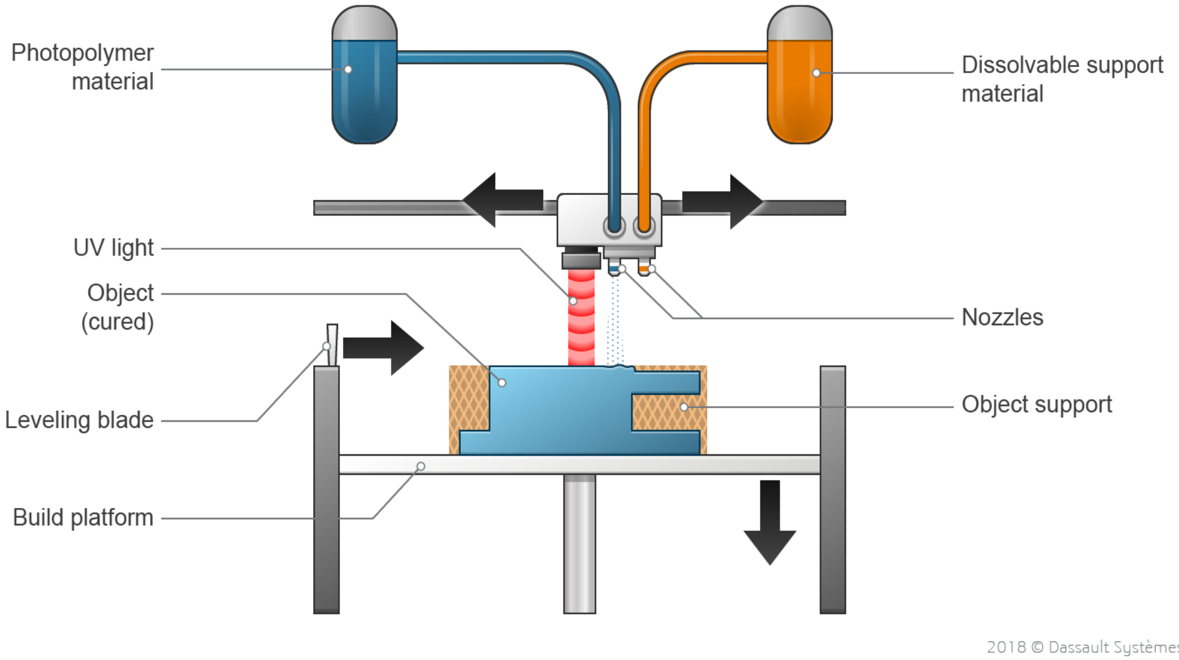
- Relatively expensive
- Lengthly post processing time and reomval from resin
- Limited material use of photo-resins
- Often requires support structures and post curing for parts to be strong enough for structural use

Material Jetting:

Material jetting creates objects in a similar method to a two dimensional ink jet printer. Material is jetted onto a build platform using either a continuous or Drop on Demand (DOD) approach.

Material is jetted onto the build surface or platform, where it solidifies and the model is built layer by layer. Material is deposited from a nozzle which moves horizontally across the build platform. Machines vary in complexity and in their methods of controlling the deposition of material. The material layers are then cured or hardened using ultraviolet (UV) light.

As material must be deposited in drops, the number of materials available to use is limited. Polymers and waxes are suitable and commonly used materials, due to their viscous nature and ability to form drops.



Material Jetting – Step by Step

1. The print head is positioned above build platform.
2. Droplets of material are deposited from the print head onto surface where required, using either thermal or piezoelectric method.
3. Droplets of material solidify and make up the first layer.
4. Further layers are built up as before on top of the previous.
5. Layers are allowed to cool and harden or are cured by UV light. Post processing includes removal of support material.

Advantages:

- The process benefits from a high accuracy of deposition of droplets and therefore low waste
- The process allows for multiple material parts and colours under one process

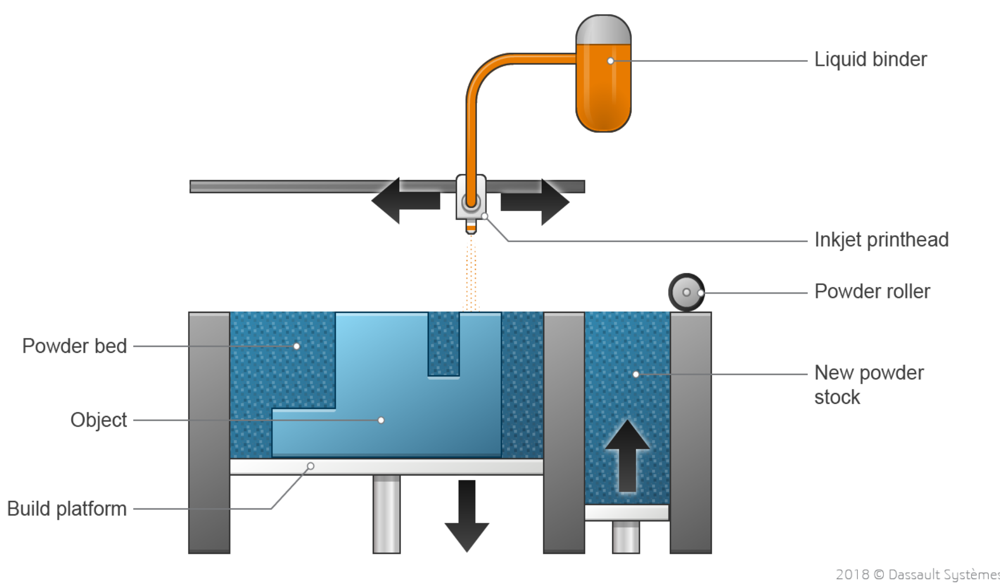
Disadvantages:

- Support material is often required
- A high accuracy can be achieved but materials are limited and only polymers and waxes can be used

Binder Jetting

The binder jetting process uses two materials; a powder based material and a binder. The powdered materials are either ceramic-based (for example glass or gypsum) or metal (for example stainless steel). There are various types of binder materials, each suited for a specific application. They can be listed in categories including furan binder (for sand casting applications), phenolic binder (for sand molds and cores), silicate binder (environmentally-friendly, for sand molds and cores) and aqueous-based binder (for metals). The binder acts as an adhesive between powder layers. The binder is usually in liquid form and the build material in powder form.

A print head moves horizontally along the x and y axes of the machine and deposits alternating layers of the build material and the binding material. After each layer, the object being printed is lowered on its build platform. The technology is often referred to as 3DP technology and is copyrighted under this name.



Binder Jetting – Step by Step

1. Powder material is spread over the build platform using a roller.
2. The print head deposits the binder adhesive on top of the powder where required.
3. The build platform is lowered by the model's layer thickness.

4. Another layer of powder is spread over the previous layer. The object is formed where the powder is bound to the liquid.
5. Unbound powder remains in position surrounding the object.
6. The process is repeated until the entire object has been made.

Advantages:

- Parts can be made with a range of different colours
- Uses a range of materials: metal, polymers and ceramics
- The process is generally faster than others
- The two material method allows for a large number of different binder-powder combinations and various mechanical properties

Disadvantages:

- Not always suitable for structural parts, due to the use of binder material
- Additional post processing can add significant time to the overall process

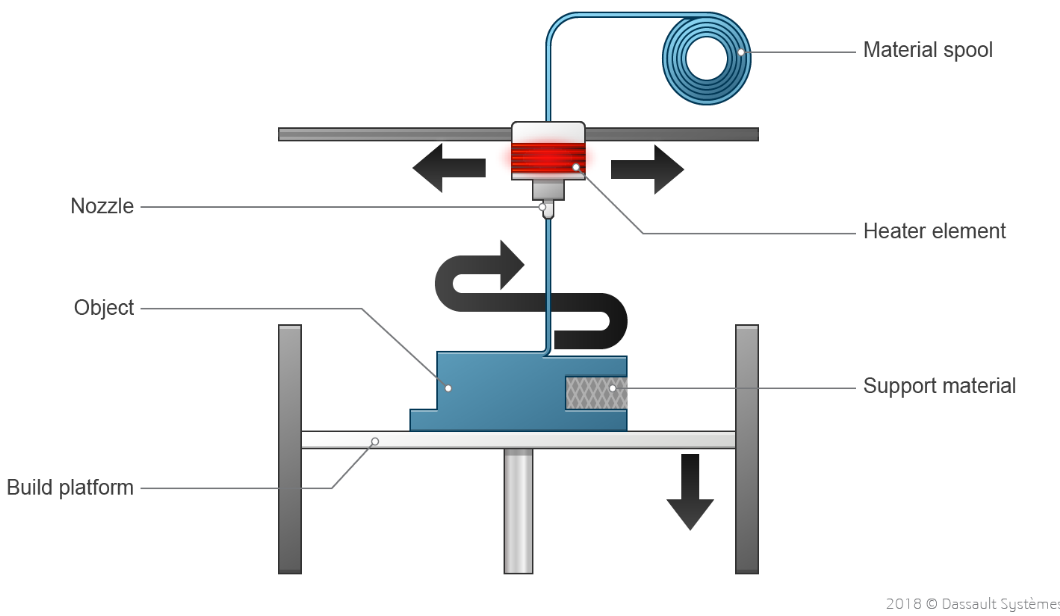
Material Extrusion Techniques

Fused Deposition Modelling (FDM) is a common material extrusion process and is trademarked by the company Stratasys. Material is drawn through a nozzle, where it is heated and is then deposited layer by layer. The nozzle can move horizontally and a platform moves up and down vertically after each new layer is deposited. It is a commonly used technique used on many inexpensive, domestic and hobby 3D printers.

Material Extrusion 3D printing technology uses a continuous filament of a thermoplastic material as a base material. The filament is fed from a coil, through a moving heated printer extruder head, often abbreviated as an extruder. The molten material is forced out of the extruder's nozzle and is deposited first onto a 3D printing platform.

Once the first layer is completed, the extruder and the platform are parted away in one step, and the second layer can then be directly deposited onto the growing workpiece. The process has many factors that influence the final model quality but has great potential and viability when these factors are controlled successfully. Whilst FDM is similar to all other 3D printing processes, as it builds layer by layer, it varies in the fact that material is added through a nozzle under constant pressure and in a continuous stream. This pressure must be kept steady and at a constant speed to enable accurate results. Material layers can be bonded by temperature control or through the use of chemical agents. Material is often added to the machine in spool form as shown in the diagram.

The extruder head is moved under computer control. At least three axes are required for the extruder to move in Cartesian architectures. A wide variety of materials can be extruded, the most popular being thermoplastics, such as Acrylonitrile Butadiene Styrene (ABS), PolyLactic Acid (PLA), High-Impact Polystyrene (HIPS), Thermoplastic PolyUrethane (TPU), aliphatic PolyAmides (PA, also known as Nylon), and more recently high performance plastics such as PolyEther Ether Ketone PEEK or PolyEtherimide PEI.



Material Extrusion – Step by Step

1. First layer is built as nozzle deposits material where required onto the cross sectional area of first object slice.
2. The following layers are added on top of previous layers.
3. Layers are fused together upon deposition as the material is in a melted state.

Advantages:

- Widespread and inexpensive process
- ABS plastic can be used, which has good structural properties and is easily accessible

Disadvantages:

- The nozzle radius limits and reduces the final quality
- Accuracy and speed are low when compared to other processes and accuracy of the final model is limited to material nozzle thickness
- Constant pressure of material is required in order to increase quality of finish

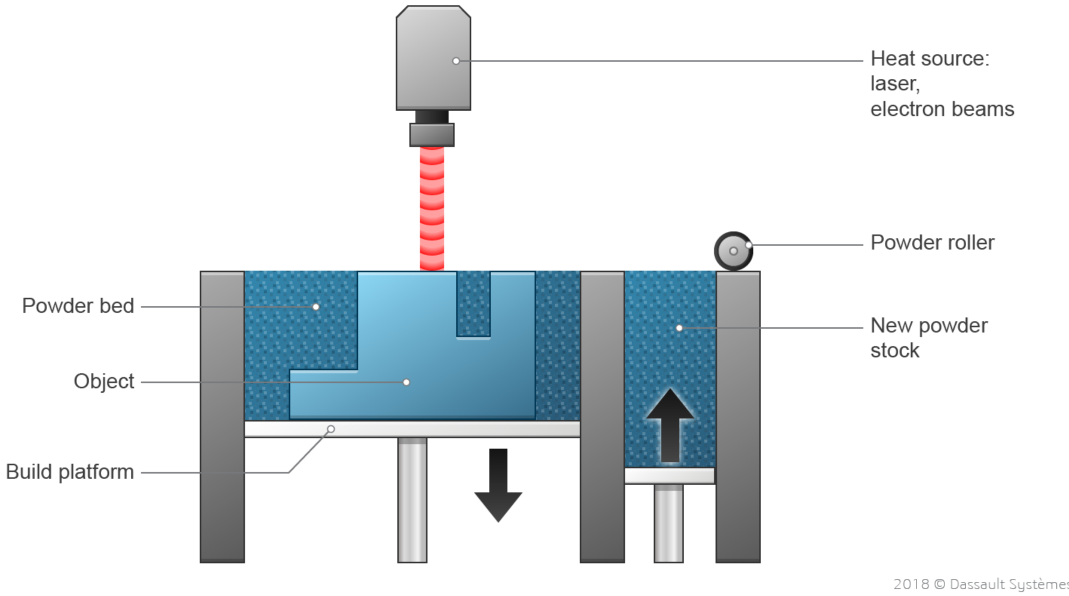
Powder Bed Fusion Sintering Techniques

Powder bed fusion (PBF) methods use either a laser or electron beam to melt and fuse material powder together. In this method, the layers of powder are fused together using a heat source, such as a laser or election beam. The Powder Bed Fusion process includes the following commonly used printing techniques: Direct metal laser sintering (DMLS), Electron beam melting (EBM), Selective heat sintering (SHS), Selective laser melting (SLM) and Selective laser sintering (SLS).

Selective Laser Sintering (SLS) is the process of compacting and forming a solid mass of material by heat and/or pressure without melting. Selective laser sintering (SLS) machines are made up of three components: a heat source to fuse the material, a method to control this heat source and a mechanism to add new layers of material over the previous.

Powder Bed Fusion – Step by Step

1. A layer, typically 0.1mm thick of material is spread over the build platform.
2. A laser fuses the first layer or first cross section of the model.
3. A new layer of powder is spread across the previous layer using a roller.
4. Further layers or cross sections are fused and added.
5. The process repeats until the entire model is created. Loose, unfused powder is remains in position but is removed during post processing.



Advantages:

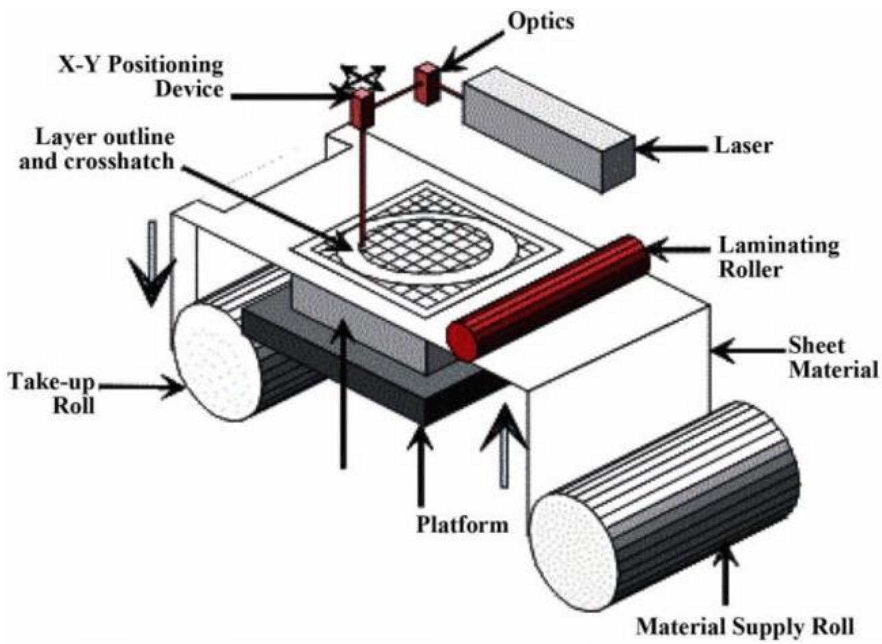
- Relatively inexpensive
- Suitable for visual models and prototypes
- Ability to integrate technology into small scale, office sized machine
- Powder acts as an integrated support structure
- Large range of material options

Disadvantages:

- Relatively slow speed
- Lack of structural properties in materials
- Size limitations
- High power usage
- Finish is dependent on powder grain size

Sheet Lamination Techniques

Sheet lamination processes include ultrasonic additive manufacturing (UAM) and laminated object manufacturing (LOM). The Ultrasonic Additive Manufacturing process uses sheets or ribbons of metal, which are bound together using ultrasonic welding. The process does require additional CNC machining and removal of the unbound metal, often during the welding process. Laminated object manufacturing (LOM) uses a similar layer by layer approach but uses paper as material and adhesive instead of welding. The LOM process uses a cross hatching method during the printing process to allow for easy removal post build. Laminated objects are often used for aesthetic and visual models and are not suitable for structural use.



Sheet Lamination – Step by Step

1. The material is positioned in place on the cutting bed.
2. The material is bonded in place, over the previous layer, using the adhesive.
3. The required shape is then cut from the layer, by laser or knife.
4. The next layer is added.
5. Steps two and three can be reversed and alternatively, the material can be cut before being positioned and bonded.

Advantages:

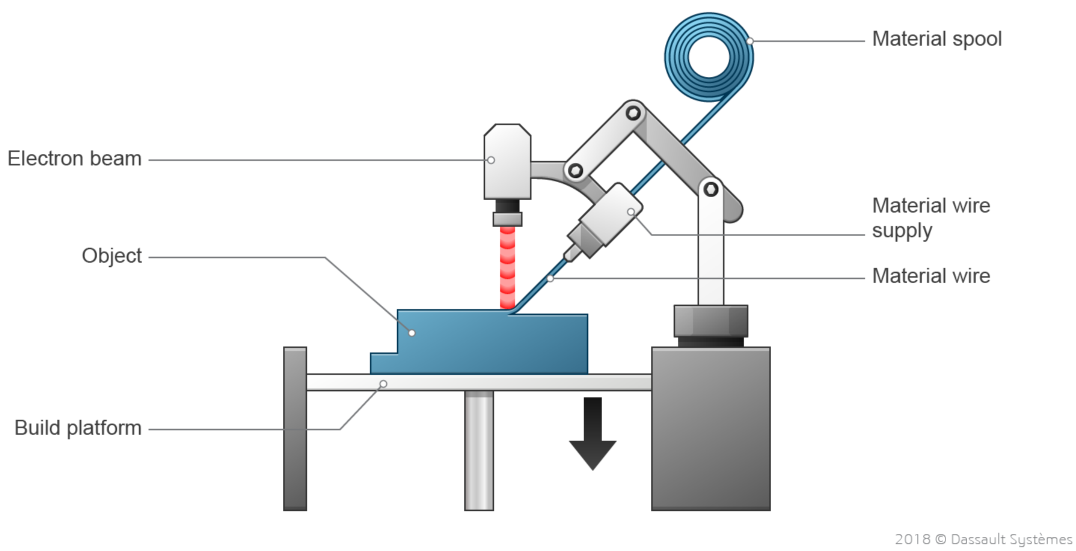
- Benefits include speed, low cost, ease of material handling, but the strength and integrity of models is reliant on the adhesive used
- Cutting can be very fast due to the cutting route only being that of the shape outline, not the entire cross sectional area

Disadvantages:

- Finishes can vary depending on paper or plastic material but may require post processing to achieve desired effect
- Limited material use
- Fusion processes require more research to further advance the process into a more mainstream positioning

Directed Energy Deposition Techniques

Direct energy deposition processes generally do not use polymeric materials but employ metal wire or powder. High energy heating sources such as a laser are directed at the material to melt it and build-up the product. Directed energy deposition is considered to be a more complex and expensive additive manufacturing process, but it is commonly used to repair or add additional materials to existing components.



Direct Energy Deposition – Step by Step

1. A4 or 5 axis arm with nozzle moves around a 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 and solidifies, creating or repairing new material features on the existing object.

Advantages

- Ability to control the grain structure to a high degree, which lends the process to repair work of high quality, functional parts
- A balance is needed between surface quality and speed, although with repair applications, speed can often be sacrificed for a high accuracy and a pre- determined microstructure

Disadvantages:

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Recent trends in manufacturing:

The following are the commonly known practices used today that facilitate cost reduction, quality improvement and flexibility in the manufacturing environment.

- Lean Manufacturing
- Demand Flow Manufacturing
- Just-in-Time
- Agile Manufacturing
- Rapid Manufacturing
- Flexible Manufacturing System
- Advanced Planning and Scheduling

Lean Manufacturing: Lean manufacturing or lean productions, which is often known simply as "Lean", is a production practice that considers the expenditure of resources for any goal other than the creation of value for the end customer to be wasteful, and thus a target for elimination. Basically, lean is centred on preserving value with less work.

Demand Flow Manufacturing: The most value and variation is created here: both in the product and the service of supply. Demand Flow Manufacturing starts with the method for combining demand and releasing orders into production. It works to optimise the allocation of asset capacity and inventory to the required service level to the customer. The paradigm aim is a daily order release of the exact product mix and volume according to customer demand.

Just-in-time (JIT): This is an inventory strategy that strives to improve a business's return on investment by reducing in- process inventory and associated carrying costs. To meet JIT objectives, the process relies on signals or Kanban between different points in the process, which tell production when to make the next part. Kanban are usually 'tickets' but can be simple visual signals, such as the presence or absence of a part on a shelf. Implemented correctly, JIT can improve a manufacturing organization's return on investment, quality, and efficiency.

Agile Manufacturing: It is a term of light to an organisation that has created the processes, tools and training to enable it to respond quickly to customer and market changes by still controlling cost and quality. Agile manufacturing is seen as the next step after leaning the evolution of production and methodical.

Rapid Manufacturing: It is an additive fabrication technique for manufacturing solid objects by the sequential delivery of energy and materials to specify points in space to produce that part Crane practice is to control the manufacturing process by computer using a mathematical model created with the aid of computer.

Flexible Manufacturing System: Flexible manufacturing is a manufacturing system in which there is some amount of flexibility that allows the system to react to the case of changes, whether predicted or unpredicted. This flexibility generally considered in two categories

Machine Flexibility: It covers the system ability to be changed to produce new products type and ability to change the order of operations executed on a part.

Routine Flexibility: Which consists the ability to use multiple machine to perform same operations on a part, as well as the system ability to absorb large scale changes, such as in volume capacity or capability.

Advanced Planning and Scheduling: This is also referred to as APS and advanced manufacturing where there is a manufacturing management process by which raw materials and production capacity are optimally allocated to meet demand. APS is especially well-suited to environments where simpler planning methods cannot adequately address complex trade-offs between competing priorities. Production scheduling is intrinsically very difficult due to the (approximately) factorial dependence of the size of the solution space on the number of items/products to be manufactured.

Hybrid Manufacturing:

Hybrid manufacturing process combines two or more established manufacturing processes into a new combined set-up whereby the advantages of each discrete process can be exploited synergistically. It is also defined as the processes comprise a simultaneous acting of different (chemical, physical, controlled) processing principles on the same processing zone.

The various Hybrid manufacturing process are as follows:

- Mechanical machining and ECM
- Mechanical machining and Electric Discharge Machining (EDM)
- Mechanical machining and laser cutting
- Laser cutting and EDM
- Laser cutting and ECM
- EDM and ECM
- Turn-mill, mill-grind
- Ultrasonic assisted mechanical machining
- Ultrasonic assisted grinding
- Ultrasonic assisted turning
- Wire-EDM and etching
- Laser heat treatment and sheet metal forming
- Laser cladding and mechanical machining
- Injection moulding and milling

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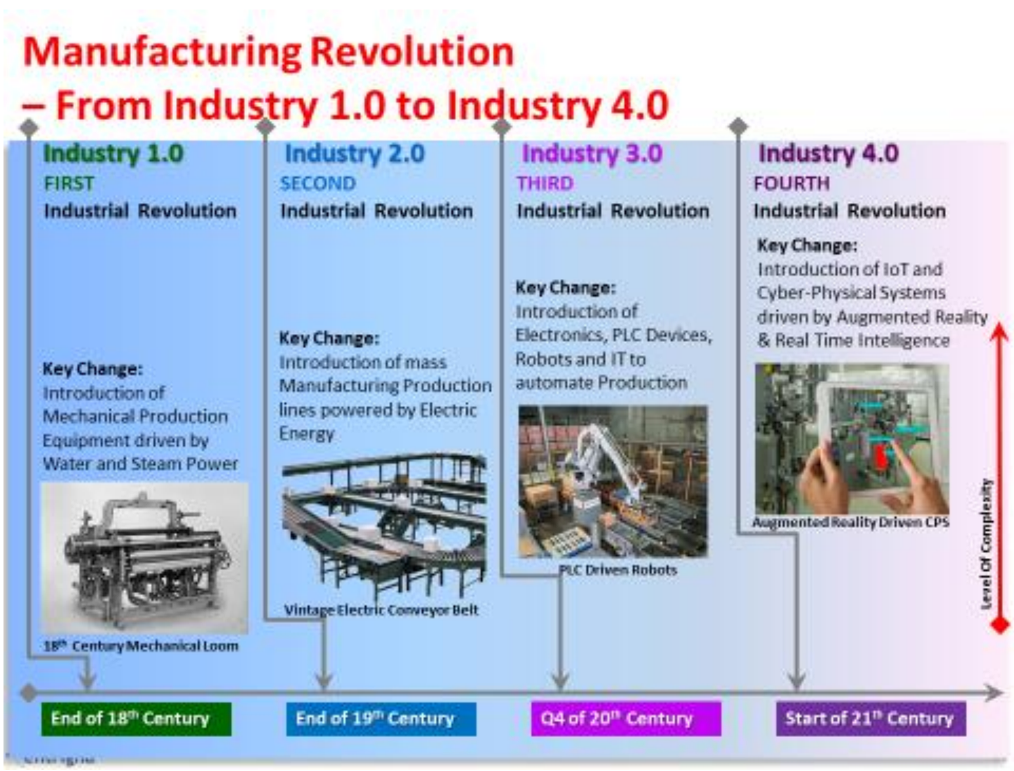
FUTURE OF AUTOMATED FACTORY

Dr. K. M. Sathish Kumar
Professor and HoD, Dept. of ME, BMSIT&M

Industry 4.0:

Industry 4.0 is a name for the current trend of automation and data exchange in manufacturing technologies. It includes cyber physical systems, the Internet of Things (IoT), Cloud computing and Cognitive computing. Industry 4.0 is commonly referred to as the 4th Industrial revolution. Industry 4.0 creates what has been called a "smart factory".

The term "Industry 4.0" originates from a project in the high-tech strategy of the German government. The term "Industry 4.0" was revived in 2011 at the Hannover Fair. In October 2012 the Working Group on Industry 4.0 presented a set of Industry 4.0 implementation recommendations to the German federal government. On 8th April 2013 at the Hannover Fair, the final report of the Industry 4.0 was presented.



Functions of Industry 4.0:

There are four **design principles** or **functions** or **Features** of Industry 4.0:

- **Interoperability:** where machines, devices, sensors and people are connected and communicated with each another.
- **Information transparency:** The transparency afforded by Industry 4.0 technology provides operators with vast amounts of useful information needed to make appropriate decisions. Inter-connectivity allows operators to collect immense amounts of data and information from all points in the manufacturing process, thus aiding functionality and identifying key areas that can benefit from innovation and improvement.
- **Technical assistance:** First, the ability of assistance systems to support humans by aggregating and visualizing information comprehensively for making informed decisions and solving urgent problems on short notice. Second, the ability of cyber physical systems to physically support humans by conducting a range of tasks that are unpleasant, too exhausting, or unsafe for their human co-workers.
- **Decentralized decision:** the ability of cyber-physical systems to make simple decisions on their own and perform their tasks as autonomously as possible.

Benefits of Industry 4.0 (Advantages of Industry 4.0):

- Improved Productivity
- Improved Efficiency
- Increased Knowledge Sharing and Collaborative Working
- Flexibility and Agility
- Makes Compliance Easier
- Better Customer Experience
- Reduces Costs
- Creates Innovation Opportunities
- Higher Revenues
- Increased Profitability
- Getting A Return On Investment

Applications of Industry 4.0:

- Internet of Objects (IoT)
- Embedded Software
- Big Data and Data Analytics
- Machine to Machine Communication (M2M)
- Cloud Solutions
- Intelligent Robot Automation Systems
- Augmented Reality
- Simulation
- Additive Manufacturing (3D PRINTING)
- Cyber Security
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- Smart Sensors (RFID, BARCODE)
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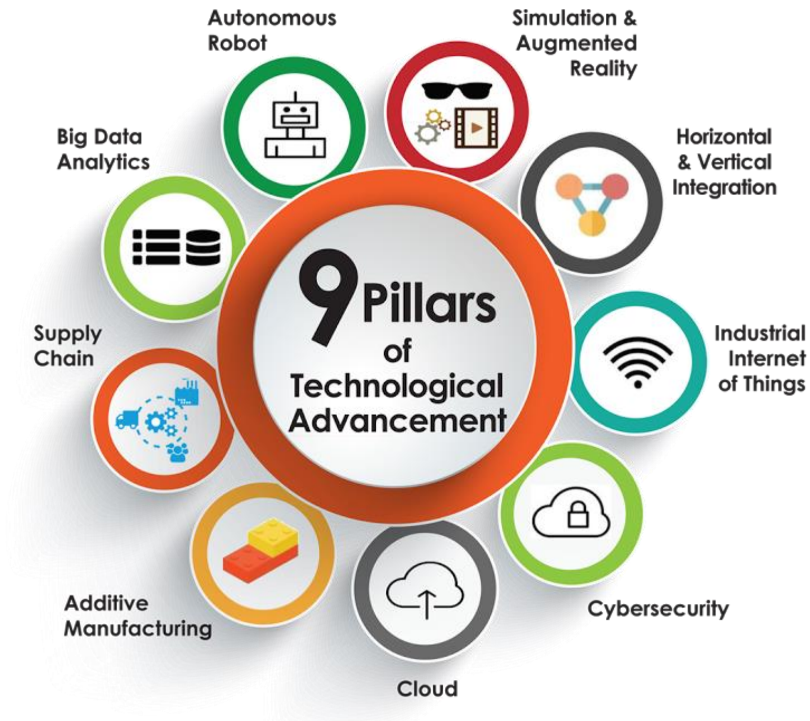
- Remote control

Components of Industry 4.0 (Pillars of Industry 4.0):



Industrial Internet of Things (IIoT): The Internet of Things refers to the networking and connectivity of smart devices. When you think of IoT, devices such as smartphones, tablets, and laptops are usually top of mind. In the world of manufacturing, this technology is often referred to as the Industrial Internet of Things (IIoT). Manufacturers are attaching sensors to machines and other physical assets on the plant floor to collect data which influences decisions real time and leads to increased efficiency and productivity.

Cybersecurity: Cybersecurity is responsible for providing protection to the stored information, either on a device, or on the network. The system is capable to protect the information from threats like computer strikes, or even from physical kind of threats.

Cloud Computing: With the advent of IoT and Industry 4.0, the reality is that data is being generated at a staggering speed and at high volumes, making it impossible to handle manually. This creates a need for an infrastructure that can store and manage this data more efficiently. This is where cloud computing comes in. Cloud computing offers a platform for users to store and process vast amounts of data on remote servers. It enables organisations to use computer resources without having to develop a computing infrastructure on premise. The term cloud computing refers to information being stored in the "cloud", accessed remotely via the Internet.

Big Data Analytics: The concept of big data applies to large, diverse and complex datasets that affect the organizational decision making of a company concerning their strategy. Therefore, the increase in level of data and improvements on technological capabilities accelerates firms' competitive advantage by increasing productivity, innovation and competition.

Autonomous Robots: Robots are used in manufacturing industries in order to solve complex tasks which cannot be solved easily by a human. By the traditional automation strategy, companies could not fully implement JIT strategies and continuous improvements if they do not opt for autonomous robots. The usage of more industrial robots in factories accelerates with Industry 4.0. Robots could be used in several areas such as production, logistics, distribution activities and could be controlled remotely by humans thanks to the human robot cooperation.

Additive Manufacturing: Additive manufacturing, or 3D printing, is a key technology driving Industry 4.0. Additive manufacturing is a process of converting digital 3D models to create parts with a 3D printer layer by layer. Within the context of Industry 4.0, 3D printing is emerging as a valuable digital manufacturing technology. AM offers a huge scope of possibilities for manufacturing from tooling to mass customisation across virtually all industries.

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Horizontal and Vertical Integration: Horizontal integration means every device and system at the same level of manufacturing in the same facility or the other is connected with each other. As this enables communication between systems in different facilities, jobs can be planned and adjusted by the machines themselves. Vertical integration makes it even better. Every system and humans at all hierarchy has all the data with required abstraction. Notable challenge faced in vertical integration is the communication protocol.

Supply Chain: The manufacturing industry is moving towards a more digitised, automated, agile and, ultimately, efficient operation and there is no better example of this than in the supply chain network. In today's world, the supply chain is a multi-faceted ecosystem linking product development, manufacturing and distribution networks into one fully transparent and digitised system.

Internet of Things (IOT):

Internet of Things (IoT) refers to a system of connected physical objects via the internet. The 'thing' in IoT can refer to a person or any device which is assigned through an IP address. A 'thing' collects and transfers data over the internet without any manual intervention with the help of embedded technology. It helps them to interact with the external environment or internal states to take the decisions.

IOT Applications in Manufacturing:

- Digital/Connected Factory
- Facility Management
- Production Flow Monitoring
- Inventory Management
- Plant Safety and Security
- Quality Control
- Packaging Optimization
- Logistics and Supply Chain Optimization

Big-Data and Cloud Computing for IOT:

Big Data: Big Data means a large set of structured, unstructured or semi-structured data and analyzing those data to get the insights of the business trend.

Cloud Computing: Cloud Computing gives the centralized platform to access the data from anywhere in the world with the shared infrastructure. Thus, you can save a lot of money. Cloud computing offers services to users on a pay-as-you-go model.

Cloud providers offer three primary services. These services are outlined below:

Infrastructure as a Service (IAAS): The Cloud service provider offers entire infrastructure along with the maintenance related tasks.

Platform as a Service (PAAS): The Cloud provider offers resources like object storage, runtime, queuing, databases, etc. However, the responsibility of configuration and implementation related tasks depend on the consumer.

Software as a Service (SAAS): This service is the most facilitated one which offers all the necessary settings and infrastructure provided IaaS for the platform and infrastructure are in place.

IoT for smart manufacturing:

Smart manufacturing accelerates productivity, increases efficiency, minimizes delays and provides a competitive edge for businesses. Smart manufacturing is enabled by IoT connected devices, big data, data analytics, robotics, machine learning, sensor technologies, and artificial intelligence. Each of these technologies are used together to optimize manufacturing processes, assist manufacturers, and keep workers safe.

The potential benefits of smart manufacturing:

Improved employee productivity: Using real-time data from sensors allows employees to monitor and improve processes efficiently without delays, which enhances productivity.

Asset optimization**:** Sensors track assets (machinery, equipment, tools, trucks, etc.) in real-time, providing visibility of their potential. On the basis of this data, businesses can make quick decisions and optimize their asset usage at maximum capacity.

Reduction of operating costs: Intelligent machines and data analytics lead to reduced consumption of fuel and electricity, cuts inefficiencies and decreases overall expenses.

Improved quality of goods: Automation eliminates human error, and companies are able to produce higher-quality goods.

Influence of IOT on predictive maintenance:

The study states that worldwide, only 18% of equipment has failed due to its age, while 82% of failures occur randomly. It proves that a time-based approach is not cost-effective. To avoid ineffective maintenance routine and costs that accompany it, manufacturers can leverage Industrial IoT and data science. An IoT-based predictive maintenance solution can help to predict potential damage by collecting data from ultrasonic and vibration sensors attached to the spindle. Analyzing the collected data helps to identify fragile spindles before they break. Next-gen manufacturing equipment uses built-in sensors and sophisticated programming to perform predictive analytics and forecast potential issues before they happen. Effective predictive maintenance helps to optimize and streamline maintenance routines in other ways, too. Predictive analytics often highlights machines or parts that require constant attention.

With new sensor information, IoT can help manufacturers improve overall equipment effectiveness (OEE), save money by minimizing equipment failure, allow the company to perform planned maintenance, and avoid issues before they happen.

Predictive maintenance capabilities will alert operators when a component needs attention or repair, reducing the need for ongoing inspections.

Influence of IOT on Industrial Automation

IoT plus Industrial Automation would get on together and create IIoT (Industrial IoT). IIoT networks of smart & intelligent devices allow organizations to connect their employee every time wirelessly and manage their activity for their safety on factory floor. Some companies are already benefiting from the IIoT through cost savings due to predictive maintenance, improved safety, and other operational efficiencies. The new technology would increase efficiency as well as work output.

Internet of things (IoT) in automation industry is proving to be a game changer for automation companies. Industrial automation companies that use IoT solutions can reap new benefits. The Internet of Things (IoT) helps to create new technologies to solve problems, enhance operations, and increase productivity. Internet of Things (IoT) Impact on Industrial Automation is very high and it makes us to use tablet computers, smart phones, virtualized systems, and cloud storage of data and so on.

Supply-chain & Logistics

Logistics is just one component of a supply chain. Logistics has to do with the coordination and movement of goods. Supply chain involves multiple facets such as operations and procurement that keep a company running smoothly.

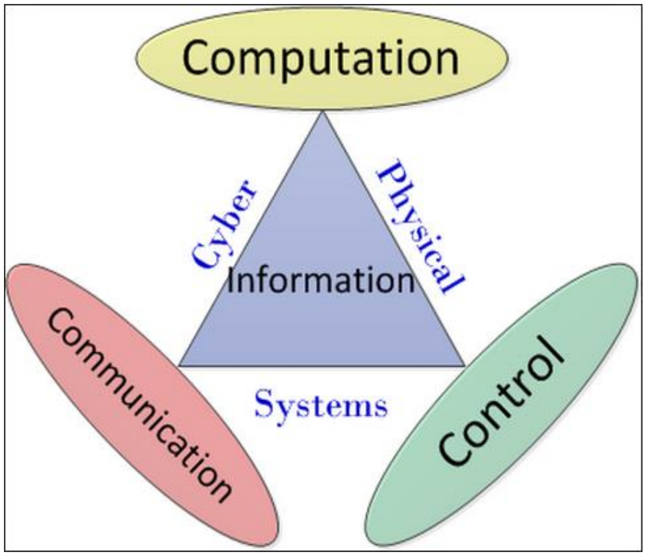
Supply chain is the entire flow that brings a product or service to sale. Logistics is a segment of that, focused on the transportation and storage of goods.

In the supply chain, Internet of Things devices are an effective way to track and authenticate products and shipments using GPS and other technologies. They can also monitor the storage conditions of products which enhances quality management throughout the supply chain.

Supply Chain Optimization:

IoT enabled systems can be configured for location tracking, remote health monitoring of inventory, and reporting of parts and products as they move through the supply chain. IoT systems can also collect and feed delivery information into an ERP system; providing up-to-date information to accounting functions for billing. Real-time information access will help manufacturers identify issues before they happen, lower their inventory costs, and potentially reduce capital requirements.

Cyber-physical manufacturing systems:



A Cyber Physical Manufacturing System (CPMS) is a system of collaborating computational elements controlling physical entities. CPS are physical and engineered systems whose operations are monitored, coordinated, controlled and integrated by a computing and communication core.

Cyber-Physical Systems (CPS) are integrations of computation, networking, and physical processes. Embedded computers and networks monitor and control the physical processes, with feedback loops where physical processes affect computations and vice versa. The economic and societal potential of such systems is vastly greater than what has been realized, and major investments are being made worldwide to develop the technology.

The technology builds on the older (but still very young) discipline of embedded systems, computers and software embedded in devices whose principle mission is not computation, such as cars, toys, medical devices, and scientific instruments. CPS integrates the dynamics of the physical processes with those of the software and networking, providing abstractions and modeling, design, and analysis techniques for the integrated whole.

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Future of Automated Factory

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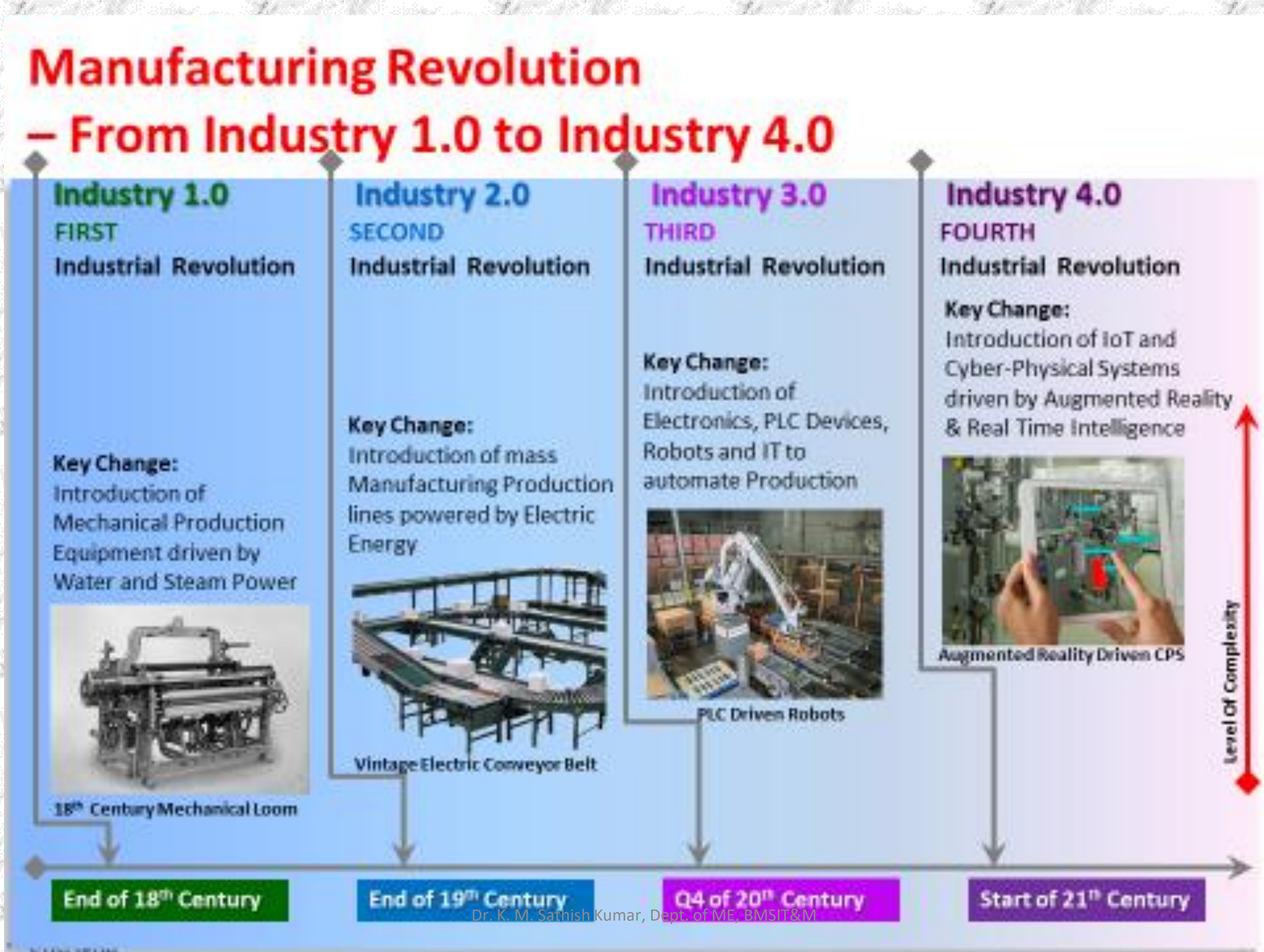
Manufacturing Revolution
– From Industry 1.0 to Industry 4.0
Industry 1.0
FIRST
Industrial Revolution
Key Change:
Introduction of Mechanical Production Equipment driven by Water and Steam Power
18th Century Mechanical Loom
Industry 2.0
SECOND
Industrial Revolution
Key Change:
Introduction of mass Manufacturing Production lines powered by Electric Energy
Vintage Electric Conveyor Belt
Industry 3.0
THIRD
Industrial Revolution
Key Change:
Introduction of Electronics, PLC Devices, Robots and IT to automate Production
PLC Driven Robots
Industry 4.0
FOURTH
Industrial Revolution
Key Change:
Introduction of IoT and Cyber-Physical Systems driven by Augmented Reality & Real Time Intelligence
Augmented Reality Driven CPS
Level Of Complexity
End of 18th Century
End of 19th Century
Q4 of 20th Century
Start of 21st Century

- The industrial revolution 4.0 is happening through the use of cyber-physical systems.

- It means that physical systems such as machines and robots will be controlled by automation systems equipped with machine learning algorithms. Minimal input from human operators will be needed.

- Industry 4.0 is smart devices turning into smart products turning into smart factories.

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- Flexibility And Agility
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Applications of Industry 4.0

- Internet of Objects (IoT)
- Embedded Software
- Big Data and Data Analytics
- Machine to Machine Communication (M2M)
- Cloud Solutions
- Intelligent Robot Automation Systems
- Augmented Reality
- Simulation
- Additive Manufacturing (3D PRINTING)
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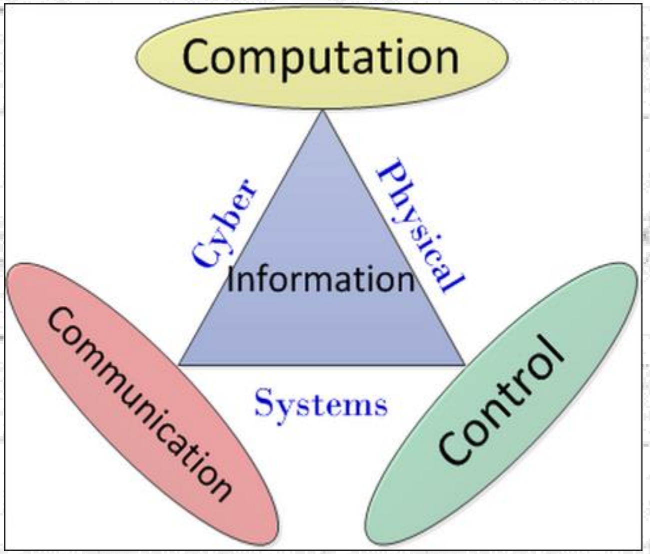
Cyber Physical Manufacturing Systems



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Challenges in implementation of Industry 4.0

- IT security issues
- Reliability and stability needed for critical machine-to-machine communication (M2M), including very short and stable latency times
- Need to maintain the integrity of production processes
- Need to avoid any IT snags, as those would cause expensive production outages

- Lack of adequate skill-sets to expedite the march towards fourth industrial revolution
- General reluctance to change by stakeholders
- Loss of many jobs to automatic processes and IT-controlled processes, especially for lower educated parts of society

Internet of Things (IoT)

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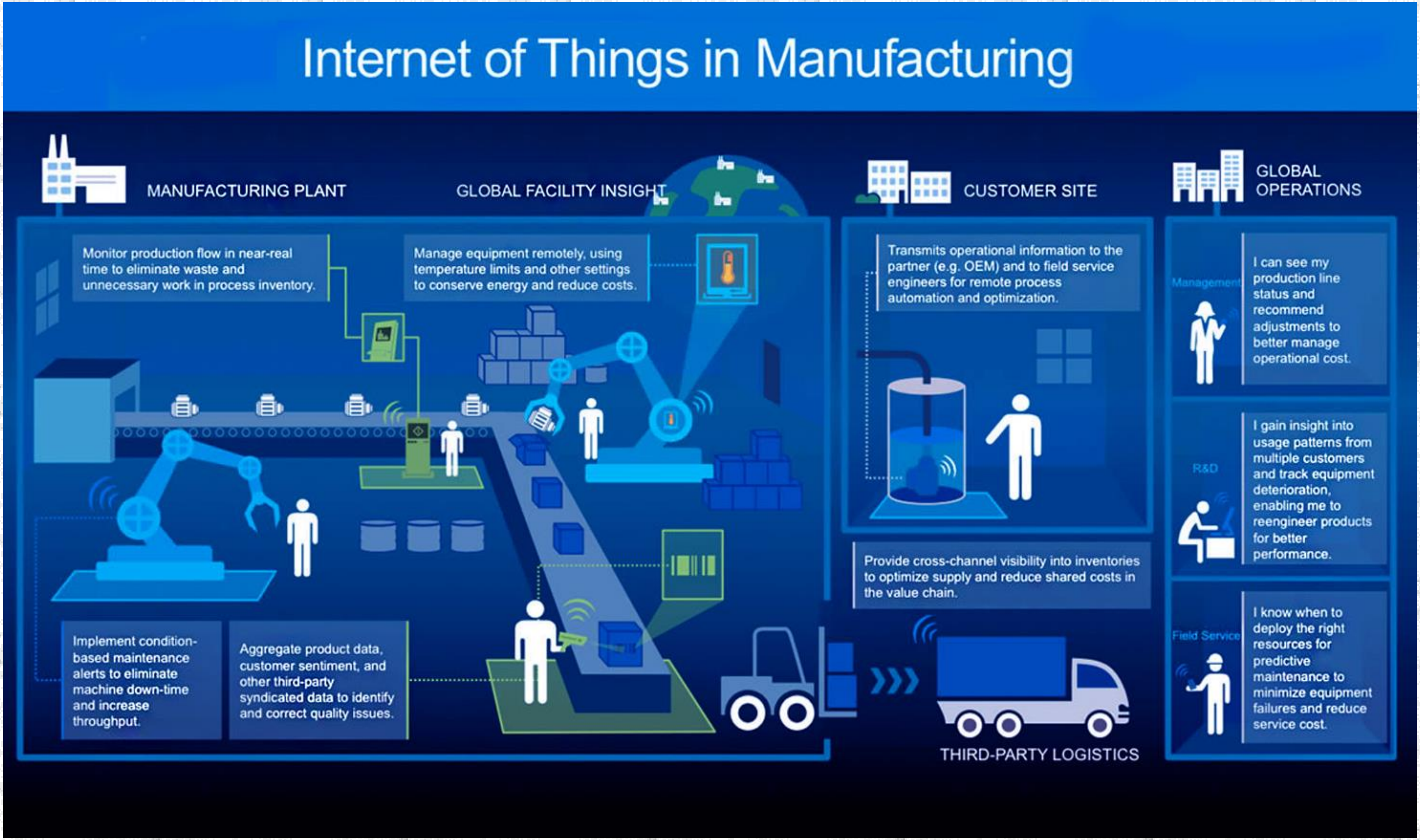
IOT Applications in Manufacturing



- Digital/Connected Factory
- Facility Management
- Production Flow Monitoring
- Inventory Management
- Plant Safety and Security
- Quality Control
- Packaging Optimization
- Logistics and Supply Chain Optimization

Big-Data and Cloud Computing for IOT

Big Data: Big Data means a large set of structured, unstructured or semi-structured data and analyzing those data to get the insights of the business trend.

Cloud Computing: Cloud Computing gives the centralized platform to access the data from anywhere in the world with the shared infrastructure. Thus, you can save a lot of money. Cloud computing offers services to users on a pay-as-you-go model.

Cloud providers offer three primary services. These services are outlined below:

Infrastructure as a Service (IAAS)

The Cloud service provider offers entire infrastructure along with the maintenance related tasks.

Platform as a Service (PAAS)

The Cloud provider offers resources like object storage, runtime, queuing, databases, etc. However, the responsibility of configuration and implementation related tasks depend on the consumer.

Software as a Service (SAAS)

This service is the most facilitated one which offers all the necessary settings and infrastructure provided IaaS for the platform and infrastructure are in place.

IoT for smart manufacturing

- **Smart manufacturing** accelerates productivity, increases efficiency, minimizes delays and provides a competitive edge for businesses.
- **Smart manufacturing** is enabled by IoT connected devices, big data, data analytics, robotics, machine learning, sensor technologies, and artificial intelligence.
- Each of these technologies are used together to optimize manufacturing processes, assist manufacturers, and keep workers safe.

The potential benefits of smart manufacturing:

Improved employee productivity: Using real-time data from sensors allows employees to monitor and improve processes efficiently without delays, which enhances productivity.

Asset optimization: Sensors track assets (machinery, equipment, tools, trucks, etc.) in real-time, providing visibility of their potential. On the basis of this data, businesses can make quick decisions and optimize their asset usage at maximum capacity.

Reduction of operating costs: Intelligent machines and data analytics lead to reduced consumption of fuel and electricity, cuts inefficiencies and decreases overall expenses.

Improved quality of goods: Automation eliminates human error, and companies are able to produce higher-quality goods.

Influence of IOT on predictive maintenance

- The study states that worldwide, only 18% of equipment has failed due to its age, while 82% of failures occur randomly. It proves that a **time-based approach is not cost-effective.**
- To avoid ineffective maintenance routine and costs that accompany it, manufacturers can leverage Industrial IoT and data science.
- An IoT-based predictive maintenance solution can help to predict potential damage by collecting data from ultrasonic and vibration sensors attached to the spindle. Analyzing the collected data helps to identify fragile spindles before they break.

- Next-gen manufacturing equipment uses built-in sensors and sophisticated programming to perform predictive analytics and forecast potential issues before they happen.

- Effective predictive maintenance helps to optimize and streamline maintenance routines in other ways, too. Predictive analytics often highlights machines or parts that require constant attention,

- With new sensor information, IoT can help manufacturers improve overall equipment effectiveness (OEE), save money by minimizing equipment failure, allow the company to perform planned maintenance, and avoid issues before they happen.

- Predictive maintenance capabilities will alert operators when a component needs attention or repair, reducing the need for ongoing inspections.

Influence of IOT on Industrial Automation

- IoT plus Industrial Automation would get on together and create IIoT (Industrial IoT).
- IIoT networks of smart & intelligent devices allow organizations to connect their employee every time wirelessly and manage their activity for their safety on factory floor.
- Some companies are already benefiting from the IIoT through cost savings due to predictive maintenance, improved safety, and other operational efficiencies.
- The new technology would increase efficiency as well as work output.

- Internet of things (IoT) in automation industry is proving to be a game changer for automation companies. Industrial automation companies that use IoT solutions can reap new benefits.
- The Internet of Things (IoT) helps to create new technologies to solve problems, enhance operations, and increase productivity.
- Internet of Things (IoT) Impact on Industrial Automation is very high and it makes us to use tablet computers, smart phones, virtualized systems, and cloud storage of data and so on.

Supply Chain Optimization:

- IoT enabled systems can be configured for location tracking, remote health monitoring of inventory, and reporting of parts and products as they move through the supply chain.
- IoT systems can also collect and feed delivery information into an ERP system; providing up-to-date information to accounting functions for billing.
- Real-time information access will help manufacturers identify issues before they happen, lower their inventory costs, and potentially reduce capital requirements.

Supply-chain & Logistics

- Logistics is just one component of a supply chain. Logistics has to do with the coordination and movement of goods. Supply chain involves multiple facets such as operations and procurement that keep a company running smoothly.

- Supply chain is the entire flow that brings a product or service to sale. Logistics is a segment of that, focused on the transportation and storage of goods.

- In the supply chain, Internet of Things devices are an effective way to track and authenticate products and shipments using GPS and other technologies.

- They can also monitor the storage conditions of products which enhances quality management throughout the supply chain.

Thank you