ME 8691

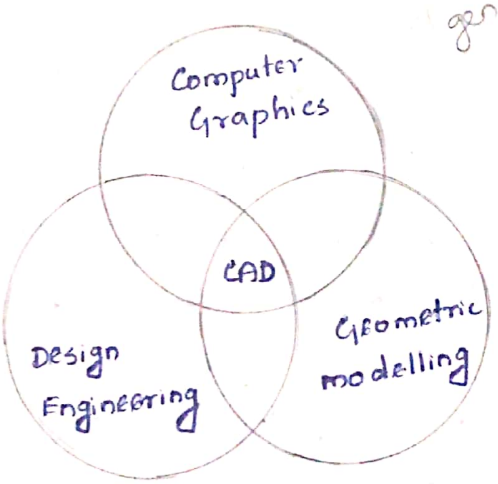
COMPUTER AIDED DESIGN AND MANUFACTURING

UNIT I

INTRODUCTION TO CAD / CAM

Computer Aided Design (CAD) is the technology concerned with the use of computer systems to assist the creation, modification, analysis and optimization of a design.

generating images with the use of computers



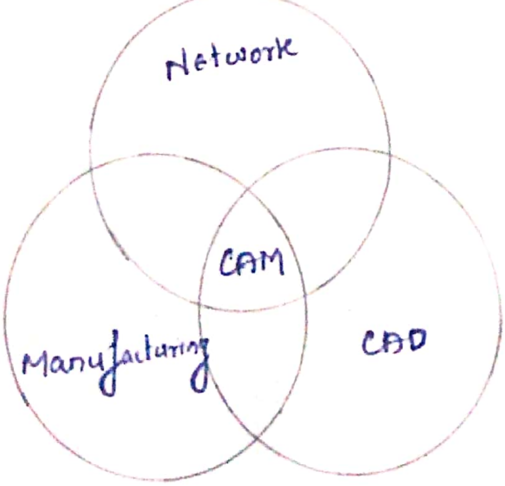
← CAD Process

← construct a geometry 2D CAD shape, dimensions

Computer Aided Manufacturing (CAM) is the technology concerned with the use of computer system to plan, manage and control manufacturing operations.

sharing data

Ring, Star, Tree, Bus



← CAM Process

CAM uses the geometrical design data to control the automated machineries.

CAM systems are associated with computer Numerical control (CNC) or Direct Numerical control (DNC) systems.

Both CAD and CAM technologies use computer based methods for encoding the geometrical data.

Integration of CAD and CAM leads to automation.

1.1 Product cycle:

The cycle through which a product goes from product development to retirement is called product life cycle or product cycle.

The product cycle includes all activities starting from identification for product to deliver the finished product to the customer.

The product cycle starts with developing the product concept, ~~Bar~~ evolving the design, engineering the product, manufacturing the part, marketing and servicing.

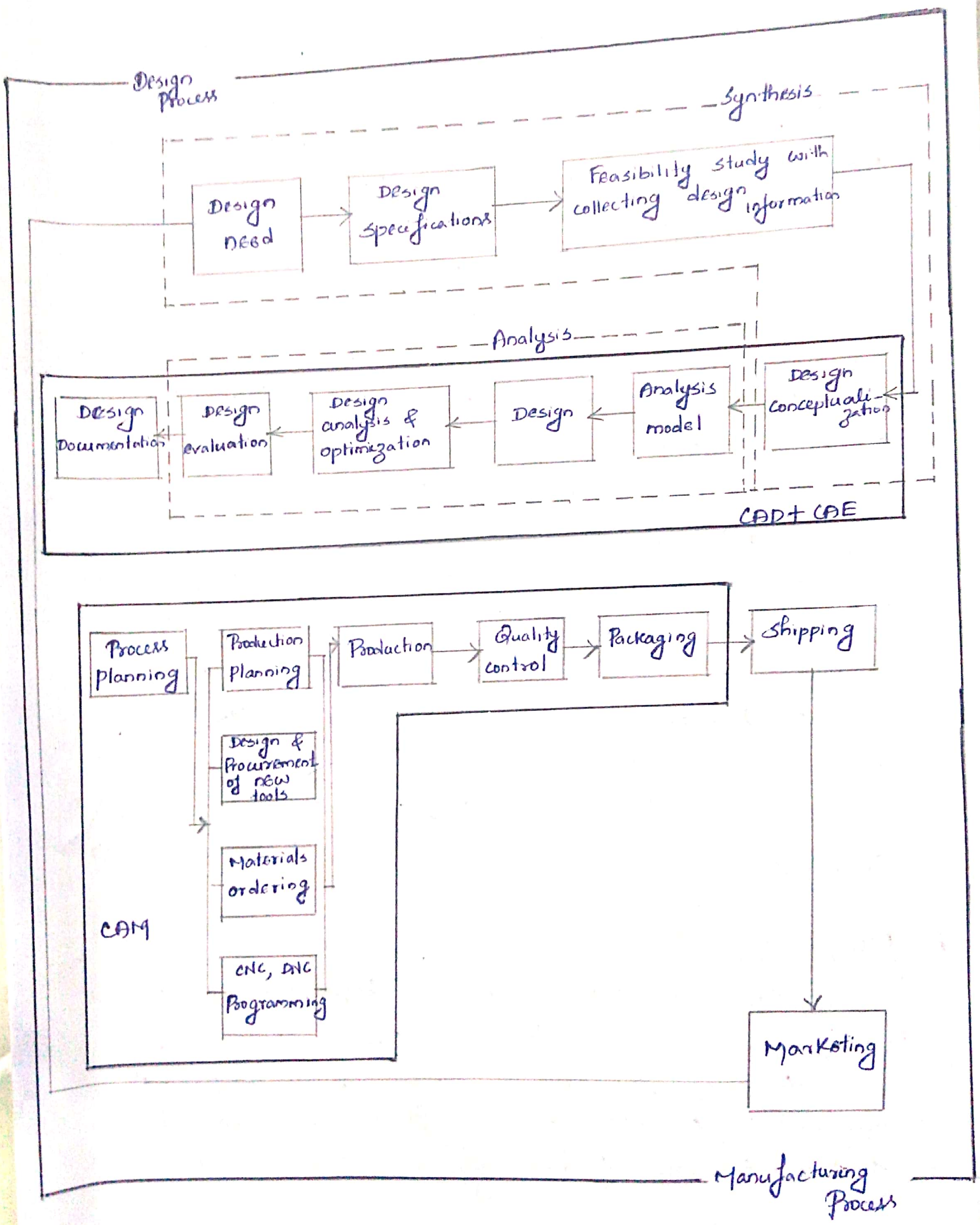
The product undergoes the following two main processes from starting inception to finished product.

(controlled by a set of instruction)

NC - programs feed to punch cards

i. Design Process

ii. Manufacturing process.


Design Process
Synthesis
Design need
Design specifications
Feasibility study with collecting design information
Analysis
Design conceptualization
Analysis model
Design
Design analysis & optimization
Design evaluation
Design Documentation
CAD + CAE
Process Planning
Production Planning
Design & Procurement of new tools
Materials ordering
CNC, DNC Programming
Production
Quality control
Packaging
Shipping
CAM
Marketing
Manufacturing Process

i. Design process

The Product cycle begins with the design process. Synthesis and analysis are the two important sub-processes of the design process.

The design process starts with the identification of need for the particular Product. It may be obtained from a patent, suggestion of customers, feed back of sales and Service department and market research.

The analysis of sub-process starts with the careful design of each assembly and each component of the assembly. The design department creates these design through a top down approach or a bottom up approach.

In top down approach, the entire assembly is first designed and individual designs are done latter.

In bottom up approach, the component design is done first and the product is realized by assembling the components suitably.

A detailed design analysis and optimization are also carried out at this stage.

The final stage of the analysis sub-process is the design documentation in the form of detailed engineering drawings.

ii. Manufacturing Process

The manufacturing process begins with the process planning and ends with the real product.

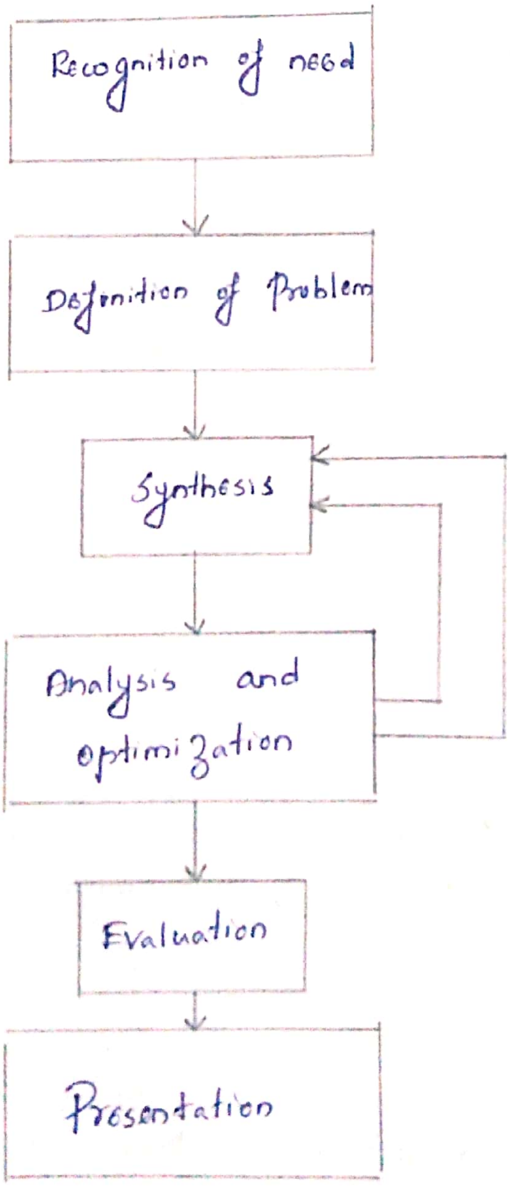
A process plan is formulated which specifies the sequences of production operations to be carried out to produce the new Product.

In some cases, a special manufacturing method is required such as jigs and fixtures or inspection gauges which may be planned.

The production is followed by quality testing. The parts which pass the quality check are assembled, packages, labeled and delivered to customer.

1.2. Design Process

1.2.1. Shighely model



Step 1: Recognition of need:

Problems in the existing products (or) potential for new products in the market have to be identified

Step 2: Definition of Problem:

The problem in the existing product or specification of the new product is specified as 'Design Brief' to the designers. It includes the specification of physical and functional characteristics, cost, quality, performance requirements.

Step 3: Synthesis

In this stage, the designer develops number of designs to meet the requirement of design brief.

Step 4: Analysis and Optimization:

Each design from the synthesis stages is analysed and the optimum one is selected.

Based on the analysis, improvements are made and re designed.

The process is repeated until the design is optimized within all constraints imposed by designer.

Step 5: Evaluation:

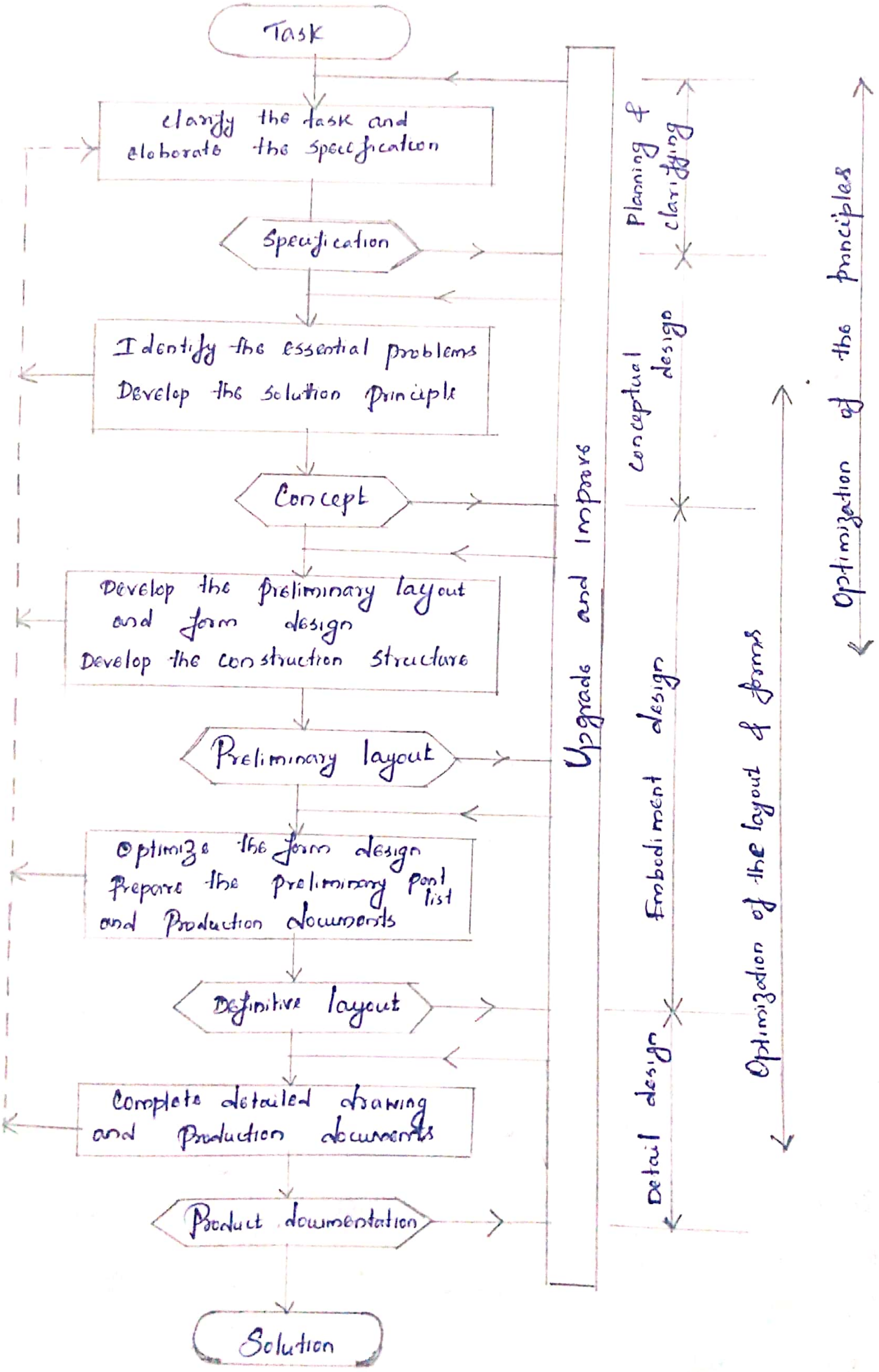
In this stage, optimized design from the previous stage is checked for all specifications mentioned in the 'Design Brief'.

Step 6: Presentation:

After the product design passing through the evaluation stage, drawings, diagrams, material specification, assembly lists, bill of materials etc which are required for product manufacturing are prepared and given to the process planning department and production department.

Embodiment — [illegible]

1.2.2. Pahl and Beitz model



a. **Classification of task:**

This phase involves the collection of information about the design requirements and the constraints on the design as well as describing them as design specification.

b **Conceptual design:**

This phase involves the establishment of functions to be included in the design, and identification and development of suitable solution.

c. **Embodiment design:**

In this phase, the conceptual solution is developed in more detail, problems are resolved and weak aspects are eliminated.

d. **Detail design:**

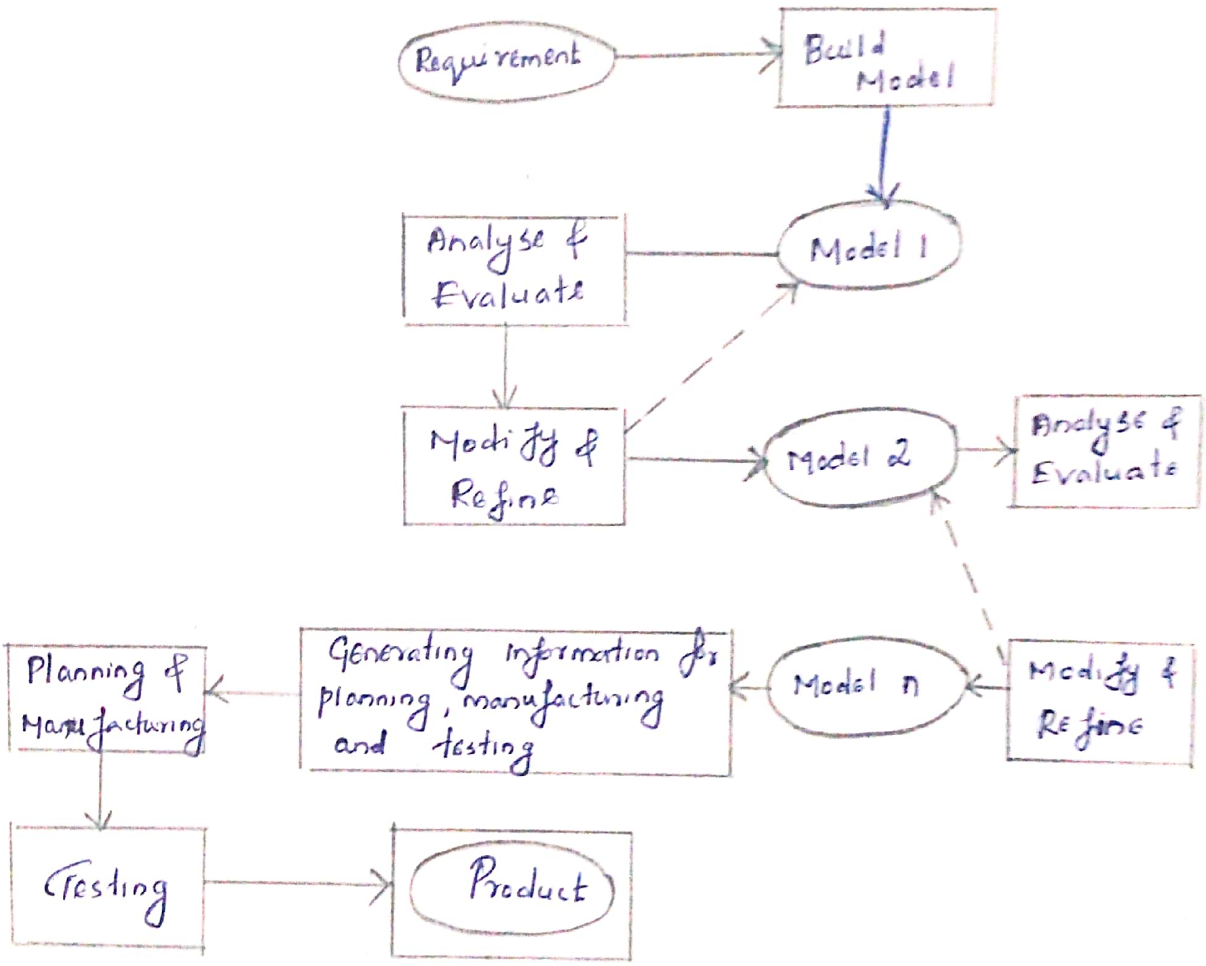
In this phase, dimensions, tolerance, materials and form of each individual components of the design are specifed in detail which will be useful for manufacturing.

1.2.3: Ohsuga model

Ohsuga describes the design as a series of stages progressing from requirements through the conceptual design and preliminary design to detail design.

At the begining stage of design, a tentative solution is proposed by the designer. This tentative solution is evaluated from a number of view points to establish the fitness of a proposed design in relation to given requirements.

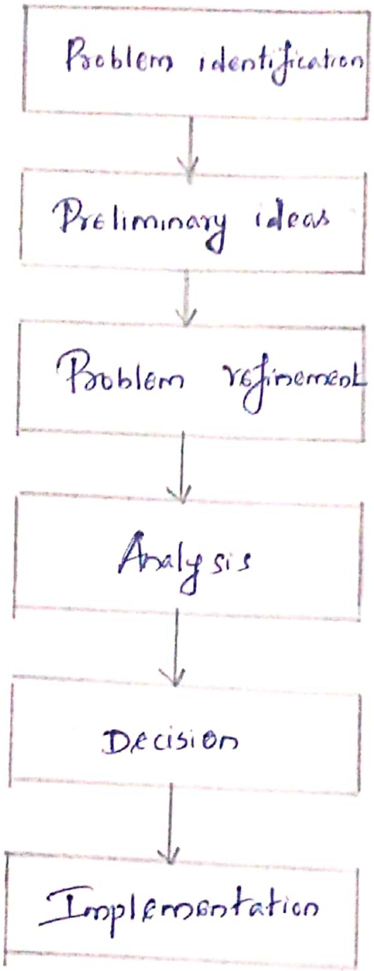
If the Proposal is unsuitable, then it is modified. This Process is repeated at a point where it can be developed in more depth and the preliminary design stage starts.



1.2.4: Earle Model:

i. Problem identification:

- Identification of design need — Begining point of the design process. It may be a defect in the existing or need for a new product.
- Identification of design criteria — In-depth investigation of specifications.



The following steps should be used in Problem identification

a. Problem statement:

The Problem statement is written to begin the thinking Process. The statement should be complete and comprehensive but it should be concise.

including everything for particular subject

Brief

b. Problem requirements:

The positive requirements are listed which must be achieved through a proper design.

Set within the limit

c. Problem limitations:

Negative factors are listed that confine the Problem to be specified as limitations.

d. Sketches:

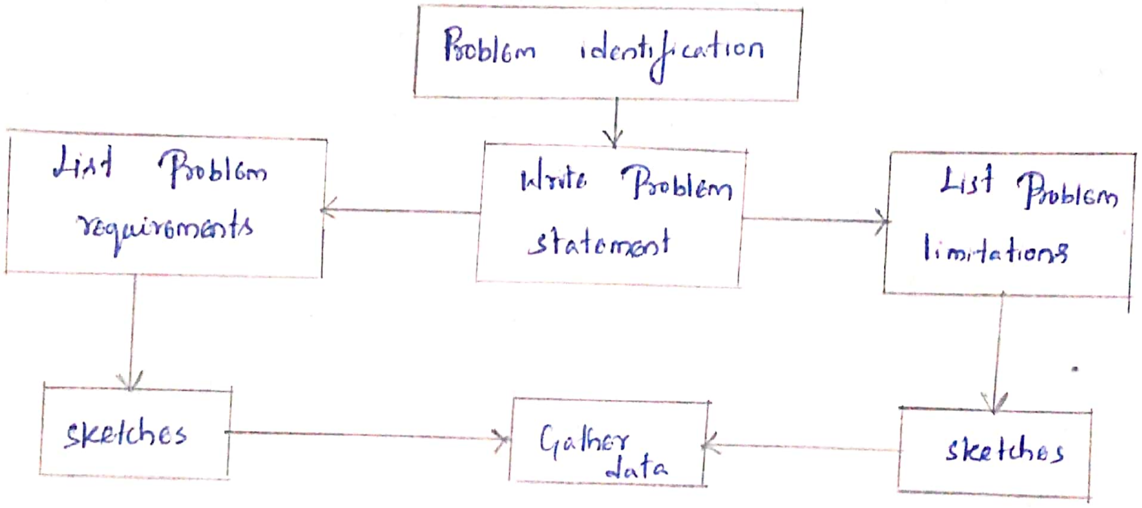
Sketches of physical characteristics of the problem are made. Notes and dimensions are added that would make these sketches more understandable.

e. Gather data:

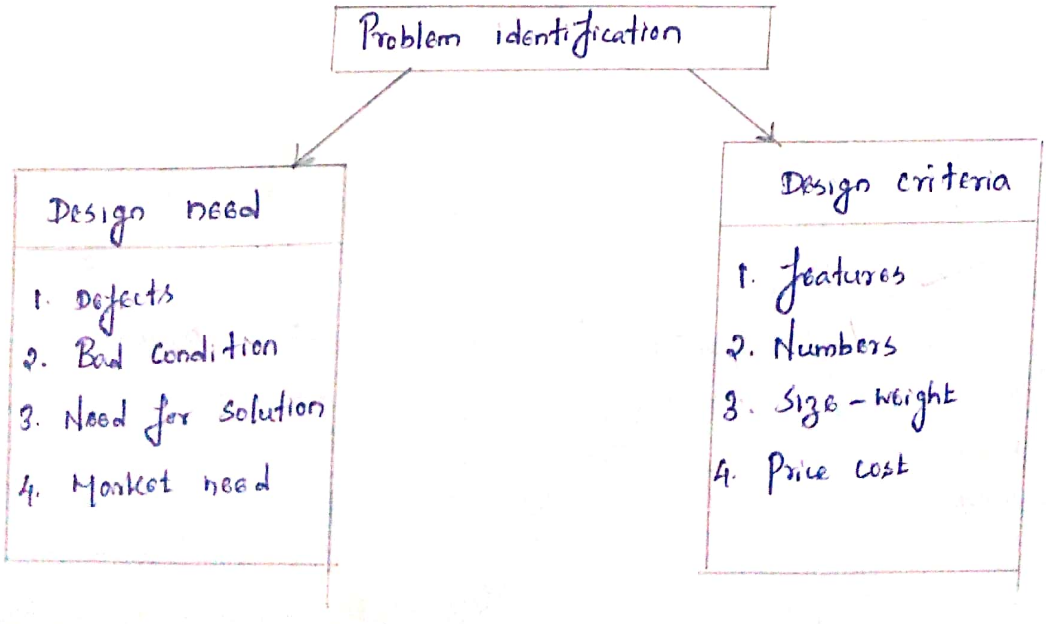
The gathered data should be graphed for easy interpretation.

Explain

Steps followed in problem identification



Types of Problem identification



Typical quality important part characteristics

ii. Preliminary ideas:

Preliminary ideas are the generation of as many ideas as possible for the efficient solution.

The following sequence of steps is suggested.

a. Conduct brain storming session

Brainstorm is a conference technique by which a group attempts to find a solution for a specific problem by amassing all ideas spontaneously contributed by its members.

not planned suddenly

b. Prepare sketches & notes:

Sketching is most important medium for developing Preliminary ideas. Computer graphics can be used for modifying and developing a number of ideas.

c. Research existing designs:

Preliminary ideas can be obtained through research of similar Products, designs from technical magazines, manufacturer's brochures, patents and consultants.

d. Conduct Survey:

Survey methods are used to gather opinions and reactions to a preliminary design or complete design. It could be accomplished by interviews, questionnaire. etc.

iii. Design refinement:

Several of better preliminary ideas are selected for further refinement to determine their true merits. A descriptive geometry can be applied for this purpose. Computer graphics is a powerful tool that can be used to refine the Preliminary data.

iv. Analysis:

A product must be analyzed to determine its acceptance by the market before it is released for production. The general areas of analysis are as follows.

a. functional analysis - Decision making
b. Human engineering — Ergonomics (information on physical & psychological characteristics)
c. Market and product analysis
d. Specification analysis
e. Strength analysis
f. Economic analysis
g. Model analysis. - properties of product

V. Decision:

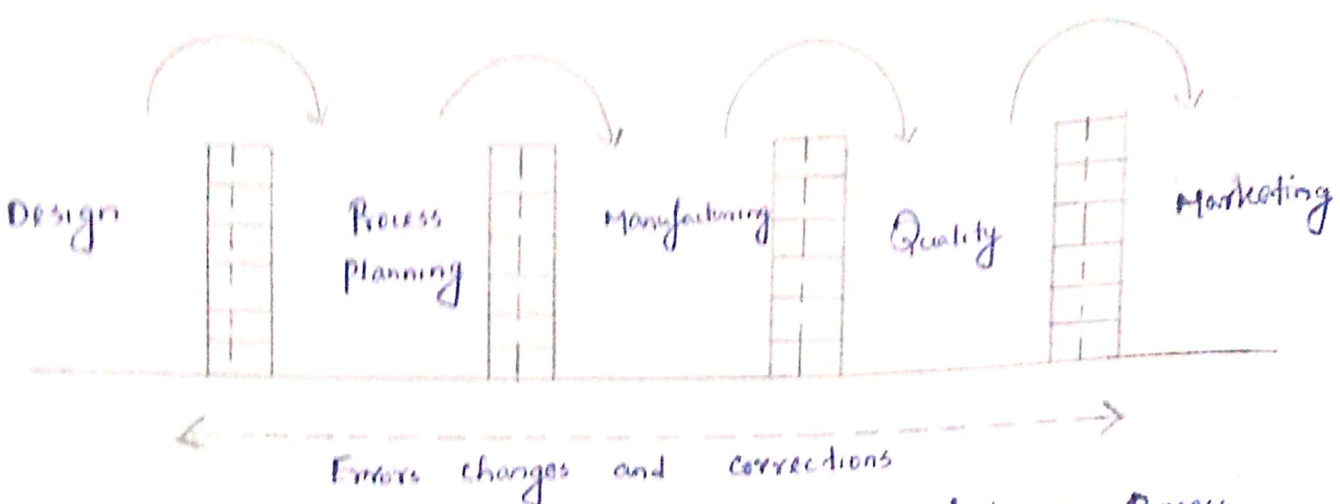
At this stage, a single design is accepted as solution to the design problem. By comparing the cost of manufacturing, weights, operational characteristics and other data final decision will be arrived at the end.

vi. Implementation:

It is the presentation of the final design concept in workable form as working drawings and specifications that can be used for the actual production of product.

1.3. Sequential Engineering:

Three major phases of conventional manufacturing process are design, process planning and manufacturing. All these phases are sequentially carried out.



In design phase of the conventional manufacturing process, the product is designed on the basis of specifications /requirements and methods of manufacturing are decided.

In the process planning phase, manufacturing instructions are given on the basis of method of manufacturing and decoded in the design phase. These instructions are interpreted and Production works are carried out in the manufacturing phase.

All these phases and supporting activities such as quality, testing activities and marketing activities are carried out one after the other.

The other name for sequential approach is "over wall" or "across the wall" approach.

If a serious mistake in the product is detected during the final stage, the revision process has to start from design which may result the materials and loss of time.

Advantages:

1. It is very simple, well-defined method and allows everyone to remain on the same page.
2. It is an enforced-discipline approach.

Disadvantages :

1. As the decisions are taken by individuals, product modifications and changes will be slow.
2. Since each activity is sequentially carried out, this approach requires longer lead time.
3. Because of above reasons, the product quality will be low.

1.4 Concurrent Engineering

In the conventional manufacturing method, both design and manufacturing are separated. Because of this, quality may be lost and design modifications cannot be possible at the last stage of production. Global competition pressurizes the firms to produce products with high performance, reliable and low cost with less lead time.

To achieve this, in the product planning stage itself, a co-opertion work between design and manufacturing and other specialists has to be made. It is known as "concurrent Engineering" or "Simultaneous Engineering" or "Parallel Engineering".

Done at same time →

During a concurrent Engineering production cycle, several teams work on different parts of the design at the same time. This technique is adopted to improve the efficiency of product design and to reduce the product development cycle time.

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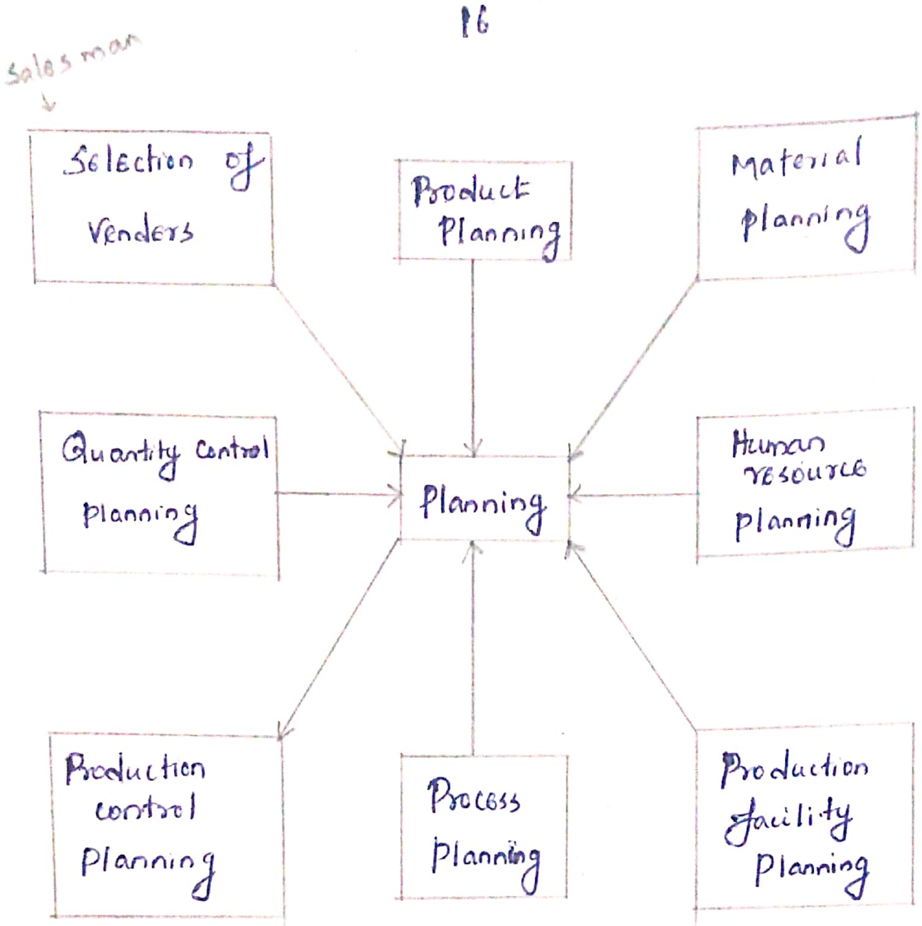

1.4.1. characteristics of concurrent engineering:

1. Product responsibilities lie on the team of multi disciplinary group.
2. Integration of design, process planning and production will be achieved.
3. product lead time will be less because cross-functional activities are started simultaneously.
4. Most of the modification changes are carried out in the planning stage itself.
5. frequent review of design and development process.
6. Rapid Prototyping
7. More attention will be given to satisfy the customer needs and to include newer technologies in the product development.

refer page 56 ↗
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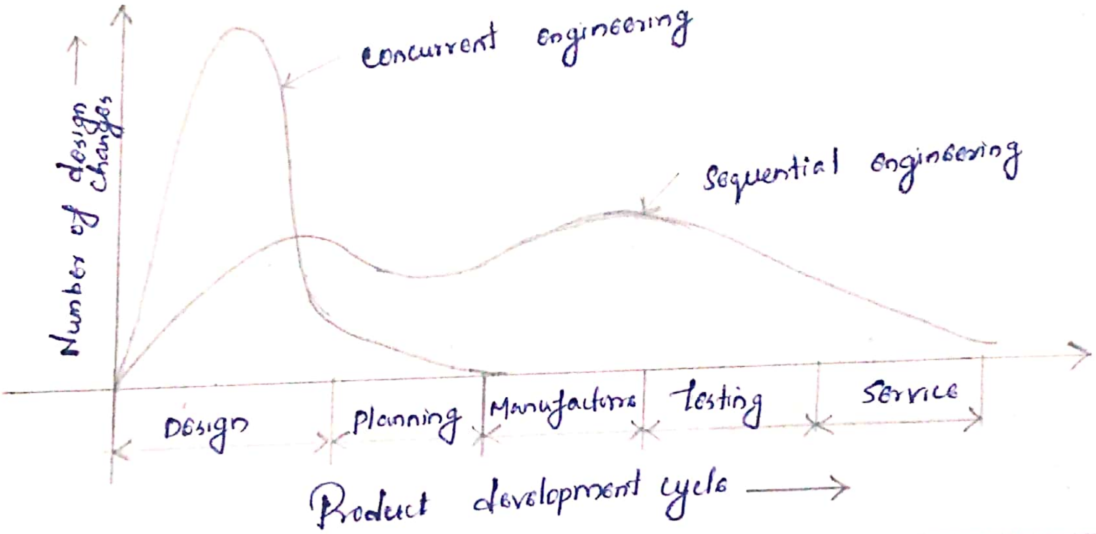
1.4.2: Advantages of concurrent engineering

1. As the design decisions are taken by a team of multi disciplinary experts, changes and modifications on the Product design will be faster
2. It has shorter lead time.
3. It ensures better quality.

1.4.3. Comparison between concurrent engineering and Sequential engineering.



comparison basis	Concurrent Engineering	Sequential Engineering
a. Product development cost	Development cost & Product cost are low	Development & product costs are high.
b. Number of design Changes	Number of changes will be distributed throughout the Product development cycle	Number of changes will be maximum at the beginning of the Product development cycle.
c. Lead time for product development	It Reduces the lead time of product development	The lead time increases considerably.
d. customer Satisfaction	Better customer Satisfaction	customer satisfaction not better.
e. coordination between departments	Better Communication & coordination among various departments.	coordination is Not better than concurrent engineering

1.5 Computer Aided Design:

CAD is the technology concerned with the use of computer systems to assist the creation, modification, analysis and optimization of a design.

CAD may also be defined as the use of information technology in the design process.

1.5.1 Roles of CAD in design:

a. It is accurately generated and easily modifiable graphical representation of the product.

b. It performs the complex design analysis in short time. By implementing FEA methods, the user can perform as follows.

i. static, dynamic & natural frequency analysis
ii. Heat transfer analysis
iii. Plastic analysis
iv. fluid flow analysis v. Motion analysis vi. Tolerance analysis
vii. Design optimization.

c. It records and recalls information with consistency and speed.

1.5.2 CAD Process

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

i. Geometric modeling
ii. Engineering analysis
iii. Design review and evaluation
iv. Automated drafting.

Geometric modeling is classified in to three types
a. wire frame modeling
b. surface modeling c. Solid modeling

Two types of Engineering analysis are
a. Analysis for mass properties
b. FEA

Accuracy check

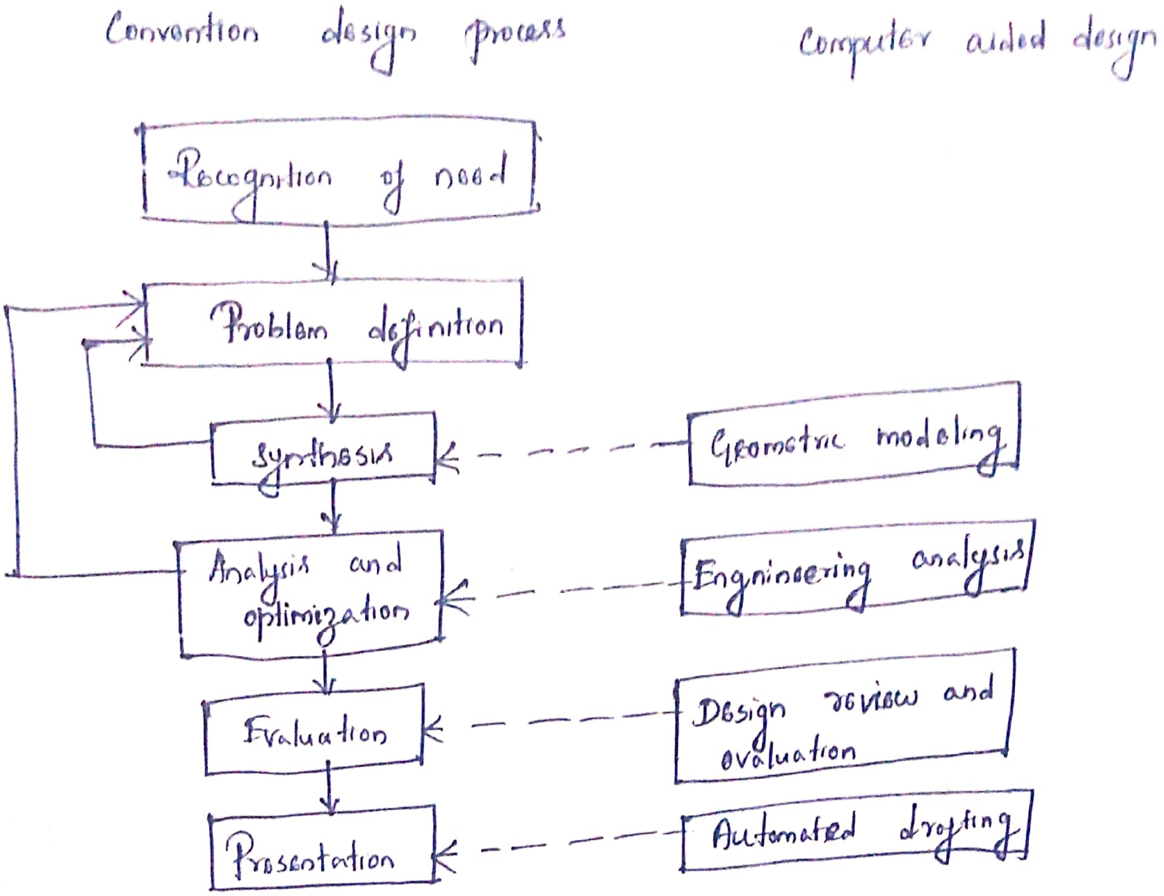
orthographic isometric, perspective view
to CAD

create border insert dim Draw

→ Software
Automatic Dynamic Analysis of mechanical Systems

to surface area weight c.g. etc

Commands used in Geometric modelling
1 Basic geometries points, lines, circles etc
2. Manipulation work such as scaling translation rotation etc
3. Boolen operation to form image of the object in computer screen



1.5.3 Applications of CAD:

i. Mechanical Engineering Sector
Milling , turning , Wire cut EDM , punching .

ii. Civil engineering and architecture sector:
Simple building design to large scale projects, interior design , static and dynamic analysis .

iii. Electrical and Electronics Engineering:
Printed circuit board
Design activities such as electric motor , PCB design, IC design .

iv. The apparel industry:
cloth
systems for clothing using specialized equipment such as large plotters , cutters for patterns and automatic machines for cutting the fabrics

Simulation of any given physical phenomenon using the numerical technique called FEA

practical
Prototype

1.5.4 Advantages of CAD:

i. Easy editing and modification
ii. Copies of the same drawing can be duplicated without sacrificing image quality.
iii. High quality
iv. Drawings can be plotted quickly in different scales and colours.
v. Information about length, area, perimeter, volume, mass are calculated easily.
vi. Compact storage: Drawings can be stored in CDs, DVDs or hard disks.
vii. 3-D drawings can be seen from any viewpoint for better visualization.
viii. Commonly used components & symbols can be pre-stored in graphic library.

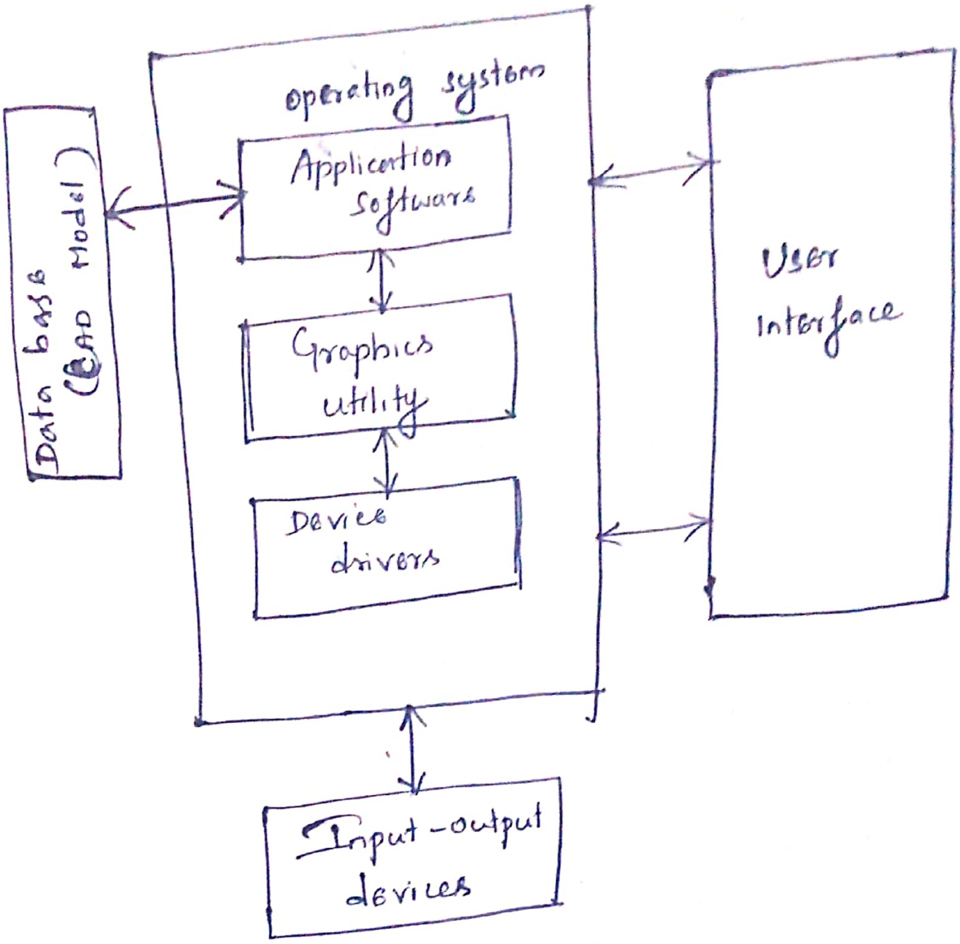
1.6 CAD system architecture:

The architecture of CAD system consists of four major components such as database, operating system, input-output devices and user interface.

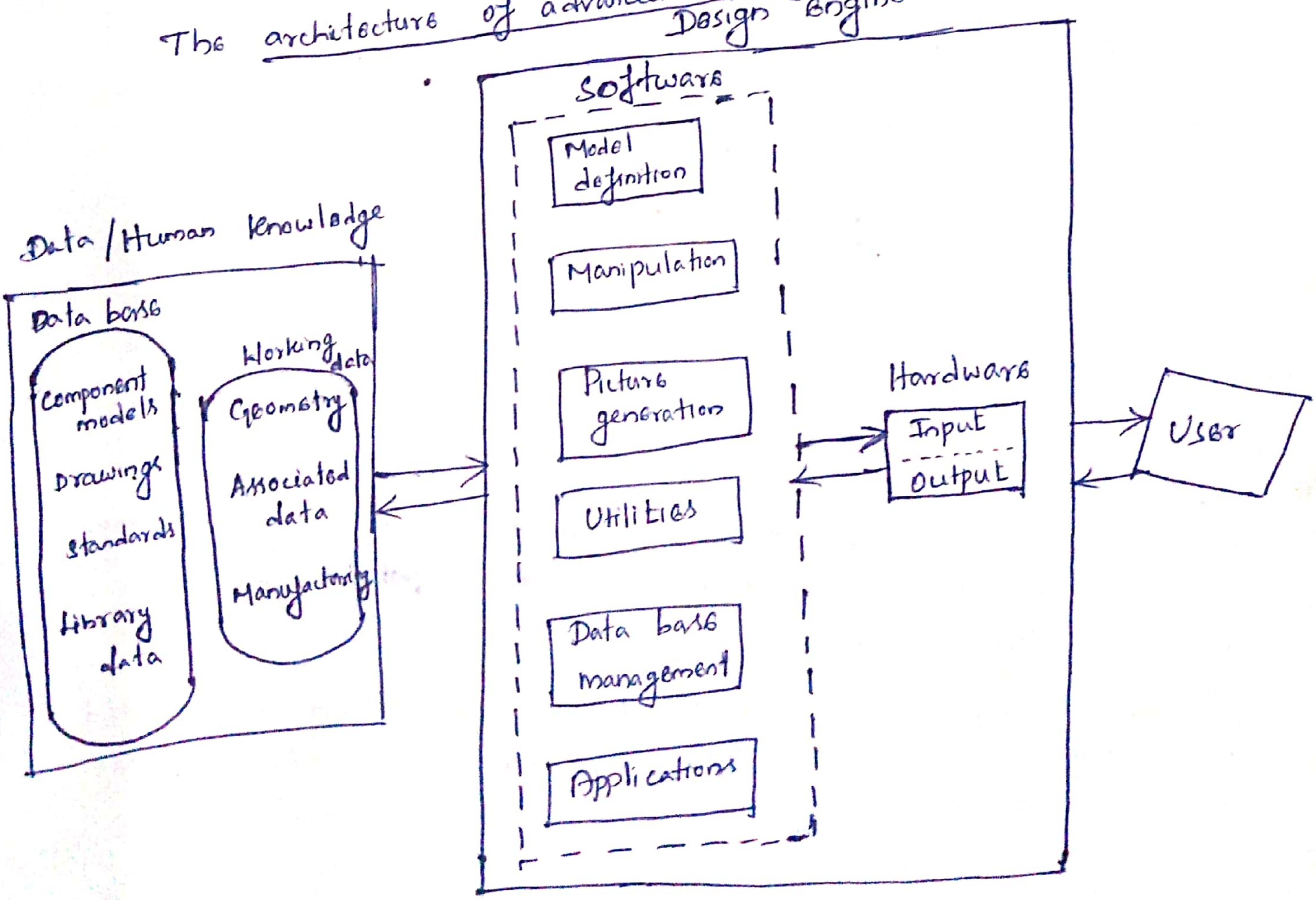
Database composed of CAD component models, drawings, standards and library data.

The working data of the CAD system comprises of geometry of the drawings, associated data and manufacturing data. The database and working data together are called data / human knowledge.

Basic architecture of CAD system



The architecture of advanced CAD system



1.7 Computer Graphics:

It is the technology which uses the display of the drawing or the geometric model of the component in CAD. computer graphics may be defined as the process of creation, storage and manipulation of drawings and pictures with the aid of a computer.

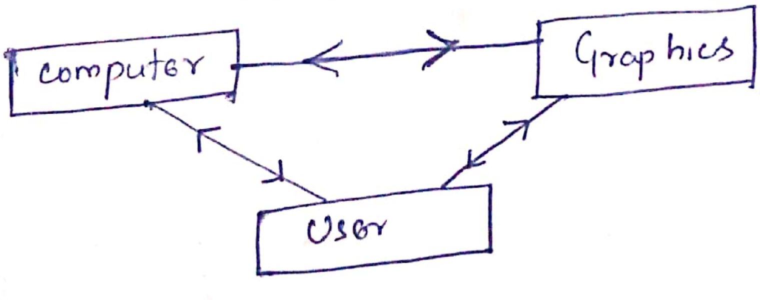
There are two types of computer graphics:

1. Passive computer graphics
2. Interactive computer graphics.

In passive computer graphics, the user has no control over the images occured in display device. The graphic images can be watched.

In interactive computer graphics (ICG), the user may interact with the graphics and the program generating them. The user can create, edit and modify the images according to his needs.

Concepts of IGC



Functions of the IGC

i. Modeling: It is the process of creating an object in the computer by using basic primitives such as points, lines, arc, circle, edges, areas, surfaces and volumes.

ii. Storage: It means that the process of storing the created data i.e. Model in the memory of the computer.

iii. Manipulation: It is used in the construction of model from basic primitives in combination with Boolean algebra.

iv. Viewing: It refers the looking of the model in various angles, Zooming, orthographic and isometric views.

1.7.1 Advantages of computer graphics:

i. The object drawings can be denoted by its geometric model in three dimensions, i.e x, y & z coordinates.

ii. Various views of the object such as orthographic, isometric, axonometric or perspective projections can be easily created.

iii. Accurate drawings can be made.

iv. Sectional drawings can be easily created.

v. Modification of geometric model of objects is easy.

vi. It is easy storage and retrieval of drawings.

vii. Drawings can be reused as per our convenience.

1.7.2 Applications of computer graphics:

i. Paint programs

ii. Illustration/Design programs.

iii. presentation graphics software

iv. Animation software.

v. CAD software

vi. Desktop publishing

vii. Education & Training

viii. Image processing

1.8 Coordinate systems in Computer graphics:

In general, there are two types of coordinate systems such as cartesian coordinate system and polar coordinate system. In cartesian coordinate system, the axes are represented by linear distances x, y & Z whereas Polar coordinate system uses angles such as θ, α & ϕ.

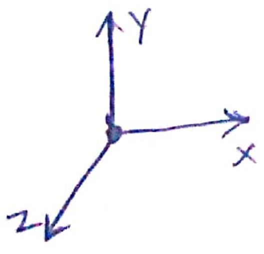
In 2-D coordinate system, X axis is generally pointed from left to right and Y axis is from bottom to up. When the third coordinate Z is added, it refers a 3-D coordinate system.

1.8.1: Left & Right handed coordinate systems.

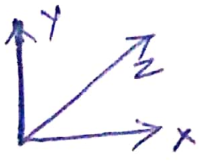
In 3-D coordinate system the three axes are understood to be at right angles to each other. X denotes the horizontal axis, Y refers vertical axis and Z axis is for the depth.

It is the usual right-handed coordinate system seen in computer graphics.

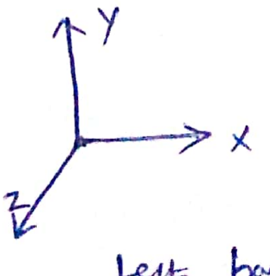
In right handed coordinate system, since if you place your thumb, index finger and middle finger of the right hand at right angles to each other. The thumb represents the x axis, the index finger represents the Y axis and the middle finger represents the Z axis.



3D



Right hand



Left hand

1.8.2: Multiple coordinate systems:

i. World coordinate system:

ii. object coordinate system

iii. Hierarchical coordinate system

iv. View point coordinate system

v. Model window coordinate system

vi. Screen coordinate system

vii. View port coordinate system.

1.9: Transformations:

It converts the geometry from one coordinate system to the other coordinate system. By means of transformation, the images can be enlarged in size or reduced, rotated or moved on the screen.

Typical CAD commands to translate, rotate, zoom and mirror entities are based on geometric transformations.

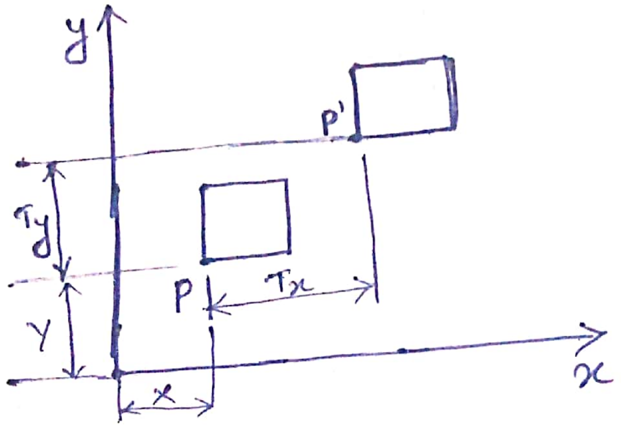
Two dimensional (2D) Transformation:

The main types of 2D transformations are

1. translation
2. Scaling
3. Reflection
4. Rotation
5. Shearing

1. Translation:

It is the movement of an object from one position to another position. It is accomplished by adding the distance to the co-ordinates through which the drawing is to be moved to the coordinates of each corner point.



The new coordinate after transformation is given by the following equation:

$P' = [x', y']$

$x' = x + T_x$

$y' = y + T_y$

$P' = [x + T_x , y + T_y]$

$= [x \; y] + [T_x \; T_y]$

In matrix form

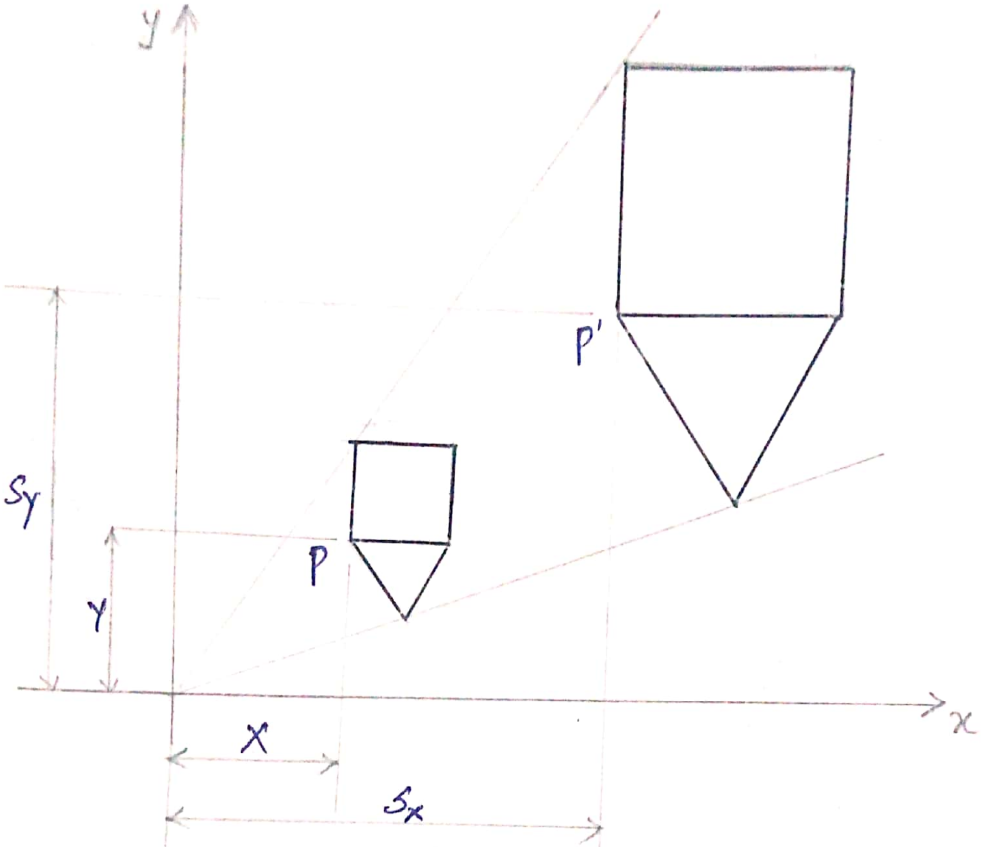
$$[P'] = [x' \; y' \; 1]$$

$$= [x \; y \; 1] \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ T_x & T_y & 1 \end{bmatrix}$$

$P' = P.T$ T = translation matrix

2. Scaling:

It is the transformation applied to change the scale of an entity. It is done by increasing the distance between points of the drawing. It means that it can be done by multiplying the coordinates of the drawing by an enlargement or reduction factor called scaling factor.



The new coordinates after scaling are given by the following eqn:

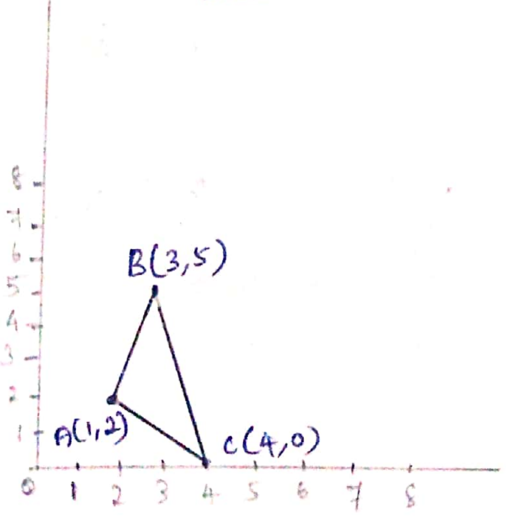
$$P' = [x', y'] = [S_x \times X, S_y \times Y]$$

Matrix form

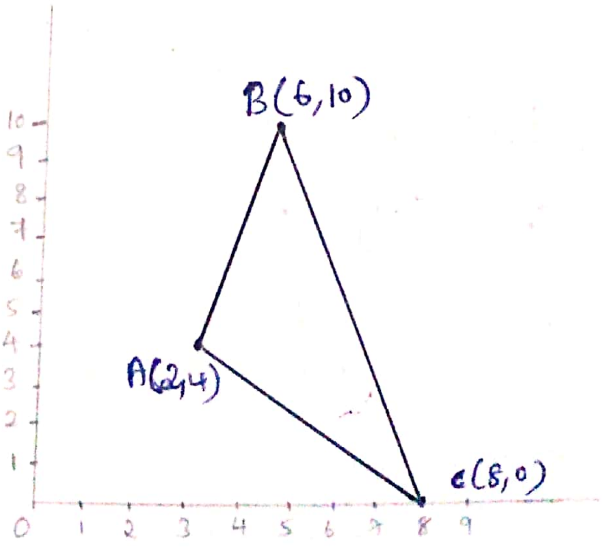
$$[P'] = \begin{bmatrix} S_x & 0 \\ 0 & S_y \end{bmatrix} \begin{bmatrix} X \\ Y \end{bmatrix} = [S]\,[P]$$

$$[S] = \begin{bmatrix} S_x & 0 \\ 0 & S_y \end{bmatrix} = \text{Scaling matrix}$$

Triangle before scaling



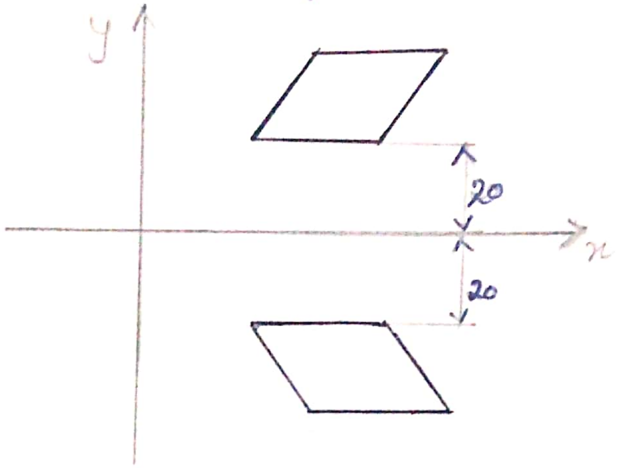
After scaling



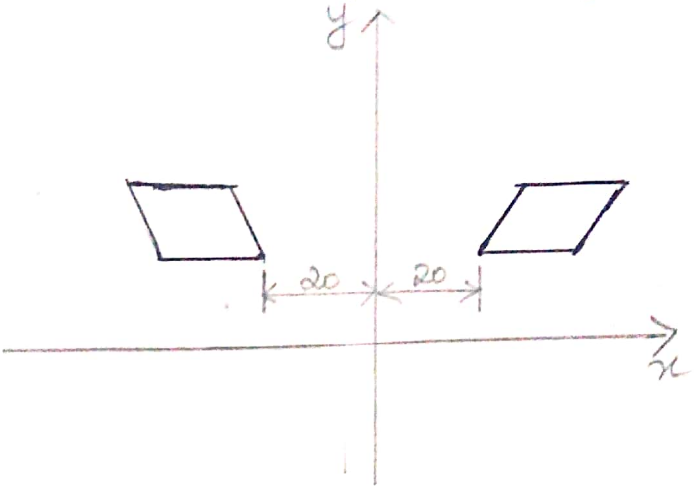
3. **Reflection:**

Reflection or mirror transformation is useful in constructing symmetric models.

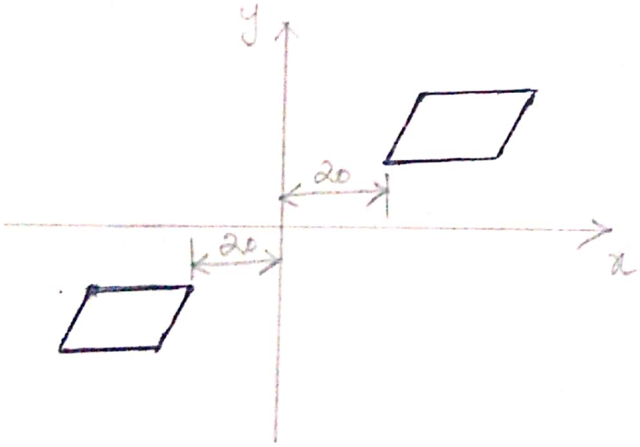
a. Reflection about X-axis



b. Reflection about Y-axis



c. Reflection about origin



for getting reflection about X axis

$P' = [x', y'] = [x, -y]$

Matrix form:

$$[P'] = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

$$[P'] = [M_x][P]$$

Reflection matrix $M_x = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix}$

for getting reflection about Y-axis

$$[P'] = \begin{bmatrix} -1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

$$[P'] = [M_y][P]$$

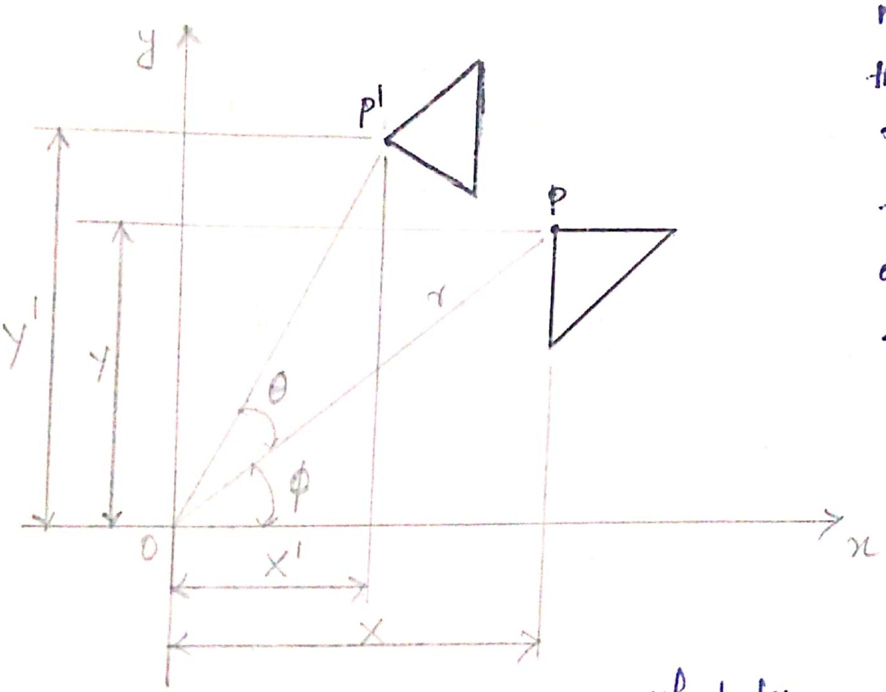
$$M_y = \begin{bmatrix} -1 & 0 \\ 0 & 1 \end{bmatrix}$$

for getting reflection about X & Y axes [(i.e) origin], both the values are negative.

$$[P'] = \begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix} [P]$$

4. Rotation:

The drawing is rotated about a fixed point. The final position and orientation of geometry is decided by the angle of rotation (θ) and the base point about which the rotation is to be done.



To develop the transformation matrix, consider a point P as the object in XY plane, being rotated anticlockwise direction to the new position P' by an angle θ.

The new position P' is given by

$$P' = [x', y']$$

The original position is specified by

$$X = r \cos\phi$$

$$Y = r \sin\phi$$

The new position P' is specified by

$$X' = r \cos \overset{(\theta+\phi)}{\cancel{(\phi+\theta)}}$$

$$= r\cos\theta\cos\phi - r\sin\theta\sin\phi$$

~~$= x\cos\theta - y\sin$~~

$$= x\cos\theta - y\sin\theta$$

$$y' = r \sin \overset{(\theta+\phi)}{\cancel{(\phi+\theta)}}$$

$$= r\sin\theta\cos\phi + r\cos\theta\sin\phi$$

$$= x\sin\theta + y\cos\theta$$

$\cos(A+B) = \cos A.\cos B - \sin A.\sin B$

$r\cos\phi = x$

$r\sin\phi = y$

$\sin(A+B) = \sin A\cos B + \cos A\sin B$

Matrix form:

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

$$[P'] = [R].[P]$$

$$[R] = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix} = \text{Rotation matrix}$$

5. **Shearing:**

It produces distortion of an object or an entire image.

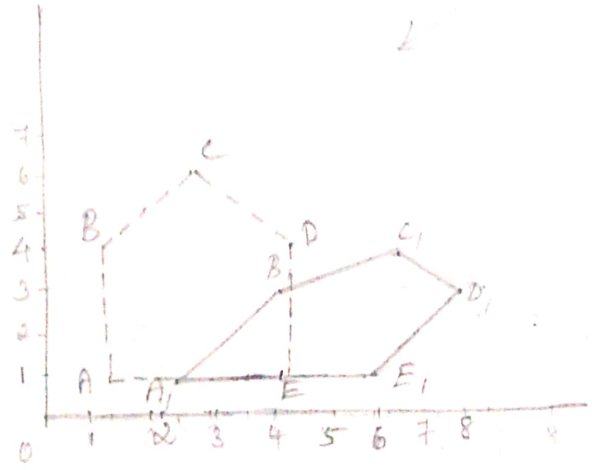
a. X-shear

b. Y-shear

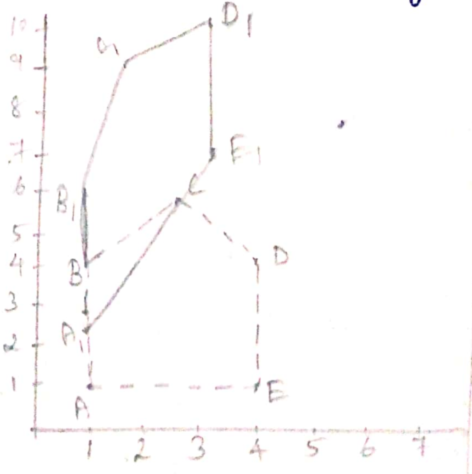
A X-shear ~~the~~ transforms the point (x, y) to (x', y') by a shear factor S_{hx}, where

$$x' = x - S_{hx}\, y$$
$$y' = y$$

X-shear applied to a base drawing A-B-C-D-E. The entity A_1-B_1-C_1-D_1-E_1 represents X-sheared drawing



X shear transformation



Y-shear transformation

A Y-shear transforms the point (x, y) to (x', y') by a shear factor ~~of~~ S_{hy}, where

$$x' = x \qquad y' = S_{hy}\, x + y$$

Y shear applied to a base drawing represented by A-B-C-D-E. The entity A_1-B_1-C_1-D_1-E_1 represents the Y-sheared drawing.

1.10 Homogeneous coordinates:

Homogeneous co-ordinates are another way to represent the points to simplify the way in which affine transformations are expressed. It unify translation, rotation & Scaling in one transformation matrix.

The basic transformation process can be expressed by the generalised matrix form

$$p' = P.M_1 + M_2$$

i. for translation:

$$P' = P.\begin{bmatrix}1 & 0\\ 0 & 1\end{bmatrix} + \begin{bmatrix}T_x\\ T_y\end{bmatrix}$$

M_1 = Identity matrix or unit matrix which is denoted by T

M_2 = Translation matrix

ii. for rotation:

$$P' = P.\begin{bmatrix}\cos\theta & \sin\theta\\ -\sin\theta & \cos\theta\end{bmatrix} + \begin{bmatrix}0\\ 0\end{bmatrix}$$

M_1 = Rotational matrix which is denoted by R

$M_2 = 0$

iii. for scaling:

$$P' = P.\begin{bmatrix}S_x & 0\\ 0 & S_y\end{bmatrix} + \begin{bmatrix}0\\ 0\end{bmatrix}$$

M_1 = Scaling matrix which is denoted by S

$M_2 = 0$

1.14: Homogeneous transformation:

The conversion of a 2D coordinate pair (x, y) into a 3D vector can be achieved by representing point $a[x\ y\ 1]$. After multiplying this vector by a 3×3 matrix another homogeneous row vector is obtained $[x_1\ y_1\ 1]$. This three dimensional representation of a two dimensional plane is called homogeneous representation and the transformation using the homogeneous representation is called homogeneous transformation.

i. Translation:

$$T = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ T_x & T_y & 1 \end{bmatrix}$$

$$[x_1\ y_1\ 1] = [x\ y\ 1] \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ T_x & T_y & 1 \end{bmatrix}$$

ii. Rotation:

$$R = \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$[x_1\ y_1\ 1] = [x\ y\ 1] \begin{bmatrix} \cos\theta & \sin\theta & 0 \\ -\sin\theta & \cos\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

iii. Scaling:

$$S = \begin{bmatrix} S_x & 0 & 0 \\ 0 & S_y & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$[x_1\ y_1\ 1] = [x\ y\ 1] = \begin{bmatrix} S_x & 0 & 0 \\ 0 & S_y & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

iv. Shearing: x-shear $[x_1\ y_1\ 1] = [x\ y\ 1] \begin{bmatrix} 1 & 0 & 0 \\ Sh_x & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$

y-shear $[x_1\ y_1\ 1] = [x\ y\ 1] \begin{bmatrix} 1 & Sh_y & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix}$

1.12 Line Drawing:

Straight line forms the basis for the display of all types of shapes in computer graphics.

The following are the requirements for drawing lines.

i. Lines should appear straight

ii. Lines should terminate accurately

iii. Lines should have constant density / brightness.

iv. Lines density should be independent of length and angle.

v. Line should be drawn rapidly.

A straight line is to be drawn from point $P_1 (x_1, y_1)$ to Point $P_2 (x_2, y_2)$.

1.12.1 Digital Differential Analyzer (DDA) Algorithm.

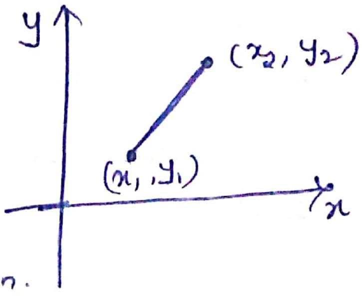
The DDA generates lines from their differential equations. In DDA, the equation of a line is expressed as a pair of parametric equations. For a line segment joining two points P_1 & P_2, a parametric representation is given by

$$P(u) = P_1 + (P_2 - P_1)\, u \qquad 0 \leq t \leq 1$$

Since $P(u)$ is a position vector, each of the components of $P(u)$ has a parametric representation $x(u)$ & $y(u)$ between P_1 & P_2.

$$\therefore \quad x(u) = x_1 + (x_2 - x_1)\, u$$

$$y(u) = y_1 + (y_2 - y_1)\, u$$



Advantages of DDA Algorithm:

1. It is the simplest algorithm and it does not need special skills for implementation.
2. It is a faster method to calculate pixel positions than the direct use of straight line equation which is given by $y = mx + c$.

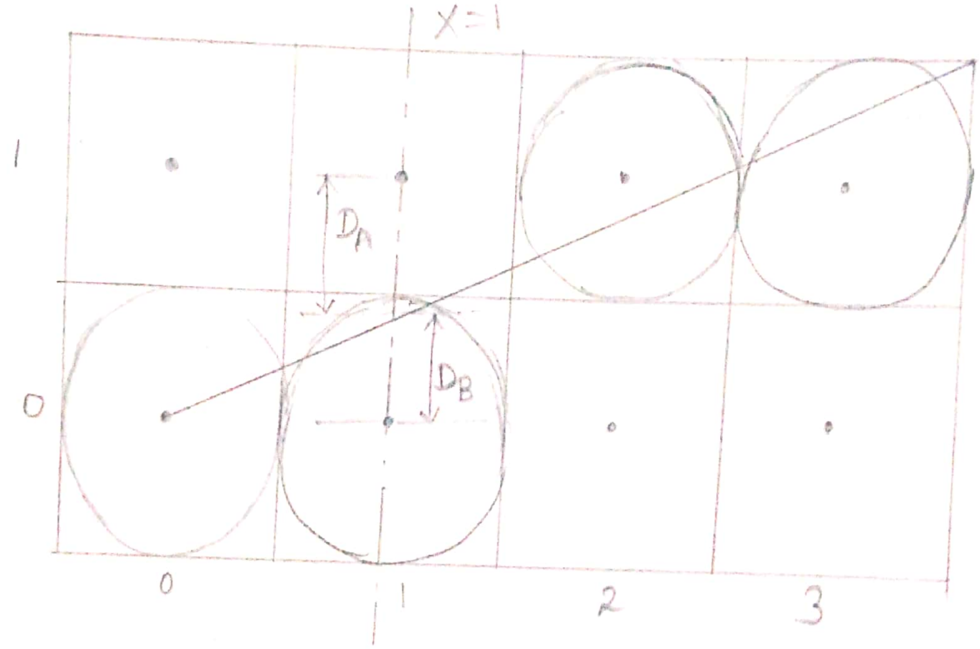
Disadvantages:

1. Floating point arithmetic in DDA algorithm is still time consuming.
2. The algorithm is orientation dependent. ∴ end point accuracy is poor.

1.12.2: Bresenham's line Algorithm:

It is an improvement over DDA algorithm as it completely eliminates the floating point arithmetic except for initial computations. The disadvantages of DDA line drawing algorithm are eliminated by Bresenham's line algorithm.

The basic principle of Bresenham's line algorithm is to select the optimum raster locations to represent a straight line.



D_A = Distance above D_B = Distance below

To achieve optimum raster scan, the algorithm always increments either x or y by one unit depending on the slope of line. The increment in the other variable is determined by examining the distance between the actual line location and the nearest pixel. This distance is called decision variable or error.

In mathematical terms, a decision variable or error is defined as $\boxed{e = d_b - d_a}$ ~~or~~ If $e > 0$ it means that $d_b > d_a$ i.e. the pixel above the line is closer to the true line.

If $e < 0$, it means that $d_b < d_a$ i.e, the pixel below the line is closer to the true line.

The error term is initially set as

$\boxed{e = 2\Delta y - \Delta x}$ where $\Delta y = y_2 - y_1$

$\Delta x = x_2 - x_1$

- when $e \geq 0$, error is initialized with $\boxed{e_{new} = e + 2\Delta y - 2\Delta x}$

It is continued till error is negative

x and y are incremented by 1.

- when $e < 0$, error is initialized with $\boxed{e_{new} = e + 2\Delta y}$. In this case, only x is incremented by 1.

1.13 : Clipping :

It is the process of determining the visible portion of a drawing lying within a window and discarding the rest.

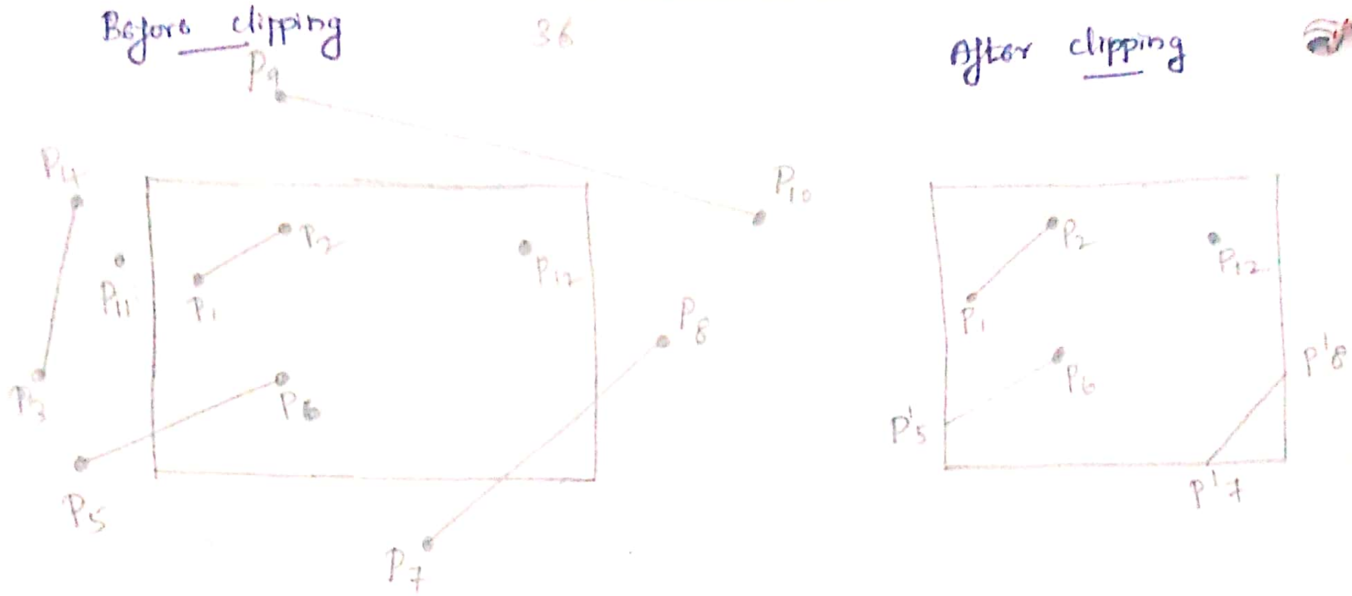
In clipping process, each graphic elements of the display is examined whether it is completely inside the window or completely outside the window or crosses a window boundary.

Portions outside the boundary are not drawn.

In addition to extraction of part of the drawing for viewing, clipping is used in the following applications.

- Identifying visible surfaces in 3D views.
- Displaying multi-window environment.
- Antialiasing line segments or object boundaries
- Creating objects using solid-modeling procedures.
- Drawing and painting operations.

The region against which an object is to be clipped is called clip window or clipping window.



1.13.1. Point clipping:

Assuming that the clip window is a rectangle in standard position, the points are said to be interior to the clipping window

$$x_{w\,min} \le x \le x_{w\,max}$$

$$y_{w\,min} \le y \le y_{w\,max}$$

1.13.2. Line clipping:

for a line segment with endpoints (x_1, y_1) and (x_2, y_2) and one or both end points outside the clipping rectangle, the parametric representation is given by

$$x = x_1 + u(x_1 - x_2)$$

$$y = y_1 + u(y_2 - y_1) \qquad \text{where } 0 \le u \le 1$$

Cohen-sutherland clipping algorithm:

It is one of the oldest and most popular line-clipping algorithms. It quickly detects and dispenses with two common and simple cases.

In this method, all lines are classified to see if they are in, out or partially inside the clipping window by doing an edge test.

The end points of the line in a picture are assigned a four-digit binary code called a region code.

The code is given as TBRL.

The code is identified as follows:

If the point is above top of the window T=1, otherwise T=0

If the point is above the bottom of the window B=1, or B=0

If the point is above the right of the window R=1, or R=0

If the point is above the left of the window L=1, or L=0

where T= top, B= Bottom, R= Right & L= Left.

TBRL code for nine regions

1001	1000	1010
0001	0000 window	0010
0101	0100	0110

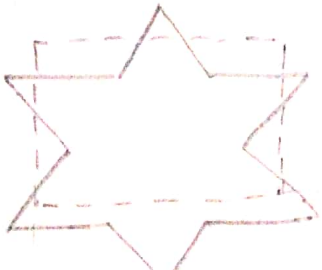
1.13.3: Polygon clipping:

A polygon is the collection of lines. ∴ the line clipping algorithm can be used directly for polygon clipping.

A polygon can be clipped by processing its boundary as a whole against each window edge. It is accomplished by processing all polygon vertices against each clip rectangle boundary one after the other.

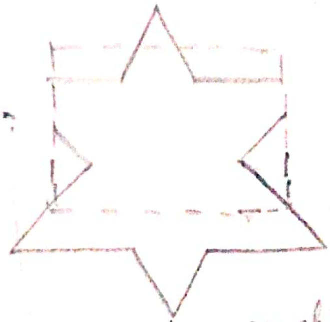
Sutherland - Hodgoman polygon clipping algorithm:

There are four possible cases when processing vertices in the sequence around the perimeter of a Polygon as follows.

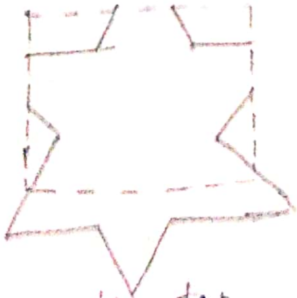


Before clipping

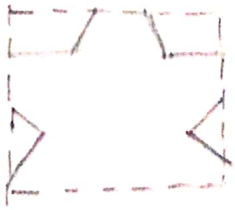
clip left



clip right



clip top

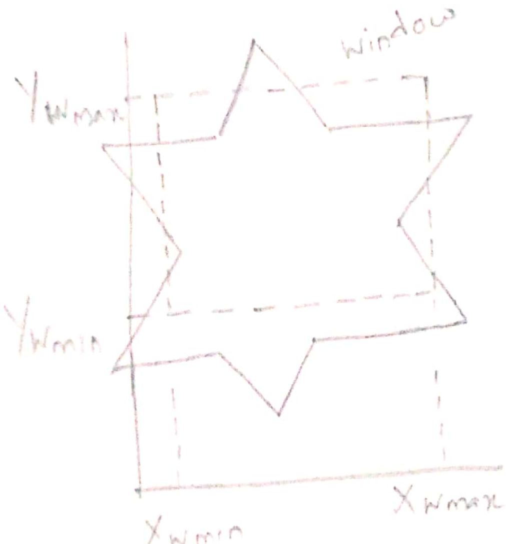


clip bottom

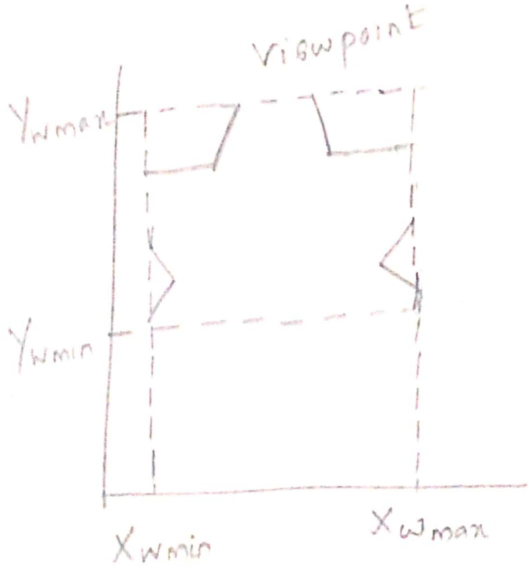
1.14: Viewing Transformation:

Displaying an image of a picture in mapping the coordinates of the picture into the appropriate coordinates on the device where the image is to be displayed. It is done through the use of coordinate transformations known as viewing transformation.

In general the mapping of a part of a world-coordinate ~~Scene~~ Scene to device coordinates is referred as a viewing transformation.



world coordinates



Device coordinates

a. Nord coordinate system (WCS):

WCS describes the picture to be displayed with coordinates.

b. Physical device coordinate system (PDCS):

PDCS is corresponds to a device where the image of Particular is to be displayed.

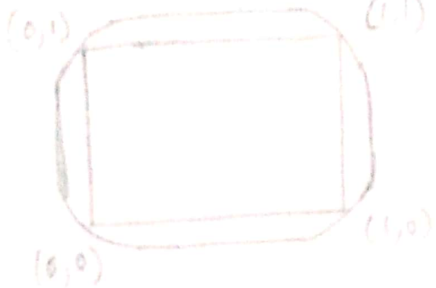
c. Normalized device coordinate system (NDCS)

NDCS is one of the coordinate systems in which display area of virtual display device is to unit (1x1) Square whose lower left corner is at origin of the coordinate system.

The viewing transformation is performed by the following transformations.

1. Normalized transformation (N) which maps Word coordinate system (WCS) to Normalized Device coordinate system (NDCS).
2. Workstation transformation (W) which maps Normalized Device coordinate system (NDCS) to physical Device coordinate system (PDCS).

Normalized transformation:



The interpreter uses a simple linear formula to convert the normalized device coordinates to actual device coordinates

$$x = x_n \times X_w$$

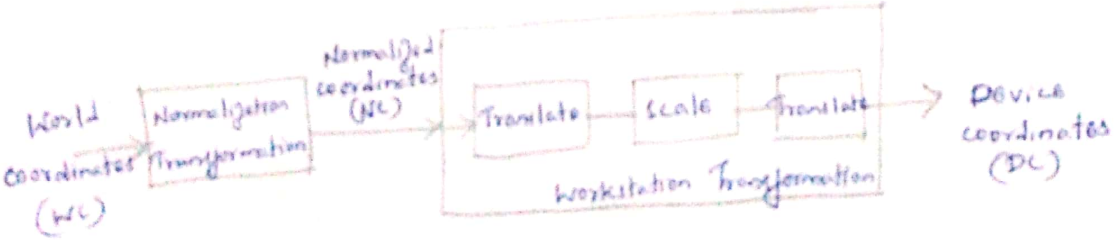
$$y = y_n \times Y_H$$

$x \rightarrow$ actual device x coordinates
$y \rightarrow$ actual device y "
$x_n \rightarrow$ normalized x "
$y_n \rightarrow$ normalized y "
$X_w \rightarrow$ width of actual screen in pixels
Y_H - Height of actual screen in pixels.

Workstation transformation:

The workstation transformations given by

$$V = W . N$$



$$V = T . S . T^{-1}$$

$$T = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -x_{wmin} & -y_{wmin} & 1 \end{bmatrix} \quad S = \begin{bmatrix} S_x & 0 & 0 \\ 0 & S_y & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$S_x = \frac{x_{v\,max} - x_{v\,min}}{x_{w\,max} - x_{w\,min}} \qquad S_y = \frac{y_{v\,max} - y_{v\,min}}{y_{w\,max} - y_{w\,min}}$$

$$T^{-1} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ x_{v\,min} & y_{v\,min} & 1 \end{bmatrix}$$

$$V = T \cdot S \cdot T^{-1}$$

$$T \cdot S \cdot T^{-1} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -x_{w\,min} & -y_{w\,min} & 1 \end{bmatrix} \begin{bmatrix} S_x & 0 & 0 \\ 0 & S_y & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ x_{v\,min} & y_{v\,min} & 1 \end{bmatrix}$$

$$= \begin{bmatrix} S_x & 0 & 0 \\ 0 & S_y & 0 \\ x_{v\,min} - x_{w\,min} \cdot S_x & y_{v\,min} - y_{w\,min} \cdot S_y & 1 \end{bmatrix}$$

1.15 Computer Aided Manufacturing (CAM)

CAM may be defined as an effective use of computers and computer technology in the planning management and control of the manufacturing function.

Application of CAM

1. Manufacturing planning
2. Manufacturing control

1.16 Manufacturing planning

The manufacturing planning applications of CAM are those in which computers are used indirectly to support the production function but there is no direct connection b/n the computer and the process.

The important manufacturing planning applications of CAM includes:

i. Computer-aided process planning (CAPP)
ii. computer-assisted NC part programming
iii. Computerised machinability data systems.
iv. Development of work standards.
v. Cost estimating.
vi. Production and inventory planning
vii. Computer-aided line balancing.

i. Computer-Aided process planning (CAPP)

Process planning is an act of preparing a detailed work instructions for the manufacture and assembly of components into a finished production in discrete part manufacturing environments

Process planning consists of:

a. the selection of manufacturing processes and operations, Production equipment, tooling and jigs and fixtures.
b. the determination of manufacturing parameters
c. the specification of selection criteria for the quality assurance (QA) methods to ensure product quality.

The two basic approaches or types of CAPP system are:

a. Retrieval (or Variant) CAPP system
b. Generative CAPP system.

ii. Computer-Assisted NC part programming:

Numerical control part programming is the planned and documented procedure by which the sequence of processing steps to be performed on the NC machine.

the part program is denoted by a symbol (%) which defines the sequence of the machining operations and collection of the data such as spindle speed, feed rate, tool path, etc. required to produce the ~~collection~~ part.

Types of part programming:

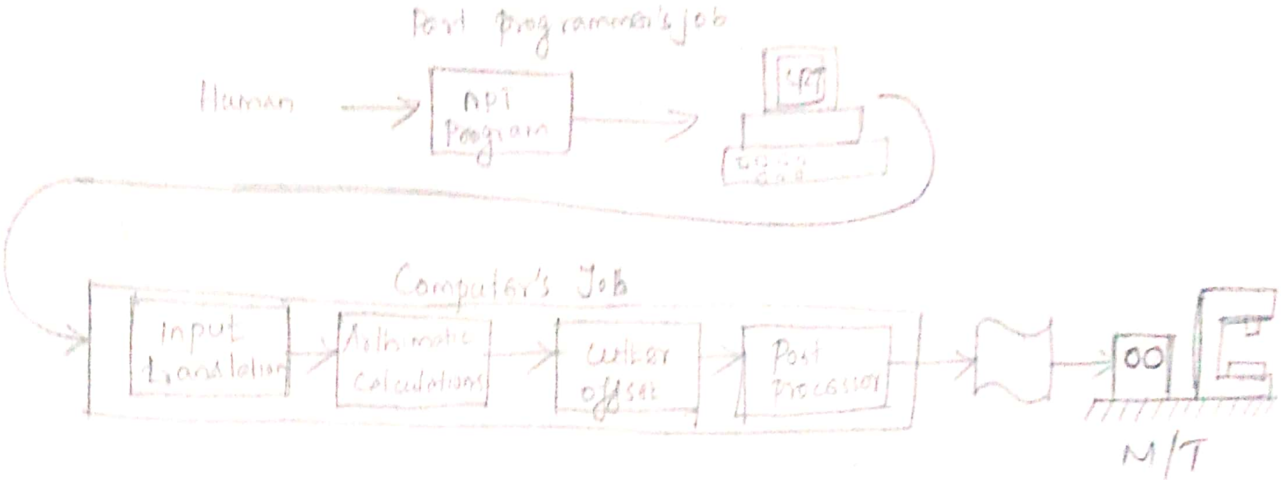
1. Manual part programming
2. Computer-assisted part programming.

In manual part programming, the programmer writes the machining instructions of the part diagram on a special form called part program manuscripts.

In computer-assisted part programming, computers are employed to assist in the part programming process, especially for complex part geometries.

4/14

Steps in computer-assisted part programming



iii. Computerized machinability data system.

Computer program have been written to recommended the appropriate cutting parameters such as speed, feed, depth of cut to use for different materials.

A computerized data system has the following advantages over a book type data bank.

a. It can store data from different sources
b. It can use shop parameters instead of theoretical and general data
c. The data base can be kept up to date.
d. Fast retrieval of selected data is possible
e. Comparison of alternative cutting conditions is easy.

iv. Computerized work standards:

Computer packages that can be employed to determine time standards for direct labour jobs in the factory.

The computerized systems are based on the use of standard data of basic work elements stored in computer either in a data file or in the form of a mathematical formulae.

Advantages of using computerized system for engineering time standards are:

i. Reduction in time required to set the standard.
ii. Greater accuracy and uniformity in the time standards
iii. Ease of maintaining the methods and standard file
iv. Settling the time standards before the job gets into production.

V. Cost Estimating

It is the process of determining the probable cost of the product before the start of its manufacture.

Computerized cost estimating is a program that can estimate the cost of a new product, by computerizing several of the key steps required to prepare the estimate.

Thus the total cost for a new product can be estimated by the computer program by summing up the individual component costs from the engineering bill of materials.

Vi. Production and Inventory planning

Production planning is a pre-production activity. It is the pre-determination of manufacturing requirements such as manpower, materials, machines & manufacturing process.

Production planning is concerned with:

i. deciding which products to make, how many of each, and when they should be completed.
ii. Scheduling the production and delivery of the parts & products.
iii. Planning the manpower and equipment resources needed to accomplish the production plan.

Production planning activities includes:

1. Aggregate production planning
2. Master production schedule (MPS)
3. Material requirements planning (MRP)
4. Capacity planning &
5. Inventory planning.

vii. Computer - Aided line balancing:

Line balancing problem is concerned with assigning the individual work elements to workstations so that all workers have an equal amount of work.

Computer-aided line balancing program ~~helps~~ helps to find the best allocation of work elements among stations on an assembly line.

1.17 Manufacturing control

The manufacturing control applications of CAM are concerned with developing computer systems for implementing the manufacturing control function.

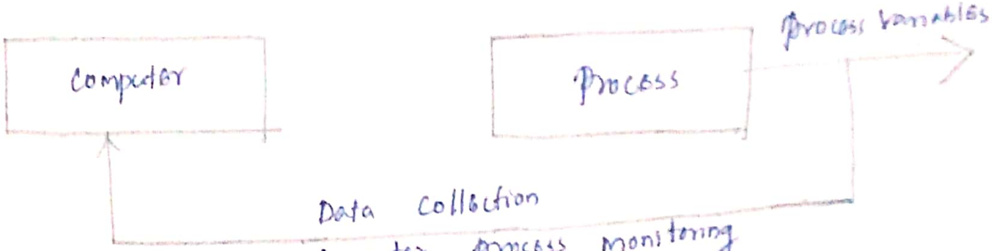
Manufacturing control is concerned with managing & controlling the physical operations in the factory.

The important manufacturing control applications of CAM includes:

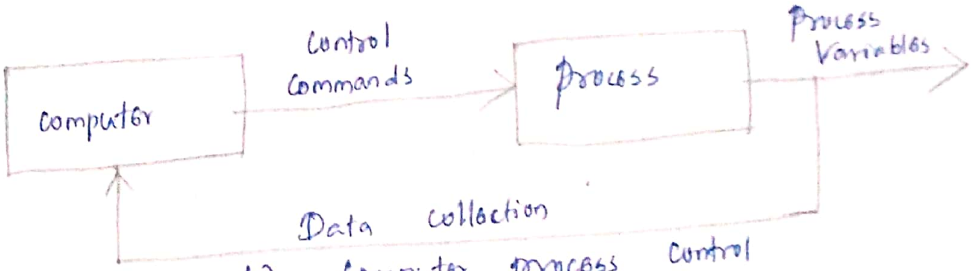
i. Process monitoring and control
ii. Quality control
iii. Shop floor control
iv. Inventory control
v. Just-in-time production systems.

1. Process Monitoring & control

a. Computer process monitoring and control is the use of a Stored program digital computer to monitor and control and Industrial process.



a) Computer process monitoring



b) Computer process control

Three important topics related to the technology & applications of automated data collection system for computer process monitoring are:

1. Data acquisition systems
2. Data logging system.
3. Multilevel scanning.

Computer Process control is a process of controlling the controllable input variables with the use of computers so as to achieve the desired performance evaluation variables.

The important process control strategies are:

1. feed back control strategy
2. Regulatory " "
3. Feed forward " "
4. Preplanned " "
5. Steady - state optimal " "
6. Adaptive control strategy

2. Quality control

Modern technologies in quality control are

a. Quality engineering
b. Quality function deployment
c. 100% automated inspection
d. On-line inspection.
e. Coordinate measurement machines for dimensional measurements.
f Non-contact sensors such as machine vision for inspection.

3. Shop Floor control

SFC system is defined as a system for utilizing data from the shop floor as well as data processing files to maintain and communicate status information on shop orders and work centre.

SFC is concerned with:

i. The release of production orders to the factory.
ii. Monitoring & controlling the progress of the orders through the various work centres
iii. acquiring information on the status of the orders.

4. Inventory control:

It is the scientific method of determining what to order, when to order and how much to order and how much to stock so that costs associated with buying and storing are optimal without interrupting production and sales.

Two types of inventory models are:

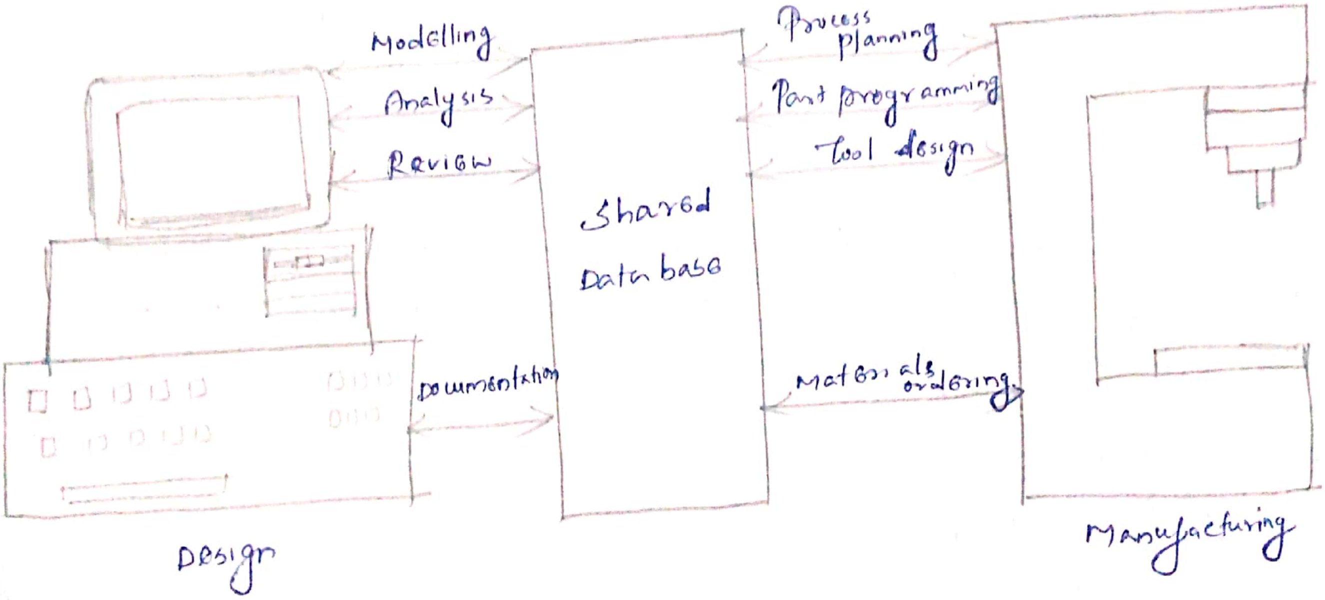
i. Fixed-order quantity models (Q-models)
ii Fixed - time period models (P-models).

5. Just-in-time production systems

JIT is a management philosophy that strives to Eliminate sources of manufacturing waste by producing the right Part in the right time. JIT is also known as stockless production.

JIT Production system produces and delivers only the required items, at the required time and in the required quantities.

1.18: CAD/CAM concepts



1.19: Types of production

According to volume and standardisation of the production of the products, the production systems are classified as.

1. Job shop production
2. Batch production
3. Mass production
4. Process or continuous production.

1. Job shop production:

~~Job~~ Job or unit production involves the manufacturing of a single complete unit as per the customer's order. Each job or product is different from others and no repetition is involved.

There are three types of job production:

1. A small number of pieces produced once.
2. A small number of pieces produced intermittently when the need arises.
3. A small number of pieces produced periodically at known time intervals.

2. Batch production:

In this type, the products are made in small batches and in large variety. Each batch contain identical items but every batch is different from the others.

Three types of batch production are:

1. A batch produced only once
2. A batch produced repeatedly at irregular intervals, when the need arises.
3. A batch produced periodically at known intervals, to satisfy continuous demand.

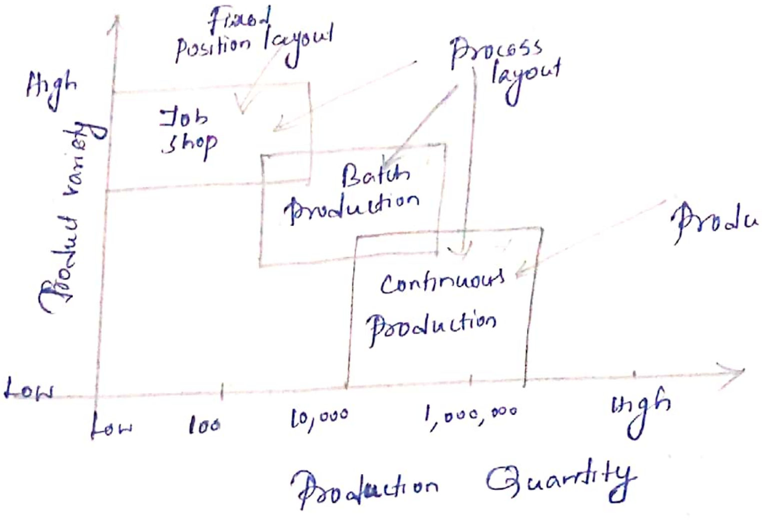
3. Mass production:

In this type of production, only one type of product or maximum 2 or 3 types are manufactured in large quantities.

Mass production system offers economies of scale as the volume of output is large.

4. Process production:

This type of production is used for manufacture of those items whose demand is continuous and high. Here single raw material can be transformed into different kind of products at different stages of the production processes.



1.20: Manufacturing metrices

It is used to quantitatively measures the performance of the production facility or a manufacturing company.

Manufacturing metrices is a system of related measures that facilitates the quantification of some particular characteristics of production.

Why use manufacturing metrics:

i. To track performance of the production system in successive periods.

ii. To determine the merits, and demerits of the potential new technologies and system.

iii. To compare alternative methods

iv. To make good decisions.

Categories of manufacturing metrics:

1. Production performance measures
2. Manufacturing costs.

commonly used are
cycle time
production time
plant capacity
utilization

Availability
mfg lead time
work-in-process.

1.21 Mathematical models of production performance.

1. Cycle time (T_c)

The operation cycle time (T_c) is the total time from when the operation begins to the point-of-time at which the operation ends.

Cycle time consists of

a. actual processing time
b. workpart handling time
c. tool handling time

Typical cycle time for a production operation is given by

$$\boxed{T_c = T_o + T_h + T_{th}}$$

T_c – cycle time in (min/pc)
T_o – processing or assembly operation time (min/pc)
T_h – Handling time (min/pc) (loading & unloading the production m/c)
T_{th} – tool handling time (min/pc) (time to change tools).

2. Production Rate (R_p)

Production rate for an individual production operation is nothing but the number of work units completed per hour.

The production rate is usually expressed as an hourly rate. Thus the unit of production rate is pc/hr.

i. Production rate is job shop production:

$$\boxed{T_p = T_{su} + T_c}$$

T_p = production time per work unit (min/pc)

T_{su} = setup time (min/pc)

T_c = cycle time (min/pc)

Production rate ~~$R_p = \frac{60}{T_p}$~~

$$\boxed{R_p = \frac{60}{T_p}}$$

Production Rate is the reciprocal of the production time.

R_p = Hourly production Rate (pc/hr)

ii. Production rate in batch production:

$$\boxed{T_b = T_{su} + Q \times T_c}$$

T_b = Batch processing time (min)

T_{su} = Setup time for batch (min/batch)

Q = Batch quantity (pc)

T_c = cycle time (min/pc)

$$\boxed{T_p = \frac{T_b}{Q}}$$

T_p = Average production time per min (min/pc)

$$\boxed{R_p = \frac{60}{T_p}}$$

iii. Production rate in mass production:

for mass production Setup time = 0

Production rate = Cycle rate of the m/c

$$\boxed{R_p = R_c = \frac{60}{T_c}}$$

R_p = Hourly production rate of the m/c (pc/hr)

R_c = Hourly cycle rate of m/c (pc/hr)

T_c = Operation cycle time (min/pc)

3. Production Capacity:

It is also known as capacity or plant capacity is defined as the maximum rate of output that a production facility is able to produce under a given set of assumed operating conditions.

i. Production capacity for production facility in which parts are made in one operation ($n_o = 1$)

$$\boxed{P_{cw} = n \cdot S_w \cdot H_{sh} \cdot R_p}$$

P_{cw} = weekly production capacity of the facility (units/wk)

n = No. of work centres working in parallel producing in the facility

S_w = No. of shifts per period (shift/wk)

H_{sh} = No. of hours per shift (hr/shift)

R_p = Hourly production rate of each work centre (units/hr)

n_o = No. of distinct operations/wk through which work units are routed

ii. Plant capacity for production facility in which part requires multiple operations ($n_o > 1$)

$$\boxed{P_{cw} = \frac{n \cdot S_w \cdot H_{sh} \cdot R_p}{n_o}}$$

4. Utilization:

Utilization of the production facility (U) is the ratio of the number of parts made by the production facility relative to its capacity

$$U = \frac{\text{Output}}{\text{Capacity}} \times 100$$

$$U = \frac{Q}{P_{cw}} \times 100$$

U – Utilization of the facility (%)

Q = Actual quantity produced by the facility during a given time period (pc/wk)

P_{cw} = Production capacity for same period (pc/wk)

5. Availability:

It is a measure of reliability for equipment and usually expressed as a percentage

Availability provides a measures of how well the equipments in the plant are serviced and maintained.

$$A = \frac{MTBF - MTTR}{MTBF} \times 100$$

A = Availability of plant facility (%)

MTBF = Mean time b/n failure (hr) — indicates the average length of time the equipment runs b/n breakdown.

MTTR = Mean time to repair (hr) — indicates the avg time required to service the equipment and put it back into operation when a breakdown occur.

6. Manufacturing lead time (MLT)

It is the total time required to process a given product through the plant.

1. MLT for batch production

$$\boxed{MLT = n_o (T_{su} + Q T_c + T_{no})}$$

MLT = Mfg lead time for a part or product (min)

n_o = No. of distinct operations through which work units are routed

T_{su} = Setup time per batch (min/batch)

Q = Batch quantity (pc) T_c = Cycle time per part (min/pc)

T_{no} = Non-operation time associated with m/c (min)

2. MLT for Job production

$$\boxed{MLT = n_o (T_{su} + T_c + T_{no})}$$

3. MLT for Mass production → $n_o = 1$, $T_{su} = T_{no} = 0$

$$\boxed{MLT = T_c}$$

7. Work-in-process (WIP)

It is the quantity of parts or products currently located in the factory that are either being processed or are b/n processing operations

$$\boxed{WIP = \frac{A \times U \times (P_{cw}) \times (MLT)}{S_w \times H_{sh}}}$$

WIP = work-in-process in the facility (pc), A = Availability,

U = Utilization, Pcw = weekly production capacity of the facility (pc/wk)

MLT = Mfg lead time (wk)

Sw = No. of shifts per week (shift/wk)

Hsh = No. of hours per shift (hr/shift).

Extra points

	concurrent engineering	sequential ~~Sequential~~ Engg
1.	It used to explain the method of production in a non linear system	" linear system.
2.	Various tasks are done at same ~~one after~~ ~~another~~ time	" done one after another
3.	Both product & process design run in parallel and take place in the same time	Both product & process design run in series and take place in the different time.

UNIT II

GEOMETRIC MODELING

2.1 Representation of Curves:

Mathematically, curve is a continuous map from one-dimensional space to n-dimensional space.

A curve is an infinitely large set of points. the points in a curve have a property and any point has two neighbors except for a small number of points which have one neighbor.

Some curves have no endpoints either because they are infinite or they are closed. the problem that we need to address is how to describe a curve or to give names or representations to all curves so that we can represent them on a computer.

2.1.1 Mathematical representation of curves:

A curve or a surface may be described or represented by a set of equations.

a. Explicit:

The explicit form of a curve in two dimensions gives the value of one variable. It may be dependent variable in terms of the other or independent variable.

A mathematical function $y = f(x)$ canb be plotted as a curve.

The explicit representation is not general since it cannot represent vertical lines and it is also a single valued. for each value of x, only a single value of y is normally computed by the function.

b. Implicit :

An implicit curve in two dimensions is defined by an implicit function of the form $f(x,y)=0$ so that the curve is a set of points for which this equation is true.

The implicit function is a scalar function (it returns a single real number). It can represent multi-valued curves (more than one 'y' value for an 'x' value).

A common example is the circle whose implicit representation is $x^2+y^2-R^2=0$.

In three dimensions, the implicit form is $f(x,y,z)=0$.

c. Parametric curve:

The explicit and implicit curve representations can be used only when the function is known. In practical applications, where complex curves such as the shape of a car or of a flight are needed the function is normally unknown. This is the necessary reason that why a prametric approach is required.

The defining equations of this type of curve are in terms of a simple and common independent variable known as parametric variable.

A two-dimensional parametric curve may be represented by

$$x = X(u), \quad y = Y(u)$$

'x' and 'y' are coordinates of the points on the curve which are the functions of a parameter u and the parametric variable is constrained in the interval.

In three-dimensions, the parametric curve may be represented as follows.

$$x = X(u) \quad y = Y(u) \quad z = Z(u)$$

One of the advantages of the parametric form is that it is the same in two and three dimensions.

for example, a circle with its center at the origin and radius = 1 can be written in implicit form given by

$$f(x, y) = x^2 + y^2 = 0$$

In parametric form given by

$$x, y = f(\theta) = \cos\theta, \sin\theta.$$

2.1.2. Free form or synthetic Curves:

The synthetic curves design is necessary on the following situations.

a. when a curve is represented by a collection of measured data points.

b. when an existing curve needs to be modified to meet new requirements of design.

2.1.3: Order of Continuity:

There are two types of curves continuities: geometric and parametric.

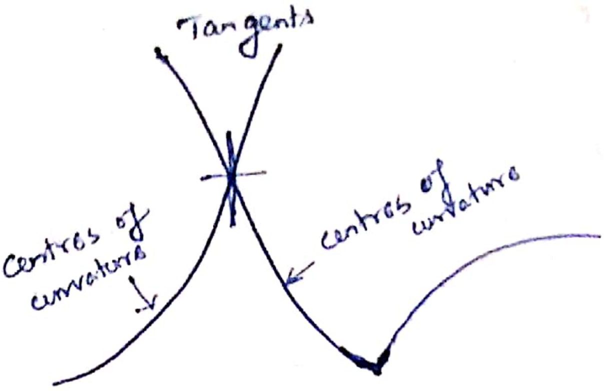
The order of continuity is very important when a complex curve is modeled by joining several curve segments.

Zero order continuity (C^0) means simply that the curves meet.

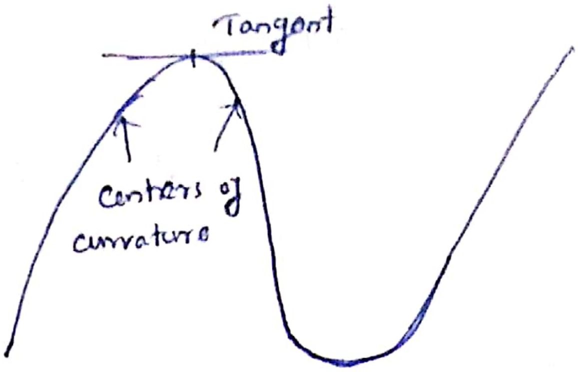
First order continuity (C^1) means that the first parametric derivatives of the coordinate functions for two successive curve sections are equal at their joining points.

Second order continuity (C^2) refers that both first and second parametric derivatives of two curve sections are the same at the intersection.

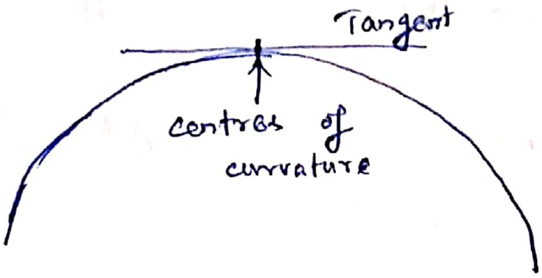
Zero-order continuity
C^0 curves



First-order continuity
C^1 curve



Second-order continuity
C^2 curve.



2.1.4: Interpolation and Approximation Modeling:

When polynomial sections are fitted so that the curve passes through each control point, then the resulting curve is said to interpolate the set of control points.

When the polynomials are fitted to the general control-point path without necessarily passing through any control points then the resulting curve is said to approximate the set of control points.

Interpolation curve

Approximation curve

2.2 : Hermite curve

It is a type of cubic spline described by french mathematician Charles Hermite. Generally, splines are functions which are used to fit a curve through a number of data points.

Splines is a flexible strip which is used to produce a smooth curve through a designated set of data points.

The equation for a single parametric cubic spline segment is given by

$$P(u) = \sum_{i=1}^{4} P_i \, u^{i-1} \qquad 0 \le u \le 1 \quad —①$$

where 'u' is the parameter and P_i are the polynomial coefficient.

In an expanded vector form, the eqn ①

$$P(u) = a_x u^3 + b_x u^2 + C_x u + d_x \qquad 0 \le u \le 1 \quad —②$$

Where x components of P is $x(u) = a_x u^3 + b_x u^2 + C_x u + d_x$ and similarly, for the y and z. coordinates.

∴ The equation in scalar form written as

$$x(u) = a_x u^3 + b_x u^2 + C_x u + d_x$$

$$y(u) = a_y u^3 + b_y u^2 + C_y u + d_y$$

$$z(u) = a_z u^3 + b_z u^2 + C_z u + d_z$$

The Hermite form of a cubic spline is obtained by defining positions and tangent vectors at control points.

Hermite splines can be adjusted locally because each curve section is only dependent on it endpoint constraints.

If $P(u)$ represents a parametric cubic point function for the curve section between end points P_n and P_{n+1}, then the boundary conditions that define this Hermite curve section are

$$P(0) = P_n \qquad P'(0) = p'_n$$
$$P(1) = P_{n+1} \qquad P(1) = p'_{n+1}$$

where p'_n & p'_{n+1} are the parametric derivatives (slope of the curve) at end points P_n and P_{n+1} respectively.

The eqn ② can also written in a matrix form as follows

$$P(u) = \begin{bmatrix} u^3 & u^2 & u & 1 \end{bmatrix} \cdot \begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix} \quad \text{———} \ ③$$

and the derivative of thin point function can be expressed as

$$P(u) = \begin{bmatrix} 3u^2 & 2u & 1 & 0 \end{bmatrix} \cdot \begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix} \quad \text{———} \ ④$$

Sub endpoint values 0 & 1 for parameter u in previous two equations.

$$\begin{bmatrix} P_n \\ P_{n+1} \\ p'_n \\ p'_{n+1} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 \\ 3 & 2 & 1 & 0 \end{bmatrix} \cdot \begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix}$$

Solving this eqn for the polynomial coefficients

$$\begin{bmatrix} a \\ b \\ c \\ d \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 \\ 3 & 2 & 1 & 0 \end{bmatrix}^{-1} \cdot \begin{bmatrix} P_n \\ P_{n+1} \\ p'_n \\ p'_{n+1} \end{bmatrix}$$

$$= \begin{bmatrix} 2 & -2 & 1 & 1 \\ -3 & 3 & -2 & -1 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix} \cdot \begin{bmatrix} P_n \\ P_{n+1} \\ P'_n \\ P'_{n+1} \end{bmatrix}$$

$$= M_H \cdot \begin{bmatrix} P_n \\ P_{n+1} \\ P'_n \\ P'_{n+1} \end{bmatrix}$$

M_H is the Hermite matrix = $\begin{bmatrix} 2 & -2 & 1 & 1 \\ -3 & 3 & -2 & -1 \\ 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$ —⑤

It is the inverse of the boundary constraint matrix. ∴ the eqn ③ can be written in terms of the boundary conditions as

$$P(u) = \begin{bmatrix} u^3 & u^2 & u & 1 \end{bmatrix} \cdot M_H \cdot \begin{bmatrix} P_n \\ P_{n+1} \\ P'_n \\ P'_{n+1} \end{bmatrix} \quad \text{—⑥}$$

Polynomial eqn for a single cubic spline segment as

$$P(u) = P_n(2u^3 - 3u^2 + 1) + P_{n+1}(-2u^3 + 3u^2) + P'_n(u^3 - 2u^2 + u) + P'_{n+1}(u^3 - u^2) \qquad 0 \le u \le 1 \quad \text{—⑦}$$

where P_n, P_{n+1}, P'_n, P'_{n+1} are called geometric coefficients.

The polynomials $H_n(u)$ for $n = 0, 1, 2, 3$ are referred as blending functions.

$$P(u) = P_n H_0(u) + P_{n+1} H_1(u) + P'_n H_2(u) + P'_{n+1} H_3(u)$$

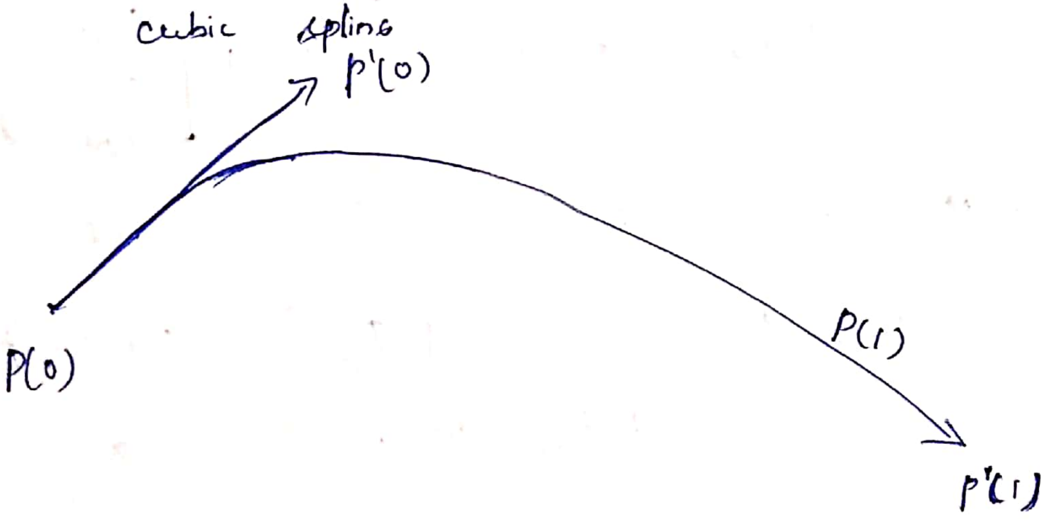
The tangent vector becomes

$$P'(u) = P_n\,(6u^2 - 6u) + P_{n+1}\,(-6u^2 + 6u) + P'_n\,(3u^2 - 4u + 1)$$
$$+\ P'_{n+1}\,(3u^2 - 2u) \qquad 0 \le u \le 1 \qquad \text{—⑧}$$

In matrix form, eqn ⑧ can be written as

$$P'(u) = \begin{bmatrix} u^3 & u^2 & u & 1 \end{bmatrix} \cdot \begin{bmatrix} M_H \end{bmatrix}^u \cdot \begin{bmatrix} P_n \\ P_{n+1} \\ P'_n \\ P'_{n+1} \end{bmatrix} \qquad \text{—⑨}$$

where $$\begin{bmatrix} M_H \end{bmatrix}^u = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 6 & -6 & 3 & 3 \\ -6 & 6 & -4 & -2 \\ 0 & 0 & 1 & 0 \end{bmatrix} \qquad \text{—⑩}$$



Hermit polynomials can be useful for some digitizing applications where it may not be too difficult to specify or approximate the curve slopes.

2.3: Bezier curve:

Bezier and B-spline curves are created based on the approximation techniques.

Bezier curve was developed by pierre Bezier at french car company "Renault Automobile Company". He used these curves to design automobile bodies.

This curve have a number of properties which make them highly useful and convenient for curve and surface design.

A Bezier curve Provides the reasonable design flexibility and avoids large number of calculation. They are also easy to implement. For these reasons, Bezier curves are widely available in various CAD systems.

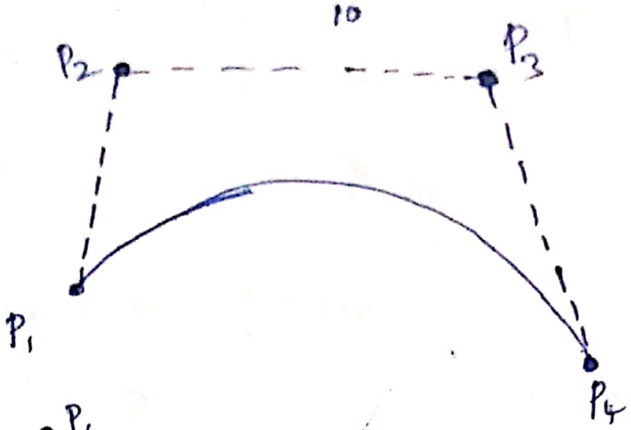
Most graphics software includes a pen tool for drawing paths with Bezier curves.

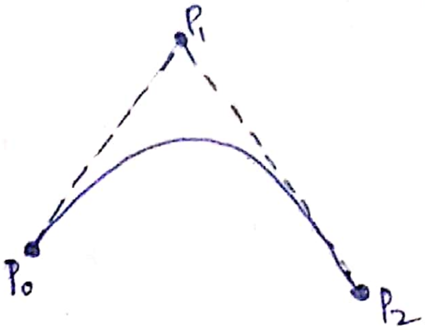
2.3.1: Mathematical formulation of Bezier curves:

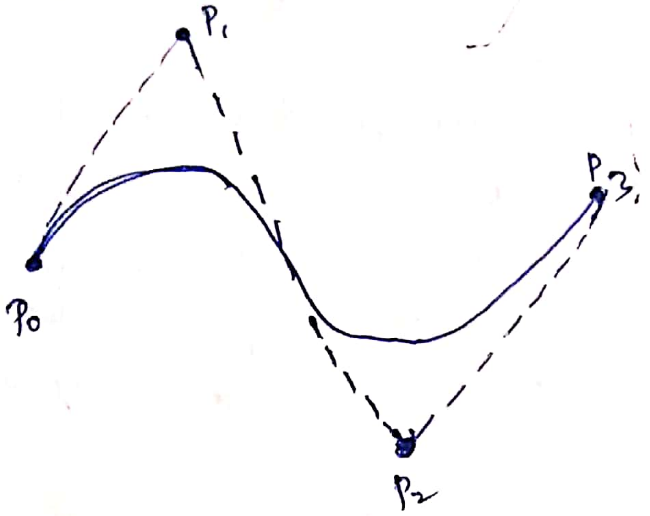
Bezier uses a control polygon for curves in place of Points and tangent vectors as in the case of cubic splines. The Bezier curve is defined in terms of locations with n+1 points which are called control points.

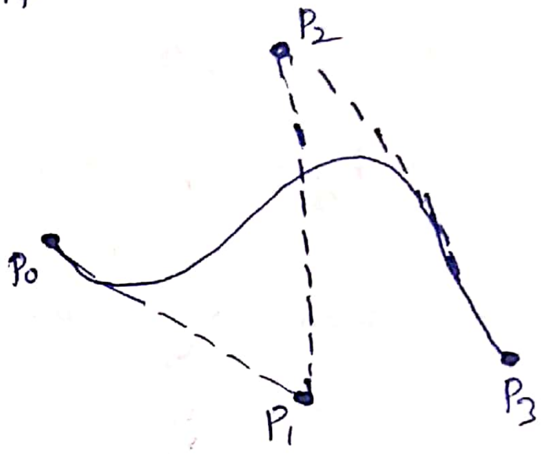
This curve has four Control points (P_1, P_2, P_3 & P_4). Dashed lines connect the control point positions which forms the characteristics polygon. Only first and last control points or vertices of the characteristics polygon actually lie on the curve. The other two vertices define the order derivates and shape of the curve. The curve is always tangent to first and last polygon segments.

cubic Bezier curve

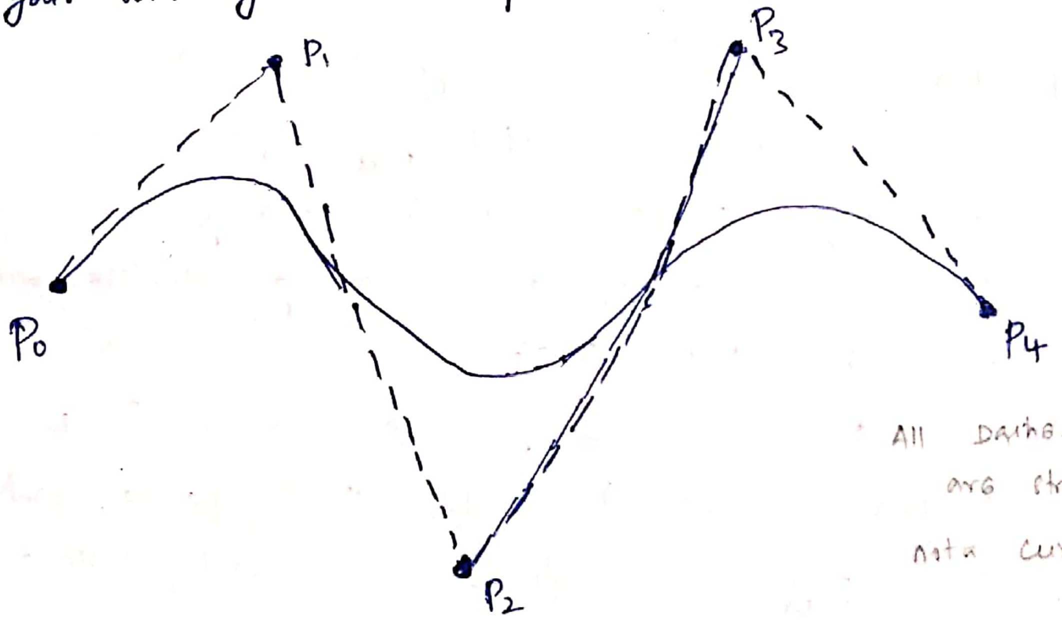








Examples of two-dimensional Bezier curves generated from three, four and five control points



All Dashed lines are straight lines not a curve

Mathematically, a parametric Bezier curve for n+1 control points is defined by

$$P(u) = \sum_{i=0}^{n} P_i \, B_{i,n}(u) \qquad 0 \le u \le 1 \qquad — ①$$

where P(u) is any point on the curve and P_i is a control point which describes the path of an approximating Bezier polynomial function between P_0 and P_n. $B_{i,n}(u)$ are the Bezier blending functions, called Bernstein polynomials.

This Bernstein basis or blending function is given by

$$B_{i,n}(u) = {}^{n}C_i \, u^i (1-u)^{n-1} \qquad — ②$$

where ${}^{n}C_i$ is the binomial coefficients which is given by

$${}^{n}C_i = \frac{n!}{i!(n-i)!} \qquad — ③$$

$$\boxed{B_{i,n}(u) = (1-u)\, B_{i,n-1}(u) + u\, B_{i-1,n-1}(u)} \qquad B_{i,i} = u^i \qquad B_{0,i} = (1-u)^i \qquad — ④$$

$$n > i \le 1$$

By using ② & ③ and observing that ${}^{n}C_0 = {}^{n}C_n = 1$ eqn ① can be expanded as follows.

$$P(u) = P_0 \, {}^{n}C_0 (1-u)^n + P_1 \, {}^{n}C_1 u (1-u)^{n-1} + P_2 \, {}^{n}C_2 u^2 (1-u)^{n-2} + \dots$$

$$+ P_{n-1} \, {}^{n}C_{n-1} u^{n-1} (1-u) + P_n \, {}^{n}C_n u^n \qquad 0 \le u \le 1 \quad — ⑤$$

The above eqn can be simplified into

$$P(u) = \sum_{i}^{n} P_i \, {}^{n}C_i \, u^i (1-u)^{n-i} \qquad — ⑥$$

2.3.2 cubic Bezier curves

Cubic Bezier curve are generated with four control Points. the four blending functions for cubic Bezier curve obtained by substituting $n=3$ into eqn ① are

①=> $B_{i,n}(u) = {}^{n}C_i \, u^i (1-u)^{n-i}$

$$B_{0,3}(u) = (1-u)^3$$

$$B_{1,3}(u) = 3u(1-u)^2$$

$$B_{2,3}(u) = 3u^2(1-u)$$

$$B_{3,3}(u) = u^3 .$$

The cubic Bezier curve will always pass through the control points P_0 & P_3.

At the end positions of the cubic Bezier curve, the Parametric first derivatives (slopes) are

$$P'(0) = 3(P_1 - P_0),$$

$$P'(1) = 3(P_3 - P_2)$$

Parametric second derivatives are

$$P''(0) = 6(P_0 - 2P_1 + P), \qquad P''(1) = 6(P_1 - 2P_2 + P_3)$$

Matrix form can be written as

$$P(u) = \begin{bmatrix} u^3 & u^2 & u & 1 \end{bmatrix} \cdot M_{Bez} \cdot \begin{bmatrix} P_0 \\ P_1 \\ P_2 \\ P_3 \end{bmatrix} \longrightarrow ⑦$$

where M_{Bez} is the Bezier matrix which is given by

$$M_{Bez} = \begin{bmatrix} -1 & 3 & -3 & 1 \\ 3 & -6 & 3 & 0 \\ -3 & 3 & 0 & 0 \\ 1 & 0 & 0 & 0 \end{bmatrix}$$

2.3.3. Characteristics of the Bezier curves:

1. A Bezier curve is defined on n+1 points $P_0, \ldots, P_n$ and is represented as a parametric polynomial curve of degree n.
2. Bezier curve always passes through the first and last control points. i.e. it passes through B_0 and B_n if we substitute $u=0$ & 1 in eqn ⑤.
3. Bezier curve is tangent to the first and last segments of the characteristics polygon.
4. The curve generally follows the shape of the characteristics polygon.
5. the degree of the polynomial defining the curve segment is one less that the number defines the polygon points. ∴ for 4 control points, the degree of the polynomial is three, i.e. cubic polynomial.
6. Bezier curves exhibit a symmetry property. The curve is symmetric with respect to u and (1-u).
7. Each control point is weighted by its blending function for each 'u' value.
8. The curve shape can be modified either by changing one or by more vertices of its polygon.
9. A closed Bezier curve can simply be generated by closing its characteristic polygon or choosing B_0 & B_n to be coincident.
10. The curve lies entirely within the convex hull formed by four control points.
11. The curve is invariant under an affine transformation but they are not invariant under projective transformation.
12. The curve exhibits the variation diminishing property.

2.3.4 Difference between cubic spline & Bezier curves

Sl.No	Bezier curve	cubic spline curve
1	the shape of this curve is controlled by its defining Points only	First order derivatives are used in the curve development.
2	The curve does not pass through the given data points. Instead, these points are used to control the shape of the resulting curves.	These curves pass through the given data points exactly.
3.	This curve permits higher-order continuity as the degree or order of Bezier curve is variable and it is depending on the number of defining data points. for example, n+1 points define nth degree curve.	The order or the degree of cubic splines is fixed one. It is always cubic for a spline segment.
4.	The shape of the Bezier curve is smoother than the cubic spline curve because of its higher-order continuity.	It is not much smoother as Bezier curve.
5.	The flexibility of Bezier curve is more.	The flexibility is less.

2.4: B-Spline Curve

B-spline curves provide an effective method of generating curves defined by polygons.

B-spline curve are the most widely used class of approximating splines.

The B-spline exhibits local control over the order of the basis function. ∴ whenever a single vertex is moved, only those vertices around will be affected while the rest remains the same. The degree of the B-spline curves can be changed without changing the number of defining polygon vertices.

B-spline curves have the ability to interpolate or approximate a set of given data points.

Let $P(u)$ be the position vectors along the curve as a function of the parameter u. Then a B-spline curve is given by.

$$P(u) = \sum_{i=0}^{n} P_i B_{i,k}(u) \qquad 0 \leq u \leq u_{max}$$

where the P_i are an input set of $n+1$ control points and $B_{i,k}(u)$ are the normalized B-splines basis functions.

For ith normalized B-spline basis function of order k (degree $k-1$), the basis functions $B_{i,k}(u)$ are defined by Cox-De Boor recursion formula.

$$B_{i,k}(u) = \frac{u-u_i}{u_{i+k-1}} B_{i,k-1}(u) + \frac{u_{i+k}-u}{u_{i+k}-u_{i+1}} B_{i+1,k-1}(u)$$

where $B_{i,1}(u) = \begin{cases} 1 & \text{if } u_i \leq u \leq u_{i+1} \\ 0 & \text{otherwise} \end{cases}$

The B-spline functions have the following properties

1. Partition of unity:

$\sum_{i=0}^{n} P_i B_{i,k}(u) = 1$. This property ensures that the relationship between the curve and its defining control points is invariant under after transformations.

2. Positivity:

$B_{i,k}(u) \geq 0$. This property guarantees that the curve segment lies completely within the convex hull of P_i.

3. Local support:

$B_{i,k}(u) = 0$ if $u \neq [u_i, u_{i+k+1}]$. This property indicates that each control point affects only k curve segments.

4. Continuity:

the polynomial curve has degree k-1 and C^{k-2} continuity over the range of u. Therefore, $B_{i,k}(u)$ is (k-2) times continuously differentiable.

5. for n+1 control points, the curve is described with n+1 blending functions.

6. the range of parameter u is divided into n+k subintervals by n+k+1 values specified in the knot vector.

7. Each section of the spline curve is influenced by k control points.

8. Any one control point can affect the shape of at most k curve sections.

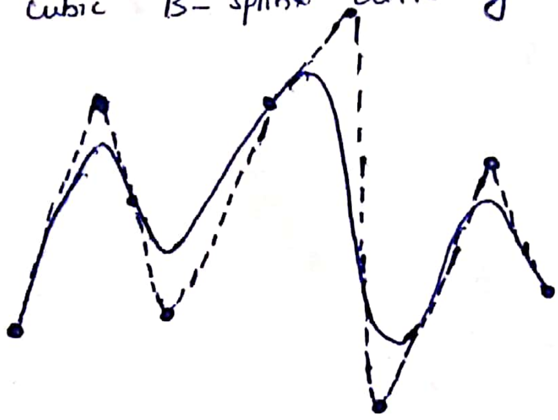
formally, B-spline curve is defined as a polynomial spline function of order k (degree k-1) since it satisfies the following two conditions.

i. The function $p(u)$ is a polynomial of degree $k-1$ an each interval $u_i \le u \le u_{i+1}$.

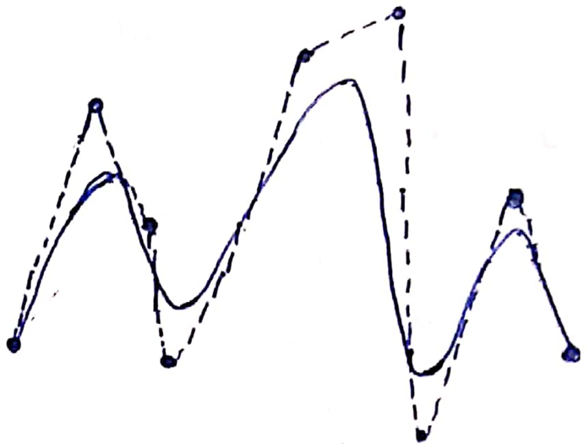
ii. $P(u)$ and its derivatives of order $1, 2, \ldots k-2$ are all continuous over the entire curve.

2.4.1 Characteristics of the B-spline curves.

1. The local control of the curve can be obtained by changing the position of a control point or using multiple control points by placing several points at the same location. The local control of a cubic B-spline curve by moving the control points.



Before modification



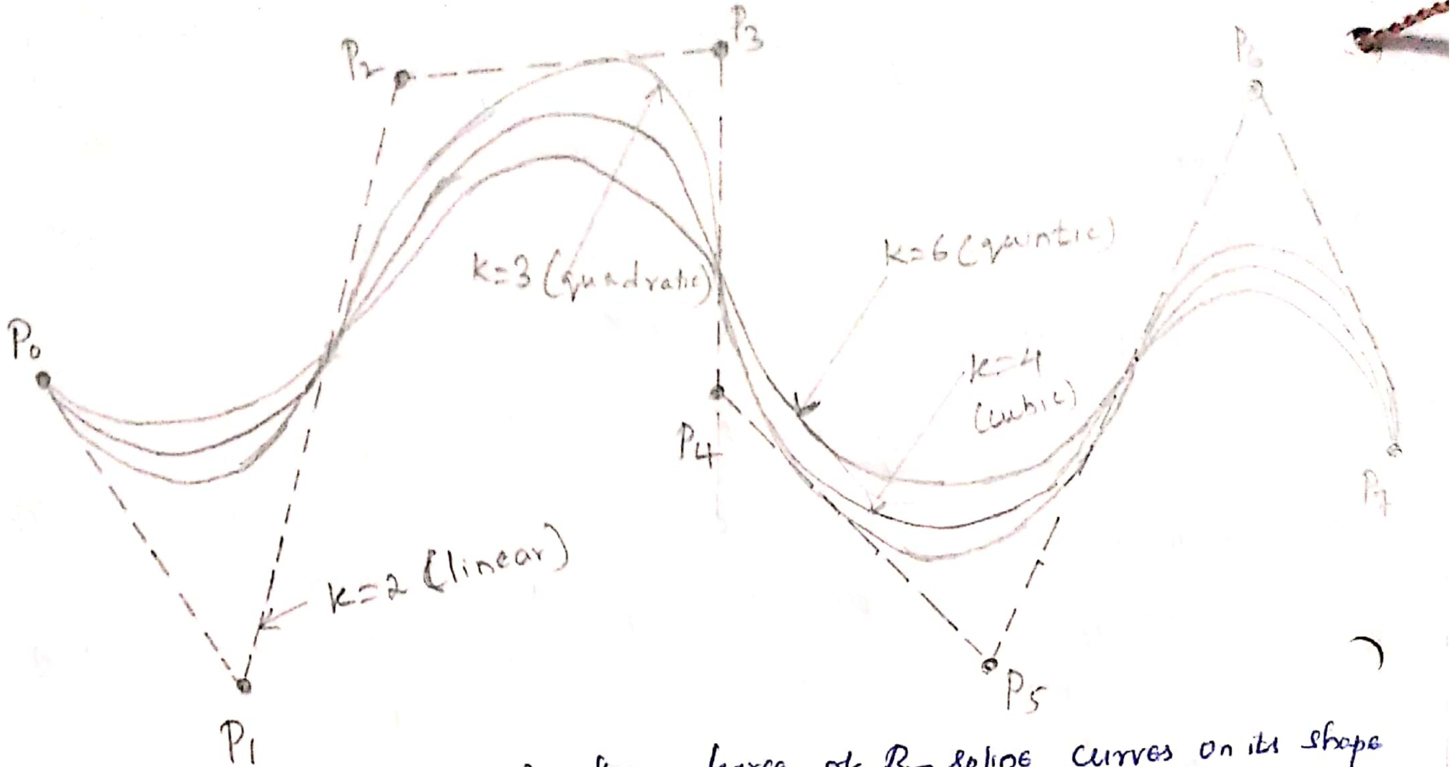
After modification

2. The B-spline curves do not pass through the first and last control points except when the linear blending functions are used.

3. B-splines allow us to vary the number of control points used to design a curve without changing the degree of the polynomial.

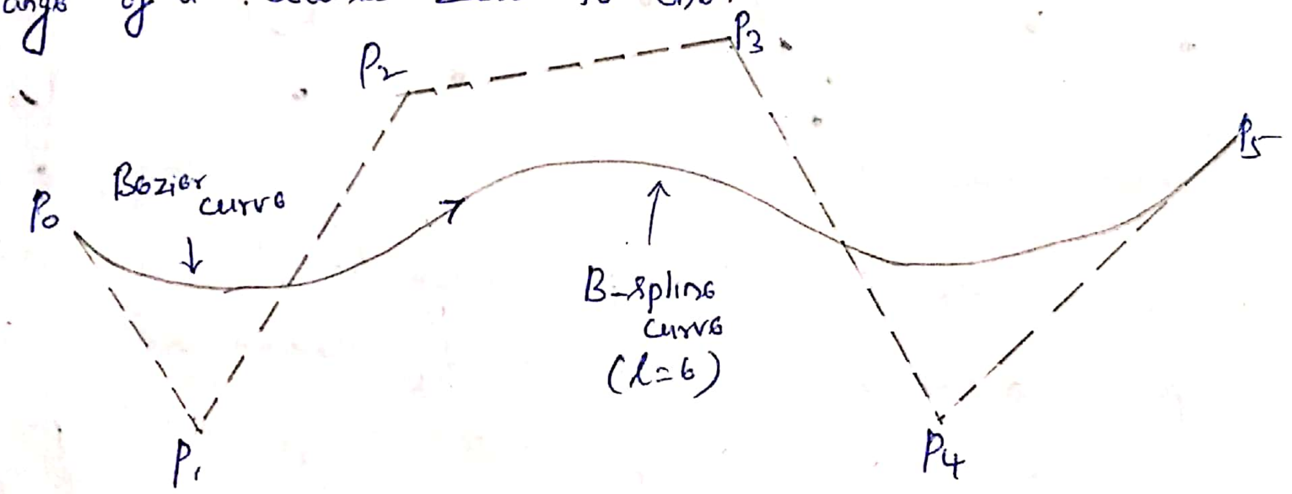
4. A non-periodic B-spline curve pass through the first and last control points and it is tangent to the first and last segments of the control polygon.

5. A second-degree curve $(k=3)$ is always tangent to the midpoints of all interval polygon segments. This condition is not suitable for other degrees.



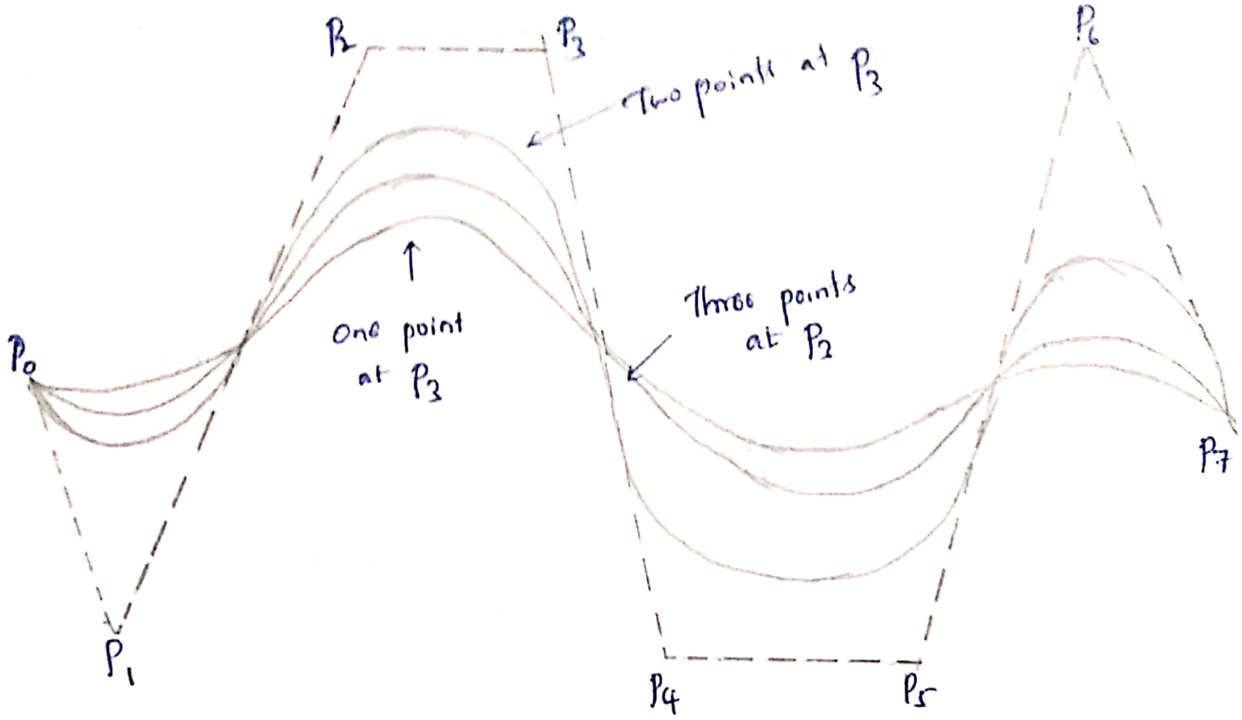
Effect of the degree of B-spline curves on its shape

6. The B-spline curve becomes a Bezier curve if k equals the number of control points (n+1) shown in fig. In this case, the range of u becomes zero to one.



7. Multiple control points results the regions of high curvature of a B-spline curve. following fig shows this property of the curve.

8. As the degree of curve increases, it is more difficult to control and calculate accurately.



Multiple control points B - spline curve

2.4.2: Uniform & Non-uniform B- spline curves

When the spacing between knot values is constant, the resulting curve is called a uniform B- spline.

for example, a uniform knot vector is set up by

$\{-1.0, -0.5, 0.0, 0.5, 1.0, 1.5\}$

often knot values are normalized to the range between 0 & 1 as in $\{0.0, 0.25, 0.5, 0.75, 1.0\}$

specification schemes $\{0, 1, 2, 3, 4, 5, 6\}$

$$B_{i,k}(u) = B_{i+1,k}(u+\Delta u) = B_{i+2,k}(u+2\Delta u)$$

Δu is the interval between adjacent knot values.

for non-uniform B-spline, the spacing between knot values is not constant and hence, any values and intervals can be specified for the knot vector.

for example, a non-uniform knot ~~Values~~ vectors can be set up as

$\{0, 1, 2, 2, 3, 4\}$ $\{0, 1, 1, 2, 3, 3, 5\}$ $\{0, 0.25, 0.4, 0.5, 0.8, 1.0\}$

2.4.3 Open & closed B-spline curves:

Open uniform B-spline curve is a cross between uniform B-splines and non-uniform B-splines.

The following are two examples of open uniform, integer knot vectors and each with a starting value of 0,

$\{0, 0, 1, 2, 3, 3, 4\}$ for $k = 2$ & $n = 3$

$\{0, 0, 0, 0, 1, 2, 2, 2, 2,\}$, for $k = 4$ & $n = 4$

These knot vectors can be normalized to the unit interval from 0 to 1

$\{0, 0, 0.25, 0.5, 0.75, 0.75, 1,\}$, for $k = 2$ & $n = 3$

$\{0, 0, 0, 0, 0.5, 1, 1, 1, 1,\}$, for $k = 4$ & $n = 4$

for any values of parameters k & n, an open uniform knot vector can be generated with integer values using the calculations

$$u_j = \begin{cases} 0, & \text{for } 0 \leq j < k \\ j - k + 1, & \text{for } k \leq j \leq n \\ n - k + 2, & \text{for } j > n \end{cases}$$

for values of j ranging from 0 to $n+k$ & the range of u is given by $0 \leq u \leq n - k + 2$.

The closed B-spline curve of degree $(k-1)$ or order k defined by $(n+1)$ control points is given by eqn ① (chapter 2.4) as the open curve.

for closed B-spline curves eqn, B-spline function is given by

$$B_{i,k}(u) = B_{0,k}((u-i+n+1) \bmod (n+1))$$

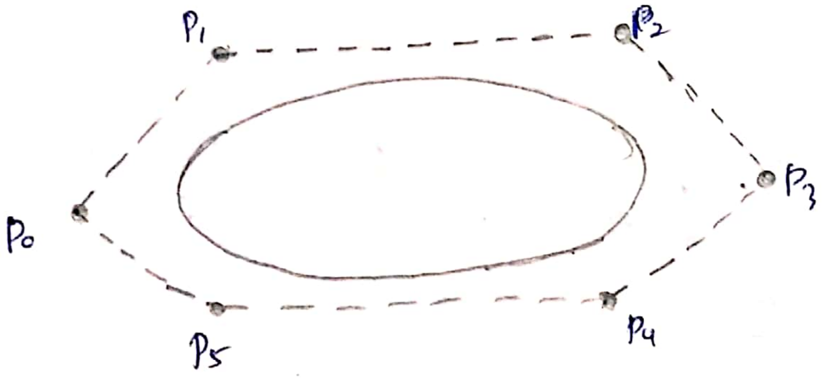
where $u_j = j$, $0 \le j \le n+1$

and the range of u is

$$0 \le u \le n+1$$

The mod (n+1) in the above eqn is the module function which is defined as

$$A \bmod n = \begin{cases} A, & \cancel{A<n} \; A<n \\ 0, & \cancel{A=n} \; A=n \\ \text{remainder of } A/n, & A>n \end{cases}$$



closed B-spline curve.

2.4.4. Cubic B-spline curves:

The boundary conditions for periodic cubic B-splines with four consecutive control points, labeled P_0, P_1, P_2, P_3 are

$$P(0) = \frac{1}{6}(P_0 + 4P_1, P_2) \qquad P'(0) = \frac{1}{2}(P_2 - P_0)$$

$$P(1) = \frac{1}{6}(P_1 + 4P_2, P_3) \qquad P'(1) = \frac{1}{2}(P_3 - P_1)$$

Matrix formulation for cubic-periodic B-spline with four control points

$$P(u) = [u^3 . u^2 \; u \; 1] . M_B . \begin{bmatrix} P_0 \\ P_1 \\ P_2 \\ P_3 \end{bmatrix}$$

M_B - B spline matrix

$$M_B = \frac{1}{6}\begin{bmatrix} -1 & 3 & -3 & 1 \\ 3 & -6 & 3 & 0 \\ -3 & 0 & 3 & 0 \\ 1 & 4 & 1 & 0 \end{bmatrix}$$

2.5 Rational curves:

Rational curves were first introduced for the computer graphics by coons. Rational curve is defined as the ratio of two Polynomials whereas a non-rational curve is defined by one Polynomial.

Various rational curves such as rational Bezier curves, rational B-spline and β spline curves, rational conic sections and rational cubics have been formulated. The most widely used rational curves are non-uniform rational B-splines (NURBS).

A rational B-spline curves defined by n+1 control points P_i is given by

$$P(u) = \sum_{i=0}^{n} P_i \, B_{i,k}(u) \qquad 0 \le u \le u_{max}$$

where P_i are a set of n+1 control points for the rational B-spline curve. $B_{i,k}(u)$ is the rational B-spline basis function and it is given by

$$B_{i,k}(u) = \frac{w_i R_{i,k}(u)}{\sum_{i=0}^{n} w_i R_{i,k}(u)}$$

the rational B-spline representation is given by

$$p(u) = \frac{P_0 B_{0,3}(u) + \left(\frac{r}{1-r}\right) P_1 B_{1,3}(u) + P_2 B_{2,3}(u)}{B_{0,3}(u) + \left(\frac{r}{1-r}\right) B_{1,3}(u) + B_{2,3}(u)}$$

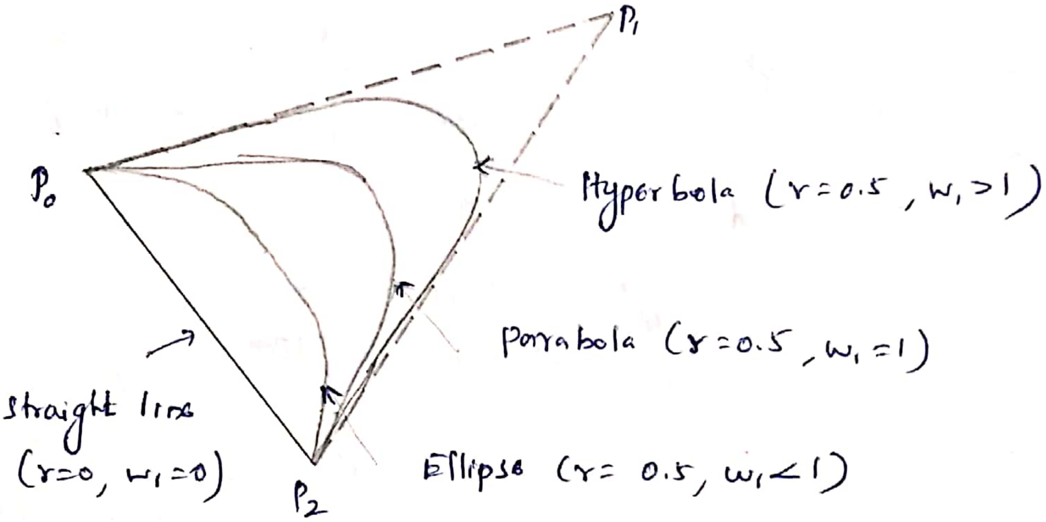
Conic section from rational curves

$r > 1/2$, $w_1 > 1$ (hyperbola section)

$r = \frac{1}{2}$, $w_1 = 1$ (Parabola ")

$r < 1/2$, $w_1 < 1$ (Ellipse ")

$r = 0$, $w_1 = 0$ (straight - line segment)



2.6 : Surface Modeling:

Boundaries of the solid are defined by surfaces. Surfaces themselves are bounded by curves.

It is an extension of a wire frame model with additional information. A complex surface can be very difficult to visualize without a physical model and surface modeling using a computer eases this process considerably.

Surface modeling defines a component with greater mathematical integrity as it models the surfaces to give more definitive spatial boundaries to the design.

It is useful for modeling objects which can be modeled as shells such as car body panels, aircraft fuselages or fan blades.

Surface modeling can be used for calculating mass Properties, interference between parts, generating cross-sectioned views, generating finite element mesh and generating NC tool paths for continuous path machining.

2.6.1 Types of surfaces:

The surfaces generated by the surface modeling are classified as follows.

a. Flat surface – most basic feature of surface model.

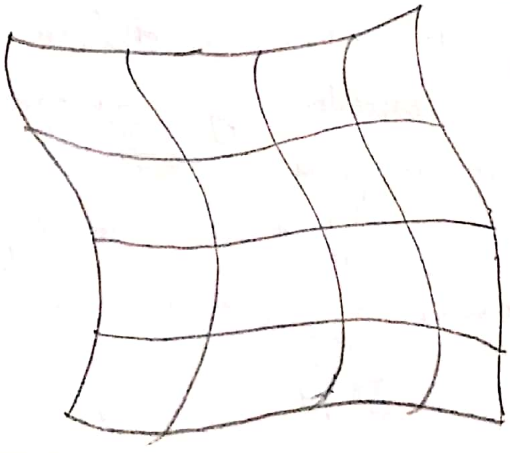
b. Sculptured surfaces – Based on flat face mostly used in FE analysis.

c. Sculptured surfaces based on patches,

d. Analytical surfaces (very rarely used)

e. Combination of the above types.

A Simple and basic form of surface is flat surface. The most general and complex surface representations are generally known as sculptured surface.



Sculptured surface

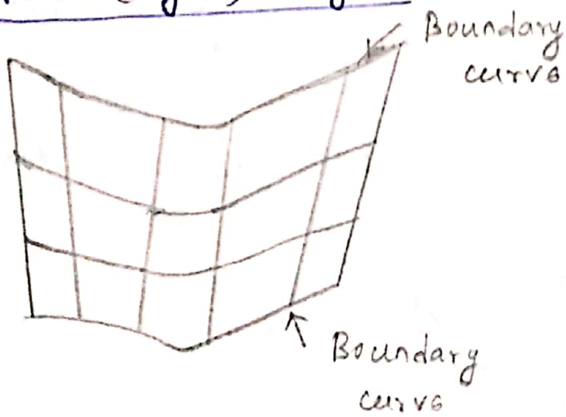
Common surface entities used in a surface modeling are as follows.

a. Plane surface
b. Ruled (lofted) surface.
c. Surface of revolution
d. Tabulated surface
e. Bezier surface
f. B-spline surface
g. Coons patch
h. Fillet surface
i. offset surface.
j. Bi-linear surface

a. plane surface:

the most elementary and simplest form of the surface types is the plane surface which may be defined between two parallel straight lines through three points or through a line and a point.

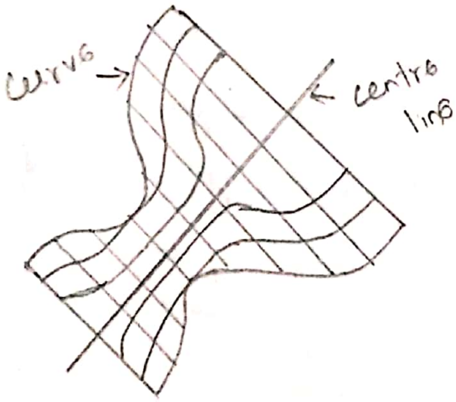
b. Ruled (lofted) surface:



A ruled surface is produced by linear interpolation b/n two different boundary curves that define the surface shown in fig.

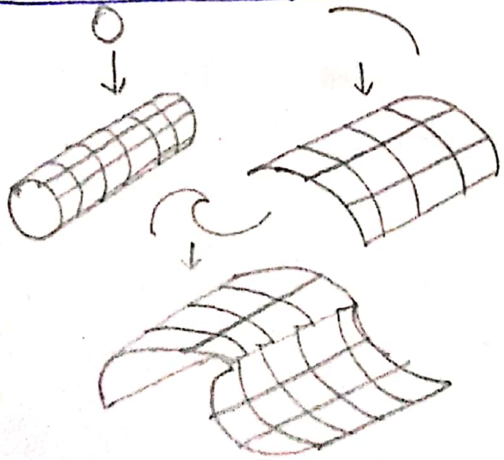
This type of surface is more suitable for representing the surfaces which do not have any twists or kinks.

c. Surface of revolution



A surface of revolution can be generated by revolving a generating curve about a centerline or vector. This surface is particularly useful when modeling turned parts or parts which possess the axial symmetry.

d. Tabulated surface:



It is a surface generated by translating a planar curve for a given distance along a specified direction.

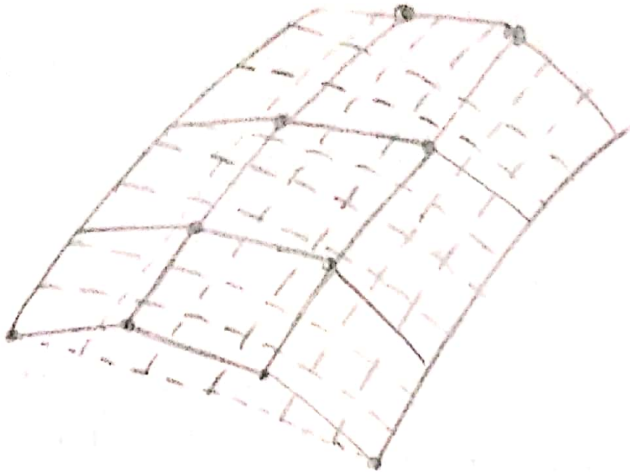
The plane of curve is perpendicular to the axis of the generated cylinder.

e. Bezier surface:

The Bezier surface is generated from the basis of Bezier curve.

It is a general surface which permits twist and kinks.

The Bezier surface allows only global control of the surface.

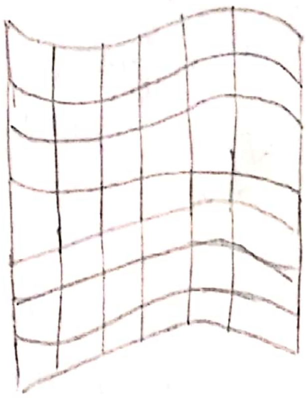


f. B-spline surface:

The B-spline surface is generated from the basis of B-spline curve. This surface which can approximate or interpolate given data points.

The surface is capable of giving very smooth contours and it can be reshaped with local controls.

Data points

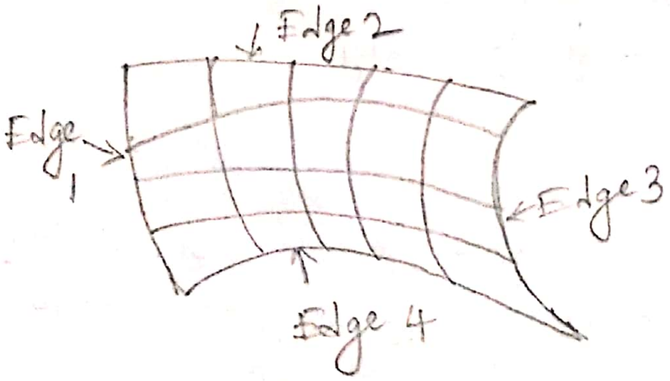


B-spline surface

g. Coons patch:

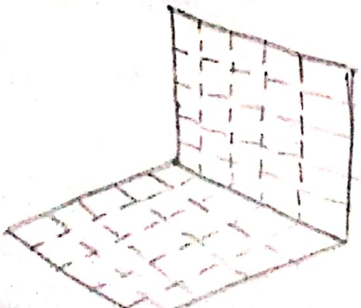
A Coons patch or surface is generated by the interpolation of four edge curves.

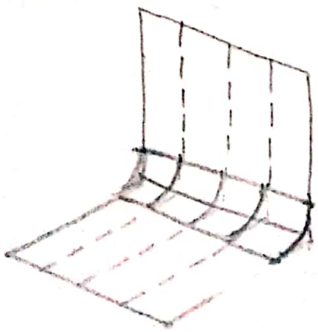
The coons patch is used to create a surface using curves which form closed boundaries.



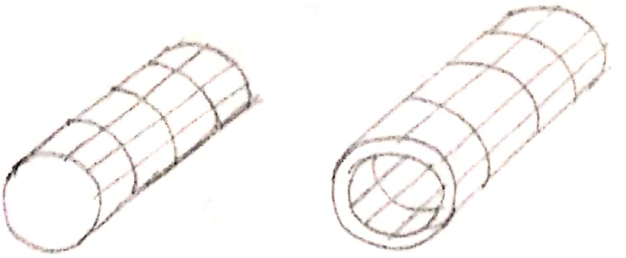
h. Fillet surface:

It is defined as a surface connecting two other surfaces in a smooth transition (radius of curvature).



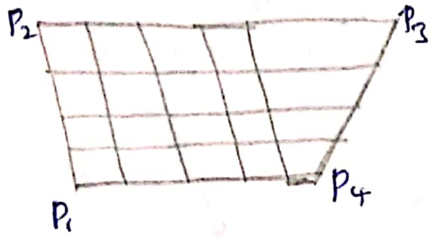


i. offset surface:



Existing surfaces can be offset to create new ones identical in shape but they have different dimensions. for example, to create a holding cylinder, first inner or outer cylinder can be created using a cylinder command. Based on this surface, other cylindrical surface can be created by using an offset command.

j. Bi-linear surface:



This 3-D surface is generated by interpolation of four endpoints. Bi-linear surfaces are very useful in finite element analysis.

A mechanical structure is discretized into elements which are generated by interpolating four node points to form a 2-D solid element.

2.6.2. Applications of surface modeling:

1. Body panels of passenger cars, structural components of aircrafts and marine structures.
2. plastic containers, telephones, impellers of pump and turbine, development of surface for cutting shoe leather, glass marking etc.
3. To model exterior shell objects such as sheet metal works and thin moulded plastic parts.

2.6.3. Advantages and Dis advantages of surface modeling:

Advantages:

1. Unambiguities in the interpretation of object are less than wire frame models by using the provision of hidden line removal.
2. Surface modeling can be used to perform interference checking (i.e. penetration of one part with other)
3. Surface modeling can be used to check the aesthetic look of the product (By using coloring and shade facilities).

4. As the surface models precisely define the part geometry such as surface and boundaries, they can help to produce NC machine instructions automatically.

5. Complex surface features such as shoes, car panels, doors etc can be created very easily.

Disadvantages:

1. Interpretation of surface model is still ambiguous.
2. Surface models require more computational time when compared to wire frame models.
3. More skill is required for surface modeling.
4. ~~Mass properties Such as~~ surface models cannot be used as a basis for FEA for stress strain prediction.

~~6.~~

2.7. Techniques for Surface Modeling:

Surface design may be treated as an extension of curve design in parametric dimensions. The implicit, explicit and parametric forms of curves can be extended to surfaces.

In explicit form, a surface is represented by an equation of the form $z = f(x,y)$

The implicit form of surface representation is $f(x,y,z) = 0$

In parametric form a surface may be represented as

$$x = X(u,v)$$
$$y = Y(u,v)$$
$$z = Z(u,v)$$

where X, Y, Z are suitable functions of two parameters u & v.

For example, the parametric representation of the surface of a sphere whose centre is at the origin of coordinates and of radius 'R' is

$$x = X(\theta, \varphi) = R \sin\varphi \cos\theta$$

$$y = Y(\theta, \psi) = R \sin\psi \sin\theta$$

$$z = Z(\theta, \psi) = R \cos\varphi$$

Parametric surfaces may be defined in one of the following methods:

a. In terms of points of data (positions, tangents, normals)

b. In terms of data on a number of space curves lying in these surfaces.

The resulting surface will either interpolate or approximate the data. Surfaces are normally designed in patches, each patch corresponding to a rectangular domain in u-v space.

2.8 Surface Patch:

A patch is considered the basic mathematical element to model a composite surface. In computer graphics, the parametric surfaces are sometimes called patches, curved surfaces, or just surfaces. Some surfaces consist of a single patch while others may consist of few patches connected together.

A surface patch defined in terms of point data will usually be based on a rectangular array of data points.

The general eqn of the surface or surface patch is given by

$$P = [x \quad y \quad z]^T = [x \quad y \quad f(x,y)]^T$$

Where 'P' is the position vector of a point on the surface. The natural form of the function f(x,y) for a surface to pass through all the given data points is a polynomial given by

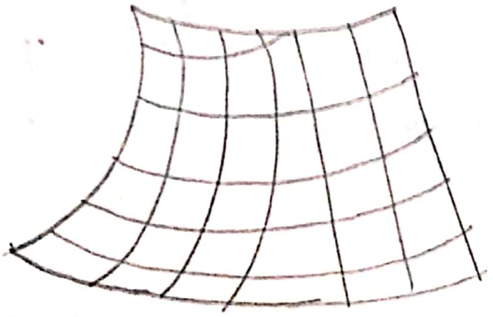
$$z = f(x,y) = \sum_{j=0}^{m} \sum_{k=0}^{n} a_{j,k} x^j y^k$$

Where the surface is described by an XY grid of size (m+1) × (n+1) points.

In parametric representation, 3-D curved surface in space is given by

$$P(u,v) = [x \quad y \quad z]^T = [x(u,v) \quad y(u,v) \quad z(u,v)]^T,$$

$$u_{min} \leq u \leq u_{max}, \quad v_{min} \leq v \leq v_{max}$$



2.8.1. Analytical & Synthetic surfaces

Analytical surfaces are based on wireframe entities. These includes plane surface, rule surface, surface of revolution & tabulated cylinder.

Synthetic surfaces are formed from a given set of data points or curves. They include bicubic, Bezier, B-spline and Coons patches.

Synthetic surfaces are generated by the following methods.

a. Tensor product method

b. Rational method

c. Blending method

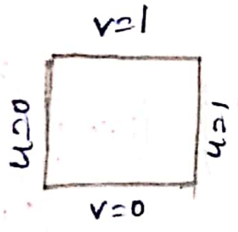
2.9 : Coons Surface:

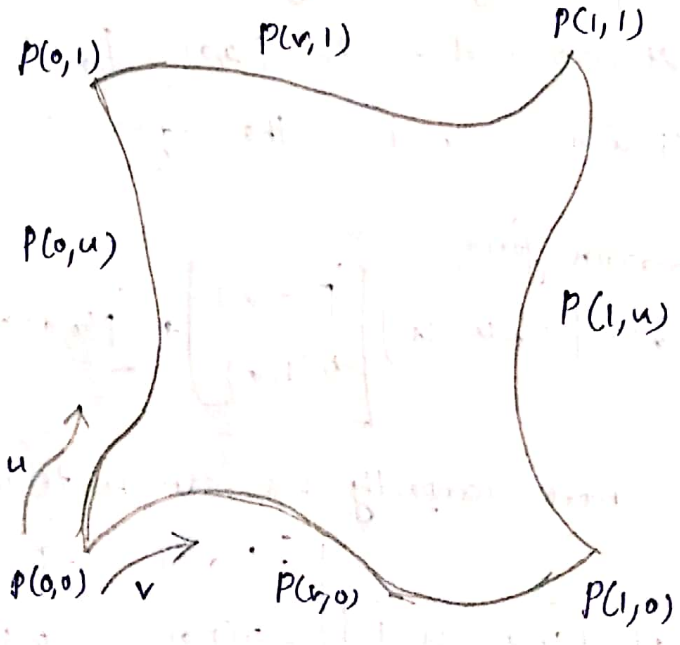
A linear interpolation between four bounded curves is used to generate a Coons surface, which is also called Coons patch. This type of surface is based on the pioneering work of steven Anson coons.

The generalized coons surface is defined by four rectangular surface patches. By changing the shape of the constituents, the shape of the resulting surface will change as well even if the boundary lines are fixed.

Consider a surface patch enclosed by four curves shown in fig. Let u and v be two parameters used to express this surface patch. It is assumed that u & v range from 0 to 1 along these boundaries and each pair of opposite boundary curves are identically parameterized.

Let $P(0,0)$, $P(0,1)$, $P(1,0)$ and $P(1,1)$ be the position vectors at the four corners, and they denote the four boundary curves by $P(u,0)$, $P(u,1)$, $P(1,v)$ & $P(1,v)$.





2.9.1: Bilinear Coons surface:

The linear Coons surface is the simplest of all Coons surface and it is a more general Coons surface possible.

$$P(u,v) = \{P(u,0)(1-v) + (P(u,1)v\} + \{P(0,v)(1-u) + (P(1,v)u\} \quad ①$$

Sub $u=0$ & $v=0$ in the above eqn, P_{00} should be obtained by

$$P(0,0) = P(0,0) + P(0,0) = 2P$$

but it is not, Also, at the edge $u=0$

$$P(0,v) = P(0,0)(1-v) + P(0,1)v + P(0,v).$$

$$P(u,v) = \{P(u,0)(1-v) + (P(u,1)v\} + \{P(0,v)(1-u) + P(1,v)u\} - \{P(0,0)(1-u)(1-v)\} - \{P(0,1)(1-u)v\} - \{P(1,0)u(1-v)\} - \{P(1,1)uv\} \quad ②$$

By substituting the boundary conditions at the corner points and boundary edges, we get the original data.

At $u=0$ & $v=0$, $P(0,0) = P_{00}$ etc.

At $u=0$ & $v=1$, the edges become $P(0,v)$ & $P(u,1)$ respectively.

In matrix form,

$$P(u,v) = \begin{bmatrix} 1-u, & u \end{bmatrix} \begin{bmatrix} P(0,v) \\ P(1,v) \end{bmatrix} + \begin{bmatrix} P(u,0) & P(u,1) \end{bmatrix} \begin{bmatrix} 1-v \\ v \end{bmatrix} - \begin{bmatrix} 1-u, & u \end{bmatrix} \begin{bmatrix} P(0,0) & P(0,1) \\ P(1,0) & P(1,1) \end{bmatrix} \begin{bmatrix} 1-v \\ v \end{bmatrix}$$

Or more compactly we can write the above eqn in the form

$$P(u,v) = \begin{bmatrix} 1-u & u & 1 \end{bmatrix} \begin{bmatrix} -P(0,0) & -P(0,1) & P(0,v) \\ -P(1,0) & -P(1,1) & P(1,v) \\ -P(u,0) & P(u,1) & 0 \end{bmatrix} \begin{Bmatrix} 1-v \\ v \\ 1 \end{Bmatrix}$$

The functions $(1-u)$, u, $(1-v)$ & v are called blending functions because they blend the boundary curves to produce the internal shape of the surface.

2.9.2. Applications of coons surface

i. Coons surface is easy to create and therefore, many 2-D CAD packages utilize it for generating models.

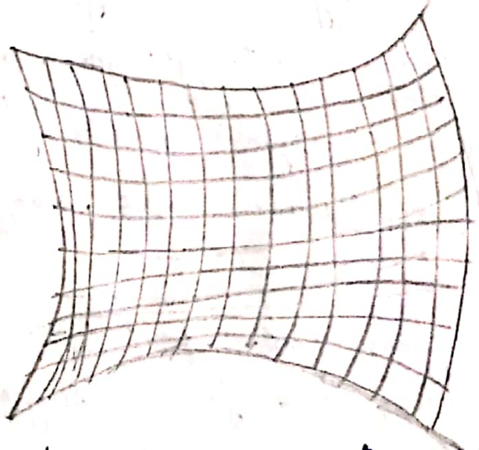
ii. Several CAD softwares including Auto CAD use this surface for generating surfaces between 4-bounded edges.

2.10: Bicubic Surface Patch:

Parametric bicubic patch or surface is generated by four boundary curves which are parametric bicubic polynomials.

Bicubic parametric patches are defined over a rectangular domain in uv-space and the boundary curves of the patch are themselves cubic polynomial curves.

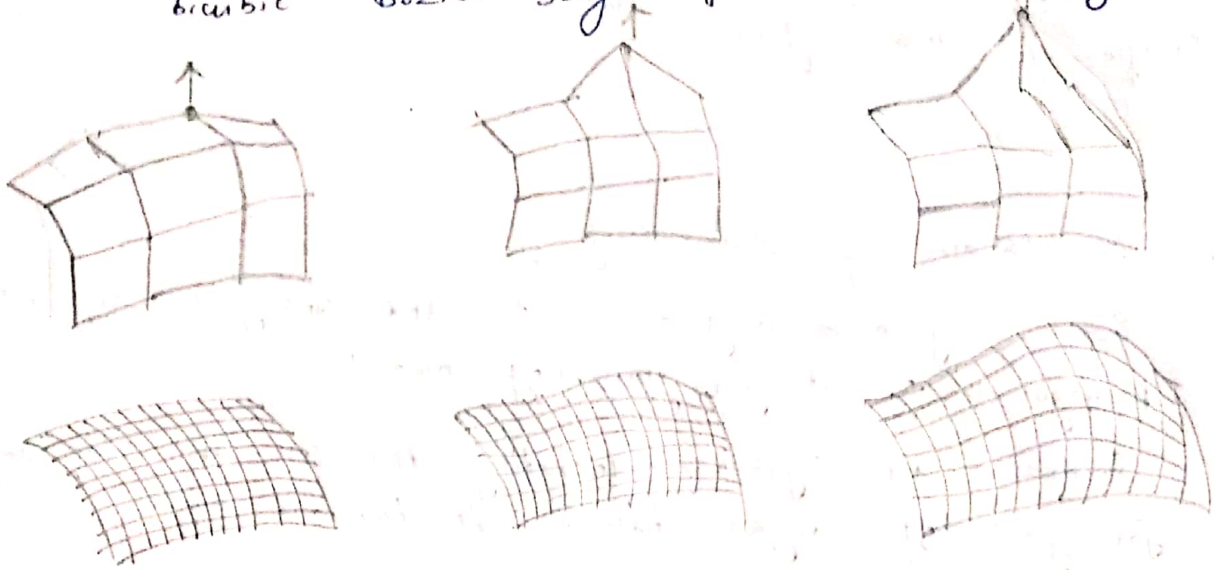
The bicubic surface can be thought of as 4 curves along 'u' parameter.



Analogous to a cubic curve, a parametric cubic surface can be defined by 16 points.

- 4 points for coordinates of the corner points
- 8 points for slopes in the u & v directions
- 4 points for twist vectors.

Example: The effect of lifting one of the control points of a bicubic Bezier surface patch is shown in fig.



The following are major types of parametric Bi-cubic surfaces used in CAD:

- Hermite surfaces
- Bezier surfaces
- B-spline surfaces.

2.11. Bezier surface:

Bezier curves may be extended to Bezier surface patch. The Bezier surface is a type of parametric surface. Bezier surfaces are a straight forward extension to Bezier curves. A Bezier patch is a surface patch formed by sweeping each control point of a Bezier curve along a path which is itself a Bezier curve.

There are four control points for a Bezier curve, total of 16 control points is required for a single bi-cubic Bezier surface patch. The general eqn of Bezier surface can then be expressed as

$$p(u,v) = \sum_{i=0}^{n} \sum_{j=0}^{m} P_{i,j}\, B_{i,n}(u)\, B_{j,m}(v), \qquad 0 \le u \le 1; \quad 0 \le v \le 1 \quad \text{— ①}$$

where $P(u,v)$ is any point on the surface and $P_{i,j}$ are the control points. $B_{i,n}(u)$ and $B_{j,m}(v)$ are the Bernstein blending functions in u & v directions.

In matrix form as

$$P(u,v) = U \cdot [M_B] \cdot [P] \cdot [M_B]^T \cdot V^T \quad ——②$$

where $[M_B]$ = B-Spline matrix as discussed in Bezier curve formulation

$[P]$ = Geometric coefficient matrix or boundary condition matrix.

$U = [u^n \; u^{n-1} \; u \; 1]$ &

$V = [v^m \; v^{m-1} \; v \; 1]$

A Bezier surface patch is defined by a rectangular grid of $(n+1) \times (m+1)$ control points.

$$P = \begin{bmatrix} P_{00} & P_{01} & \cdots & P_{0m} \\ P_{10} & P_{11} & \cdots & P_{1m} \\ \cdots & \cdots & \cdots & \vdots \\ P_{n0} & P_{n1} & \cdots & P_{nm} \end{bmatrix}$$

2.11.1 cubic Bezier surface:

This surfaces are very useful in computer graphics for software development.

$$P(u,v) = \sum_{i=0}^{3} \sum_{j=0}^{3} P_{i,j} \, B_{i,3}(u) \, B_{j,3}(v), \quad 0 \le u \le 1, \quad 0 \le v \le 1$$

$$P(u,v) = U[M_B][P][M_B]^T V^T$$

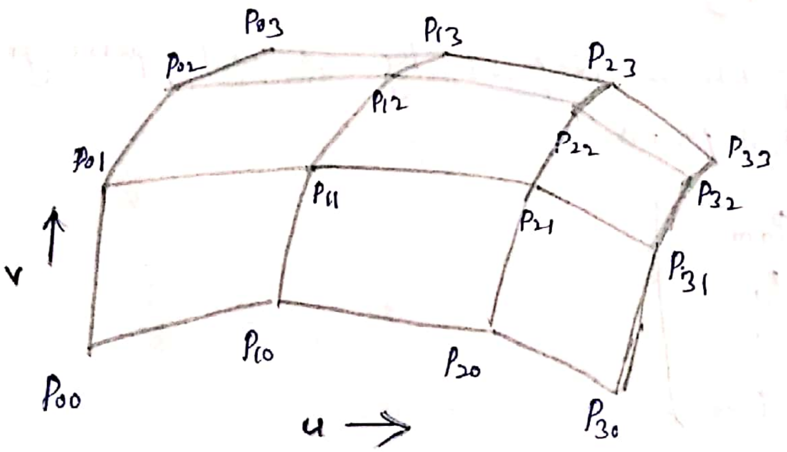
$$U = \begin{bmatrix} (1-u)^3 & 3u(1-u)^2 & 3u^2(1-u) & u^3 \end{bmatrix}$$

$$[P] = \begin{bmatrix} P_{00} & P_{01} & P_{02} & P_{03} \\ P_{10} & P_{11} & P_{12} & P_{13} \\ P_{20} & P_{21} & P_{22} & P_{23} \\ P_{30} & P_{31} & P_{32} & P_{33} \end{bmatrix} \qquad [M_B] = \begin{bmatrix} -1 & 3 & -3 & 1 \\ 3 & -6 & 3 & 0 \\ -3 & 3 & 0 & 1 \\ 1 & 0 & 0 & 1 \end{bmatrix}$$

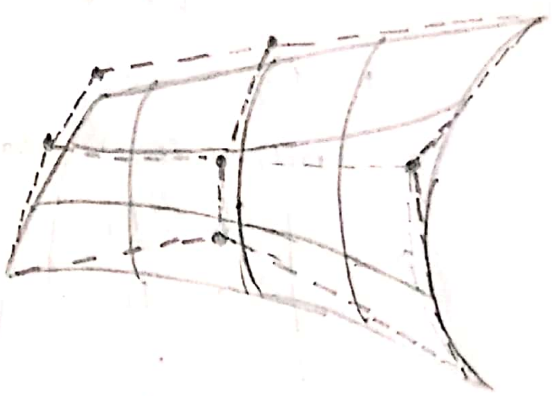
$$V^T = \begin{bmatrix} (1-v)^3 \\ 3v(1-v)^2 \\ 3v^2(1-v) \\ v^3 \end{bmatrix}$$

Hence, $V = \begin{bmatrix} (1-v)^3 & 3v(1-v)^2 & 3v^2(1-v) & v^3 \end{bmatrix}$.

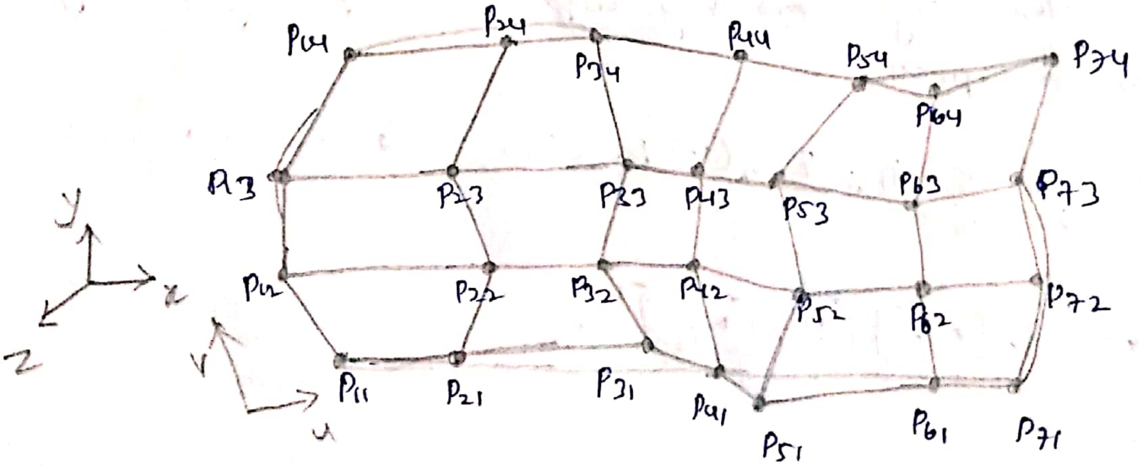
Bezier bicubic control mesh



Bezier surfaces



Blending Bezier ~~Surf~~ patches



In Bezier surface.

i. the surface takes the general shape of the control points.

ii. the surface is contained within the convex hull of the control points.

iii. the corner of the surface and the corner control points are coincident.

2.11.2: Properties of Bezier surface

i. Similar to Bezier curves, Bezier Surfaces retain the convex hull property so that any point on the actual surface will fall within the convex hull of the control points.

ii. With Bezier curves, the curve will interpolate the first and last control points but it will only approximate other control points.

iii. With Bezier surfaces, 4 corners will interpolate and other 12 points in the control mesh are only approximated.

iv. the 4 boundaries of the Bezier surface are just Bezier curves defined by points on edges of the surface.

v. By matching these points, two Bezier surfaces can be precisely connected

vi. the surface generally follows the shape of the control net.

vii. the surface passes through only the 4 corner points of the control net.

2.11.3 Advantages & Disadvantages of Bezier Surface:

Advantages:

i. Bezier surfaces are much more compact, easier to manipulate and they have much better continuity properties.

ii. It is easy to enumerate points on surface.

iii. It is possible to describe complex shapes.

Disadvantages:

i. Bezier patch meshes are directly difficult to render.

ii. Their intersections calculations with lines are difficult.

iii. Control mesh must be quadrilaterals.

iv. Continuity constrains are difficult to maintain.

v. It is hard to find intersections.

2.12: B-Spline Surface:

Using a corresponding basis function, uniform cubic B-spline surface can be formed.

The uniform B-spline surface patch is constructed as a Cartesian product of two uniform B-spline curves. A rectangular set of control points creates the B-spline surface.

A B-spline surface defined by an $(n+1) \times (m+1)$ array of control points is defined as

$$P(u,v) = \sum_{i=0}^{m} \sum_{j=0}^{m} P_{i,j} \, B_{i,k}(u) \, B_{j,l}(v), \quad 0 \le u \le u_{max}, \quad 0 \le v \le v_{max}$$

In matrix form:

$$\boxed{P(u,v) = U . [M_{Bez}] . [P] . [M_{Bez}]^T . V^T}$$

$U = [u^n \quad u^{n-1} \quad u \quad 1]$

$V = [v^m \quad v^{m-1} \quad v \quad 1]$

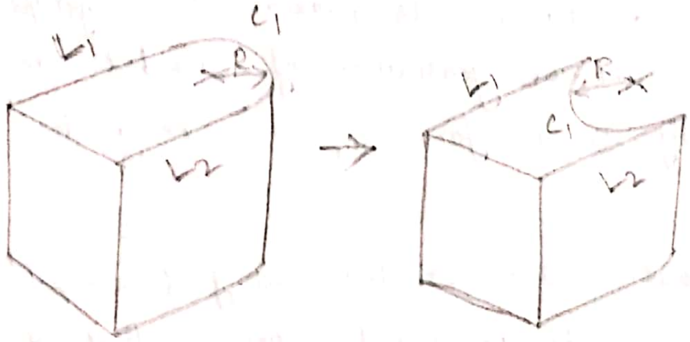
$[P]$ = Geometric coefficient matrix or boundary condition matrix.

$[M_{Bez}]$ = Bezier matrix.

2.13 Solid Modeling

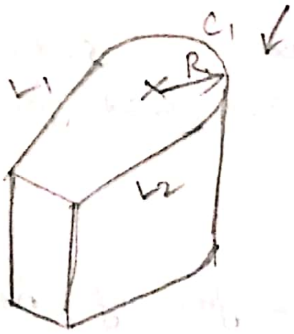
Solid modeling is the most powerful 3D modeling technique. Solid models are considered as complete, valid and unambiguous representation of objects. In many applications, it is important to distinguish between inside, outside and surface of a 3D object.

Solid models can be quickly created without having to define the individual location as in case of wireframe models. Inmany cases, creating solid models are easier than wireframe or surface models.



Same geometry -
Different topology

~~Different geometry~~



Different geometry - Same topology

Solid models should contain two types of information such as metric or geometric data and connectivity or topological data. The geometric data relate to the coordinate positions of the entities of the object or actual dimensions that define entities of the object. The topological data refers the connectivity and associatively of the object entities.

2.13.1 Solid Model representation:

There are three different forms in which a solid models can be represented in CAD.

a. Wire frame model
b. Surface model
c. Solid model.

a. Wire frame models:

Joining points and curves creates wireframe models. These models can be ambiguous and unable to provide mass property calculations, hidden surface removal or generation of shaded images. Wireframe models are mainly used for a quick verification of design ideas.

b. Surface models:

Surface models are created using points, lines & planes. A surface model is unable to identify points that do not lie on the surface, and therefore, the moment of inertia, volume or sections of the model cannot be obtained. Surface models are used for modeling surfaces of engineering components.

c. Solid models:

Solid models are the most preferred form of CAD models and they represent unambiguous image of a component. A solid model can be used to analyze the moment of inertia, mass, volume, sections of the model.

2.13.2: Solid Modeling Entities

Solid modeling entities are building blocks which are also called primitives.

Block

Cylinder

Sphere

Cone

Wedge

Torus

Basic Solid Primitives

a. **Block:** It is a cuboid or box which is represented by its width, height and depth.

b. **Cylinder:** It is a right circular cylinder whose geometry is defined by its radius or diameter and length.

c. **Cone:** It is a right circular cone or frustum of a right circular cone whose geometry is defined by its base radius, top radius and height.

d. **Sphere:** It is defined by its radius or diameter and it is centered about the origin.

e. **Wedge:** It is a right angled wedge whose geometry is defined by its height, width and base depth.

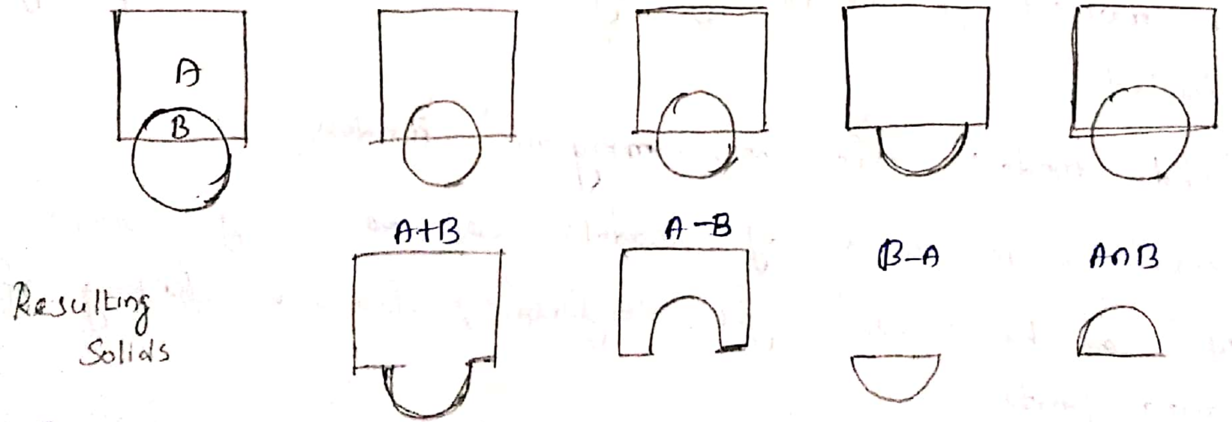
f. **Torus:** It is generated by the revolution of a circle about an axis lying in its plane. The geometry can be defined by both inner radius and outer radius.

2.13.2: Solid modelling approaches:

These are two different types of solid modeling approaches: Primitives based modeling and feature based modeling.

In primitive based modeling, designers use the predefined primitives described above to create complex solids. Designers must use Boolean operations to combine the primitives and produce the required shape.

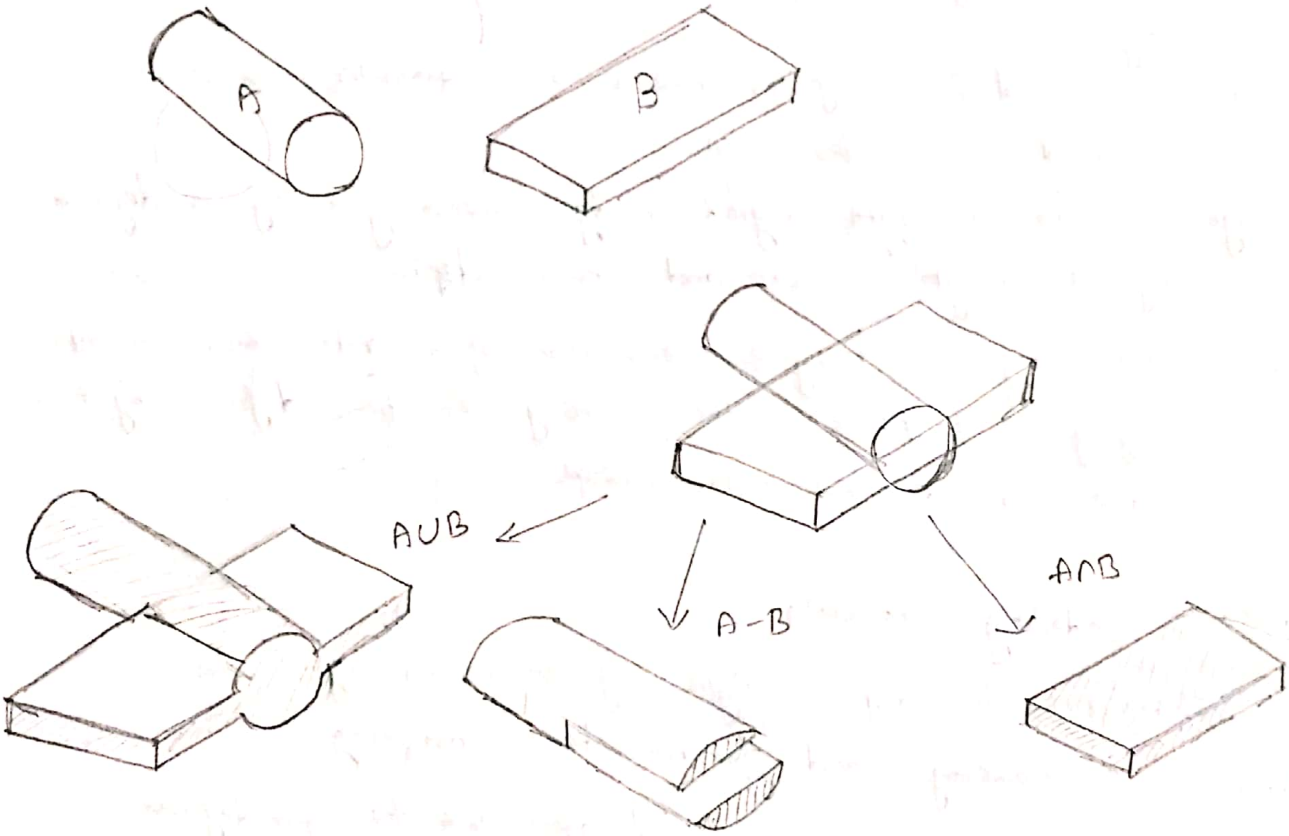
2D Boolean operations



a) Primitives b) Union c) Subtraction d) Intersection.

Feature based modeling is more flexible because it allows the construction of more complex shapes and it elaborates solids more readily than the Primitive based modeling. Here also, Boolean operations are used but they are hidden from the user.

3D Boolean operations



2.13.3: Advantages of Solid modeling:

1. Mass properties such as area, volume, weight, center of gravity and moment of inertia of physical model can be quickly calculated.
2. Solid models are un-ambiguous models.
3. Cross-section views of models can be easily obtained.
4. It can be used for interference / clearance checking of moving parts.

5. Aesthetic look of finished object can be visualized in the computer screen itself with colour shading, high lighting and facilities available in solid modelers.

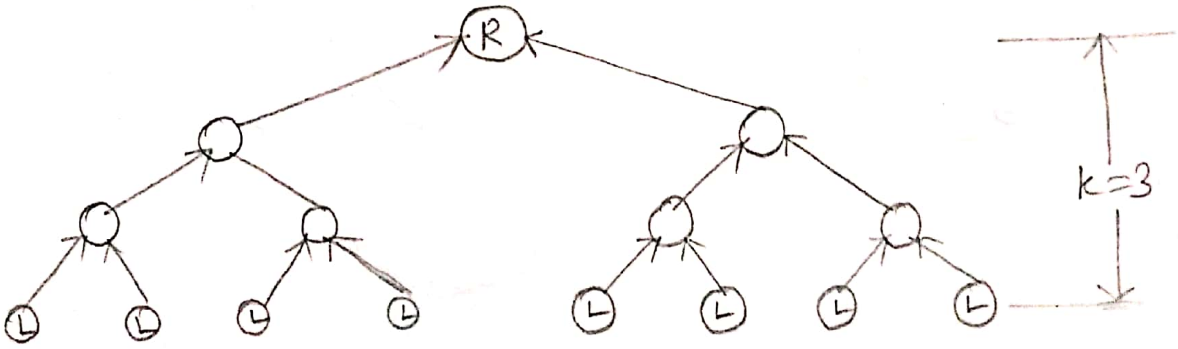
6. Different views of object (Isometric, Perspective & Orthographic view) can be obtained easily.

7. Solid Model is very much useful for finite element analysis.

8. They can help to produce NC machining instructions automatically.

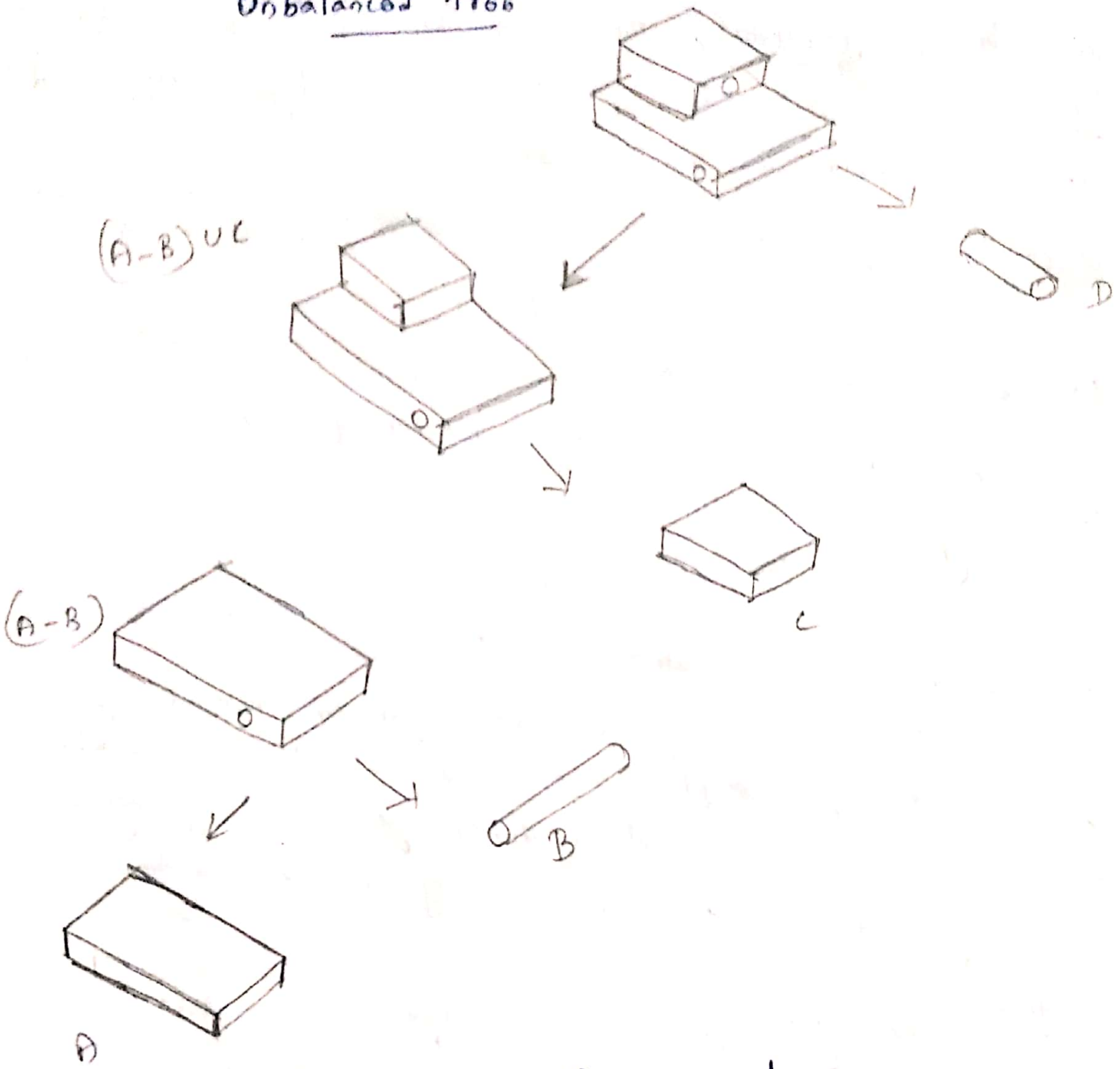
2.14: Constructive Solid Geometry (CSG)

CSG is one of the most popular methods of representing and building complex solids. In this scheme, simple primitives are combined in certain order by means of regularized Boolean set operators which are directly included in the representation. The type of Boolean operations is used in CSG are Union (∪), difference (−) and intersection (∩). The data representation of CSG objects is represented by a binary tree. The root node (R) has no parent and leaf node (L) has no children. The binary tree gives the complete information of how individual primitives are combined to represent the object.

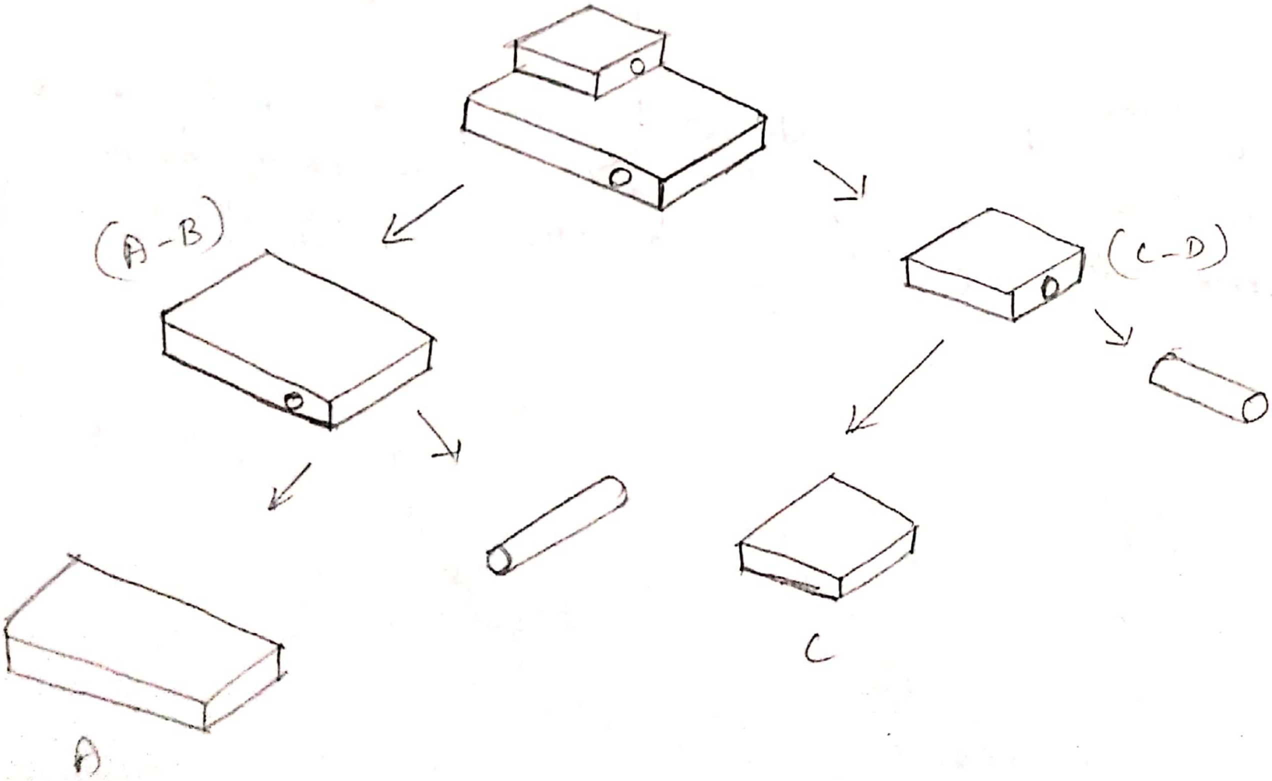


R= Root node
L= Leaf node

Unbalanced tree



Balanced tree



for example to create a model as shown in fig. four primitives two rectangular blocks and two cylinders are required. to create the final object following Boolean operation has to be carried out.

$$Object = (A-B) \cup (C-D)$$ — Balanced tree.

Advantages:

1. Since, the data to be stored are less and the memory required will be less.
2. It creates fully valid geometrical solid model.
3. Complex shapes may be developed relatively quicker with the available set of primitives.
4. Less skill is enough.
5. The data file of CSG is concise.
6. CSG is more user friendly.
7. Algorithms for converting CSG into B-rep have been developed.

Disadvantages:

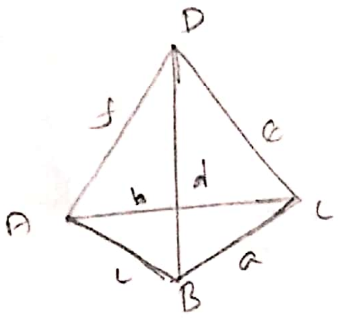
1. More computational effort and time are required whenever the model is to be displayed in the screen.
2. Getting fillet, chamfer and taperness in the model are very difficult.
3. The validity of a feature of an object cannot be assessed without evaluating the entire tree.
4. The tree is not unique for the same part design.

2.15: Boundary Representation (B-Rep)

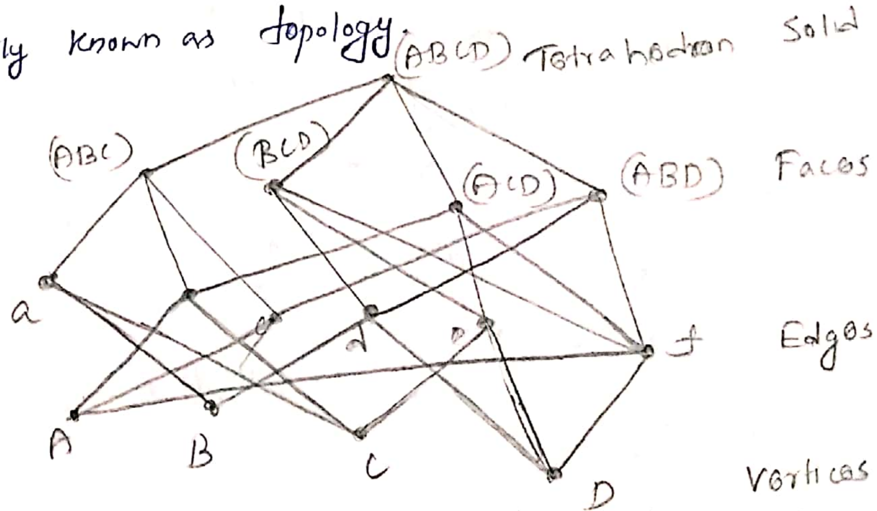
This approach is widely used in most of the solid modelers. This scheme describes an object in terms of its surface boundaries: vertices, edges, and faces.

The solid models created by using B-rep technique may be stored in graph based on data structure system.

The tetrahedron is composed of four vertices namely, A, B, C & D. The coordinates of these vertices is stored in the database. The following figure(b) shows how the vertices are connected to form edges (a, b, c, d, e & f) and how these edges are connected together to form the face (ABC, BCD, ACD, ABD) which makes the complete solid of tetrahedron. This connectivity to form the solid is popularly known as topology.



a. Tetrahedron



b. Graph based data structure of tetrahedron.

For topological consistency, certain rules have to be followed.

a. Faces should be bound by a simple loop of edges and they should be not intersected by itself.

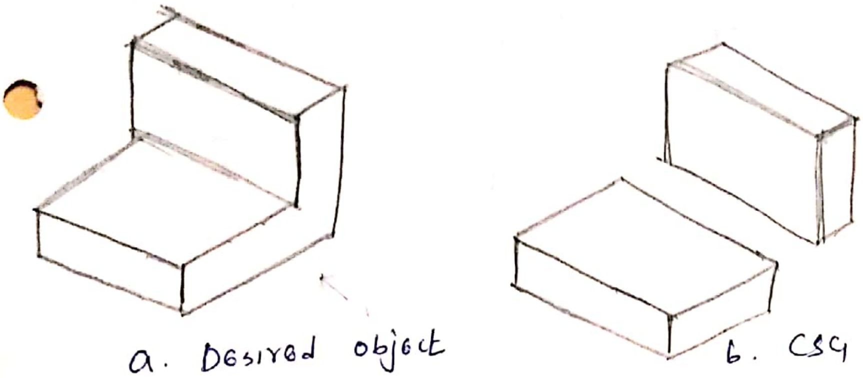
b. Each edges should exactly adjoin two faces and each edge should have a vertex at each end.

c. At least three edges, it should meet at each vertex.

The two important areas for B-rep models are the topological and geometrical information.

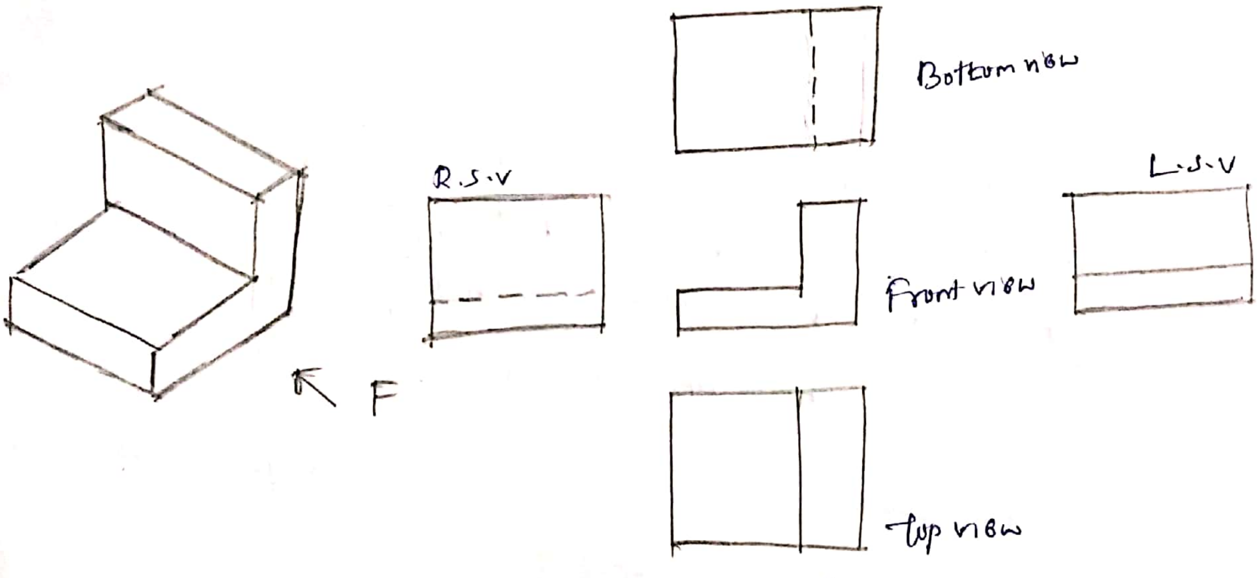
Topological information provides the relationship about vertices, edges and faces. In addition to connectivity, topological information also includes the orientation of edges and faces.

Geometric information is usually in terms of equations of the edges and faces.



a. Desired object

b. CSG information



c. B-rep information

Comparison of CSG & B-rep information (First angle projection is followed)

Advantages

1. Computational effort and time required to display the model are less compared with CSG.
2. Combining wire frame and surface model are possible.
3. Complex engineering objects can be easily modeled compared with CSG. Examples are aircraft fuselage and automobile body styling.
4. The information is complete especially for adjacent topology relations.
5. This format gives efficient picture generation and easy access to other geometric information.
6. The B-rep model is widely used due to the number of basic primitives available is limited in CSG.

Disadvantages:

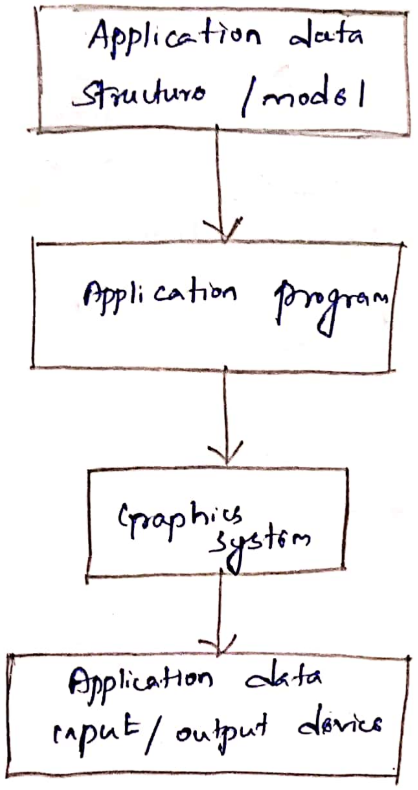
1. The data to be stored is more and hence, it requires more memory. So it is not suitable for tool path generation.
2. Sometimes, geometrically valid solids are not possible.
3. It is generally less robust than the half-space method.
4. The data structure of B-rep is complex compared to CSG.
5. Conversion of CSG to B-rep is possible. At the same time, the conversion for B-rep to CSG is impossible.

UNIT III

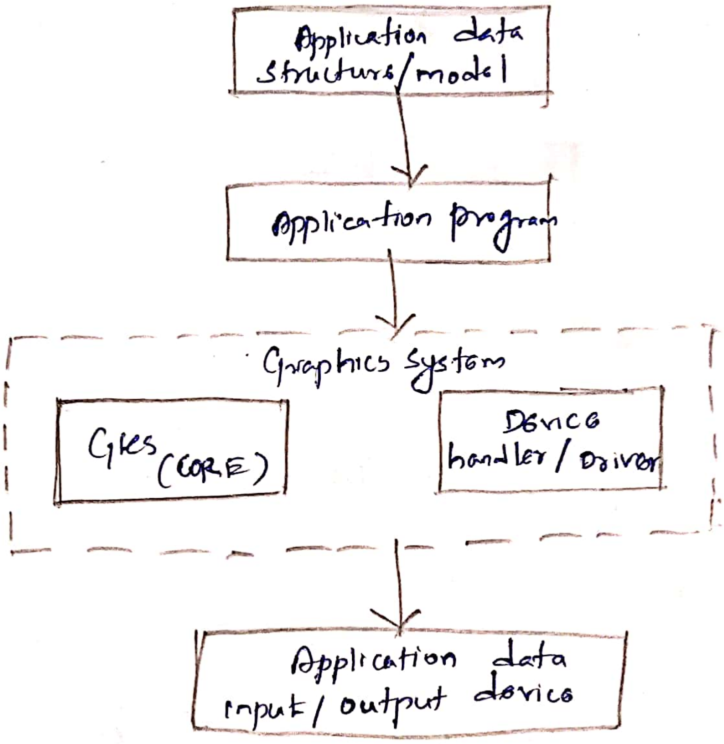
CAD STANDARDS

3.1. Introduction to CAD Standards:

A large number of applications are used in CAD/CAM manufactured by various vendors. Initially, the critical concern with CAD & CAM was the communication of design & manufacturing data within the engineering organization. So, there was a need to create standards in CAD.



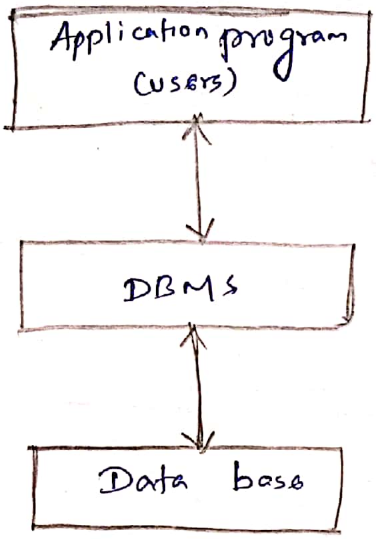
Organization of a typical CAD/CAM structure without graphics standards



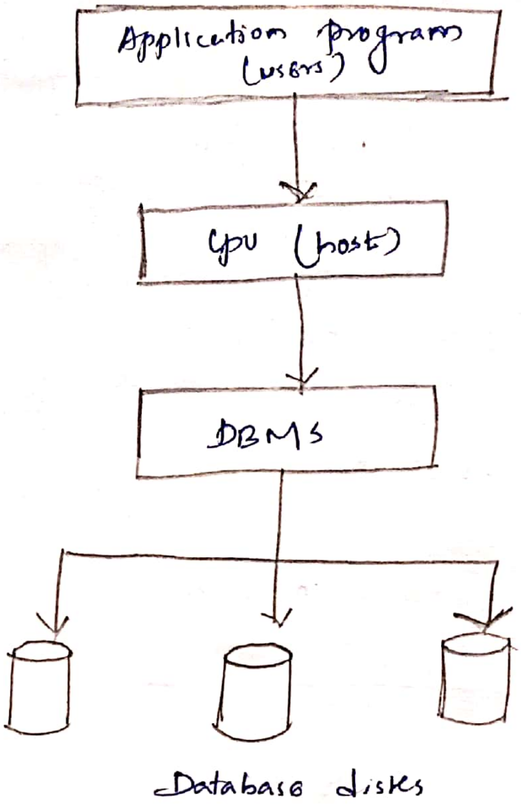
Organization of a typical CAD/CAM structure with graphics standards

3.2. Database Management:

Database is a collection of data at a single location to be used by various people for different applications.



a. Simplified DBMS



b. A typical DBMS

Objectives of database:

i. It reduces or eliminates redundant data.
ii. It integrates the existing data
iii. It provides Security
iv. It shares the data among users.
v. It incorporates the changes quickly and efficiently.
vi. It exercises effective control over data.
vii. It simplifies the method of using data.
viii. It reduces the cost of storage and retrieval of data.
ix. It improves accuracy & integrity of data.

3.3: Standards for computer graphics:

Need for graphics standards:

i. There is a need for the portability of geometric model among different hardware platforms.

ii. Where there is a situation to exchange drawing database among software packages.

iii. There is a need for exchanging graphic data between different computer systems.

iv. To understand the graphic Kernel system and its extensions for developing the graphic software systems.

v. There is a need for the requirements of graphic data exchange formats and their details such as IGES, DXF & STEP.

vi. Dimensional measurements interface specification for communication is b/n coordinate measuring machine and CAD data.

There are interface standards at various levels as follows:

- GKS (Graphical Kernel System)
- PHIGS (Programmer's Hierarchical Interface for Graphics)
- CORE (ACM - SIGGRAPH)
- GKS -3D
- IGES (Initial Graphics Exchange specification)
- DXF (Drawing Exchange Format)
- STEP (Standard for the Exchange of Product Model Data)
- DMIS (Dimensional Measurement Interface specification)
- ~~SEEP~~ VDI (Virtual Device Interface)
- VDM (Virtual Device Metafile)
- GKSM (GKS Metafile)
- NAPLPS (North American Presentation Level protocol Syntax).

3.4. Classification of CAD standards:

1. Graphics and computing standards
2. Data exchange standards
3. Communication standard.

1. Graphics and computing standards

Aim:

i. To provide the versatility in the combination of software and hardware items of turnkey systems.

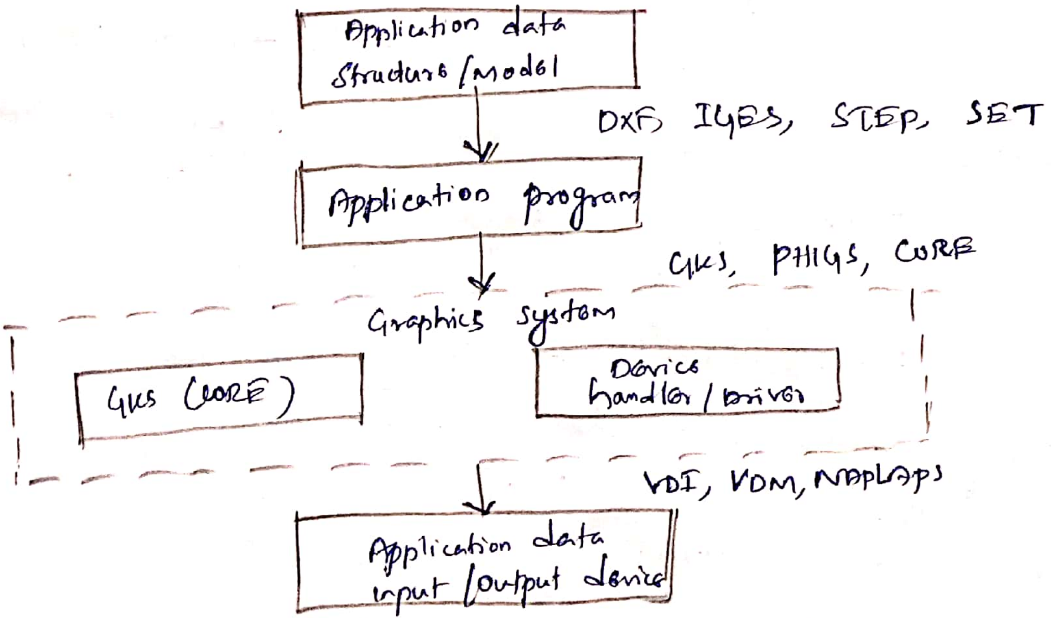
ii. To allow the creation of portable application software package, applicable for the wide range of hardware makes and configurations.

iii. To allow the transfer of graphic data between two or more different companies which may completely have different CAD systems.

iv. To provide the complete range of graphical facilities in 2D including the interactive capabilities.

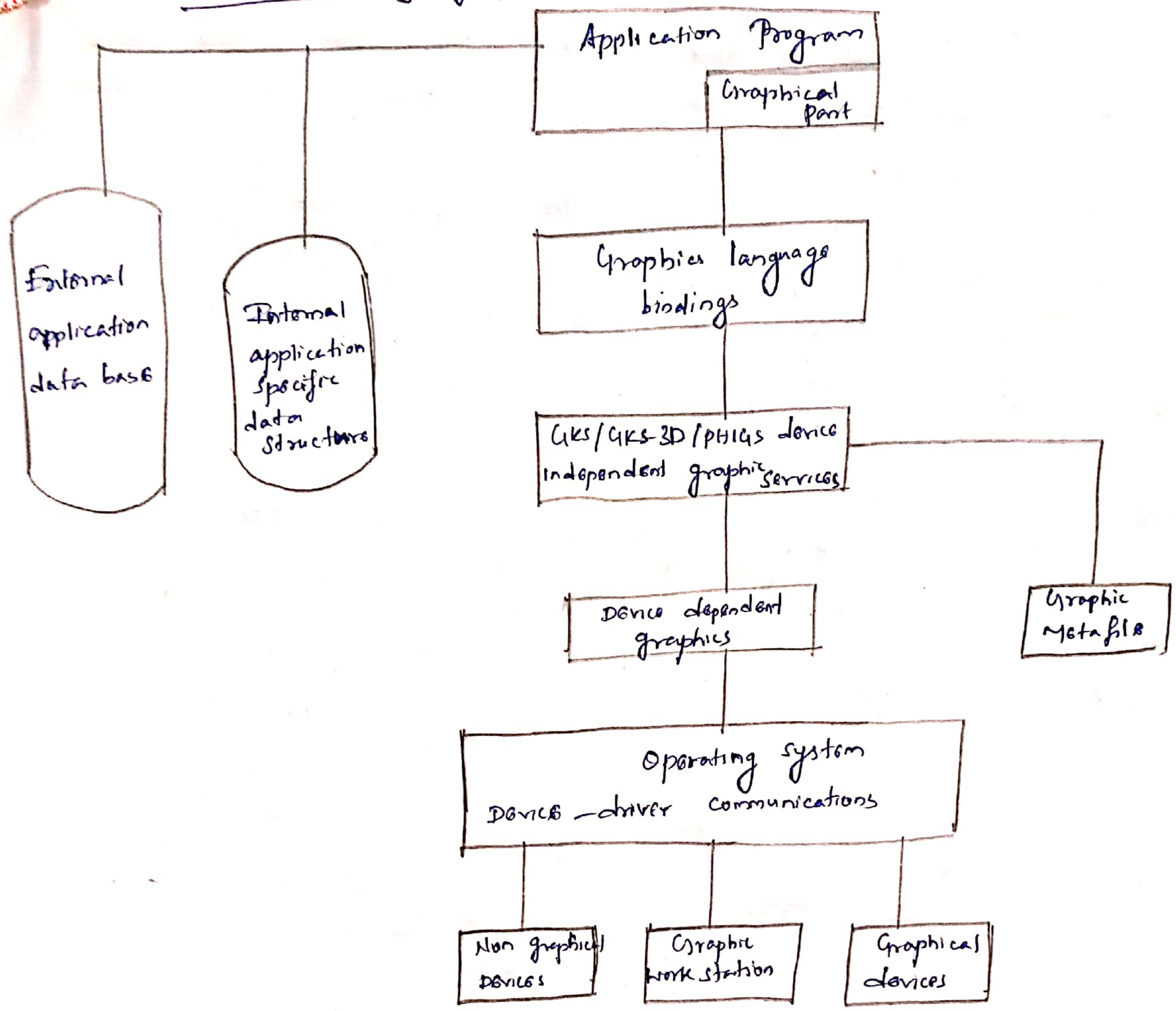
v. To control all type of graphic devices such as plotters and display devices in a consistent manner.

vi. To be small enough for a variety of programs.



Working of Graphics Standard.

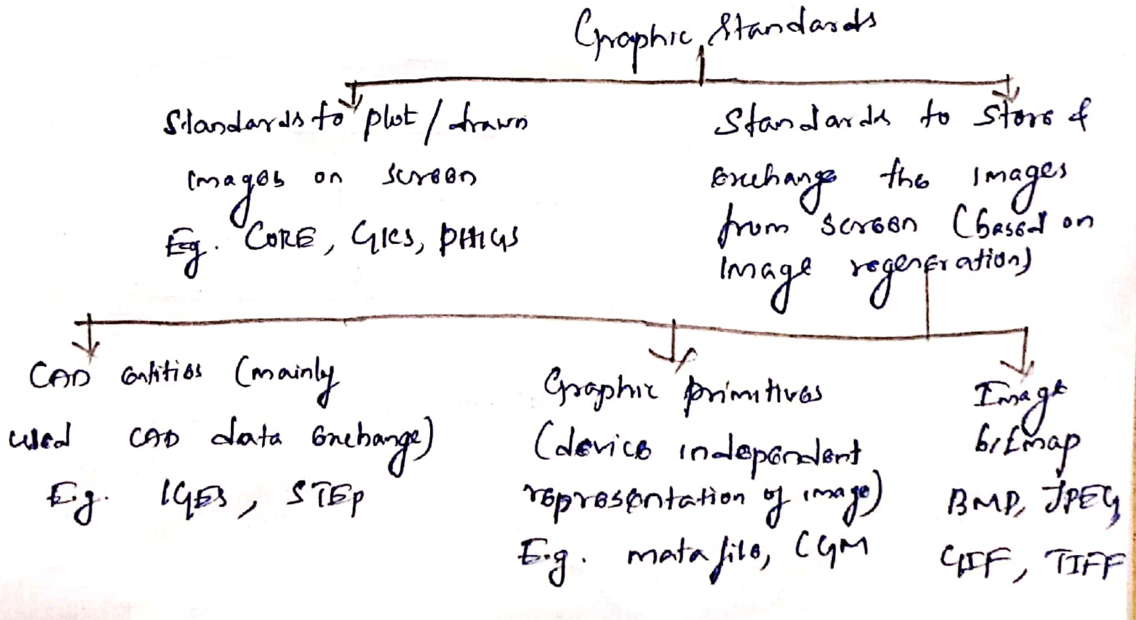
Overall Structure of graphics Standards



Types of Graphics Standards:

i. GKS
ii. PHIGS
iii. CORE
iv. GKS-3D
v. IGES

Classification of graphics Standards based on functions



3.5. Graphics kernel system (GKS)

GKS is basically a set of procedures which can be called by user programs to carry out certain generalized functions such as arc, ellipse, circle etc.

GKS is defined in terms of number of levels describing the level of support in terms of facilities.

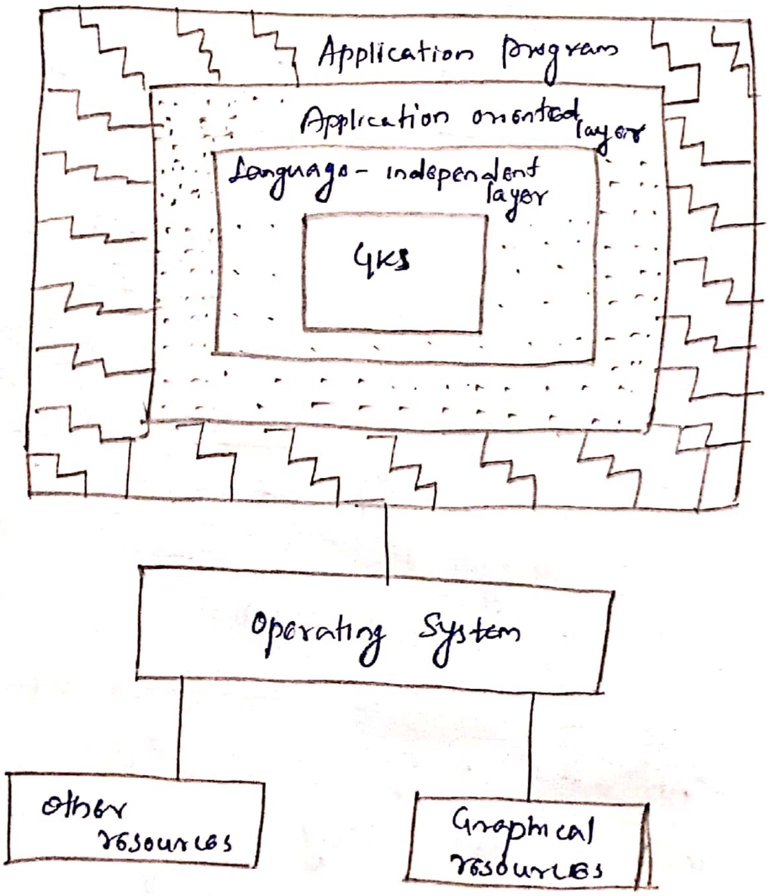
GKS is a form of computer language which consists of set of commands for graphical operations.

GKS was developed in Europe & standardized in 1985.

It is strongly influenced by CORE - 2D graphics. It is a standardized system of graphical functions for processing graphical data to create and process 2D images.

It covers 3D graphics through GSK -3D.

Layer model of graphics kernel systems



3.5.1 Features of GKS:

i. It is an independent device, so, it can work with all types of input and output devices.

ii. All text and annotation can be prepared and stored in natural languages.

iii. Graphic functions are defined for both 2D & 3D.

iv. It includes all types of display elements.

v. GKS supports picture data into two routines.

vi. ~~GKS~~ GKS defines an international coordinate system called normalized device coordinates.

3.5.2 Coordinates in GKS

three coordinate system are used in GKS such as

i. World coordinates (WC)
ii. Normalized device coordinates (NDC)
iii. Device Coordinates (DC)

3.5.3 Classification of GKS:

GKS is classified into eight categories depending on their functions such as

i. Control functions
ii. Output attributes
iii. Output primitives
iv. Segment ~~for~~ functions.
v. Transformations
vi. Input functions
vii. Metafile functions
viii. Inquiry functions.

3.5.4 GKS Primitives:

Two basic items of an object in GKS ~~such~~ such as Primitives & attributes.

i. **Primitives:** The basic or elementary graphical object units which consists of one or a combination of to form a complete graphical object.

ii. **Attributes:** The features or characteristics of a primitives are called attributes. If circle is a primitive, its attributes may be colour, line width & line type.

Bar Arc Pie Slice circle

Primitives

Mainly five output primitives involved in GKS as follows:

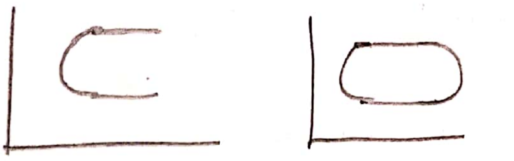
i. Polyline — It includes colour, line type or width of line & color of the line.

ii. Polymakers — The maker attributes may size, colour etc.

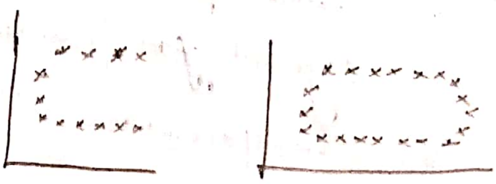
iii. Text — It contains Text content, path of font, font annotative, font alignment, font size, colour of fonts, height of fonts, type of font, spacing b/n fonts, etc.

iv. Fill area — Hollow fill, solid fill, pattern fill or hatch fill, colour of fill area etc.

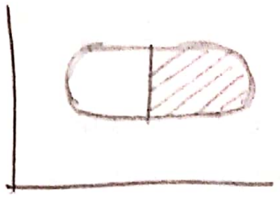
v. Cell Array



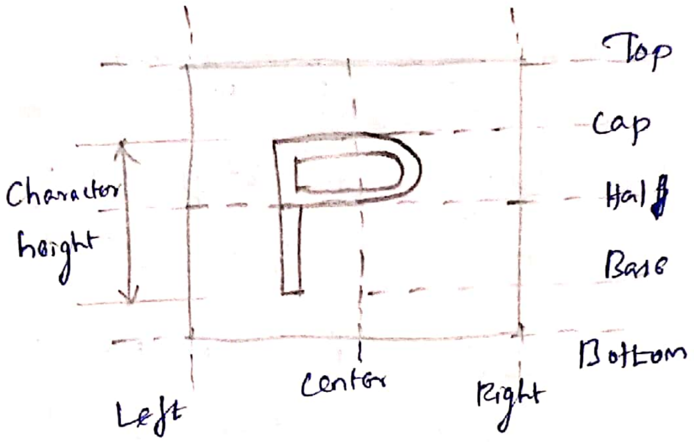
Polyline (N, XPTS, YPTS)



Polymaker (N, XPTS, YPTS)



Fill area (N, XPTS, YPTS)



Text

.5.5 GKS Inquiry functions

These functions are used to find the current status of any variable in GKS.

In GKS, segments are treated by segment functions. So the available segments are as follows.

i. Segment storage:
It store a segment.

ii. Segment creation, deletion & renaming:
It creates, deletes & renames a created segments.

iii. Segment name:
It defines the name of segments.

iv. Segment association, copying & insertion.
It defines the attributes of selected segments. The attributes are visibility, highlighting, priority, detectability etc.

v. Pick identifier:
It defines the identifier to pick a particular segment of image.

vi. Segment redrawing:
It forces any segment for redrawing.

3.5.6: GKS Input functions:

i. String: A set of string of character values is modeled by the action of a keyboard.

ii. Choice: It simulate a selection among several possibilities offered by the bank of buttons of a keyboard or a mouse or any other input devices. In choice, the integer options are 0,1,2,3. etc.

iii. Valuator: It performs the logical function to generate a value between 0 & 1 by simulating the adjustment of any knob between two specified limits. In valuator, the real values are specified in terms of distances.

iv. Locator: It functions to locate a device such as mouse or light pen from point to a specific location. It helps the device to enter into the world coordinates.

v. Stroke: It provides the location values continuously in world coordinates. It is an extension of a locator which generates the sequence of marked points.

vi. Pick: It helps to select the object or segment in drawing which is already drawn.

Some concepts are introduced in GKS such as

1. Logical input modes — Request, sample, Event.
ii. Logical workstation
iii. GKS Meta files
iv. GKS – 3D. — Store, retrive & display the graphical data

3.6. Standards for Exchange images.

the images can be exchanged by using open graphics library standard.

3.6.1 Open Graphics library (Open GL)

Open GL is a cross language multi-plat form application programming interface (API) for rendering 2D & 3D vector graphics.

API is a typically used to interact with a Graphics Processing unit (GPU) to obtain hardware accelerated rendering. Silicon Graphics Inc (SGI) started developing Open GL in 1991. It is extensively used in the fields of CAD, virtual reality, scientif. visualization, information visualization, flight simulation and video games.

features of open GL:

i. Based on IRIS GL:

Open GL is supported on silicon graphics Integrated Rater Imaging System (IRIS) Graphics library (IRIS GL).

ii. Low-level:

A critical target of open GL is to suggest device independence while still permitting the total contact to hardware.

iii. Fine-Grained Control

Due to minimize the needs of application utilizing, the Application Programmable Interface (API) must save and Present its information.

iv. Modal: A modal API arises in executions in which Processes function in parallel on various primitives.

v. Frame buffer:

Most of Open GL requires the graphics hardware along with a frame buffer because almost all interactive graphics run on systems with frame buffers.

vi. Not programmable:

Open GL does not not provide a programming language.

vii. Geometry and images:

Open GL supports to manage both 2D & 3D geometry.

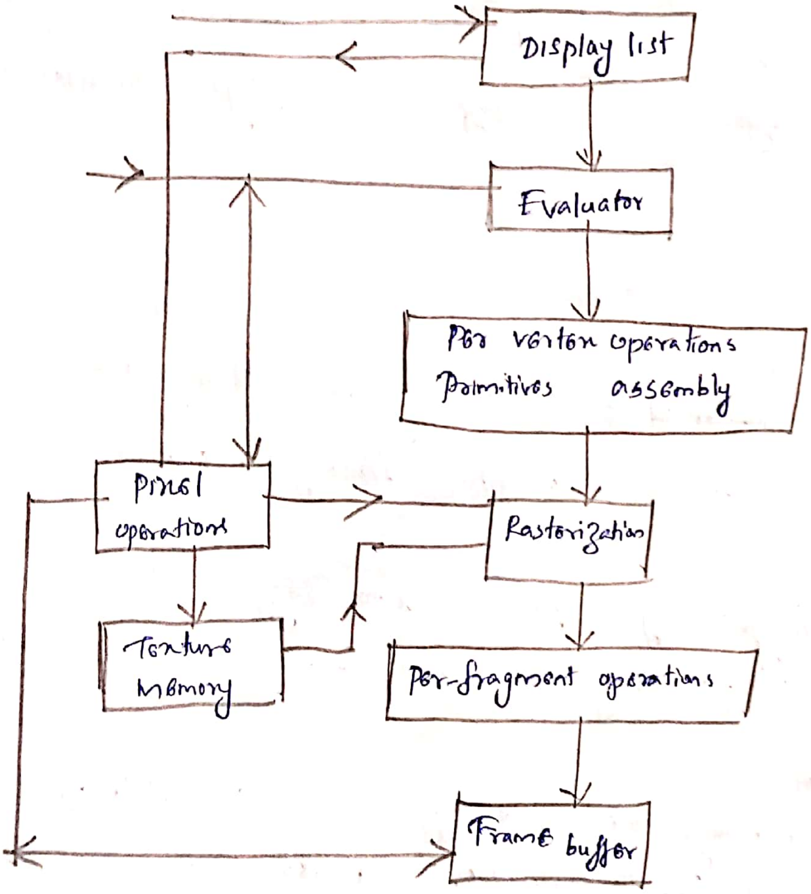
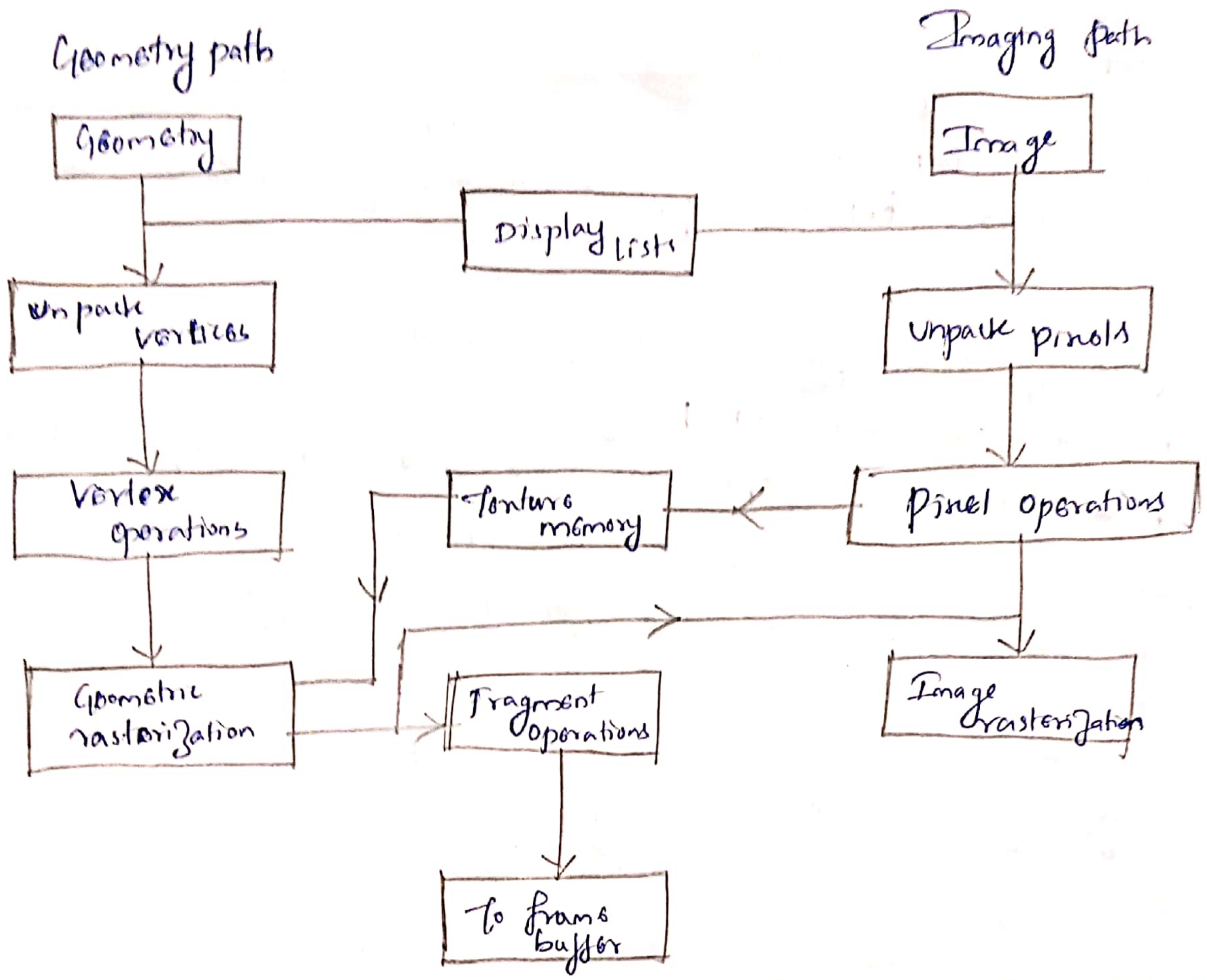


Image exchange using Open GL

i. Documentation
ii. Associated libraries
iii. content and window toolkits:
iv. Extension loading libraries
v. Implementation
vi. Most widely adopted graphics standard
vii. High visual quality & performance
~~v. Implementation~~



OpenGL operates on image data as well as geometric Primitives.

Advantages of Open GL

i. Industry standard
ii. Stable
iii. Reliable + portable
iv ~~Evo~~ Evolving
v. Scalable
vi. Easy to use
vii. Well-documented
viii. Simplified software development, speeds time-to-market.

3.7 Data Exchange standards:

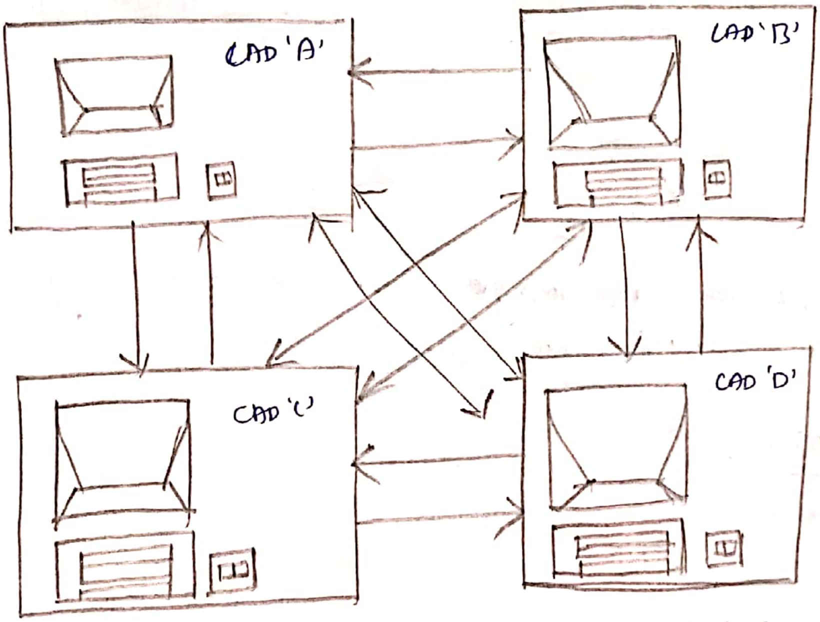
Data exchange refers to the share geometric data between locations, between different proprietary modelers and between CAD/CAM systems.

The following reasons for exchanging the data are that

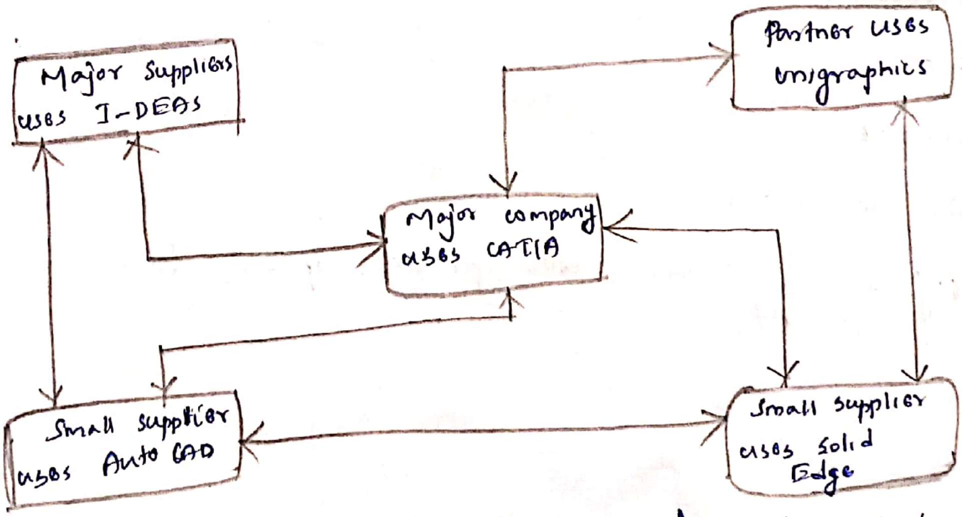
i. All use the same CAD package.

ii. Special translator applications are used to change the data from one format to specific one needed.

iii. A neutral format is used for data exchange.



Data exchange between various systems



Need of standardization for data exchange

3.7.1 Requirements of Data Exchange:

i. Shape data: It contains both geometric and topological information, part or form features, Fonts, color and annotation are part of the geometric information.

ii. Non-shape data: It has graphics data such as shaded image and model global data as measuring units of the database and the resolution of storing the database numerical values.

iii. Design data: It consists of information about the designer's generation data from geometric models for the analysis purposes. Mass Property and finite element mesh data belong to this type of data.

iv. Manufacturing data: It is the information as tooling, NC tool paths, tolerancing, process planning, tool design and bill of materials. For example, the model can be created in Pro-E and generated geometric data. The generated geometric data needs to be exchanged to analyse the model.

Pro-E → ANSYS.

3.7.2: Methods of Data Exchange

i. Direct CAD system export/import

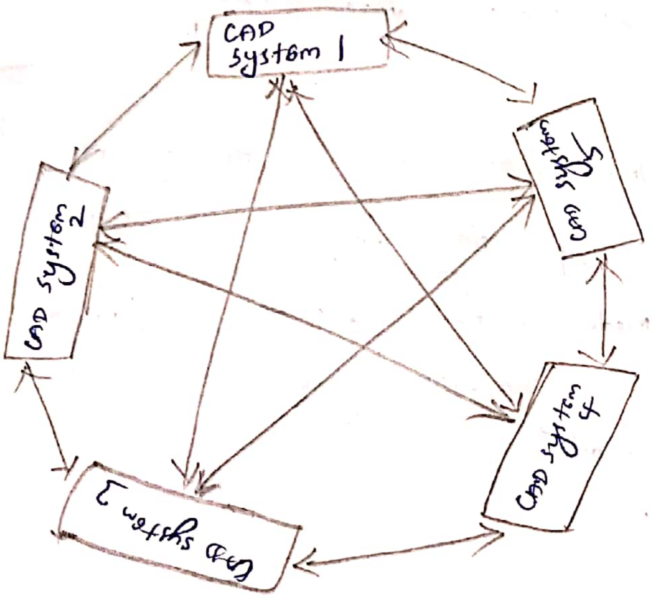
The data is exchanged based on the concept of one to one relationship. Some CAD systems can directly read or write other CAD formats by using the file open and file save as options. The problems of many file formats are to be supported. As most CAD file formats are not open, this option is limited to the CAD systems offered by the same software developer.

ii. Direct translation software:

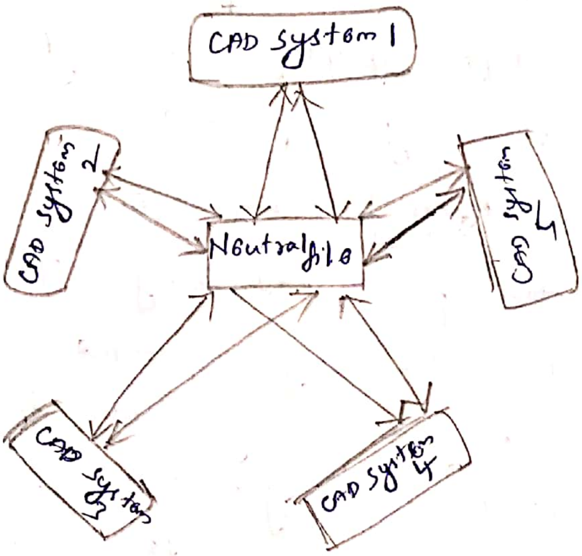
Companies who specialize in CAD data translation software provide which can read one system and write the information in another CAD system format. They have their own proprietary intermediate format. Some of these translators work stand-alone while others require one or both of the CAD software installed.

iii. Neutral data exchange format:

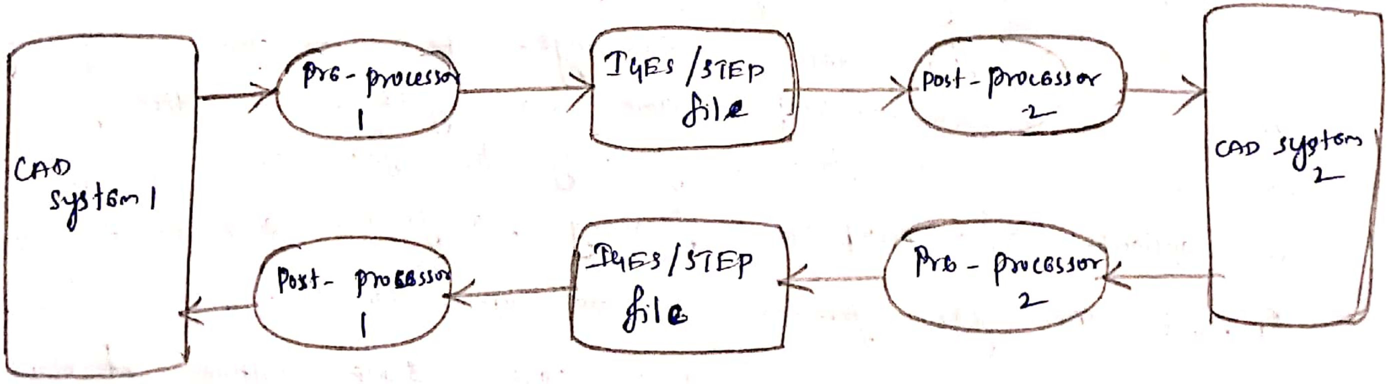
If three software packages are available, six translators are required among them. It will necessitate a large number of translators.



Direct CAD system export/import



Neutral data exchange format



CAD data exchange using neutral files

3.7.3 Approaches in Data Exchange format

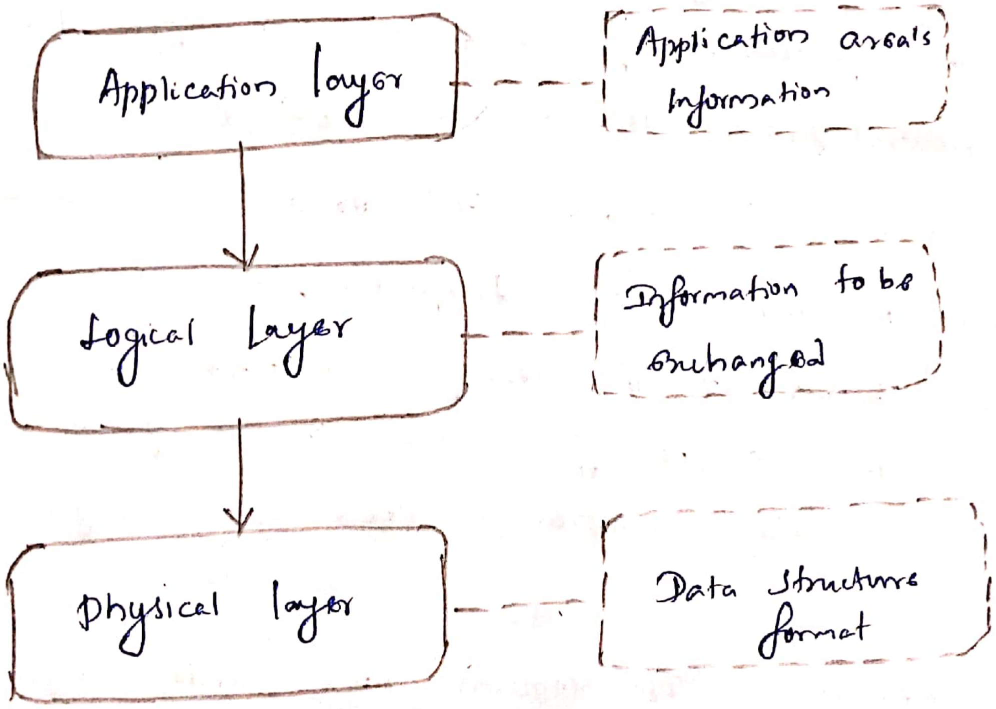
1. Shape based format

In this case, all data exchange files are neutral files. These files donot have any software specific function. It was developed by US Air force Boeing company.

Ex. DXF & IGES are shaped format.

2. Product data based format:

Initial effort US Air force led to obtain Product Data Defined Interface (PDDI) and STEP (Standard for transfer and Exchange of product data). Some other formats are identified as Standard Product Data exchange format (SDF), Electronic Design Interface format (EDIF) & Product Data exchange using step (PDES).



Three layered architecture for Product data exchange

3.7.4: Classification of Data Exchange standards or Neutral file formats.

1. IGES
2. STEP
3. DXF
4. STL

3.8. IGES – Initial Graphics Exchange Specification

It is mainly for CAD data exchange. IGES was developed by U.S. National bureau of Standards in 1979 and developed a version of IGES is controlled by IGES organization.

It exchanges primarily shape and non-shape data which is referred as CAD to CAD exchange.

The basis for IGES is to store a file detail of entities to be transferred between systems. IGES also allows the compressed ASCII format and binary files. Every software supporting IGES will have the processor software to translate from their software to IGES neutral file. It requires a file of 80 columns. First 72 columns are data column. 73rd to 80th columns are for the sequence number with identification for data.

IGES works at the level of application database structure. It is based on the concept of entities such as points, lines, circles, and surfaces etc. These entities in IGES are classified into three types.

a. Geometric entities: It contains lines, circles, surfaces etc.

b. Annotations entities: they contain ~~of~~ additional information such as dimensions, blocks, additional notes etc.

c. Structure entities: They have information required for the descriptions of objects to define how object is made using basic entities.

An IGES file consists of the following file sections

i. Flag: It is optional one and used to denote the form in which the data is specified.

ii. Start section:
It contains a man readable prologue file. It assists the user at the destination such as features of orginating of a system. It is used for initializing the IGES file.

iii. Global section: It contains details about the product, organization, software, date, etc. They are necessary to translate the file from any graphic software to other graphic software.

iv. Directory section: It contains attribute informations such as color, line type etc. It references the entities and necessary data required for entities which are given on the next section.

v. Parameter data section: It contains data associated with entities such as constraint details, co-ordinate value, font. etc.

3.9: STEP – Standard for Exchange of Product Model data

New CAD data standard is developed through world wide effort known as STEP in year 1997.

The ability to share data across applications, across vendor, platforms and between contractors, suppliers and customers is the main objective of STEP standard.

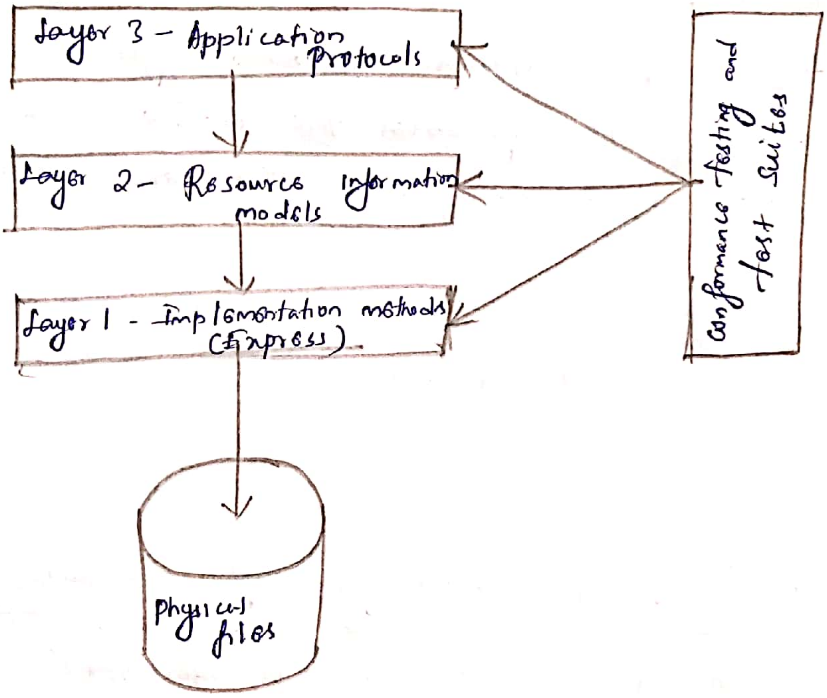
STEP seeks to address a number of limitations of IGES.

The broad scope of STEP is as follows:

1. The standard method of representing the information necessary to completely define a product throughout its entire life, i.e. from the product conception to the end of useful life.
ii. Standard methods for exchanging the data electronically between two different systems.

STEP uses the formal model for the data exchange which is described using an information modeling language called EXPRESS. It is both human readable and computer processable.

Three layer architecture of STEP



The STEP documentation has eight major areas which are described below

1. Introductory: It contains the details about general introduction and overview of the standard. It forms the part 1 of the ISO standard 10303. It comprises of part 1 which has overview and general principles.

2. Description method:

When compared to other standards, the application protocols are planned to reach vendors. So, a new descriptive formal information modelling language called EXPRESS is developed and defined. It is given in part 11 to 17.

3. Implementation method:

It describes how express map physical file and storage mechanisms are represented for the data exchange. It is given in part 21 to 26.

4. Conformance testing methodology and framework

It provides the methods for testing implementation and test suites to be used during conformance testing. It also gives the specifications for conformance testing of the processors, guidance for creating abstract-test suites and the responsibilities of testing laboratories. These details are given in part 31 to 35.

5. Integrated - generic resources:

It contains the specifications of the information models about generic resources such as geometry and structure representation. These details are given in part 41 to 99.

6. Application information models:

They specify the information models used for the particular application areas such as draughting, finite element analysis, kinematic, building core model and engineering analysis core. The details are given in part 101.

7. Application Protocols:

It describes implementations of STEP specific to a particular industrial application and they are associated with implementation methods to form the basis of a STEP implementation which provide test suites for each of the application protocol.

8. Application interpreted construct:

It describes the various model entity construct and specific modeling approach. They relate to the specific, resources useful for defining the generic structures useful for applications.

2.10 Continuous Acquisition and Life-cycle support (CALS)

It was developed by US department of Defense. It prescribes the formats for storage and exchange of technical data. It focuses mainly technical publications. It is also known as CALS, CAL, RAS.

Important CALS standards:

1. Standard Generalized Markup language (SGML) is an important standard. It was developed in 1960s IBM. It has the document description language. It separates content from structure. It uses 'tags' to define headings, sections, chapters etc. Mainly HTML is based on SGML.

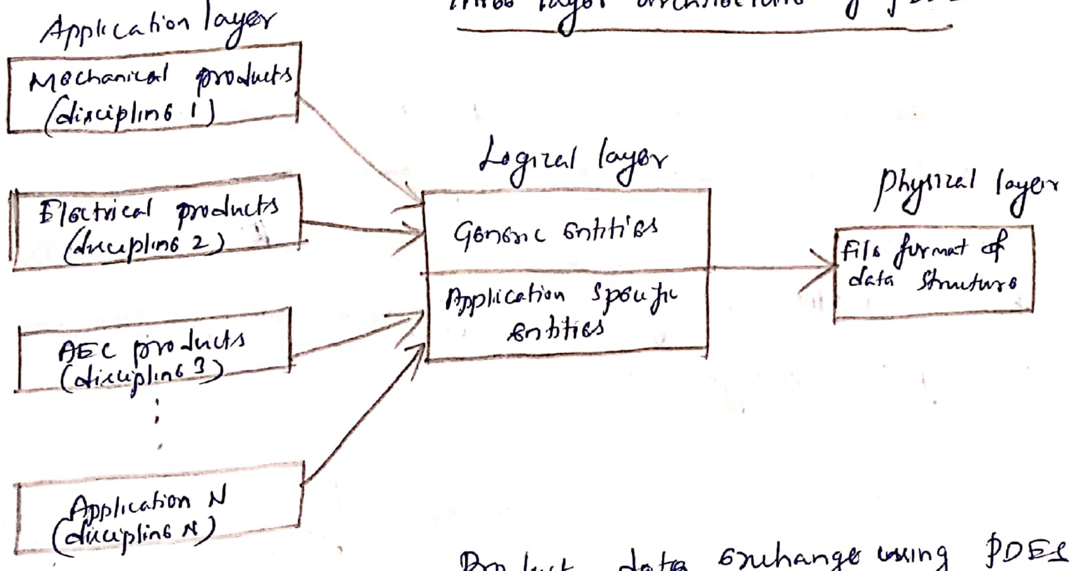
2. Computer Graphics Metafile (CGM) is the next important standard. It was developed in 1986. It is used for the vector file format for illustrations and drawings. All graphical elements can be specified in a textual source file which can be compiled into a binary file or one of two text representations.

CALS is an attempt to integrate text, graphics and image data into standard document architecture. Its ultimate goal is to improve and integrate the logistics functions of the military and its contractors

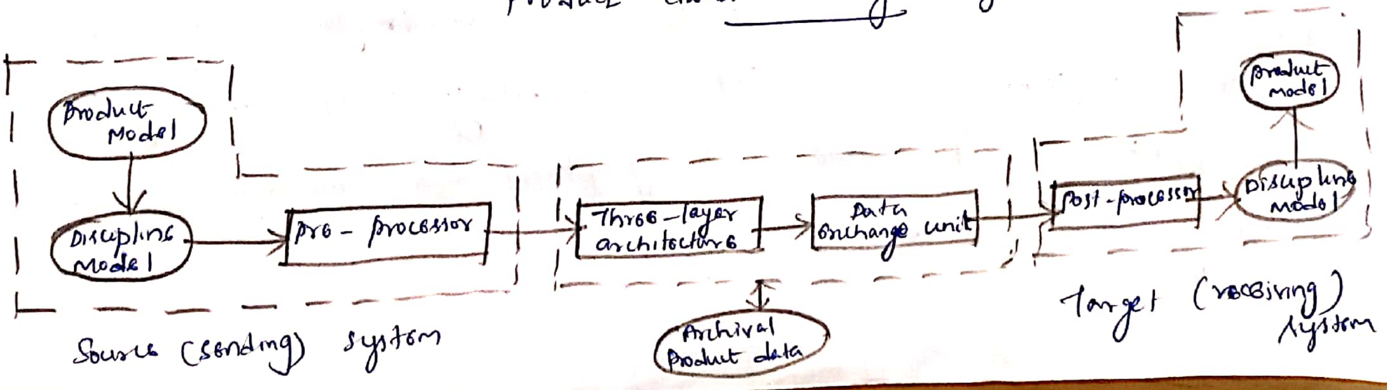
i. file details
ii. Header Record data book
iii. Image record Identifiers
iv. Source DocId
v. Dest DocId
vi. Text Field
vii. FigureId
viii. Source Graph
ix. Doc Class
x. Raster Type
xi. Orientation
xii. Pel count
xiii. Density

2.11. PDES – Product Data Exchange Standard

Three layer architecture of PDES

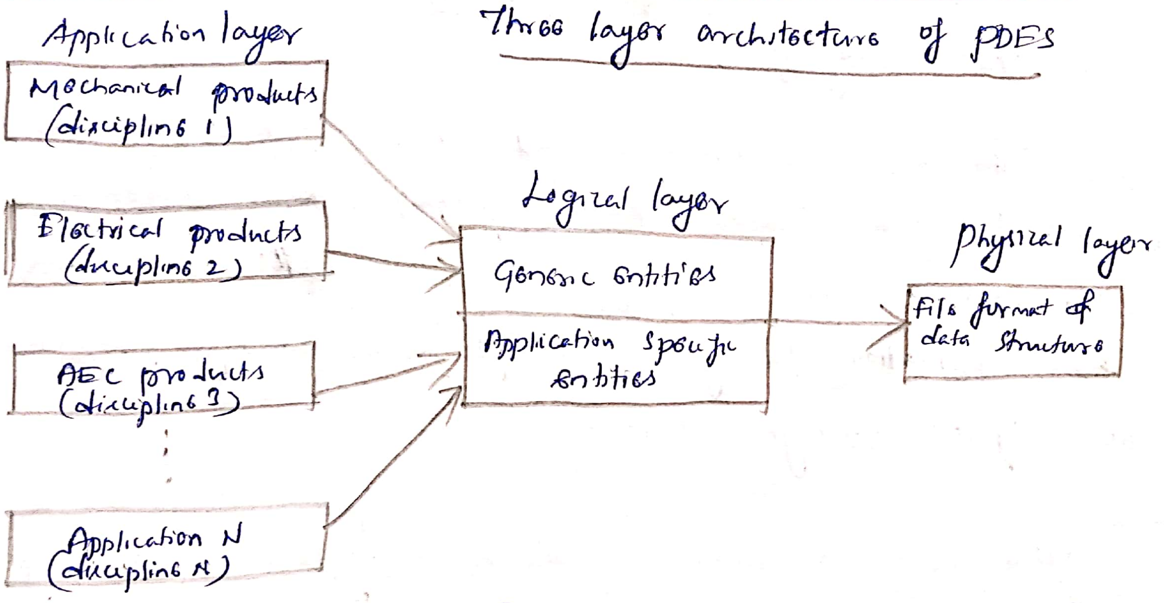


Product data exchange using PDES

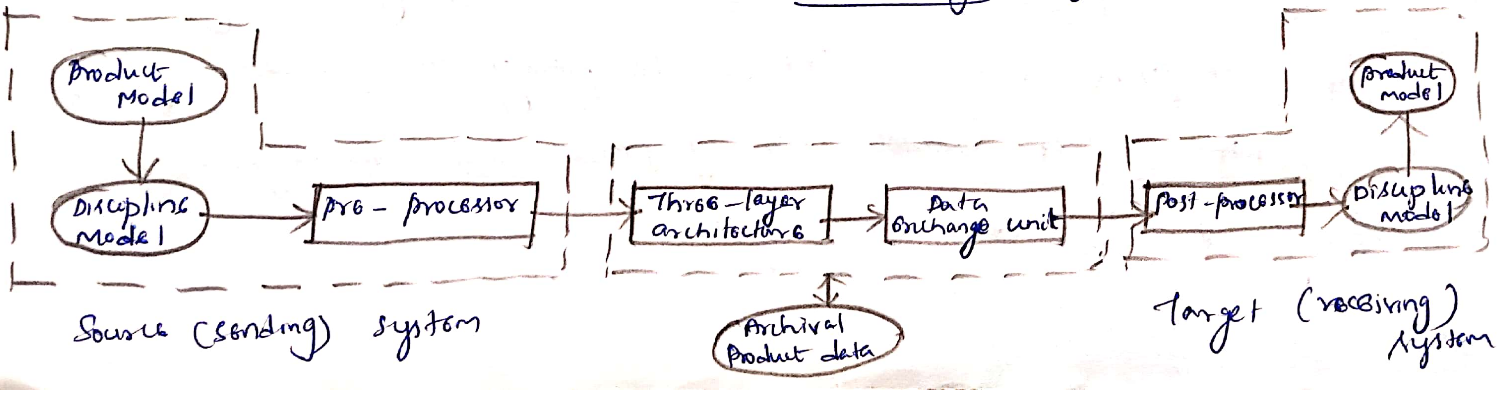


2.11. PDES – Product Data Exchange Standard

Three layer architecture of PDES



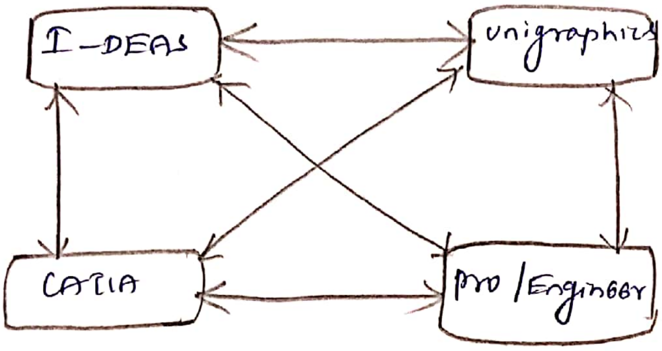
Product data exchange using PDES



3.12: Communication Standards

In local area network (LANs) & wide area networks (WANs), there are wide variations in physical means such as twisted pair or coaxial cables, optical fibre links, microwave links in format used to encode the data.

Data communication among softwares.



Levels of graphics standards communications:

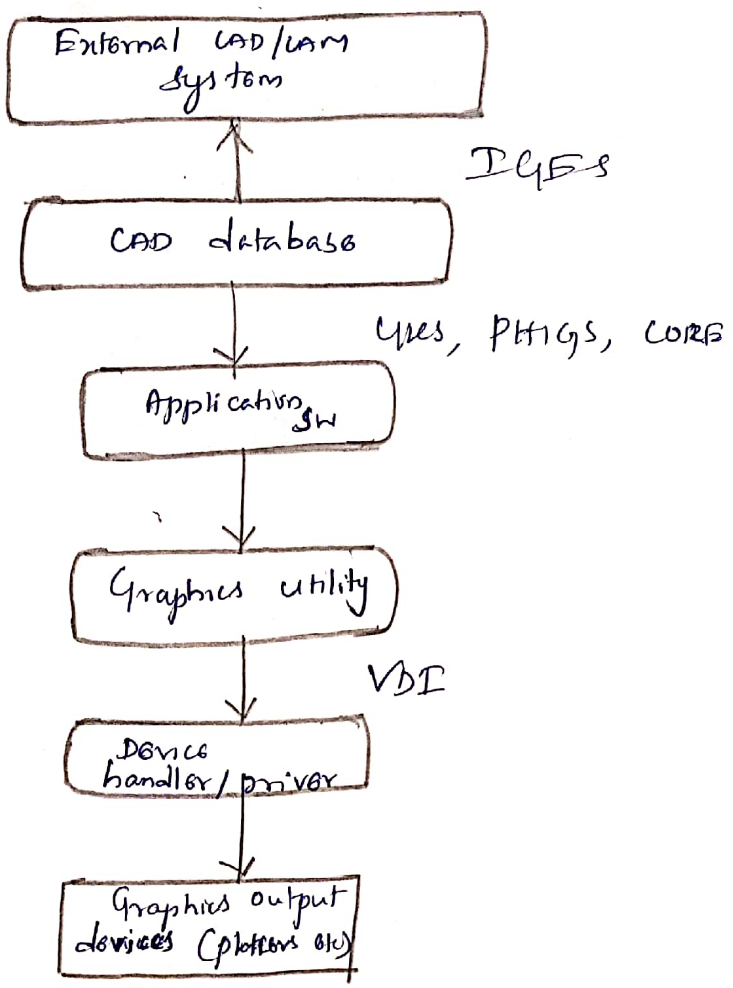
1. Level - ~~1~~1: the data is communicated between graphics utility SW and graphics output device (screens, plotters, etc.). VDI (virtual Device Interface) or CGI (computer Graphics Interface) is the most important standard in this category.

2. Level - 2: the data is communicated b/n application SW and graphics utility. GKS (Graphics Kernel System). most universally accepted standard developed in W. Germany in 1979. ~~GKS~~ GKS provides interface b/n application package and graphics utility programs for any CAD system through CORE.

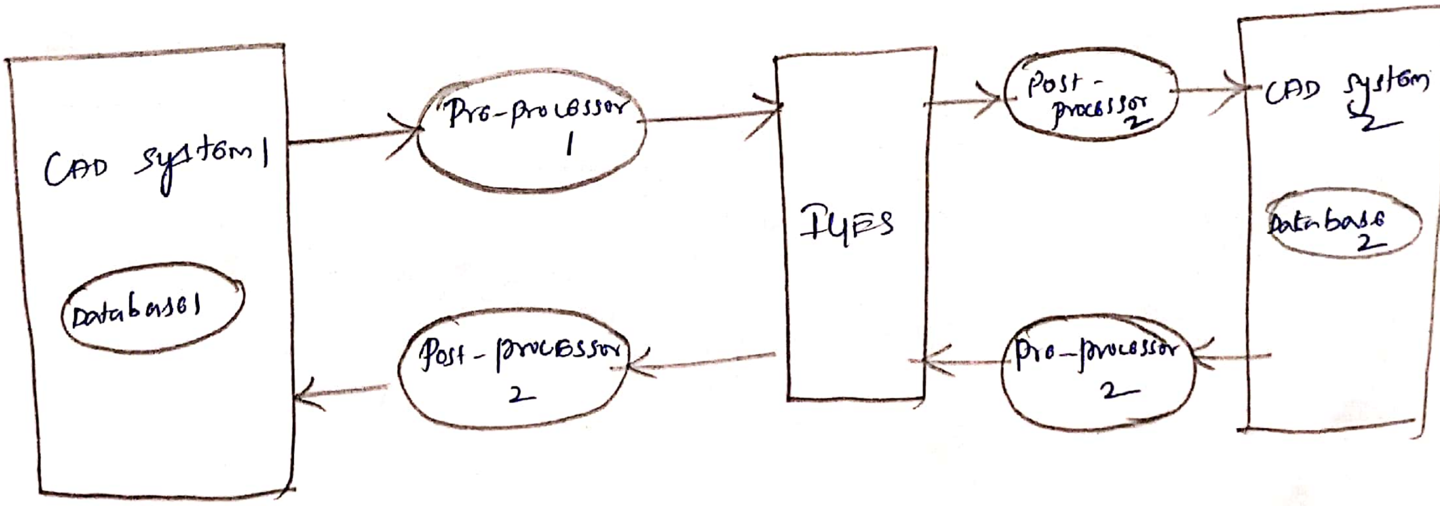
3. Level - 3: the data is communicated b/n different CAD systems such as IGES and ANSI. Standard format of codes is for CAD/CAM data. It is completely independent of any system supplier. It enables both graphical and manufacturing data ~~to~~ to be transferred b/n dissimilar systems.

Q5

Levels of graphic Standards communication



Communication via IGES



Unit IV

FUNDAMENTAL OF CNC & PART PROGRAMING

4.1 Introduction to Numerical control (NC) system:

NC refers to a form of programmable automation in which the mechanical actions of a machine tool or other equipment are controlled by a program containing coded alphanumeric data encoded on a storage medium.

NC machine tools are the machine tools operated by programmed commands in contrast to the manual control through hand wheels or levers, or mechanically automated through cams alone.

In NC machine tools, one or more of the following functions may be automatic.

i. starting & stopping of machine tool spindle.

ii. Controlling the spindle speed.

iii. Positioning the tool tip at desired locations and guiding it along desired paths by automatic control of the motion of slides.

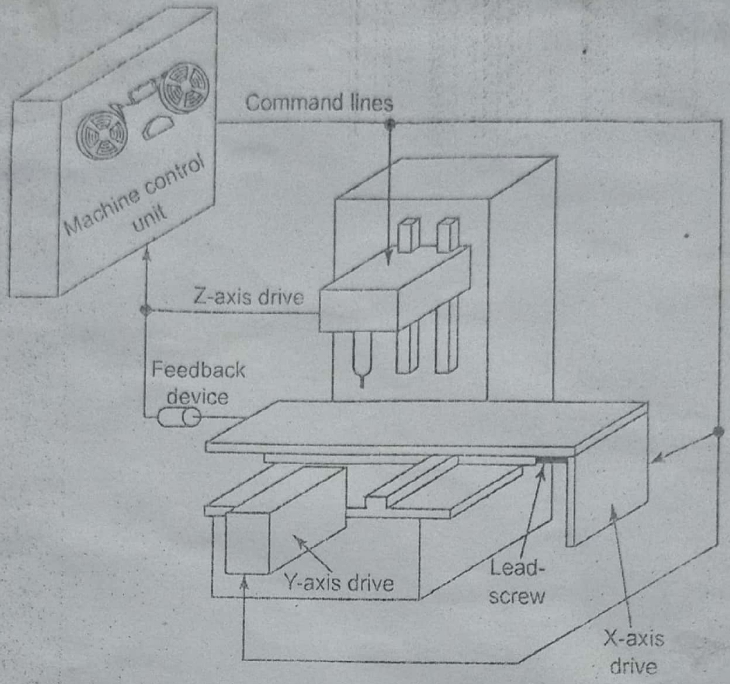
iv. controlling the rate of movement of tool tip (feed rate)

v. changing of tools in the spindle.

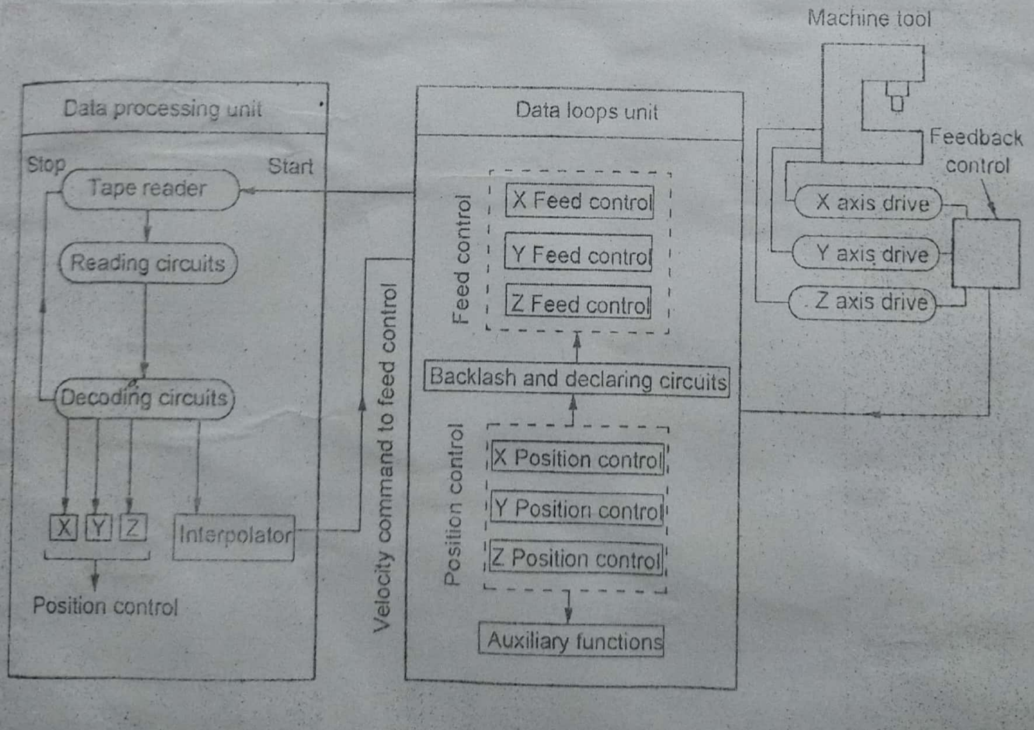
Basic principle of NC machines:

controlling a machine tool by means of a prepared Program is known as Numerical control or NC.
A system in which actions are controlled by the direct insertion of numerical data at some point is known as NC system.

A NC machine tool consists of Machine control unit (MCU) and the machine tool. The machine tool has various drives such as X-axis, Y-axis & Z-axis drives which are driven by the servomotors. The feedback device or feedback control is used to integrate the MCU and the machine tool.



(a) NC Machine tool



(b) Configuration of NC system

Figure 4.1 Numerical control machine tool system

4.2 Machine axis and co-ordinate system

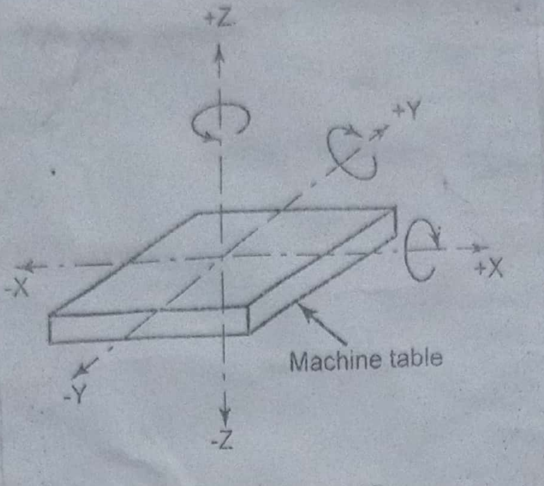
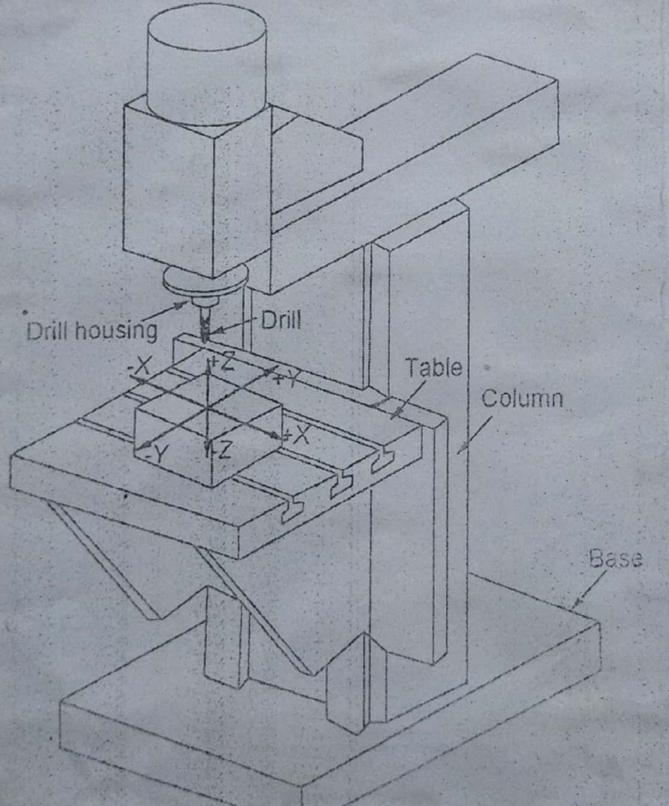
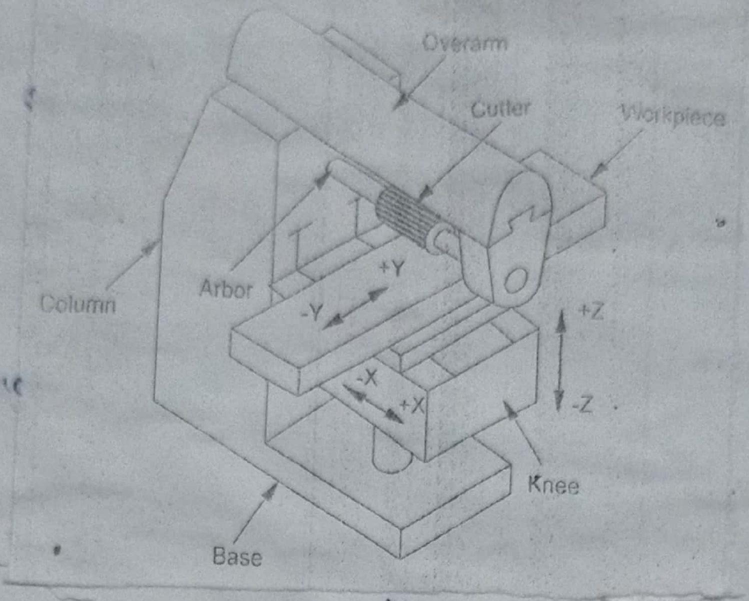


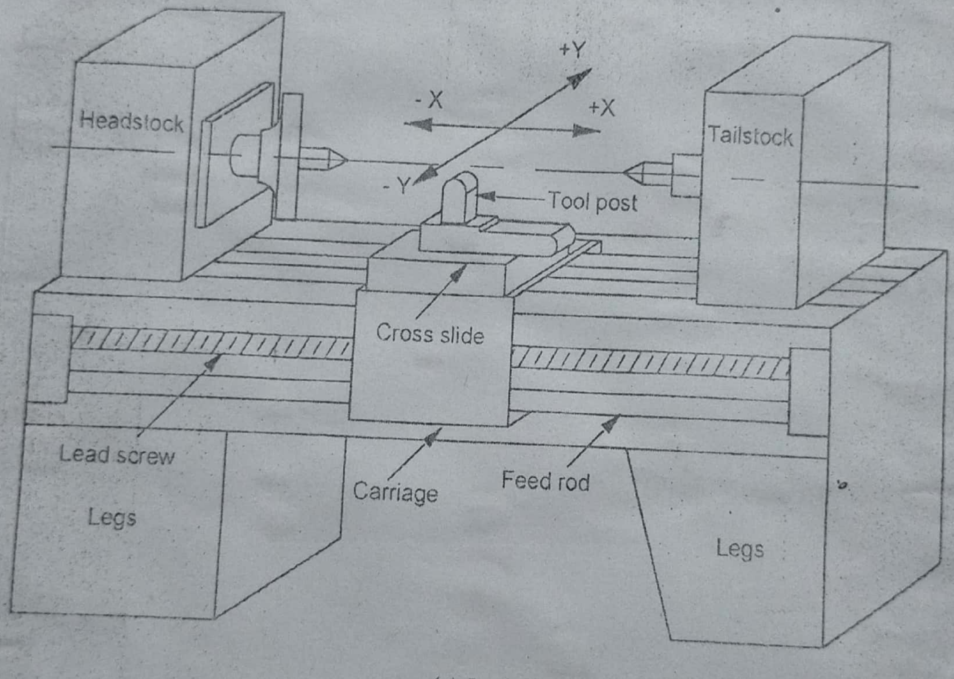
Figure 4.2 Coordinates of NC system





b. Milling machine

(~~b) Milling machin~~e



(c) Lathe

Figure 4.3 Coordinates in NC machine tools

4.2.1: Fixed zero & floating zero positioning

Origin is considered as zero-point of the coordinate system. There are two methods of specifying the zero point.

1. fixed zero positioning
2. floating zero positioning

In a fixed zero positioning system, the origin is always located at the southwest corner that is lower left-hand corner of the table and all tool locations will be defined by Positive x & y coordinates.

In floating zero positioning system, the machine operator sets the zero point at any positions on the machine table. The part programmer decides the zero point to be located. It is also known as reference point.

4.2.2: Absolute positioning & Incremental positioning

The machine tool require the position of cutting tool and workpiece. they move relative to each other. Absolute and incremental positions are concerned with whether the tool positions are defined relative to the origin of the coordinate system or relative to the previous location of the tool.

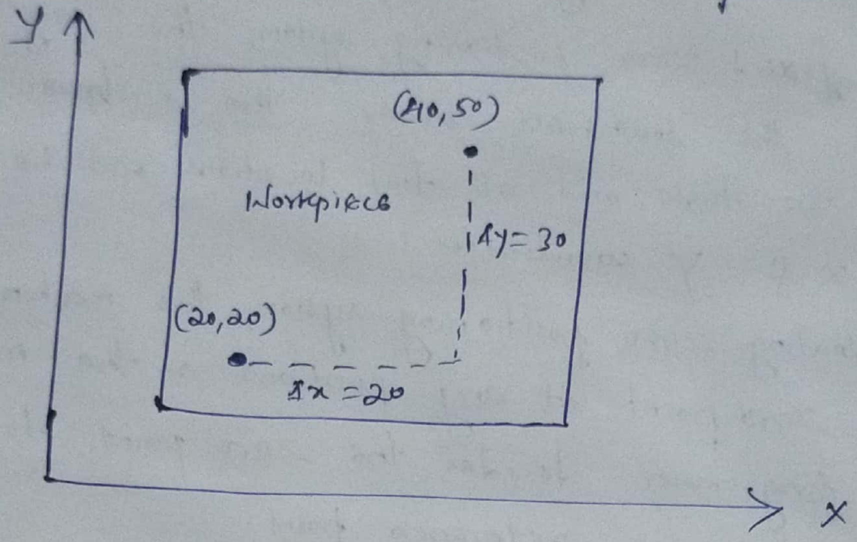
There are two ways of positioning the tool in relative to the workpiece as follows:

1. Absolute positioning
2. Incremental positioning

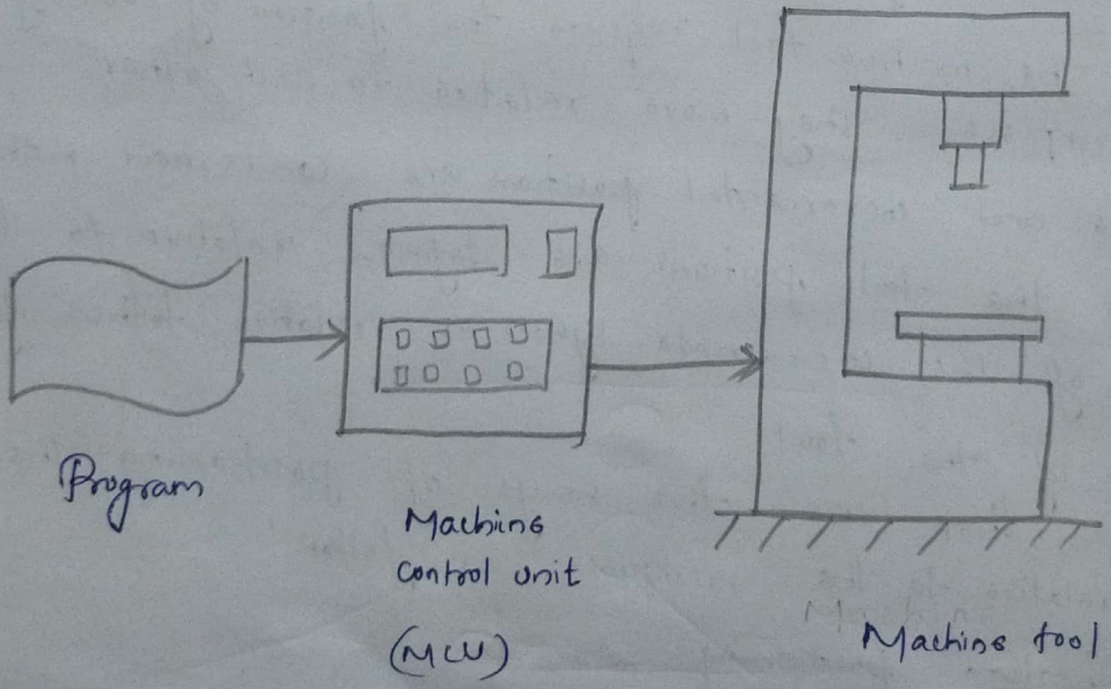
Absolute positioning means that the tool locations are always defined in relation to zero point.

Incremental positioning means that the next tool location must be defined with reference to the previous tool location.

Absolute vs incremental positioning



4.3. Elements of NC system:



a. part programme or soft ware

b. Machine control unit (MCU)

MCU consists of the following units

- i. Input or reader unit
- ii. Memory
- iii. Processor
- iv. Output channels
- v. control panel
- vi. Feed back channels

c. Machine tool

4.4: Types of NC systems

I. Types of NC systems ~~based~~ based on the type of machine control

a. Traditional numerical control (NC)

b. computer Numerical control (CNC)

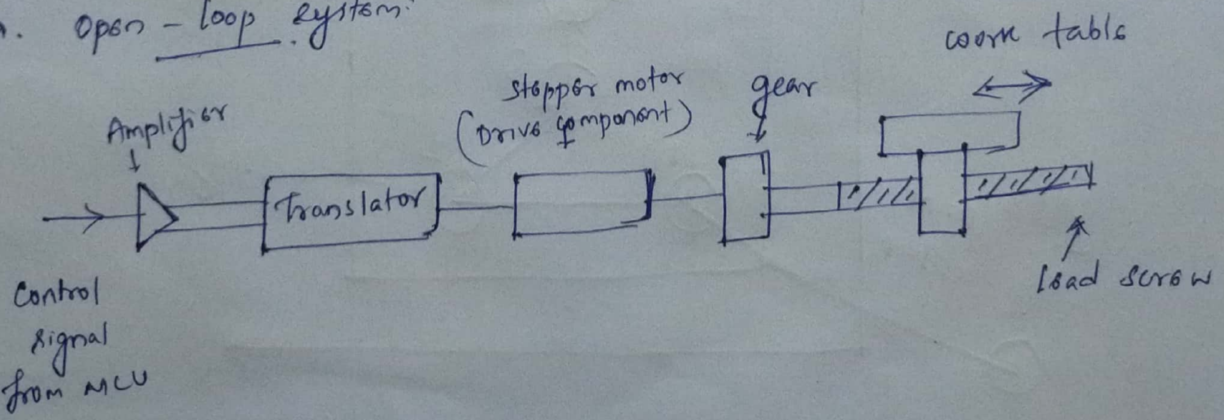
c. Distributed Numerical control (DNC)

II. classification of NC machines based on the type of control system

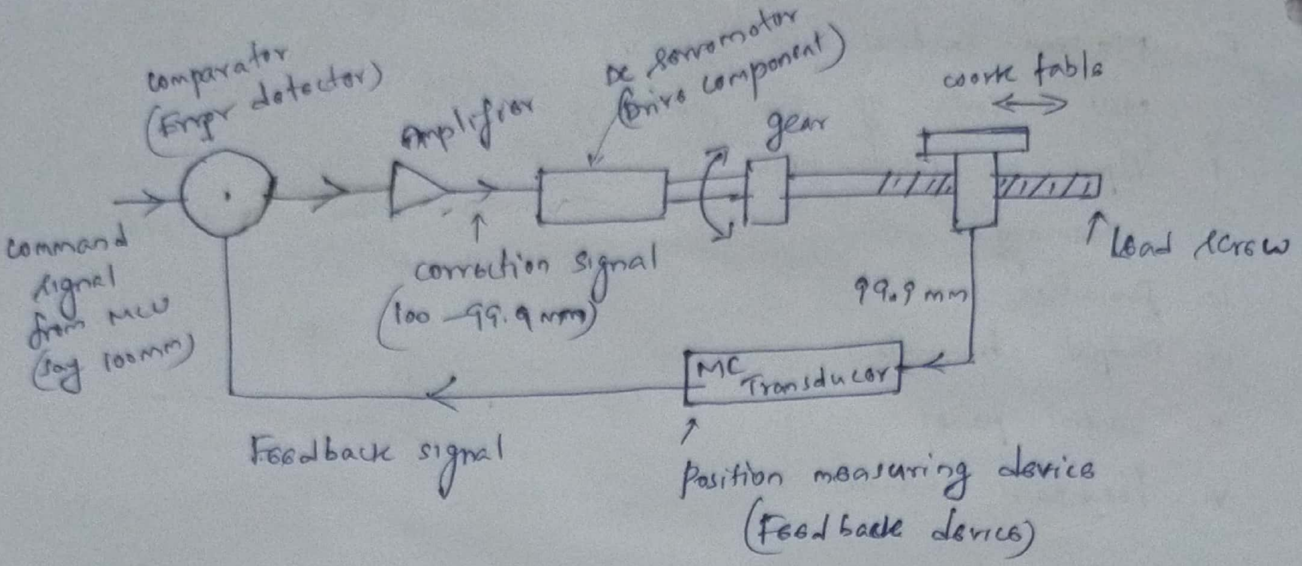
a. Open-loop system

b. closed-loop system

a. open-loop system:



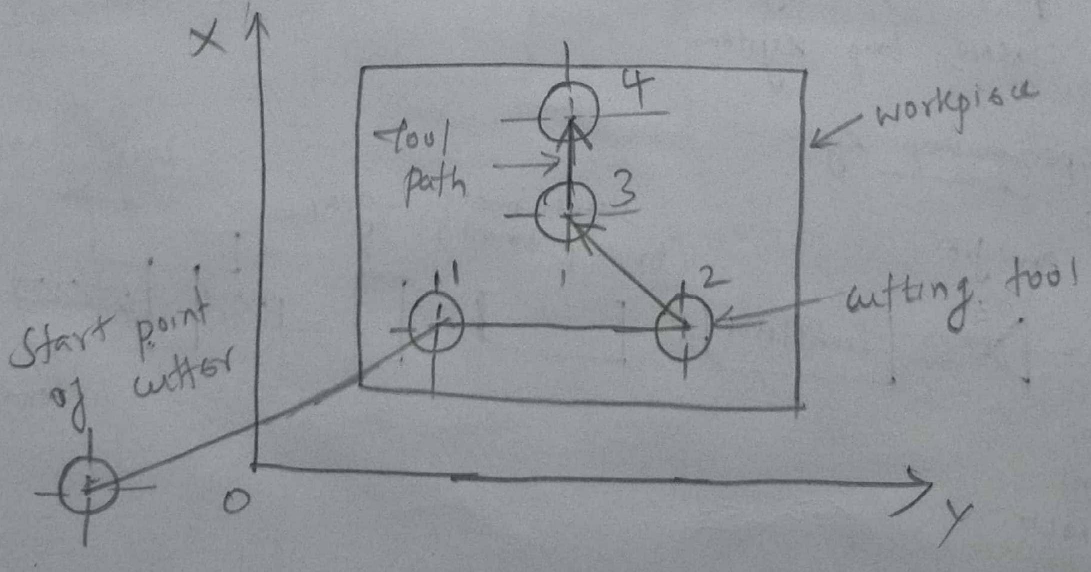
b. closed - loop system:



III. classification of NC machines based on the type of motion control

a. point-to-point NC system
b. continuous path NC system
  i. straight cut system
  ii. contouring system

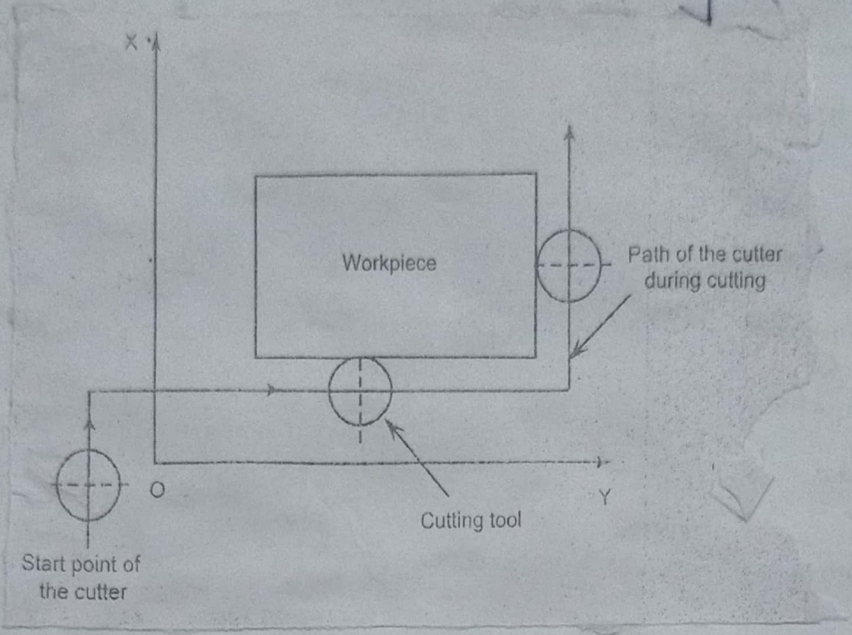
a. point - to - point NC system — In this ~~system~~ system cutter and the workpiece to be placed at certain fixed relative position at which they must remain while the cutter does it work.



b. continuous path NC system:

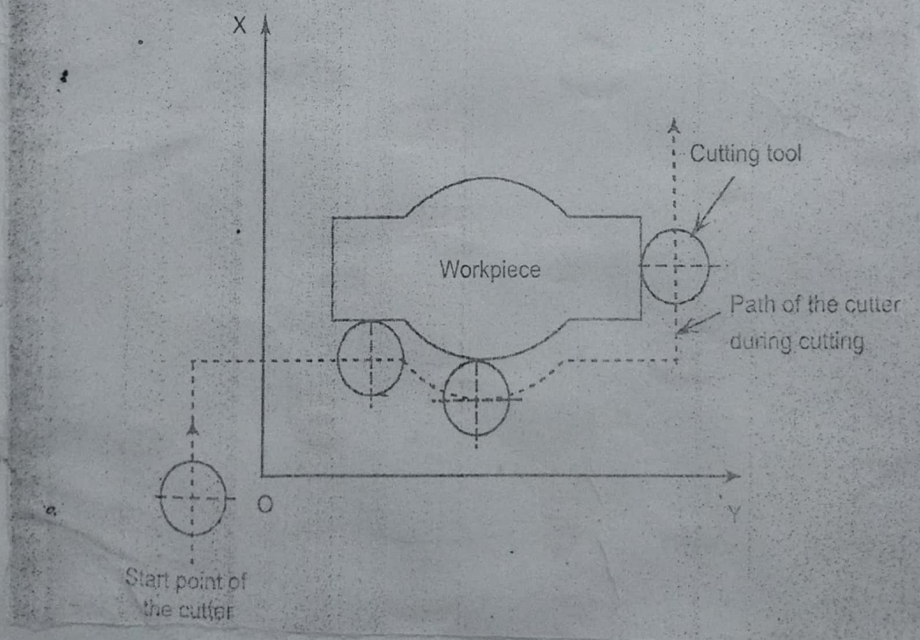
In continuous path machines, the tool perform the process while the work table is moving.

i. straight cut NC system



ii. Contouring system:

b) Contouring system:



4.5: Applications of NC machines

1. Machine tool applications, such as drilling, milling, turning and other metal working.
2. Non-machine tool applications, such as assembly, drafting & inspection.
3. Other applications:

i. Press working machine tools
ii. Welding machines
iii. Inspection machines
iv. Automatic drafting
v. Assembly machines
vi. Tube bending
vii. Flame cutting
viii. Industrial robots
ix. Automatics riveting.

4.6 Advantages of NC machines:

i. Reduced nonproductive time
ii. Provides greater accuracy & repeatability.
iii. Lower labour cost.
iv. High production rates
v. Improved product quality.
vi. Lower scrap rates
vii. Reduced inspection requirements
viii. Simple fixtures are needed
ix. Shorter manufacturing lead times
x. Reduced part inventory
xi. Fewer setup per workpiece
xii. Accurate costing & scheduling
xiii. Less operator skill is required
xiv. Longer tool life
xv. flexibility in changes of component design

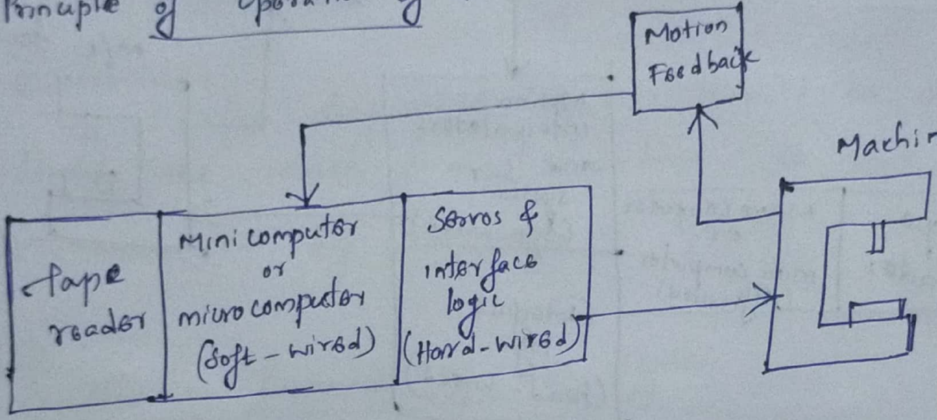
4.7: Disadvantages of NC machines:

i. Higher investment cost
ii. Higher labour cost
iii. Higher maintenance effort
iv. Higher running cost
v. Demand for higher utilization of NC equipment.

4.8: Introduction to Computer Numerical control (CNC) machines:

CNC is a NC system that utilizes a stored program to perform the basic numerical control functions. A mini or micro computer based controller unit is used.

I. Principle of Operation of CNC



II. Features of CNC:

1. Storage of more than one part program: → To store multiple program
2. Various forms of program input – (Punched Tape) It posses multiple data entry capabilities, such as floppy disk, Hard disk, CD, DVD, USB.
3. Program editing at the machine tool:
4. Fixed cycles & programming subroutines:
5. Interpolation
6. Positioning features for setup

7. Tool length compensation:

8. Acceleration & decleration calculations

9. Communications interface

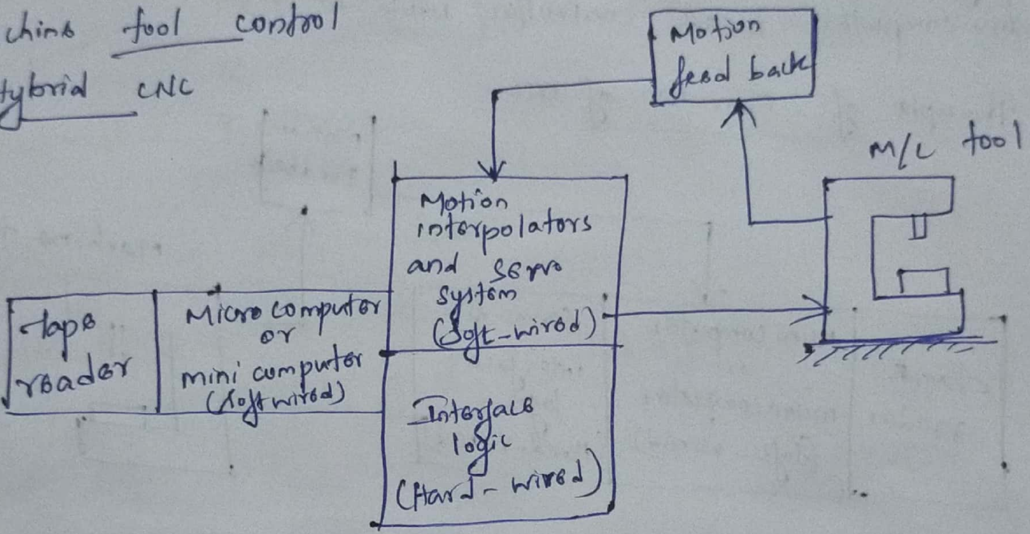
10. Diagnostics

III. functions of CNC systems in Machine tool

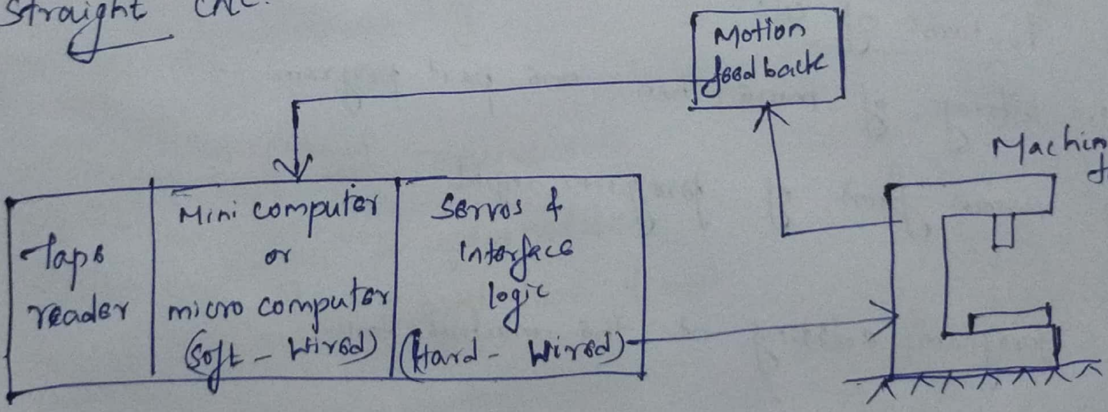
1. Machine tool control
2. In-process compensation
3. Diagnostics

1. Machine tool control

a. Hybrid CNC



b. Straight CNC:



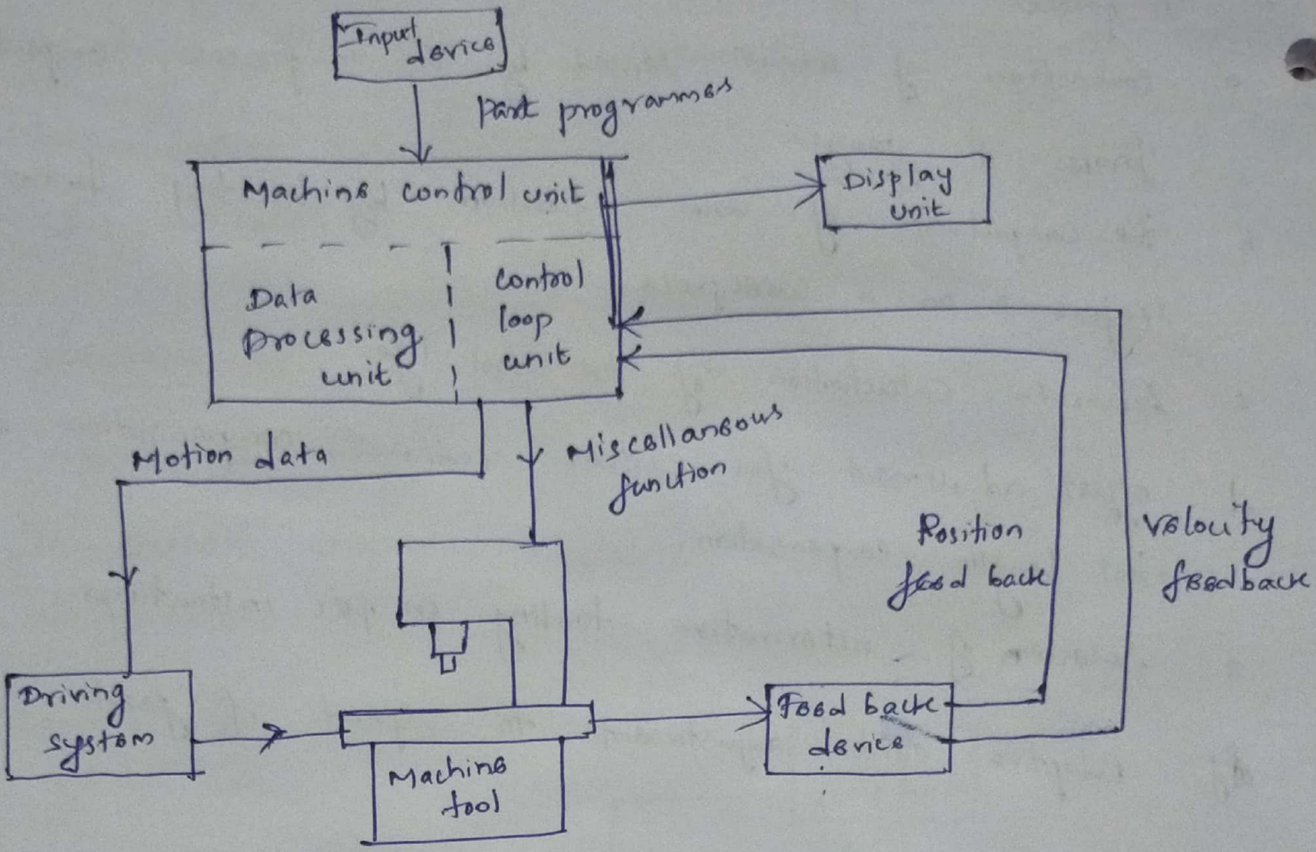
2. In-process Compensation:
   a. Correction of errors sensed by the in-process inspection probes & gauges.
   b. Re-computation of axis position by locating datum reference on a work piece.
   c. Accurate calculation of the tool life.
   d. offset adjustment for cutter radius compensation & tool length compensation.
   e. Selection of alternative tooling as per instructions
   f. Adaptive control adjustments. to speed & feed.

3. Diagnostics: the diagnostics system would be able to identify the reason for a down time so that it could be minimised by attending it quickly.

4.9: Construction features of CNC system:

the different elements of the CNC systems are as follows

a. part program
b. Program input device
c. Machine control unit < Data processing unit (DPU)
   Control loop unit (CLU)
d. Machine tool
e. Driving system
f. Feed back devices
g. Display unit.


Input device
Part programmes
Machine control unit
Display unit
Data processing unit
Control loop unit
Motion data
Miscellaneous function
Position feed back
Velocity feedback
Driving system
Machine tool
Feed back device

4.10: Spindle Drives in CNC machines:

The spindle drives are used to provide angular motion to the workpiece or a cutting tool. The speed ranges from 10 rpm to 20,000 rpm.

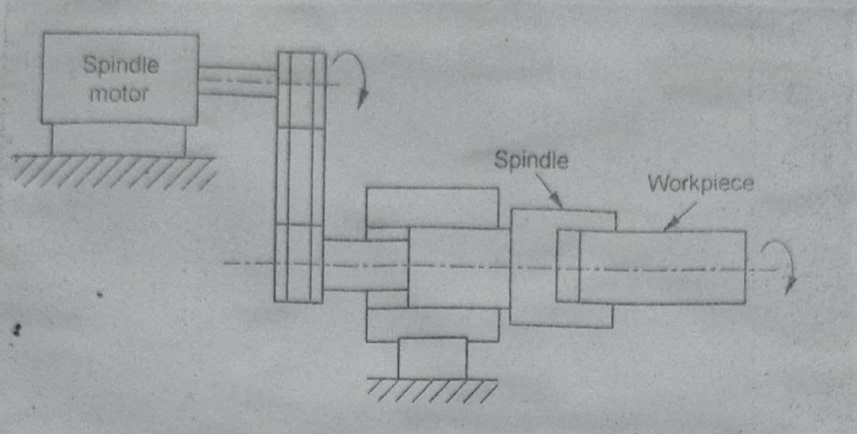


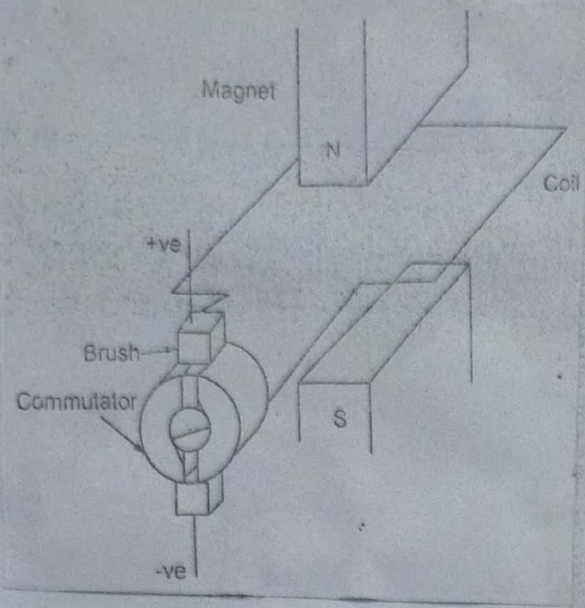
Figure 4.20 Components of a spindle drive

Two types of electrical motors are commonly used for spindle drives as follows:

1. DC motors:
   a. Brush type
   b. permanent magnet DC motor or Bruchless DC motor.

2. AC motors
   a. AC synchronous motors
   b. AC induction motors:

DC Motors



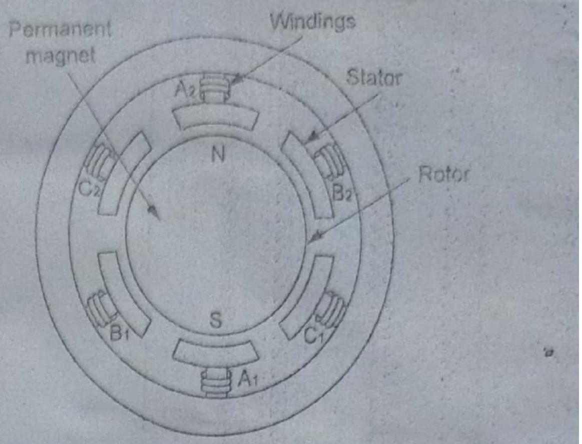


Figure 4.22 Permanent magnet DC motors or Brushless DC motor

AC Motors

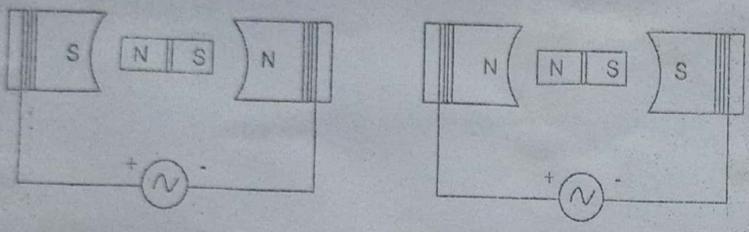


Figure 4.23 Working principle of AC motor

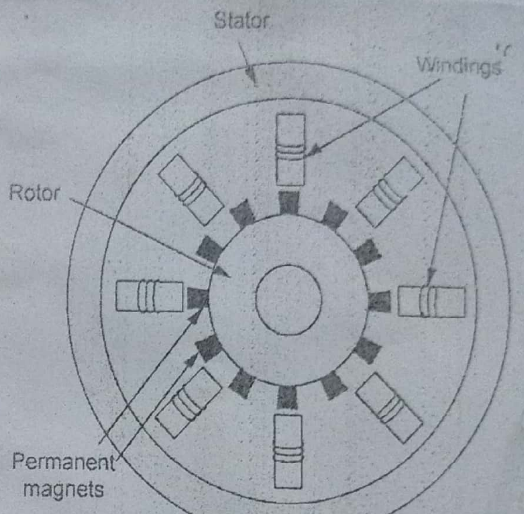
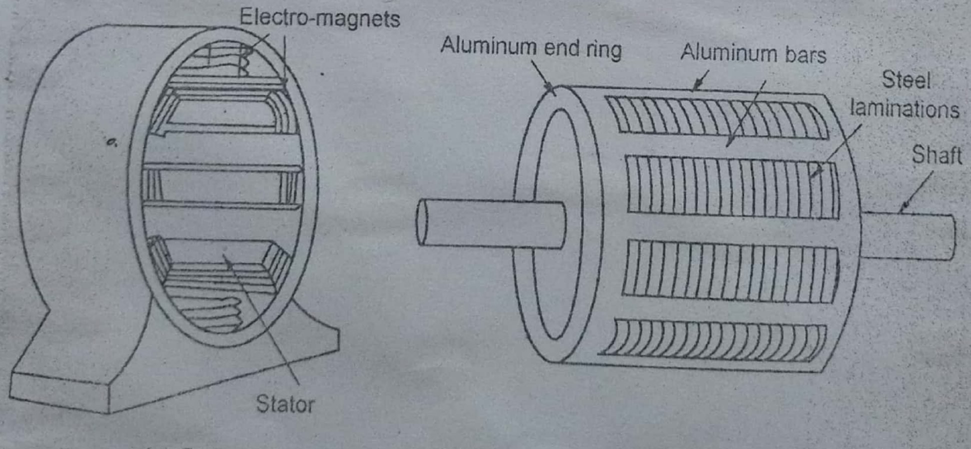


Figure 4.24 Synchronous AC motor



(a) Stator

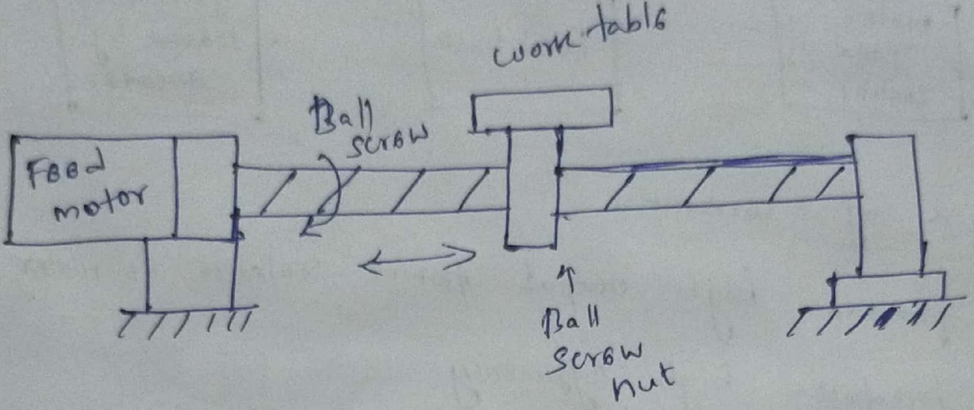
(b) Rotor

Figure 4.25 AC induction motor

4.11: Feed drive in CNC machines:

feed drives are used to drive the slide or a table. feed drives consists of a feed servomotor and electronic controller.

Components of a feed drive



Feed drives used in CNC machine tools are as follows:

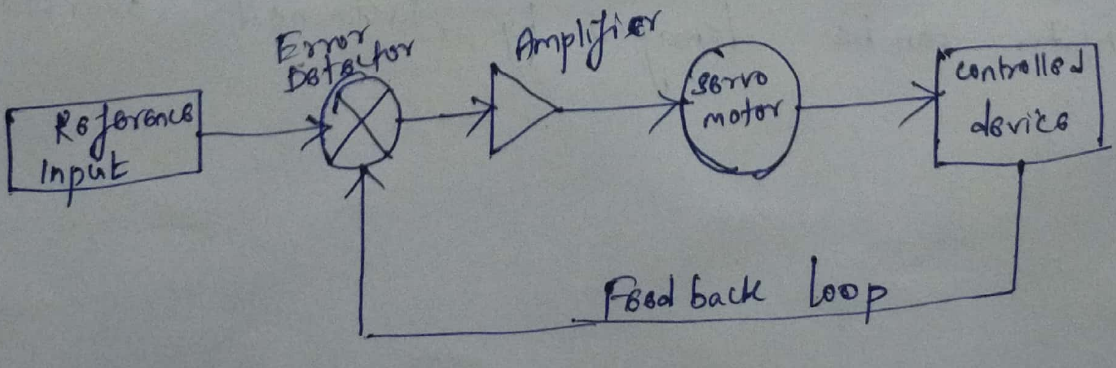
a. Servo motors
  i. DC Servomotors
  ii. AC Servomotors
b. stepper motors
c. linear motors
d. Hydraulic drives
e. pneumatic drives

a. Servo motors:

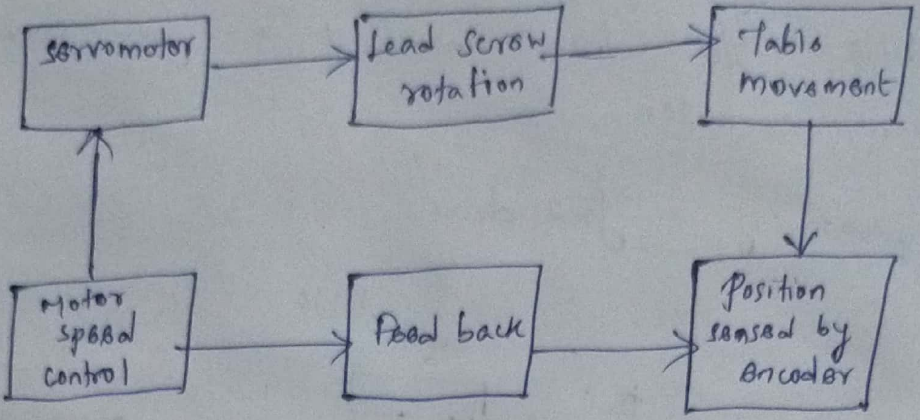
The important characteristics of servo motor are as follows:

i. fast response
ii. High accuracy
iii. fast and accurate speed
iv. Very high starting torque
v. Direction control
vi. Remote operation

Closed loop servo system



components of servo controlled CNC



Advantages of servomotor:

i. It provides high output power relative to motor size & weight

ii. It produces high efficiency.

iii. It can rapidly accelerate loads.

iv. It has high speed torque

v. It has audibly quiet at high speed.

vi. Vibration free operation will occur.

Disadvantages of servomotor:

i. Motor develops peak power at higher speeds. Hence gearing is often required.

ii. Poor motor cooling. Ventilated motors are easily contaminated

iii. Design is complex. It requires encoder.

iv. Motor can be damaged by sustained overload.

6. Stepper motors:

It has the following performance characteristics

i. It can rotate in both directions

ii. It can move in precise angular increments.

iii. It can sustain a holding torque at zero speed

iv. It can be controlled with digital circuits.

Types of stepper motors:

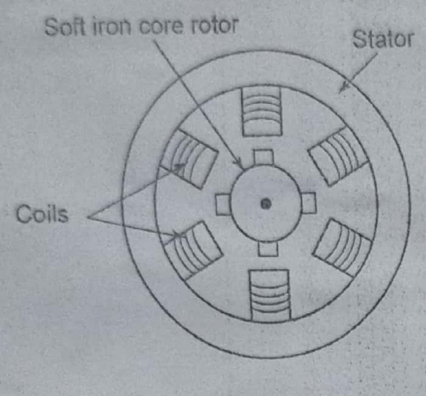


Figure 4.27 Three-phase variable reluctance stepper motor

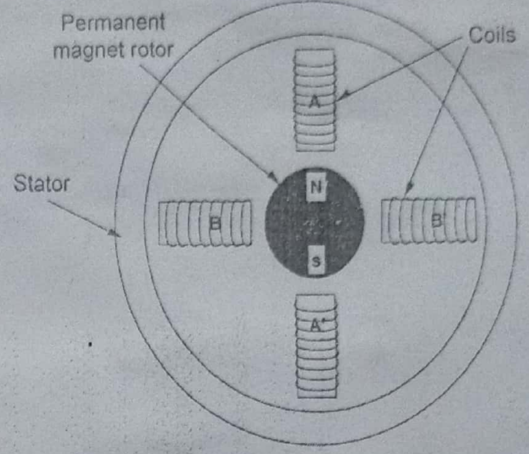


Figure 4.28 Two-phase permanent magnet stepper motor

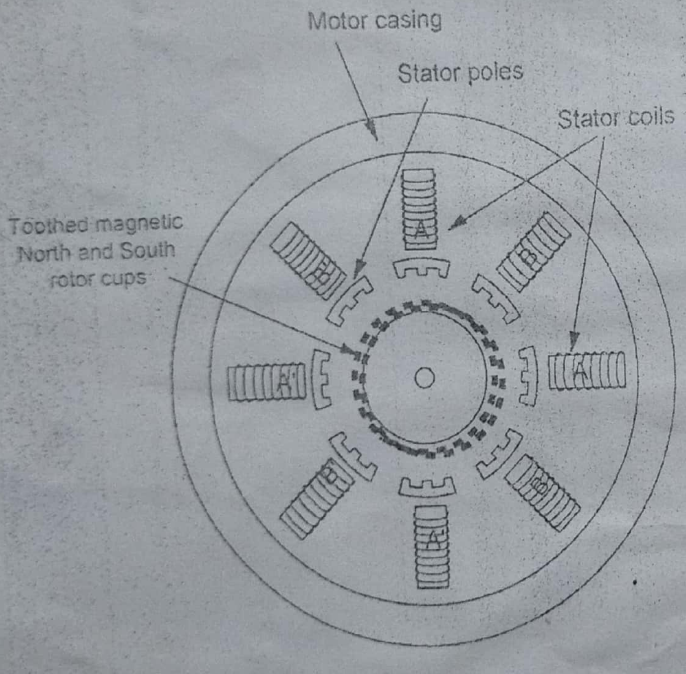


Figure 4.29 Two-phase hybrid stepper motor

Advantages of stepper motors:

i. Low cost

ii. Ruggedness

iii. Simplicity of construction

iv. Low maintenance

v. Will work in any environment

vi. Excellent start-stop & reversing response.

Disadvantages of Stepper motors:

i. Low torque capacity compared to DC motors.

ii. Limited speed.

iii. During overloading, the synchronization will be broken

iv. Vibration & noise occur when running at high speed.

c. Linear motors:

The working principle of a linear motor is similar to a rotary electric motor. It has a rotor and the stator circular magnetic field components are laid down in a straight line. Sine the motor moves in a linear fashion, no lead screw is needed to convert the rotary motion into linear.

Linear motors can be used in outdoor or dirty environments, the electromagnetic drive should be water proofed and sealed against moisture and corrosion.

d. Hydraulic drives:

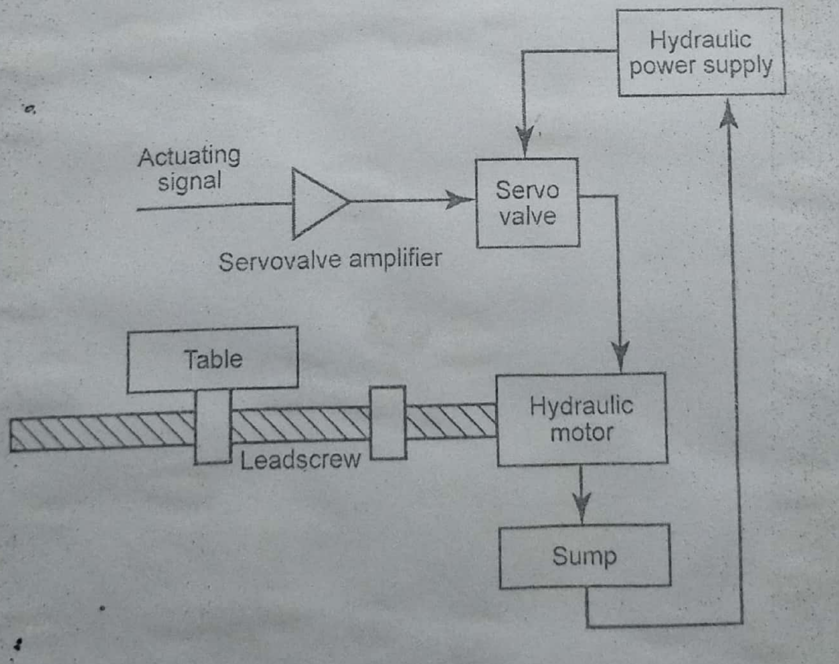


Figure 4.33 A hydraulic system

e. Pneumatic drives:

the pneumatic drives also obey the same principle of hydraulic system. It drives uses air as working medium which is available in abundant and it is fire proof. they are simple and cheap in construction. these drives generate low power, have less positioning accuracy and are noisy.

4.12: Automatic tool changer (ATC)

ATC is the equipment that reduces cycle times by automatically changing tools between cuts through programmed instructions. The tools are fitted on a tool magazine or drum. When a tool needs to be changed, the drum will rotate to an empty position, approaches the old tool and pulls it.

Types of automatic tool changer:

1. Tool change system with gripper arm

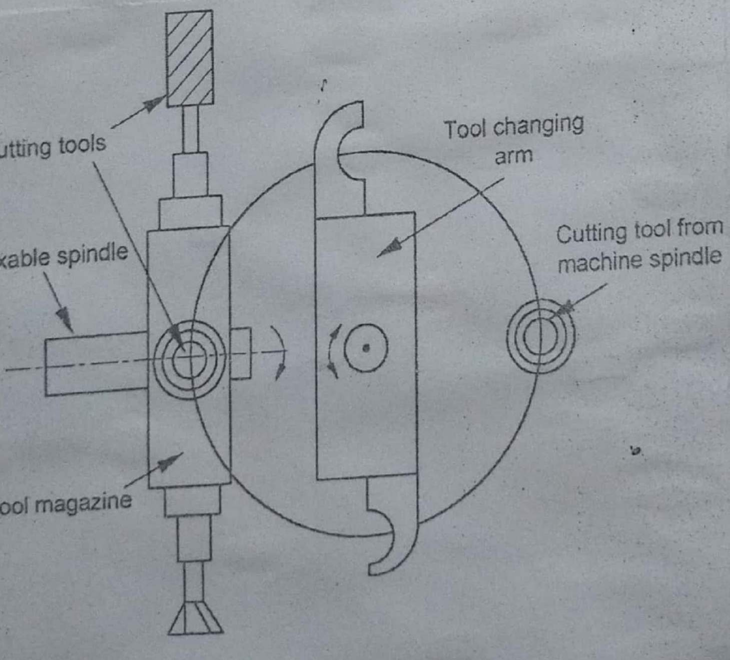


Figure 4.36 Automatic tool changer

2. Tool change system with chain magazine.

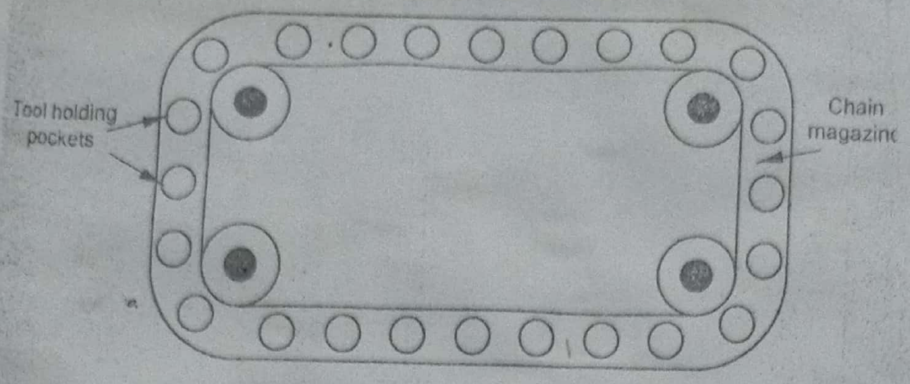


Figure 4.37 Chain magazine

3. Tool change system with disc magazine.

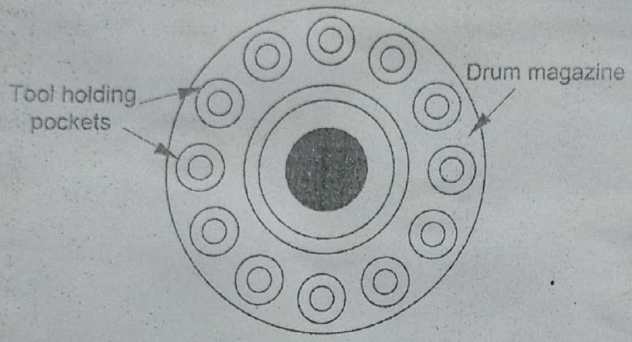


Figure 4.38 DISC *magazine*

Advantages of ATC:

1. It increases the machine tool's productive time.

ii. It reduces the times for changing worn tools.

iii. It provides storage of the cutting tools which are returned automatically to the machine tool after carrying out the required operations.

iv. New cutting tools are automatically delivered to the machine by the tool changing system.

4.13: 2D & 3D machining on CNC:

Refer machine axis and co-ordinate system (chapter 4.2 notes)

4.14: Machining centres:

It is a highly automated machine tool capable of performing multiple machining operations under computer numerical control in one setup and it can work on more than one face of a component with minimal human attention.

The following operations can be carried out on a machining centre.

1. Milling
2. Drilling
3. Reaming
4. Boring
5. Tapping.

Features of machining centers:

i. Automatic tool changer.
ii. Automatic component positioner
iii. Automatic pallet changer
iv. Multiple operations in one setup.

classification of machining centres:

According to the spindle configuration, machining centres are classified as follows.

1. Horizontal spindle machining centre
2. Vertical spindle machining centre
3. Universal machining centre.

1. Horizontal spindle machining centre.

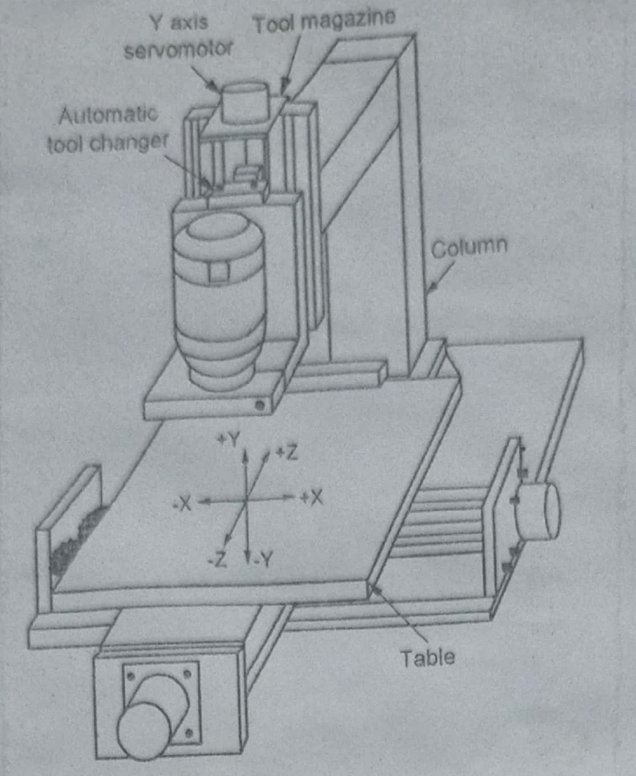


Figure 4.39 Horizontal machining centre

x axis → table or column motion left to right as viewed from spindle

y axis → spindle head motion up & down

z axis → saddle / column / spindle head motion toward & away from the spindle.

2. Vertical spindle machining centre:

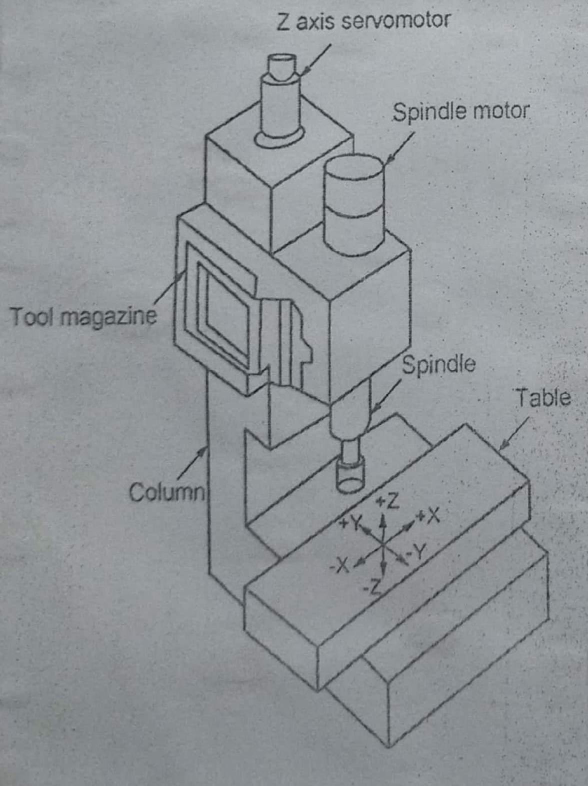


Figure 4.40 Vertical machining centre

x axis → Table or colum motion left to right as viewed from the spindle

y axis → saddle or table motion foward & away from the spindle.

z axis → spindle head or headstock motion up & down.

3. Universal machining centre:

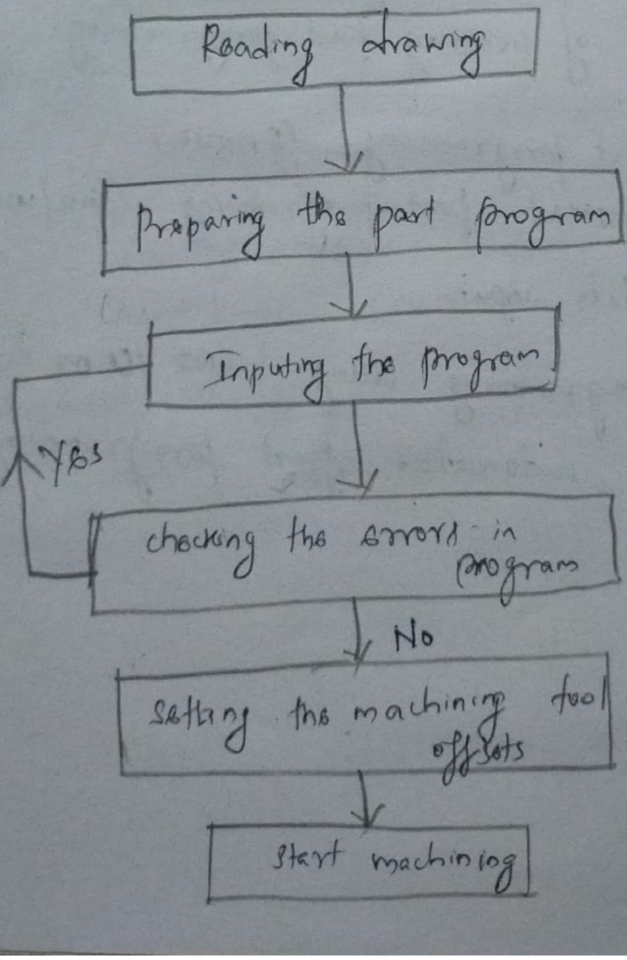
Universal machining centres are similar to horizontal machining centres but it is with the spindle axis capable of tilting from horizontal to the vertical position. this feature allows ease of machining inclined surfaces.

the other features of the universal machining centre are:

i. It has a single spindle
ii. It has five axes of machine
iii. the flexibility is more than other two types
iv. Tool breakage detection is possible.
v. Automatic loading & unloading of the workpiece are possible.

4.15: Introduction to part programming

. The conversion of engineering blueprint to a part program can manually be performed with the assistance of a high-level computer language.



Part program:

The part program is a set of instructions proposed to get the machined part starting with the desired blank and NC machine tool. part programming contains geometric data about the part and motion information to move the cutting tool with respect to the workpiece.

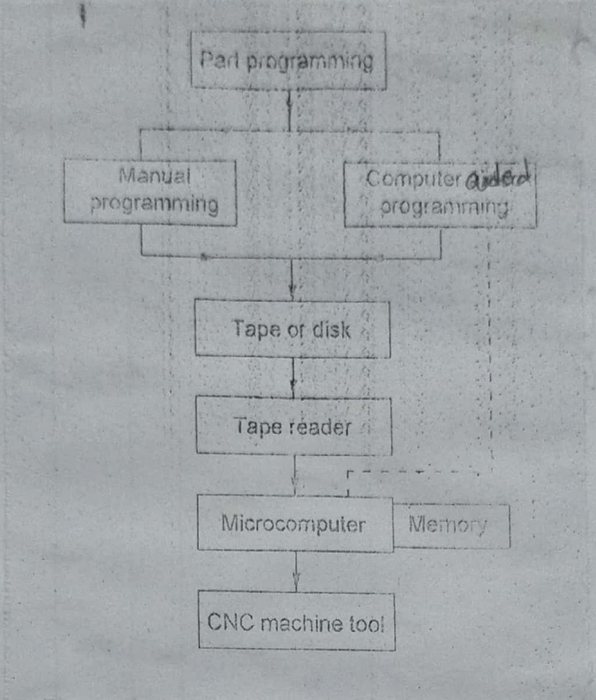
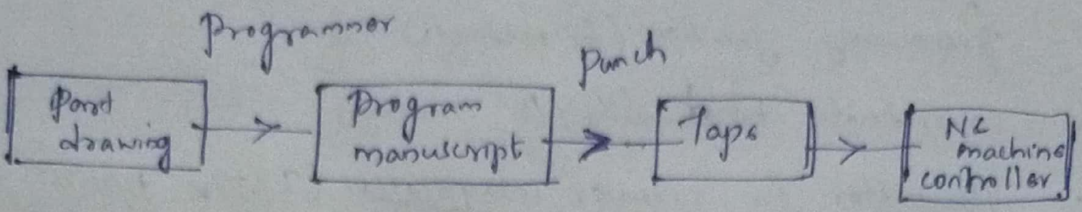


Figure 4.42 Layout of part program procedure

4.16: Methods of creating part programming

i. Manual part programming (FANUC)
ii. Computer-assisted part programming (CAD/CAM based programm system).
iii. Manual data input
iv. NC programming using CAD/CAM
v. Computer automated part programming

4.17: Manual part programming: (FANUC)



To be able to create a part program manually, it needs the following information:

i. knowledge about various manufacturing processes & machines.
ii. Sequence of operations to be performed for a given component
iii. knowledge of the selection of cutting parameters
iv. Editing the part program according to the design changes.
v. knowledge about the codes and functions used in part programs

The manual programming jobs can be divided in two categories

i. Point-to-point jobs
ii. Contouring jobs.

Typical program format is

N10 G01 X50 Y100 Z30 F100 S200 T02 M03

N10 → Block number
G01 → preparatory function
X50 Y100 Z30 → Target coordinates
F100 → Feed rate
S200 → spindle speed
T02 → tool number
M03 → Miscellaneous function

Important terms used in part programming:

i. Sequence number (N Address)
ii. Preparatory function (G Address)
iii. Co-ordinate word (X/Y/Z Address)
iv. Parameter for circular interpolation (I/J/K Address)
v. Spindle function (S Address)
vi. Feed function (F Address)
vii. Tool function (T Address)
viii. Miscellaneous function (M Address)

4.18: Steps for CNC part programming:

i. fixation of the coordinate system
ii. Reference of G & M codes
iii. Dimensions of work & tools
iv. locating the fixture & machine tools.
v. speed & feed according to the work and tool material

4.19: Data required for part programming:

i. Job dimension / workpiece
ii. Work holding (clamping, In-chucking)
iii. feed / cutting speed
iv. finished dimension with tolerance
v. sequence of operation
vi. Types of tools
vii. Mounting of tools.

4.20 Work coordinate setting:

a. Machine Zero point (machine datum) reference

b. Workpiece origin reference

c. Tool home position reference.

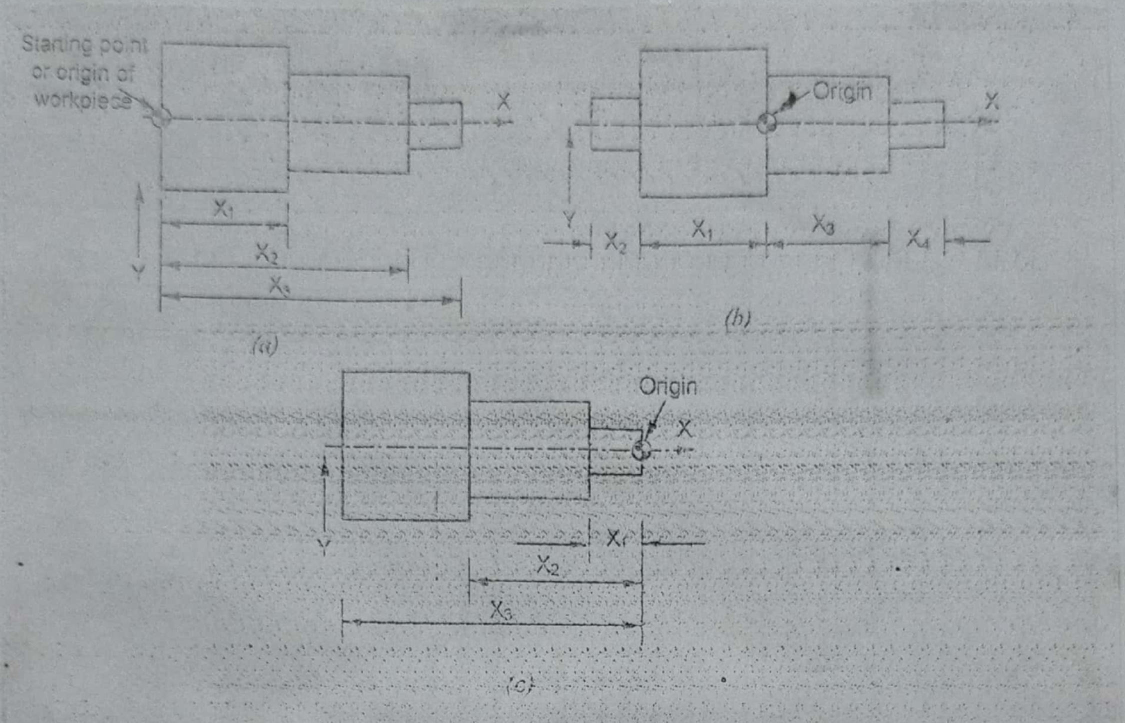
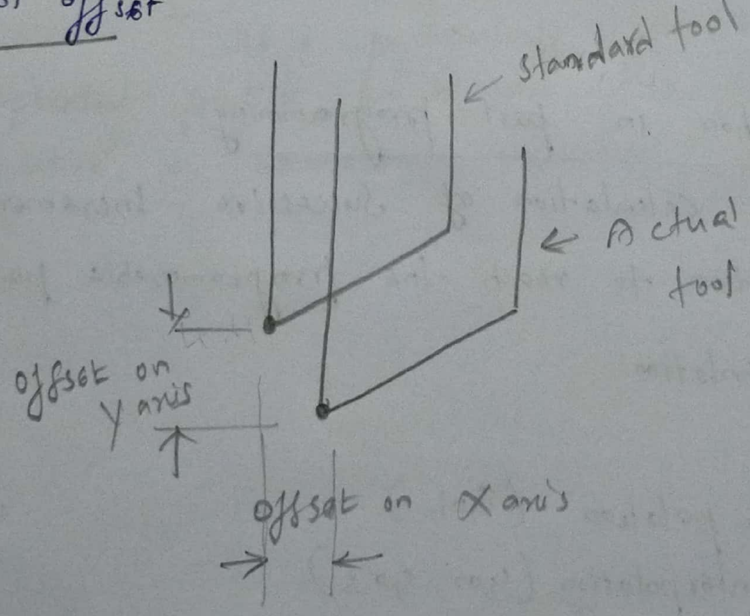


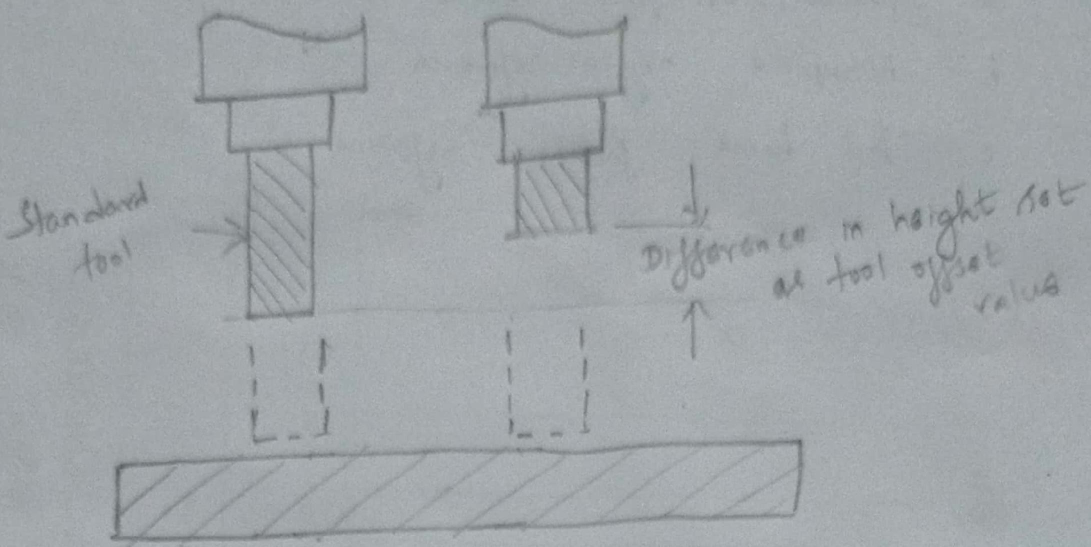
Figure 4.45 WPC origin from where the part features are dimensioned

4.21 Tool information in part programming

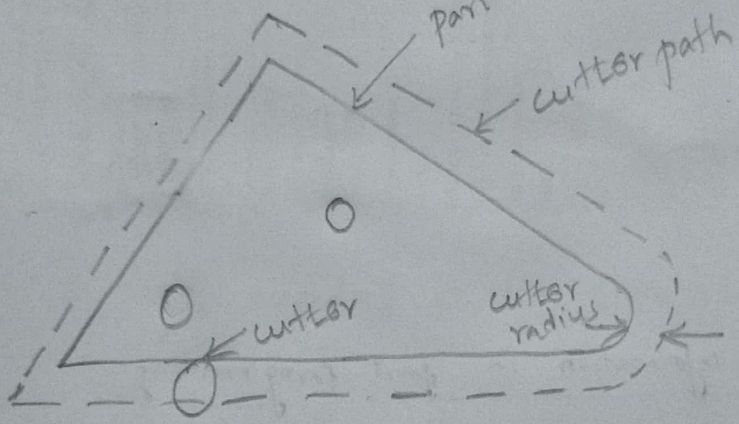
i. Tool offset



ii. Tool length compensation



iii. cutter radius or diameter compensation:



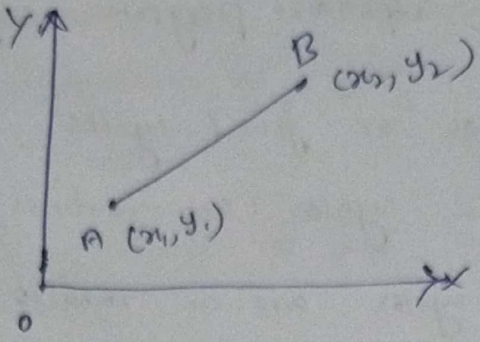
4.22: Interpolation in part programming

the calculation of Successive Increments in slide position to reach the programmable point is called interpolation.

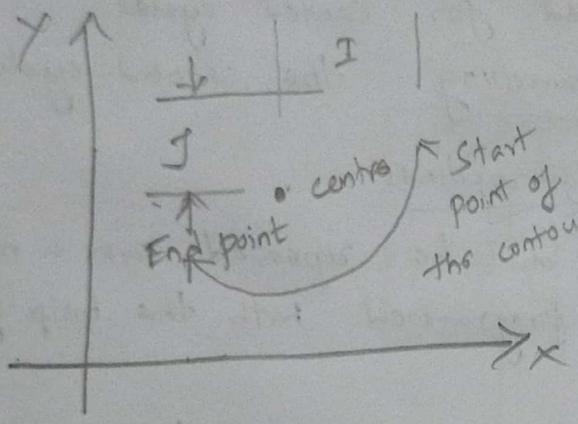
Types:

1. Linear interpolation (G01)
2. circular interpolation (G02, G03)
3. Cubic/ parabolic interpolation.

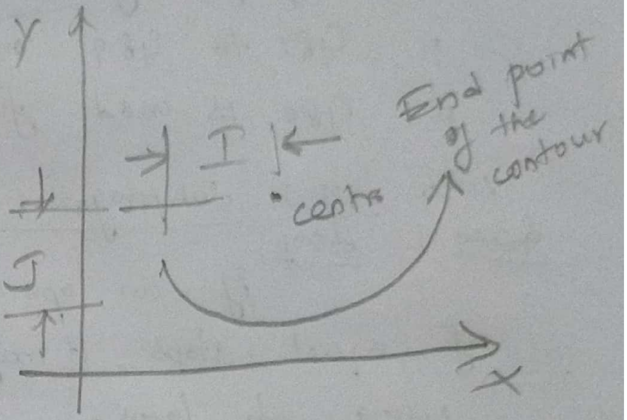
1. Linear interpolation:



2. Circular interpolation:



clockwise



Counter clockwise

3. Cubic / parabolic interpolation

It is particularly suitable in machining complicated profiles which are free-formed as in the automotive or aeronautical industries.

4.23: Cutting cycles:

The repetitive program sequence is called a cycle.

a. Canned cycles or fixed cycles

b. User-defined cycles (sub-routines)

Canned cycles are an inbuilt features of the NC system. A canned cycle is a combination of machine movements that performs any one particular machining function such as drilling, turning, milling, boring, tapping.

The preparatory functions for canned cycle are:

i. G81 to G89 are used for canned cycles

ii. G80 is used for cancelling the canned cycle.

4.24 Loop, subprogram & subroutines

~~4.~~:1. **Loop:**

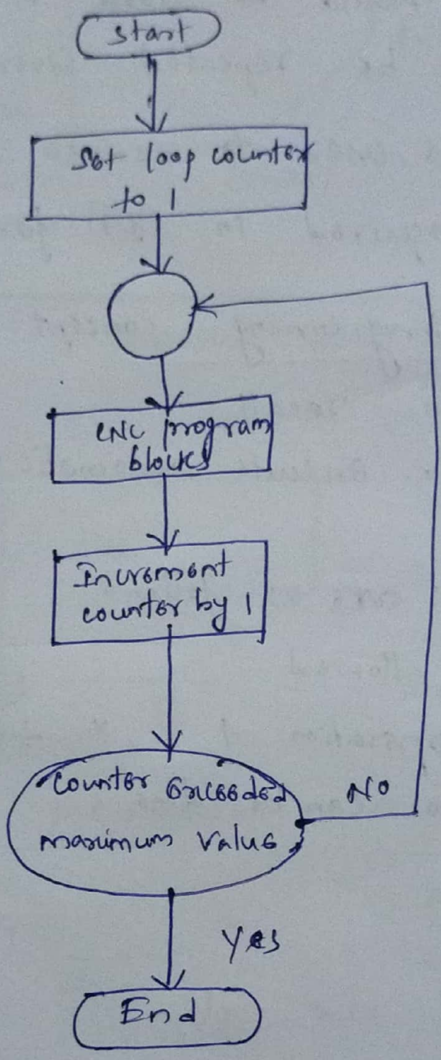
If an operation is to be repeated over a number of equal steps, it may be programmed with the help of using do loops.

In a do loop, MCU is instructed to repeat an operation rather than be programmed for number of separate hole ~~function~~ locations. A do loop simply instructs MCU to repeat a series of NC program statements a specified number of times.

4.5:2. Sub program:

It is a seperate program called by another Program. the uses of subprograms can significantly reduce the amount of programming required on some parts.

Process flow of do loop



3. Sub routines:

The user subroutines is an NC program which describes a sequence of operations which is often repeated when machining a particular part.

If the same machining operation which was carried out already is to be performed at many diferent positions on the same workpieces, it can be executed by means of a program called subroutine. Subroutines is called from Nc program with a M97 or M98 command. M99 is the End of subroutine.

4.25: Macros

A special type of user-defined cycles is called micros. which are generic cycles with parametric variables. It would be used where certain ~~t~~ motion sequences would be repeated several times within a program. It is used to reduce the total number of statement required in APT program.

Macro is a programming concept used to

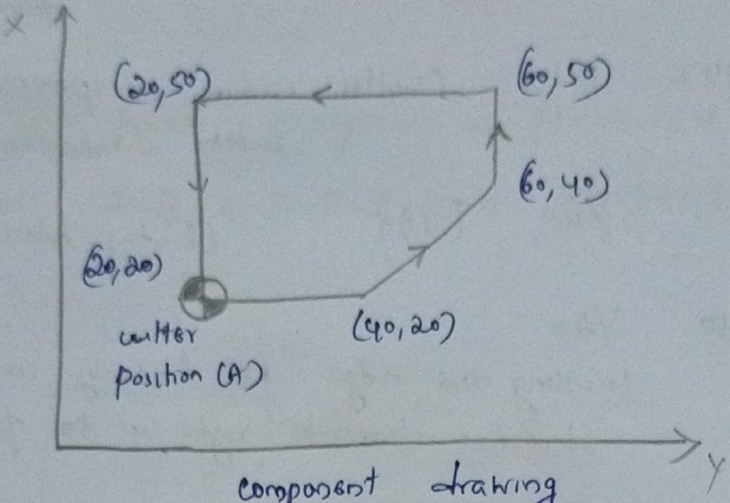
i. program
ii. store
iii. recall
iv. execute automatic cycle & family of programs

Features of macros are as follows

i. variables are allowed
ii. Mathematical operation +, −, ×, ÷ are possible.
iii. Interrupt control can be done.

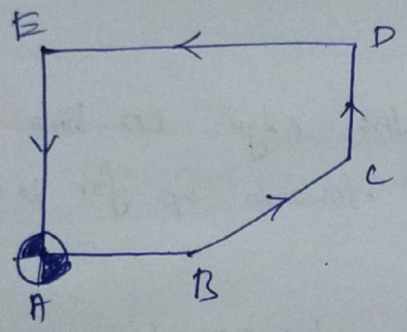
Manual part programming for milling process.

1. Prepare a part program for manufacturing the given component show in fig. profile milling process in a cnc milling machine by considering cutter compensation.



component drawing

Soln:



tool positions

Part program in incremental mode:

```
O0012                                  (program number)

N00   G28   T00   U00   W00

N01   M06   T01                        (place tool number one in the spindle)

N02   G54   G91   S400   M03   T01
      (select coordinate system, incremental mode, start
       spindle cw at 400 rpm, get tool number one
       ready)

N03   M08                              (Turn on coolant)

N04   G17                              (Interpolation xy plane)
```

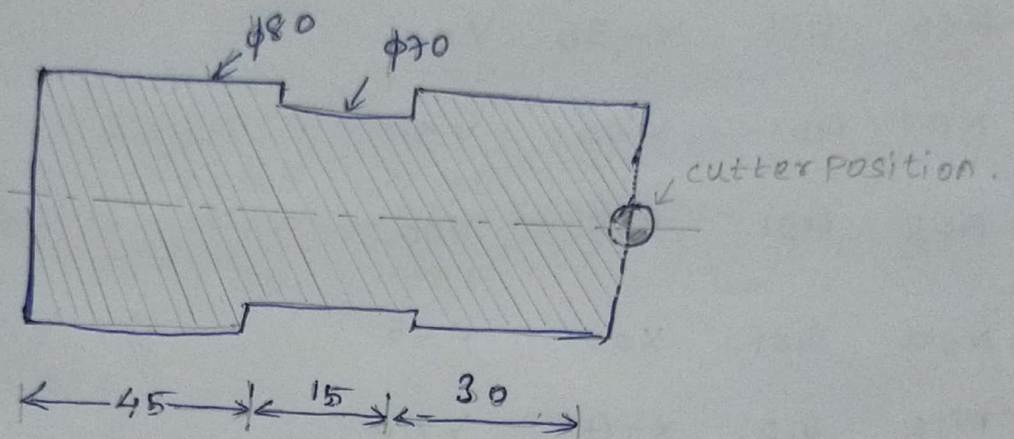
```
N05   G01   X00   Y00   Z00   (Rapid traversing of the tool to (0,0))
N06   G00   X20   Y20   (Rapid traversing of the tool to position A)
N07   Z-10   F0.8   (Z rejers to the depth of cut & feed = 0.8)
N08   G42   D1   (Cutter radius compensation - right & cutter dimension ON)
N09   G1   Y20   F199   (Entry block)
N10   X40   Y20
      (Milling the edge AB linearly in the horizontal direction towards right up to position B for 20 mm length)
N11   X60   Y40   (Milling the edge BC up to position C)
N12   X60   Y50
      (Milling the edge CD linearly in the vertical direction towards up for 10 mm length up to position D)
N13   X20   Y50
      (Milling the edge DE linearly in the horizontal direction towards left up to position E for 40mm length).
N14   X60   Y50
      (Milling the edge EF linearly in the vertical direction towards down for 30mm length up to position F)
N15   X00   Y00   Z00   (Rapid traversing of the tool to position A)
N16   G40   D0   (cutter dimension OFF & cutter compensation cancel)
N17   M05   (Spindle stop)
N18   M09   (Turn OFF Coolant)
N19   M02   (End of Program)
N20   G28   Z00   M19   (Return to tool change position, orient spindle)
```

Manual part programming on lathes.

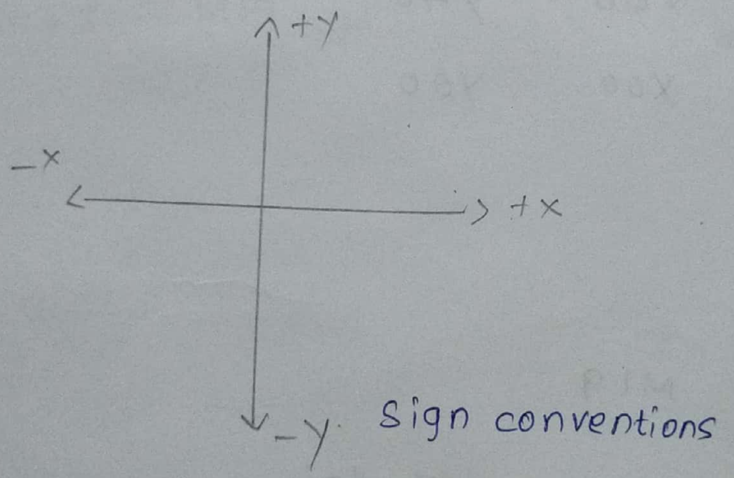
Prepare a part program for manufacturing the given component for the given dimensions as shown in figure

Solution

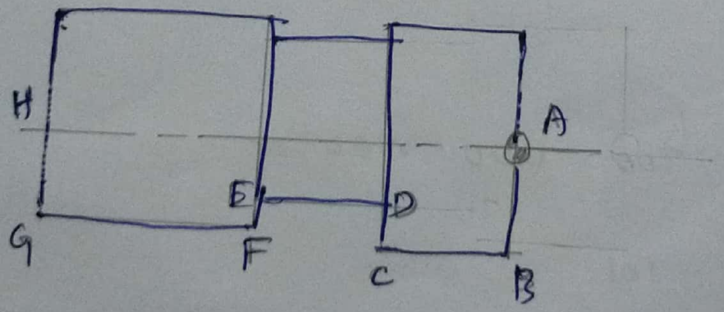
The part program is prepared for the tool position from A-B-C-D-E-F-G-H to perform the given. component.



Component Drawing



Sign conventions



Tool Positions for turning

Programming in incremental mode

```
O0001
N00   G28   T00   U00   W00
N01   M06   T01
N02   G54   G91   S1500   M03   T01

N03   M08
N04   G00   X00   Y00
N05   G01   X00   Y-40   F80
N06   G01   X-30   Y00
N07   G01   X00   Y5
N08   G01   X15   Y00
N09   G01   X00   Y-5
N10   G01   X-45   Y00
N11   G01   X00   Y40
N12   G00   X00   Y00
N13   M09
N14   M02
N15   G28   M19
```

Programming in absolute mode:

```
O0002
N00   G28   T00   U00   W00
N01   M06   T01
N02   G54   G90   S1500   M03   T01
```

```
N03   M08
N04   G00   X00    Y00
N05   G01   X00    Y-40   F80
N06   G01   X-30   Y-40
N07   G01   X-30   Y-35
N08   G01   X-45   Y-35
N09   G01   X-45   Y-40
N10   G01   X-90   Y-40
N11   G01   X-90   Y40
N12   G00   X00    Y00
N13   M09
N14   M02
N15   G28   M19
```

Introduction of CAM package:

CAM is the use of software and computer-controlled machinery to automate a manufacturing process.

The components for a CAM system to function are:

i. Software to feed data to a machine to make a product by generating tool paths.

ii. Machinery that can turn raw material into a finished product.

iii. post-processing elements that converts tool paths into a language machines ~~Cam~~ can understand.

Unit - V

Cellular Manufacturing & Flexible Manufacturing System

5.1 Group Technology (GT)

GT is a manufacturing philosophy to increase production efficiency by grouping a variety of parts having similarities of shape, dimension and process route.

Role of GT in CAD/CAM integration:

- Identifying the part families
- Rearranging production machines into machine cells
- Increase communication across all manufacturing functions
- Minimizing production cost
- Maximizing production rate
- Results closer dimensional tolerances
- Working with increased variety of materials.

5.2 Part families

A part family is a collection of parts which are similar either because of geometric shape & size or because similar processing steps are required in their manufacture.

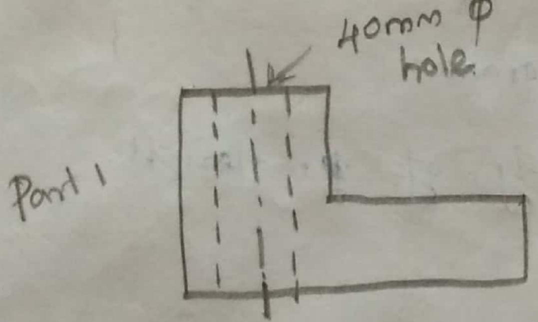
i. Design part family

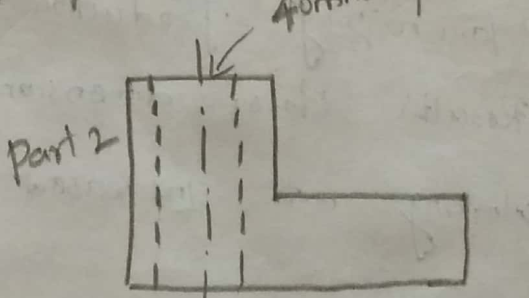
The parts which are similar in their design characteristics (shape & geometry) are grouped in a family referred to as a design part family

ii. Manufacturing part family:

The parts which are similar in their manufacturing characteristics are grouped in a family referred to as a manufacturing part family.

Design part family

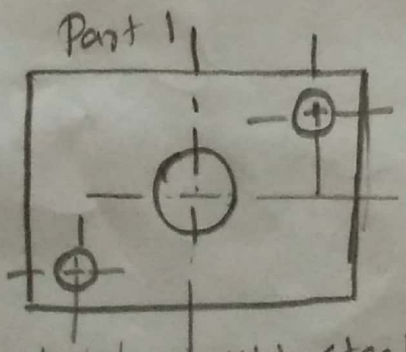


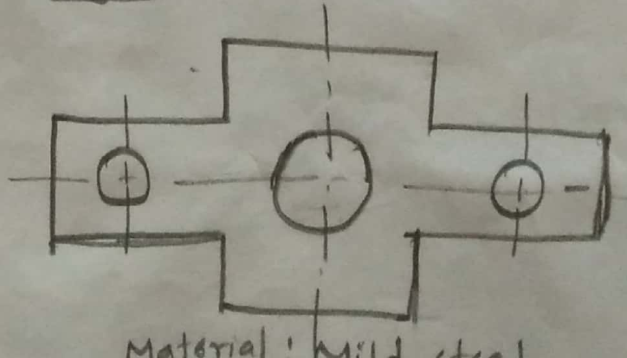


Material: Cold Rolled steel
Tolerances: ± 0.525 mm
Finish: Two coats Primer

Material: Aluminium
Tolerances: ± 0.075 MM
Finish; Sand & Buff

Manufacturing part family





Material: Mild steel
Tolerances: ±0.06 mm
Production: 500 pcs/month

Material: Mild steel
Tolerances: ± 0.06 mm
Production: 500 Pcs/ Month

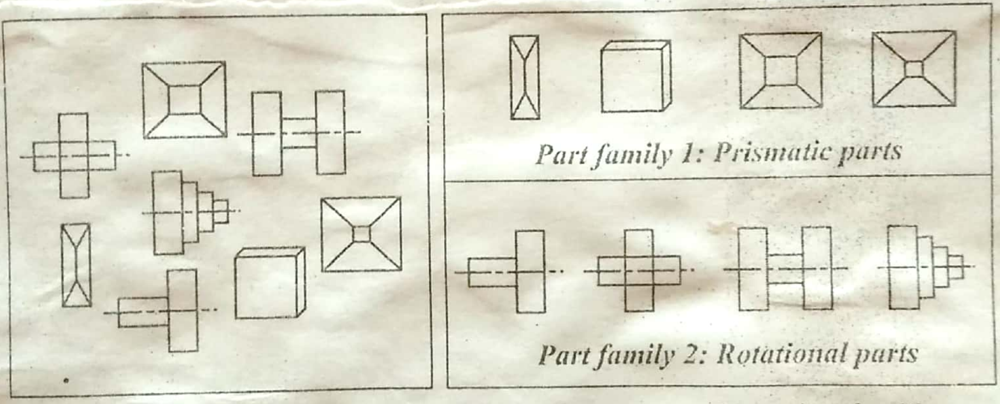
5.3 Methods for part family formation

The three general methods for grouping parts into families are:

1. Visual inspection
2. parts classification and coding system
3. Production flow analysis

5.4: Visual inspection method:

* It involves looking at parts, photos of parts or drawing of parts and arranging them into similar groups.
* Simplest and least expensive method.



(a) A set of parts with dissimilar features

(b) Parts grouped into part families by visual inspection

Figure 5.4 Visual inspection method

5.5: Parts classification & Coding method

Coding is a systematic process of establishing an alphanumeric value for parts based on selected part features. Classification is the grouping of parts based on code values.

Part classification and coding method is ~~the~~ most difficult, most time-consuming and widely used method.

In parts classification and coding, the various design and manufacturing attributes of a part are identified, listed and assigned a code number.

I. Design & manufacturing attributes:

Any parts classification systems fall into one of the following three categories:

1. Systems based on part design attributes
2. Systems based on part manufacturing attributes
3. Systems based on both design & manufacturing attributes.

- Parts classified by design attributes can be coded from information on the engineering drawing. This first category systems are useful for design retrieval and to promote design standardisation.

- In grouping of manufacturing attributes, in addition to drawing information, other information such as operation sequence, lot size, machines used, Production process, surface finish, ~~etc~~ are also considered. Systems in the second category are used for computer-aided process planning, tool design and other production related functions.

- The third category represents an attempt to combine the functions, and advantages of the other two systems into a single classification scheme.

Common design and manufacturing attributes

Part design attributes	Part manufacturing attributes
↓	↓
Basic external shape	Major production process
Basic internal shape	Minor operations
Rotational or rectangular shape	operation sequence
Major dimensions	Major dimension
Minor dimensions	Production time
Material type	tools required
Part function	fixtures required
Length to diameter ratio (rotational parts)	Batch size
Aspect ratio (rectangular parts)	Machine tool
surface finish	Annual production
tolerances	surface finish

II. Coding system structure:

There are three basic code structures used in group technology applications.

1. Hierarchical codes (or monocode or tree structure)
2. Attribute codes (or polycodes or chain type structure)
3. Decision tree codes (or hybrid codes or mixed codes)

1. Hierarchical code

In hierarchical structure, the interpretation of each successive symbol depends on the value of the Preceding symbols. Each symbols amplifies the information contained in the preceding digit, so a digit in the code cannot be interpreted alone.

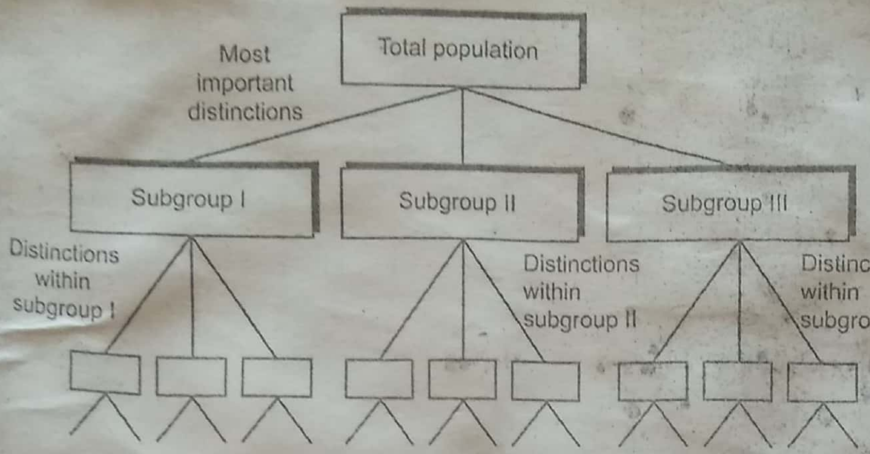
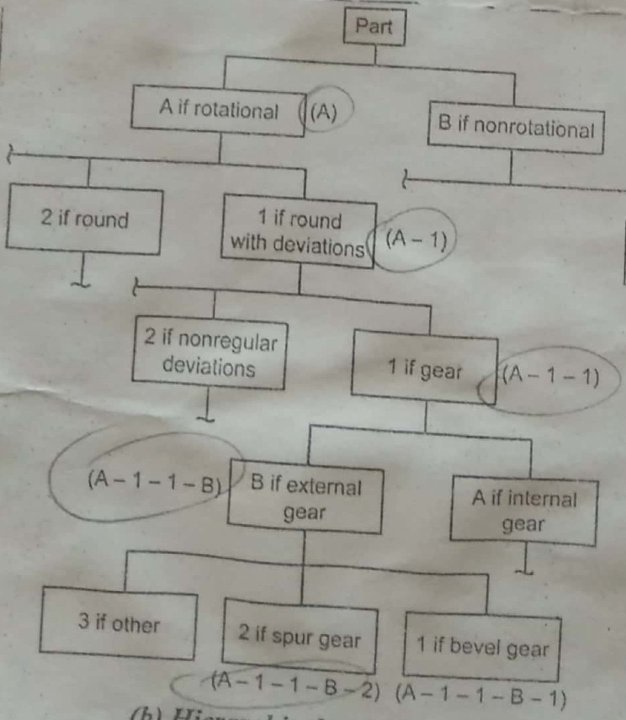


Figure 5.5 Structure of monocodes

The structure of these codes is like a tree in which each symbol amplifies the information provided in the previous digit.



(b) Hierarchical code for the spur gear

Spur gear

Hierarchical code for Spur gear is 'A11B2'

Merits & demerits of Monocode system

i. It provides a large amount of information in a relatively Small number of digits.

ii. This tree structure works well for designing an existing ordered structure but is more difficult to use in classifying things that have no apparent order.

iii. Construction is difficult.

iv. Monocodes are frequently used in design departments for Part retrieval. But their utility is limited in manufacturing departments.

Attribute code for spur gear is '22213'

2. Attribute code

In this structure, the interpretation of each symbol in the sequence does not depend on the value of preceding symbols. that is, each digit in this. code represents information in its own right and does not directly qualify the information provided by the other digits.

Digit	class of feature	~~Possible~~ Possible value of digits			
		1	2	3	4
1	External shape	cylindrical without deviation	[✓ cylindrical with deviation]	Box like	- - - -
2	Internal shape	None	[✓ center hole]	Blind center hole	- - -
3	Number of holes	0	[✓ 1–2]	3 – 5	- -
4	type of holes	[✓ Axial]	Cross	Axial cross	- -
5	Gear teeth	worm	Internal spur	[✓ External spur]	- - -

Merits & demerits of polycode:

i. they are compact and easy to use and develop.

ii. this attribute code system is popular with manufacturing departments because it makes it easy to identify parts that have similar features that require similar processing

iii. the primary disadvantage is that, for comparable code size, a polycode lacks the detail present in a mono code structure.

3. Decision-tree code:

A hybrid code captures the best features of the hierarchical and polycode structures. this system combines both design and manufacturing attributes:

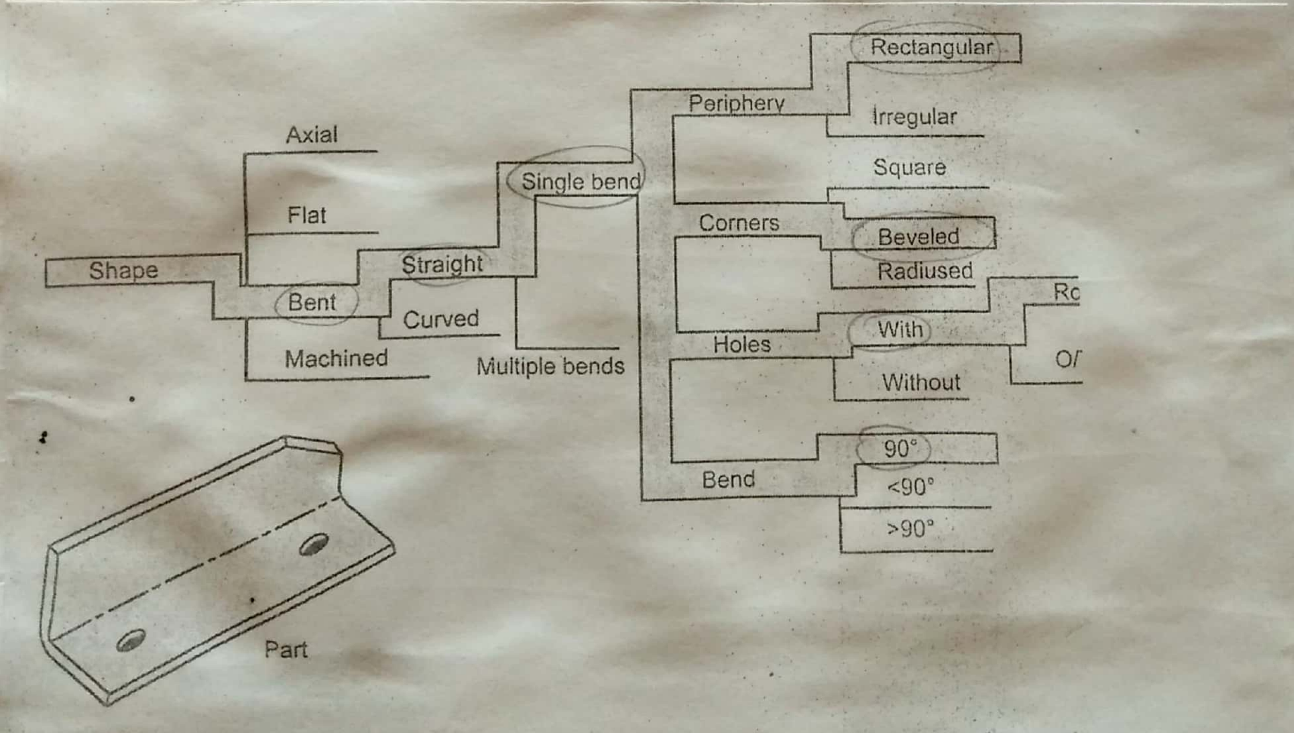


Figure 5.8 Decision-tree classification for a sheet-metal bracket

III. Reasons for using a Coding Scheme:

1. Design retrieval
2. Automated process planning
3. Machine cell design

IV. Selection of a coding system

1. objectives
2. Robustness
3. Expandability
4. Differentiation
5. Automation
6. Efficiency
7. Cost.
8. Simplicity

5.6: Coding System:

1. Optiz classification system:

The optiz system was developed by H. Optiz of Aachen in Germany.

It was the most popular and one of the first Published classification and coding schemes for mechanical parts. This system uses alpha-numeric symbols to represent the various attributes of a part.

The optiz coding scheme uses the following digit sequence:

12345 6789 ABCD

The first five digits (12345) code the major design attributes of a part and are called the 'form code'.

The next four digits (6789) are for coding manufacturing-related attributes and are called the 'Supplementary code'.

the letters (A B C D) code the production operation and sequence and are referred to as the 'secondary code'. the secondary code can be designated by the firm to serve its own particular needs.

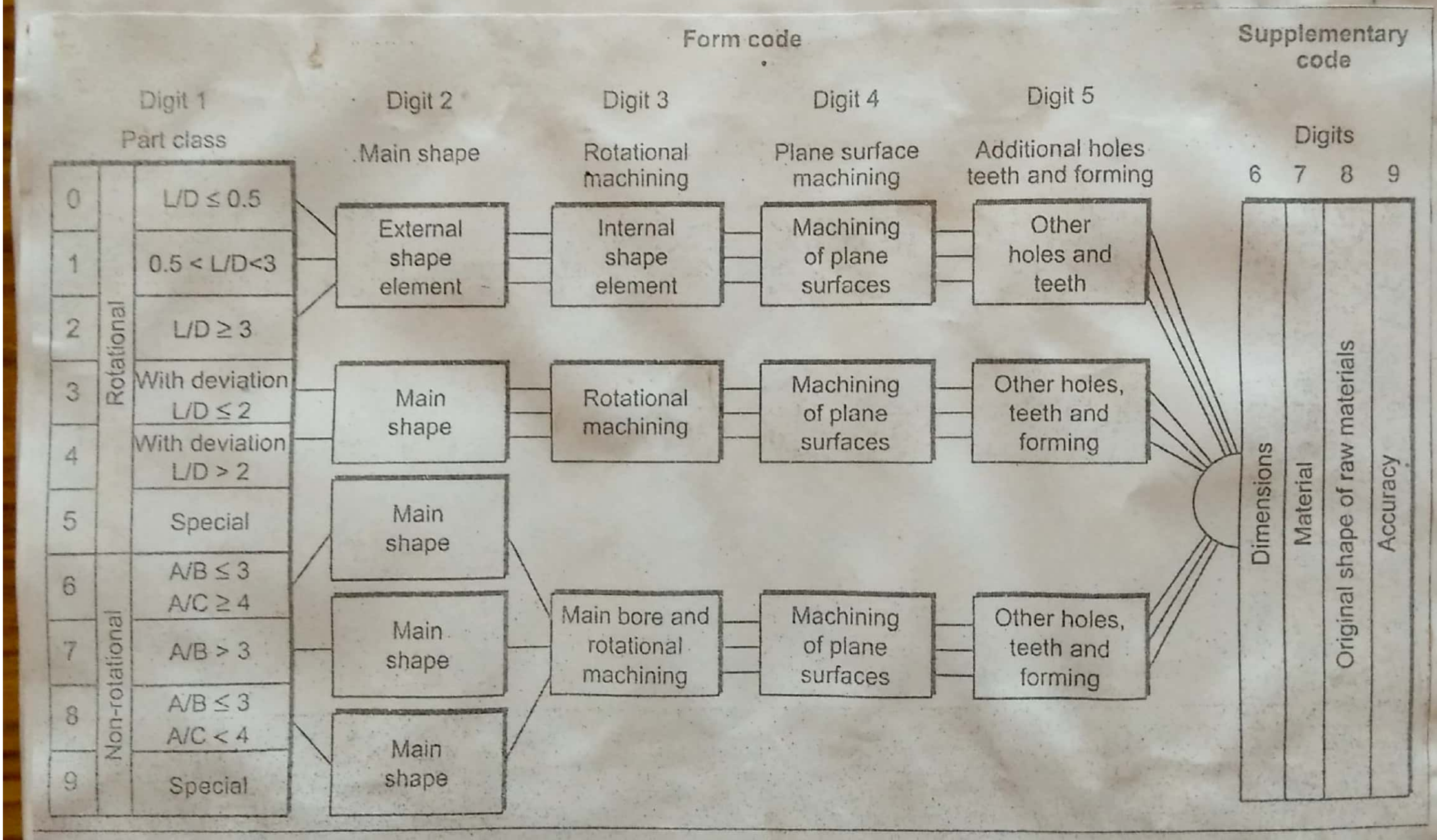
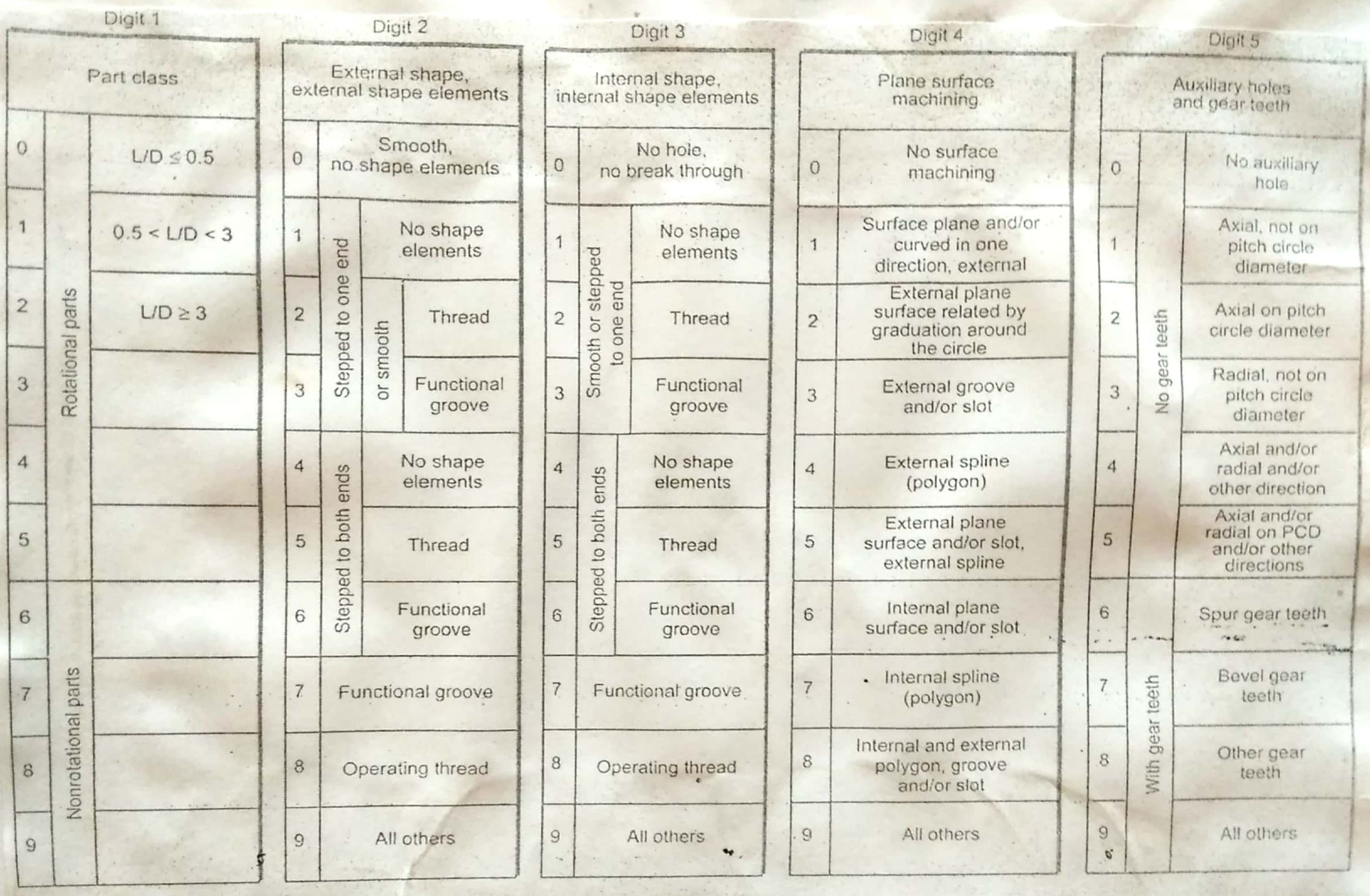


Figure 5.9 Basic structure of the Optiz system of parts

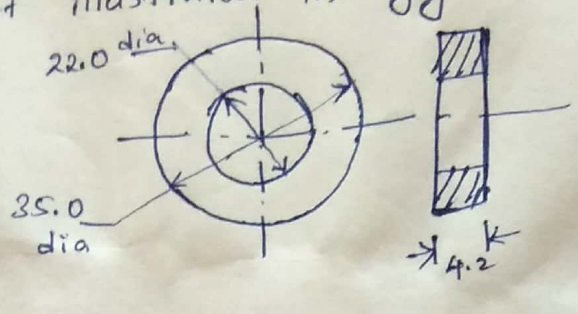


	Digit 1		Digit 2			Digit 3		Digit 4	Digit 5	
	Part class		External shape, external shape elements			Internal shape, internal shape elements		Plane surface machining	Auxiliary holes and gear teeth	
0	Rotational parts	L/D ≤ 0.5			Smooth, no shape elements		No hole, no break through	No surface machining	No gear teeth	No auxiliary hole
1		0.5 < L/D < 3	Stepped to one end		No shape elements	Smooth or stepped to one end	No shape elements	Surface plane and/or curved in one direction, external		Axial, not on pitch circle diameter
2		L/D ≥ 3		or smooth	Thread		Thread	External plane surface related by graduation around the circle		Axial on pitch circle diameter
3					Functional groove		Functional groove	External groove and/or slot		Radial, not on pitch circle diameter
4			Stepped to both ends		No shape elements	Stepped to both ends	No shape elements	External spline (polygon)		Axial and/or radial and/or other direction
5					Thread		Thread	External plane surface and/or slot, external spline		Axial and/or radial on PCD and/or other directions
6	Nonrotational parts				Functional groove		Functional groove	Internal plane surface and/or slot	With gear teeth	Spur gear teeth
7					Functional groove		Functional groove	Internal spline (polygon)		Bevel gear teeth
8					Operating thread		Operating thread	Internal and external polygon, groove and/or slot		Other gear teeth
9					All others		All others	All others		All others

Figure 5.10 Form code (digits 1–5) for rotational parts in the Opitz coding

Solved problems on Optiz classification system:

1. Develop the form code (five digits) in the optiz system for the part illustrated in figure. All dimensions are in mm.



Step 1: $\frac{L}{D} = \frac{4.2}{35} = 0.12$

$\frac{L}{D} = 0.12 < 0.5$

$\frac{L}{D} \leq 0.5 \Rightarrow$ Digit 1 = 0

Step 2: External shape : Smooth, no shape elements

∴ Digit 2 = 0

Step 3: Internal shape : Throug hole, smooth, no shape elements.

∴ Digit 3 = 1

Step 4: : plane surface machining : None

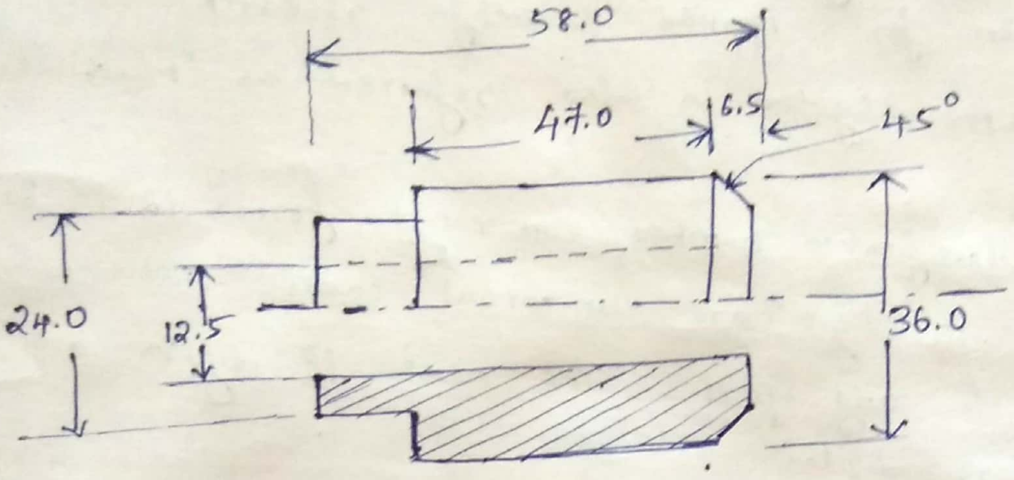
∴ Digit 4 = 0

Step 5: Auxiliary holes and gear teeth : None

∴ Digit 5 = 0

Thus, the form code in the optiz system for the part is '00100'.

2. Develop the form code (first five digits) in the optiz system for the part illustrated in figure. All dimensions are in 'mm'.



Step 1: $\frac{L}{D} = \frac{58}{36} = 1.611$

$0.5 < \frac{L}{D} < 3$ ∴ Digit 1 = $\underline{\underline{1}}$

Step 2: External shape: stepped to one end with functional groove.

∴ Digit 2 = $\underline{\underline{3}}$

Step 3: Internal shape: part contains a through-hole.

∴ Digit 3 = $\underline{\underline{1}}$

Step 4: plane surface machining: None

∴ Digit 4 = 0

Step 5: Auxiliary holes and gear teeth: None

∴ Digit 5 = 0

Thus the form code in the optiz system for the part is '13100'.

2. The MICLASS system:

MICLASS stands for Metal Institute classification system. This system was developed by Netherland organisation for Applied scientific research.

MICLASS system is also referred as 'Multiclass system'.

This classification number can range from 12 to 30 digits. The first 12 digits are 'universal codes' that can be applied to any part. The next 18 digits are called supplementary digits.

The first 12-digits are mandatory and are used to classify the engineering and manufacturing characteristics of a part.

Digits	Attributes
1st digit	Main shape
2nd & 3rd digits	shape elements
4	position of shape elements
5&6	Main dimensions
7	Dimension ratio
8	Auxiliary dimension
9&10	tolerance codes
11&12	Material codes

3. DCLASS Coding System:

DCLASS stands for Design and classification Information system. This part family code is comprised of eight digits partitioned into five code segments.

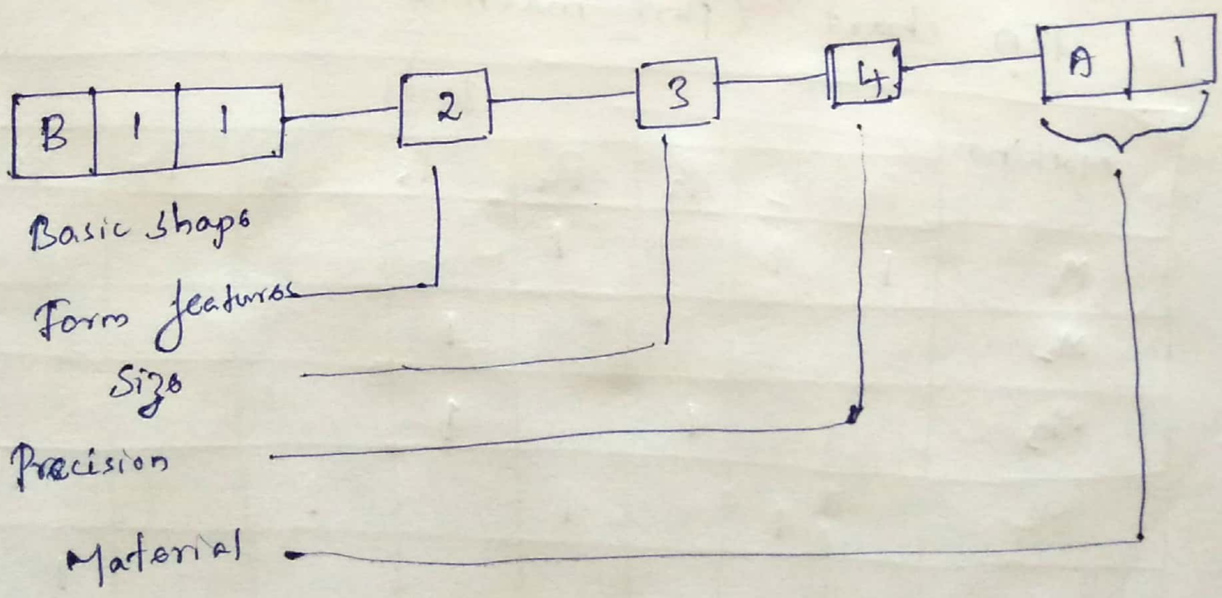
First segment (consisting three digits) – Basic shape

Second segment (Fourth digit) – Specify the complexity of the part (holes, slots, heat treatment special surface finishes)

Third Segment (Fifth digit) – Specify the overall size of the coded part.

Fourth segment (sixth digits) – Represents precision

Final segment (consisting two digits) – Denote the material type



5.7: Production Flow Analysis (PFA)

PFA is a method for identifying part families and associated machine groupings that uses the information contained on production route sheets rather on part drawings.

This method is based on the route sheet information, it is sometimes referred as the route sheet inspection method.

Steps involved in PFA

i. Data collection
ii. Sortation of process routings
iii. Preparation of PFA chart
iv. cluster analysis.

PFA chart (part-machine incidence matrix)

Machines	Parts								
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9
M_1	1	1		1				1	
M_2					1				1
M_3			1		1				1
M_4		1		1		1			
M_5	1							1	
M_6			1						1
M_7		1				1	1		

Cluster analysis:

Rearranged PFA chart, indicating possible m/c grouping

	P_1	P_8	P_2	P_4	P_6	P_7	P_9	P_3	P_5
M_1	1	1	1	1					
M_5	1	1							
M_4			1	1	1				
M_7			1		1	1			
M_3							1	1	1
M_6							1	1	
M_2							1		1

5.8: Facility design using GT

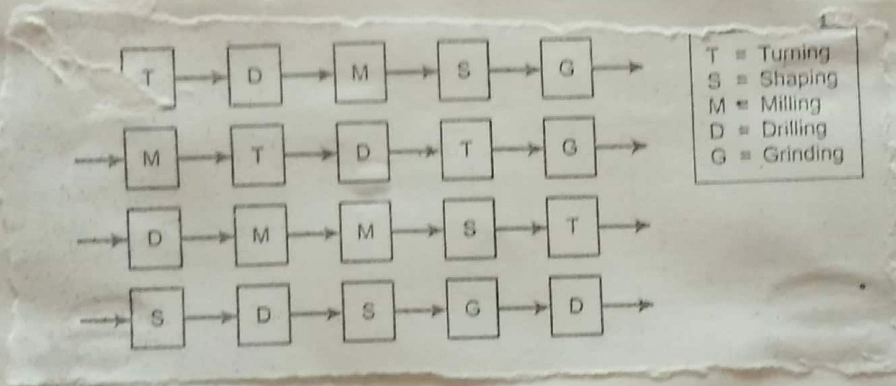
Facility layout also known as plant layout, refers to the physical arrangement of production facilities.

The objective of facility layout is to design a physical arrangement that most economically meets the required output quantity and quality.

There are three basic ways to arrange machines in a shop. They are:

1. Line (or product) layout.
2. Functional (or process) layout
3. Group (or combination) layout

1. Line layout (product layout)
In a line layout, the machines are arranged in the sequence as required by the product.



Suitable for mass production

2. Functional layout (process layout)
this is charactorized by keeping ~~sim~~ Similar machines/ operations at one location. i.e. all lathes at one place, all milling machines at another place.

In Process layout machines are arranged according to their functions.

Suitability suitable for job order / non-repetitive type Production

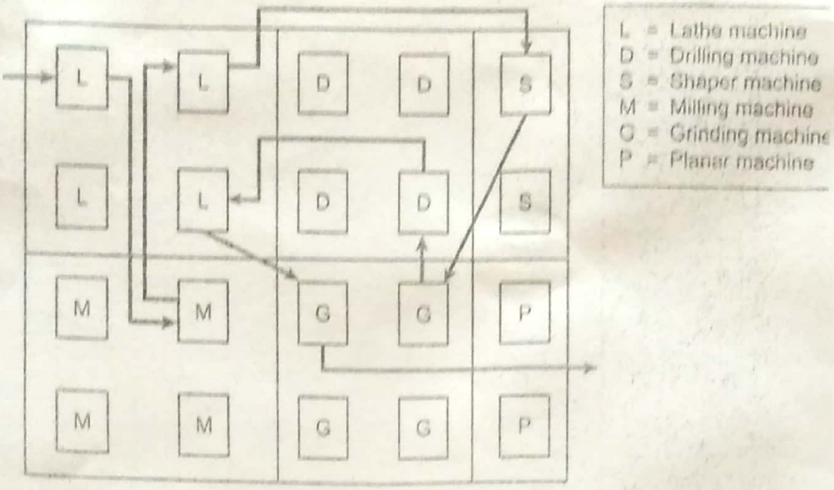


Figure 5.17 Functional layout

3. Group layout (combination layout)

It is a combination of the product layout and process layout.

In group layout, machines are arranged into cells. Each cell is capable of performing manufacturing operations on one or more families of part.

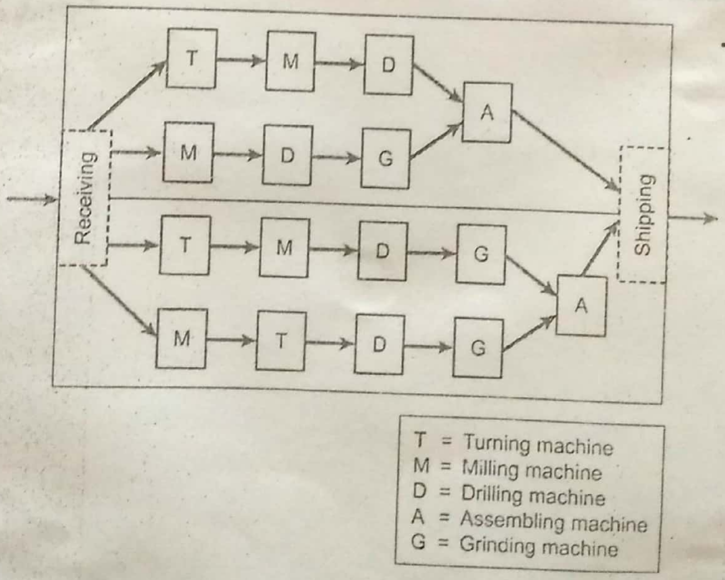


Figure 5.18 Group technology layout (with two cells)

Suitable for batch type production

Small batch & large variety

5.9: Benefits of GT

1. Product design
2. Tooling & setups
3. Materials handling
4. Production & Inventory control
5. Process planning
6. Management & employees:

5.10: Limitation of GT

1. Implementing GT is expensive.
2. Installing a coding & classification system is very time consuming.
3. Implementation of GT is difficult.

5.11: Cellular Manufacturing

CM is an application of group technology in which dissimilar machines have been aggregated into cells, each of which is dedicated to the production of a part family.

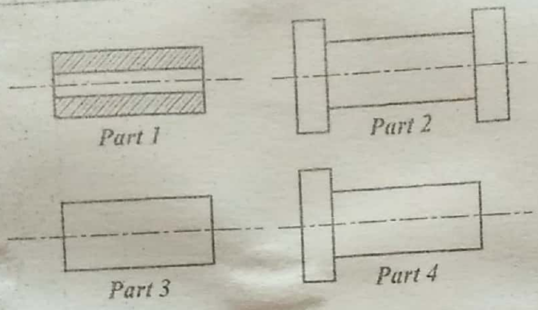
The primary advantag of CM implementation is that a large manufacturing system can be decomposed into smaller subsystems of machine called cells. These cells are dedicated to process part families based on similarities in manufacturing requirements.

Benefits of cellular manufacturing

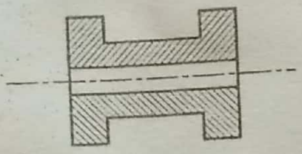
1. Reduce manufacturing lead time
2. Reduce work-in-process
3. Improve part and product quality
4. Reduce response time for customer orders
5. Reduce more distances / more times.
6. Increase manufacturing flexibility.
7. Reduce unit costs
8. Simplify production planning & control
9. facilitate employee involvement.
10. Reduce set up times
11. Reduce finished goods inventory.

5.12 : Composite part concept

A composite part is a hypothetical part which includes all of the design and manufacturing attributes of a family. the composite is a single hypothetical part that can be completely processed in a manufacturing cell.

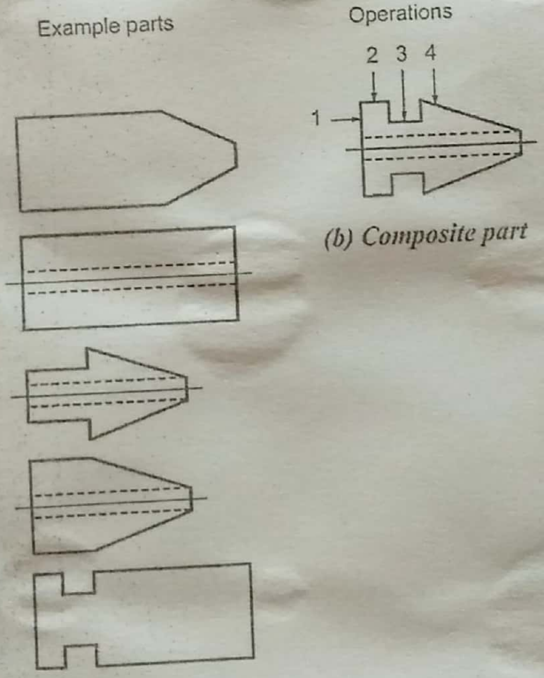


(a) Individual parts



(b) Composite part considering of all attributes of the four parts

Figure 5.19 Concept of composite part



(b) Composite part

(a) Individual parts

Figure 5.20 Composite GT part

Use of composite part concept:

i. The identification of composite parts simplifies the identification of groups.

ii. It provides a basis for the design of group tooling.

iii. It helps to develop the optimized process plan for the parts

iv. Standard machine setups are often possible with little or no changeover required between parts within the composite family.

5.13: Flexible Manufacturing Systems (FMS)

FMS is nothing but a highly automate GT machine cell. A FMS is an individual machine or group of machines served by an automated materials handling system that is computer controlled and has a tool handling capability.

A FMS is one ~~of the~~ manufacturing machine, or multiple machines that are integrated by an automated material handling system, whose operation is managed by a computerized control system.

Common elements of FMS

i. NC, CNC or smart production machine tools,

ii. Automatic material handling.

iii. central computer control

iv. Data integration.

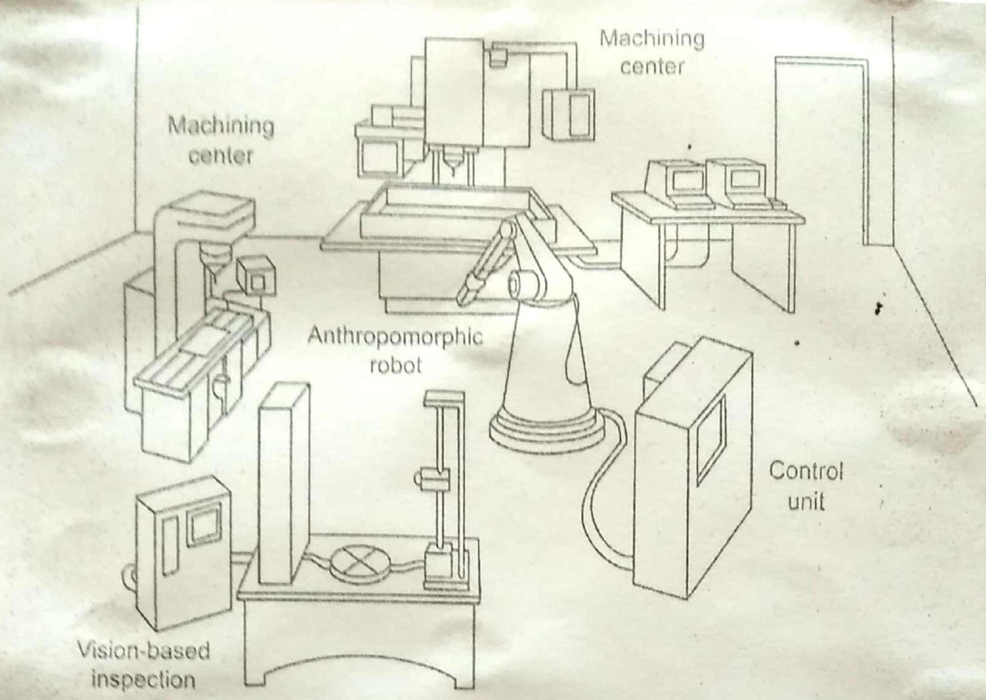


Figure 5.21 Schematic view of a flexible manufacturing system/cell

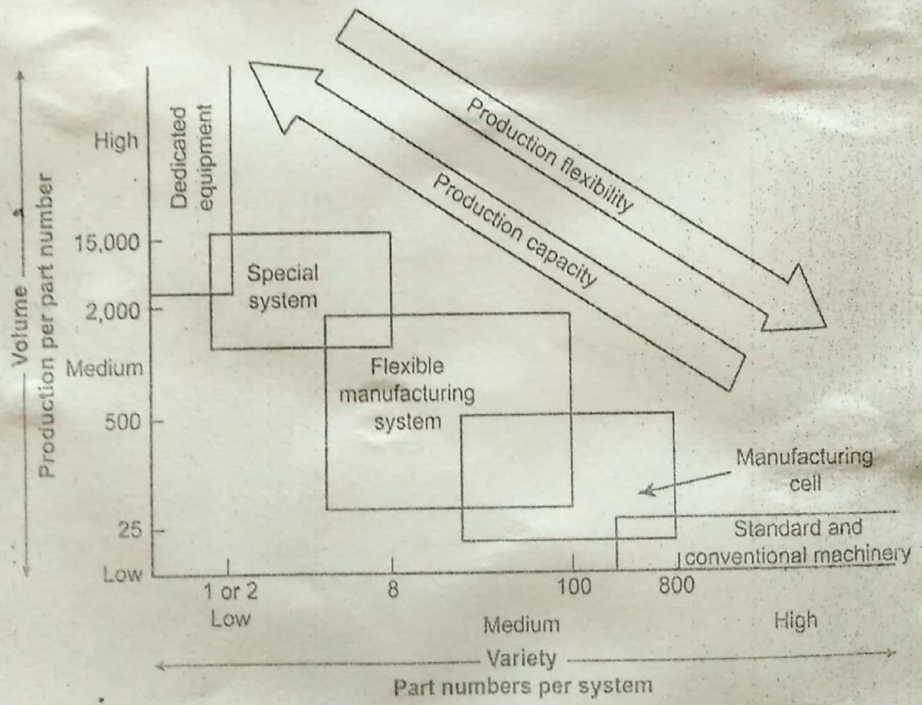


Figure 5.22 Volume Vs. Variety in manufacture

5.14 : Flexibility and its types:

Flexibility is an attribute that allows a manufacturing system to cope up with a certain level of variations in part or product type, without having any interruption in production due to changeovers between models.

Flexibility measures the ability to adopt to a wide range of possible environment.

Tests of flexibility

i. Part variety — Ability of the system to process different part types in non batch mode.
ii. Schedule change test — Ability of the system to readily accept changes in production schedule.
iii. Error recovery test — Ability of the system to recover swiftly from equipment malfunctions & breakdowns.
iv. New part test — Ability of the system to introduce new part designs.

5.15: Types of flexibility

1. Machine flexibility
2. production flexibility
3. Mix (or process) flexibility
4. Product flexibility
5. Routing flexibility

6. Volume (or capacity) flexibility

7. Expansion flexibility.

5.16 Types of FMS

I. Classification based on the kind of operations they perform:

1. Processing operation
2. Assembly operation

II. Classification based on the number of machines in the system:

1. Single machine cell (SMC)
2. Flexible machine cell (FMC)
3. Flexible manufacturing system (FMS)

III. Classification based on the level of flexibility associated with the system:

1. ~~Dedica~~ Dedicated FMS
2. Random - order FMS

I. Classification of FMS based on the kinds of operations they perform

1. Processing operation:
It transforms a work material from one state to another moving towards the final desired part or product. It adds value by changing the starting geometry, properties or appearance of the ~~starting~~ materials.

2. Assembly operation:

It involves joining of two or more components to create a new entity which is called an assembly / sub assembly.

II. classification of FMS based on the number of machines in the system

1. Single machine cell (SMC)

Single machine cell consists of a fully automated machine tool capable of unattended operations for a time period longer than one machine ~~cell~~ cycle.

SMC is capable of

i. processing different part types
ii. responding to changes in production schedule
iii. accepting new part introductions.

In SMC, processing is sequential not simultaneous.

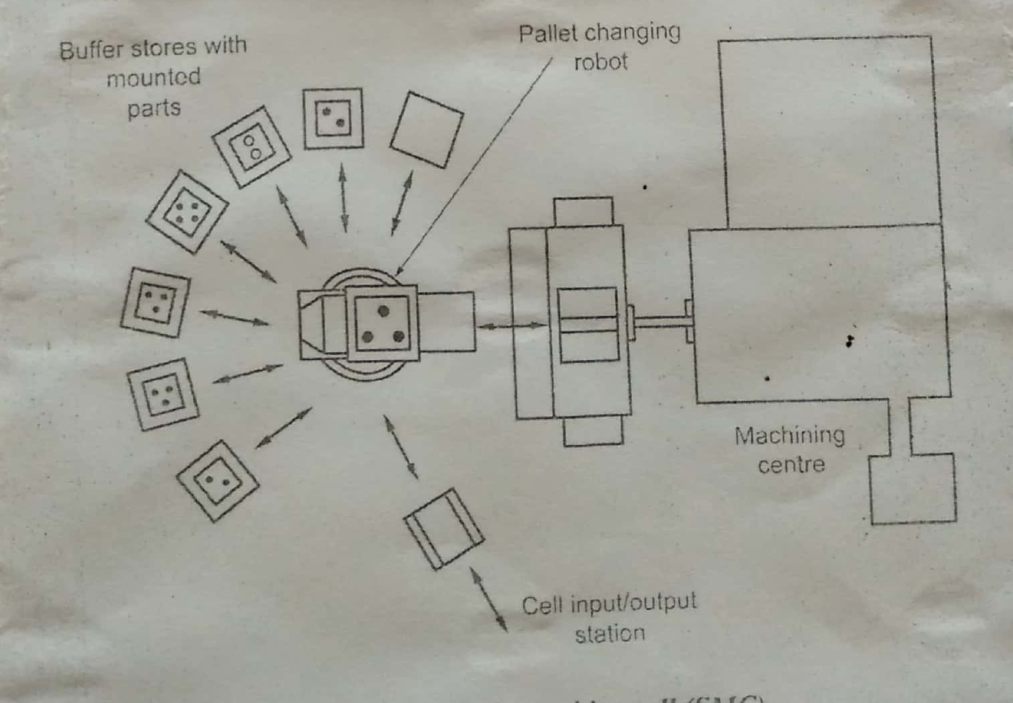


Figure 5.23 Single machine cell (SMC)

2. Flexible manufacturing cell (FMC)

It consist of two or three processing workstations (usually CNC machining centres or turning centres), a part handling system, load / unload station, and

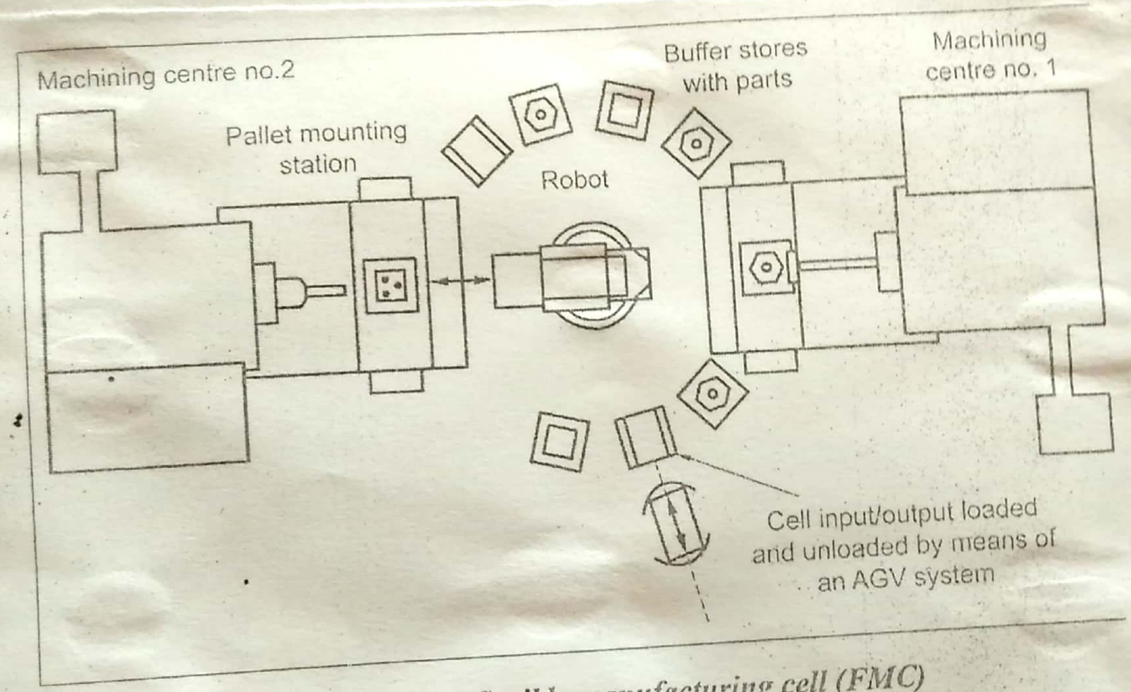
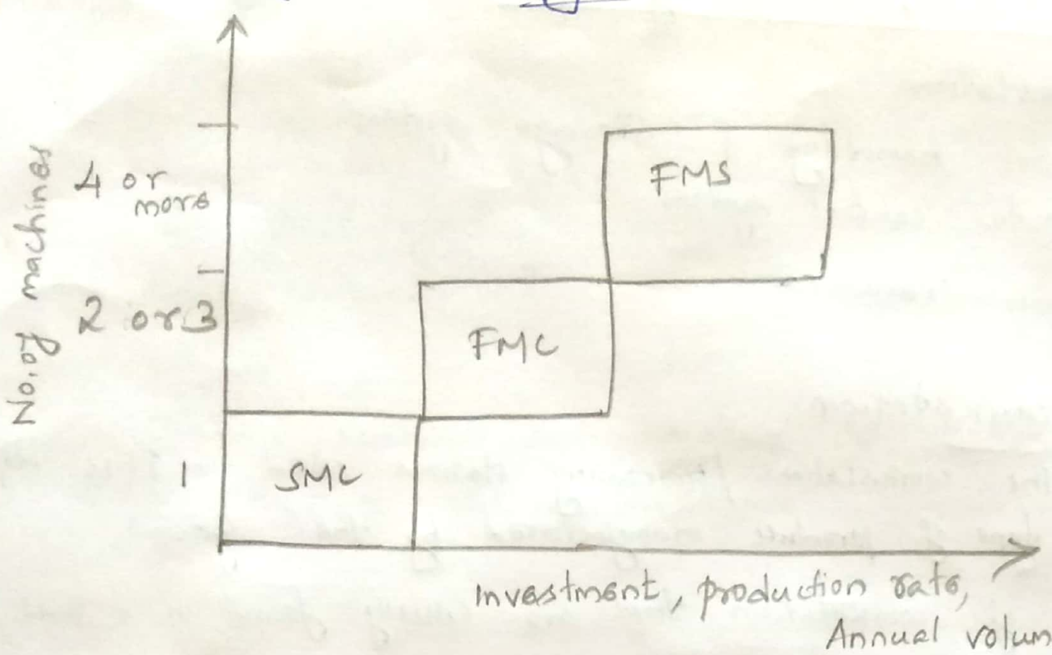


Figure 5.24 A flexible manufacturing cell (FMC)

3. Flexible Manufacturing system (FMS)

It consists of four or more processing workstations connected mechanically by a common part handling system and controlled automatically by a distributed computer system.

Features of three categories of flexible cells & systems



III. classification of FMS based on level of flexibility

1. Dedicated FMS

It is designed to produce a limited variety of part configurations.

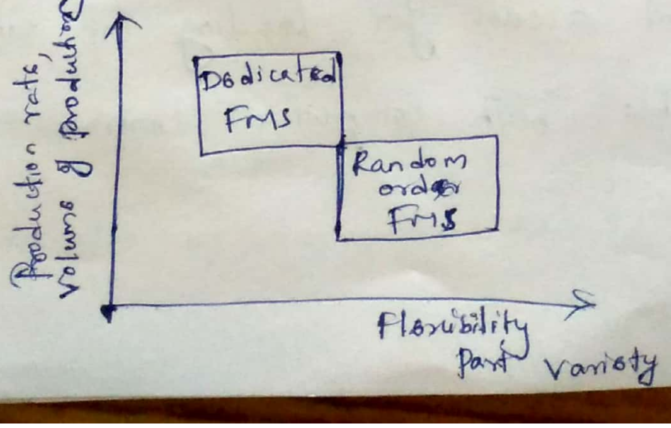
It is also referred as 'flexible transfer line' & 'special manufacturing system'.

2. Random - Order FMS:

It is more flexible than the dedicated FMS.

A random order FMS is preferred when:

i. the part family is large
ii. there are considerable variations in part configuration.
iii. the production schedule is subject to change from day-to-day.



5.17: Components / Elements of FMS

1. Workstations
2. Material handling & Storage system
3. Computer control system
4. Human resources.

5.18: FMS workstations:

The workstations / processing stations used in FMS depend upon the type of product manufactured by the system.

The types of workstations that are usually found in a FMS are

1. Load / unload stations
   Distributed Numeric control
2. Machining stations, – CNC, DNC, Automatic tool changing, tool storage
3. Assembly workstations.
4. Inspection stations – CMM, special inspection probes, Machine vision
5. Other processing stations – sheet metal processing workstations, forging processing stations.

5.19: Material Handling & Storage system

I. functions of the material handling system:

i. Random, independent movement of workparts between stations

ii. Handle a variety of workpart configurations
Prismatic or rotational parts

iii. temporary storage for increase machine utilisation

iv. Convenient access for loading & unloading workparts

v. Compatible with computer control

Scanned by CamScanner

II. FMS layout configurations

1. Inline layout
2. Loop layout
3. Ladder layout
4. Open-field layout
5. Robot-centered cell.

1. In-line layout:

The materials and handling systems are arranged in a straight line in the in-line layout.

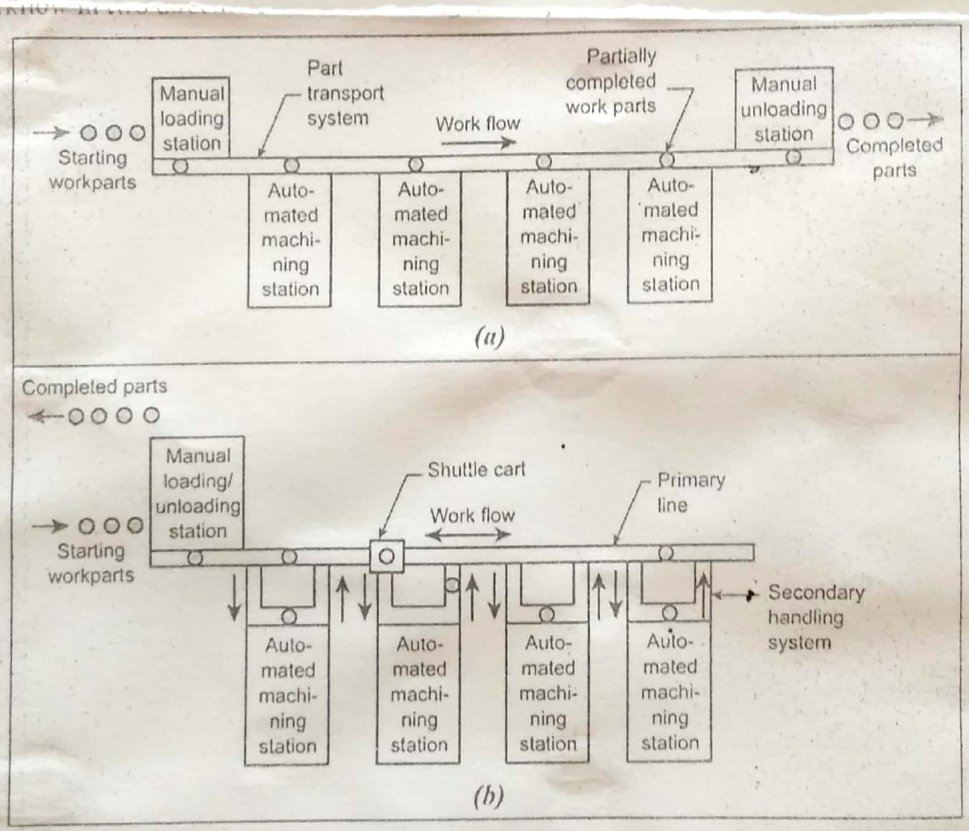
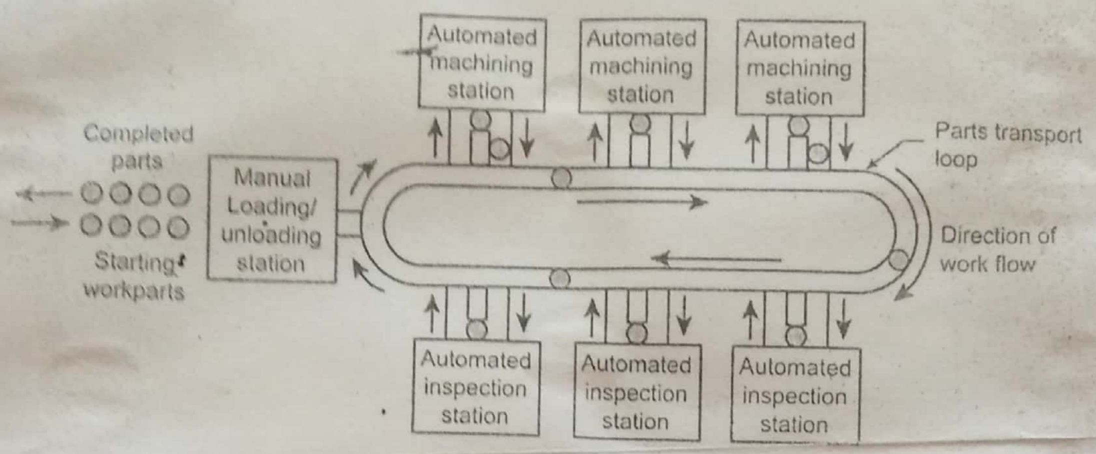


Figure 5.27 In-line FMS layouts

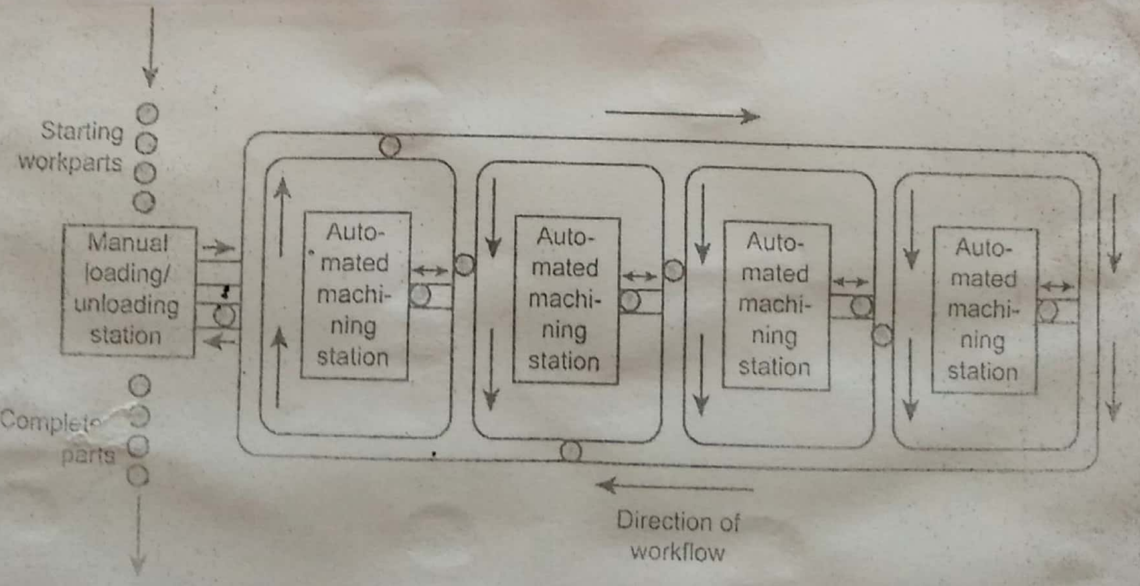
2. Loop layout:

In loop layout, the workstations are arranged in a loop. In this workparts usually move from one workstation to another in one direction around the loop, with the capability to stop at any station.



3. Ladder layout:

The ladder layout, an adaptation of the loop layout, consists of a loop with rungs on which workstations are located.



4. Open-field layout:

The open field layout, also an adaptation of the loop configuration, consists of multiple loops, ladders, and slidings organized to achieve the desired processing requirements.

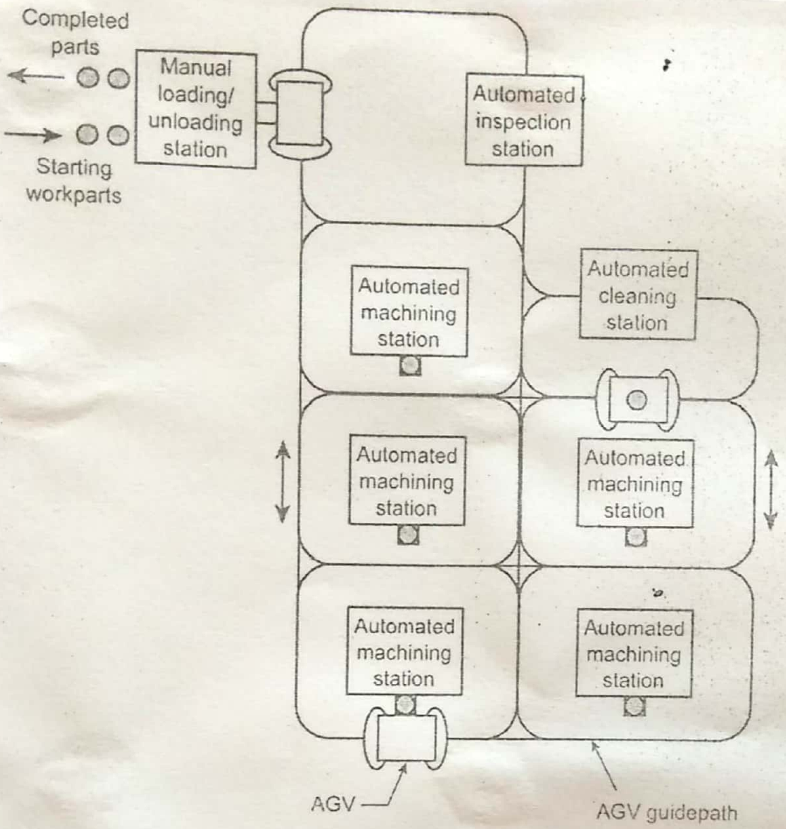
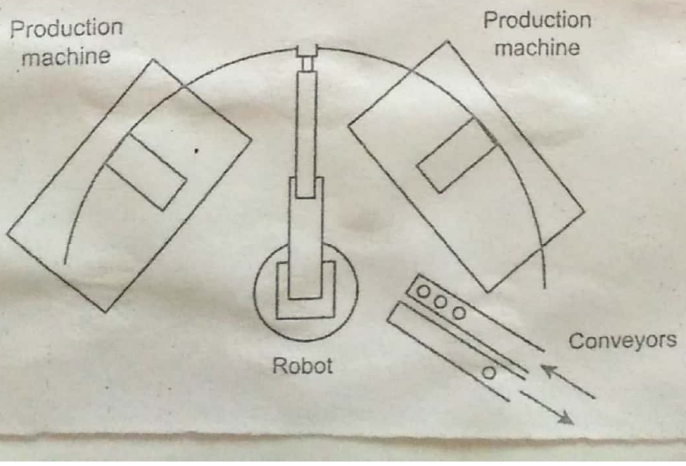


Figure 5.30 Open field FMS layout

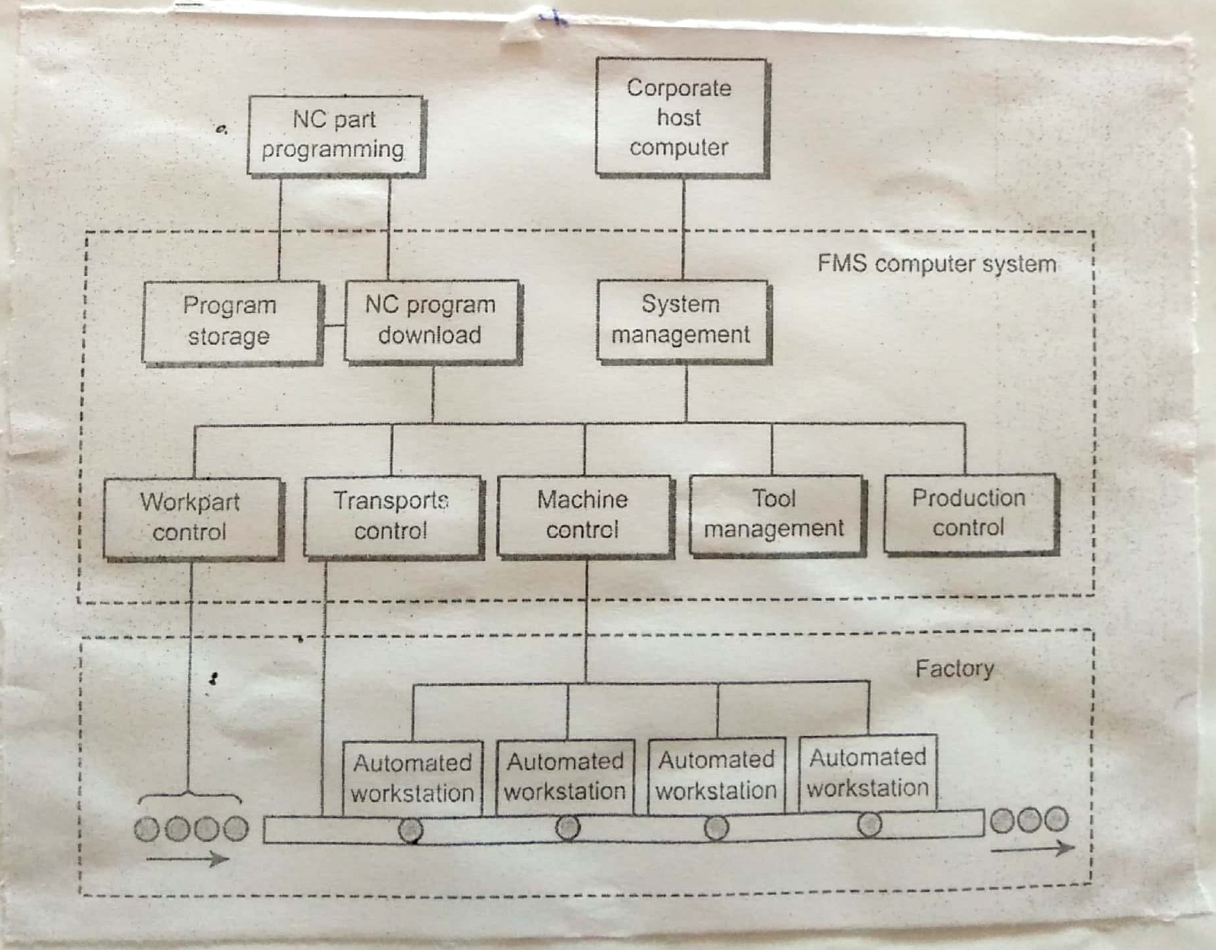
5. Robot-centered cell:

In this cell, one or more robots are used as the material handling system



5.20: FMS computer control system

1. Workstation / processing station control
2. Distribution of control instructions to workstations
3. Production control
4. Material handling system control
5. workpiece monitoring
6. Tool control
7. Quality control
8. failure diagnosis
9. safety monitoring
10. Performance monitoring & reporting.



5.21: Human resources:

1. To load raw workparts into the system.
2. To unload finished workparts from the system.
3. for tool changing & tool setting.
4. for equipment maintenance and repair.
5. To furnish NC part programming in a machining system.
6. To program and operate the computer system
7. To accomplish overall management of the system

5.22: FMS Applications:

1. Machining
2. Assembly
3. sheet-metal press working
4. Forging
5. plastic injection moulding
6. Welding
7. Textile machinery manufacture
8. Semiconductor component manufacture.

5.23: Advantages of FMS

1. Increased machine utilization
2. Reduced inventory
3. Reduced manufacturing lead time
4. Greater flexibility in production scheduling.
5. Reduced direct labour cost
6. Increased labour productivity
7. shorter response time
8. consistent quality
9. ~~redu~~ reduced factory floor space
10. Improved product quality

Disadvantages of FMS

1. High capital investment
2. Special training required to labour
3. Skilled labour is required
4. More cost for developing softwares.

5.24 FMS planning & control

I. FMS planning and design issues
II. FMS control (or operational) issues.

I.A. FMS planning issues:

1. Part family considerations
2. Processing requirements
3. Physical characteristics of the workparts
4. Production volume.

I.B. FMS Design issues:

1. Types of workstations
2. Variations in process routings & FMS layout
3. Material handling system.
4. Work-in-process & storage capacity.
5. Tooling
6. Pallet fixtures.

II. FMS operational issues

i. Scheduling & dispatching
ii. Machine ~~loadin~~ loading
iii. Part routing
iv. Part grouping
v. Tool management
vi. Pallet & fixture allocation

5.25: Quantitative analysis of FMS

The four different categories of FMS analysis models are.

1. Deterministic models – To provide gross estimation such as production rate, capacity & utilization
2. Queuing models – ~~Mathemat~~ mathematical theory, examine various simple system configurations
3. Discrete ~~ev~~ event simulation – To determine the most accurate methods for modelling specific attributes of FMS
4. Other techniques – It include mathematical programming, heuristic approaches, & number of operational research (OR) techniques.