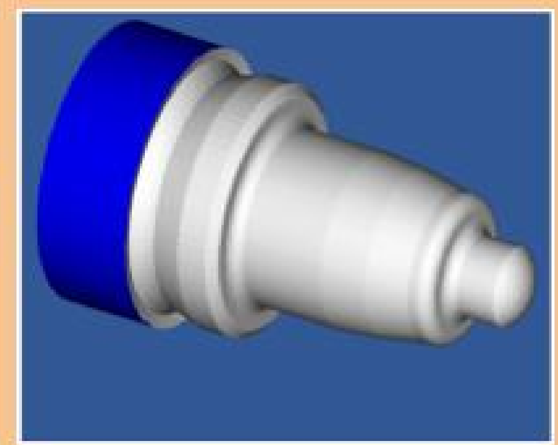
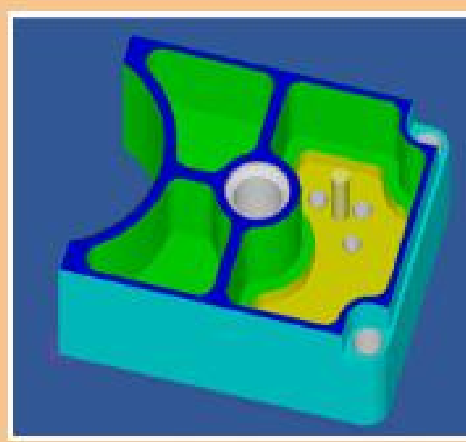
COMPUTER AIDED DESIGN AND MANUFACTURING

DIPLOMA COURSE IN ENGINEERING
M SCHEME

VI SEMESTER MECHANICAL

DIRECTORATE OF TECHNICAL EDUCATION
GOVERNMENT OF TAMILNADU

GOVERNMENT OF TAMILNADU

DIRECTORATE OF TECHNICAL EDUCATION CHENNAI – 600 025

STATE PROJECT COORDINATION UNIT

Diploma in Mechanical Engineering

Course Code: 1020

M – Scheme

e-TEXTBOOK

on

COMPUTER AIDED DESIGN AND MANUFACTURING

for

VI Semester Diploma Mechanical Engg. & Allied Courses

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M-SCHEME

(Implements from the Academic year 2015-2016 onwards)

Course Name : DIPLOMA IN MECHANICAL ENGINEERING

Course Code : 1020

Subject Code : 32062

Semester : VI

Subject Title : COMPUTER AIDED DESIGN AND MANUFACTURING

TEACHING AND SCHEME OF EXAMINATIONS:

No. of weeks per semester: 15 Weeks

<table>
<tr><th>Subject</th><th colspan="2">Instructions</th><th colspan="4">Examination</th></tr>
<tr><td rowspan="3">Computer Aided Design and Manufacturing</td><td>Hours / Week</td><td>Hours / Semester</td><td colspan="3">Marks</td><td>Duration</td></tr>
<tr><td rowspan="2">5</td><td rowspan="2">75</td><td>Internal Assessment</td><td>Board Examination</td><td>Total</td><td rowspan="2">3 Hrs</td></tr>
<tr><td>25</td><td>75</td><td>100</td></tr>
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Topics and Allocation of Hours:

Unit	Topics	Hours
I	COMPUTER AIDED DESIGN	14
II	COMPUTER AIDED MANUFACTURING	14
III	CNC PROGRAMMING, RAPID PROTOTYPING	14
IV	COMPUTER INTEGRATED MANUFACTURING, FLEXIBLE MANUFACTURING SYSTEMS, AUTOMATIC GUIDED VEHICLE, ROBOT	13
V	CONCURRENT ENGINEERING, QUALITY FUNCTION DEPLOYMENT, PRODUCT DEVELOPMENT CYCLE, AUGMENTED REALITY.	13
	REVISION AND TEST	7
	Total	**75**

COMPUTER AIDED DESIGN AND MANUFACTURING

DETAILED SYLLABUS

Contents: Theory

Unit	Name of the Topic	Hours
I	**COMPUTER AIDED DESIGN**	14
	Computer Aided Design: Introduction – definition – Shigley's design process – Ohsuga Model - CAD activities – benefits of CAD - CAD software packages.	
	Transformations: 2D & 3D transformations – translation, scaling, rotation and concatenation.	
	Geometric modelling: Techniques - Wire frame modelling – applications – advantages and disadvantages. Surface modelling – types of surfaces – applications – advantages and disadvantages – Solid modelling – entities – advantages and disadvantages – Boolean operations - Boundary representation – Constructive Solid Geometry – Comparison.	
	Graphics standard: Definition – Need - GKS – OpenGL - IGES – DXF.	
	Finite Element Analysis: Introduction – Development - Basic steps – Advantage.	
II	**COMPUTER AIDED MANUFACTURING**	14
	Computer Aided Manufacturing: Introduction - Definition – functions of CAM – benefits of CAM.	
	Group technology: Part families - Parts classification and coding - coding structure – Optiz system, MICLASS system and CODE System.	
	Process Planning: Introduction – Computer Assisted Process Planning (CAPP) – Types of CAPP - Variant type, Generative type – advantages of CAPP.	
	Production Planning and Control (PPC): Definition – objectives - Computer Integrated Production management system – Master Production Schedule (MPS) – Capacity Planning – Materials Requirement Planning (MRP) – Manufacturing Resources Planning (MRP-II) – Shop Floor Control system (SFC) - Just In Time manufacturing philosophy (JIT) - Introduction to Enterprise Resources Planning (ERP).	
III	**CNC PROGRAMMING, RAPID PROTOTYPING**	14
	CNC PART PROGRAMMING: Manual part programming - coordinate system – Datum points: machine zero, work zero, tool zero - reference points - NC dimensioning –	

G codes and M codes – linear interpolation and circular interpolation - CNC program procedure - sub-program – canned cycles - stock removal – thread cutting – mirroring – drilling cycle – pocketing.

Rapid prototyping: Classification – subtractive – additive – advantages and applications - materials. Types - Stereo lithography (STL) – Fused deposition model (FDM) – Selective laser sintering SLS) - three dimensional printing (3D) – Rapid tooling.

IV	**COMPUTER INTEGRATED MANUFACTURING, FLEXIBLE MANUFACTURING SYSTEMS, AUTOMATIC GUIDED VEHICLE, ROBOT**	**13**

CIM: Introduction of CIM – concept of CIM - evolution of CIM – CIM wheel – Benefits – integrated CAD/CAM.

FMS: Introduction – FMS components – FMS layouts – Types of FMS: Flexible Manufacturing Cell (FMC) – Flexible Turning Cell (FTC) – Flexible Transfer Line (FTL) – Flexible Machining System (FMS) – benefits of FMS - introduction to intelligent manufacturing system.

AGV: Introduction – AGV - working principle – types – benefits.

ROBOT: Definition – robot configurations – basic robot motion – robot programming method – robotic sensors – end effectors – mechanical grippers – vacuum grippers - Industrial applications of Robot**:** Characteristics - material transfer and loading – welding - spray coating - assembly and inspection.

V	**CONCURRENT ENGINEERING, QUALITY FUNCTION DEPLOYMENT, PRODUCT DEVELOPMENT CYCLE, AUGMENTED REALITY.**	**13**

Concurrent Engineering: Definition – Sequential Vs Concurrent engineering – need of CE – benefits of CE.

Quality Function Deployment (QFD)**:** Definition – House of Quality (HOQ) – advantages – disadvantages. Steps in Failure Modes and Effects Analysis (FMEA) – Value Engineering (VE) – types of values – identification of poor value areas – techniques – benefits. Guide lines of Design for Manufacture and Assembly (DFMA).

Product Development Cycle: Product Life Cycle - New product development processes.

Augmented Reality (AR) – Introduction - concept – Applications.

Text Books :

1) CAD/CAM/CIM , R.Radhakrishnan, S.Subramanian, New Age International Pvt. Ltd.
2) CAD/CAM , Mikell P.Groover, Emory Zimmers, Jr.Prentice Hall of India Pvt., Ltd.

Reference Books:

1) CAD/CAM Principles and Applications, Dr.P.N.Rao, Tata Mc Graw Hill Publishing Company Ltd.
2) CAD/CAM, Ibrahim Zeid, Mastering Tata McGraw-Hill Publishing Company Ltd., New Delhi.
3) Automation, Production Systems, and Computer-Integrated Manufacturing, Mikell P. Groover, Pearson Education Asia.
4) Computer control of manufacturing systems, Yoram Koren, McGraw Hill Book.

Board Examination - Question paper pattern

Time: 3 Hrs. **Max. Marks: 75**

PART A - (1 to 8) 5 Questions to be answered out of **8** for 2 marks each. Question No. 8 will be the compulsory question and can be asked from any one of the units. (From each unit maximum of two 2 marks questions alone can be asked)

PART B - (9 to 16) 5 Questions to be answered out of **8** for 3 marks each. Question No. 16 will be the compulsory question and can be asked from any one of the units. (From each unit maximum of two 3 marks questions alone can be asked)

PART C - (17 to 21) Five Questions will be in the Either OR Pattern. Students have to answer these five questions. Each question carries 10 marks. (Based on the discretion of the question setter, he/she can ask two five mark questions (with sub division A & sub division B) instead of one ten marks question if required)

PART A (1 TO 8) Definitions, Statements, Formulae, Theorems etc..	5 x 2 marks	**10** Marks
PART B (9 TO 16) Short answer type questions	5 x 3 marks	**15** Marks
PART C (17 TO 21) Descriptive answer type questions. Five Questions will be in the Either OR Pattern.	5 x 10 marks	**50** Marks
Total		**75** Marks

UNIT – I
COMPUTER AIDED DESIGN

1.1.0. Introduction

Computer Aided Design (CAD) is the technology concerned with the integrated design activities using a digital computer. This includes creation and modification of graphic images on a display, printing these images on a printer or plotter as a hard copy, analyzing and optimizing the design and storing and retrieving of design information for further process as database.

CAD can be described as any design activity that involves the effective use of computer to create and modify an engineering design. The use of a computer in the design of a product is to increase the productivity of the designer and to create a database for manufacturing.

1.1.1. CAD definition

CAD is the term which means Computer Aided Design. CAD can be defined that the computer is utilized in the creation of model, modification and analysis of a design to get the optimum model.

1.1.2. Design process

The design process is the pattern of activities followed by the designer in arriving at the solution of a technological problem generated. The design progresses are a step-by-step manner from identification of the problem to give the better solution for the problem.

There are different models available in the design process. They are Shigley, Pahl and Beitz, Ohsuga and Earle.

1.1.3. Shigley's Design process

The six steps involved in the Shigley model is shown in the flow chart and explained below.

Recognition of need

Recognition of need involves the realization of a problem exists for which some feasible solution has to be found. This might be the identification of some defect in a current machine designed by an engineer or the perception of a new product marketing opportunity by a salesman.

Definition of a problem

Definition of a problem involves a thorough specification of the item to be designed. This specification will generally include functional and physical characteristics, cost, quality, performance, etc.

Synthesis

During the synthesis phase of the design process, various preliminary ideas are developed through research of similar products or designs in use.

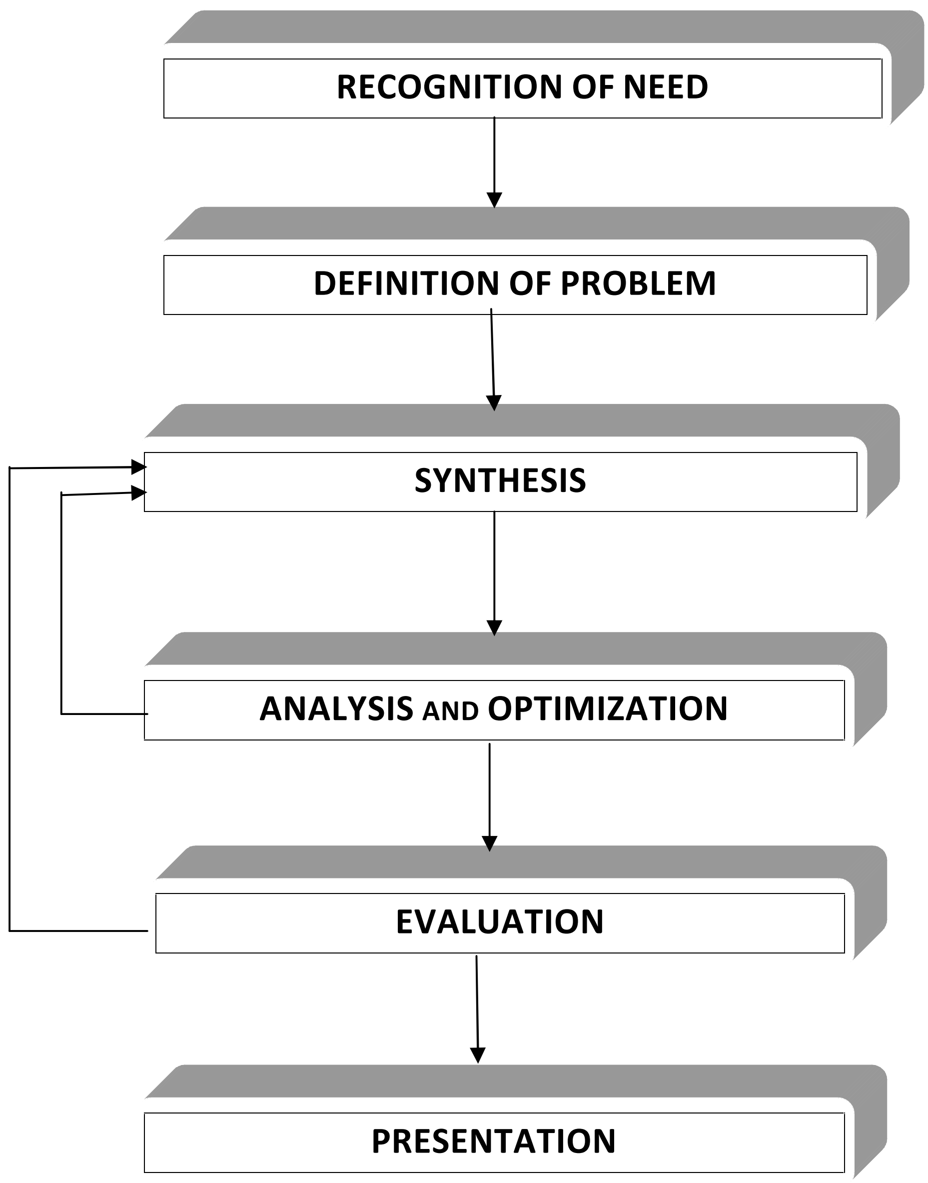


Figure 1.1 Shigley's Design process

Analysis and optimization

The resulting preliminary designs are then subjected to the appropriate analysis to determine their suitability for the specified design constraints. If these designs fail to satisfy the constraints, they are then redesigned or modified on the basis of the information gained from the analysis. This iterative process continues until the proposed designs meet the specifications of the designer. The components, sub-assemblies or sub-systems are then synthesized into the final overall system in a similar iterative manner.

Evaluation

The optimized design as per the specifications is checked during this stage. This requires the fabrication and testing of a prototype model to evaluate operating performance, quality, reliability, etc. If any discrepancies are faced, it is recommended to redesign the product which should be fed back to designer in the synthesis stage.

Presentation

The final phase in the design process is the presentation of the design. This includes documentation of the design through drawings, material specifications, assembly lists, and so on. These are the input for the production department for the process planning and product planning.

1.1.4. Ohsuga Model

The Ohsuga model design process is shown in flow chart below. According to Ohsuga design, it is an iterative process.

Ohsuga describes the design as a series of stages progressing from requirements through the conceptual design and preliminary design to detail design. However, the various stages of design process are generalized into a common form in which models are developed through a process of analysis and evaluation leading to modification and refinement of model.

At the beginning stage of design, a tentative solution is proposed by the designer. This tentative solution is evaluated from a number of viewpoints 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. In this stage, the design is refined evaluated and modified at a greater level of details. It is followed by the detailed design which will be more useful for manufacturing.

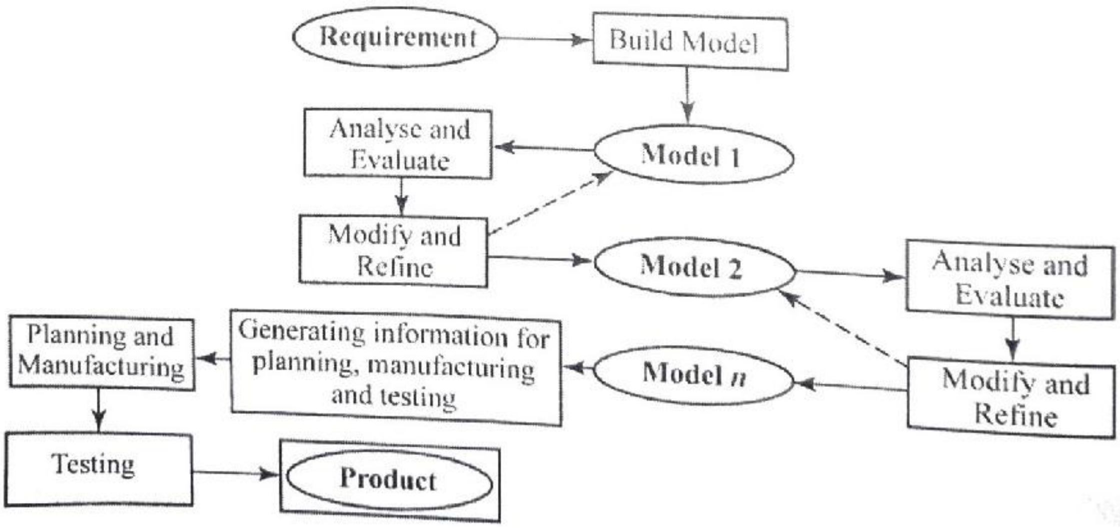


Figure 1.2 Ohsuga Model

1.1.5. CAD activities

Engineering design has traditionally been accomplished on drawing boards with the design being documented in the form of a detailed engineering drawing. This process are iterative in nature and time consuming. The computer can beneficially be used in the design process.

In the Design process, the design tasks are performed with system rather than a designer working over a drawing board. The various design related tasks which are performed in the CAD system can be grouped into major four areas.

1. Geometric modeling.
2. Engineering analysis.
3. Design review and evaluation.
4. Automated drafting.

1. Geometric Modelling

Geometric modeling is concerned with the computer compatible mathematical description of the geometry of an object. The mathematical description allows the image of the object to be displayed and manipulated on a graphics terminal. The modification on the geometry of the object can be easily done. It can be stored and retrieved back. The modeling software should provide the basic commands for the creation of the object and the commands to manipulate such as scaling, translation and rotation etc.

There are several different methods of representing the object in modeling. The geometric modeling are created in three methods.

1. 2D - Two-dimensional representation is used for a flat object.
2. 2½D - This goes somewhat beyond the 2D capability by permitting a three dimensional object to be represented as long as it has no side wall details.
3. 3D - This allows for solid modeling of a more complex geometry.

Solid model can be represented in CAD by three methods.

Wire frame model: The basic form uses wire frames to represent the object. In this form, the object is displayed by interconnected lines. These models can be ambiguous and unable to provide mass property calculations.

Surface model: These are created using points, lines and planes. This can be shaded for better visibility.

Solid model: The most advanced method of geometric modeling is solid modeling in three dimensions. This method can be used to analyze the moment of inertia, mass, volume, sections of the model. etc.

2. Engineering Analysis

In the formulation of any engineering design project, some type of analysis are required. The analysis may involve stress-strain calculations, heat transfer computations, or the use of differential equations to describe the dynamic behaviour of the system being designed. The computer can be used to aid in this analysis work. The analysis of mass properties is the analysis feature of a CAD system that has probably the widest application. It provides properties of a solid object being analysed, such as the surface area, weight, volume, centre of gravity and moment of inertia.

Probably the most powerful analysis feature of a CAD system is the finite element method. With this technique, the object is divided into a large number of finite elements which form an interconnecting network of concentrated nodes. By using a computer with significant computational capabilities, the entire object can be analysed for stress-strain, heat transfer, and other characteristics by calculating the behaviour of each node. By determining the interrelating behaviour of all the nodes in the system, the behaviour of the entire object can be assessed.

3. Design review and evaluation

The feature called layering is helpful in design review. For example, a good application of layering involves over layering the geometric image of the final shape of the machined part on top of the image of the rough casting. This ensures that sufficient material is available on the casting to accomplish the final machined dimensions. This procedure can be performed in stages to check each successive step in the processing of the part.

Another related procedure for design review is interference checking. This involves the analysis of an assembled structure in which there is a risk that the components of the assembly may occupy the same space. This risk occurs in the design of large chemical plants, air separation cold boxes, and other complicated piping structure.

One of the most interesting evaluation features available on computer aided design systems is kinematics. The available kinematics packages provide the capability to animate the motion of simple designed mechanisms such as hinged components and linkages. This capability enhances the designer's visualization of the operation of the mechanism and helps to ensures against interference with other components. Without graphical kinematics on a CAD system, designers must often resort to the use of pin and cardboard models to represent the mechanism.

4. Automated drafting

Automated drafting involves the creation of hard copy of engineering drawings directly from CAD database. The important features of a drafting software are automated dimensioning, scaling of the drawing, capable of generating sectional views, enlargement of parts and to generate different views of the object. Thus CAD system can increase the productivity on drafting.

1.1.6. Benefits of CAD

- Increased design productivity
- Reduced time for developing conceptual design, analysis and drafting.
- Shorter lead time.
- Easy modification of design to accommodate customer's specific requirements.
- Improved design analysis.
- Improves design accuracy and reduces the material used.
- Calculation of mass properties can be made quickly.
- Avoid errors in design, drafting and documentation.
- The single databases used in CAD provide a common basis for design, analysis and drafting process.
- Easier creation and correction of engineering drawings.
- Easier visualization of drawings.

1.1.7. CAD SOFTWARE

The software in computer-aided design include the following:

1. System software or operating system
2. Application software

System software

System software is a set program, which manages the operation of a computer. The important functions of operating system are

1. Transferring data between computer and peripheral devices for input and output.
2. Managing various file manipulation in the computer
3. Loading computer programs into memory and controlling the execution of program.
4. Create environment to run the application software.

Windows, OS/2, UNIX, and Linux are some of the wellknown operating systems.

Application software

The application software in CAD include the following:

1. Software to create and modify 2D and 3D models of components.
2. Software for engineering analysis in the created model.
3. Compatibility between the software.

Free CAD, AutoCAD, ProE, IDEAS, UniGrpahics, CADian, Solid works, CAD Key and CATIA are some of the well known application software used in computer aided design.

AutoCAD

AutoCAD is a drawing software package developed by the company Autodesk Inc., USA. It is one of the most widely used software for creating engineering drawings easily and quickly. The important features of AutoCAD are listed below.

Features of AutoCAD

1. Creating basic geometrical objects line, circle, arc, rectangle, etc. can be easily drawn.
2. We can easily modify the size, shape, and location of objects by using AutoCAD commands.
3. We can erase, move, and rotate the selected objects.
4. We can create duplicates of objects by using COPY, ARRAY, OFFSET, and MIRROR features.
5. We can change the size of objects by using commands like TRIM, EXTEND, LENGTHEN, STRETCH, SCALE, etc. It is also possible to create FILLET, CHAMFER and BREAK in objects.
6. The Zooming feature enables to magnify the details in a drawing.
7. The Layering feature, various portions of a drawing can be drawn on different layers, which can be superimposed according to the need.
8. Dimensioning of the facility improves the details of the drawing.
9. Hatching feature is used to fill area of a drawing with a predefined pattern. The pattern is used to differentiate components of an object. It is also possible to create our own hatch patterns.
10. AutoCAD supports 3D modeling such as wireframe, surface, and solid modeling. Each type has its own creation and editing techniques.
11. We can split the drawing area into two or more adjacent rectangular areas and display different view of the model using viewport.
12. The surfaces of 3D models have been viewed with realistic effects. It is also possible to create hidden-line or shaded image of model.
13. Plotting the drawing is very easy.

1.2.1. Transformation

The transformation actually converts the geometry from one coordinate system to the other coordinate system. By means of the transformation, the images can be enlarged in size or reduced, rotated or moved on the screen. It plays a central role in model construction and viewing the image.

1.2.2. Two Dimensional (2D) Transformation

During modeling of an object, it becomes necessary to transform the geometry many times. The transformation actually converts the geometry from one coordinate system to other coordinate system. The main types of 2D transformation which are often come across are as follows.

- Translation
- Scaling
- Rotation

Translation

It is one of the most important and easily understood transformations in CAD. Translation is the movement of an object from one position to another position. It is to be moved to the co-ordinates of each comer point. Figure shows a square object. Let us now consider a point on the object, represented by P which is translated along x and y axes by added T, and Ty to a new position P.

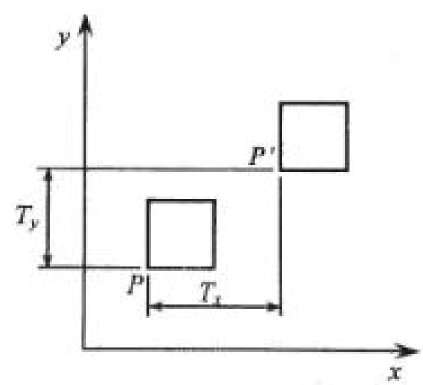


Figure 1.3 Translation

The new co-ordinate 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, we can write the above equation as

$$[P'] = [X' \; Y' \; 1] = [X \; Y \; 1] \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ Tx & Ty & 1 \end{bmatrix}$$

$P' = P \, . \, T$

Where T = Translation matrix.

It is normally the operation used in the CAD system as MOVE command.

Scaling

Scaling 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 be done by multiplying the coordinates of the drawing by an enlargement or reduction factor called scaling factor. The size of the entity altered by the application of scaling factor is shown in figure 1.4.

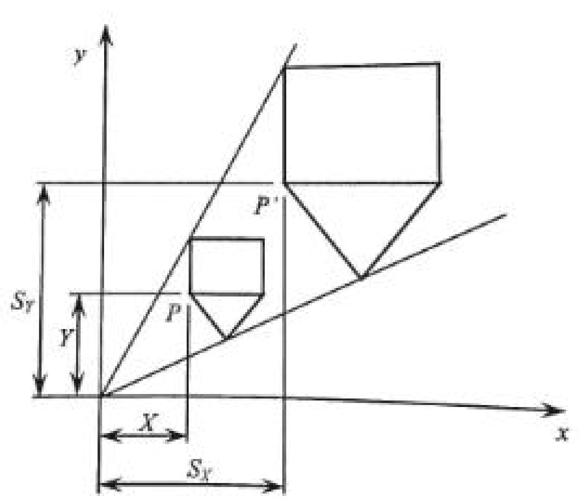


Figure 1.4 Scaling

The new co-ordinates after scaling are given by the following equations

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

This equation can also represented in a matrix form as

$$[P'] = \begin{bmatrix} Sx & 0 \\ 0 & Sy \end{bmatrix} \begin{bmatrix} X \\ Y \end{bmatrix}$$

$[P'] = [S]\,[P]$

where

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

For example, figure 1.5 shows a triangle to be scaled before scaling. Figure shows the same triangle after scaling. Here, all coordinates of the entity are multiplied by scaling matrix. Therefore, it is enlarged two times the original one.

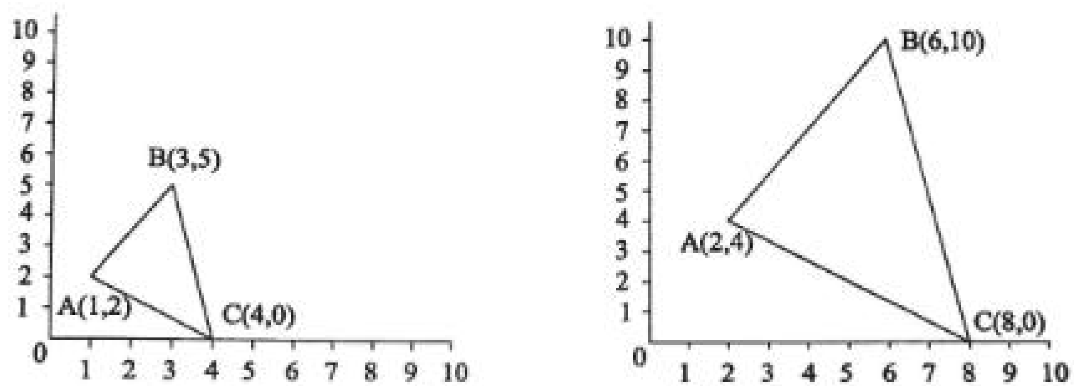


Figure 1.5 Scaling

Rotation

Rotation is another important geometric transformation in CAD. Here, 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. Figure 1.6 shows a rotation transformation of an object about origin 0. To develop the transformation matrix, consider a point P as the object in XY plane, being rotated in anticlockwise direction to the new position P' by an angle θ. The new position P' is given by

$P' = [X', Y']$

From Figure, the original position is specified by

X = r cos ϕ

y = r sin ϕ

The new position P' is specified by

X' = r cos(ϕ + θ)

= r cos θ cos ϕ - r sin θ sin ϕ

= x cos θ - y sin θ

Y' = r sin (ϕ + θ)

= r sin θ cos ϕ + r cos θ sin ϕ

= x sin θ + y cos θ

It can be written in a matrix form as

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

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

where

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

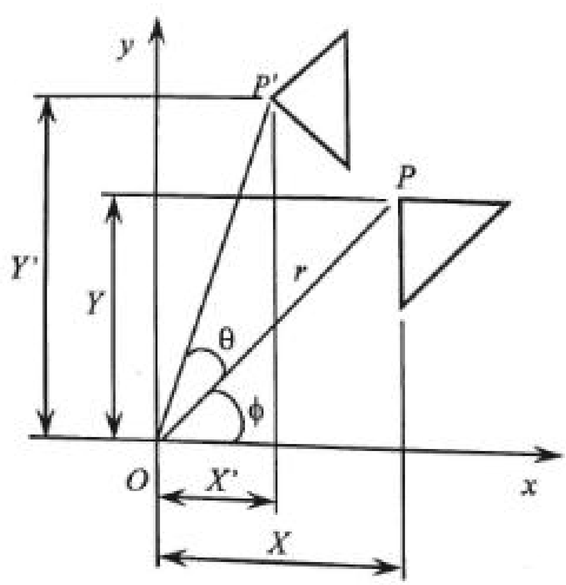


Figure 1.6 Rotation

CONCATENATION OR COMBINED TRANSFORMATION

Many times, it becomes necessary to combine the aforementioned transformations in order to achieve the required results. In such cases, the combined transformation matrix can be obtained by multiplying the respective transformation matrices. The sequence of transformations can be combined into a single transformation using the concatenation process. For example, a line AB shown in figure is to be rotated through 45° in clockwise direction about point A. This process can be achieved by the following three processes:

(a) Inverse translation of AB to A_1B_1.

(b) A_1B_1 is then rotated through an angle of 45° to A_2B_2.

(c) The line A_2B_2 is then translated to A_3B_3.

The respective transformation matrices are given by

For inverse translation $\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -Tx & -Ty & 1 \end{bmatrix}$

For rotation $\begin{bmatrix} \cos^{-} & \sin^{-} & 0 \\ -\sin^{-} & \cos^{-} & 0 \\ 0 & 0 & 0 \end{bmatrix}$ and

Translation to A_3B_3 $\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ Tx & Ty & 1 \end{bmatrix}$

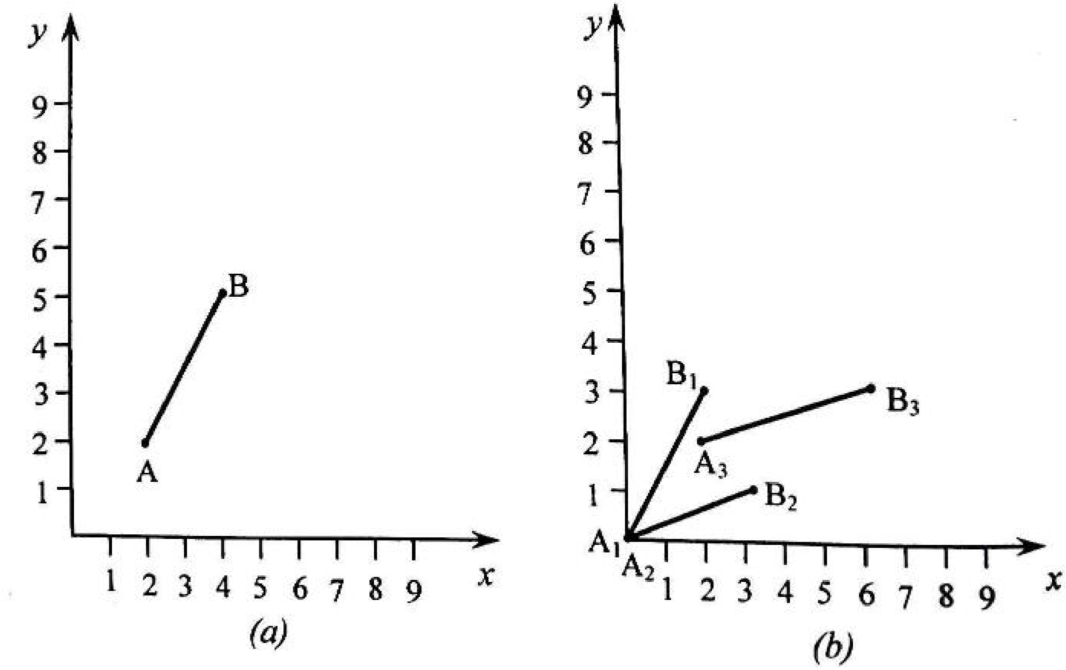


Figure 1.7

The same effect can be achieved using the concatenated matrix or overall transformation given below.

$$[X1\ \ Y1\ \ 1] = [X\ \ Y\ \ 1]\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ -Tx & -Ty & 1 \end{bmatrix}\begin{bmatrix} \cos^{-} & \sin^{-} & 0 \\ -\sin^{-} & \cos^{-} & 0 \\ 0 & 0 & 0 \end{bmatrix}\begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ Tx & Ty & 1 \end{bmatrix}$$

1.2.3. Three Dimensional 3D Transformations

It is often necessary to display objects in 3D on the graphics screen. The 2D transformations as explained in earlier sections can be extended into 3D by adding a Zaxis parameter. The transformation matrix will now be 4X4. This section deals tee simple cases of 3D transformations.

Translation

Similar to 2D translation, the translation for 3D is done as follows.

$$T' = \begin{bmatrix} X' \\ Y' \\ Z' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & dX \\ 0 & 1 & 0 & dY \\ 0 & 0 & 1 & dZ \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

$$[T] = \begin{bmatrix} 1 & 0 & 0 & dX \\ 0 & 1 & 0 & dY \\ 0 & 0 & 1 & dZ \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Scaling

$$S' = \begin{bmatrix} X' \\ Y' \\ Z' \\ 1 \end{bmatrix} = \begin{bmatrix} Sx & 0 & 0 & 0 \\ 0 & Sy & 0 & 0 \\ 0 & 0 & Sz & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

$$[S] = \begin{bmatrix} Sx & 0 & 0 & 0 \\ 0 & Sy & 0 & 0 \\ 0 & 0 & Sz & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Rotation

Rotation about x-axis (yz plane)

$$R' = \begin{bmatrix} X' \\ Y' \\ Z' \\ 1 \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 \\ \sin^{-} & -\cos^{-} & 0 & 0 \\ \cos^{-} & \sin^{-} & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

$$[Rx] = \begin{bmatrix} 1 & 0 & 0 & 0 \\ \sin^{-} & -\cos^{-} & 0 & 0 \\ \cos^{-} & \sin^{-} & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Rotation about y-axis (zx plane)

$$[Ry] = \begin{bmatrix} \cos^{-} & 0 & \sin^{-} & 0 \\ 0 & 1 & 0 & 0 \\ \sin^{-} & 0 & -\cos^{-} & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Rotation about z-axis (xy plane)

$$[Rz] = \begin{bmatrix} \sin^{-} & -\cos^{-} & 0 & 0 \\ \cos^{-} & \sin^{-} & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

1.3.1. Geometric modeling techniques

The mathematical description of the geometry of an object is called *model.* Geometric modeling involves the use of a CAD system to develop a mathematical description of the geometry of an object.

The geometric models can be classified as below.

Two dimensional (2D) models

Three dimensional (3D) models.

Two-dimensional models

Two dimensional drafting is the most commonly used by mechanical drafters, desingers and engineers. The 2D models sufficiently and accurately describes the part geometry. Two dimensional systems store co-ordinate data with x and y values.

Three-dimensional models

Three dimensional systems offer more capability, but are typically complex and more difficult to learn. Wireframe, surface and solid modeling are supported by 3D systems. This system allow for hidden line removal and shaded images provide realistic views.

The three principal classifications are as follows.

Wireframe model or line model

Surface model

Solid model or volume model

1.3.2. Wireframe modeling

Wireframe model is the simplest geometric model that can be used to represent an object mathematically in the computer. It is also called as *line model* or *edge representation* of the object.

Typically, a wire frame model consists of points, lines, arcs, circles, conics, and curves. The word 'wireframe' is related to the fact that one may imagine a wire that is bent to follow the object edge to generate the model. An edge may be straight line, arc, or any other well defined space curve. A wireframe model of a three dimensional object consists of a finite set of points together with the edges connecting various pairs of these points.

1.*3.3. Wireframe entities:* *F*or constructing wireframe models the following entities are used. Cubic splines, B-splines and Bezier curves.

Cubic splines

Cubic splines are the curves with the parametric intervals defined at equal lengths. It passes over a given set of data points and start & end slopes. Cubic splines do not allow the user to change the smoothness of the curve.

Bezier curves

Bezier curve is a polynomial curve defined by a set of control points that are used for approximating the generated curve. The curve will pass through the first and last point with all other points acting as control points. Bezier curves exhibit a global control. Whenever a single vertex in the control polygon is moved, the entire curve will be affected. The flexibility of the curve becomes more with more control points.

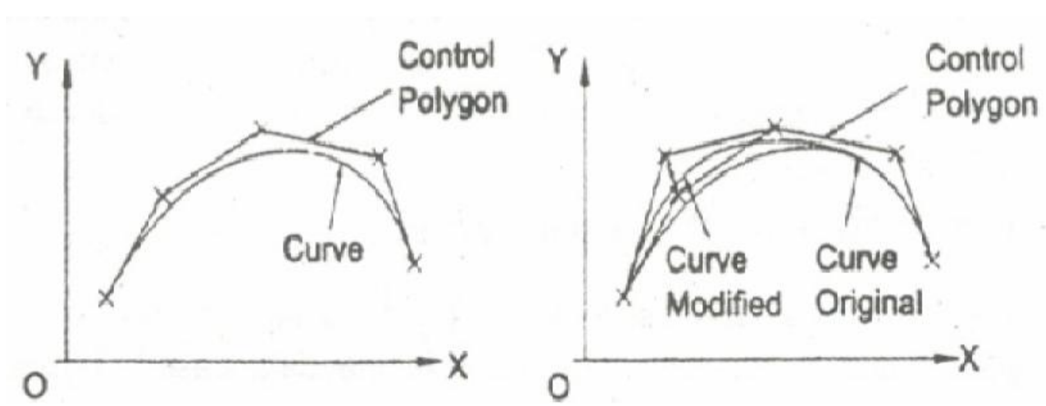


Figure 1.8 ***Bezier curves***

B-splines

B-spline is a single piecewise polynomial curve passing through a given set of control points. B-splines exhibit a local control. Whenever a single vertex is moved, only those vertices around that will be affected while the rest remains the same.

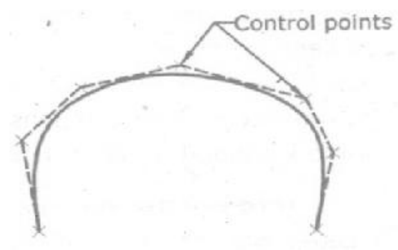
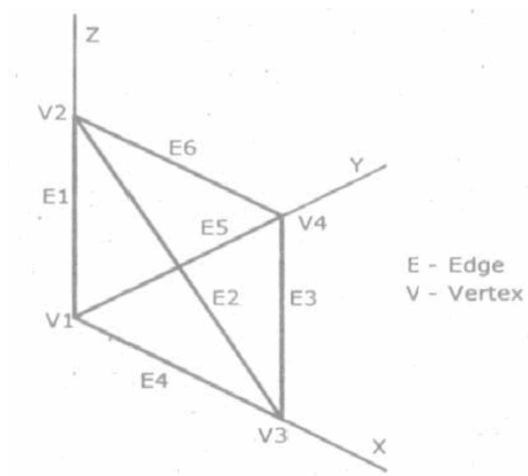


Figure 1.9 ***B-spline curves***

1.3.4. Wireframe model with linear edge

Wireframe models with linear edges consist of straight-line segments joining pair of points. For example, a tetrahedron consists of four points in space with six linear edges joining pairs of these points are shown in the figure. The geometry of the tetrahedron is represented by a vertex list giving the (x,y,z) coordinates of its vertices.



Linear wireframe model of tetrahedron

Vertex list	Edge list	Edge type
V1 (0,0,0)	E1 (Vl.V2)	Linear
V2 (0,0,1)	E2 (V2,V3)	Linear
V3 (1,0,0)	E3 (V3,V1)	Linear
V4 (0,1,0)	E4 (V3,V4)	Linear
	E5 (V1,V4)	Linear
	E6 (V4,V2)	Linear

1.3.5. Wireframe model with curvilinear edges

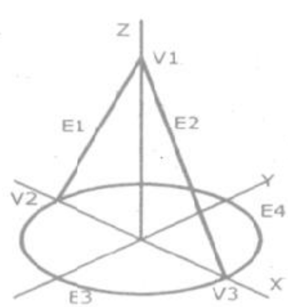


Figure 1.11 ***Wireframe model of cone***

Many objects have curved boundaries. They are best represented in wireframe with curved and linear edges. Cone is the simplest curvilinear wireframe model. This consists of a single apex point and a circular base. The apex is joined to the base by an infinite set of straight line segments called generators.

In representing the geometry of the cone, the simplex vertex list contains three vertices. The apex (V1) and two other vertices, one on either end of a diameter across the circular base.

The edge list contains four edges. Two linear eages from apex to base and two semicircular edges forming the circular base.

Vertex list	Edge list	Edge type
V1 (0,0,3)	El (V1,V2)	Linear
V2 (-1,0,0)	E2 (V1,V3).	Linear
V3 (1,0,0)	E3 (V2,V3)	semicircular
	E4 (V3,V2)	semicircular

Improvement in representing a cone in wireframe model is achieved by dividing the base circle with more number of vertices. As the number of vertices increased, the wireframe model becomes more realistic.

In the similar way, the wireframe model of any object can be developed with the help of linear edges and curvilinear edges.

1.3.6. Merits of wireframe modeling

- It is easy to construct.
- It needs less memory space.
- It takes less manipulation time.
- It does not require any extensive training for users.
- It is best suitable for manipulations as orthographic, isometric and perspective views.

1.3.7. Demerits

- There is more doubt in identifying the surfaces.
- The images of wireframe model cause confusion to the viewer.
- It is not possible to calculate mass properties.

- It is not useful for NC tool path generation, cross sectioning, interference detection, etc.
- It is not suitable for representing complex solids.
- Hidden line removal is a time consuming task.
- Both topological and geometrical data are required for wireframe modeling.

1.3.8. Surface modeling

A surface model of an object is more complete and less confusing representation than its wireframe model. A surface model can be built by defining the surface on the wireframe model. The procedure of constructing a surface model is stretching a thin piece of material over a framework.

Modeling of curves and surfaces are essential to describe objects in several areas of mechanical design such as

- Body panel of automobiles
- Aircraft structural members
- Marine vehicles
- Consumer products, etc.

The boundary of an object may consist of surfaces, which are bounded by straight lines and curves either single or in combination. The figure shows the illustration of a surface model built with number of surfaces as shown.

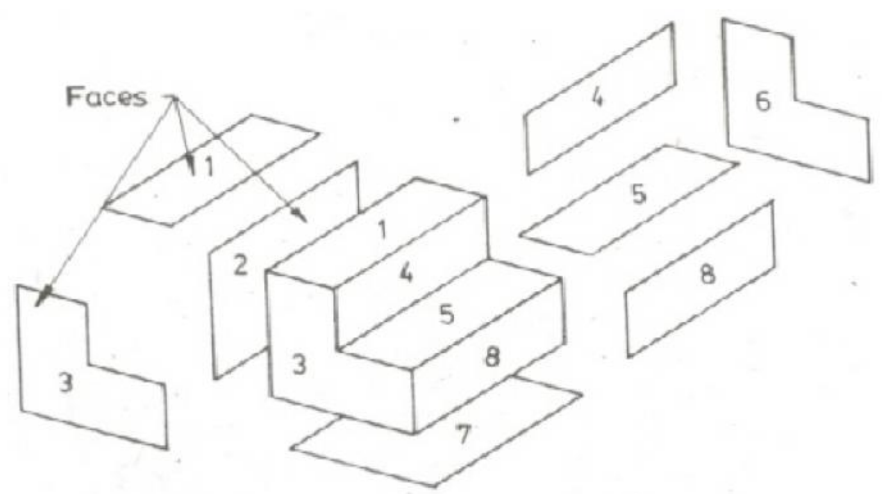


Figure 1.12 Surface modeling

1.3.9. Surface entities

The following are the major types of surface entities used for constructing surface modes.

1. Plane surface

This is the simplest flat 2D surface. It requires three noncoincident points to define an infinite plane.

2. Curved surface

The two types of curved surfaces are (a) single curved surfaces (b) double curved surfaces.

Single curved surface: It is a simple curved surface. It is generated by using straight line. Cylindrical surface, conical surface, surfaces of pyramids, prisms, and conics are examples of single curved surfaces.

Double curved surface: It is a complex surface generated by using curves. Spheres, ellipsoids, paraboloids, torus are some example of double curved surfaces.

3.10 Types of surfaces

a) Plane surface: This is the simplest flat 2D surface. It requires three noncoincident points to define an infinite plane.

b) ***Tabulated cylinder:*** This Is a surface generated by translating a planar curve a certain distance along a specified direction.

c) ***Ruled surface****:* Ruled surface is constructed by transitioning between two or more curves by using linear blending between each section of the surface. This is used to generate the surfaces that do not have any twist.

d) Surface of revolution: This is an axis-symmetric surface. It is generated by revolving a planar wireframe entity in space about an axis of symmetry at certain angle.

e) Swept surface: This surface is produced by sweeping the defining curve along an arbitrary spline curve instead of a circular arc.

f) Sculptured or curved mesh surface: This surface is produced by a grid of geometric curves, which intersect to form a patchwork of surface patches.

g) ***Fillet surface:*** It is a B-spline surface that blends two surfaces together. The original surface may or may not be trimmed.

h) Bezier surface: This is a surface that can be generated approximately with the given input data. It is a synthetic surface. It is a general surface that permits twists and bends. These surfaces allow any global control of the surface. It can be used in open boundaries.

i) ***B-spline surface:*** This surface can be generated approximately or interpolate with the given set of input data. It is a synthetic surface. This surface exhibits a local control. It is used in open boundaries.

j) Coons surfaces: A coon surface or patch is obtained by blending four boundary curves. The single patch can be extended in both the directions by adding further patches. The blending of these patches can be done either by means of linear or cubic blending function. This gives a smooth surface linking all the patches.

k) Offset surface: Existing surfaces can be offset to create new ones identical in shape by different dimensions. It is used to speed up surface construction.

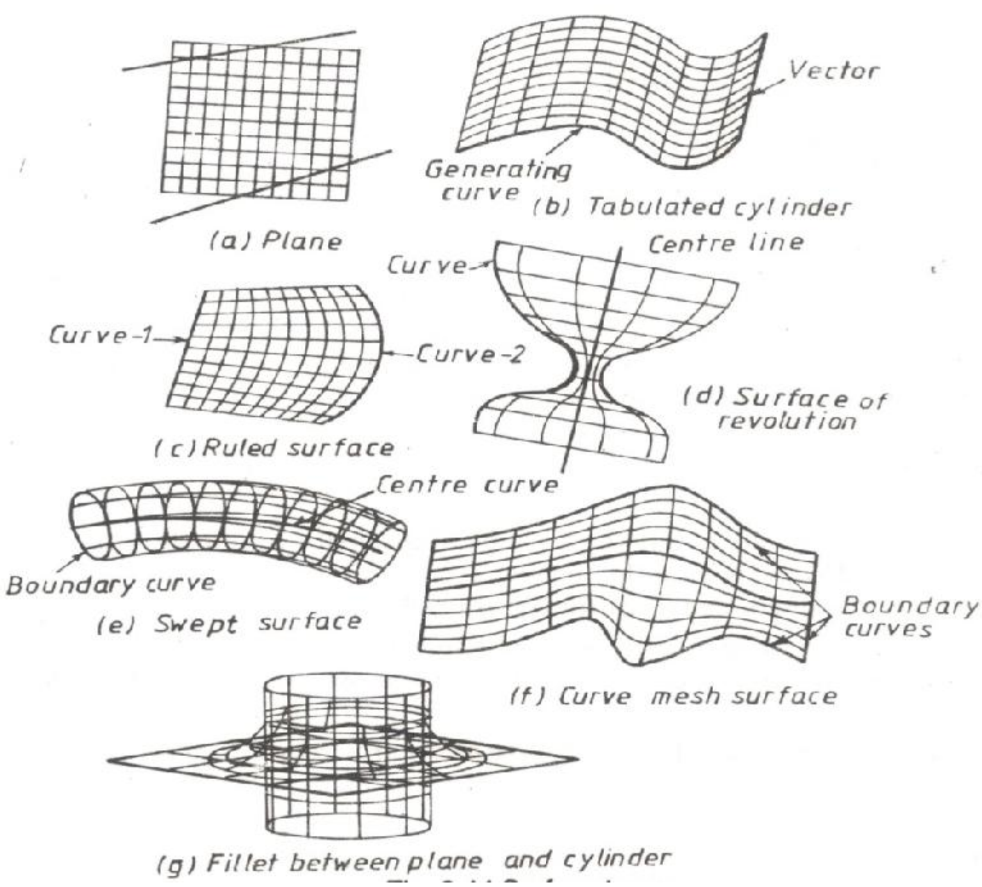


Figure 1.13 Surface modeling entities

1.3.11. Application of wireframe model

Wireframe modeling is generally used in the following applications.

- Checking for interference between mating parts.
- Generating cross sectional views.
- Generating finite element meshes.
- Generating NC tool paths for continuous path machining.

1.3.12. Merits

- Surface models are less confusing than wireframe model.
- They provide hidden line and surface algorithms to add realism to the displayed geometry.
- Shading algorithms are also available.

1.3.13. Demerits

- The interior details of the model cannot be represented.
- The designer requires more training and mathematical background.
- It takes more time to create.
- It requires more storage capacity.
- It requires more manipulation time.
- The construction is not as simple as wireframe model.

1.3.14. Solid modeling

The best method for the three dimensional model construction is the solid modeling technique. It provides the user with complete information about the model. In this approach, the models are displayed as solid objects to the viewer, with very little risk of mis understanding. When colour is added to the image, the resulting picture becomes very realistic. All solid modeling systems provide facilities for creating, modifying, and inspecting models of threedimensional solid objects.

The following representation schemes are available for creating solid models.

- Constructive solid geometry (CSG)
- Boundary representation (B-rep)
- Hybrid scheme

Among these schemes, constructive solid geometry and boundary representation techniques are widely used in CAD systems.

1.3.15. Solid modeling primitives

Some typical primitives utilizes in the solid models are block, cylinder, cone, hexahedron, sphere, quadrilateral, torus, tube and wedge.

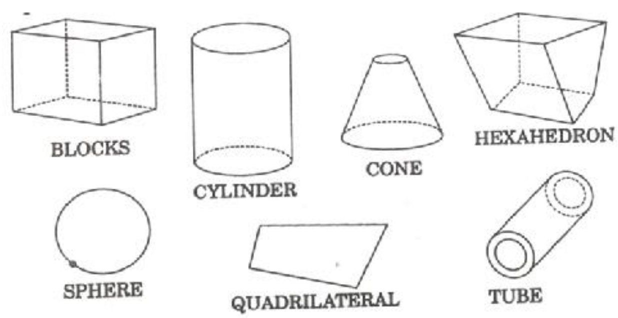


Figure 1.14 Solid modeling primitives

1.3.16. Applications of solid modeling

Solid modeling can be used for the following applications.

- Creating hidden line drawings, sections, and shaded images.
- Calculating mass properties such as total surface area, volume, centre of gravity, moments of inertia, radius of gyration, etc.
- Self-adaptive finite element meshes generation.
- Kinematics analysis of solid assemblies.
- Dynamics interference analysis.
- Process planning for manufacture.
- CNC program generation.
- CNC tool path simulation and program verification

1.3.17. Advantages

- Solid model is complete and more understandable.
- Solid models can be created easily.
- It gives information about interior details.
- There is little human intervention for automated application like creating part program, etc.
- It stores more information about geometry and topology of the object.
- It is best suitable for mass properties calculation.

1.3.18. Disadvantages

- Solid model occupies more memory space.
- It requires more manipulation time.

1.3.19. CSG using Boolean operators

Boolean operators are used for combining the primitives to form the complete solid object. The available Boolean operators are *union* (ą or +), *intersection* (Ć) and the *difference* (-)

Union (ą): When two or more solids are combined with the Boolean operator UNION, the result is the single solid shape incorporating all the space occupied by any of the individual components. Simply, this is like adding components together.

***Difference* (-)**: When two or more solids are combined with the Boolean operator DIFFERENCE, the result is the single solid incorporating the space, which is occupied by the first component but is outside all of the remaining components. This is like subtracting the second and subsequent components from the first component.

***Intersection (Ć)*:** When two or more solids combined with intersection, the result is a single solid object incorporating the space, which is occupied in common by each of the components.

The effect of these operators on the simple primitives block and a cylinder is shown in the figure below.

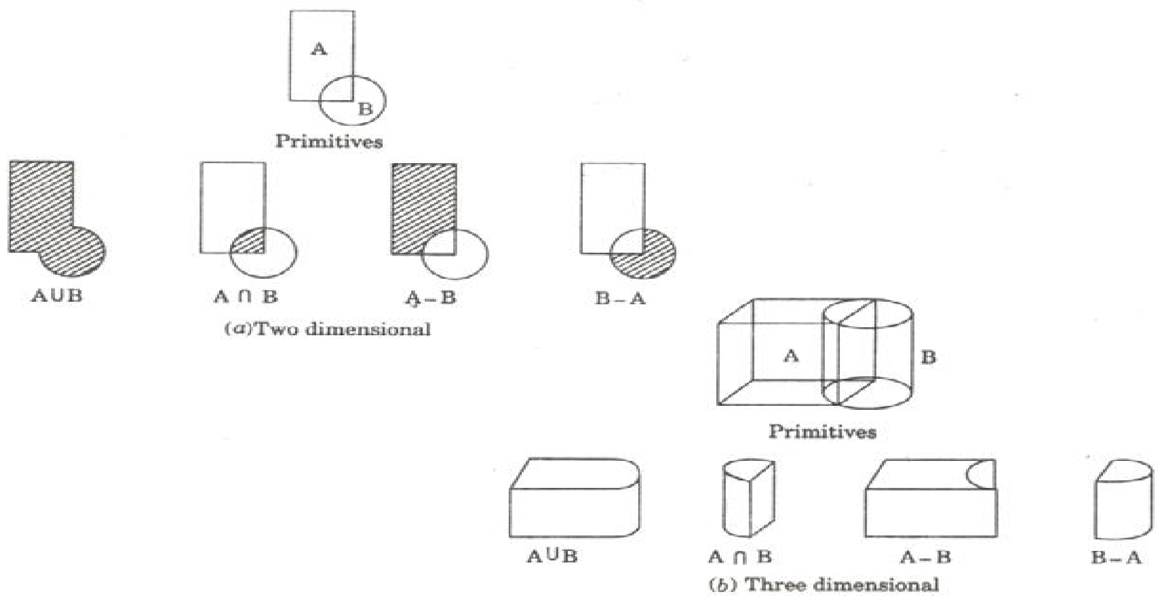


Figure 1.15 Boolean operations on a block and cylinder

1.3.20. Constructive solid geometry (CSG) or C-rep

This approach is also called *building block approach.* In the constructive solid geometry approach, a solid object is represented in a computer as a combination of simple solid objects, called *primitives.* Some typical primitives utilizes in the solid models are block, sphere, hemisphere, cylinder, cone, torus, and wedge. The primitives are normally stored internally using the analytical representation.

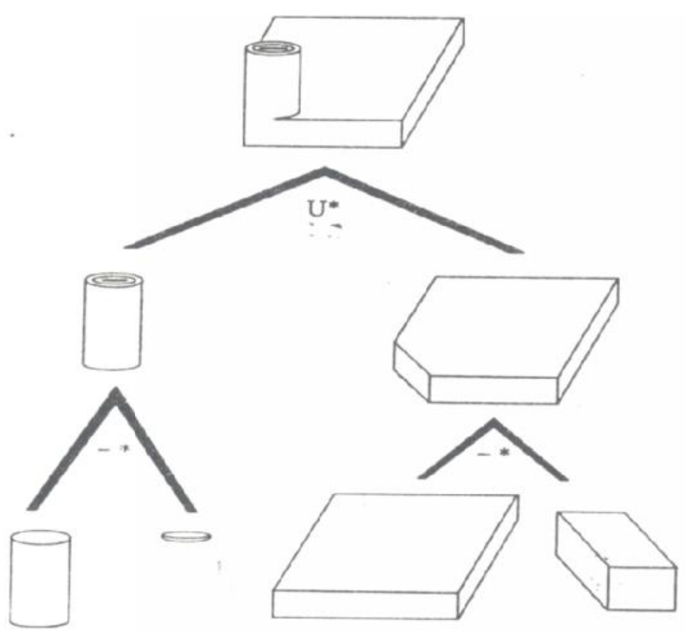


Figure 1.16 ***CSG tree***

In CSG, the storage of data required for the complex job is only the construction tree of the operators and the relevant dimensions of the primitives. This facilitates the reduction of the storage requirement. Also by making modifications on the CSG tree, a new object can be obtained by any time. The Boolean operators always guarantee that the objects formed by those rules are physically realizable.

1.3.21. Boundary representation (B-Rep)

In the boundary representation scheme, a solid is represented by the data structure containing the elements, which describes its boundary. These elements are divided into topological elements and geometric elements.

The topological elements are linked together in a network or group which represents their inter-connections or connectivity in terms of vertices, edges and faces. The geometric elements are points, curves, and surfaces. These geometric elements are linked to the appropriated topological elements as follows:

Face <--> Surface

Edge <--> Curve

Vertex <--> Point

It means that a face in a B-rep model is simply a bounded area of surfaces.

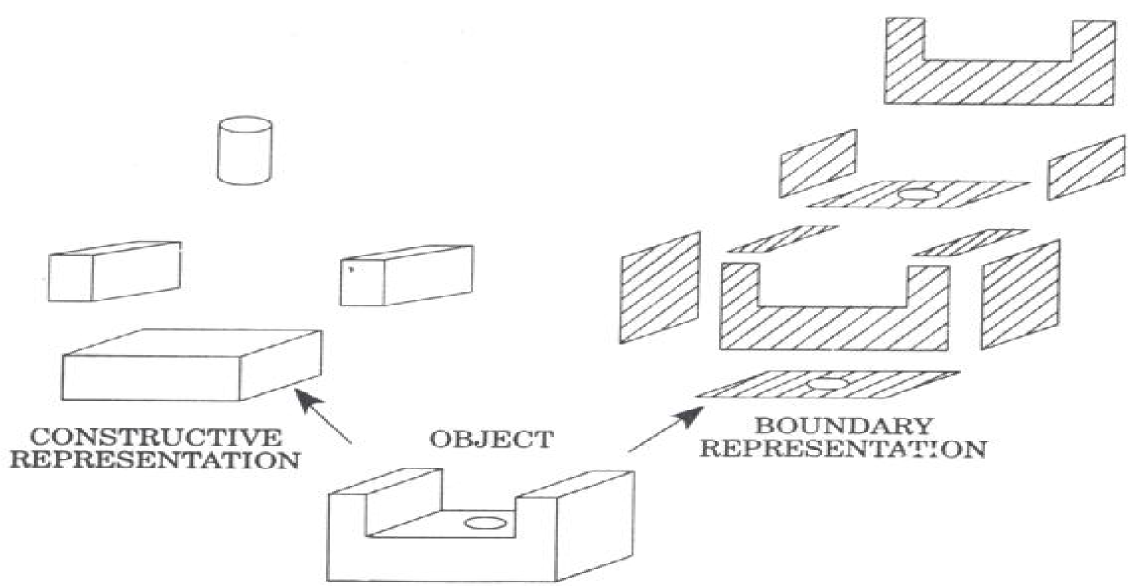


Figure 1.17

1.3.22. Comparison of CSG and B-Rep

Sl.No.	CSG	B-Rep
1	Solid model is built from solid graphic primitives.	Solid model is obtained by creating the outline or boundary of the object.
2	It is easy to construct a precise solid model.	It is not so easy to construct the model.
3	It uses Boolean operations.	It uses topological elements.
4	It requires less storage space.	It rquires more storage space.
5	It requires more computational to reproduce the model.	It requires less computation to reproduce the model.
6	Non analytical surfaces such as Bezier surfaces cannot be created.	Non analytical and complicated surfaces can be created.
7	Conversion between C-rep and corresponding wire frame model is very difficult.	Conversion between boundary representation and corresponding wireframe model is easy.

1.3.23. Hybrid schemes

It is the combination of both constructive solid geometry and boundary representation approach. It makes use of the relative benefits of both approaches overcoming their relative weaknesses. By using this approach, solid models can be created by either C-rep or B-rep whichever is more appropriate to the particular problem.

1.3.24. Comparison of wire frame, surface and solid modeling

	Detail	Wire frame model	Surface model	Solid model
1.	Representation	Collection of corner points and edge lines.	Collection of corner points, edge lines and surfaces.	Collection of corner points, edge lines, surfaces and internal volume.
2.	Ambiguity	More	Less	Unambiguous
3.	Memory requirement	Less	More than wire frame model	More than surface model
4.	Manipulation time	Less	More	Less
S.	Time for construction	Less	More	Less
6.	Interior details	Not possible	Not possible	Possible

7.	Automatic view generation (Perspective and orthographic)	Impossible	Impossible	Possible
8.	Cross sectioning	Manually guided	Manually guided	Possible even automatically
9.	Elimination of hidden lines	Manually guided	Manually guided	Possible
10.	Mass property calculation	Not possible	Not possible	Possible
11.	Numerical control application	Difficult or impossible	Automatic possible	Automatic possible

1.4.1. Graphic standards

A large number of applications are used in CAD/CAM, which are manufactured by different vendors. Therefore, there is a need to establish standards in CAD that help in linking different hardware and software systems from different vendors. In addition, the data from a CAD system is to be transferred to the CAM system to achieve Computer Integrated Manufacturing (CIM). The standards used in CAD for exchanging data are called graphics standards.

1.4.2. Need or benefits of graphics standards

Graphics standards are needed to achieve the following benefits in CAD.

Application program portability: The program in a CAD system should not be hardware dependent. It is desired to have programs, which are interchangeable with a number of systems.

Picture data portability: Description and storage of picture should be independent of different graphic devices.

Text portability: Representation of text associated with the graphics should be independent of hardware.

Object database portability: In CAD, analysis and manufacturing operations should be integrated for sharing design database.

The following are the common graphics standards used in CAD/CAM applications.

- GKS (Graphical Kernel System)
- PHIGS (Programmer's Hierarchical Interface for Graphics)
- IGES (Initial Graphics Exchange Specification)
- DXF (Drawing Exchange Format)
- STEP (STandard for the Exchange of Product model data)
- DMIS (Dimensional Measurement Interface Specifications)
- VOl (Virtual Device InterfaceD
- VDM (Virtual Device Met3file)
- GKSM (GKS'Metafile)
- NAPLPS (North American Presentation Level Protocol Syntax)
- WMF (Windows Meta File)

1.4.3. Graphic Kernel System (GKS)

GKS is essentially a set of procedures that can be called by user programs for carrying out certain generalized functions. Taking all the existing graphic packages, ISO has standardized the GKS as a 2D standard.

An environment for user to work is termed as workstation in GKS. For a programmer, all workstations are identical. The characteristics of these workstations are built into GKS. It is also possible to work simultaneously on more than one workstation.

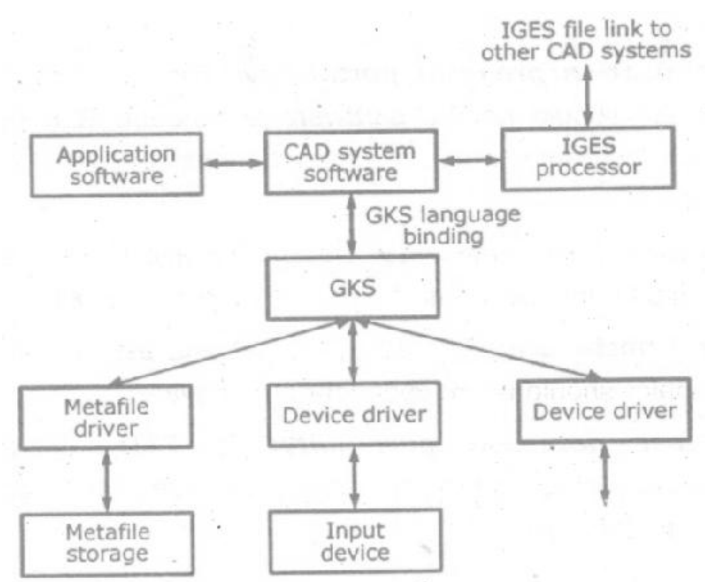


Figure 1.18 GKS implementation in CAD workstation

Objectives of GKS

- To provide the complete range of graphical facilities in 2D, including the interactive capabilities.
- To control all the graphic devices such as plotters and display devices in a consistent manner.
- To be small enough for a variety of programs.

Features of GKS

- **Device independence:** This standard does not require any specific feature for the input or output devices.
- **Text or annotation:** All the text or annotations are in a natural language like English.
- **Display management:** A complete set of display management functions, cursor control, and other features are provided.
- **Graphics functions:** Graphics functions can be defined in 2D or 3D.
- **Metafile drivers:** It makes use of metafile drivers, which are devices with no graphic capability like a disc unit.

Graphic primitives

The concept of *PEN* is used for drawing lines. PEN has the attributes of colour, thickness, and linetype. Lines can be drawn with any PEN that can be defined. The following are the basic graphic primitives available in GKS.

- *POLYLINE:* To draw lines after specifying the linetype, line width and line colour.
- *POLYMARKER:* To create specific marker types after specifying the type, size, and colour.
- *GENERALISED DRAWING PRIMITIVES (GDP):* To specify the drawing entity such as arc, circle, ellipse, spline, etc.
- *TEXT:* To create text after specifying font type, precision, colour, height of box, expansion factor, spacing up vector and the path (left, right, up or down).
- *FILLAREA:* To create hatching and filling of areas.

1.4.4. OpenGL

OpenGL draws primitives into a structured buffer focus to a various selectable modes. Every Point, line, polygon, or bitmap are called as a primitive. Each mode can be modified separately; the parameters of one do not affect the parameters of others. Modes defined, primitives detailed, and other OpenGL operations explained by giving commands in the form of procedure calls.

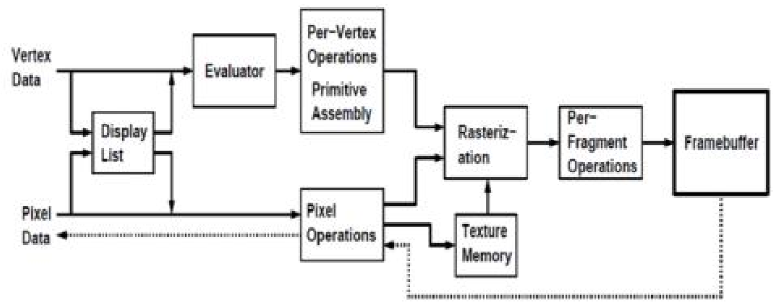


Figure 1.19 Schematic diagram of OpenGL

The above figure shows a schematic diagram of OpenGL. Commands go into OpenGL on the left. The majority commands may be collected in a 'display list' for executing at a later time. If not, commands are successfully sent through a pipeline for processing.

The first stage gives an effective means for resembling curve and surface geometry by estimating polynomial functions of input data. The next stage works on geometric primitives explained by vertices. In this stage vertices are converted, and primitives are clipped to a seeing volume in creation for the next stage.

All 'fragment' created is supplied to the next stage that executes processes on personal fragments before they lastly change the structural buffer. These operations contain restricted updates into the structural buffer based on incoming and formerly saved depth values, combination of incoming colors with stored colors, as well as covering and other logical operations on fragment values.

To end with, rectangle pixels and bitmaps by pass the vertex processing part of the pipeline to move a group of fragments in a straight line to the individual fragment actions, finally rooting a block of pixels to be written to the frame buffer. Values can also be read back from the frame buffer or duplicated from one part of the frame buffer to another. These transfers may contain several type of encoding or decoding.

1.4.5. Initial Graphics Exchange Specification (IGES)

IGES is the most comprehensive standard. It is designed to transmit the entire product definition including that of manufacturing and any other associated information. The software, which translates data from CAD system to IGES, is called a *pre-processor.* The software, which translates IGES data to a CAD system, is called ***post-processor.***

Figure 1.20 CAD data transfer using IGES

Like most CAD systems, IGES is based on the concept of entities. The entities in IGES are divided into three categories.

- ***Geometry:*** Lines, circles, surfaces, etc. that define an object.
- ***Annotation:*** Dimension, notes, title block, etc.
- ***Structure:*** Ways in which CAD systems combine other entities to make description of object easier.

In IGES, the records are present with 80-column field. Columns 1 to 72 provide the data and columns 73 to 80 provide a sequence number for the record, which identifies the location of the subsection. This sequence number is utilized as a pointer for the data.

Sub-sections of IGES

The IGES file consists of the following six sub-sections.

a) Flag section

This is optional and is used to indicate the form in which the data is specified. ASCII mode, Binary form, and Compressed ASCII form are the format of IGES file. Flag section is found only in compressed ASCII files. It is identified by a letter "C" in column 73. This section contains information that will be required by a postprocessor.

b) Start section

This section is identified by a letter "S" in column 73. The information contained in this section is essentially for the person who would be post-processing this file for any other application. It contains any number of lines, which include the source, and description of drawing, format type, etc.

c) Global section

This section is identified by a letter "G" in column 73. This contains information about details of the drawing, the person who created the drawing, name of the company, the system that created the file, date, drafting standard used and other information required for its post-processing on the host computer.

d) Directory entry section

This section is identified by a letter "D" in column 73. It describes all the entities in the drawing. There is one entry for each entity in the drawing. Each entry consists of two lines organized into 20 fields of 8 characters each. It contains attribute information such as colour, linetype, view, pointers to transformation matrices, pointers to parameter data for entities, etc. This section also provides an index to the entities in the file. IGES entities are identified by their type number (fields 1 and 11) and a form number (field 15).

e) Parameter data section

This section is identified by the letter "P" in column 73. Thi, contains the data associated with the entities. A free format is allowed for maximum convenience. It may contain any number of records. The data includes the coordinate values, coefficient of curves and surface equations, pointers to other entities, text characters and other attributes.

The data varies with the type of entity. The parameter data stored for a typical circular arc (type 100) are given below:

i) Parallel displacement of the X, Y plane containing the arc along the Z-axis.
ii) Arc centre coordinate, X
iii) Arc centre coordinate, Y
iv) Start point of the arc, X
v) Start point of the arc, Y
vi) End point of the arc, X
vii) End point of the arc, Y
viii) Pointers required for the properties

f) Terminate section

This section is identified by the letter "1" in column 73. This contains the subtotals of records present in each of the earlier sections. This will be a single record organized into 10 fields of 8 characters each. This record must always have a sequence number of 1.

Disadvantages of IGES

1) IGES is complex and wordy.
2) The various export choices make IGES file better or worse.
3) IGES files are about five times larger than an equivalent picture file.
4) Several entities required by specialized CAD applications are yet not available.

1.4.6. Drawing Exchange Format (DXF)

The DXF format has been developed by the company Autodesk Inc., USA with the AutoCAD drawing files. It is not an industry standard developed by any standard organization. Because of the widespread use of AutoCAD, DXF is made as a default standard for use of a variety of CAD/CAM vendors.

A DXF file is simply an ASCII text file with a file extension of .DXF and specially formatted text.

Organization of DXF file

The overall organization of DXF file is as follows.

a) HEADER section

This section contains general information about the drawing. It consists of the AutoCAD database version number and a number of system variables. Each parameter contains a variable name and associated value. This information is used for database conversion purpose.

b) CLASSES section

It contains the information for application-defined classes, which appear in the BLOCKS, ENTITIES, and OBJECTS sections of the database. A class definition is permanently fixed in the class hierarchy.

c) TABLES section

This contains definitions for the following symbol tables, which directly relates to the object types available in AutoCAD.

- Linetype table
- Layer table
- Text style table
- View table
- User coordinate system table
- Viewport configuration table
- Dimension style table
- Application identification table
- Block reference table

d) BLOCKS section

This section contains block (symbol) definition and drawing entities that make up each block reference in the drawing.

e) ENTITIES section

This section contains the graphical entities in the drawing, including block references.

f) OBJECTS section

This section contains the non-graphical objects in the drawing. All objects that are not entities or symbol table are stored in this section. Examples of entities in OBJECTS section are dictionaries that contain mline (multiple lines) styles and groups.

g) END OF FILE

1.5.1. Finite Element Method (FEM)

A finite element method is a numerical technique to obtain an approximate solution by partial differential equations. Such problems are called as boundary value problems as they consist of a partial differential equation and the boundary conditions. The finite element method converts the partial differential equation into a set of algebraic equations which are easy to solve. The initial value problems which consist of a parabolic or hyperbolic differential equation and the initial conditions cannot be completely solved by the finite element method. The parabolic or hyperbolic differential equations contain the time as one of the independent variables.

1.5.2. Development

From 1960 to 1975, the FEM was developed in the following directions :

(1) FEM was extended from a static, small deformation, elastic problems to

- dynamic (i.e., vibration and transient) problems,
- small deformation fracture, contact and elastic -plastic problems,
- non-structural problems like fluid flow and heat transfer problems.

(2) In structural problems, the integral form of the balance law namely the total potential energy expression is used to develop the finite element equations. For solving non-structural problems like the fluid flow and heat transfer problems, the integral form of the balance law was developed using the weighted residual method.

(3) FEM packages like NASTRAN, ANSYS, and ABAQUS etc. were developed.

The large deformation (i.e., geometrically non-linear) structural problems, where the domain changes significantly, were solved by FEM only around 1976 using the updated Lagrangian formulation. This technique was soon extended to other problems containing geometric non-linearity :

- dynamic problems,
- fracture problems,
- contact problems,
- elastic-plastic (i.e., materially non-linear) problems.

Some new FEM packages for analyzing large deformation problems like LS-DYNA, DEFORM etc. were developed around this time. Further, the module for analyzing large deformation problems was incorporated in existing FEM packages like NASTRAN, ANSYS, ABAQUS etc.

1.5.3. Basic Steps

The finite element method involves the following steps.

- First, the governing differential equation of the problem is converted into an integral form.
- In the second step, the domain of the problem is divided into a number of parts, called as elements.

- In third step, a suitable approximation is chosen for the primary variable of the problem using interpolation functions and the unknown values of the primary variable at some pre-selected points of the element called as the nodes.
- In the fourth step, the approximation for the primary variable is substituted into the integral form.
- In this step, the algebraic equations are modified to take care of the boundary conditions on the primary variable. The modified algebraic equations are solved to find the nodal values of the primary variable.
- In the last step, the post-processing of the solution is done.

.

1.5.4. Advantage

- The method can be used for any irregular shaped domain and all types of boundary conditions. Domains consisting of more than one material can be easily analyzed.
- Accuracy of the solution can be improved either by proper refinement of the mesh or by choosing approximation of higher degree polynomials.
- The algebraic equations can be easily generated and solved on a computer. In fact, a general purpose code can be developed for the analysis of a large class of problems.

UNIT II

COMPUTER AIDED MANUFACTURING

2.1.1. CAM definition

CAM is the term that means Computer Aided Manufacturing. It can be defined as the use of computer system to plan, manage and control the operations of a shop floor. In other words, the use of computer system in manufacturing process is called CAM.

2.1.2. Functions of CAM

The functions of the CAM can be divided into two main categories.

1. Planning the manufacturing activities.
2. Controlling the manufacturing activities.

Planning the manufacturing activities:

The computer can be used to provide information for the effective planning and management of manufacturing activities. The manufacturing planning includes the following activities

Computer - Aided Process Planning (CAPP)

In this computer programs are used to decide the right sequence of operations to convert the given raw material to finished products as per the design. Route sheets, tooling required, time standards are prepared using computers.

Computer -Assisted NC part programming

Computers are used to create part programme. This will help the programmer to create best sequence with the help of simulation facilities.

Computerized machinability data system

Computer programs can be utilised to estimate the optimum feed, speed, etc., based the material databases.

Development of work standards

This deals with Time Study techniques. This decides the actual time needed for a job. Many software packages are available to find time standard and work measurement.

Cost estimating

Computers are used to estimate the product cost considering all labour cost, material cost and overhead costs.

Production and inventory planning

This includes the maintenance of inventory records, automatic recording of stock items, production scheduling, maintaining priorities for the production orders, material requirement planning and capacity planning.

Computer - aided line balancing

It is concerned with the best allocation of work elements among assembly line work stations.

Controlling the manufacturing activities:

It is concerned with the use of computer systems for managing and controlling the physical operations in the industry. The manufacturing control includes the following activities.

Process monitoring and control

It is concerned with monitoring and controlling the production equipment and manufacturing processes by using computers. It includes the control of transfer lines, assembly system, NC, robotics, material handling and FMS.

Quality control

It is concerned with the use of computers to ensure the highest possible quality levels in the manufacturing product.

Shop floor control

It refers to production management techniques for collecting data from shop floor operations and using the data to control production and inventory in the shop floor.

Inventory control

It is concerned with the use of computer for maintaining the most appropriate levels of inventory in the shop floor.

Just-in-time production system

It is concerned with the delivery of items to the customers and purchase of the raw material or spares to the machines exactly at the right time of the need.

2.1.3. Benefits of CAM

- The productivity is increased by utilization of computer.
- Use of computers in manufacturing activities allows changes in production lines by making changes in the programs. This gives the operation flexibility
- Better communication between workstations due to networking leads to shorter lead time.
- The manufacturing methods and controls make the manufacturing system more reliable. The maintenance cost is reduced because of the proper monitoring and control by the computer.
- Use of NC/CNC machines reduces the scrap and rework.
- Use of computers for various activities and their networking helps better management and control.
- Reduction in personnel requirement.
- Better communication between managers, Engineers and designers through networking.

2.2.1. Group Technology (GT)

Group Technology (GT) is a manufacturing philosophy in which similar parts are identified and grouped together. The similarities in design and production are taken the advantage for manufacturing. Similar parts are arranged into part families. Each family possesses similar design and manufacturing characteristics.

For example a plant producing more number of parts may be able to group into small number of part families. Since each part family have almost similar processing activities of design and manufacturing.

The grouping of machines required for the processing of a part family leads to best and economical method of manufacturing is known as cellular manufacturing.

2.2.2. Part Families

A part family is nothing but the collection of parts which are similar in geometric shape and size or similar steps of manufacturing process are required in the production. The parts may be grouped in group technology by the following

1. Design attributes.
2. Manufacturing attributes.

Design attributes

In design attributes the parts are grouped in a family with similar design characteristic and features. The basic idea of design engineers will be of function and performance and the design should be creative. Mostly in manufacturing industries a considerable amount of similarities available in the part manufacturing. Creating new parts and introducing new parts are expensive. Therefore the design of the parts should be modified to a common structure that will reduce the cost considerably.

The figure 2.1 (a) and (b) illustrates examples of two parts from the same family. These parts are placed in same family due to its similarity in size and other design features. They have exactly same shape and size but the production method different. Even though these parts are grouped with respect to size and shape based on the design attributes.

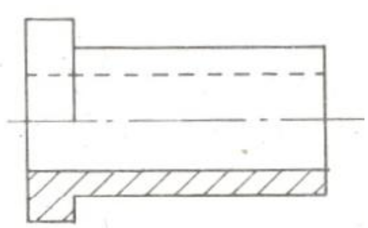


Figure 2.1 a

50,000 components / Year

Tolerance ± 0.01 mm

Material: M.S

Machine used: CNC Lathe

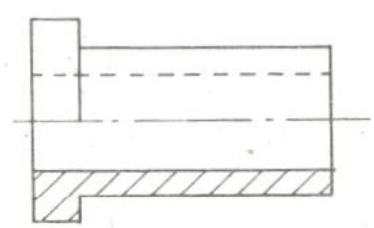


Figure 2.1 b

500 components / Year

Tolerance ± 0.001 mm

Material: Stainless steel

Machine used: Automatic Lathe

Manufacturing attributes

In manufacturing attributes the parts are grouped in a family with same manufacturing characteristics but different shapes. The figure 2.2 shows it is observed that the shape and size are different but the operations are same.

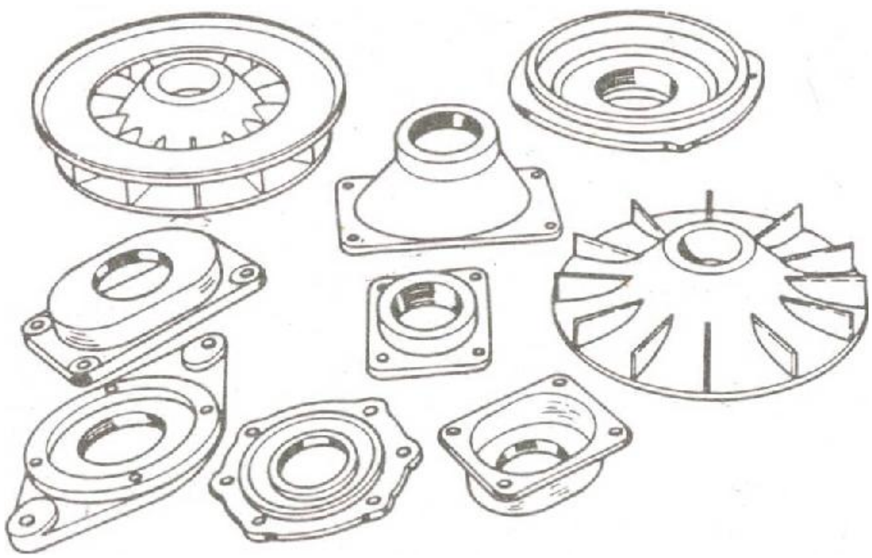


Figure 2.2 Parts with different shapes and same manufacturing attributes

Manufacturing part family is really grouping the manufacturing machines into separate work cells. That is the machines have to be arranged according to function.

In the traditional manufacturing method the same types of machines are arranged in groups then there is a considerable random movement for batch production. The figure 2.3 shows the layout of the traditional manufacturing. Now this will create unnecessary movement of work piece. During machining of a given part for a particular operation the parts repeatedly uses the same machine.

These results in

1. Improper material handling.
2. Large in process inventory
3. More manufacturing lead time
4. More loading time and
5. High cost.

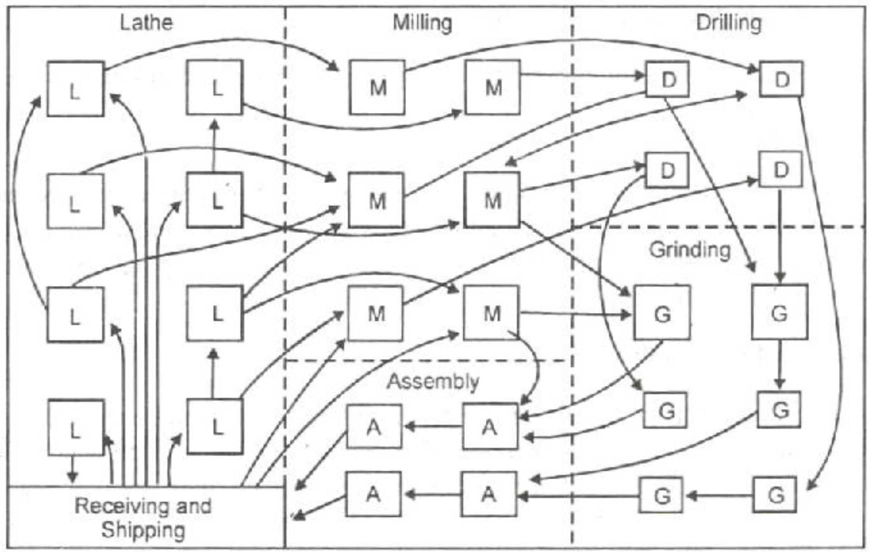


Figure 2.3 Traditional Manufacturing layout

The manufacturing of part families are used to arrange machines in a more efficiently to get a perfect product flow with reduction of lead time. In each part families, the machines are arranged into cells. Each cell is organized to specialize in the manufacture of a particular part family. The figure 2.4 shows the layout of a cellular manufacturing. In this method the machines are arranged based on the flow of product.

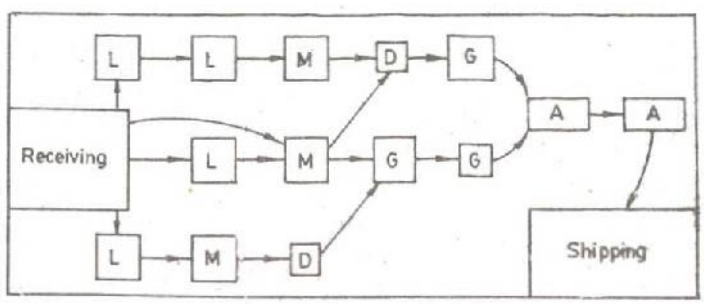


Figure 2.4 Cellular Manufacturing layout

2.2.3. Methods of Grouping Parts into Families

There are three general methods available to group the different parts into part families.

They are

1. Visual inspection.
2. Production flow analysis (PFA)
3. Classification and coding.

Visual Inspection

Visual inspection method is the simplest and less expensive method. This method involves the classification of parts into families by looking at either the physical appearance of the part. This method is less accurate to compare with other methods.

Production Flow Analysis

Production flow analysis (PFA) is a technique for identifying part families and associated grouping of machine tools. Production flow analysis makes the use of information contained on route sheets instead of part drawing. Work parts with identical or similar routings are classified into part families.

Classification and Coding system

In GT the parts are identified and grouped into families by classification and coding systems. The part classifications system is done according to the following categories.

1. System based on part design attributes.
2. System based on manufacturing attributes.
3. System based on both design and manufacturing attributes.

1. System based on part Design Attributes

It pertains to similarities in geometric features and consists of the following.

External and internal shapes and dimensions.

The ratio between length and width or length and diameter.

Dimensional tolerance.

Surface finishes.

Path functions.

Material type.

Major dimensions.

2) System based on Manufacturing Attributes

It pertains to similarities in the methods and the sequence of the manufacturing operations performed on the part. The manufacturing attributes of a part consist of the following.

The primary production processes used.

The secondary and finishing process used.

The dimensional tolerance and surface finish.

The sequence of operations performed.

The tools, dies, fixtures and machinery used.

The production quality.

The rate of production.

Production time.

Major dimensions.

Basic external shape

3) System based on Design and Manufacturing System Attributes

This system contains the best characteristics of both design and manufacturing attributes.

2.2.4. Coding structure

Coding structure is defined as a sequence of symbols that identifies the part design and manufacturing attributes. The symbols in the code can be numerical and alphabetic or combination of the both. The type of coding system structures are

1. Hierarchical structure
2. Chain type structure
3. Hybrid structure

1. Hierarchical structure

In this structure the interpretation of each succeeding symbol depends on the value of the proceeding symbols. In this system there will be a relation between the consecutive numbers. It is also called as monocode. This system has a short code contains large amount of information.

2. Chain type structure

In this type the interpretation of each symbol in the sequence is fixed. It depends on the value of proceeding digits. This is also called as polycode.

3. Hybrid structure

It is the combination of both hierarchical and chain type structure. This method is widely used in industries.

2.2.5. THE OPTIZ SYSTEM

This system uses a hybrid code structure. It has a form code and a supplementary code.

The first five digits are form code represents the design attributes.

The next four digits are supplementary code represents the manufacturing attributes.

It is extendable further by 4 more digits are secondary code.

1 2 3 4 5	6 7 8 9	A B C D
Form code	**Supplementary code**	**Secondary code**

The form code uses a 5 digit representing (i) Component class, (ii) basic shape, (iii) rotational surface machining, (iv) plane surface machining, (v) Auxiliary holes, gear teeth and forming.

A supplementary code has 4 digits in which the 1st digit denotes the major dimension. The 2nd, 3rd and 4th digits denote material, raw material shape and accuracy respectively. The figure 2.5 shows the basic structure of the OPTIZ system.

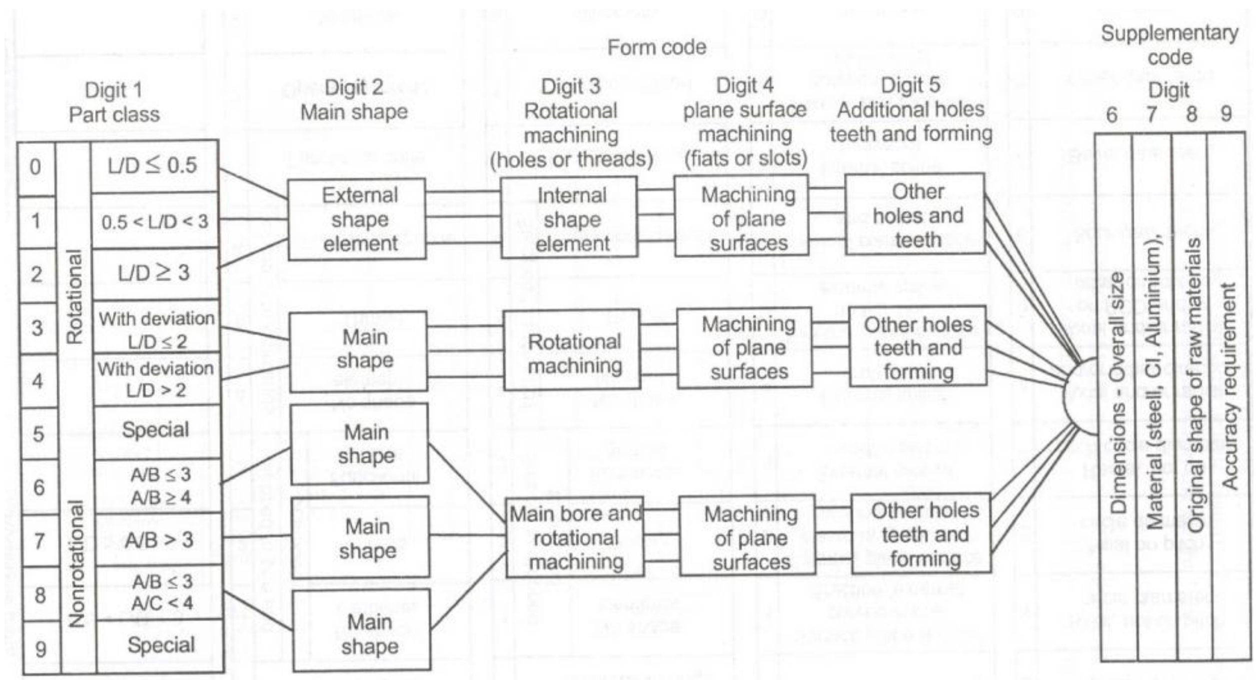


Figure 2.5 Structure of the OPTIZ system

2.2.6. MICLASS SYSTEM (Metal Institute Classification System)

It is a chain structure code of 12 digits and is designed to be universal. It includes both design and manufacturing information. An additional 18 digits of code is also available for user specified information. The supplementary digits provide flexibility for system expansion.

Universal Code Position

1st digit - Main shape

2nd & 3rd digit - Shape elements

4th digit - Position of shape elements

5th & 6th digit - Main dimensions

7th digit - Dimension ratio

8th digit - Auxiliary dimension

9th & 10th digit - Tolerance codes

11th & 12th digit - Material codes

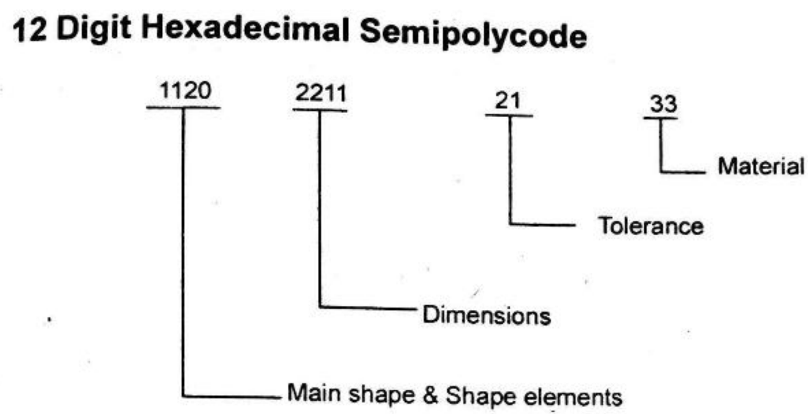


Figure 2.6

2.2.7. CODE SYSTEM

This system has 8 digits. Each digits are defined by 16 characters. They are 0 to 9 and A to F. In these characters both design and manufacturing attributes are defined. The first digit represents the geometry of the product. Next 7 digits represents the other information related to first digit. This is an example for chain type structure. This system is represented by 8 digit hexadecimal semi-poly code as shown below.

8 digit hexadecimal semi-poly code

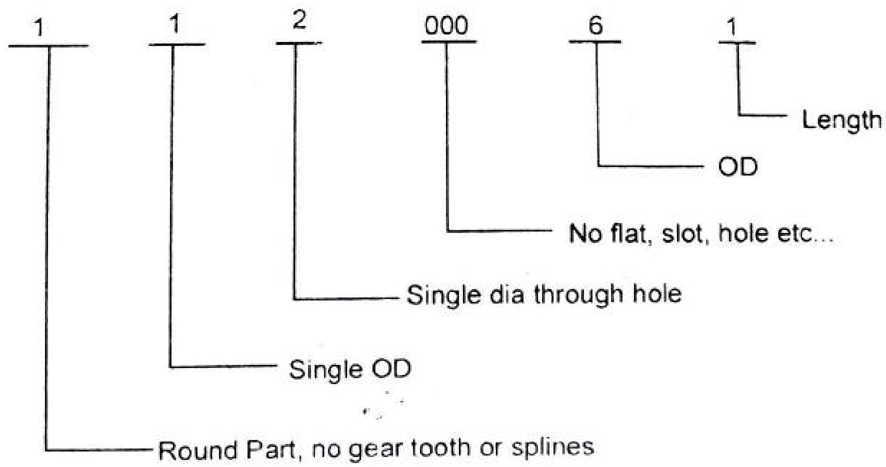


Figure 2.7

2.1.8. Benefits of Group Technology

- Design is standardized and redundancy is avoided.
- The duplicate parts are eliminated.
- Effective utilization of floor space in manufacturing.
- The material handling and transport time is reduced.
- Reduces the lead time.
- The requirement of tools and fixtures are reduced.
- It makes computer aided process planning is feasible.
- It reduces in-process inventory.
- Reduces the manufacturing cost.
- Reduces scrap and rework.

Disadvantages

1. It requires larger time for coding and classification.
2. Expensive for smaller industries.
3. The specific standard is to be followed.
4. Some machines may be utilized less.
5. Rearrangement of machines is very expensive.

2.3.1. Process planning

In the production process, there is a sequence of operations through which the raw material is converted into finished product. So, there must be a perfect production planning and product design is necessary to complete the production. This process of decision making is called process planning.

Basic Functions of a Process Planning

Process planning is carried out in two stages.

1) Process design

2) Operation design

Process Design

Process design is macroscopic decision making of an overall process route for converting the raw material into finished product.

Operation Design:

Operation Design is microscopic decision making of an individual operations contained in the process route.

2.3.2. Computer Aided Process Planning (CAPP)

CAPP is an automatic process planning functions by means of computers. CAPP accomplishes the complex task of production planning, so that the individual operations and steps involved in production are co-ordinated perfectly with other system and are performed efficiently with the help of computers. CAPP requires extensive software and co-ordinates with CAD/CAM. It is a powerful tool for efficient planning and scheduling the manufacturing operations.

CAPP is effective in small volume, more variety of parts. CAPP requires vast amount of knowledge and experience in manufacturing methods and technology.

2.3.3. Types of Process Planning

There are four basic important approaches to perform the task of process planning.

They are

- Manual approach
- Variant approach
- Generative approach
- Hybrid approach

Among these, the Hybrid approach is an approach to perform the task of process planning which combines both variant and generative type. Each approach is appropriate under certain conditions. Therefore, knowledge of nature, advantages and limitations are important.

2.3.4. Variant (or) Retrieval Process Planning

Variant process planning uses of existing process plans, and then allow the user to edit the plan for their new parts. The variant CAPP systems are based on GT and parts classification and coding. In this system, a standard process is stored in computer files for each part code number, and the process plan for new part is created by identifying and retrieving an existing plan for similar part and the plan is edited for modification.

The standard plans may be based on current routings or ideal plan is prepared for each family. The basic variant approach to process planning with group technology (GT) is,

- Go through normal group technology setup procedures.
- After part families identified, develop standard process plan for each.
- When a new plan has been designed, prepare a GT-code for each part.
- Use the GT system to lookup which part family is the closest match, and retrieve the standard plan for that part family.
- Edit standard plan so that values now match the new design parameters, and add or delete steps are required.

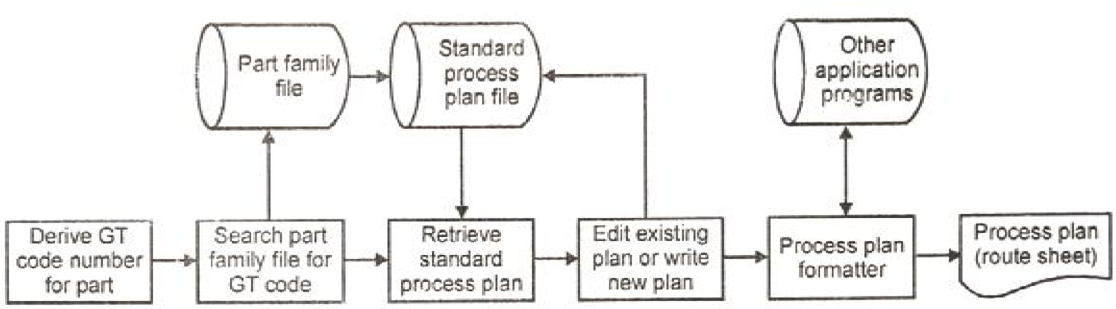


Figure 2.8 Variant (or) Retrieval Process Planning

The user begins by identifying group technology board for the component for which the process plan is to be determined. A search is made of the part family file to determine, if a standard route sheet exists for a given part code.

If a file contains a process plan for a part, it is retrieved and displayed for the user. The standard process plan is examined to determine if, there is any modification is necessary. Although the new part has the same code number, minor differences in this process might be required to make the part.

The standard is edited accordingly. If the file does not contain a process plan for the given code number, the user may search the file for a similar code number for which a standard routing exists.

By editing the existing process plan or by starting from scratch, the user develops the process plan for the new part. This becomes the standard process plan for the new part code number.

The final step is the process plan formatter, which prints the route sheet in the proper format. The formatter may call other application programs, determining cutting conditions for machine tool operations, calculating standard times for machining operations or computing cost estimates. MIPLAN is an example of retrieval type CAPP system.

Advantages

- Investment cost is low.
- Development time is less.
- It is well suited to medium to low product mixes.
- It can be rapidly developed for various companies and various parts.
- It can be interfaced with other CIM operations.
- One program can be used in radically different industries.

Disadvantages

- GT codes cannot be used for a longer period.
- Planning operations are comparatively slow.
- More chances of error than generative systems.

2.3.5. Generative CAPP

Generative process planners should create a new process plan. This does not imply that the process planner is automatic. It is an alternative systems to variant CAPP. A generative CAPP creates the process plan using systematic procedure rather than retrieving and editing the existing plans form a database. Generative plans are generated by means of decision logics, formula technology algorithms and geometric based data used for converting a part from the raw material to finished state. The rules of manufacturing and equipment capabilities are stored in a computer system.

The process sequence is planned without human assistance from the predefined standard plans. The structure of generative CAPP is shown in figure 2.9.

In the first stage, the part code is identified. This is done by searching the geometry data base. If the geometry is available in the database, the same part code is assigned. If the geometry is not available, the nearest suitable geometry is selected and by editing the existing code based on the requirement, the new part code is created.

The operation extraction sequence module is used to select the process and operation sequences. The machine and tools are selected from the machine tool selection module for the selected processes.

The machining time and idle time are calculated from the standard time library module. Cost calculation also be done from the existing library. The reports are generated after editing and modifying the existing process plan. The new process plan is generated and printed for the further action.

The design of generative CAPP is a problem in the field of expert system which is a branch of artificial intelligence. The artificial intelligence techniques used in GCAPP are PROPEL, GAGMAT, SAPT, XPLANE, STRIPS, TWEAK, EXCAP and the algorithmic system like LUPRA-TOUR for turned parts, PRICAPP and ICAPP systems for milled parts.

Advantages

- Flexibility and consistency for process planning for new parts.
- Higher overall planning quality.
- Planning operations are comparatively fast.
- Generative CAPP is fully automatic.
- It is suitable for large companies.

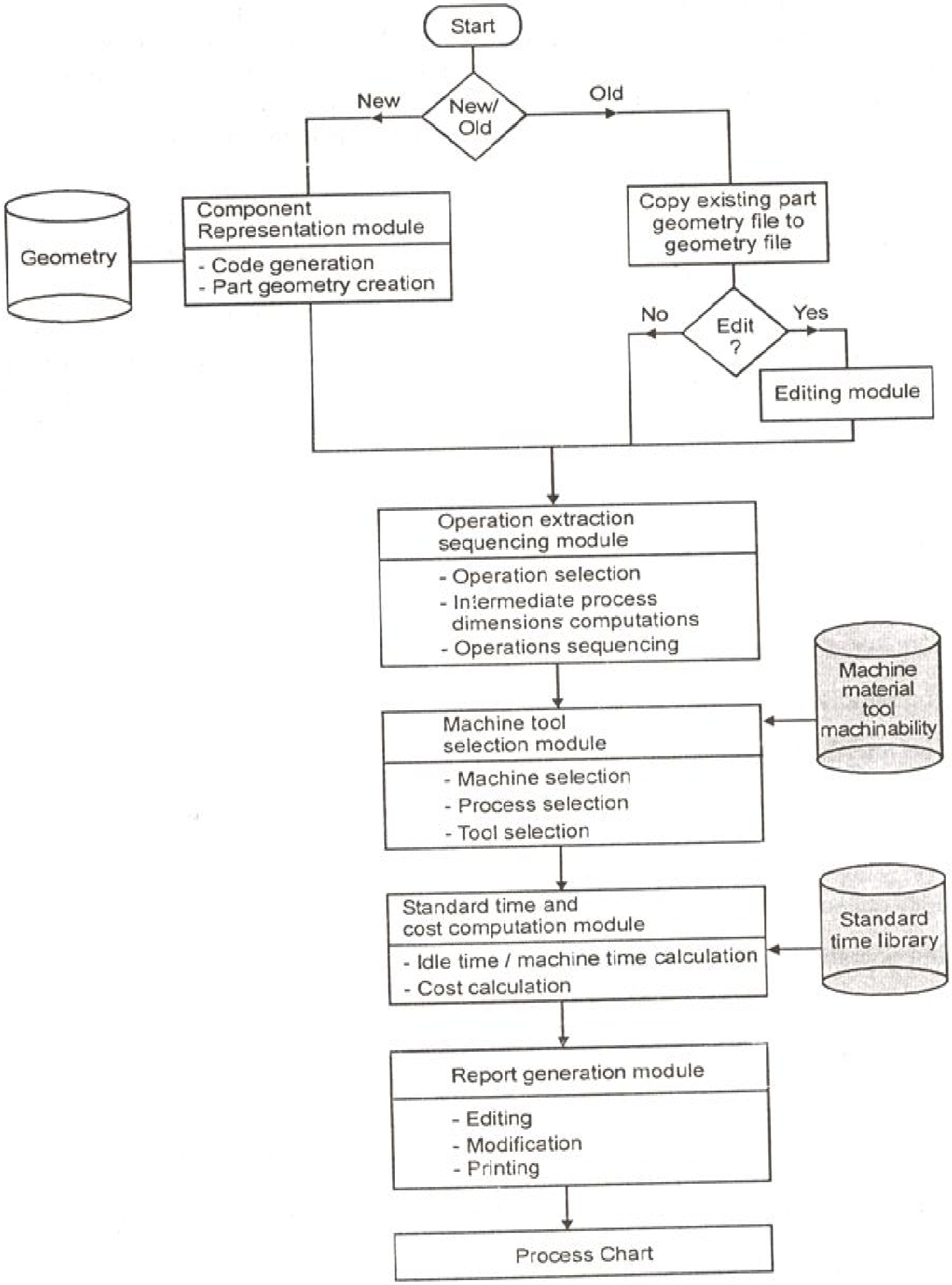


Figure 2.9 Generative Process Planning

2.3.6. Advantages of CAPP

The following are the advantages of CAPP in manufacturing.

1. It reduces process planning and production lead time.
2. It has faster response to engineering changes.
3. It improves cost estimation procedures and reduced calculation errors.
4. It gives complete and detailed process plans.
5. It improves the production scheduling and utilization capacity.
6. It reduces the effort of process planning.
7. It reduces the scrap and material cost.
8. It improves the accuracy of product.
9. It provides greater control of management in all levels.
10. It provides optimization technique in manufacturing.

2.4.1. Production and planning and control

Production planning aim at successful utilization of material resources, people and facilities in any company undertaking through planning. The optimal manner of the production is done by means of planning, coordinating and controlling the production activities. The production planning and control (PPC) department issues directives to production department of what to make, how many when and by what means. It also provides coordination and control for manufacturing activities to achieve and resource utilization.

The various activities involved in production planning and control department are designing the product, determining the equipment and capacity requirements, designing the layout of physical facilities and materials handling system, determining the sequence of operations and the nature of the operations to be performed along with time requirements and specifying certain production quantity and quality levels.

A production plan is generally improved by master schedule that identifies the exact amount and the date by which they are to be produced.

Functions of PPC department

1. Design the product
2. Finalise the machines based on the capacity of manufacturing
3. Finalise material handling system layout and other physical facilities
4. Finalise the sequence of operations
5. Based on the quantity and quality level, decide the method of operation.
6. Based on the master schedule, maintain the quantity and schedule.

2.4.2. The objectives of production planning are

Achieve a prescribed level of profit.

Capture a desired percentage of market shares.

Allocate effectively the men, materials, machinery etc.,

Satisfy the customer's requirements by producing the items in specified manner.

2.4.3. Computer integrated production management system

I an industry production planning control department gives instructions based on the production of the product. The instructions received from the PPC department is carried out by all the department with the help of computer.

Production planning control department gives instructions based on the production of the product. The instructions received from the PPC department is carried out by all the department with the help of computer.

Production planning department generates a master schedule based on the forecast, sales and marketing and customer requirement.

Depends on the master production schedule the material requirement is decided either by production or to purchase.

The production of the product was carried out in the shop floor. The assembly of the product was carried out by assembly section.

After the quality control the product was supplied to the customer by the sales and marketing department.

This sequence of operation are integrated by the computer. This is very much useful for the management of production system in an industry. This is shown in fig 2.10.

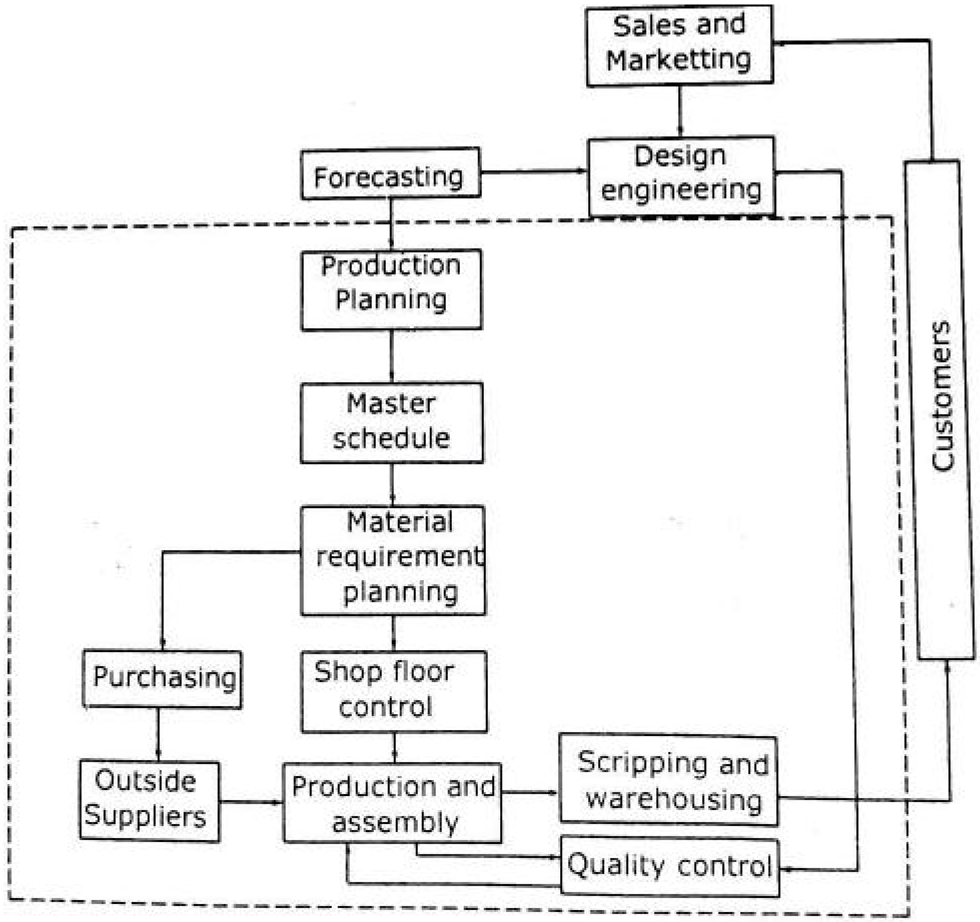


Figure 2.10 Computer integrated production management system

2.4.4. Master Production Schedule (MPS)

A MPS is generally defined as an anticipated build schedule for manufacturing of product. It is a key decision making activity. The demands coming from business planning are translated at the MPS level into demands on the manufacturing system.

The MPS is driven by a combination of actual customer orders and forecasts of likely orders. The interaction of the various components of information with the MPS is shown in figure 2.11.

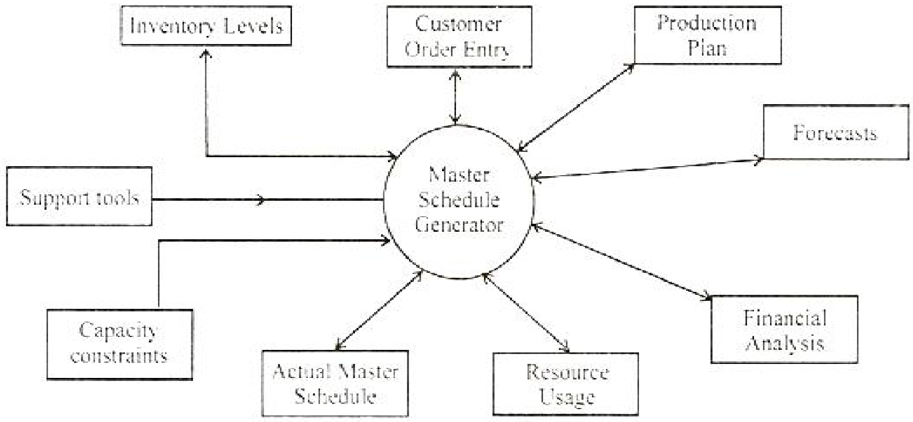


Figure 2.11 MPS

The MPS has several important uses:

- It is used to coordinate the activities of marketing, design engineering, manufacturing, and finance departments.
- It is used to plan and control workforce levels, plant facilities, equipment, materials, vendors, and costs.
- It is used by the management to plan their development activities.

The MPS is not a demand or sales forecast. It is also not a fabrication or assembly schedules, because inventories have not been considered. The table shows the illustration of the MPS.

Week	1	2	3	4	Month Total
Product PI	50		100	25	175
Product P2	60	25		10	95
Product P3		60	80	25	165
Etc.					

2.4.5. Capacity Planning

Capacity planning is concerned with determining what labour and equipment capacity is required to meet the current master production schedule as well as the long-term future production needs of the firm. Capacity planning is typically performed in terms of labour and/or machine hours available. The master schedule is transformed into material and component requirements using MRP. Then these requirements are compared with available plant capacity over the planning horizon. If the schedule is incompatible with capacity, adjustments must be made either in the master schedule or in plant capacity. Capacity adjustments can be accomplished in either the short-term or the long-term.

For short-term adjustments, decisions on the following factors are needed:

- Employment level
- Number of work shifts.
- Labour overtime hours or reduced workweek.
- Inventory stockpiling
- Order backlogs.
- Subcontracting

Long-term capacity requirements would include the following types of decisions:

- New more productive modern machines.
- New plant construction.
- Purchase of existing plants from other companies.
- Closing down or selling off existing facilities which will not be needed in the future.

2.4.6. MATERIAL REQUIREMENTS PLANNING (MRP)

MRP systems have been installed almost universally in manufacturing industries, even those considered small. The reason is that MRP is a logical, easily understandable approach to the problem of determining the number of parts, components, and materials needed to produce each end item. MRP also provides the time schedule specifying when each of these materials, parts, and components should be ordered or produced.

It is simply defined as the process to control inventory within the shop, a computerized system called Material Requirements Planning (MRP) was developed. A schedule showing the expected demand of independent items (a master production schedule) and given the relationship between independent and dependent demand items (bill of materials), MRP will calculate the quantities of dependent demand items needed and when they will be needed.

Purpose of MRP

The important purpose of a MRP system are

- Control the inventory levels.
- Assign priorities of operation.
- Plan the capacity to load the production system.

Inputs to MRP:

The main objective fo the MRP system is to convert the master production schedule (MPS) into the detailed for raw materials and components.

The following are the three major inputs to MRP system

i) The master production schedule

ii) The bill of materials (BOM) files

iii) The inventory record file.

Master Production Schedule (MPS)

The MPS specifies what products are to be produced, how many of each type of product is to be produced, and when the products are likely to be ready for dispatch.

Bill of Materials File (BOM)

The BOM files consists of the production information which must plan for all the materials, parts and sub-assemblies that make up each end product. For material planning purposes bill of materials file or product structure files shows the manufacturing sequence of the product.

Inventory Record Files

The inventory record file covers each item separately, indicating its inventory status on a period-by-period basis. This may be accomplished by utilizing computerized inventory system.

MRP Output

The major outputs from the MRP system are

a) Primary outputs

i) Inventory order action

ii) Planned order schedule.

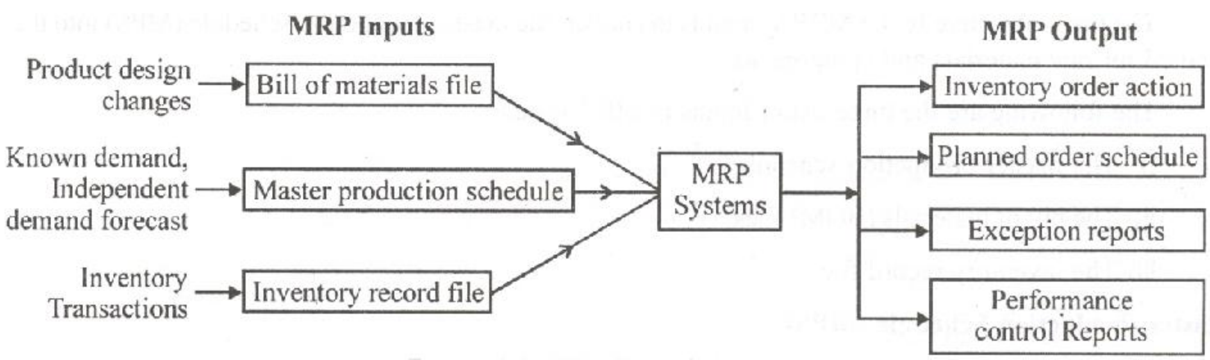
b) Secondary outputs

i) Exception records.

ii) Performance control reports.

The primary outputs contains the reports of the order release notice, reports indicating planned orders to be released in future periods, rescheduling notices, cancellation notice.

The secondary outputs particularly the exception reports of various types concerning with invalid due dates, in accurate bill of materials and inventory discrepancies. The performance reports provides valuable measures of performance. These reports focus management attention on problem areas.



2.12.MRP System

Advantages

- Reduces inventory without shortages.
- It ensures that materials and components are available in the right quantities and at the right time.
- It assists in better utilization of facilities.
- It helps to improve productivity.
- Materials are ordered with the correct due date. Thus prompt customer service is possible.

Limitations

- A valid master production schedule must exist.
- The master schedule is dependent upon good forecasts or firm orders concerning future demand.
- The product structures must be assembly oriented.
- The data used in MRP system should be reliable.

2.4.7. MANUFACTURING RESOURCE PLANNING (MRP- II)

MRP - II is a company operating system which is used to connect the material requirement planning the financial systems. This is the one of the effective planning tool of a company. It is concerned with all activities of the business, including sales, production, engineering, inventories, and cash flows. In all cases the operations of the individual departments are reduced to the same common denominator, financial data. This common base provides the company management with the information needed to manage it successfully, in essence, MRP - II is quite similar to CIM (Computer Integrated Manufacturing Systems).

Structure of MRP - II

The following figure 2.13 shows the structure of an MRP - II system

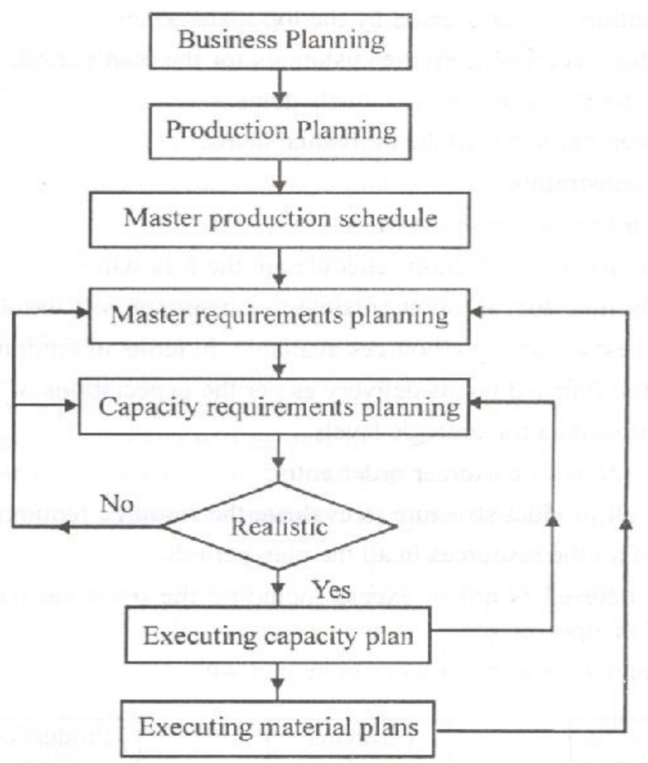


Figure 2.13 MRP II System

Business Plan:

A closed-loop MRP-II system starts, at the highest level, with a business plan which is a statement about what business a factory is in, i.e., the company producing what component (or) type or production. This plan also include the models of all the production and the brief details about that particular product.

Production Planning:

The input of the production planning system is the information from the business plan, along with sales and market forecasts. The production plan determines on a gross level, how many of which products should be manufactured. Even in a make to order environment, a company has to have some idea of what business will be like for the coming year.

Master Production Schedule (MPS):

MPS is the anticipated build schedule for those items assigned to the master schedule. It represents what the company plans to produce expressed in specific configurations, quantities and data. The MPS explains the following information.

The production plan conversed by the top management.

Actual orders received from the customers for the plan period.

Long term forecasts of the individuals items.

Present inventory levels of the individual items. - Resource constraints.

These are the major information in the MPS.

Material Requirement Planning:

The main objective of the material requirement planning (MRP) is to get right materials to the right place at the right time minimising the inventory cost. The MPS becomes direct input to the material requirements planning (MRP) function, which determines the material needed at each work centre in order to meet the master schedule.

Capacity Planning:

The desired production plan is meaningful only if there is capacity. The capacity planning therefore tries to balance the production with capacity, at aggregate level. Sometimes it is also called as aggregate capacity planning. The actual production capacity available within may be augmented by the addition of temporary worker, additional shifts, overtime payments or sub contract. Thus the capacity planning will be able to identify the capacity constraints and specify the necessary adjustments needed to achieve the required production.

2.4.8. Shop floor control system

It is concerned with the release of production orders to the factory monitoring and controlling. It is progress of the orders through the various work centers and collecting information on the status of the orders. The organization of a computerized shop floor control system is shown in fig.2.14. The diagram differentiate those portions of SFC which are computer driven and those which require human participation. The computer generates various documents which are used by people to control production in the factory.

The shop floor control system contains three steps

Order release

Order scheduling

Order progress

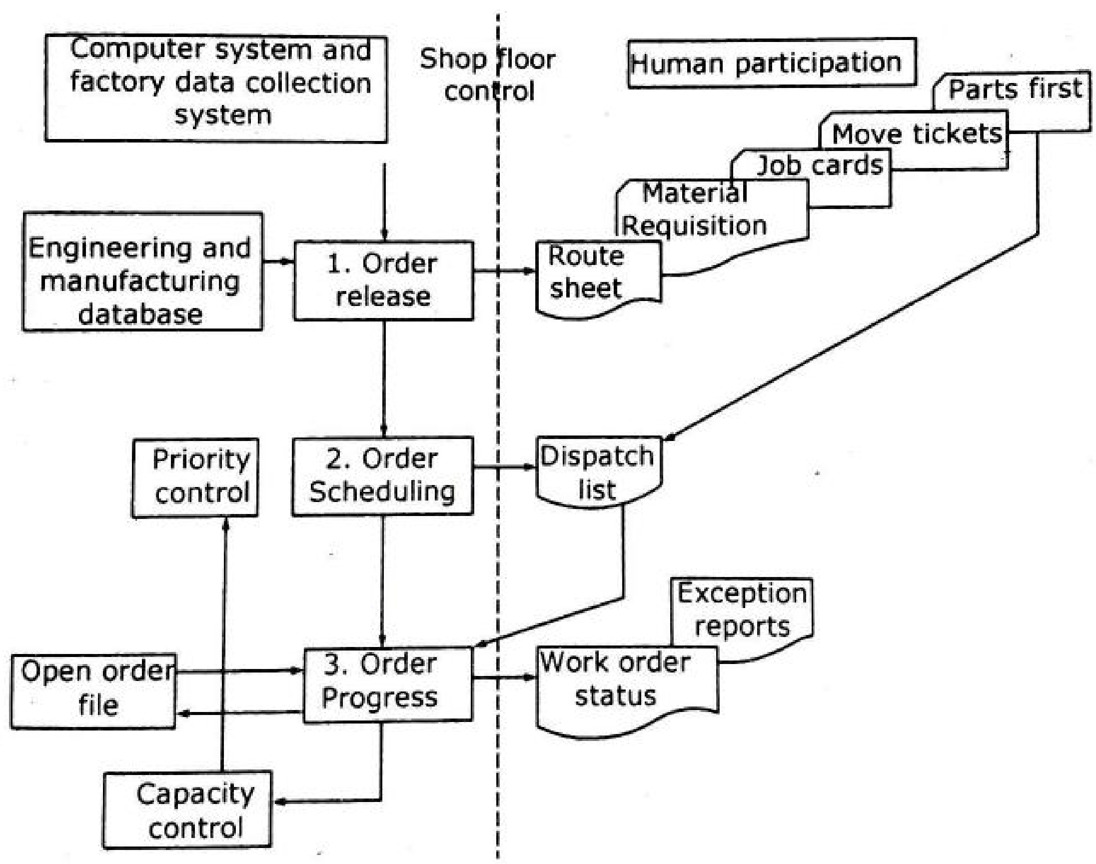


Figure 2.14 Shop floor control system

1. Order release

They are the different orders necessary to complete the job. The different orders related to a particular job are kept collectively in a packet known as shop packet. This moves with the job through the sequence of processing or assembly operations. It consists of the following.

Route sheet: It has the list of the operation sequence and tools needed.

Material requisition: It is the order to receive material from store.

Job cards: It gives the direct labor time spend to the order and also to indicate the progress of the order.

Move ticket: It gives the direction for the material handling from work centre to another work centre.

Part lists: It lists the products for assembly work.

2. Order scheduling

Its purpose is to assign orders to the various machines of the shop as per priority. This order is also known as dispatch list. It reports the jobs that should be done at each machine and some detail about the routing of the part. This list is generated each day in the shop floor. The setbacks if any in the schedule will be adjusted in the next schedule through priority control.

3. Order progress

It is concerned with the collection of data from the shop floor and to generate reports. This can be useful for production control. When the complete particular of the process are specified in the route sheet from these data the following reports are generated to control the production.

Work order status report: It gives the details of the process and its location of the work centre. This includes the processing time and priority of the process. The progress of each job is collected periodically.

Exception reports: These are the reports to point out deviations of any kind from the original schedule.

The above reports are used to control the production of the industries. Based on the reports the management can take decisions to go for the overtime and increase in the shifts.

2.4.9. JUST IN TIME APPROACH

Just In Time (JIT) is a management philosophy that to eliminate sources of manufacturing waste by producing the right part in the right place at the right time. Waste results from any activity adds cost without adding value, such as moving and storing. JIT should improve profits and return on investment by reducing inventory levels.

The basic elements of JIT were developed by Toyota in the 1950's, and became known as the Toyota Production System (TPS). JIT was firmly in place in numerous Japanese plants by the early 1970's. JIT began to be adopted in the U.S. in the 1980's.

There are strong cultural aspects associated with the emergence of JIT in Japan. The Japanese work ethic involves the following concepts.

- Workers are highly motivated to seek constant improvement upon that which already exists.
- Although high standards are currently being met, there exist even higher standards to achieve.
- Companies focus on group effort which involves the combining of talents and sharing knowledge, problem-solving skills, ideas and the achievement of a common goal.
- Work itself takes precedence over leisure. It is not unusual for a Japanese employee to work 14-hour days.
- Employees tend to remain with one company throughout the course of their career span.
- This allows the opportunity for them to hone their skills and abilities at a constant rate while offering numerous benefits to the company.

Objectives of the JIT

JIT seeks to meet the objectives by achieving the following goals

- Zero defects
- Zero set up time
- Zero inventory
- Zero handling
- Zero breakdowns
- Zero lead time
- Batch size of one

2.4.10. Enterprises Resources Planning (ERP)

Enterprise resource planning refers to a systematic process of integrating all the functions and departments of a company in an efficient computer network. The approach is cost efficient because the firm does not need to use various computer software to monitor and manage the functions and operations of the departments.

A typical enterprise resource planning system features software modules for supply chain management, customer relationship management, data warehouse, customization and access control. In addition to these, the system includes modules for human resources, financials, project management as well as manufacturing. Most international corporations use enterprise resource planning software because it is very reliable and efficient in managing the activities of firms concerning inventory, logistics, shipping, accounting and invoicing.

Advantages

1. With the implementation of this approach, employees became more productive since they can easily get the data that they need by accessing the system.
2. For instance, if a human resource department staff is doing a report about the payroll, the employee does not need to go to the finance department to get the data needed for the report.
3. By accessing the system, the employee can find and download information that will be used in the report.
4. When it comes to the security of data, companies have nothing to worry because most enterprise resource planning systems have security features.

Disadvantages

1. It is costly.
2. Additionally, the system affects the boundaries of power in corporations, which can cause troubles regarding lines of responsibility, accountability as well as employee morale.
3. Another disadvantage of using the software is that it is very complex. In this regard, companies should form a reliable IT management team that will be in-charged with the effective and successful employment of the system.
4. To avoid security breach, the team should regularly change the passwords to secure confidential data.

Unit III

CNC PROGRAMMING, RAPID PROTOTYPING

3.1.1 CNC part programming

A part program is simply a series of command blocks that execute motions and machine functions in order to manufacture a part.

Methods of creating part program

- Manual part programming
- Computer assisted part programming (APT programming)
- CAD/CAM based programming
- Interactive or Conversational programming
- Verbal programming

3.1.2 Manual part programming

The programmer writes the program from the drawing by assigning the datum points. These programs are entered in the NC machine through keypad. This is easy for the creation of simple geometric shapes and point to point motion of the tool. In this the tool path, speed, feed etc are given in the program by calculating suitably.

3.1.3. Coordinate system

The work piece of an NC program requires a coordinate system to be applied to the machine tool. As all the machine tools have more than one slide it is important that each slide is identified individually. There are three planes in which movement can take place. They are Longitudinal, Vertical and Transverse. Each plane is referred as an axis. The figure 3.1 shows the coordinate system of the turning centre (Lathe) and figure 3.2 shows the coordinate system of the machining centre (Milling).

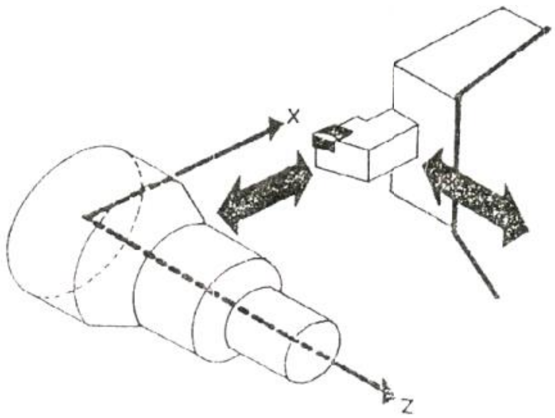


Figure 3.1 Co-ordinate system (Lathe)

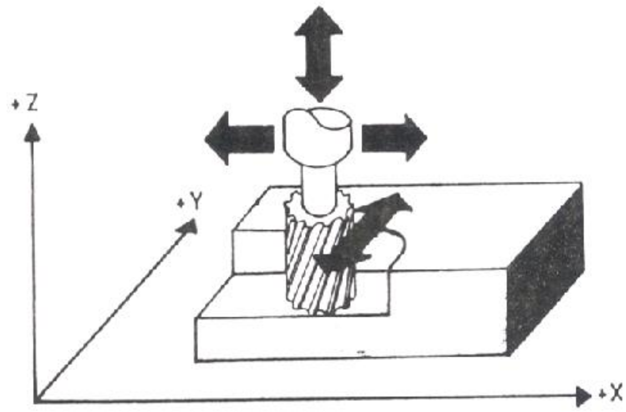


Figure 3.2 Co-ordinate system (Milling)

3.1.4 Datum points

Machine zero

The machine zero is a fixed point set by the machine manufacturer. It cannot be changed. The tool movement is measured from this point. The controller always remembers tool distance from the machine zero This is stored in the offset register.

Tool zero

It is also called zero point of the tool. Each tool has its own datum point based on the geometry of the tool. This is also a fixed point set by the manufacturer. Depends upon the operation the programmer has to compensate the tool origin. This represented in the figure 3.3 as program origin.

Work zero

The work zero can be set by the programmer at any point in the drawing. This is otherwise called as work piece datum. Based on the datum point the programmer writes the program to carry out the operation required. Normally this origin is set as the reference point. The machine origin and the tool origin are brought to coincide with this datum for the operations. This figure 3.3 shows the datum points of the turning center and machining center.

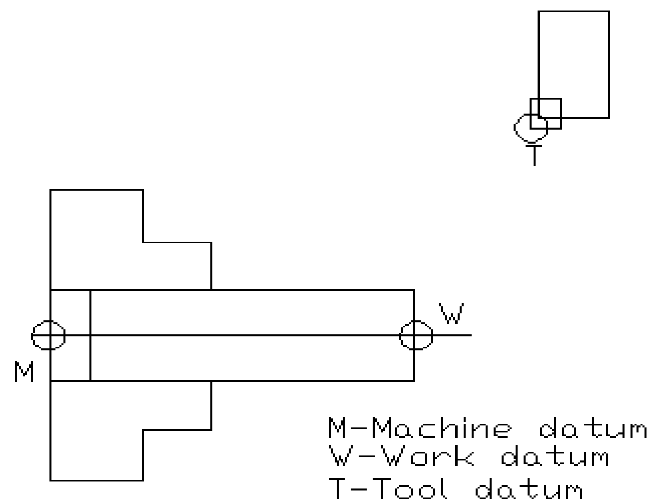


Figure 3.3 Datum points

3.1.5 Reference Points

Part programming requires establishment of some reference points. Three reference points are either set by manufacturer or user. These are called as datum points where the coordinate values are zero (0,0,0). There are three datum points are available in the CNC concept. They are Machine datum, Tool datum, and Work piece datum.

3.1.6 NC dimensioning

Dimensional information for the motions from one point to other point can be done in two ways. They are Absolute dimensioning and Incremental dimensioning.

Absolute Dimensioning (G90)

In absolute programming, all measurements are made from the part origin established by the programmer and set up by the operator. The figure 3.4 shows the absolute dimensioning.

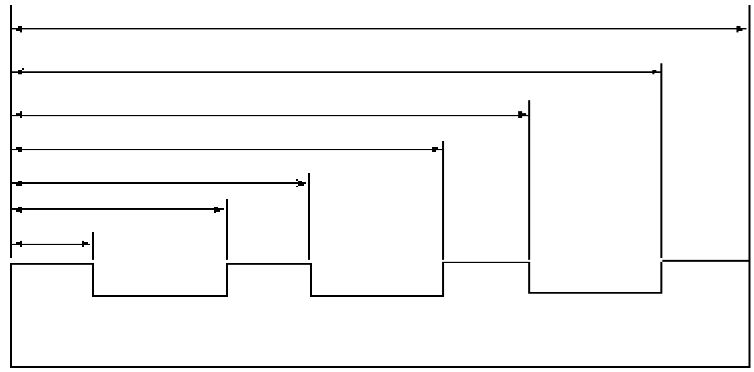


Figure 3.4 absolute dimensioning

Incremental Dimensioning (G91)

In incremental programming, the tool movement is measured from the last tool position. The programmed movement is based on the change in position between two successive points. The figure 3.5 shows the incremental dimensioning.

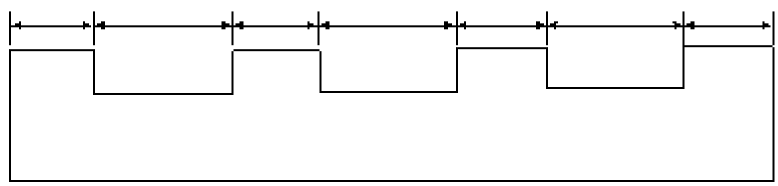


Figure 3.5 Incremental dimensioning

Example

The methods of dimensions of the object given in the figure 3.6 are tabulated.

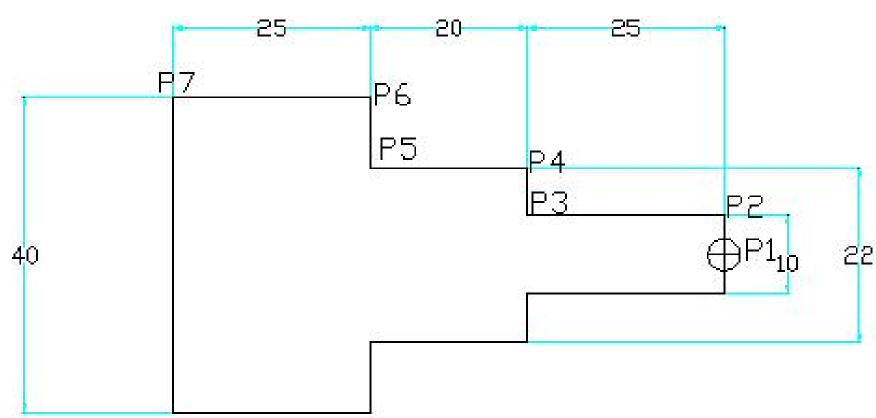


Figure 3.6 Dimensioning

Point	Absolute Dimension (X,Z)	Incremental Dimension (X,Z)
P1	0,0	0,0
P2	10,0	10,0
P3	10,-25	0,-25
P4	22, -25	12, 0
P5	22, -45	0, -20
P6	40, -45	18, 0
P7	40, -70	0, -25

3.1.7 G CODES - Preparatory functions

A preparatory function is designated in a program by the word address G followed by two digits. Preparatory functions are also called as G-codes and they specify the control mode of the operation. G-codes fall into two categories. One is non-modal or single shot codes that are only active in the block. The other one is modal codes that will remain active until another code of the same group overrides. Some of the commonly used G codes are listed below.

G00 Rapid Traverse

G00 code is used to move tool to the specified position at the maximum speed.

Example: G00 X20 Y30 Z1

Here the tool is moved to X 20mm, Y 30mm, and Z 1mm.

G01 Linear Traverse

G01 code causes linear motion to the given position.

Example: G01 X20 Y30 Z-1 F180

Here the tool is moved to X 20mm, Y 30mm, and Z -1mm at a feed rate of 180mm per minute.

G02 Clockwise Circular interpolation

G02 code causes clockwise circular motion. Arcs can be specified by either radius or by centre.

Example: G02 X30 Y20 R15 F80

X Y Z I J K

In this example the tool is moved to X 30mm and Y 20mm. The arc has a radius of 15mm.

"I" and "J" specify the arc centre relative to the arc start. If the value is 0 then it needn't be specified.

Example: G02 X30 I15

G03 Counter-Clockwise Circular interpolation

G03 code causes counter-clockwise circular motion. Arcs can be specified by either radius or arc centre. If a positive radius is specified then the shorter arc is cut. If it is negative then the longer arc is cut.

Example: G03 X30 Y20 R15 F80

In this example the tool is moved to X 30mm and Y 20mm. The arc has a radius of 15mm. "I" and "J" specify the arc centre relative to the arc start. If the value is 0 then it needn't be specified.

Example: G03 X30 I15

G04 Dwell

A Dwell of up to 500 seconds can be programmed.

Example: G04 X10

This causes a delay in machining of 10 seconds.

G20 Imperial Units

All future instruction parameters will be taken as imperial values. That is, they will specify inches.

G21 Metric Units

All future instruction parameters will be taken as metric values. That is, they will specify millimeters.

G28 Go to Reference Point

G28 causes a fast traverse to the specified position and then to the machine datum.

Example: G28 X84.0 Y80.0 Z5.0

G40 Cancel Tool Radius Compensation

G40 switches off any tool radius compensation activated by a G41 or G42.

G41 Left Hand Radius Compensation

G41 causes future movement to take place to the left of the programmed path. The offset used is equal to the radius of the current tool.

G42 Right Hand Radius Compensation

G42 causes future movement to take place to the right of the programmed path. The offset used is equal to the radius of the current tool.

G90 Absolute Movement

All future movement will be absolute until over-ridden by a G91 instruction. This is the default setting.

Example: G90

G01 X30 Y0

The position becomes X30, Y0.

G91 Incremental Movement

All future movement will be incremental until over-ridden by a G90 instruction.

Example: G90

G01 X15

G91

G01 X2

The position becomes X17.

3.1.8 M CODES - Miscellaneous functions

Miscellaneous functions use the address letter M followed by two digits. They perform a group of instructions such as coolant on/off, spindle on/off, tool change, program stop, or program end. They are often referred to as machine functions or M-functions. Some of the M codes are given below.

M00 Program Stop

M00 waits for EOB to be pressed.

M02 End of Program

M02 halts program execution. The spindle is turned off and the tool moves to the most positive position on the Z axis.

M03 Start Spindle

An M03 instruction starts forward spindle motion. It requires a speed within the range 100 to 3000 rpm.

Example: M03 S2200

The spindle should be switched on before any movement below the component surface.

M04 Reverse Spindle

An M04 instruction starts reverse spindle motion. It requires a speed within the range 100 to 3000 rpm.

Example: M04 S2200

The spindle should be switched on before any movement below the component surface.

M05 Stop Spindle

An M05 instruction stops spindle rotation. It is good programming practice to issue an M05 before a tool change, and at the end of a program. However this will be done automatically should you omit this instruction.

M06 Change Tool

The M06 instruction causes the Fanuc to change to a different tool.

Example: M06 T1

You can set tool lengths and diameters at the start of the program using the TOOLDEF directive.

M08 Coolant On

M08 turns the coolant on.

M09 Coolant Off

M09 turns the coolant off.

M30 Program end and rewind to start

M30 stops the program and rewind the program for the next cycle.

3.1.9 Interpolation

The aim of interpolation is to calculate the intermediate points between starting and end coordinates. The interpolation is required on continuous path to obtain the required machined profile.

Types of interpolations

- Linear interpolation
- Circular interpolation

Linear interpolation

It is the movement of tool in a straight line with any orientation. In part program it is given by the G code G00 and G01.In this, the co-ordinate values of the destination point is given prefixed with the code G01. Data processing unit calculate the slope and trace the path.G00 code is used for the straight line travel of the tool with maximum feed rate. The G01 code is used for the straight line travel of the tool with specified feed rate.

E.g: G00 X30 Y25

G01 X20 Y30 F25

Example for Step and taper turning

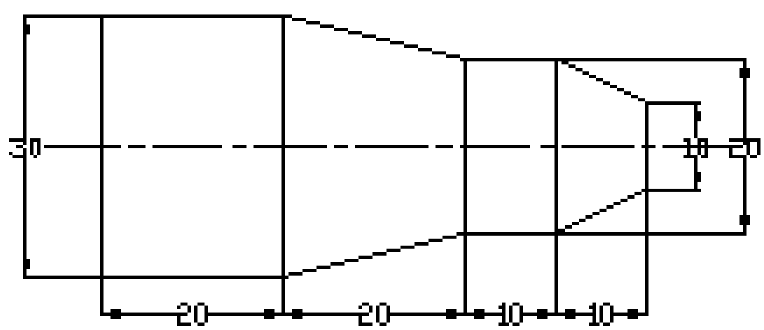


Figure 3.7 Linear interpolation

```
[BILLET X25 Z75
G21 G98
G28 U0 W0
M06 T01                - TURNING TOOL
M03 S1500
G01 X0  F20
    Z0
    X10
       X20 Z-10        - Taper turning
    Z-20
       X30 Z-40         - Taper turning
 Z-60
G28 U0 W0
M05
M30
```

Circular interpolation

The movement of the tool along the circular path is called circular interpolation. It may be either clock wise (G02) or anti clock wise (G03) with respect to the center from arc start point to end point. The destination co-ordinate value is given prefixed with the required G code G02 or G03. In addition, the arc center co-ordinate values in increment mode or arc radius are given. Data processing unit determines the various intermediate points required for the interpolation.

E.g.

```
G01 X0 Z0 F30
G03 X20 Z-10 R10  F20
G01 Z-25
G02 X30 Z-30 R5 F20
```

Example for Linear interpolation and Circular interpolation - Turning center

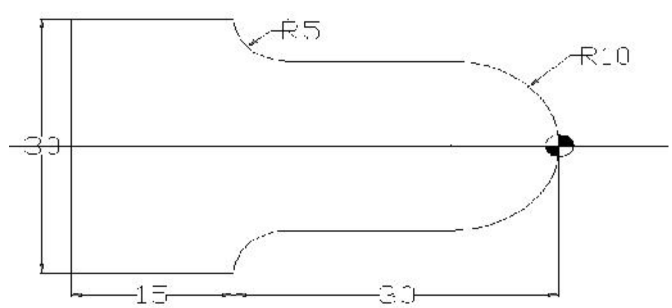


Figure 3.8 Circular interpolation

```
[BILLET X30 Z75
G21 G98
G28 U0 W0
M06 T01
M03 S1500
G00 X25 Z1
G01 X0 F10
   Z0
G03 X20 Z-10 R10 F10
G01 Z-20
G02 X30 Z-25 R5
G01 Z-35
G28 U0 W0
M05
M30
```

Example for Linear interpolation and circular interpolation – Machining center

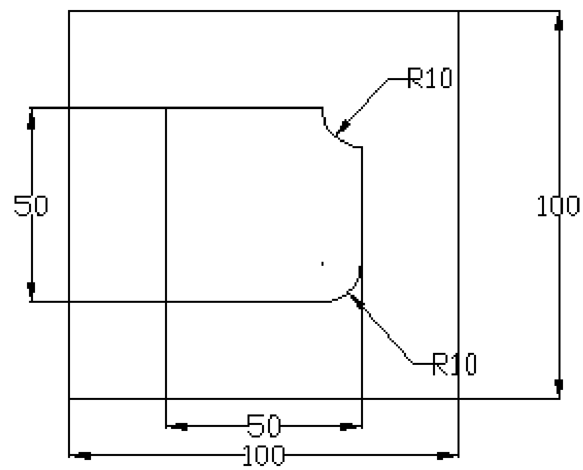


Figure 3.9 Linear and circular interpolation

```
[BILLET X100 Y100 Z20
[EDGEMOVE X0 Y0
[TOOLDEF T1 D5
G21 G94 G40
G28 U0 W0
M06 T01
M03 S2000
G00 X25 Y25
G01 Z-5 F20
Y75
X65
G03 X75 Y65 R10
G01 Y35
G02 X65 Y25 R10
G01 X25
Z5
G28 U0 W0
M05
M30
```

3.1.10 CNC Part Program Procedure

The programmer wrote the manual part programming based on the drawing of the part. The following data's are required.

- The dimensions of all the points should be calculated from the drawing.
- The sequences of operations are identified. – Process planning.
- The required tools should be selected.
- The facilities available in the CNC machines for programming should be known.
- The dimensioning method should be identified.
- The feed, speed are calculated as per the surface finish required.
- The datum points and offset values are measured and stored in the offset register.

The common procedure or format for the CNC program

Startup procedures

The commands and functions those are necessary at the beginning of the program. This involves cancellation of compensation, absolute or incremental programming, inch or metric and the setting of the work plane axis.

N10 G90 G20 G40

Tool call

M06 code is used for call tool followed by tool number T. the different methods to change tool is given below.

N25 M06 T0112

N25 M06 T01

N25 M06 T1

All the above syntax call the tool fixed in the first turret.

Work piece zero setting

The work piece location is set using G50 – G54. When using the code, the part datum location will accompany the code.

Example: G50 X120.08 Z230.27.

This would be the distance from the tool tip at the machine home position to the end and center of the work piece. Since each tool differs in length and shape, every new tool used in the program must be accompanied by its own coordinate setting.

Spindle speed control

The rpm of the spindle should be calculated based on the depth of cut and surface finish required. The direction of the spindle drive is decided by the M code M03 / M04

Example: N30 M03/ M04 S2500

Tool motion blocks

This is the body of the program. The motion of the tool is defined by the G codes available in the machine.

Program end procedures

The tool must reach the home position before the END. There are different methods to stop the program.

M05 – Stop the spindle

M02 – End of program and exit.

M30 – End of Program and rewind to start.

3.1.11 Sub programs

Any frequently programmed order of instruction or unchanging sequences can benefit by becoming a subprogram. Typical applications for subprogram applications in CNC programming are

- Repetitive machining motions
- Functions relating to tool change
- Hole patterns
- Grooves and threads
- Machine warm-up routines
- Pallet changing
- Special functions and others

Sub routines are also called as sub programs. It is a powerful time saving technique to avoid the effort of writing a long detailed program. The main and repeated operations can be written in the subprogram with separate number. The subprogram can be called wherever it requires by M98 code.

The syntax is

M98 P034000

M98 – code to call subprogram from the main program.

P – parameter used for the subprogram number

03 – number of repetition of the sub program

4000 – subprogram number.

Subprogram exit

M99 code is used to exit to main program. This returns control to the main program that called from the subprogram. This block is the last statement of the subprogram.

3.1.12 Canned cycles

A canned cycle is a preprogrammed sequence of events or motions of tool and spindle stored in memory of controller. Every canned cycle has a format. Canned cycle is modal in nature and remains activated until cancelled. Canned cycles are a great resource to make manual programming easier.

Canned cycles are the routine that automatically generates multiple tool movements from a single block instruction. These cycles are mostly used for the stock removals. This is the special facility available in the CNC machine.

Advantages

- Reduces number of statements.
- Programming is easy.
- Less memory space is required.

Disadvantages

- To provide this facility the cost of the machine is increased.

Some of the major canned cycles

Turning cycles - G90 / G71

Thread cutting cycles - G76 / G92

Drilling & peck drilling cycles - G 73 / G83

Circular Pocketing – G170 – G171

Rectangular Pocketing – G172 – G173

3.1.13 Stock Removal - Turning Cycle

Box turning cycle

Syntax

G90 X1 ____ Z____ R____ F____
X 2
X3

X- Position of the diameter

Z- Length of the cut

R – Difference in the cut start radius and the end radius. The value is + the positive slope will be produced. The value is – the negative slope will be produced.

F - Feed

Steps involved

- Moves to the X1 position
- Reduces the diameter for the length Z.
- Returns to the position.
- By varying the X values the same sequence is repeated to achieve the required dimension.
- This is applicable for the straight-line travel only.

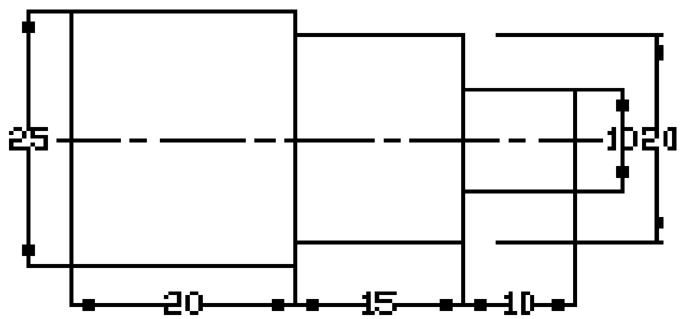


Figure 3.9 Box turning

Example

```
[BILLET X25 Z75
G21 G98
G28 U0 W0
M06 T01
M03 S1500
G00 X25 Z1
G90 X25 Z-25 F25
   X22
   X20
G00 X20 Z1
G90 X20 Z-10 F25
   X16
   X12
   X10
G01 X25
   Z-45
G28 U0 W0
M05
M30
```

Multiple turning cycle (Stock removal by turning)

G71 causes the profile to be cut by turning. After the operation is complete, the control passes on to the block next to the end block defining profile.

Syntax

G71 U____ R____ (U – Depth of cut and R – Radial retraction)

G71 P__ Q __ U___ W___ F____

P - Starting block sequence number.

Q – End block sequence number

U – Finishing allowances X – axis

W – Finishing allowances Y-axis

F – Feed

G70 P ___ Q ___

- From the current position moves to the end block.
- The sequence of operation was carried out with the given allowances in both axes.
- When the operation of the starting block finished the tool move to the position.
- The allowances are removed by the Finishing cycle. (G70)
- In G70 the operation was carried out from starting block to the end block.

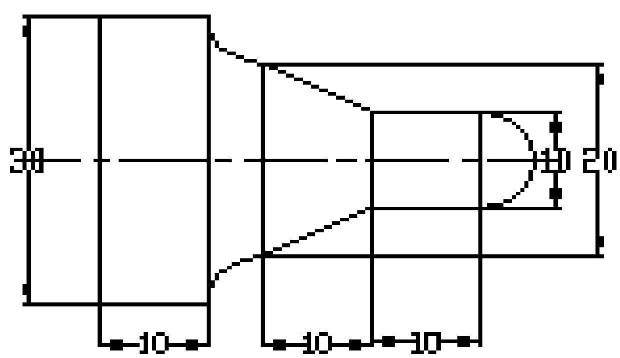


Figure 3.10 Multiple turning

Example

```
[BILLET X25 Z75
G21 G98
G28 U0 W0
M06 T01         - Rough Turning Tool
M03 S1500
G00 X25 Z1
G71 U1 W0.5
G71 P10 Q20 U0.5 W0.5
N10 G01 X0 F10
        Z0
G03 X10 Z-5 R5
G01 Z-15
```

```
        X20 Z-25
    G02 X30 Z-30 R5
    G01 X30
    N20     Z-40
    G00 X45 Z10
    M05
    M06 T02         - Finishing Turning Tool
    M03
    G70 P10 Q20
    G28 U0 W0
    M05
    M30
```

3.1.14 Thread cutting

Single threading cycle

G92 performs single threading pass. The position specified is the end of the thread. This command is repeated several times to reduce X value to avoid large depth of cut in single pass.

Syntax

G92 X _____ Z _____ F____

X - Position of the diameter (steps to reach minor diameter)

Z - Length of the thread

F – Pitch

The height of the thread and minor axis diameter is calculated from the relations.

Height of thread: 0.643 X Pitch

Minor diameter: (Major diameter – (2 X Height of thread))

Example

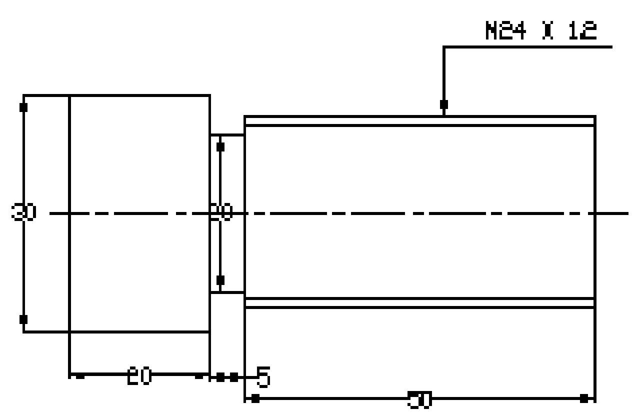


Figure 3.11 Threading

```
[BILLET X30 Z100
G90 G21
M03 S2500
M06 T01
G01 X0 Z0
X24
Z-55
X30
Z-50
G00 X50 Z15
M05
M06 T02
M03
G01 X30 Z-55
X20
X30
Z15
M05
M06 T03
M03 S2000
G00 X24 Z0
G92 X24 Z-50 F1.2
       X23.5 Z-50 F1.2
      X22.0 Z-50 F1.2
      X22.45 Z-50 F1.2
G00 X50 Z15
M05
M30
```

Multiple threading cycle

G76 causes the multiple threading cycle.

Syntax

G76 P- - - - - - Q___R ___

G76 X__ Z__ P __ Q__ F__

P – First two digits - repetition in finishing
Next two digits chamfering angle
Next two digits angle of tool.

Q – Minimum cutting depth (1000 times)

R – Finishing allowance

X – Minor axis diameter

Z – Length of thread
P – Height of thread
Q - Depth of first cut (1000 times)
F – Pitch

```
[BILLET X30 Z100
    G90 G21
    M03 S2500
    M06 T01
    G01 X0 Z0
        X24
        Z-55
        X30
        Z-50
    G00 X50 Z15
    M05
    M06 T02
    M03
    G01 X30 Z-55
        X20
        X30
        Z15
    M05
    M06 T03
    M03 S2000
    G00 X24 Z0
    G76  P031560 Q150 R 0.5
    G76 X 22.45 Z-50 P771.6 Q250 F1.2
    G00 X50 Z15
    M05
    M30
```

3.1.15 Mirroring

Mirroring is another special programming facility available in the CNC machines. The code for the image of particular shape is written in the subprogram. The program can create the same image in the all four quadrants without changing the sign of the coordinates. This can be done with the help of the following codes.

M70 X MIRROR ON
M80 X MIRROR OFF
M71 Y MIRROR ON
M81 Y MIRROR OFF

Example program for Subprogram and Mirroring

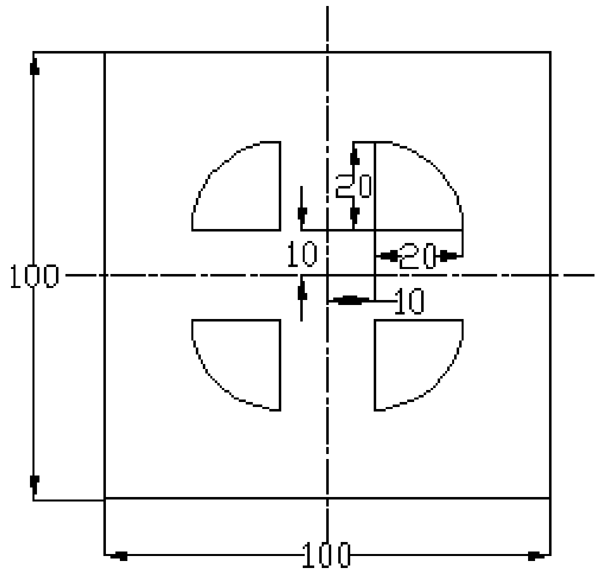


Figure 3.12 Mirroring

Main Program

```
[BILLET X100 Y100 Z20;
[TOOLDEF T1 D10;
[EDGEMOVE X-50 Y-50
G21 G90 G40
G91 G28 Z0
G28 X0 Y0
M06 T01
M03 S2000
G90 G00 X0 Y0
M98 P035555
M70
M98 P035555
M80
M71
M98 P035555
M81
M70
M71
```

M98 P035555
M05
M30

Sub Program O5555

G01 X10 Y10 F30
Z-1
X30
G03 X10 Y30 R20 F10
G01 Y10
Z5
G00 X0 Y0
M99

3.1.16 Drilling Cycle – Machining center

Peck drilling cycle- G73

Syntax: G73 X__ Y___ Z___ P___ Q___ R___ F___

X – Position X direction
Y – Position Y direction
P – dwell time in sec.
Q – Depth of cut in mm
R – Retract value in Z axis
F - Feed

Drilling cycle – G83

G83 is the modal code to cancel the repetition G80 can be used. By interrupting with the modal group code this can be cancelled.

G83 X___Y___ Z___ Q___ R___ F___

X – Position X direction
Y – Position Y direction
Q – Depth of cut in mm
R – Retract value in Z axis
F – Feed

Example

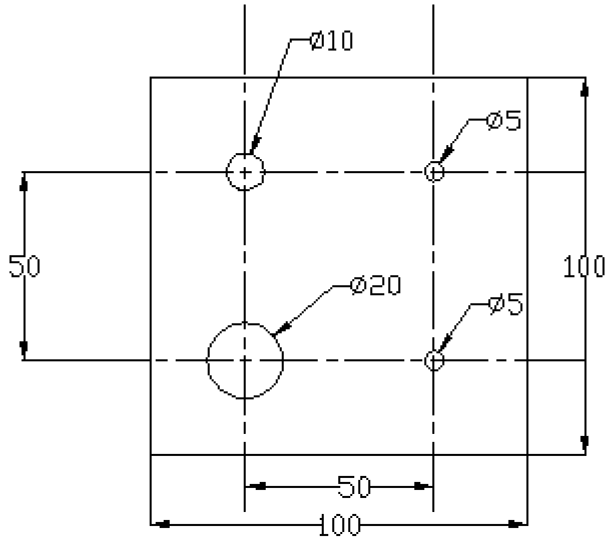


Figure 3.13 Drilling – Machining center

```
[BILLET X100 Y100 Z20
[EDGEMOVE X0 Y0
[TOOLDEF T1 D20 T2 D5 T3 D10
G21 G94 G40
G28 U0 W0
M06 T01              -Diameter 20 mm Drill
M03 S2000
G73 X25 Y25 Z-5 P100 Q0.5 R0.5 F50
M05
M06 T02              -Diameter 5mm Drill
M03 S200
G83 X75 Y25 Z-5 Q0.5 R0.5 F50
Y75
G80
M05
M06 T03              -Diameter 10 mm Drill
M03 S2000
G73 X25 Y75 Z-5 P100 Q0.5 R0.5 F50
G28 U0 W0
M05
M30
```

3.1.17 Pocketing

Rectangular pocketing can be produced with the G172 and G173 code. The example is given in the figure 3.14.

G172 I___ J___ K__ P__ Q__ R__ X__ Y__ Z__

I – Length of pocket in X direction

J - Length of pocket in Y direction

K – Corner radius (Zero)

P = 0 for roughing, = 1 for finishing

Q – Depth of cut

R – Absolute depth = 0

X – Pocket corner X distance

Y - Pocket corner Y distance

Z – Depth of pocket Z distance

G173 I__ K__ P__ T__ S____ R__ F____ B_____ J____ Z___

I – Pocket side finish allowance

K - Pocket base finish allowance

P – Cutter width percentage

T – Tool number

S – Spindle speed

R – Roughing feed in Z axis

F – Roughing feed XY axis

B – Finishing speed

J – Finishing feed

Z – Safety Z Position

Circular pocketing can be produced with the G170 and G171 code. The example is given in the figure 3.14.

G170 R___ P___ Q___ X___ Y___ Z___ I___ J___ K___

R – Position of tool to start – for flat surface = 0

P = 0 for roughing, = 1 for finishing

Q – Peck increment for each cut

X, Y, and Z – Centre of the pocket.

I – Finishing allowance for side

J – Finishing allowance for base

K – Radius of the pocket

G171 P___ S_____ R___ F___ B_____ J___

P – Cutter movement percentage

S – Roughing speed

R – Roughing feed in Z axis

F – Roughing feed XY axis

B – Finishing speed

J – Finishing feed

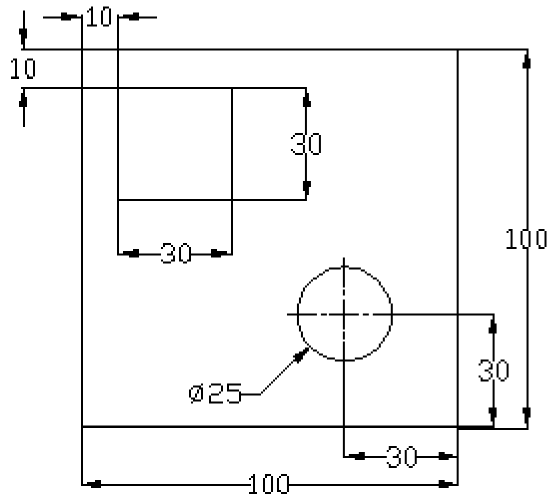


Figure 3.14 Pocketing

```
[BILLET X100 Y100 Z20
[EDGEMOVE X0 Y0
[TOOLDEF T1 D5
G21 G94 G40
G28 U0 W0
M06 T01
M03 S2000
G172 I30 J30 K0 P1 Q0.5 R0 X10 Y60 Z-3
G173 I0.2 K0.2 P75 T1 S2500 R35 F250 B2500 J100 Z5
G170 R0 P1 Q0.5 X70 Y30 Z-3 I0.2 J0.2 K25
G171 P50 S2000 R35 F45 B2500 J50
G28 U0 W0
M05
M30
```

3.2.1 RAPID PROTOTYPING

Rapid prototyping is a new manufacturing technique that allows for fast fabrication of computer models designed with three-dimension (3D) computer aided design (CAD) software. Rapid prototyping is used in a wide variety of industries.

This technique allows for fast realizations of ideas into functioning prototypes, shortening the design time, leading towards successful final products.

Steps in RPT

- Creation of the CAD model of the part design,
- Conversion of the CAD model into STL format,
- Slicing of the STL file into thin sections,
- Building part layer by layer,
- Post processing / finishing / joining.

3.2.2 Classification

1. LOM (Laminated Object Manufacturing)
2. SLA (Stereolithography)
3. FDM (Fused Deposition Modeling)
4. SLS (Selective Laser Sintering)
5. 3D Printing

Rapid prototyping technique

1. Subtractive and 2.Additive

3.2.3 Subtractive Rapid prototyping

Subtractive type is a technique in which material is removed from a solid piece of material until the desired design remains. This type of RP includes traditional milling, turning or drilling to more advanced versions includes computer numerical control (CNC), electric discharge machining (EDM).

Subtractive type rapid prototyping is typically limited to simple geometries due to the tooling process where material is removed. This type of rapid prototyping also usually takes a longer time. The main advantage is that the end product is fabricated in the desired material.

3.2.4 Additive Rapid prototyping

Additive type rapid prototyping is the opposite of subtractive type rapid prototyping. The material is added layer upon layer to build up the desired design such as stereo lithography, fused deposition modeling (FDM), and 3D printing.

Additive type rapid prototyping can fabricate most complex geometries in a shorter time and lower cost. However, additive type rapid prototyping typically includes extra post fabrication process of cleaning, post curing or finishing.

3.2.5 Advantages

- Fast and inexpensive method of prototyping design ideas
- Multiple design iterations
- Physical validation of design
- Reduced product development time

Disadvantages

- Resolution not as fine as traditional machining.
- Surface flatness is rough.

3.2.6 Applications of RPT

- It is mainly used in modeling, Product Design and Development,
- Reverse Engineering applications,
- Short Production Runs and Rapid Tooling,
- In medical applications, RPT is used to make exact models resembling the actual parts of a person, through computer scanned data, which can be used to perform trial surgeries,
- RP techniques are used to make custom-fit masks that reduce scarring on burn victims,
- Selective laser sintering (SLS) has been used to produce superior socket knees,
- Very tiny, miniature parts can be made by electrochemical fabrication,
- In jewelry designs, crafts and arts.

3.2.7 Material

Stereolithography

- Acrylics (fair selection)
- Clear and rigid
- ABS-like
- Polypropylene-like (PP)
- Flexible or elastomeric Water-resistant

3D Printing

- Polyester-based plastic
- Investment casting wax

Fused Deposition Modeling (FDM)

- ABS
- Polycarbonate (PC)
- Polyphenylsulfone
- Elastomer

Selective Laser Sintering (SLS)

- Nylon, including flame-retardant, glass-, aluminum-, carbon-filled and others providing increased strength and other properties
- Polystyrene (PS)
- Elastomeric
- Steel and stainless steel alloys
- Bronze alloy
- Cobalt

3.2.8 Stereolithography (STL)

The part is produced in a vat containing a liquid which is a photo-curable resin acrylate. Under the influence of light of a specific wavelength, small molecules are polymerized into larger solid molecules. T

he STL machine schematic is shown in Fig.3.15 creates the prototypes by tracing the layer cross sections on the surface of liquid polymer pool with a laser beam. In the initial position the elevator table in the vat is in the top most position.

The laser beam is driven in X and Y directions by programme driven mirrors to sweep across the liquid surface so as to make it solidified to a designed depth (say,1 mm). In the next cycle, the elevated table is lowered further. This is repeated until the desired 3-D model is created.

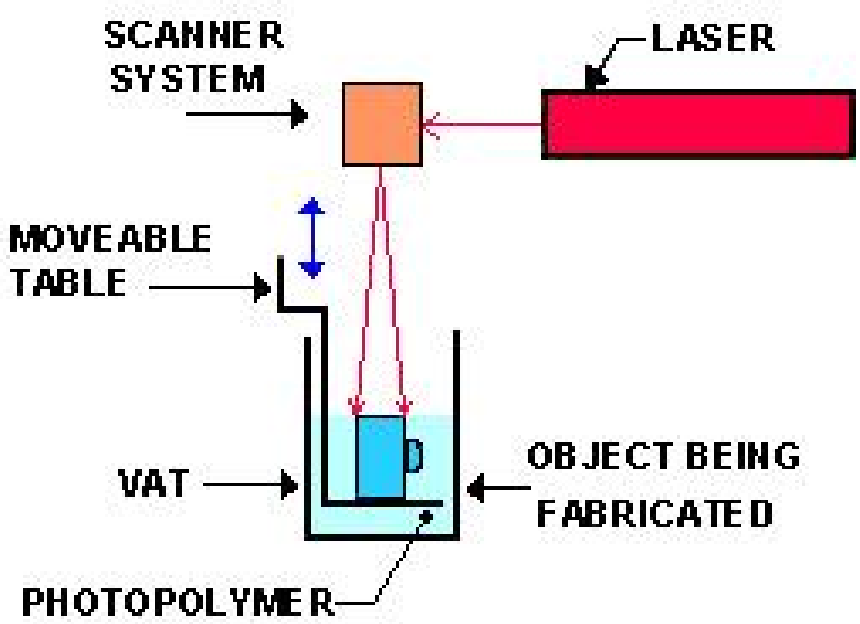


Figure 3.15 Schematic of the Stereo lithographic process used in RPT.

Applications of Stereolithography (STL)

- Very detailed parts and models for fit & form testing
- Trade show and marketing parts & models
- Rapid manufacturing of small detailed parts
- Fabrication of specialized manufacturing tools
- Patterns for investment casting
- Patterns for urethane & RTV molding

3.2.9 Fused Deposition Modeling:

A spool of thermoplastic filament is fed into a heated FDM extrusion head. The X and Y movements are controlled by a computer so that the exact outline of each section of the prototype is obtained. Each layer is bonded to the earlier by heating. This method is ideal for producing hollow objects. The schematic of the FDM is shown in Fig. 3.16.

The object is made by squeezing a continuous thread of polymer through a narrow, heated nozzle that is moved over the base plate. The thread melts as it passes through the nozzle, only to get hardened again immediately as it touches and sticks to the layer below. A support structure is needed for certain shapes, and this is provided by a second nozzle squeezing out a similar thread, usually of a different color in order to make it easier to distinguish them. At the end of the build process, the support structure is broken away and discarded, freeing the object. The FDM method produces models that are physically robust. Wax can be used as the material, but generally models are made of ABS plastic.

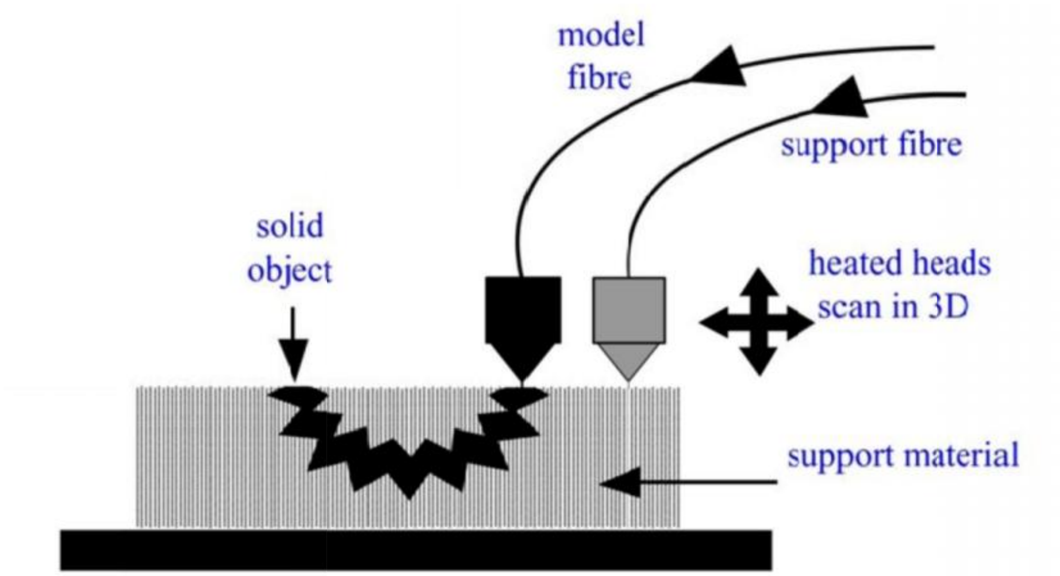


Figure 3.16 Schematic of the FDM process

Applications of Fused Deposition Modeling (FDM)

- Detailed parts and models for fit & form testing using engineering plastics
- Detailed parts for patient- and food- contacting applications
- Plastic parts for higher- temperature applications
- Trade show and marketing parts & models
- Rapid manufacturing of small detailed parts
- Patterns for investment casting
- Fabrication of specialized manufacturing tools
- Patterns for urethane & RTV molding

3.2.10 Selective Laser Sintering (SLS):

A thin layer of powder is applied using a roller. The SLS uses a laser beam to selectively fuse powdered materials, such as nylon, elastomers and metals into a solid object as shown in the Fig. 3.17. The CO_2 laser is often used to sinter successive layers of powder instead of liquid resin. Parts are built upon a platform which sits just below the surface in a bin of the heat fusible powder.

A beam of laser then traces the pattern on the very first layer thereby sintering it together. The platform is further lowered by the height of the second layer and powder is again applied. This process is continued until the part is completed. The excess amount of powder at each layer helps to support the part during its build-up.

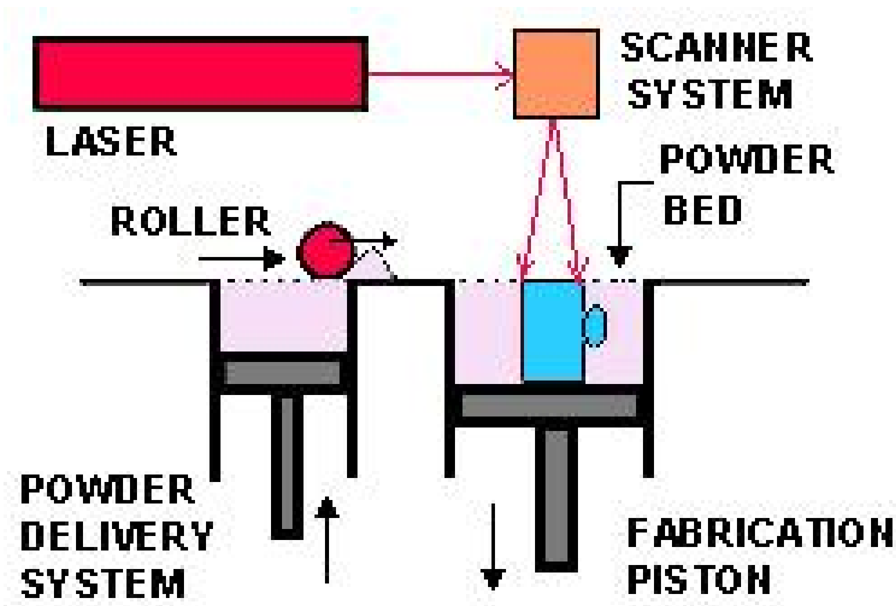


Figure 3.17 Schematic of the Selective Laser Sintering process

Applications of Selective Laser Sintering (SLS)

- Slightly less detailed parts and models for fit & form testing compared to photopolymer-based methods
- Rapid manufacturing of parts, including larger items such as air ducts
- Parts with snap- fits & living hinges
- Parts which are durable and use true engineering plastics
- Patterns for investment casting

3.2.11 Three Dimensional (3D) Printing

This machine spreads a single layer of powder onto the movable bottom of a build box. A binder is then printed onto each layer of powder to form the shape of the cross-section of the model. The bottom of the build box is then lowered by one layer thickness and a new layer of powder is spread. This process is repeated for every layer or cross- section of the model. Upon completion, the build box is filled with powder, some of which is bonded to form the part, and some of which remain loose. The steps involved in the process are shown in Fig.3.18

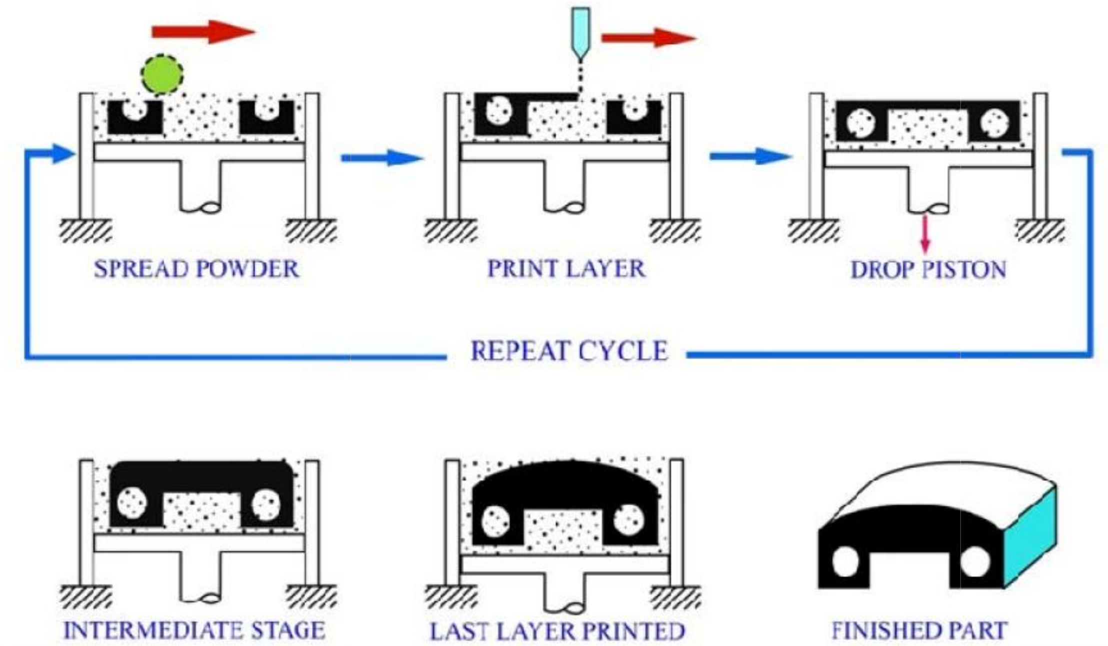


Figure 3.18 Schematic of the 3D printing

Applications of 3D Printing

- Most detailed parts and models available using additive technologies for fit & form testing
- Patterns for investment casting, especially jewelry and fine items, such as medical devices
- Patterns for urethane & RTV molding

3.2.12 Rapid tooling

Rapid process is greatly used in the fabrication of production tooling. Mechanical tooling is critical to manufacture, low production volume and high cost since rapid tooling is the excellent application.

Rapid tooling can be divided into two categories: Indirect tooling and Direct tooling.

Indirect tooling: Most rapid tooling is indirect. Rapid processing parts are used as patterns for making molds and dies. In this method pattern is used to fabricate the tool. Some of the methods are sand casting, investment casting, vaccum casting, injection moulding and slip casting.

Direct tooling: Rapid process is directly used from the CAD data. Some of the methods are rapid tool, laser engineering net shaping, direct aces injection moulding, LOM composite and sand moulding.

UNIT IV

COMPUTER INTEGRATED MANUFACTURING, FLEXIBLE MANUFACTURING SYSTEMS, AUTOMATED GUIDED VEHICLE

4.1.1 COMPUTER INTEGRATED MANUFACTURING

Introduction

CIM is the term used to describe the complete automation of the factory with all processes functions under computer control. It is the total integration of all components involved in converting raw materials into finished products and getting the products to the market. CIM includes all the engineering functions of CAD/CAM and it also includes the business functions of the firm as well.

4.1.2 Concept of CIM

CIM is the short form of Computer Integrated Manufacturing. It includes all of the engineering functions of design, manufacturing and the business functions related to manufacturing. In this system computer is used to communicate and control the operational functions and information processing functions in manufacturing. The concept of CIM is shown in the figure 4.1.

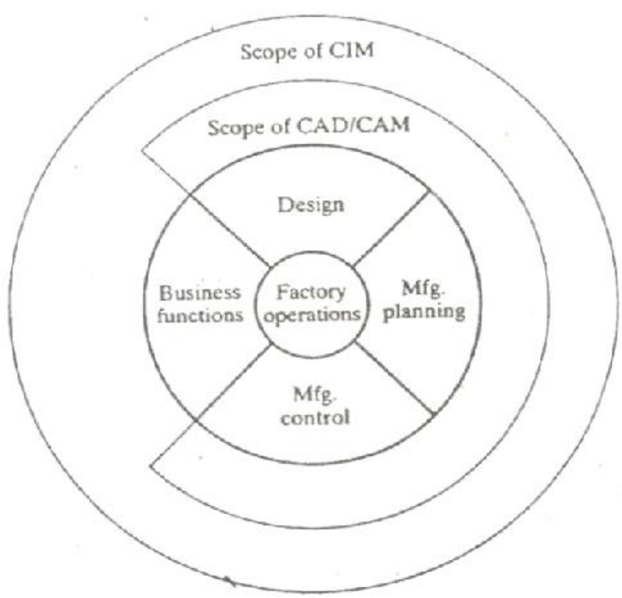


Figure 4.1 Concept of CIM

In the concept of CIM all the operations related to production are computerized and interlinked. In this integrated system, the output of one activity serves as the input to the next activity starting from the customer order to product shipment.

The customer order contains the specification of the product. It is the input to the design department. In design department the product is identified and prepares the bill of material and assembly drawing. This output of the design department is the input to the production engineering department. With the above input the production engineering department does the process planning, tool design and similar activities which are necessary for production. This output of the production Engineering department serves as the input for production planning and control department, where material planning and scheduling are done using the computer system.

This chain of action from customer order to shipment using computers implements the CIM, resulting full automation of the industry. The activities of CIM are shown figure 4.2.

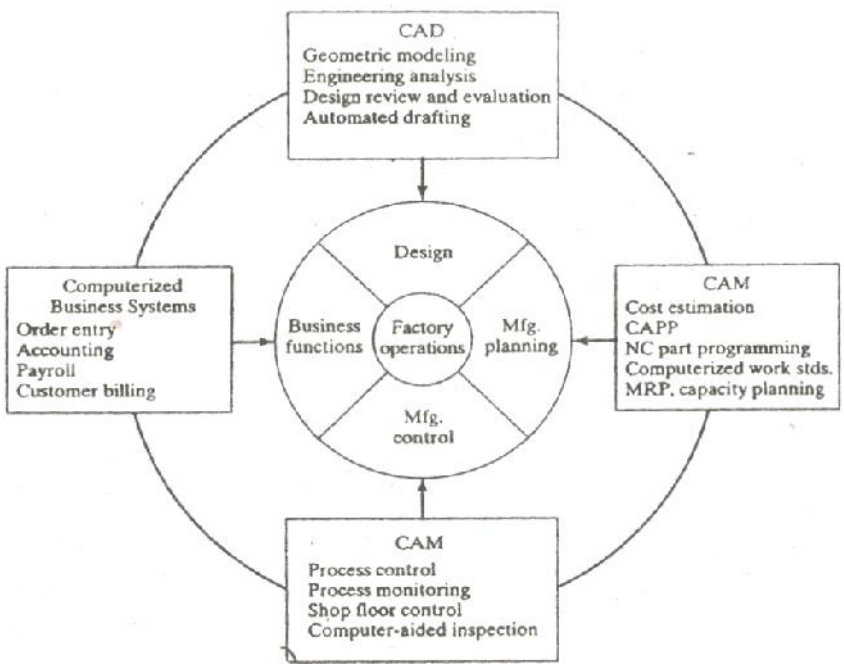


Figure 4.2 CIM components

4.1.3 Evolution of CIM

Computer Integrated Manufacturing is considered as the evolution of CAD/CAM in nature, which is evolved by the integration of CAD and CAM. Massachusetts Institute of Technology (MIT), USA is credited for the development of both CAD and CAM.

CAD was used for the geometric modeling needs of automobile and aeronautical industries. The developments in the following areas provide the necessary tools to automate the design process.

1. Computer hardware
2. Display devices with graphics cards
3. Input and Output devices
4. Powerful software packages for modeling, analyzing and optimization.

MIT developed a first NC part programming language (APT) in 1950s. Further development in the APT language automatically develops NC codes from the geometric model of the component. Now, one can create the NC code and simulate the machining operation sitting at a workstation.

The first NC machine was demonstrated at MIT in 1952. By mid-1960s mainframe computers were used to control the group of NC machines called Direct Numerical Control (DNC). In late 1960s NC uses dedicated computers with the facilities of mass program storage, off-line editing and software logic control and processing. This development is called CNC.

CNC technology led to the development of coordinate measuring machines (CMMs) which is called as automated inspection. All these developments led the evolution of flexible manufacturing system (FMS) in 1980s.

Similarly computer control is implemented in several areas like material requirements planning, manufacturing resource planning, accounting, sales, marketing, purchase, etc... The full potential of computerization could not be obtained unless all the segments of manufacturing are integrated by permitting the transfer of data across various functional modules. This realization led to the concept of Computer Integrated Manufacturing.

4.1.4 CIM WHEEL

The product development and manufacturing activities with all the functions being carried out with the help of dedicated software packages in the CIM. The data required for various functions are passed from one application software to another. The product data is created during design. the data has to be transferred from the modeling software to manufacturing software without any loss of data. CIM uses a common database. CIM reduces the human component of manufacturing. The integrated approach is applied to all activities from the design of the product to customer support. CIM based manufacturing industries are integrating the design, manufacturing and business functions using the common data base in the computer. This is defined based on the product of manufacturing. The various activities of the CIM are given in the figure 4.3. This is called as CIM wheel.

The design, analysis, simulation and drafting activities of CAD use the common database in the system. Similarly the CAM activities like shop floor control, material selection, CAPP and quality planning and process are also uses the common data base. The material handling, assembly, inspection and testing and shipping activities of the factory are also integrated by the common data base in the computer. The manufacturing activities and sales and service activities of an industry are also integrated with by the common database.

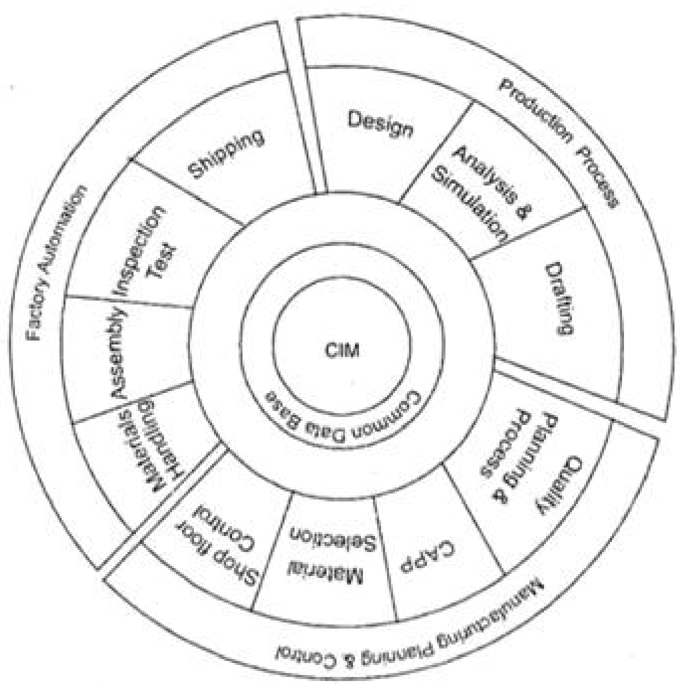


Figure 4.3 CIM WHEEL

4.1.5 Benefits of CIM

- Manufacturing lead-time is reduced.
- Flexibility in scheduling is greater.
- Low in-process inventory.
- Effective utilization of machines are increased
- Scrap and rework are reduced.
- Production capacity is increased.
- Safe working environment.

4.1.6 Integrated CAD/CAM

A manufacturing industry is concerned with three functions such as design, manufacturing and business functions. These three are connected with each other.

In earlier days, the design and manufacturing are considered as separate department. In design department, the product was identified and the drawing is supplied to the manufacturing department. The manufacturing department prepares data to plan, manage and control the manufacturing from the drawing. Here there is more time involvement and duplication of effort by way of collecting data to their purposes.

Now a days the application of computers on design and manufacturing not only automated the design and manufacturing functions of the firm, but also interlinked the design and manufacturing functions. Application of computer on design is known as CAD and on manufacturing is known as CAM.

The interlinking of CAD and CAM provides an automated transmission of data form design phase to manufacturing phase and the same is known as integrated CAD/CAM.

In integrated CAD/CAM, the CAD activities such as geometric modeling, engineering analysis, design review and automated drafting creates the model. The database contains geometric data, bill of material, specifications etc. The same database are used for CAPP, manufacturing planning and control functions, CNC programming and cost estimation are also integrated by the common database. The organization of integrated CAD/CAM is shown in fig. 4.4.

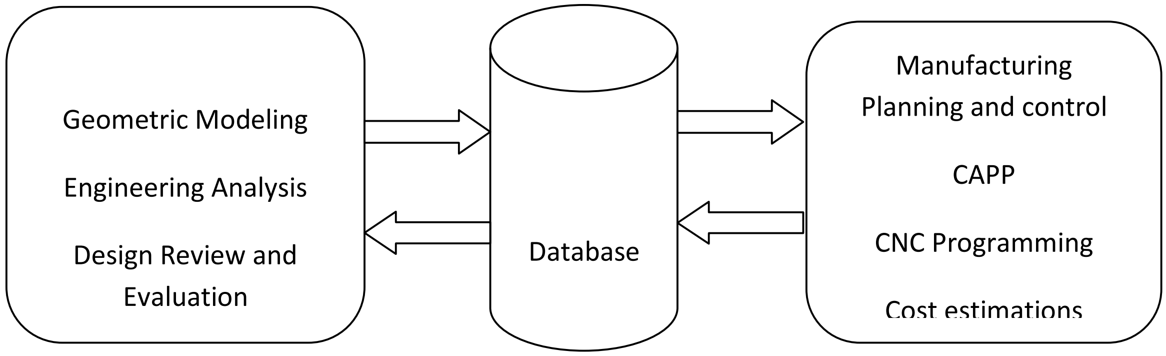


Figure 4.4 Integrated CAD/CAM

4.2.1 Flexible Manufacturing Systems (FMS)

Introduction

FMS is an integrated approach to automate the production in industries. The competition in the global market has compelled the manufacturers to reduce delivery times and to quote competitive prices even for relatively small orders. To meet specific customer requirements considerable flexibility in the manufacturing system is to be required for small batch sizes too. Flexible manufacturing cells and flexible manufacturing systems have been evolved to meet the requirements.

Definition

FMS is a computer controlled manufacturing system integrates the automated production machines and material handling equipments. The FMS is designed to be flexible so that it can fabricate a variety of different products of relatively low volumes.

4.2.2 FMS components

The major components of the FMS are

- Computer controlled manufacturing equipments
- Automated material storage, transport and transfer system
- Computer control system
- Human labour

Computer controlled manufacturing equipments: This is otherwise called as workstations or processing stations. The major work stations are CNC machine tools for machining operations. The other types of processing equipments including inspection stations, assembly stations and sheet metal stations are also under this component.

Automated material storage, transport and transfer system: Various types of automated material handling equipments are used to transport the work parts and subassemblies between the processing stations. Some times it includes automatic storage and retrieval system also.

Computer control system: Computers are used to control and coordinate the activities of the various processing stations and the material handling system in the FMS.

Human labour: Human beings are required for the following operations of FMS

1. Loading of raw materials into the system
2. Unloading of finished components from the system
3. Changing and setting tools.
4. Maintenance of equipments.
5. Programming the workstations.
6. Controlling the whole operations.

Manufacturing equipments

It is the first major component of the FMS. It includes the following type of machines

- Machining centers
- Turning centers
- Head changers
- Head indexers
- Assembly workstations
- Inspection stations
- Special purpose workstations

Machining centers: It is a multi purpose CNC machine capable of machining more than 3 axes. It also has the features of automatic tool changing, automatic work part positioning and palletized work parts. It may be of vertical or horizontal spindle types.

Turning centers: It is a CNC turning machine capable of producing cylindrical components. It has features to carryout multiple operations simultaneously to increase the productivity. It may be of vertical or horizontal spindle types.

Head changers: It is a machine tool with the capability to change the tool heads itself. A single tool head is provided with multiple spindle tools to carry out simultaneous multiple operations. They tools are separately stored in rack or drum. The required one is brought to position for operation. They are useful for specialized machining applicantions involving multiple tool cuts on the work part.

Head indexers: It is same as head changers but here the heads are attached to an indexing mechanism. By indexing the required one is brought to position. Its usage in FMS is very limited.

Assembly workstations: It is the station with automatic assembly arrangements. Industrial robots and conveyers are widely used in these workstations of FMS.

Inspection stations: The inspection of part may be done at the workstation itself or at a separate station designed specially for inspection. Co-ordinate measuring machine, inspection probes at the machine tool and machine vision technique are the three inspection methods followed in FMS.

Special purpose workstations: It is the workstation for the special purpose operations like press work, forging and other machining operations. It is also a machining centre for the particular nature of work. It is the workstation with tools for press working operations such as punching, shearing, bending and forming needed for sheet metal works and the workstation with heating furnace, forging press and trimming station for forging operations are the examples.

Automated material storage, transport and transfer system

The following are the important operations of the material handling system in the FMS.

- A FMS needs several materials handling systems to service the machines.
- A transport system to move work pieces into and out of the FMS. The overhead conveyors, gantry systems and AGV are used for this purpose.
- A buffer storage system for queues of work pieces at the machines. The pallets systems are used to reduce the queues and ideal time of the machine.
- A transfer system to load and unload the machines. The industrial robots and fixtures are used for the transport.

For these systems to work effectively they must be synchronized with the machine operations. The location and movement of work pieces must be tracked automatically. This is done by using sensors on the materials handling system and workstations. These may be either by switches or sensors.

Computer control system: The computer control system of an FMS integrates several sub systems including

- CNC Systems
- Support system controllers
- Materials handling system controller
- Monitoring and sensing devices
- Data communication system
- Data collection system
- Programmable logic controllers
- Supervisory computer

This control system must also integrate other computer systems if existing in the factory. The FMS system must also communicate with the following systems.

- The CAD/CAM system which generates the CNC programs for the machine tools.
- The shop floor control systems which schedules loading and routing of the work.
- The MIS system which provides management with reports on the performance of the system.

The operations are controlled with the help of supervisory computers connected by LAN.

4.2.3 FMS layout

The material handling system forms the FMS layout. The different layouts are,

1. In-line
2. Loop
3. Ladder
4. Open-Field
5. Robot-centered cell

1. In-line layout

The figure 4.5 shows an inline layout.

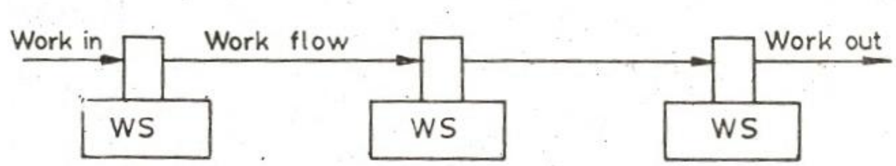


Figure 4.5 Inline layout

The work flows in one direction from one station to another. The workstations are in a line. This is suitable where the machining operations progress from one station to another in sequence.

2. Loop Layout

The figure 4.6 shows a loop layout.

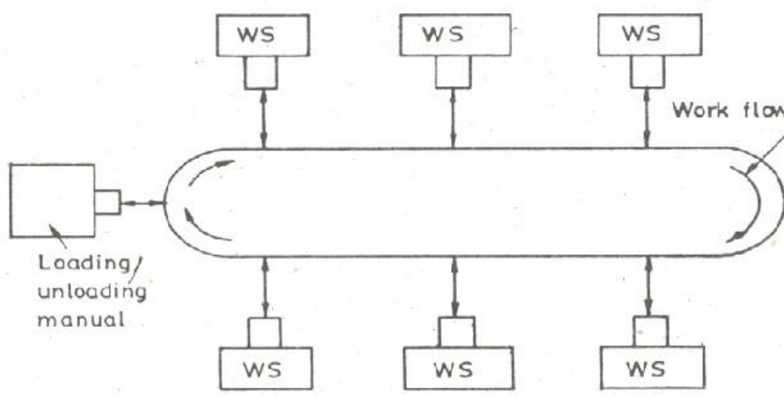


Figure 4.6 Loop layout

The work moves in one direction around the loop. The work can be stopped at any work station. There is separate material handling system to flow in the loop. The loading and unloading was done manually at the same end.

3. Ladder Layout

The figure 4.7 shows a ladder layout.

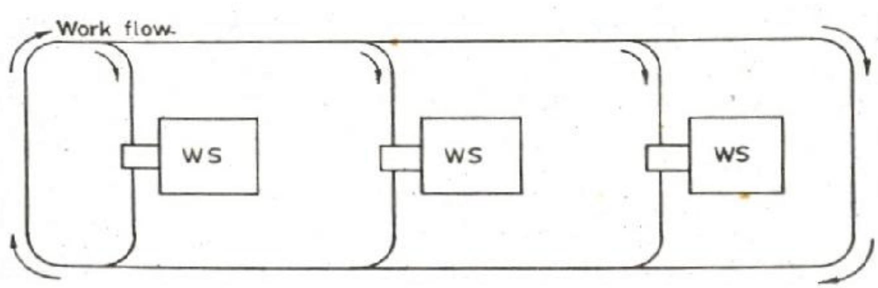


Figure 4.7 Ladder layout

It is the modified form of loop layout to reduce distance to be traveled. The arrangements of the workstations are in ladder form and each station forms an inner loop. The work can be stopped at any work station. No separate handling system necessary required as in loop layout.

4. Open field layout

It is the combination of loop and ladder layouts to achieve the required processing requirement. It is best suitable to process large family of work parts. The works are routed to the machine which is free.

5. Robot centered cell layout

The figure 4.8 shows a robot centered cell layout.

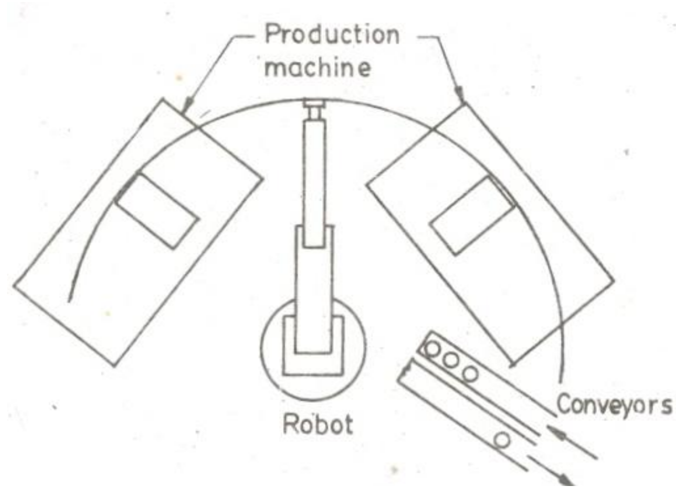


Figure 4.8 Robot centered cell layout

One or more robots are used for material handling purpose. Since robots are equipped with grippers and best suitable to handle cylindrical jobs.

4.2.4 Types of FMS

FMS has been classified in several ways. Some of the classifications are

1. Flexible Manufacturing Cells (FMC)

The simplest and most flexible type of FMS is a flexible manufacturing cell. It consists of one or more CNC machine tools with automated material handling and tool changers. FMC's are capable of automatically machining a wide range of different work pieces.

One or two horizontal machining centers with multiple pallets, advanced tool management system, automatic tool changer, automatic head changer, robots or other material handling systems to facilitate access of the jobs to the machine also constitute a flexible machining cell.

2. Flexible Turning Cells (FTC)

A turning centre fitted with a gantry loading and unloading system and pallets for storing work pieces and finished parts is a typical flexible turning cell. If the turning centre is incorporated with post process metrology equipment like probes or inductive measuring equipment for automatic offset correction, the efficiency of the system improves. Automatic tool changers, tool magazines, block tooling, automatic tool offset measurement, and automatic chuck change and chuck jaw change etc, help to make the cell to be more productive.

3. Flexible Transfer Lines (FTL)

Flexible transfer lines are intended for high volume production. A part in a high volume production may have to undergo large number of operations. Each operation is assigned to and performed on only one machine. This results in a fixed route for each part through the system. The material handling system is usually a pallet or carousel or conveyor. In addition to general purpose machines, it can consist of special purpose machines, robots and some dedicated equipment. Scheduling to balance the machine loads is easier. Unlike conventional transfer lines, a number of different work pieces can be manufactured on the FTL. The resetting procedure is largely automatic.

4. Flexible Machining Systems (FMS)

Flexible machining systems consist of several flexible automated machine tools of the universal or special type which are flexibly interlinked by an automatic work piece flow system so that different work pieces can be machined at the same time. The characteristic feature is the external interlinkage of the machines, unrestricted by cycle considerations. Different machining times at the individual stations are compensated for by central or decentralized work piece buffer stores. Flexibility is applied to machines because of CNC control and flow of products from one machine to another which is possible through flexible transport system. Flexibility is characterized by the system's ability to adapt to changes in the volumes in the product mix and of the machining processes and sequences. This means that a FMS will be able to respond quickly to changing market and customer demands.

4.2.5 Benefits of FMS

- Reduced cycle time.
- Lower work in process (WIP) inventory.
- Low direct labour costs.
- Ability to change over to different parts quickly.
- Improved quality of product.
- Higher utilization of equipment and resources.
- Quicker response to market changes.
- Reduced space requirements.
- Ability to optimize loading and throughput of machines.
- Expandability for additional processes or added capacity.
- Reduced number of tools and machines required.
- Motivation for designers to add variations and features to meet customer requirements.
- Compatible with CIM.

4.2.6 Introduction to Intelligent Manufacturing System

Intelligent manufacturing system is one in which computer based Artificial Intelligence (AI) techniques are used to substitute humans in the decision making process of manufacturing. In AI, the facts are organized in systematic manner. As per the logic laid down computer makes decision or help the human with advice to make decisions. The various fields of AI related to manufacturing are expert system, computer vision, Robotics, voice recognition, neural networks and fuzzy logic.

An Expert system is a software package that includes,

i. A knowledge base in a specialized area and,
ii. Capacity to probe knowledge base and making decisions.

The function of Expert system is different from ordinary computer activity. Expert system receives information and analyzes it and gives out solution to the query. The Expert systems in manufacturing includes act,

- As an interpreter to analyze the information got on image processing.
- As a predictor to estimate the tool wear

- As a diagnose to identify the faults of the machine
- As a designer to design engineering components
- As planner to plan the process
- As a monitor to control the production

Expert system in process planning: Process planning is the systematic determination of the methods by which a product is to be manufactured economically and competitively it involves

1. Selection of process, machines, tools, operations and their sequences
2. Calculation of feed, speed, tolerances and costs
3. Documentation in the form of instructions

An expert system does the above with the design data available from CAD.

AI and Machine visions: Industrial activity involves,

1. Automatic inspection
2. Automatic guidance of materials handling systems
3. Control aspects.

All these activities involve a system of relational matching and decisions making. The vision system collects the seen and expert system matches the seen and makes decisions accordingly

AI based scheduling in CIM environment: Scheduling is the process of allocating time for various activities of the job considering the availability man, machine and delivery time. Expert System does this within no time and the same is the required aspect for CIM with number of job in process and number of jobs in queue waiting for process.

Decision support system in the CIM environment: In the CIM environment, there are series of decision makings which ranges from job acceptance, planning and scheduling to process, man and machine allotment. Also there must be co-ordination among these decision makings. For such environment expert system is most suitable.

4.3.1 Automatic Guided Vehicles (AGV)

The important operations of the material handling system in the FMS are depends upon the machines.

FMS needs several materials handling systems such as,

- The conveyors, gantry systems and AGV are used for the transport system.
- The pallets systems are used to reduce the queues and ideal time of the machine.
- Automatic storage and retrieval system (ASRS) is used to for storage of the works.
- The industrial robots and fixtures are used for the transport system.

The above systems must be synchronized with the machine operations to work effectively. The location and movement of work pieces are tracked by using sensors on the materials handling system and workstations. These may be either by contact devises (e.g. switches) or non contact devices (e.g. Optical and proximity sensors).

4.3.2 Description

AGV is one of the widely used types of material handling device in an FMS. These are battery powered vehicles. AGV can move and transfer materials by following prescribed paths around the manufacturing floor. They are physically tied to the production line or driven by an operator like a forklift. Some vehicles can be programmed for complicated and varying routes. The computer controls the dispatching, routing, traffic control, and collision avoidance. AGV's usually complementing an automated production line. It provides the flexibility of complex and programmable movement around the manufacturing shop.

4.3.3 Working principle of AGV

Working of AGV is based the methods of the following components.

- Vehicle guidance and routing methods
- Traffic control and safety methods
- System control and management methods

Vehicle guidance and routing components

Guidance System: It refers to the method by which the AGV's pathways are defined and controlled. There are two methods. i. Guide wire method and ii. Paint strip method.

In the *guide wire method*, two wires are laid along the AGV's path. This wire is supplied with electric signal which creates a magnetic field along the path. AGV follows the path independently by sensing devices. The figure 4.9 shows guide wired AGV.

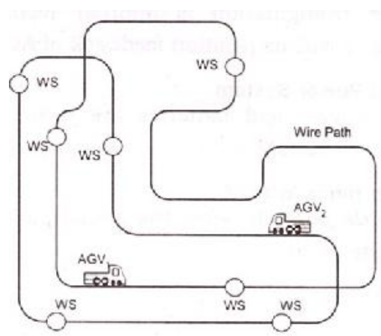


Figure 4.9 Guide Wired method

In the *paint strip method*, suitable paint is painted along the AGV's path. The optical sensor available in the AGV senses this path and moves independently. There are microprocessor control systems provided in the AGV to avoid its moving away the path and collision. The figure 4.10 shows the pain strip method AGV.

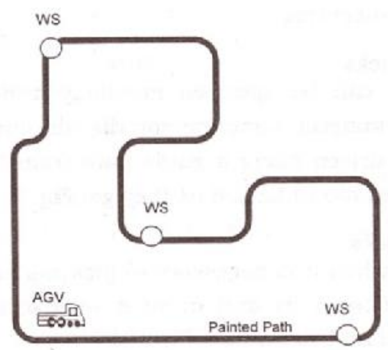


Figure 4.10 Paint strip method

Routing System: It is concerned with the problem of selecting the correct path among the alternative paths available to a vehicle at the junction. There are two methods available for this.

i) Frequency select method: Current in the different paths will be of different frequencies.

ii) Path switch select method: Current in the other parts will be switched off.

Traffic control and safety components

Traffic control: It relates to the prevention of collision between vehicles traveling along the same path. It is done by a blocking control system. This blocking system works in two ways.

i) Using onboard vehicle sensing devices to sense the presence of vehicle ahead.

ii) The AGV's path layout is divided into number of zones. Entering of one vehicle to a zone which is already with another vehicle will be avoided. This is called as zone blocking.

Safety: It relates the collision of vehicle on human being who is on the way. It is also possible by suitable sensors in front of the AGV to touch and feel the presence of human being and to stop the vehicles. Also there may be warning signals from the AGV.

System Control Management

It relates to the moving of an AGV to the exact point at the correct time of need. It is possible with the following.

i) Providing with on-board control panels on the AGV.

Each guided vehicle is equipped with some of on board control panel. It serves the purposes of vehicle programming and other functions. It gives flexibility to change and vary in delivery requirements.

ii) By using remote control.

This arrangement helps to call the nearest available AGV at the time of requirements. From that point it is moved to the dispatch station using on-board control panel facility. Some remote controls have the facility to programme the dispatch. It leads to an automated system of dispatching.

iii) By using control computer control

This arrangement helps automatic vehicle dispatching as per preplanned schedule. The pickups and deliveries in response to calls form the various stations are programmed. It gives a full flexible AGV system.

4.3.4 AGV types

Depending on the functions of AGV, they are divided into the following three categories.

- Driverless trains
- Pallet trucks
- Unit load carriers.

Driverless trains: It is the AGV which pulls one or more trailers to form a train as shown in figure 4.11. Its function is to move heavy loads to large distance in the industry with or without intermediate stops.

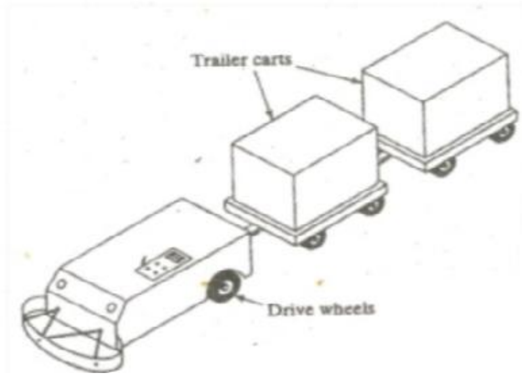


Figure 4.11 Driverless trains

Pallet trucks: A pallet truck is shown in figure 4.12. This type of AGV's provided with manual steering and fork arrangement. Its function is to move palletized loads along predetermined routes. It is steered manually to the load point which is away form the AGV path. Using the forks load is made to lift and steered back manually to the guide path. The destination is programmed, the vehicle proceeds to the unload point automatically

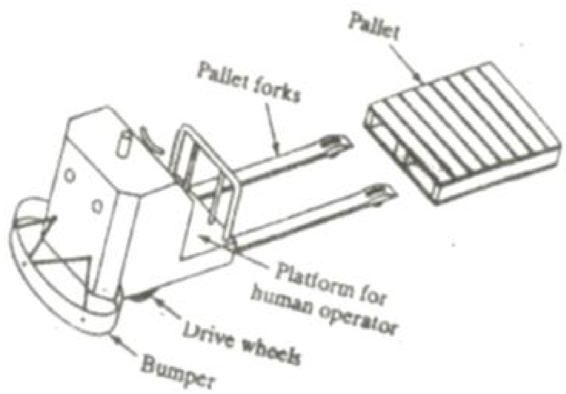


Figure 4.12 Pallet trucks

Unit load carriers: It is the AGV to carry single load at a time with automatic loading and unloading arrangement as shown in figure 4.12. Its function is to move unit loads from one station to another with automatic loading and unloading arrangement.

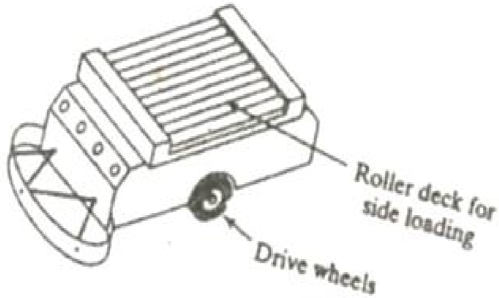


Figure 4.12 Unit load carrier

4.3.5 Benefits of AGV

i. The route of the AGVs can be easily altered, expanded and modified by changing the guide path of the vehicles.

ii. This is more cost effective than modifying fixed conveyor lines or rail guided vehicles.

iii. Because of computer control, AGVs can be monitored in real time.

iv. The vehicles can be re-routed for urgent requests can be served.

v. AGVs can travel at a slow speed.

vi. The traffic and prevent collisions between vehicles are possible.

vii. With the computer control best path was identified by simulation.

viii. Increases the performance of the FMS.

4.4.1 Robot

Robots are programmable machines with some human like capabilities. They are automation systems made up of mechanical components, a control system and a computer. These elements can be arranged in different ways and varied size and complexity to perform different tasks.

Definition: A robot is a programmable, multifunction manipulator designed to move material, parts, tools, or special devices through variable programmed motions for the performance of a variety of tasks.

4.4.2 Robot Configurations

Industrial robots come in a variety of shapes and sizes. They are capable of various arm manipulations and they possess different motion systems. The industrial robots have one of the following four configurations.

- Rectangular coordinate system
- Cylindrical coordinate system
- Polar coordinate system
- Joint arm coordinate system

Rectangular coordinate configuration

This is also known as Cartesian coordinate system. A robot which is constructed around this configuration consists of three orthogonal slides, as pictured in figure 4.13. The three slides are parallel to the *x,* y, and z axes of the Cartesian coordinate system. By appropriate movements of these slides, the robot is capable of moving its arm to any point within its three dimensional rectangular shaped workspace.

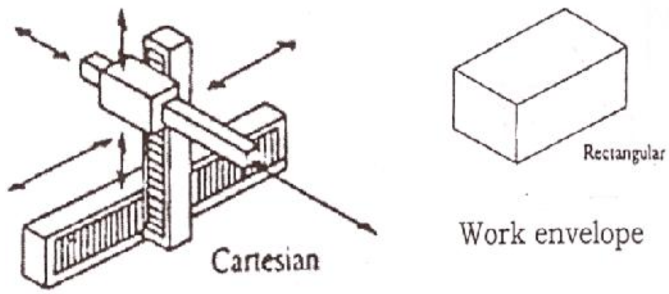


Figure 4.13 Cartesian coordinate system

Cylindrical coordinate configuration

In this the robot body is a vertical column that rotates about a vertical axis. The arm consists of orthogonal slides which allow the arm to be moved up or down and in and out with respect to the body. This is illustrated in figure 4.14. The work volume of this configuration is cylinder.

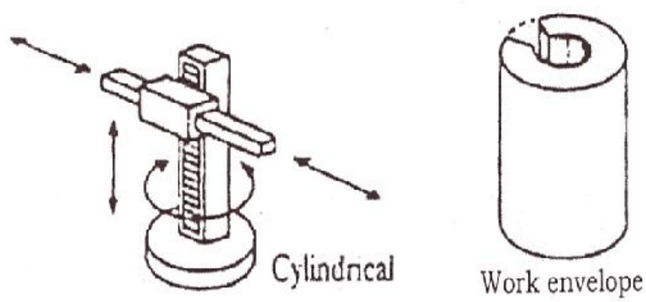


Figure 4.14 Cylindrical coordinate system

Polar coordinate configuration

This configuration also called as spherical coordinate system. The workspace of this is a partial sphere. The robot has a rotary base and a pivot that can be used to raise and lower the arm. This is shown in the figure 4.15.

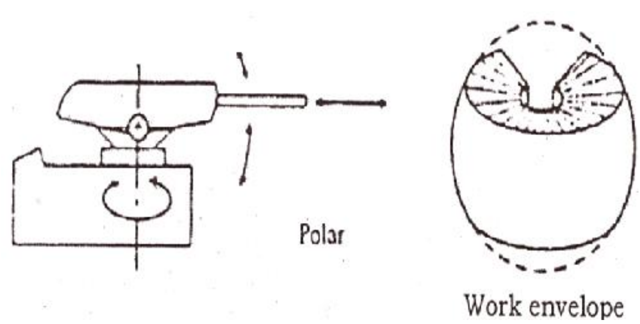


Figure 4.15 Polar coordinate system

Jointed arm configuration

The jointed arm configuration is similar in appearance to the human arm. This is shown in figure 4.16. The entire three axes are rotated to make this configuration.

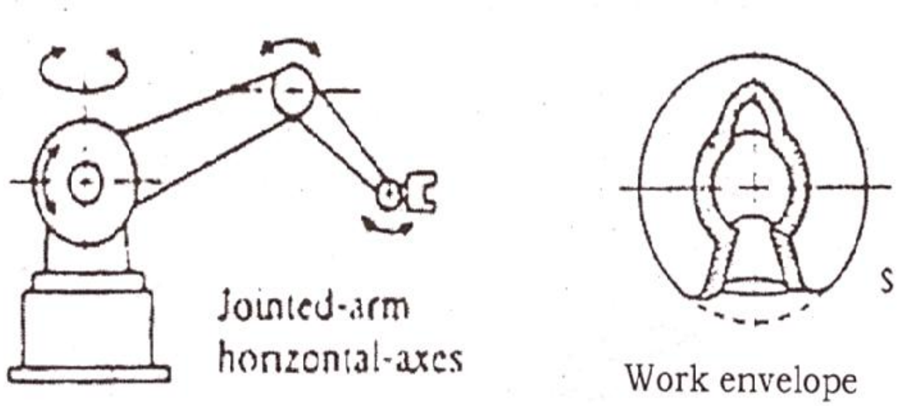


Figure 4.16 Joint arm coordinate system

Basic components of Robot (Anatomy)

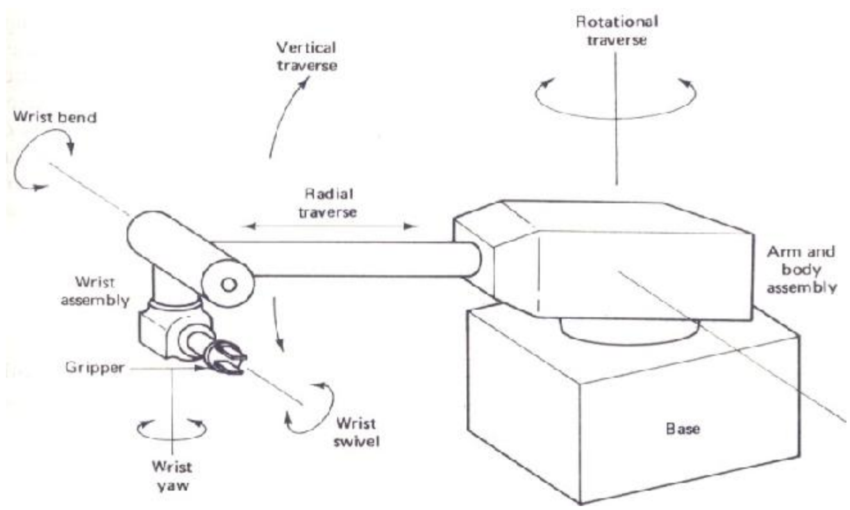


Figure 4.17 Components of robot

An industrial robot contains the following components:

- Base
- Manipulator
- End effectors
- Drives or actuators
- Sensors

- Controller
- Interfaces

A components of robot is shown in figure 4.17.

1. Base: It is the bottom of the robot. It may be fixed or mobile. The manipulator is attached to this base.

2. Manipulator: The body and arm assembly and the wrist assembly parts of a robot are known as manipulator. Body and arm assembly are attached to the base. Wrist assembly is attached to the end of arm. It does various tasks by making different physical movements. The body and arm assembly does positioning. The wrist assembly does orientation. Robot anatomy deals with the construction of manipulator. The manipulator is constructed with series of links and joints. Each joint makes one motion known as degrees of freedom of joint. The combination of different joints in the arm assembly gives various robot configurations.

The six degrees of freedom or basic motions of robot are

i. *Vertical traverse:* up and down motions of the arm, caused by pivoting the entire arm about a horizontal axis or moving the arm along a vertical slide
ii. *Radial traverse:* extension and retraction of the arm (in-and-out movement)
iii. *Rotational traverse:* rotation about the vertical axis (right or left swivel of the robot arm)
iv. *Wrist swivel:* rotation of the wrist
v. *Wrist bend:* up or down movement of the wrist, this also involves a rotational movement
vi. *Wrist yaw:* right-or-left swivel of the wrist

3. End effectors: Attached to the wrist is a hand. The hand is known as end effectors. It can be used as gripper to grip the parts or tool to do the processing operations like welding, spray painting etc.

4. Drives or actuators: They are the means to drive the body arm and wrist. Robot makes use of three drive system. They are 1. Hydraulic, 2.Electric and 3.Pneumatic drive

5. Sensors: They are the devices in robot used as feedback control system component.

6. Controller: It is the mean of controlling the drive system of a robot to regulate its motions.

7. Interfaces: They are the devices of the robot to connect the same with the external world like other robots, computer etc.

4.4.3 Basic Robot Motion

The robot arm is fixed with an end effector to carry out the particular operation. The robot arm moves the end effector to the position by the continuous motion. The six degrees of freedom or basic motions of the robot are as below.

Vertical traverse: Up and Down motions of the arm. This is caused by pivoting the entire arm about a horizontal axis or moving the arm along a vertical side.

Radial traverse: Extension and Retraction of the arm (in and out movement).

Rotational traverse: Rotation about the vertical axis (right and left swivel of the robot arm).

Wrist swivel: Rotation of the wrist.

Wrist bend: Up and Down movement of the wrist, this also involves a rotational movement.

Wrist yaw: Right or Left swivel of the wrist.

In addition the robot was moved in a track for slide motion. The motion system of the robot are point to point or continuous path.

Point to Point System: The point to point system is used to move the robot form one point to other point. Each point are stored in the robot control. The robot is moved from one point to other point to carry out the operation. In this motion the path is not defined. This is used for machine loading & unloading, pick and place and spot welding.

Continuous Path System: The motion between the one point to other point are defined through the particular path. All the points of the path is stored in the robot control. Continuous motion of the robot is used fro various operations. They are paint spraying, arc welding and grasping the object on the conveyor.

4.4.4 METHODS OF ROBOT PROGRAMMING

Robot programming is accomplished in several ways. In industrial practice we divide the programming method into two basic types.

1. Lead through method
2. Textual robot language

1. Lead through method

This method requires the programmer to move the manipulator. The robot is moved through the desired motion path in order to record the path into the controller memory. There are two ways of accomplishing lead through programming.

- Powered lead through
- Manual lead through

In the powered lead through method, a teach pendant is used to store the path through a series of points. It is largely limited to point to point motions. This is used for machine loading and unloading, transfer line and spot welding.

The manual lead through method is mostly used for continuous path programming. The robot arm is moved manually by the programmer and the path is stored. This kind of robot is used for spray painting and for continuous arc welding.

The control systems for both lead through procedures operate in two modes. They are teach mode or run mode. The teach mode is used to program. The run mode is used to execute the program.

2. Textual Robot Language

Robot programming with textual languages is accomplished like computer programming. The programmer types the program using syntax of the high level programming language in the computer.

Since the programming languages are entered and stored in the computer, this can be executed offline to check. This avoids the error in the movement of the robot. Program was identified by the program number. The position of the robot was done by the degree of motion of the drives. This was carried out by the program of instruction. The speed of the robot motion was controlled by the speed of the drive motors.

Some of the robot languages are given below.

- VAL – VESATILE Algorithmic Language
- AML – A Manufacturing Language
- MCL – Manufacturing Control Language
- RAIL – Robotic Automatic Incorporated Language
- VML – Virtual Machine Language
- SRL – Structured Robot Language
- RAPT – Robot Automatic Programmed Tools
- AL, HELP etc…

4.4.5 Introduction to Sensors

Sensors are devices that are used to measure physical variables like temperature, pH, velocity, rotational rate, flow rate, pressure and many others. Today, most sensors produce a voltage or a digital signal that is indicative of the physical variable they measure. Those signals are often imported into computer programs, stored in files, plotted on computers and analyzed. Sensors come in many kinds and shapes to measure all kinds of physical variables.

The use of *sensors* in robots has taken them into the next level of creativity. Most importantly, the sensors have increased the performance of robots to a large extent. It also allows the robots to perform several functions like a human being. The robots are even made *intelligent* with the help of Visual Sensors which helps them to respond according to the situation.

Different types of sensors:

There are plenty of sensors used in the robots, and some of the important types are listed below:

- Proximity Sensor,
- Range Sensor, and
- Tactile Sensor.

Proximity Sensor:

This type of sensor is capable of pointing out the availability of a component. Generally, the *proximity sensor* will be placed in the robot moving part such as end effector. This sensor will be turned ON at a specified distance, which will be measured by means of length. It is also used to find the presence of a human being in the work volume so that the accidents can be reduced.

Range Sensor:

Range Sensor is implemented in the end effector of a robot to calculate the distance between the sensor and a work part. The values for the distance can be given by the workers on visual data. It can evaluate the size of images and analysis of common objects. The range is measured using the Sonar receivers & transmitters or two TV cameras.

Tactile Sensors:

A sensing device that specifies the contact between an object, and sensor is considered as the *Tactile Sensor*. This sensor can be sorted into two key types namely: Touch Sensor, and Force Sensor.

The *touch sensor* has got the ability to sense and detect the touching of a sensor and object. Some of the commonly used simple devices as touch sensors are micro switches, limit switches, etc. If the end effector gets some contact with any solid part, then this sensor will be handy one to stop the movement of the robot. In addition, it can be used as an inspection device, which has a probe to measure the size of a component.

The *force sensor* is included for calculating the forces of several functions like the machine loading & unloading, material handling, and so on that are performed by a robot. This sensor will also be a better one in the assembly process for checking the problems.

4.4.6 End Effectors

In the robotic world it is generally understood that the end of the wrist is the end of the robot. The robot has the capability of moving to various positions within the limits of its work envelope. The robot is not yet prepared for the operation that it has to carry out; it does not have the correct “Hand”.

The end effector is the correct name for the attachment that can be mounted to a bolting plate fitted to the wrist. These attachments can be for grasping, lifting, welding, painting and many more. This means that the standard robot can be carry out a vast range of different applications depending on the end effector that is fitted to it.

There are two types of end effectors, they are **grippers** and **tools.** Tools are used where an operations such as welding, painting or drilling need to be performed. Their shapes and types are numerous and varied.

There are three basic categories of grippers, they are mechanical, magnetic and pneumatic.

Mechanical Gripper:

The most common type of gripper is the two finger type as seen in the figure. There are multiple finger types capable of more complex tasks available also.

Figure 4.18 Mechanical Gripper

The mechanics of a gripper is that the gripper fingers close against the object with sufficient mechanical force to hold the object firmly against gravity and movement forces. The force should not however be too severe and cause damage to the component. The grippers may be powered by servos, pneumatic or hydraulic power.

Mechanical grippers may not always be suitable for handling some components due to their size or delicacy. Magnetic or pneumatic grippers offer alternative solutions to managing components.

Magnetic Gripper

These grippers are use to handle ferrous material. The grippers will be electromagnetic or permanent magnets. The electromagnetic can pick and release the component by switching on and off the magnet. Using a permanent magnet means that the component cannot be simply dropped from the magnet, it must be slid off using a pneumatic piston. This may seem pointless when an electromagnet can be used. There is reduced risk of sparking because no electrical power is used, makes these types more suited in certain hazardous environments.

Figure 4.19 Magnetic gripper

Vacuum Gripper

Circular vacuum or suction cups made from plastic or rubber form pneumatic grippers. The cups press against the material to be lifted and the air drawn out by means of a pump, creating a plunger effect. This suction force allows the component to be lifted. The weight and centre of gravity of the components determines the number of suction cups used.

Figure 4.20 Vacuum gripper

To allow for an effective suction the object to be lifted must have a relatively smooth flat and clean surface. Releasing of the part once it reaches its destination simply means neutralising the vacuum and allowing air into the suction pads

4.4.7 Characteristics of industrial application of robot

- Hazardous or uncomfortable working conditions the robot is the substitute for the human worker. Example: hot forging, die casting, spray painting, and foundry operations.
- Repetitive tasks robot can be used. Example: Pick-and-place operations and machine loading.
- Operations involving the handling of heavy work parts.
- For continuous operation the robot can be used.

4.4.8 Applications of robots

The robots have been applied in various areas like

1. Material transfer
2. Machine loading

3. Welding
4. Spray coating
5. Processing operations
6. Assembly and Inspection

Material transfer

The robot is used to move work parts from one location to another. In some cases a reorientation of the part may be required. Some of the operations are

- Simple pick-and-place operations
- Transfer of work parts from one conveyor to another conveyor
- Palletizing operations
- Stacking operations
- Loading parts from a conveyor into boxes
- Loading the parts from the box on to conveyor

Material transfer operations are the easiest and most straight forward of robot applications.

Robots used for these tasks may be low level of technological sophistication. In palletizing operations the motion of the robot can become complicated. In palletizing the part must be positioned in its own location on the pallet for each layer. Computer controlled robot are used to execute such a motion sequence. The figure 4.21 shows the simple material transfer robot.

Figure 4.21 Material Transfer Robot

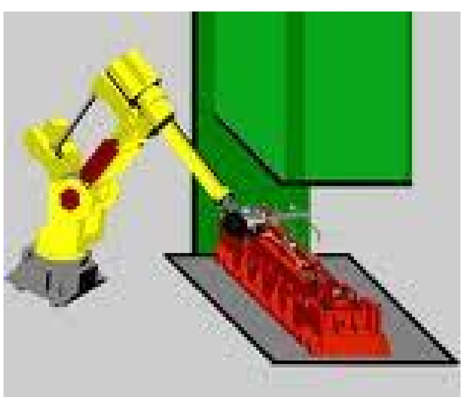
MACHINE LOADING

Machine loading applications are material handling operations. The robot is required to load raw work parts and to unload finished parts from the machine. Machine loading is different than material transfer since the robot works directly with the processing equipment.

The robot would grasp a raw work part from a conveyor and load it into the machine. In some cases, the robot holds the part in position during processing. When processing is completed, the robot unloads the part from the machine and places it onto another conveyor. Some of the operations are

- Die casting
- Injection moulding
- Hot forging
- Upset forging
- Stamping press operations
- Machining operations such as turning and milling

In die casting and plastic molding the robot only unloads the finished parts. For machining processes the robot loads and unloads. In upsetting and stamping operations the robot holds the work part. In some cases the robot is used for the various tasks. The figure 4.22 shows the simple material loading robot.



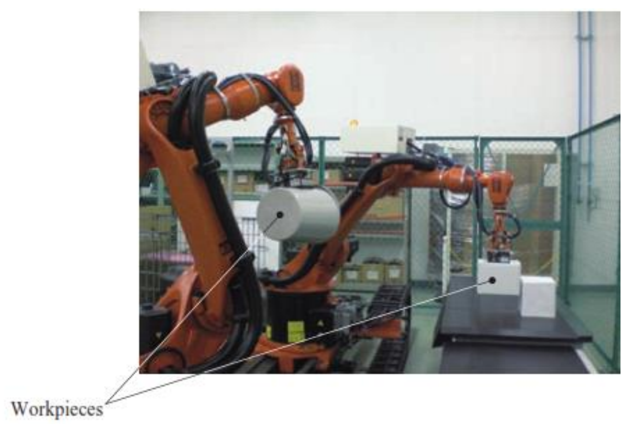


Figure 4.22 Material Loading Robot

Welding

The welding processes are a very important application area for industrial robots. The applications logically divide into two basic categories, spot welding and arc welding.

Spot welding

Spot welding is a process in which sheets or plates are fused together at localized points by passing a large electric current through the two parts at the points of contact. The following are the sequence of operations in the spot weld.

1. Position the welding gun in the desired location against the two pieces.
2. Squeezing the two electrodes against the mating pieces.
3. Weld and hold, when the current is applied to cause heating and fusion of the two surfaces in contact.
4. Release and cool. The electrodes open and sufficient time is allowed to cool the electrodes.

Spot welding has become one of the largest application areas for the automotive industry. Nowadays all automobile manufacturers are using robots for spot welding car bodies. The spot welding robots are used include motorcycle and bicycle frames, truck cabs, and appliances.

Arc welding

Several types of continuous arc welding processes can be accomplished by industrial robots. These processes include gas metal arc welding and gas tungsten arc welding. These operations are performed by welders under conditions which are hot, uncomfortable, and sometimes dangerous. Such conditions lead to the application of industrial robots. A typical robotic arc welding station would consist of the following components. The figure 4.23 shows the welding robot.

1. A robot, capable of continuous path control.
2. A welding unit, consisting of the welding tool, power source, and the wire feed system.
3. A work part manipulator, which fixtures the components and positions them for welding.

Figure 4.23 Welding Robots

Advantages

1. Higher productivity
2. Improved safety
3. More consistent welds

Limitations

1. Not economical in the low volume fabrications
2. Dimensional variations cannot be solved.
3. Difficult to weld inside the cylindrical parts.

SPRAY COATING

Spray coating is one of the major operations in the automotive industry. The spray painting process poses certain health hazards to the human operator. Some of them are

1. Fumes and mist from the spraying operation.
2. Noise from the spray nozzle.
3. Fire hazard.
4. Possible cancer dangers.

Because of these health hazards, human workers are not interested to the spray painting environment. The industries have been forced to use specialized industrial robots. Robots are used frequently to perform spray painting and related processes. Spray painting requires a robot capable of executing a smooth motion which will apply the paint evenly. These robots are equipped with continuous-path control. The paint spray nozzle becomes the end effector. The figure 4.24 shows a spray coating robot.

Figure 4.24 Spray coating Robot

Advantages

1. Safety for the human operators.
2. Coating is uniform and consistence.
3. Lower material usage.
4. Less energy used.
5. Greater productivity.

Assembly

Most of the assembly is carried out by manually. This is not economical and time consuming process. Nowadays in automobile industries the assembly was carried out by robots. The robotic application in this area is significant economic potential. A number of small servo controlled robots have been developed for assembly functions. Vision and tactile sensing capabilities are being developed to this new generation of robots. The inherent economic benefits, improved quality and increased productivity encouraged development in this area.

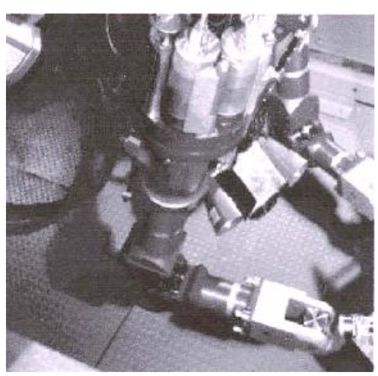


Figure 4.25 Advanced servo manipulator

Figure 4.25 shows the Advanced Servo Manipulator **(ASM),** which is remotely operated and which is used in complex chemical process. Using standard tools ASM operators are able to dismantle the rack, including tubing jumpers, instruments, motors, tanks etc.

Inspection

It is also a new area for the application of robot. The inspection is slow, tedious and boring operations performed by human beings. The sampling inspection was carried out instead of 100%. The robots equipped with mechanical probes, optical sensing capabilities can be programmed to check the dimensions. The inspection can be possible for all the parts.

In the developed world, highways are a critical component of the transportation network. The volume of traffic on the roadways has been steadily increasing. The maintenance of the roadways and funding to maintain become difficult. Robotic solutions to highway maintenance applications are attractive due their potential of increasing the safety of the highway worker, reducing delays in traffic flow, increasing productivity, reducing labour costs and increasing quality of the repairs.

The robots can be applied in the following areas in highways

- crack sealing, pothole repair
- pavement marker replacement, paint re-striping
- litter bag pickup, hazardous spill cleanup, snow removal.
- sign and guide marker washing, roadway advisory
- automatic warning system, lightweight movable barriers, automatic cone placement and retrieval.

Figure 4.26 shows a machine senses, prepares and seals cracks and joints along the highway. Sensing of cracks along the entire width of a lane is performed using two-line scan cameras at the front of the vehicle. Sealing operations occur at the rear of the vehicle using an inverted slide mounted SCARA robot. A laser range finder at the tooling verifies the presence of the cracks and provides guidance for the sealing operation. The vehicle is able to perform this operation moving at about 1.6 to 3.2 km/hr.

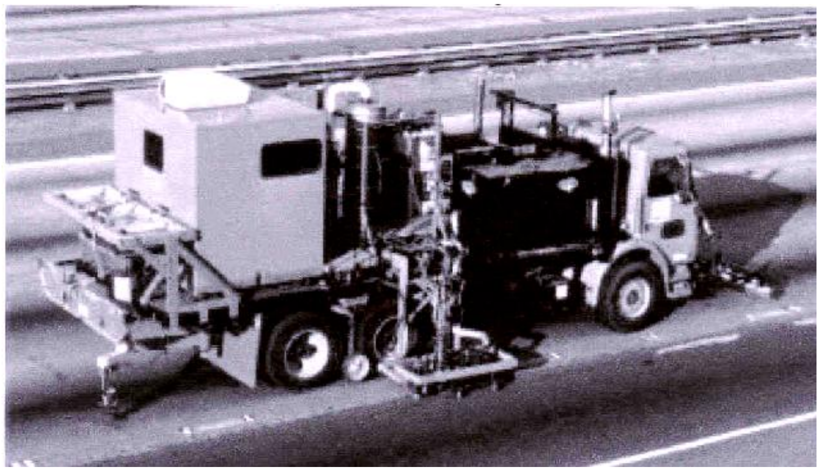


Figure 4.26 Automated Crack Sealing Machine

Human operators on live lines perform many common maintenance operations on overhead transmission lines. Examples of these tasks include replacing ceramic insulators that support conductor wire and opening and closing the circuit between poles. These tasks are very dangerous for the human workers, due to risks of falling from high places and the risk of electric shock. Obtaining skilled worker and performing the maintenance while the lines are de-energized is difficult and causes some problems. The dual arm robot system for the live line maintenance is shown in figure 4.27.

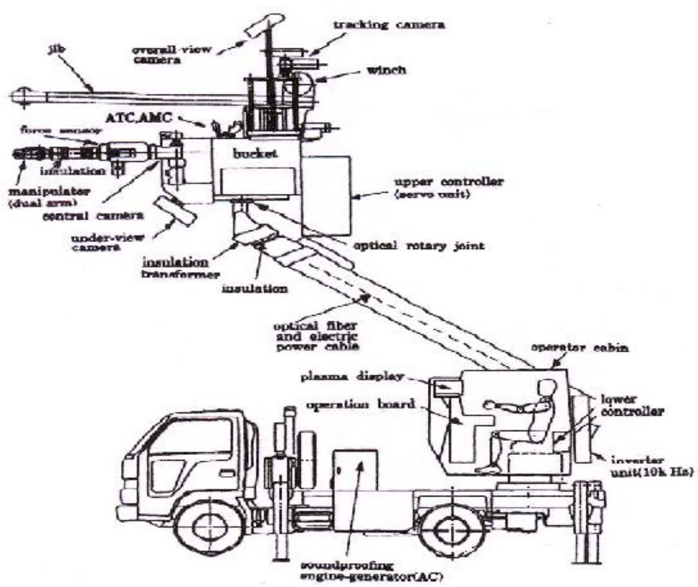


Figure 4.27 Live Line Inspection Robot

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UNIT - V

CONCURRENT ENGINEERING, QUALITY FUNCTION DEPLOYMENT, PRODUCT DEVELOPMENT CYCLE, AUGMENTED REALITY

5.1.1 CONCURRENT ENGINEERING - Definition

Concurrent engineering is the simultaneous execution of various phases in the product development process to shorten the development lead time.

Concurrent Engineering is a systematic technique used for product development, which provides an integrated approach to the design of products and their related processes from concept to disposal.

5.1.2. Sequential Engineering Vs Concurrent Engineering

In sequential engineering, the marketing department of an industry identifies the need of a product, expected performance and the viable cost from the customer. This information transferred to the design department to develop the technical requirement for the design. The design department makes a design, which is usually best from the view of design department. This design is passed to the manufacturing department to develop manufacturing processes necessary to produce the design. If any changes required then the design is passed back to the design department for necessary modifications. When the manufacturing department is satisfied with the design, it passes the design to the next departments for the production. This requires large number of modifications and corrections. It is more expensive and difficult to do. It requires specialized excellence in every phases.

In concurrent engineering, the needs of the customers are identified, a multi functional team is formed that will consider all the aspects of the product life cycle at the time of design itself. There is a close integration between the various departments during the design. This reduces the corrections and modifications. This reduces the expanses and product cycle time. The improved quality product can be brought quickly.

The comparison of traditional product development cycle with the concurrent engineering product development cycle are shown in figure 5.1. This represents, how the production cycle time of the sequential engineering product development cycle (a) with the concurrent engineering product development cycle (b).

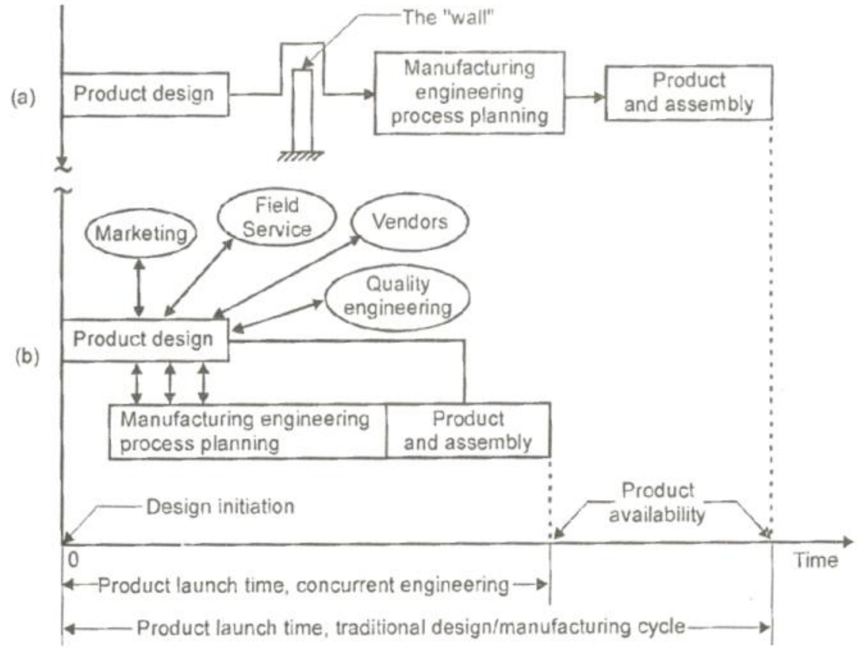

Figure 5.1 a) Sequential Engineering product development cycle and b) CE product development cycle

Table: 1 Differentiate between Sequential and Concurrent Engineering

Sl.No.	Sequential Engineering	Concurrent Engineering
1	Increases development life cycle time.	Reduces development life cycle time.
2	Individual department decision.	Team is empowered to take decision.
3	Wasted resources in making changes	Effective utilization of resources
4	Ineffective communication.	Effective and efficient communication
5	No role for the customer.	Scope for the customer requirement.
6	More corrections and modifications	Reduces corrections and modifications.

5.1.4 Need of Concurrent Engineering

- A company to survive and remain competitive, It has to decrease the product development time maintaining the high quality and low cost.
- New manufacturing processes are being developed continuously.

- Newer methods may bring down the costs, production time and even may improve the quality.
- Companies have to be not only effective but also innovative too to fulfill the demand of customer requirements.
- Companies has to develop and introduce innovative products well ahead of the competitor.
- Delay in the introduction of the product causes loss of profit for the organization.

5.1.5 Benefits of Concurrent Engineering:

- Reduction in time to market.
- Improved product quality.
- Increased customer satisfaction.
- Reduced cost of production.
- Increases the interdepartmental cooperation.
- Increased employee satisfaction.
- Reduction in deployment cycle.
- Increased flexibility to accommodate changes.
- Better use of technical resources.

5.2.1. Quality Function Deployment (QFD):

Definition

QFD is a systematic process to identify and prioritize the customer requirements and to translate these requirements into product and process specifications.

Product development process starts when the marketing department visualize the need of a product in the market. These needs of the customers are put as a goal to achieve. The purpose of QFD was to enable organization to excite the customers with their products. This generate higher sales, develop larger market shares and generate higher profits. The basic goals of QFD are to increase customer satisfaction while reducing the cycle time of product development

5.2.2. House of Quality (HOQ)

House of Quality (HOQ) translates the customer needs into measurable technical attributes. It has two principal parts; horizontal portion and vertical portion. The horizontal portion contains information relative to the customer and vertical portion contains technical information that responds to the customer inputs. These are represented in the figure 5.2.

Customers express their needs and wants from the product . This is called the voice of the customer and this basic input required to begin a QFD process. The customers importance rating and competitive evaluation are examined by QFD team to determine the priority issues for the company.

Once the customer portion of a matrix has been formed, the next step is to find technical requirements to fulfill the customer's needs. The relationship between the customers' voice and technical requirements are recorded in the matrix. Next, the company product performance against the competitor performance are related and evaluated. This will be recorded in the competitive technical assessment portion.

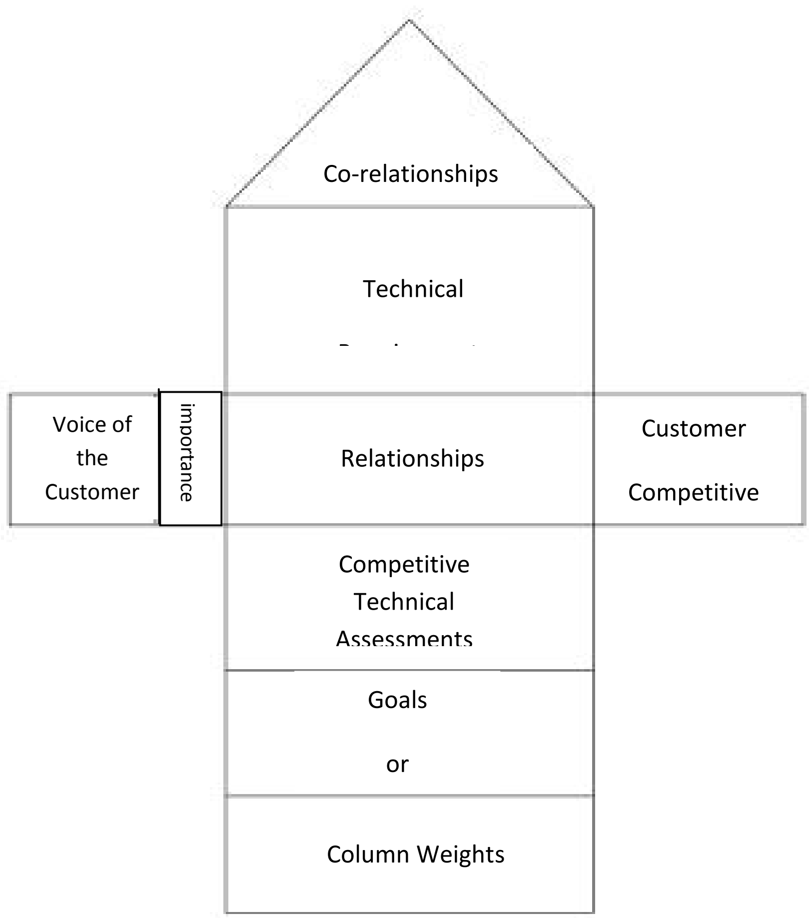

Figure 5.2. House of Quality

Compare the each technical requirements to determine the net result that changing one requirement has on others. These are recorded in the co-relationship matrix. These may be of positive and negative relations. The goals and targets are set by the company to achieve the competitiveness. A measure that can be used to evaluate priorities based on the strength of relationships and importance levels.

5.2.3 Advantages

- Defines the product specification that meet the customer requirement, while paying attention to the competitors.
- Ensure the consistency between the customer requirement and the measurable characteristics of the product.
- Improves the productivity of technical and other staff.
- Brings people together from various disciplines and facilitates the formation of team capable of meeting customer requirement.
- Builds a database for designing, planning continuous improvement activities etc.
- Improves the information databank about the competitor products on a continuous basis.
- Improves quality, company performance, product reliability, marketing opportunities, decision making etc..
- Provides an opportunity for improving the overall profitability of the company.
- Ultimately the bottom line of QFD is higher quality, lower cost, shorter timing and substantial marketing advantage.
- Reduces the number of engineering changes.
- Reduces the product lead time.
- Increases the customer satisfaction.
- Ensures the warranty claims.
- Ensures consistency between the planning and the production process.
- Mistaken interpretation of priorities and objectives are minimized.

5.2.4. Disadvantages

- The quality house has a tendency to grow too big.
- It takes a long time to develop a QFD chart fully.
- It is often difficult to get the right kind of information from customers.
- Many of the answers that customers give are difficult to categorize as demands.
- It can be difficult to determine the connection between customer demands and technical properties.

5.3.1 Steps in Failure Modes and Effects Analysis (FMEA)

A failure modes and effects analysis (FMEA) is a process by which the identification and the evaluation of potential failure modes for a system, product, component or a process is done for classification by the severity and likelihood of the failures.

A successful FMEA activity helps to identify potential failure mode, its causes, identifying the impact of these potential failures and then prioritizing actions to reduce or eliminate these failures out of the system with the minimum of effort and resource expenditure, thereby reducing development time and costs.

Failure modes are faults or defects in a design, component, or system, especially those that affect the intended function of the product and or process, and can be potential or actual. Effects analysis refers to studying the consequences of those failures. The underlying principle of FMEA is to resolve potential problems before they occur, enhancing safety, and increasing customer satisfaction

Review the design

The reviewing of the design is to identify all of the components of the system at given level of the design hierarchy and determine the functions of each of those components. Many components have more than one function.

Brainstorm potential failure modes

Identify failure modes for each component. Typically there will be several ways in which a component can fail. Potential Failure Mode comes from things that have gone wrong in the past, concerns of designers, and brainstorming. A potential failure mode represents any manner in which the component step could fail to perform its intended function. Brainstorm the potential failure modes for each function for each of the components identified.

List potential failure effects

Determine the effects associated with each failure mode on the system. The effect is related directly to the ability of that specific component to perform its intended function. An effect is the impact a failure could make if it occurred.

Assign Severity ratings

Assign a severity ranking to each effect that has been identified. The severity ranking is an estimate of how serious an effect would be occurred. To determine the severity, consider the impact the effect would have on the customer, on downstream operations, or on the employees operating the process. The severity ranking is based on a relative scale ranging from 1 to 10. Table 5.1.1 depicts relative severity and corresponding rankings.

Table 5.1.1 Severity and corresponding ranks of failures

Rank	Effect	Rank	Effect
1	None	6	Severe
2	Very Slight	7	High Severity
3	Slight	8	Very High Severity
4	Minor	9	Extreme Severity
5	Moderate	10	Maximum Severity

Assign Occurrence ratings

Determine the failure's probability of occurrence. Assign an occurrence ranking to each of those causes or failure mechanisms. The occurrence ranking is based on the likelihood or frequency, that the cause will occur. The occurrence ranking scale, like the severity ranking, is on a relative scale from 1 to 10 as shown in Table 5.1.2.

Table 5.1.2 Likely occurrences of failures and corresponding ranking

Rank	Occurrence	Rank	Occurrence
1	Extremely Unlikely	6	Medium Likelihood
2	Remote Likelihood	7	Moderately High Likelihood
3	Very Low Likelihood	8	Very High Likelihood
4	Low Likelihood	9	Extreme Likelihood
5	Moderately Low Likelihood	10	Maximum Likelihood

Assign detection rating

To assign detection rankings, identify the process or products related controls in place for each failure mode and then assign a detection ranking to each control. Detection rankings evaluate the current process controls in place. The Detection ranking scale, like the Severity and Occurrence scales, is on a relative scale from 1 to 10 as shown in Table 5.1.3.

Table 5.1.3 Likely detection of failures and corresponding ranking

Rank	Occurrence	Rank	Occurrence
1	Extremely Likely	6	Moderately Low Likelihood
2	Very High Likelihood	7	Low Likelihood
3	High Likelihood	8	Very Low Likelihood
4	Moderately High Likelihood	9	Remote Likelihood
5	Medium Likelihood	10	Extremely Unlikely

Calculate RPN

The RPN is the Risk Priority Number. The RPN gives us a relative risk ranking. The RPN is calculated by multiplying the three rankings together. Multiply the Severity ranking times the Occurrence ranking times the Detection ranking.

For example,

Risk Priority Number (RPN) = (Severity) X (Occurrence) X (Detection)

Calculate the RPN for each failure mode and the corresponding effect. RPN will always be between 1 and 1000. The higher the RPN, the higher will be the relative risk. The RPN gives us an excellent way to prioritize focused improvement efforts.

Develop an action plan to address high RPN's

Develop an action plan by which reduction in the RPN. The RPN can be reduced by lowering any of the three rankings (severity, occurrence, or detection) individually or in combination with one another.

Take action

The action plan outlines what steps are needed to implement the solution, who will do them, and when they will be completed. Responsibilities and target completion dates for specific actions to be taken are identified. All recommended actions must have a person assigned responsibility for completion of the action. There must be a completion date accompanying each recommended action. Unless the failure mode has been eliminated, severity should not change. Occurrence may or may not be lowered based upon the results of actions. Detection may or may not be lowered based upon the results of actions. If severity, occurrence or detection ratings are not improved, additional recommended actions must to be defined

Reevaluate the RPN after the actions are completed

This step is to confirm the action plan had the desired results by calculating the resulting RPN. To recalculate the RPN, reassess the severity, occurrence, and detection rankings for the failure modes after the action plan has been completed.

Tables 5.1.4 and 5.1.5 respectively show a typical worksheet and an example of failure mode and effect analysis for typical failures of engineering components.

Table 5.1.4 Schematic worksheet for Failure mode and effect analysis (FMEA)

Component	Function	Potential Failure mode	Severity		Occurrence		Detection		RPN	Recommended Action	Responsibility and Target completion date	Action taken	Action Result			
			Potential Effect of failure	Rating	Cause of failure	Rating	Current Control	Rating					Sev	Occ	Det	RPN

Table 5.1.5 An example of Failure mode and effect analysis (FMEA)

Component	Function	Potential Failure mode	Severity		Occurrence		Detection		RPN	Recommended Action	Responsibility and Target completion date	Action taken	Action Result			
			Potential Effect of Failure	Rating	Cause of Failure	Rating	Current Control	Rating					Sev	Occ	Det	RPN
Gas Cooler	Conducts heat to the external environment	Blockage in refrigerant flow	Low cooling capacity, increase in pressure	6	Bends, blockages	2	Deformation guard; design of components	10	120	Parallel procedures, pressure sensor switched in front of the gas cooler, plausibility control via regulation control	Mr. Rahul 17th May 2012	Yes	6	2	6	72

5.3.2 Value Engineering (VE)

Value engineering is an organized effort to attain value in a product by providing the necessary functions at the minimum cost. VE requires all functional requirements to be judged from their worth and cost. VE requires specialized knowledge and skills of different disciplines at the design stage of a product development. The objective of value engineering is to achieve equivalent or better performance at a lower cost while maintaining all functional and quality requirement. It does this largely by identifying and eliminating hidden, invisible and unnecessary costs. VE should not be treated as a mere cost reduction technique. It is more comprehensive and improvement in value is attained without any sacrifice in quality, reliability, maintainability, availability, aesthetics etc.

The value to a product can be added by the following factors.

- Upgrading product performance
- Improving product worth and product esteem
- Improving quality at reduced cost
- Cost avoidance in addition to cost reduction
- Innovation and creativity
- Preventing unnecessary use of resources.

5.3.3. Types of values

Value is increased by decreasing cost or value is increased by increasing quality and performance.

Use value: The properties, features and qualities accomplish the use, the work or the service causing the item to perform or serve an end.

Esteem Value: The properties, features or attractiveness that cause us to own it.

Exchange value: The properties or qualities which enable us to exchange an item for something else we want or it is that part of value of any product which is responsible for and contribute to the transferability, acceptability and exchange of product.

Cost value: The total material, labour and other costs that have to be incurred to produce an item.

Place value: This can be defined as that part of any product which is responsible for and contribute to continuous changes from place to place.

Time value: That part of value that is affected at different times. The time changes the value radically and severally. A product having high value may turn out to be product of least value after specified period of time.

Person value: It is that part of value of any product, which changes from person to person. Person value is dependent upon factors like life, qualification, characteristics and circumstances.

5.3.4. Identification of poor value areas

Value engineering deals with the function of a product or system and procedures. Function mean the purpose or use of a product. Functions can be divided into two categories.

Basic function: The primary purpose of a product.

Secondary function: Other purposes not directly accomplishing the primary purpose but supporting it or resulting from a specific design approach.

Many times poor value results because the function has not been precisely understood and redundant or unnecessary functions have been imposed.

The poor value areas, which are responsible for unnecessary costs could be in the design of the product, procurement, handling and storage of materials, production processes, packaging and distribution of the final product eliminate unnecessary features to improve poor value areas.

If a function is relatively less important but accounts for a larger percentage of products cost then it is a potential area for value improvement.

5.3.5. Techniques

- Job Plan
- Function Analysis System Technique (FAST) Diagrams

Job Plan

It is well recognized approach consisting of seven phases as given below.

- General phase
- Information phase
- Function phase
- Creation phase
- Evaluation phase
- Investigation phase
- Recommendation phase

Each phases is supported by one by one or more techniques. In step by step application of the job plan the project unfolds from information phase right up to recommendation phase.

General phase: It plays vital role throughout and provides a good base. This phase create right environment for VE job plan. During this phase, the stage is set by organising the task force, identifying the decision maker, selecting the area of effort assigning the specific task to each member of the team and inspiring them for coordinated team work.

Information phase: The objective of this phase is to gain an understanding of the project being studied and to obtain all essential facts relating to the project as also to estimate the potential value improvement.

Function phase: The objectives of this phase are to define the functions of the product and to relate these function to the worth and cost of providing them. This phase is the key to the VE job plan.

Creation phase: The objective of this phase is to generate a multitude of ideas to accomplish the defined functions in the preview phase. This phase requires creativity to be the focal point. The first step is to try answering the question "what else will do?" It involves mental processes.

Evaluation phase: In this phase judicial mind is brought into action. The objective of this phase is to find the most promising of the ideas generated in the previous phase and the subject the ideas to a preliminary screening to identify the ideas which satisfy the following criteria.

- Will it work?
- Is it less costly than the present design?
- Is it feasible to implement?

Investigation phase: In this phase the selected ideas are further refined into workable and acceptable solutions providing lower cost methods for performing the desired functions.

Recommendation phase: This is the final phase of the job plan. Here the finally selected value alternative is recommended for acceptance and implementation. It is vital in the sense that the entire project of conducting VE would succeed only if the recommendation is accepted. Many a time the acceptance of the suggested alternative depends upon the way it is presented to the management. One may show the present costs and proposed costs side by side and also the net saving the organization will have by accepting the recommendation.

FAST DIAGRAMS

It visually represents the relationships of functions performed by a product and identifies where the functions have the greatest impact on costs. It is useful in determining the function inter-relationship in analyzing an entire system and gives a better understanding of the interaction of function and cost. FAST is like a network diagram. The steps involved in constructing the FAST diagram are as follows.

Prepare a list of all functions of the product using verb and noun technique of functional analysis.

Write each function on a small card. Select the card pertaining to basic function. Determine the position of the next higher and lower function by answering the following questions.

- How is this accomplished?
- Why is this function performed?
- When is this function perfromed?

The answers to why are placed to the right and answers to the how are placed to the left. When the final network is completed, we can progress across the networks from left to right by asking why and from right to left by asking how. In simple terms this means that the box on right represents the parametric function for systems operation. A critical function path may result from the logic sequence of the basic and secondary functions. it is composed of only those functions that must be performed to accomplish the functions. the FAST diagrams are usually bounded on both ends by the scope lines, which deliberate the limits of responsibility of the study.

Once the FAST diagram has been drawn, each functional element can be considered from the point view of cost. The cost of manufacturing the parts that contribute to the function is estimated and written into the individual boxes that make up the diagram. These costs give the designer a feel in each case as to whether the particular function represented by the box is reasonable figure and whether it gives reasonable value to money.

The box to the far left represents individual parts where the costing occurs and can be modified if felt necessary. Once a group of boxes has been costed separately, the sum of these costs can be entered into the box that is fed by the individual functions or in other words, costs accumulate as one moves right to the diagram.

The box at the far right side of the diagram represents the cost of providing full functional system or the total product. This gives an indication as to whether the arrangement of the functional system has been optimised to a level sufficient to provide a viable product. It identifies the high cost functions where potential for saving exists.

5.3.6 Benefits.

- Enables to pinpoint areas that need attention and improvement.
- Provides a method of generating ideas and alternatives for possible solution to a problem.
- Provides a mean of evaluating alternatives including intangible factors.
- Provides a vehicle for dialogue.
- Documents the rationale behind decisions.
- Materially improves the value of products.

5.3.7 Guide lines of Design for Manufacture and Assembly (DFMA).

- Reduce the number of parts to minimize the opportunity for a defective part or an assembly error, to decrease the total cost of fabricating and assembling the product, and to improve the chance to automate the process.
- Foolproof the assembly design (poka-yoke) so that the assembly process is unambiguous.
- Design verifiability into the product and its components to provide a natural test or inspection of the item.
- Avoid tight tolerances beyond the natural capability of the manufacturing processes and design in the middle of a part's tolerance range
- Design "robustness" into products to compensate for uncertainty in the product's manufacturing, testing and use.
- Design for parts orientation and handling to minimize non-value-added manual effort, to avoid ambiguity in orienting and merging parts, and to facilitate automation.
- Design for ease of assembly by utilizing simple patterns of movement and minimizing fastening steps.
- Utilize common parts and materials to facilitate design activities, to minimize the amount of inventory in the system and to standardize handling and assembly operations.
- Design modular products to facilitate assembly with building block components and subassemblies
- Design for ease of servicing the product.
- Standardize and use common parts and materials.
- Design within process capabilities and avoid unneeded surface finish requirements.
- Minimize flexible parts and interconnections.
- Design for ease of assembly, efficient joining and fastening.
- Design modular products to facilitate assembly with building block components and subassemblies.
- Design for automated production.

Advantages of Design for Manufacture and Assembly.

- Total lead time is reduced.
- Less components in the final product.
- Smoother transition into production.
- DFMA makes the assembly easier.
- It reduces the cost of production.
- It provides higher better product quality.
- Cost of the product is optimum.

5.4.1 Product Development Cycle

Based on the requirement from the customer, the products are developed. The major activities of the product development cycle is shown in the figure 5.3.

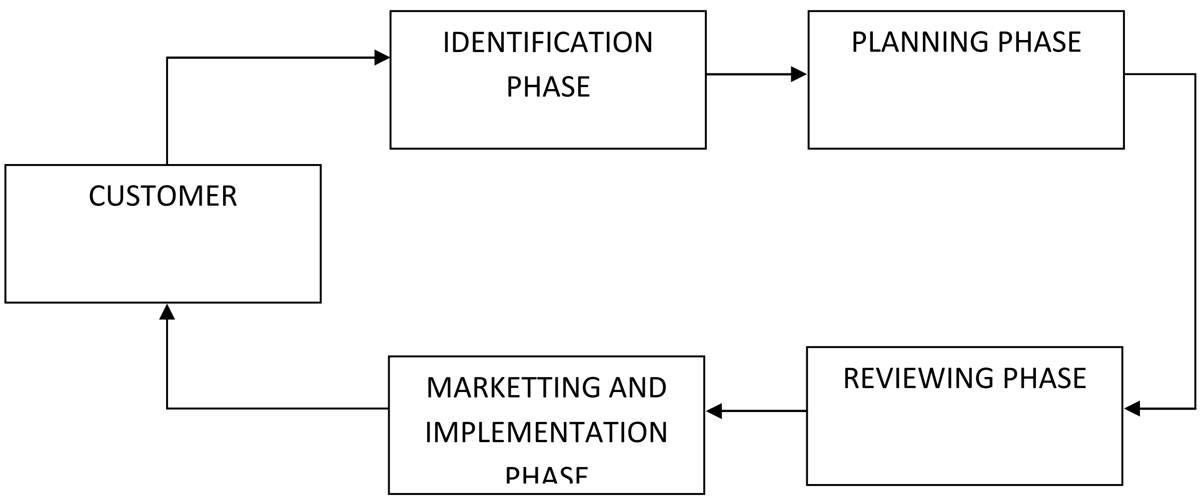

Figure 5.3. Product Development Cycle

Identification phase

The business will be structured around products. Each product will be defined and a plan will exist for each product. Each product will follow a well defined life cycle. It begins when somebody decides a good potential product. This is written up and then discussed at the planning meeting.

Planning phase

If the product might be worth doing, the partners undertake the preparation of a development plan. The development plan spells out the specifications for the final product.

- Lists potential competitive products.
- Why ours would be better for the purchaser?
- Estimate the time and other resources required for development.

Reviewing phase

The product is reviewed based on the following

- Sales
- Cost of support
- User comments
- Dealer comments
- Competitive developments

Marketing and implementation phase

After reviewing this plan, the product still looks good; we found out potential marketing channels and supplement the plan with projections for marketing cost and sales. Once development is authorized, the project goes into the implementation phase.

5.4.2. Product Life cycle

Every product goes through a cycle from birth, followed by an initial growth stage, a relatively stable matured period, and finally into a declining stage that eventually ends in the death of the product as shown schematically in Figure 5.4.

Introduction stage: In this stage the product is new and the customer acceptance is low and hence the sales are low.

Growth stage: Knowledge of the product and its capabilities reaches to a growing number of customers.

Maturity stage: The product is widely acceptable and sales are now stable, and it grows with the same rate as the economy as a whole grows.

Decline stage: At some point of time the product enters the decline stage. Its sales start decreasing because of a new and a better product has entered the market to fulfill the same customer requirements.

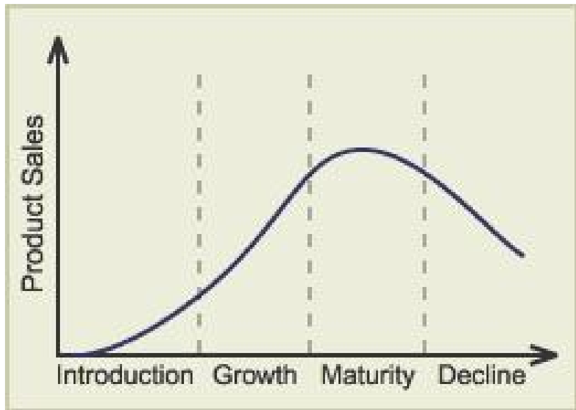

Figure 5.4. Schematic outline of a product life cycle

5.4.3. New product development processes.

The primary purpose of the planning stages is to collect all the necessary information and to decide, for example, whether manufacturing a new product is feasible or what would be the best time to market a new or modified product, or whether a specific company has the adequate resource to manufacture a new product. Usually the initial design projects can be categorized as follows.

Variation of an existing product: This includes minor changes in few parameters of an existing product e.g. change in the power of a motor or change in the design of a typical clamping bracket, and so on.

Improvement in an existing product: This involves major redesign of an existing product primarily to improve performance and quality, update features due to competitions, reduce cost in manufacturing and so on.

Development of a new product for a low-volume production run: This is primarily referred to new parts or products that would possibly be manufactured in smaller number of units. In many cases, a large manufacturing unit may wish to buy standard available components from smaller manufacturing units rather than actually making the same to avoid additional costs.

Development of a new product for mass production: These include products or parts which need to be produced in large volumes e.g. in the category of automobiles, home appliance etc. Such design projects provide the design engineer the flexibility in selecting appropriate material and manufacturing process through careful planning.

5.4.4. Augmented Reality (AR)

Introduction

To augment reality is to alter the view of the physical world through use of computer generated sensory and image processing. It is the combination of reality and virtual reality, and acts as a technological extension to our own vision. Information being overlaid on top of reality in real time could drastically improve the efficiency and effectiveness of almost any everyday activity.

5.4.5. Concept

- The user presents an image to a webcam that is used as a connector to the real world.
- The image is recognized in the real-time video flow captured from the webcam.
- A 3D computer generated object is then superimposed on the image as seen in the captured video.
- The user can then interact with the 3D object, in real-time, by moving the image in the real world.

5.4.6. Applications.

Archaeology: Display ancient ruins as they looked at a particular site the way they existed in history.

Art: Help individuals with disabilities create art by tracking eye movement and turning those movements into drawings on a screen.

Commerce: Show multiple customization options or additional information for a product.

Education: Superimpose text, graphics, video and audio onto a student's real-time environment.

Gaming: Allow users to experience and interact with a game using a real-world environment.

Medical: Show patients' internal organs superimposed over their skin via virtual X-rays.

Military: Use AR goggles in real time to show people and various objects and mark them with special informative indicators and to warn soldiers of potential dangers.

Navigation: Label road and street names along with other pertinent information on a real world map or display on your wind shield showing destination direction, weather, terrain, road conditions and traffic information as well as alerts to potential hazards.

Television: Display weather visualizations and images.