CAD-CAM

IV B. Tech I semester (JNTUH-R15)

Prepared by

Dr. D GOVARDHAN, Professor, AE

Suresh Kumar R, Assistant Professor, AE

CAD-CAM

Presentations
Unit 1 to Unit 5

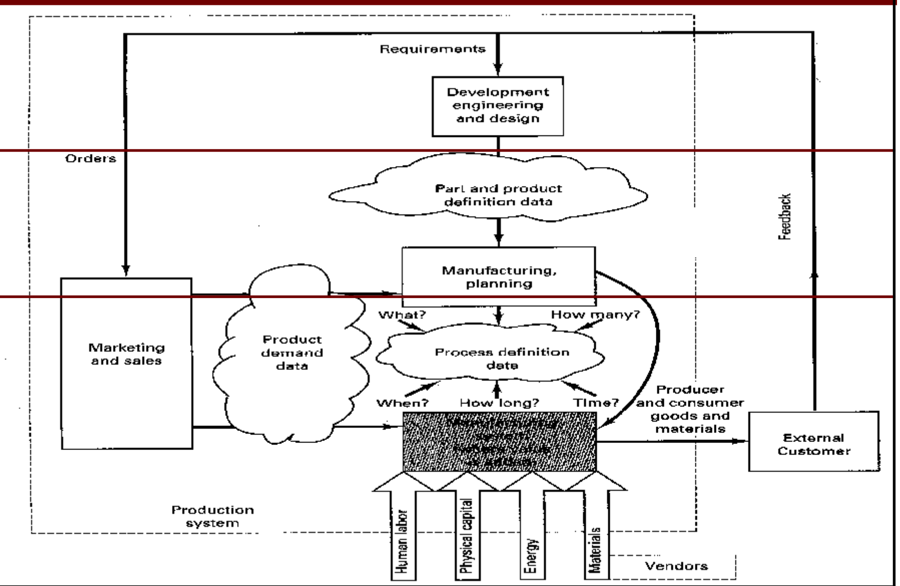
UNIT 1

INTRODUCTION TO CAD CAM

1

Production Systems

Production system is the collection of people, Equipment, and procedures organized to accomplish the manufacturing operations of a company.



Production Systems

Production systems can be divided into two levels:

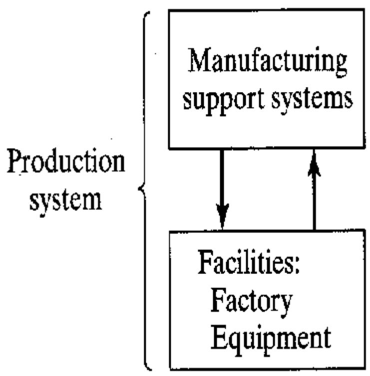
1. **Facilities**

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

2. **Manufacturing support systems**

   Set of procedures used by the company to:
   - **manage production**
   - **solve the technical and logistics problems encountered in**
     - **ordering material**
     - **moving work through the factory**
     - **ensuring that products meet quality standards.**

Production Systems



The production system consists of facilities and manufacturing support systems.

In modern manufacturing operations, portions of the production system are automated and/or computerized.

I. Production System Facilities

Facilities in the production system are:

- **The factory**
- **Production machines and tooling**
- **Material handling equipment**
- **Computer systems that control the manufacturing operations**

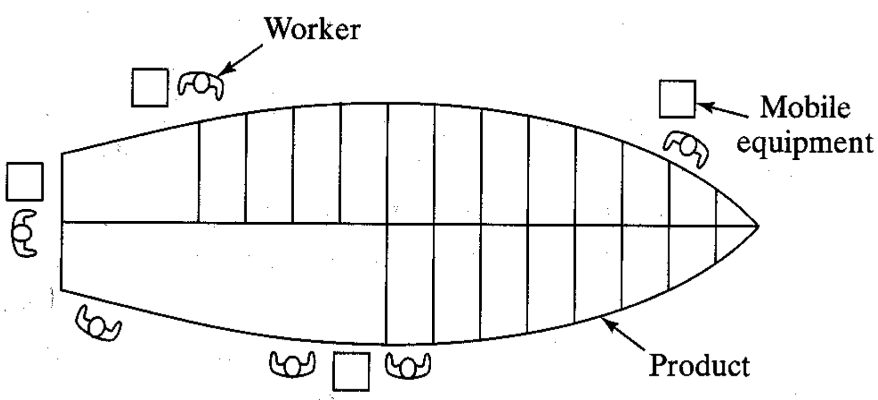
Facilities also include the plant layout, which is the way the equipment is physically arranged in the factory.

The equipment is usually organized into logical groupings, and we refer to these equipment arrangements and the workers who operate them as the manufacturing systems in the factory

Various Types of Plant Layouts

1- Fixed – position layout

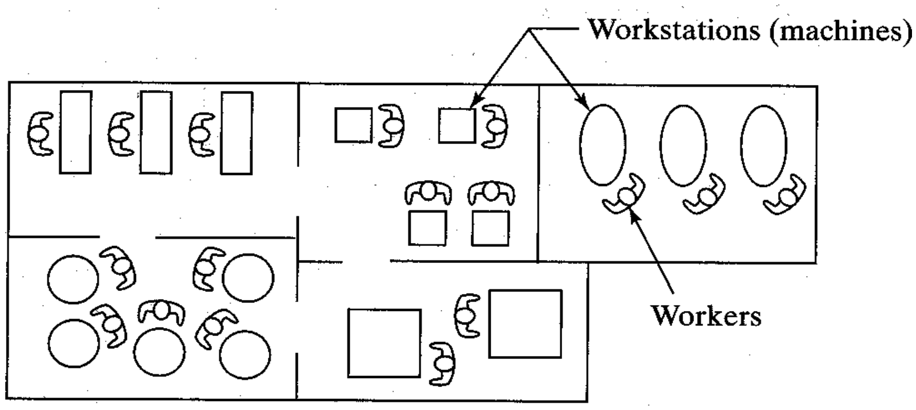
Workers and processing equipment are brought to the product, rather than moving the product to the equipment



Various Types of Plant Layouts

2- Process layout

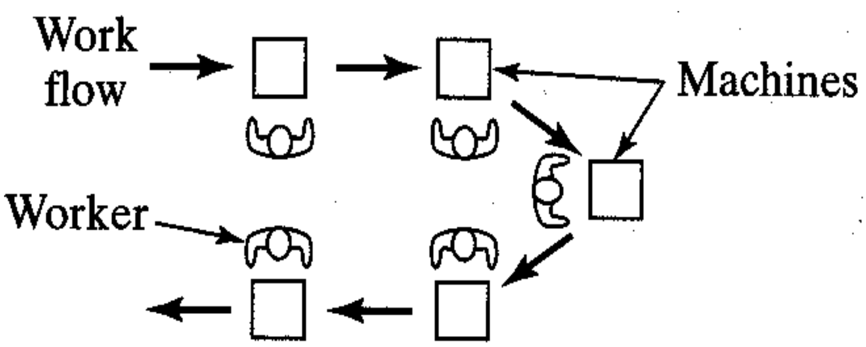
In which the equipment is arranged according to function or type. The lathes are in one department, milling machines are in another department and so on.



Various Types of Plant Layouts

3- Cellular layout

Each cell is designed to produce a limited variety of part configurations; that is the cell specializes in the production of a given set of similar parts or products, according to the principles of Group Technology.

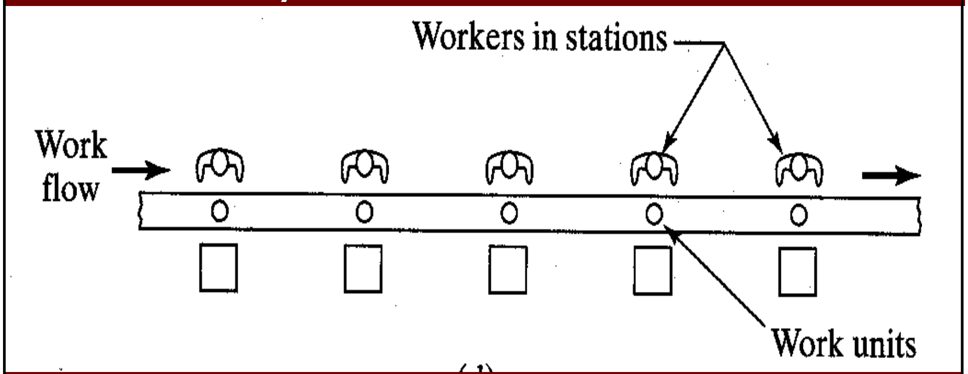


Various Types of Plant Layouts

4- Product layout

Multiple workstations arranged in sequence, and the parts or assemblies are moved through the sequence to complete the product.

The collection of stations is designed specifically for the product to maximize efficiency.



Production quantity and product variety

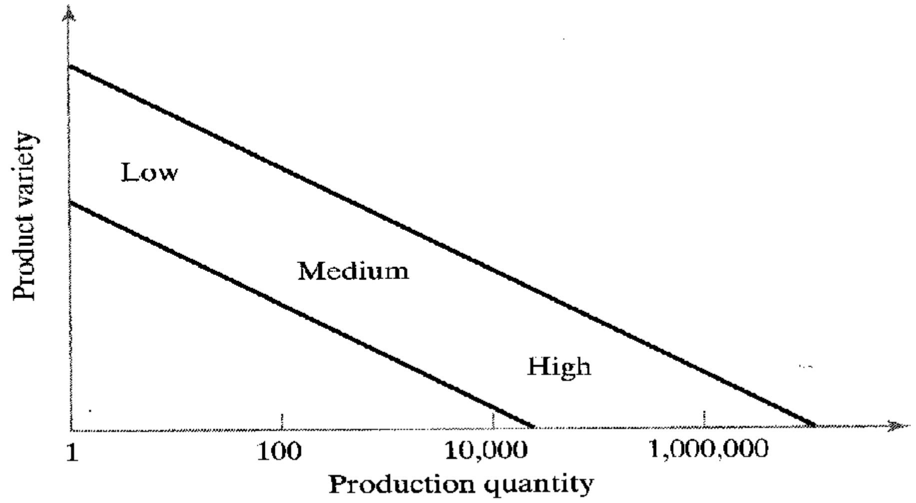
Production quantity: refers to the number of units of a given part or product produced annually by the plant.

Production quantity can be classified into three ranges

1. **Low Production (Job Shop)**
   Quantities in the range of 1 to 100 units per year
2. **Medium Production (Batch Production)**
   Quantities in the range of 100 to 10000 units per year
3. **High Production (Mass Production)**
   Quantities are 10000 to millions of units per year

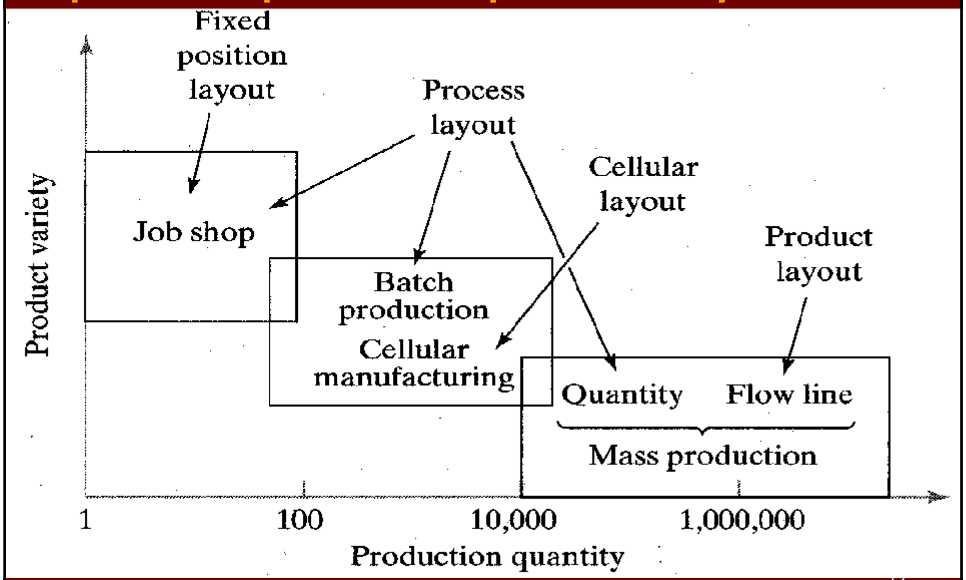
Product Variety: refers to the different product designs or types that are produced in a plant. (Different products have different shapes and sizes and styles)

Relationship between product variety and production quantity in discrete product manufacturing



When product variety is high, production quantity tends to be low; and vice versa.

Types of facilities and layouts used for different levels of production quantities and product variety



II. Manufacturing Support Systems

To operate the production facilities efficiently, a company must organize itself to

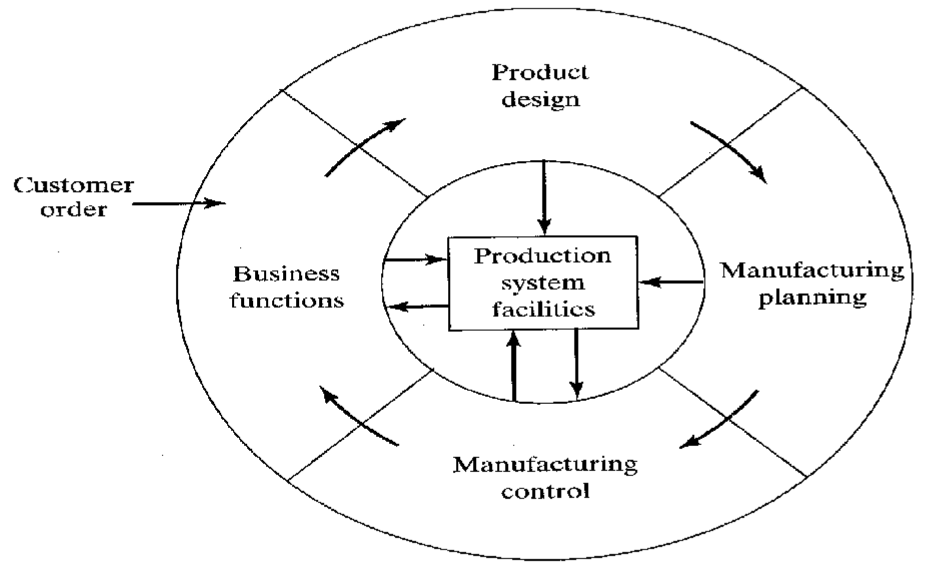
- **Design the processes and equipment**
- **Plan and control the production orders; and**
- **Satisfy product quality requirements**

This accomplished by manufacturing support systems (people and procedures)

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

II- Manufacturing Support Systems

Manufacturing support involves a cycle of information-processing activities



II- Manufacturing Support Systems

1- Business Functions

Included in business functions are

- Sales and marketing
- Sales forecasting
- Order entry
- Cost accounting
- Customer billing

II- Manufacturing Support Systems

2- Product Design

Included are

- Research and development
- Design engineering
- Drafting and modeling

II- Manufacturing Support Systems

3- Manufacturing Planning

The information-processing activities included in manufacturing planning are:

- Process planning
- Scheduling
- Material requirement planning

II- Manufacturing Support Systems

4- Manufacturing Control

Information included in manufacturing control function are

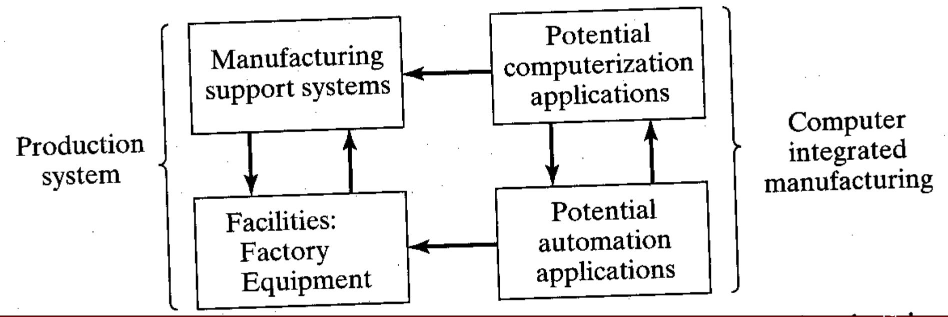
- Shop control
- Inventory control
- Quality control

Automation in Production Systems

Automation can be defined as a technology concerned with the application of AERONAUTICAL, electronic and computer-based systems to operate and control production

The automated elements of the production system can be separated into two categories:

- **Automation of the manufacturing systems in the factory**
- **Computerization of the manufacturing support systems**



Automated Manufacturing Systems

Examples of automated manufacturing system included:

- Automated machine tools that process parts
- Transfer lines that perform a series of machining operations
- Automated assembly systems
- Industrial robots to perform processing or assembly
- Automatic material handling and storage systems
- Automatic inspection systems for quality control

Automated manufacturing systems can be classified into three basic types:

- Fixed automation
- Programmable automation
- Flexible automation

20

Automated Manufacturing Systems

1- Fixed Automation

Fixed automation is a system in which the sequence of processing (or assembly) operations is fixed by the equipment configuration. Each of the operations in the sequence is usually simple.

Examples:

- machining transfer lines
- automated assembly machines

21

Automated Manufacturing Systems

2- Programmable Automation

In programmable automation, the production equipment is designed with the capability to change the sequence of operations to accommodate different product configurations. The operation sequence is controlled by a program

Examples:

- Numerically controlled machines (NC)
- Industrial robots

22

Automated Manufacturing Systems

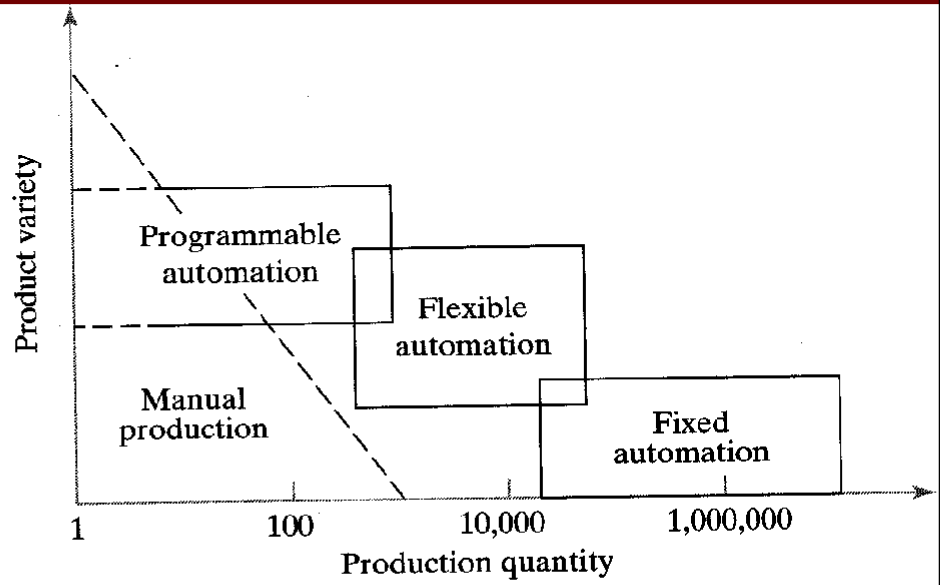
3- Flexible Automation

Flexible automation is an extension of programmable automation. A flexible automated system is capable of producing a variety of parts with virtually no time lost for changeovers from one part style to the next.

Example

- Flexible manufacturing systems

Three types of automation relative to production quantity and product variety



Computerized manufacturing support systems

Automation of the manufacturing support systems is aimed at reducing the amount of manual effort in;

- product design
- manufacturing planning
- manufacturing control; and
- business functions

All modern manufacturing support systems are implemented using computer systems

Computer technology is used to implement automation of the manufacturing systems in the factory as well

25

Computerized manufacturing support systems

Computer Integrated Manufacturing (CIM) is the use of computer systems to design the products, plan the production, control the operations, and perform the various business-related functions needed in a manufacturing firm

True CIM involves integrating all of these functions in one system that operates throughout the enterprise

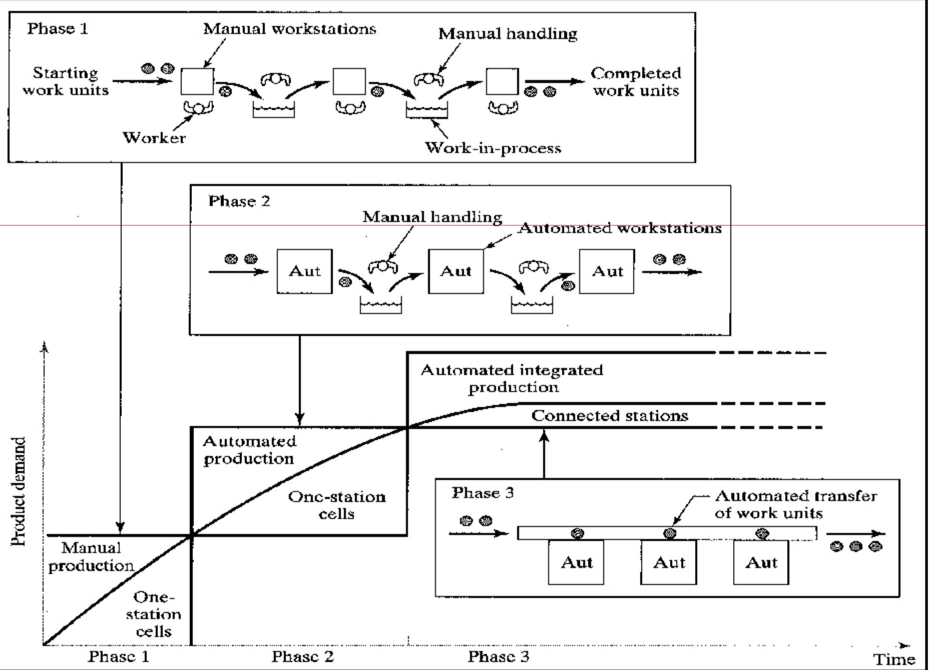
26

Reasons for Automating

- To increase labor productivity
- To reduce labor cost
- To reduce or eliminate routine manual tasks
- To improve worker safety
- To improve product quality
- To reduce manufacturing lead time
- To accomplish processes that can not be done manually
- To avoid the high cost of not automating

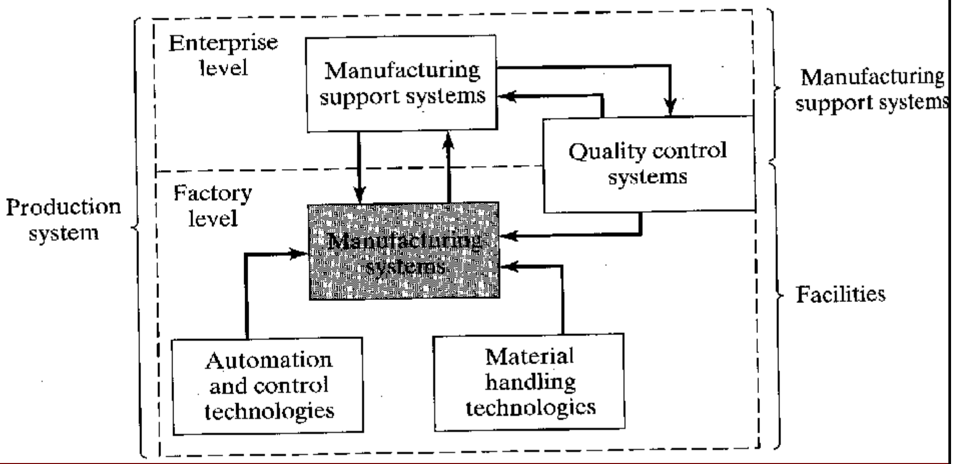
27

Automation Migration Strategy



Manufacturing Systems

A manufacturing system is a collection of integrated equipment and human resources, whose function is to perform one or more processing and/or assembly operations on a starting raw material, part, or set of parts.



The integrated equipment includes production machines and tools, material handling and work positioning devices, and computer systems

29

Components of a Manufacturing System

A manufacturing system consists of several components usually include:

- **Production machines plus tools, fixtures and other related hardware**
- **Material handling system**
- **Computer systems to coordinate and/or control the above components**
- **Human workers**

30

Production Machines

Manually operated machines are directed or supervised by a human worker.

Example : conventional machine tools

Semi-automated machines perform a portion of the work style under some form of program control and a human worker tends to the machine for the remainder of the cycle.

Example: CNC machines

Fully automated machines operate for extended periods of time with ni human attention

Example: Injection molding plants

31

Material Handling System

1- Loading, positioning and unloading

These material handling functions occur at each workstation

Loading involves moving work units into the production machine or processing equipment from a source inside the station

Positioning provides for the part to be in a known location and orientation relative to workhead or tooling that performs the operation

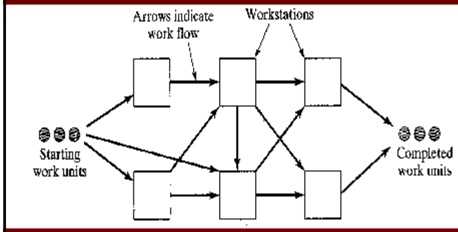
Unloading Removes the work unit from the production machine and either placed in a container at the workstation of prepared for transport to the next workstation in the processing sequence

32

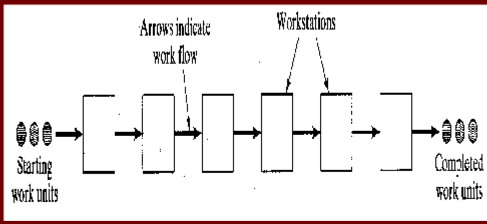
Material Handling System

2- Work Transport between Stations

- Work transport means moving parts between workstations in a multi-station system.
- The transport function can be accomplished manually or by the most appropriate transport equipment



Variable Routing, work units are transported through a variety of different station sequences.



Fixed Routing, the work units always flow through the same sequence of stations

33

Computer Control System

A computer is required to control the automated and semi-automated equipment and to participate in the overall coordination and management of the manufacturing systems

Typical computer system functions include:

- Communicate instructions to workers
- Download part programs to CNC machines
- Control material handling systems
- Schedule production
- Quality control
- Operations management (directly by supervisory computer or indirectly by preparing the necessary reports for management personnel)

34

Human Resources

Direct labor

The directly add to the value of the work unit by performing manual work on it or by controlling the machines that perform the work

Indirect labor

The manage or support the system as computer programmers, computer operators, part programmers for CNC, maintenance and repair personnel

35

Classification of Manufacturing Systems

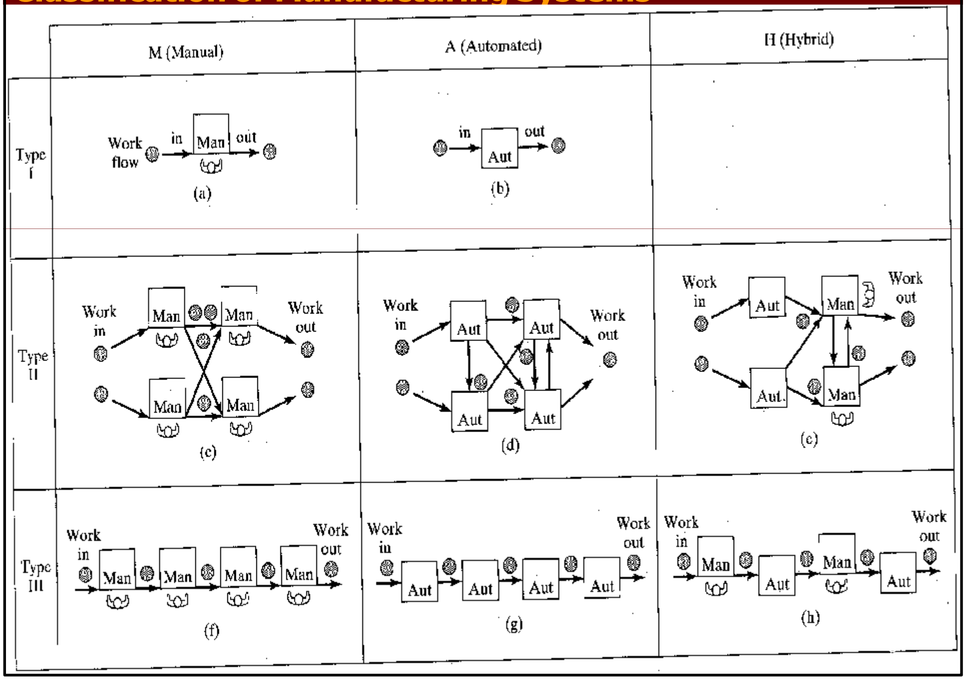
Factors that define and distinguish the different types of manufacturing systems are:

1. Types of operations performed
2. Number of workstations and system layout
3. Level of automation
4. Part or product variety

Factors in Manufacturing Systems Classification Scheme

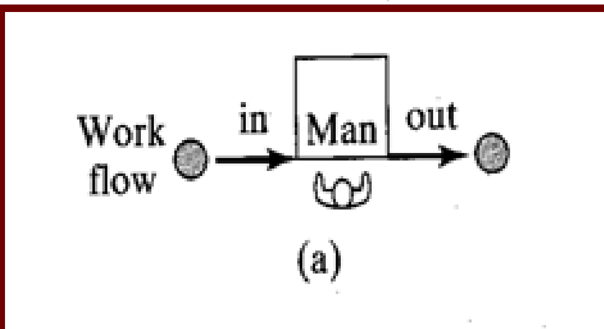
Factor	*Alternatives*
Types of operations performed	Processing operations versus assembly operations Type of processing or assembly operation
Number of workstations and system layout	One station versus more than one station For more than one station, variable routing versus fixed routing
Level of automation	Manual or semi-automated workstations that require full-time operator attention versus fully automated that require only periodic worker attention
Part or product variety	All work units identical versus variations in work units that require differences in processing

Classification of Manufacturing Systems



Classification of Manufacturing Systems

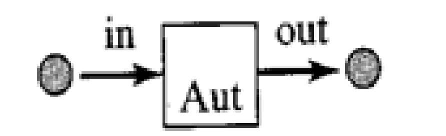
Type I M *Single-station manned cell.* The basic case is one machine and one worker ($n = 1, w = 1$). The machine is manually operated or semi-automated, and the worker must be in continuous attendance at the machine.



38

Classification of Manufacturing Systems

Type I A *Single station automated cell.* This is a fully automated machine capable of unattended operation ($M < 1$) for extended periods of time (longer than one machine cycle). A worker must periodically load and unload the machine or otherwise service it.



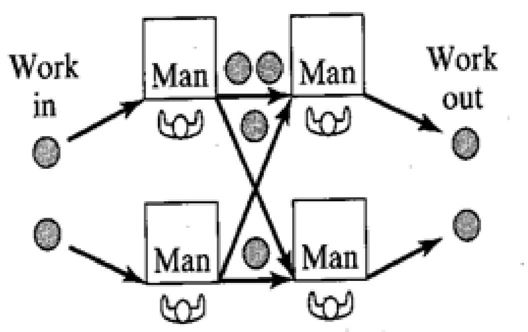
(b)

M=The manning level of a workstation is defined as the portion of time a worker is in attendance at the station

39

Classification of Manufacturing Systems

Type II M *Multi-station manual system with variable routing.* This has multiple stations that are manually operated or semi-automated. The layout and work transport system allow for various routes to be followed by the parts or products made by the system. Work transport between stations is either manual or mechanized.

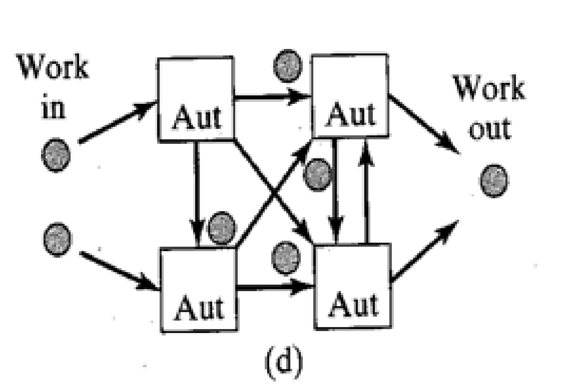


(c)

40

Classification of Manufacturing Systems

Type II A *Multi-station automated system with variable routing.* This is the same as the previous system, except the stations are fully automated $(n > 1, w_i = 0, M < 1)$. Work transport is also fully automated.



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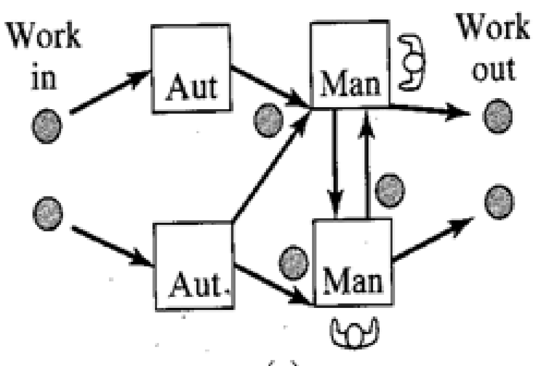
41

Classification of Manufacturing Systems

Type II H *Multi-station hybrid system with variable routing.* This manufacturing system contains both manned and automated stations. Work transport is manual, automated, or a mixture (hybrid).

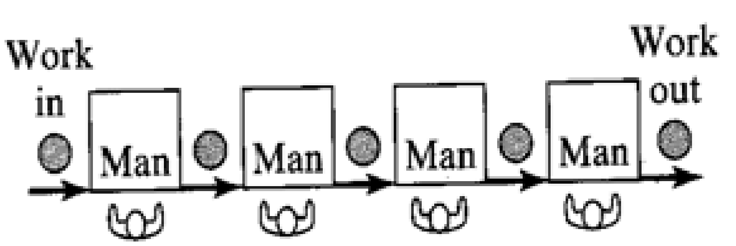


(e)

42

Classification of Manufacturing Systems

Type III M *Multi-station manual system with fixed routing.* This manufacturing system consists of two or more stations $(n > 1)$, with one or more workers at each station $(w_i \geq 1)$. The operations are sequential, thus necessitating a fixed routing, usually laid out as a production line. Work transport between stations is either manual or mechanized.

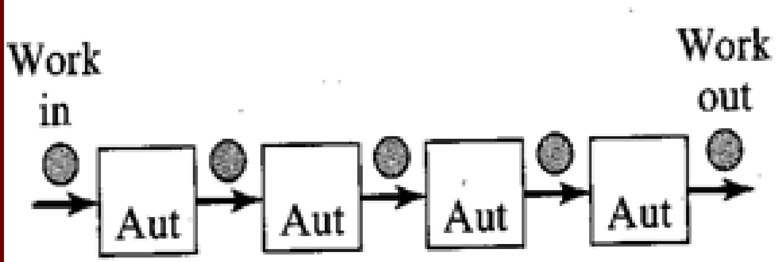


(f)

43

Classification of Manufacturing Systems

Type III A *Multi-station automated system with fixed routing.* This system consists of tw or more automated stations $(n > 1, w_i = 0, M < 1)$ arranged as a produc tion line or similar configuration. Work transport is fully automated.

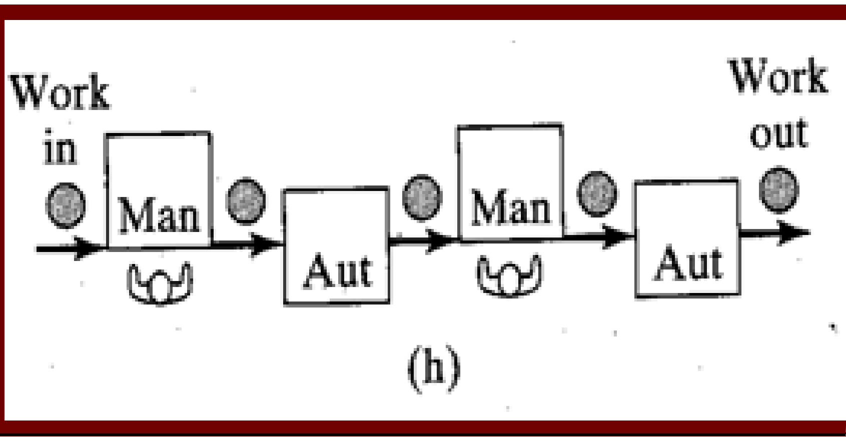


(g)

44

Classification of Manufacturing Systems

Type III H *Multi-station hybrid system with fixed routing.* This system includes both manned and automated stations ($n > 1$, $w_i \geq 1$ for some stations, $w_i = 0$ for other stations, $M > 0$). Work transport is manual, automated, or a mixture (hybrid).



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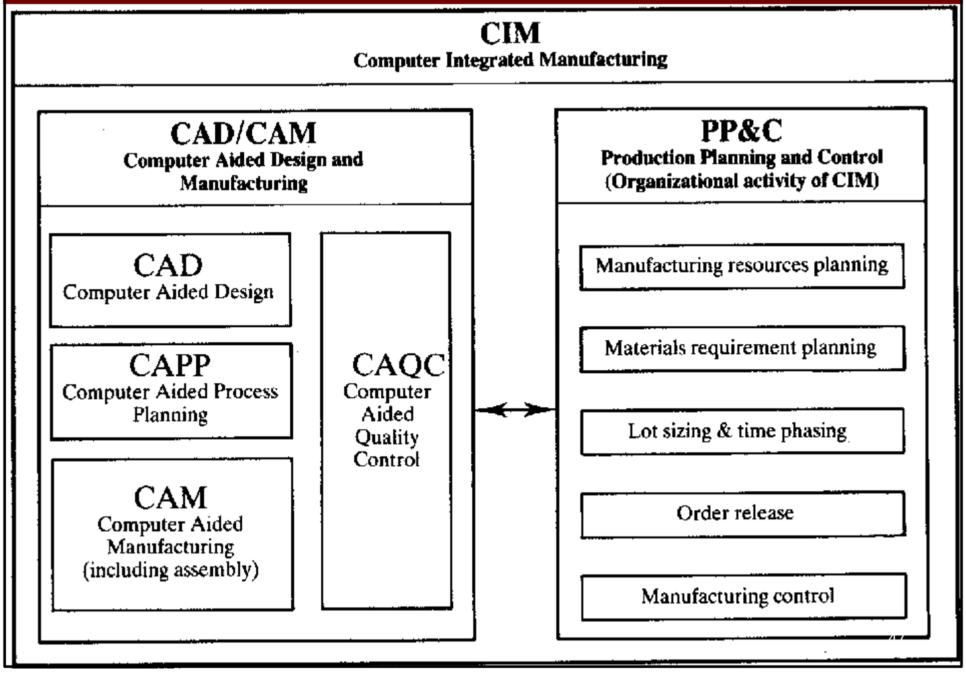
Defining CIM

- Technology, tool or method used to improve entirely the design and manufacturing process and increase productivity
- Using computers to help people and machines to communicate
- Architecture for integration of multiple technologies through computers, linking each individual island of automation to a closed loop business system
- integration of computer aided design, automatic material handling, robotics, process technologies, manufacturing planning & control, computer aided quality control, computer aided manufacturing
- focuses on the computer as the center of control of the entire factory, starting from the computerization of the fabrication and assembly processes to the information flow for production control, quality, maintenance, material handling, and inventory control in a totally integrated system

46

Computer Integrated Manufacturing Activities



Computer Integrated Manufacturing Activities

CAD (Computer Aided Design)

The activity comprises computer support design, drafting, and engineering calculations

CAPP (Computer Aided Process Planning)

This activity is concerned with the computer aided generation of a technological plan to make the product. The process plan describes the manufacturing processes and sequences to make a part.

CAM (Computer Aided Manufacturing)

This activity defines the functions of a computer to control the activities on the manufacturing floor, including direct control of production equipment

CAQC (Computer Aided Quality Control)

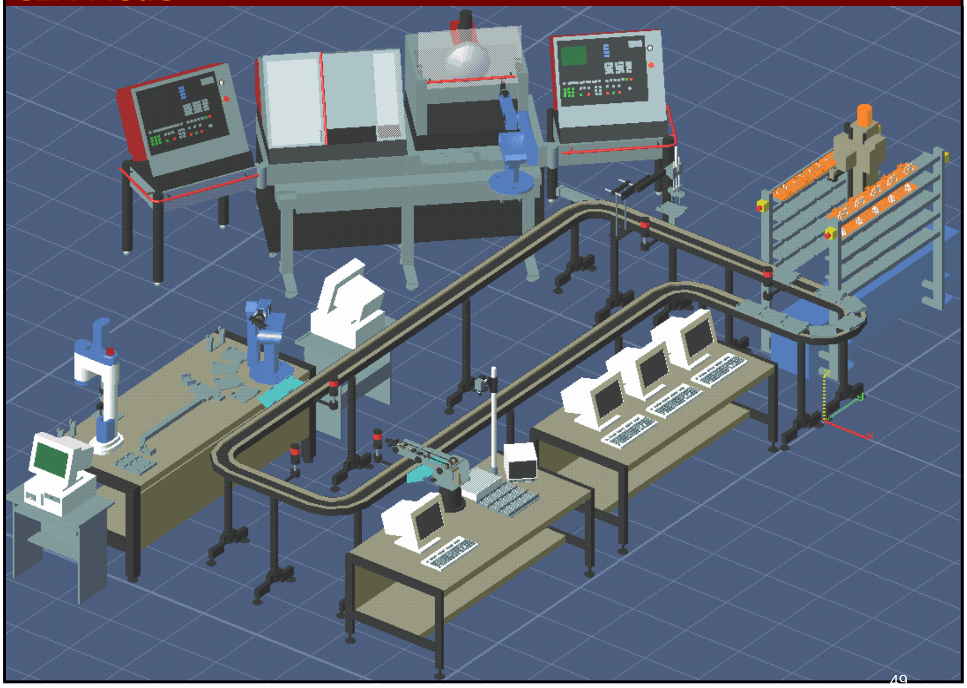
This activity combines all ongoing quality control work of a manufacturing system.

PP&C (Production, Planning and Control)

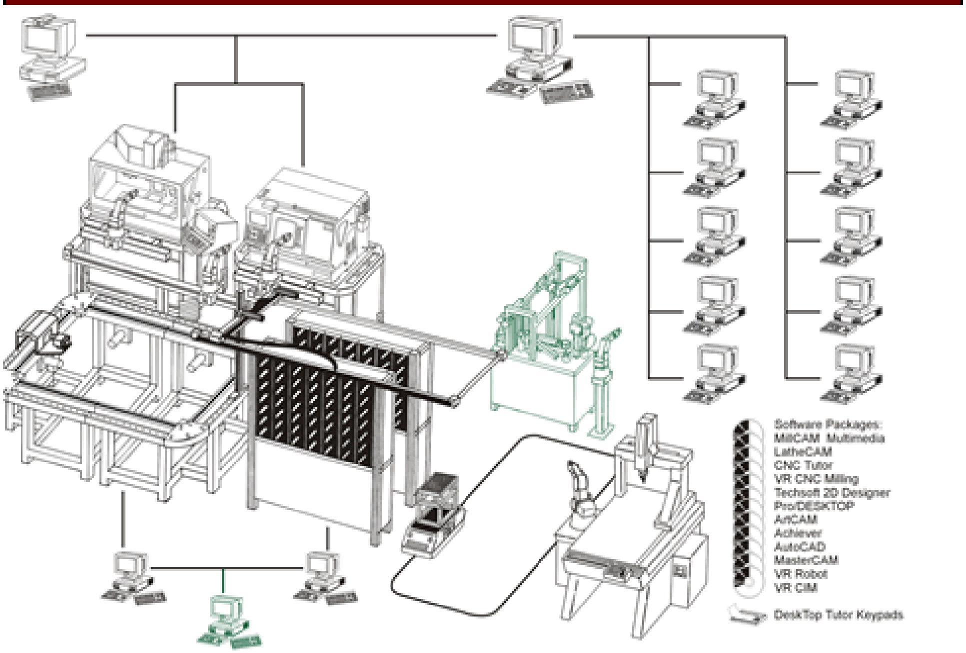
This function is the organizational activity of CIM. It is concerned with manufacturing resources planning, materials requirement planning, and scheduling

48

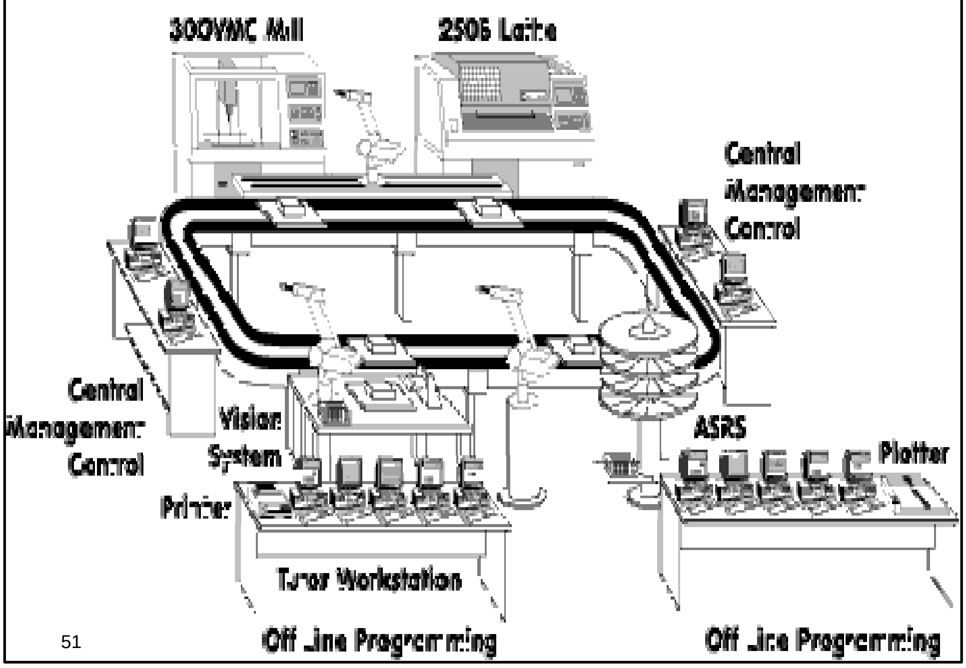
CIM Model



CIM Model



CIM Model



51

UNIT 2

COMPUTER GRAPHICS

52

Computer Graphics

An Introduction

53

What's this course all about?

We will cover…

Graphics programming and algorithms

Graphics data

structures Colour

Applied geometry, modelling and rendering

54

Computer Graphics is about
animation (films)

55

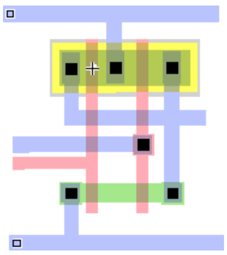
Games are very important in Computer
Graphics

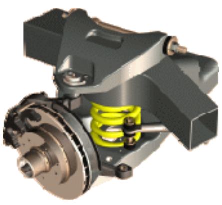
56

Medical Imaging is another driving force

57

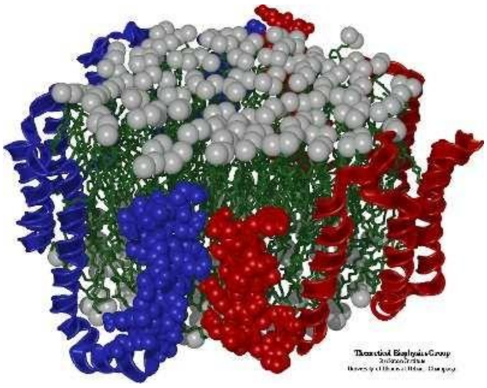
Computer Aided Design too

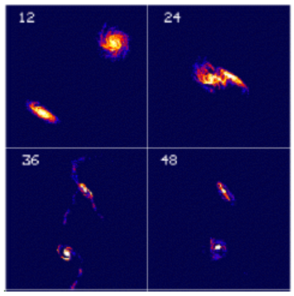




58

Scientific Visualisation





59

First Lecture

The graphics processes

What we will cover on this course

Some definitions

Fundamental units we use in these processes

First Practical

60

Overview of the Course

Graphics Pipeline (Today)
Modelling
Surface / Curve modelling
(Local lighting effects) Illumination, lighting, shading, mirroring, shadowing
Rasterization (creating the image using the 3D scene)
Ray tracing
Global illumination
Curves and Surfaces

61

Graphics/Rendering Pipeline

Graphics processes generally execute sequentially
Pipelining the process means dividing it into stages
Especially when rendering in real-time, different hardware resources are assigned for each stage

62

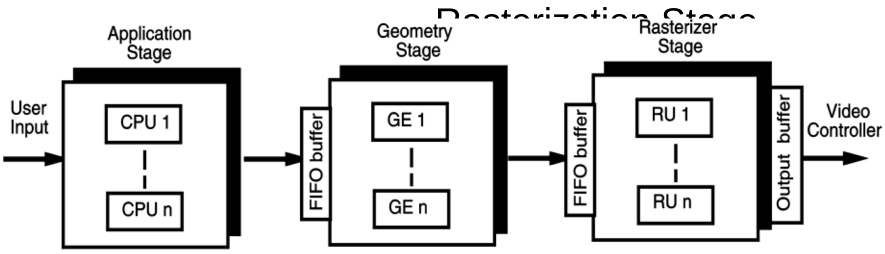
Graphics / Rendering Pipeline

There are three stages

Application Stage

Geometry Stage

Rasterization Stage



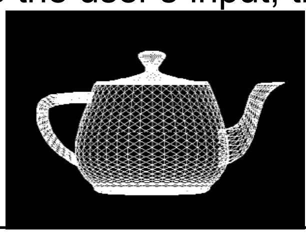
Application stage

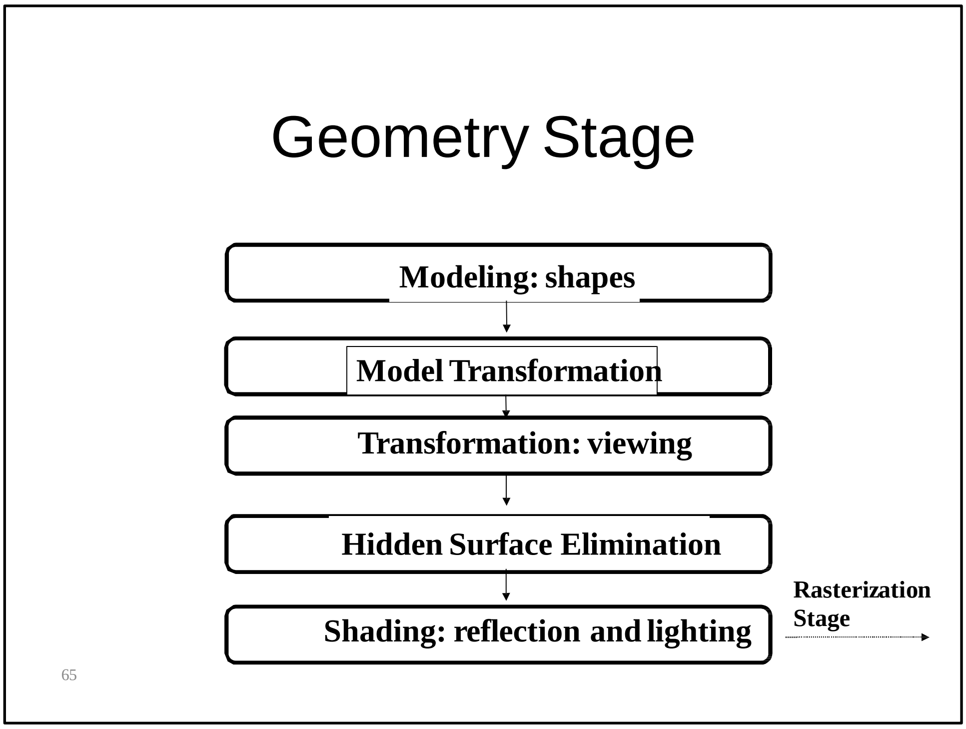
Entirely done in software by the CPU

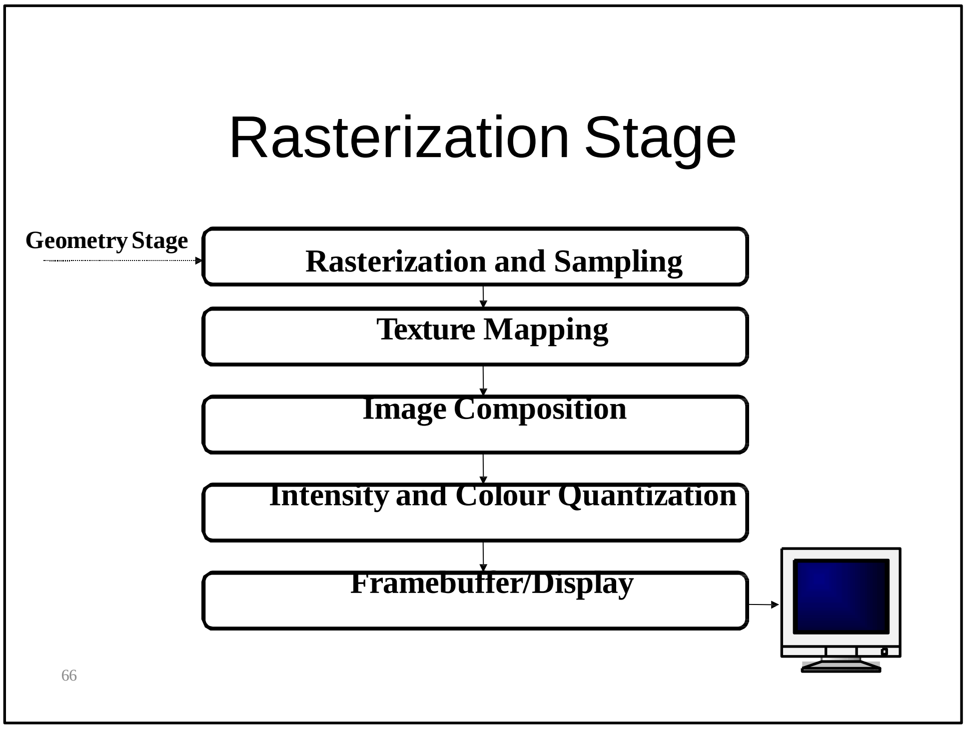
Read Data

the world geometry database, User's input by mice, trackballs, trackers, or sensing gloves

In response to the user's input, the application view




Geometry Stage
Modeling: shapes
Model Transformation
Transformation: viewing
Hidden Surface Elimination
Shading: reflection and lighting
Rasterization Stage
65


Rasterization Stage
Geometry Stage
Rasterization and Sampling
Texture Mapping
Image Composition
Intensity and Colour Quantization
Framebuffer/Display
66

An example thro' the pipeline…

The scene we are trying to represent:

67

Geometry Pipeline

Loaded 3D Models

↓

Model Transformation

↓

Transformation: viewing

↓

Hidden Surface Elimination

↓

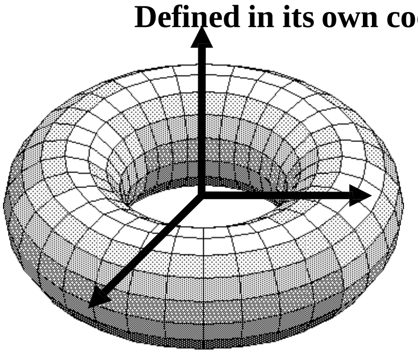
Shading: reflection and lighting → **Imaging**

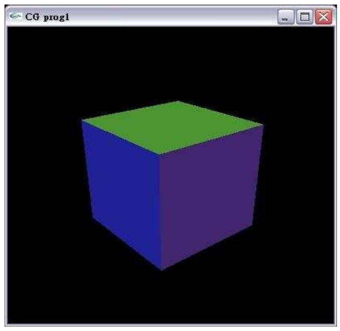
68

Preparing Shape Models

Designed by polygons, parametric curves/surfaces, implicit surfaces and etc.

Defined in its own coordinate system





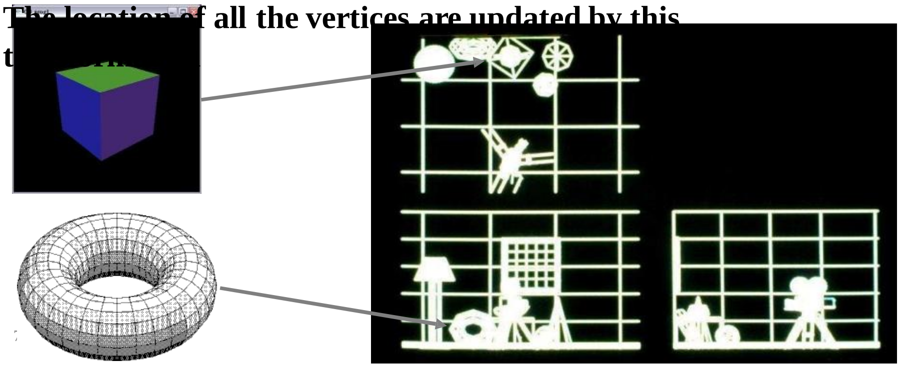
69

Model Transformation

Objects put into the scene by applying translation, scaling and rotation

Linear transformation called homogeneous transformation is used

The location of all the vertices are updated by this t

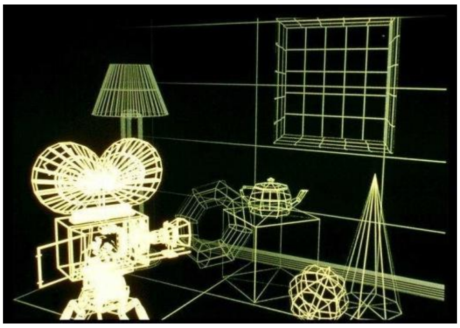


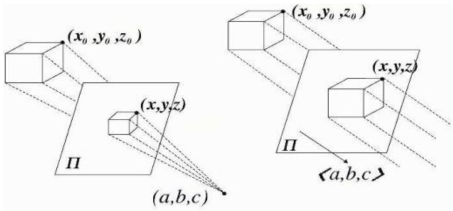
Perspective Projection

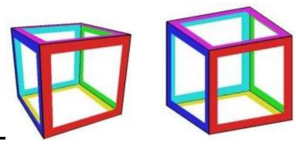
We want to create a picture of the scene viewed from the camera

We apply a perspective transformation to convert the 3D coordinates to 2D coordinates of the screen

Objects far away appear smaller, closer objects appear bigger

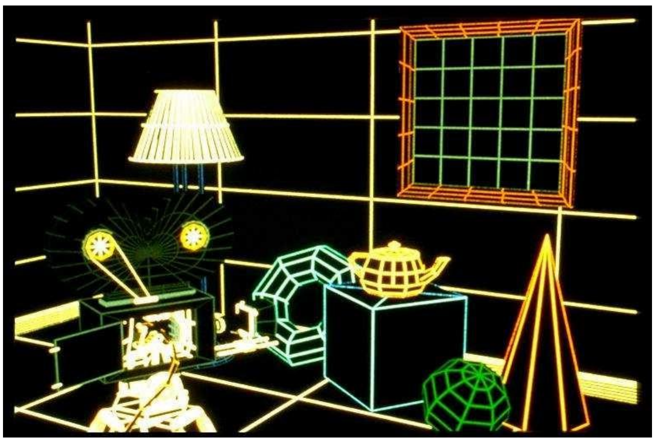






Hidden Surface Removal

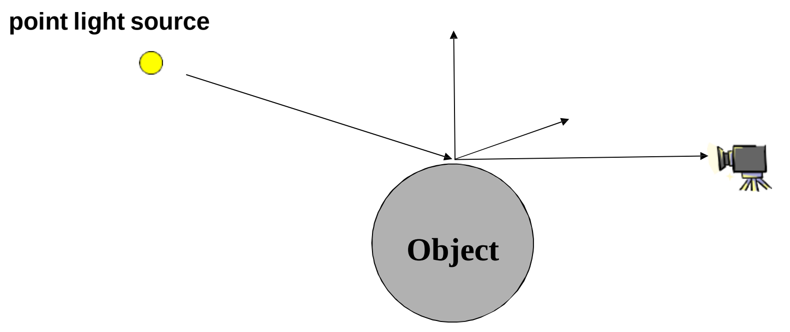
Objects occluded by other objects must not be drawn



72

Shading

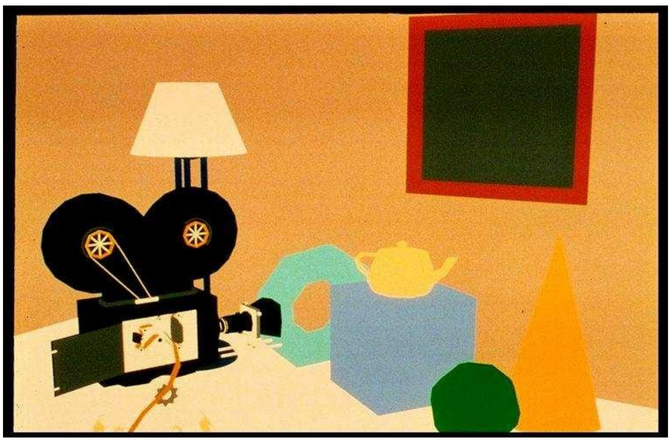
Now we need to decide the colour of each pixels taking into account the object's colour, lighting condition and the camera position



73

Shading : Constant Shading - Ambient

Objects colours by its own colour

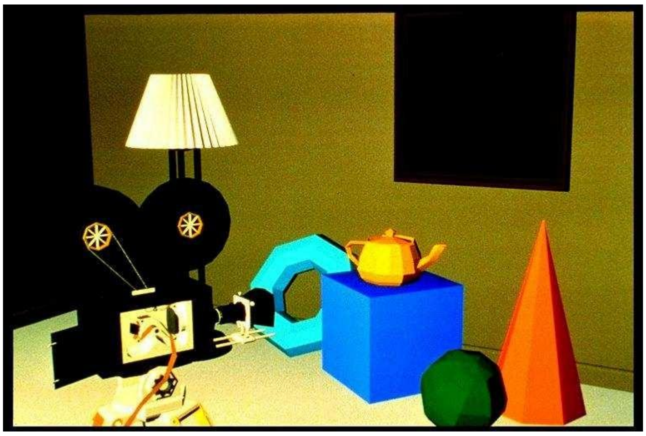


74

Shading – Flat Shading

Objects coloured based on its own colour and the lighting condition

One colour for one face



75

Gouraud shading, no specular highlights

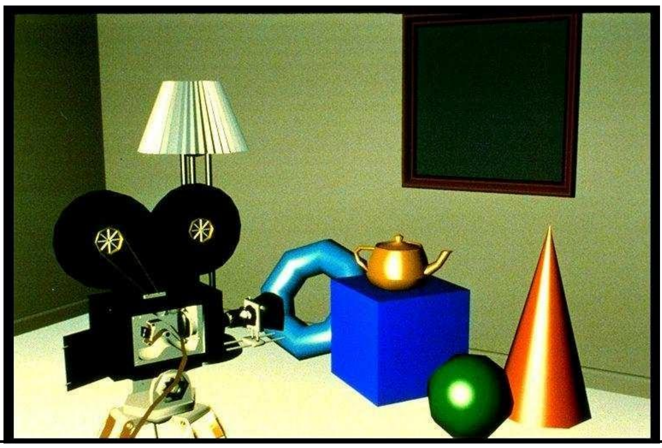
Lighting calculation per vertex

Shapes by Polynomial Surfaces

77

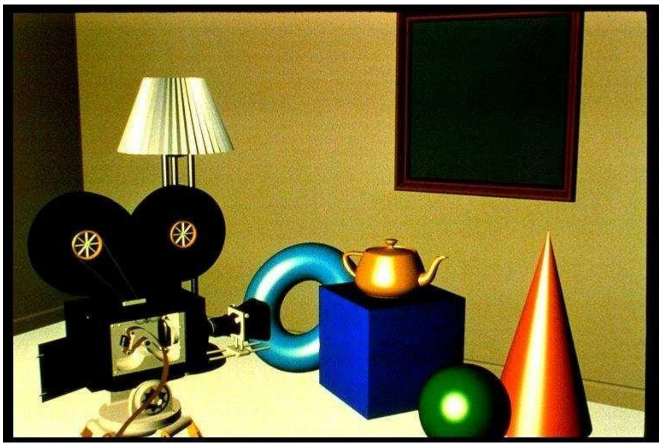
Specular highlights added

Light perfectly reflected in a mirror-like way



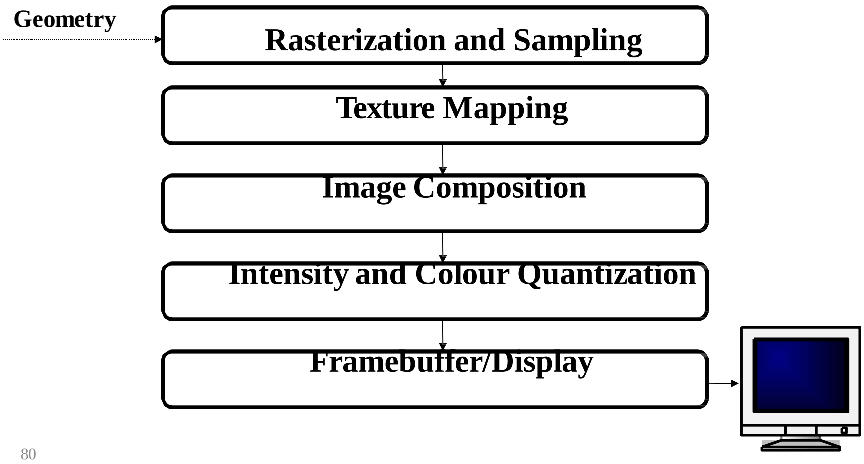
78

Phong shading



79

Next, the Imaging Pipeline



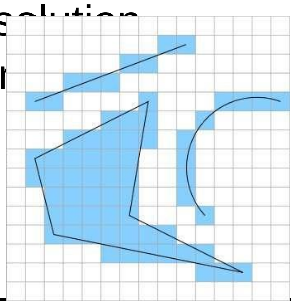
80

Rasterization

Converts the vertex information output by the geometry pipeline into pixel information needed by the video display

Aliasing: distortion artifacts produced when representing a high-resolution signal at a lower res

Anti-aliasing : technique to r



81

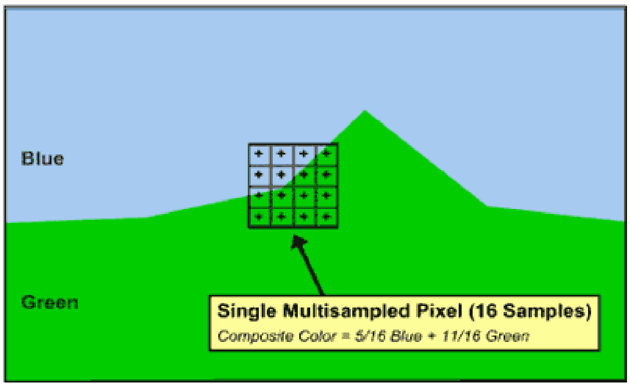
Anti-aliasing

Aliased polygons (jagged edges)

Anti-aliased polygons

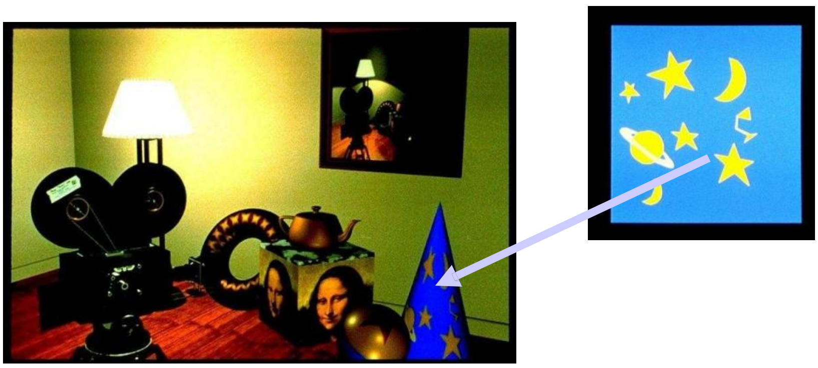
82

How is *anti-aliasing* done? Each pixel is subdivided ✓ (sub-sampled) in n regions, and each sub-pixel has a color; Compute the average color value ✓



83

Texture mapping



84

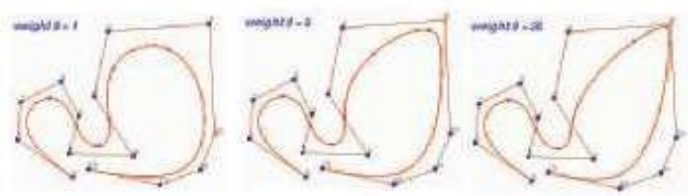
Other covered topics: Reflections, shadows & Bump mapping

85

Other covered topics: Global Illumination

86

Polynomial Curves, Surfaces



87

Graphics Definitions

Point

a location in space, 2D or 3D

sometimes denotes one pixel

Line

straight path connecting two points

infinitesimal width, consistent density

beginning and end on points

88

Graphics Definitions

Vertex

point in 3D

Edge

line in 3D connecting two vertices

Polygon/Face/Facet

arbitrary shape formed by connected vertices

fundamental unit of 3D computer graphics

Mesh

set of connected polygons forming a surface (or object)

:

89

Graphics Definitions

Rendering : process of generating an image from the model

Framebuffer : a video output device that drives a video display from a memory containing the color for every pixel

90

Course support resources

Graphics course website
http://www.inf.ed.ac.uk/teaching/courses/cg

lecture material, lecture log with general summary and recommended reading,

Links to support material for lectures and projects,

Practical description and resources

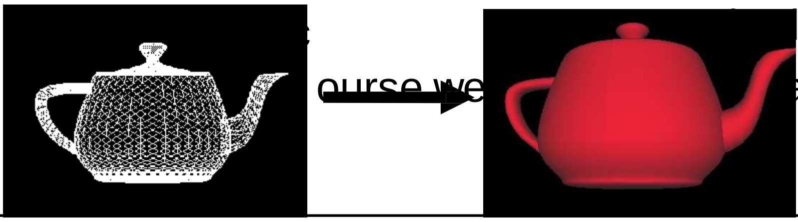
91

First Practical

Write a program that renders an image of a teapot and outputs it into an image file

I prepared a demo program to load a 3D model and draw the edges

You update it so that the surface appears
ed
ourse we ails



92

Some notifications

- 16 lectures in total
- I need to visit Japan in the beginning of October so no lecture on 5th October
- Need to attend conferences on 16th and 26th of November so no lectures there

93

Summary

The course is about algorithms, not applications

Lots of mathematics

Graphics execution is a pipelined approach

Basic definitions presented Some support resources indicated

94

Unit 3

View Port Transformation

- Perspective Depth
- Clipping

95

View Port Transformation

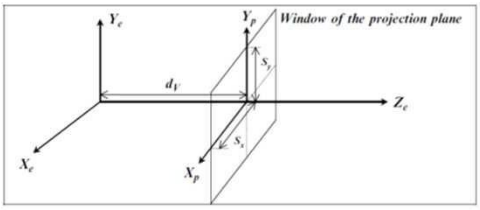


FIGURE 8.25. The projection plane window.

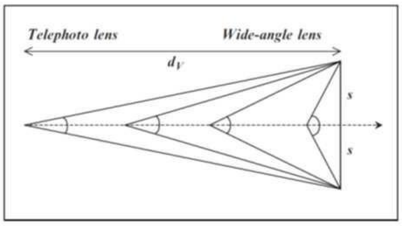
$$x_s = x_p \cdot \left(\frac{v_{sx}/2}{s_x}\right) + v_{cx}$$

$$y_s = y_p \cdot \left(\frac{v_{sy}/2}{s_y}\right) + v_{cy}$$

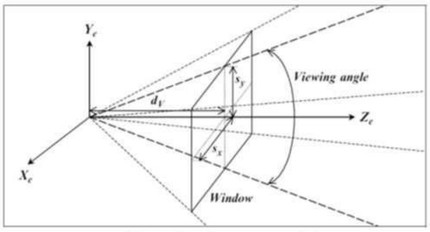
$$x_s = \left(\frac{x_e}{z_e}\right) \cdot \left(\frac{d_V}{s_x}\right) \cdot \left(\frac{v_{sx}}{2}\right) + v_{cx} \quad \text{and} \quad y_s = \left(\frac{y_e}{z_e}\right) \cdot \left(\frac{d_V}{s_y}\right) \cdot \left(\frac{v_{sy}}{2}\right) + v_{cy}$$

96

View Port Transformation



Simulating different types of lenses by varying the viewing distance.



The viewing pyramid.

97

Perspective Depth

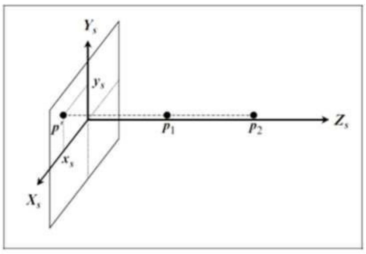


FIGURE 8.31. The screen coordinate system.

$$x_s = \left(\frac{x_c}{z_c}\right) \cdot \left(\frac{v_{sx}}{2}\right) + v_{cx}$$

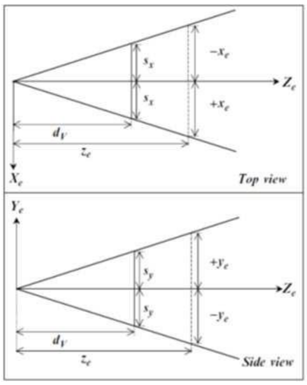
$$y_s = \left(\frac{y_c}{z_c}\right) \cdot \left(\frac{v_{sy}}{2}\right) + v_{cy}$$

$$z_s = -\frac{1}{z_c}$$

$$S = \begin{bmatrix} \left(\frac{v_{sx}}{2}\right) & 0 & 0 & 0 \\ 0 & \left(\frac{v_{sy}}{2}\right) & 0 & 0 \\ v_{cx} & v_{cy} & 0 & 1 \\ 0 & 0 & -1 & 0 \end{bmatrix}$$

98

Clipping (3-D)



IGURE 8.28. Two views of the eye-space viewing pyramid.

$$C = \begin{bmatrix} \left(\frac{d_V}{s_x}\right) & 0 & 0 & 0 \\ 0 & \left(\frac{d_V}{s_y}\right) & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

99

Hidden Surface Removal

100

Visibility

- Assumption: All polygons are **opaque**
- What polygons are visible with respect to your view frustum?
  - Outside: **View Frustum Clipping**
    - Remove polygons outside of the view volume
    - For example, Liang-Barsky 3D Clipping
  - Inside: **Hidden Surface Removal**
    - Backface culling
      - Polygons facing away from the viewer
    - Occlusion
      - Polygons farther away are obscured by closer polygons
      - Full or partially occluded portions
- Why should we remove these polygons?
    - Avoid unnecessary expensive operations on these polygons later

101

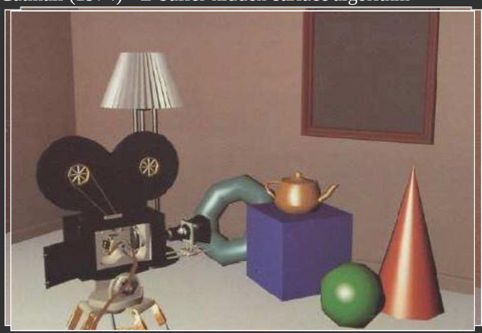
Rendering: 1960s (visibility)

- Roberts (1963), Appel (1967) - hidden-line algorithms
- Warnock (1969), Watkins (1970) - hidden-surface
- Sutherland (1974) - visibility = sorting

Images from FvDFH, Pixar's Shutterbug
Slide ideas for history of Rendering courtesy Marc Levoy

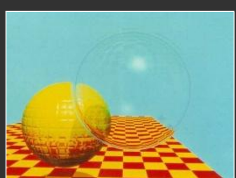
Rendering: 1970s (lighting)

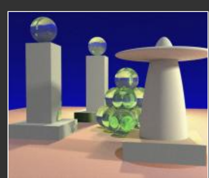
1970s - raster graphics
- Gouraud (1971) - diffuse lighting, Phong (1974) - specular lighting
- Blinn (1974)- curved surfaces, texture
- Catmull (1974) - Z-buffer hidden-surface algorithm



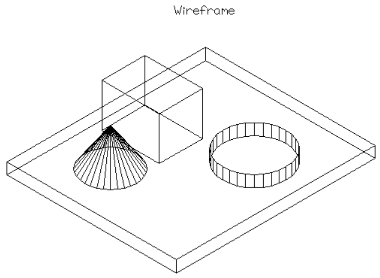
Rendering (1980s, 90s: Global Illumination)

early 1980s - global illumination
- Whitted (1980) - ray tracing
- Goral, Torrance et al. (1984) radiosity
- Kajiya (1986) - the rendering equation



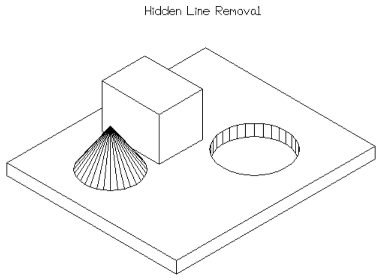


No Lines Removed



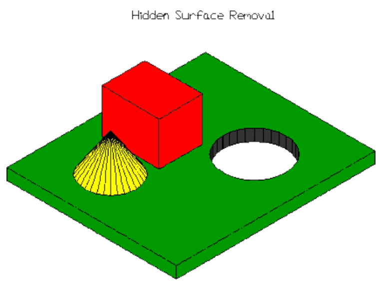
105

Hidden Lines Removed



106

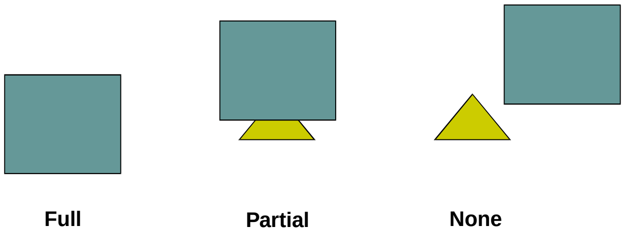
Hidden Surfaces Removed



107

Occlusion at various levels

Occlusion: Full, Partial, None

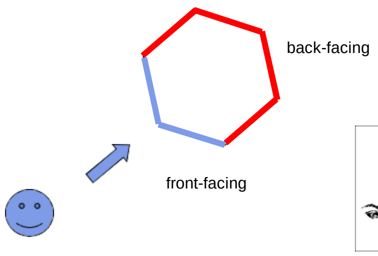


- The rectangle is closer than the triangle
- Should appear in front of the triangle

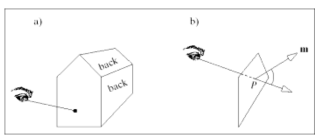
109

Backface Culling

- Avoid drawing polygons facing away from the viewer
  - Front-facing polygons occlude these polygons in a closed polyhedron
- Test if a polygon is front- or back-facing?



Ideas?



110

HIDDEN SURFACE REMOVAL

Goal: Determine which surfaces are visible and which are not.

Other names:

- Visible-surface detection
- Hidden-surface elimination
- Display all visible surfaces, do not display any occluded surfaces.

We can categorize into

- – Object-space methods
- – Image-space methods

111

Visible surface algorithms.

Definitions:

•Object space techniques: applied before vertices are mapped to pixels
  •Back face culling, Painter's algorithm, BSP trees

•Image space techniques: applied while the vertices are rasterized
  •Z-buffering

Z-Buffer Algorithm

- Test visibility of surfaces one point at a time
- The surface with the z-coordinate closest to VRP is visible (largest z in RH coordinate sytem; smallest z in LH coordinate system)

Two storage areas required:

- depth buffer - z value for each pixel at (x,y)
- display buffer – pixel value (colour) for each pixel at (x,y)

113

Z-Buffer Algorithm

The z-Buffer algorithm is one of the most commonly used routines. It is simple, easy to implement, and is often found in hardware. The idea behind it is uncomplicated: Assign a z-value to each polygon and then display the one (pixel by pixel) that has the smallest value.

Advantages

- **Easy to implement**
- **Fits well with the rendering pipeline**
- **Can be implemented in hardware**
- **Always correct results**
- **Simple to use**
- **Can be executed quickly, even with many polygons**

Disadvantages:

- **Takes up a lot of memory**
- **Can't do transparent surfaces without additional code Some inefficiency as pixels in polygons nearer the**
- **viewer will be drawn over polygons at greater depth**

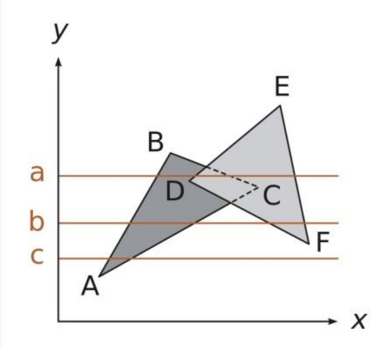
It is a standard in many graphics packages (e.g.Open GL)

```
Given
List of polygons {P1, P2, ..., Pn }
An array z-buffer[x,y] initialized to −∞
An array Intensity[x,y]
begin
for each polygon P in the polygon list do
 {
for each pixel (x,y) that intersects P do
 {
calculate z-depth of P at (x,y)
if z-depth < z-buffer[x,y] then
 {
Intensity[x,y] = intensity of P at (x,y)
z-buffer[x,y] = z-depth
}
}
}
Display Intensity array
end
```

114

SCANLINE ALGORITHM

- Scanline rendering is an algorithm for visible surface determination, in 3D computer graphics, that works on a row-by-row basis rather than a polygon-by-polygon or pixel-by-pixel basis.
- All of the polygons to be rendered are first sorted by the top y coordinate at which they first appear, then each row or scanline of the image is computed using the intersection of a scanline with the polygons on the front of the sorted list, while the sorted list is updated to discard no-longer-visible polygons as the active scan line is advanced down the picture.



115

Scan Line Algorithm

- Advantages:
  - Simple
  - Potentially fewer quantization errors (more bits available for depth)
  - Don’t over-render (each pixel only drawn once)
  - Filter anti-aliasing can be made to work (have information about all polygons at each pixel)
- Disadvantages:
  - Invisible polygons clog AEL, ET
  - Non-intersection criteria may be hard to meet

116

SCANLINE ALGORITHM

Advantages

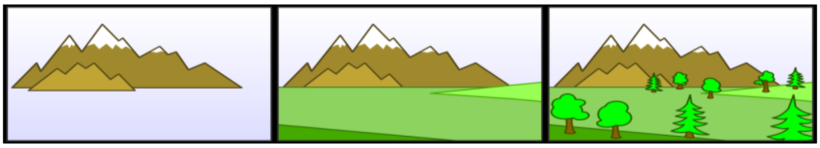
- The main advantage of this method is that sorting vertices along the normal of the scanning plane reduces the number of comparisons between edges.
- Another advantage is that it is not necessary to translate the coordinates of all vertices from the main memory into the working memory—only vertices defining edges that intersect the current scan line need to be in active memory, and each vertex is read in only once.
- The main memory is often very slow compared to the link between the central processing unit and cache memory, and thus avoiding re-accessing vertices in main memory can provide a substantial speedup.

Comparison with Z-bufferalgorithm

- The main advantage of scanline rendering over Z-buffering is that the number of times visible pixels are processed is kept to the absolute minimum which is always one time if no transparency effects are used—a benefit for the case of high resolution or expensive shading computations.
- In modern Z-buffer systems, similar benefits can be gained through rough front-to-back sorting (approaching the 'reverse painters algorithm'), early Z-reject (in conjunction with hierarchical Z), and less common deferred rendering techniques possible on programmable GPUs.
- Scanline techniques working on the raster have the drawback that overload is not handled gracefully.
- The technique is not considered to scale well as the number of primitives increases. This is because of the size of the intermediate datastructures required during rendering—which can exceed the size of a Z-buffer for a complexscene.
- Consequently, in contemporary interactive graphics applications, the Z-buffer has become ubiquitous. The Z-buffer allows larger volumes of primitives to be traversed linearly, in parallel, in a manner friendly to modern hardware. Transformed coordinates, attribute gradients, etc., need never leave the graphics chip; only the visible pixels and depth values are stored.

117

PAINTER'S ALGORITHM



The painter's algorithm, also known as a priority fill, is one of the simplest solutions to the visibility problem in 3D computer graphics. When projecting a 3D scene onto a 2D plane, it is necessary at some point to decide which polygons are visible, and which are hidden.

Advantages:

- Very good if a valid order is easy to establish; not so good
- for more complex surface topolgies (e.g. presence ofholes)
- For simple cases very easy to implement
- Fits well with the rendering pipeline

Disadvantages:

- Not very efficient – all polygons are rendered, even whenthey become invisible
- Complex processing (sorting + tests) for complex objects
- There could be no solution for sorting order
- Possibility of an infinite loop as surface order is swapped

118

Warnock's Area Subdivision
(Image Precision)

- Locate view areas (normally squares or rectangles) which represent a part of a single surface
- This is done by successively dividing the total view area into smaller rectangles
- Stop dividing a given rectangle when it contains a single surface or visibility precedence can be easily determined

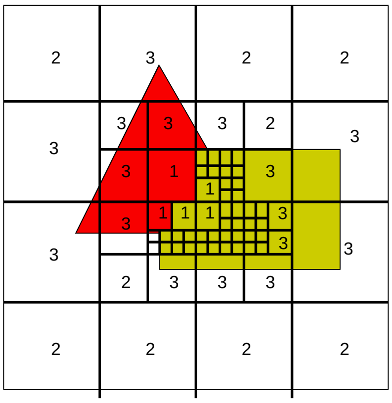
119

Warnock's Area Subdivision
(Image Precision)

- Start with whole image
- If one of the easy cases is satisfied (previous slide), draw what's in front
- Otherwise, subdivide the region and recurse
- If region is single pixel, choose surface with smallest depth
- Advantages:
  - No over-rendering
  - Anti-aliases well - just recurse deeper to get sub-pixel information
- Disadvantage:
  - Tests are quite complex and slow

120

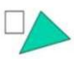
Warnock's Algorithm



- Regions labeled with case used to classify them:
  1) One polygon in front
  2) Empty
  3) One polygon inside, surrounding or intersecting
- Small regions not labeled

121

Warnock's Algorithm

- An area-subdivision technique
- Idea:
  - Divide an area into four equal sub-areas
  - At each stage, the projection of each polygon will do one of four things:
    1. Completely surround a particular area 
    2. Intersect the area 
    3. Be completely contained in the area 
    4. Be disjoint to the area 

- Disjoint polygons do not influence an area.
- Parts of an intersecting polygon that lie outside the area do not influence that area
- At each step, we determine the areas we can color and color them, then subdivide the areas that are ambiguous.

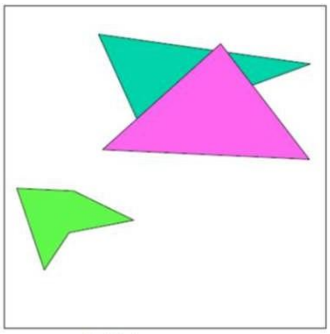
122

Warnock's Algorithm

Warnock's Algorithm

At each stage of the algorithm, examine the areas:

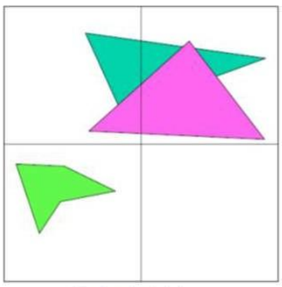
1. If no polygons lie within an area, the area is filled with the background color
2. If only one polygon is in part of the area, the area is first filled with the background color and then the polygon is scan converted within the area.
3. If one polygon surrounds the area and it is in front of any other polygons, the entire area is filled with the color of the surrounding polygon.
4. Otherwise, subdivide the area and repeat the above 4 tests.



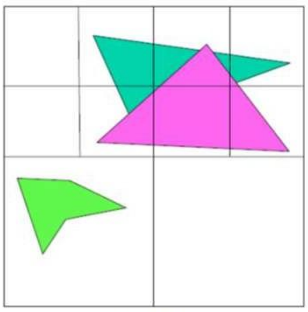
Initial scene

123

Warnock's Algorithm



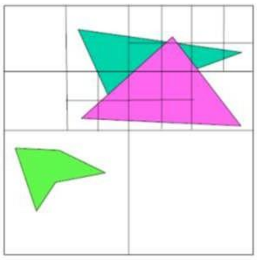
First subdivision



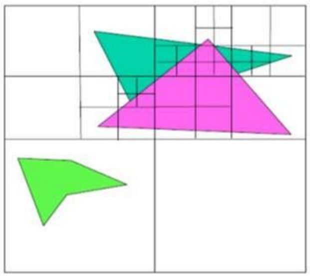
Second subdivision

124

Warnock's Algorithm



Third subdivision



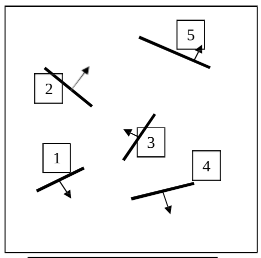
Fourth subdivision

- Subdivision continues until:
  - All areas meet one of the four criteria
  - An area is pixel size
    - in this case, the polygon with the closest point at that pixel determines the pixel color

125

BSP (Binary Space Partitioning) Tree.

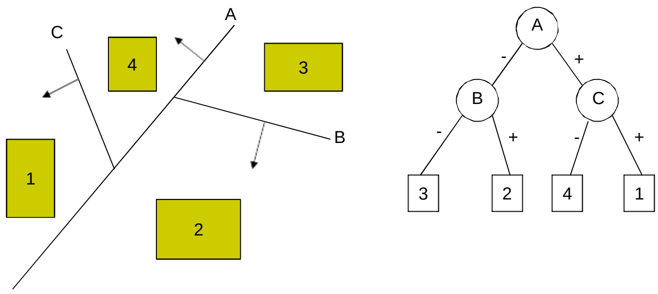
- One of class of "list-priority" algorithms – returns ordered list of polygon fragments for specified view point (static pre-processing stage).
- Choose polygon arbitrarily
- Divide scene into front (relative to normal) and back half-spaces.
- Split any polygon lying on both sides.
- Choose a polygon from each side – split scene again.
- Recursively divide each side until each node contains only 1 polygon.



View of scene from above

126

BSP-Tree Example

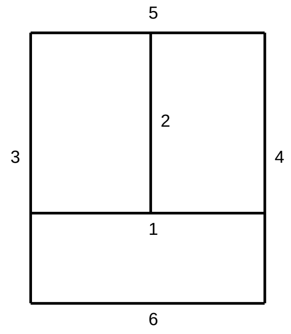


Building BSP-Trees

- Choose polygon (arbitrary)
- Split its cell using plane on which polygon lies
  - May have to chop polygons in two (Clipping!)
- Continue until each cell contains only one polygon fragment
- Splitting planes could be chosen in other ways, but there is no efficient optimal algorithm for building BSP trees
  - Optimal means minimum number of polygon fragments in a balanced tree

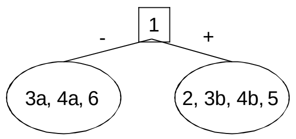
Building Example

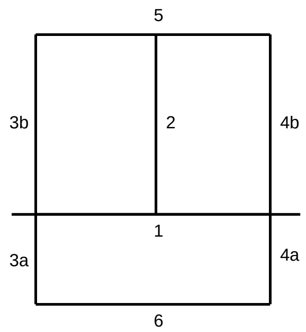
- We will build a BSP tree, in 2D, for a 3 room building
  - Ignoring doors
- Splitting edge order is shown
  - "Back" side of edge is side with the number



129

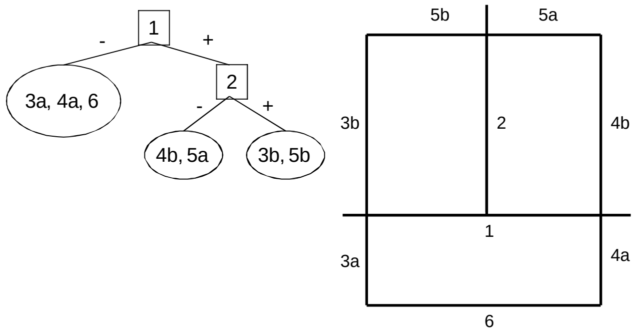
Building Example (1)





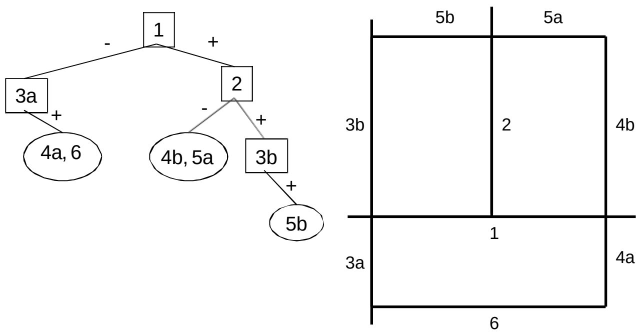
130

Building Example (2)



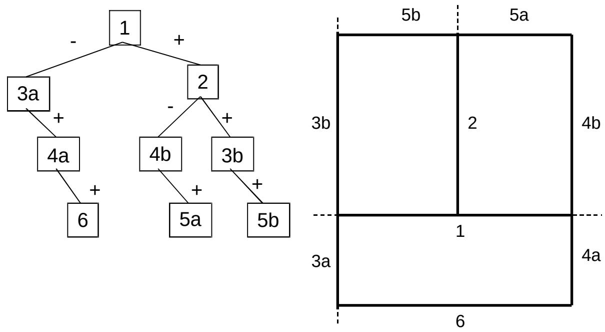
131

Building Example (3)



132

Building Example (Done)



133

Binary Space Partitioning, Ray cast &Painter's

[redacted]

134

Comparisons of Algorithms

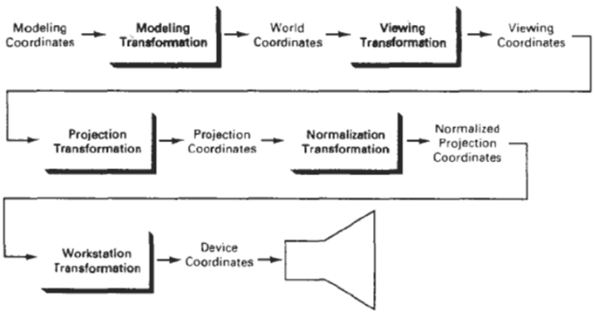
[redacted]

135

Recommendations for hidden surface methods

Surfaces are distributed in z	Depth sorting
Surfaces are well separated in y	Scan-line or area-subdivision
Only a few surfaces present	Depth sorting or scan-line
Scene with at least a few thousand surfaces	Depth-buffer method or area-subdivision

136



137

Geometrical Modelling

Chapter 3

138

Geometrical Modelling

Lesson Objectives:

- To Learn advanced concepts of feature based modelling and parametric modelling
- To understand the mathematical basis for geometric modelling of curves and surfaces and their relationship with computer graphics.
- To understand the methods of representation of wireframe, surface, and solid modelling systems.
- To Consider data associativity concepts of CAD/CAE integration; Be familiar with interoperability and data transfer techniques between design and analysis software systems.

139

Geometrical Modelling

Lesson Outcomes:

Upon completing this course, the students will be able to:

- Represent curves and surfaces using parametric equations
- Define and relate the basic concepts, tools, and algorithms in geometric modelling and digital surface processing
- Critically analyse and assess current research on surface representations and geometric modelling with the intent to apply the proposed methods in your own work
- Define the methods of representation of wireframe, surface, and solid modelling systems.

140

Geometric Modeling

The basic geometric modeling approaches available to designers on CAD systems are:

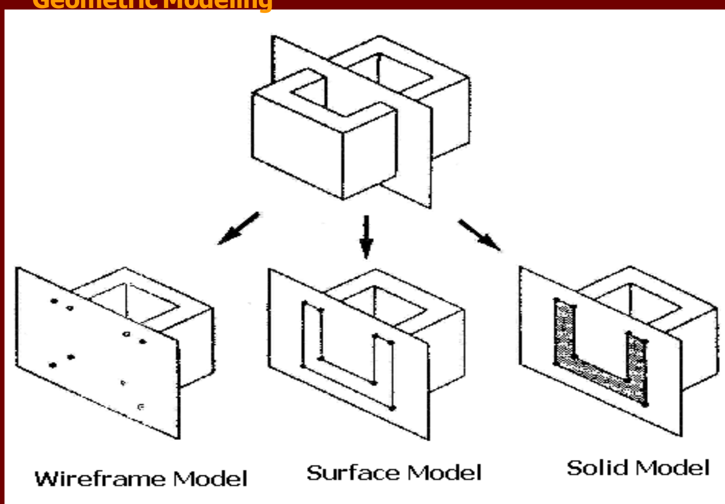
- Wireframe modeling.
- Surface modeling.
- Solid modeling.

1 **Wireframe modeling entities**

- Analytic curves (lines, circles, ellipses, …….)
- Synthesis curves (parametric cubic curves, Bezier curves, B-spline curves, …….)

141

Geometric Modeling



Geometric Modeling

2. Surface modeling entities
   - Analytic surfaces (plane surfaces, ruled surfaces, surface of revolution, tabulated surfaces)
   - Synthesis surfaces (parametric cubic surfaces, Bezier surfaces, B-spline surfaces, ….)

3. Solid modeling entities

- Construction Solid Geometry (CSG)
  - Solid primitives (cubes, spheres, cylinders, ………)
  - Boolean operations (Union, Subtraction, intersection)
- Boundary Representation (B-Rep)
  - Geometric entities (points, lines, surfaces, …….)
  - Topological entities (vertices, edges, faces, ……..)
- Sweep Representation
  - Transitional sweep (Extrusion)
  - Rotational sweep (Revolution)

143

Parametric Modeling

- Methodology utilizes dimension-driven capability.
- By dimension-driven capability we mean that an object defined by a set of dimensions can vary in size according to the dimensions associated with it at any time during the design process

144

Feature-based Modeling

A feature represents the engineering meaning or significance of the geometry of a part.

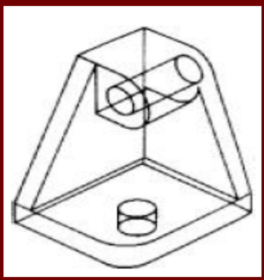
- **Feature modeling techniques**
  - **Interactive feature definition**
  - **Design by features**
    - **Destructive by features**
    - **Synthesis by features**
  - **Automatic feature recognition**
    - **Machining region recognition**
    - **Pre-defined feature recognition**

145

Wireframe Modeling

A wireframe representation is a 3-D line drawing of an object showing only the edges without any side surface in between.

The image of the object, as the name applies has the appearance of a frame constructed from thin wires representing the edges and projected lines and curves.



146

Wireframe Modeling

A computer representation of a wire-frame structure consists essentially of two types of information:

- **The first is termed metric or geometric data which relate to the 3D coordinate positions of the wire-frame node' points in space.**
- **The second is concerned with the connectivity or topological data, which relate pairs of points together as edges.**

- **Basic wire-frame entities can be divided into analytic and synthetic entities.**

<u>**Analytic entities :**</u>
Points Lines Arc Circles

<u>**Synthetic entities:**</u>
Cubic curves Bezier curves B-spline curves

147

Wireframe Modeling

<u>Limitations</u>

- **From the point of view of engineering Applications, it is not possible to calculate volume and mass properties of a design**
- **In the wireframe representation, the virtual edges (profile) are not usually provided.**
  - **(for example, a cylinder is represented by three edges, that is, two circles and one straight line)**
- **The creation of wireframe models usually involves more user effort to input necessary information than that of solid models, especially for large and complex parts.**

148

Analytical Curves

1- Non-parametric representation analytical curves

Line	$Y = mX + c$
Circle	$X^2 + Y^2 = R^2$
Ellipse	$\frac{X^2}{a^2} + \frac{Y^2}{b^2} = 1$
Parabola	$Y^2 = 4aX$

- Although non-parametric representations of curve equations are used in some cases, they are not in general suitable for CAD because:
  - The equation is dependent on the choice of the coordinate system
  - Implicit equations must be solved simultaneously to determine points on the curve, inconvenient process.
  - If the curve is to be displayed as a series of points or straight line segments, the computations involved could be extensive.

149

Analytical Curves

2- Parametric representation of analytical curves

In parametric representation, each point on a curve is expressed as a function of a parameter **u**. The parameter acts as a local coordinate for points on the curve.

For 3D Curve

$$\vec{P}(u) = [x \quad y \quad y]^T = [x(u) \quad y(u) \quad z(u)]^T$$

$$u_{min} \leq u \leq u_{max}$$

- The parametric curve is bounded by two parametric values U_{min} and U_{max}
- It is convenient to normalize the parametric variable u to have the limits 0 and 1.

150

Analytical Curves

2- Parametric representation of analytical curves

1- Lines

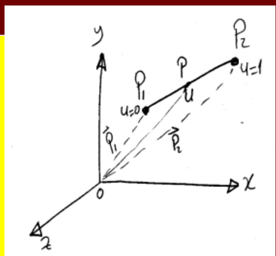
- A line connecting two points P1 and P2.
- Define a parameter **u** such that it has the values 0 and 1 at P_1 and P_2 respectively

Vector form

$$\vec{P} = \vec{P_1} + u(\vec{P_2} - \vec{P_1}) \qquad 0 \le u \le 1$$

Scalar form

$$x = x_1 + u(x_2 - x_1)$$
$$y = y_1 + u(y_2 - y_1) \qquad 0 \le u \le 1$$
$$z = z_1 + u(z_2 - z_1)$$



The above equation defines a line bounded by the endpoints P_1 and P_2 whose associated parametric value are 0 and 1

151

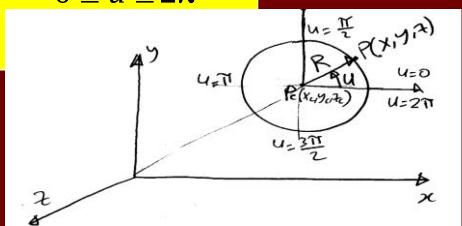
Analytical Curves

2- Parametric representation of analytical curves

2- Circles

- The basic parametric equation of a circle can be written as

$$x = x_c + R\cos u$$
$$y = y_c + R\sin u \qquad 0 \le u \le 2\pi$$
$$z = z_c$$



For circle in XY plane, the parameter u is the angle measured from the X-axis to any point P on the circle.

152

Analytical Curves

2- Parametric representation of analytical curves

3- Circular Arcs

- Circular arcs are considered a special case of circles. A circular arc parametric equation is given as

$$x = x_c + R\cos u$$
$$y = y_c + R\sin u \qquad u_s \le u \le u_e$$
$$z = z_c$$

Where u_s and u_e are the starting and ending angles of the arc respectively

153

Synthesis Curves

Curves that are constructed by many curve segments are called Synthesis Curves

- Analytic curves are not sufficient to meet geometric design requirements of AERONAUTICAL parts
- Products such as car bodies, airplanes, propeller blades, etc. are a few examples that require free-form or synthetic curves and surfaces
- Mathematical approaches to the representation of curves in CAD can be based on either
  - Interpolation
  - Approximation

- If the problem of curve design is a problem of data fitting, the classic interpolation solutions are used.
- If the problem is dealing with free form design with smooth shapes, approximation methods are used.

154

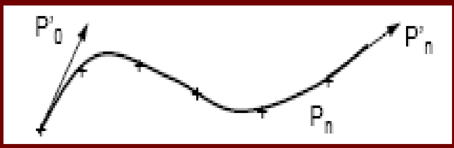
Synthesis Curves

1 **Interpolation**

Finding an arbitrary curve that fits (passes through) a set of given points. This problem is encountered, for example, when trying to fit a curve to a set of experimental values.

Types of interpolation techniques:

- Lagrange polynomial
- Parametric cubic (Hermite)



Parametric cubic

155

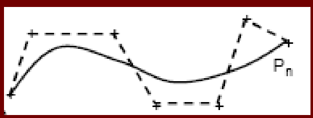
Synthesis Curves

2 **Approximation**

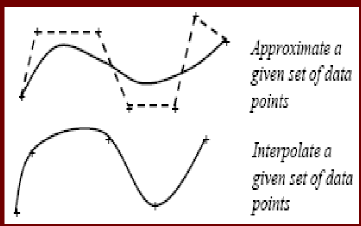
Approximation approaches to the representation of curves provide a smooth shape that approximates the original points, without exactly passing through all of them.

Two approximation methods are used:

- Bezier Curves
- B-spline Curves



Bezier Curves



B-spline curves

156

Synthesis Curves

1- Lagrange Interpolation Polynomial

- Consider a sequence of planar points defined by (x_0, y_0), (x_1, y_1), …….(x_n, y_n) where $x_i < x_j$ for $i < j$.

The interpolating polynomial of nth degree can be calculated as

$$f_n(x) = \sum_{i=0}^{n} y_i L_{i,n}(x)$$

where

$$L_{i,n}(x) = \frac{(x-x_0)\ldots\ldots(x-x_{i-1})(x-x_{i+1})\ldots\ldots(x-x_n)}{(x_i-x_0)\ldots\ldots(x_i-x_{i-1})(x_i-x_{i+1})\ldots\ldots(x_i-x_n)}$$

A short notation for this formula is

$$f_n(x) = \sum_{i=0}^{n} y_i \prod_{\substack{j=0 \\ j\neq i}}^{n} \left(\frac{x-x_j}{x_i-x_j} \right) \qquad i = 0,1,2\ldots.n$$

where

Π denotes multiplication of the n-factors obtained by varying j from 0 to n excluding j=i

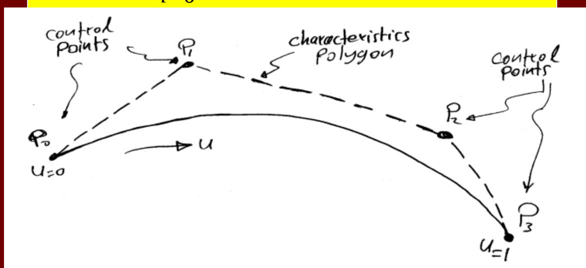
157

Synthesis Curves

2- Bezier Curves

Given n+1 control points, P_0, P_1, P_2, ….., P_n, the Bezier curve is defined by the following polynomial of degree n

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



158

Synthesis Curves

2- Bezier Curves

where

P(u) is any point on the curve

P_i is a control point, $P_i = [x_i \ y_i \ z_i]^T$

$B_{i,n}$ are polynomials (serves as basis function for the Bezier Curve)

where

$$B_{i,n}(u) = C(n,i)u^i(1-u)^{n-i}$$

$$C(n,i) = \frac{n!}{i!(n-i)!}$$

In evulating these expressions $0^0 = 1$

$0^! = 1$

C(n,0) = C(n,n)=1 when u and i are 0

159

Synthesis Curves

2- Bezier Curves

The above equation can be expanded to give

$$P(u) = P_0(1-u)^n + P_1C(n,1)u(1-u)^{n-1} + P_2C(n,2)u^2(1-u)^{n-2} + \ldots\ldots..$$
$$+P_{n-1}C(n,n-1)u^{n-1}(1-u) + P_nu^n$$

$0 \le u \le 1$

160

Example [Bezier Curve]

The coordinates of four control points relative to a current WCS are given by

$P_0 = [2 \; 2 \; 0]^T$, $P_1 = [2 \; 3 \; 0]^T$, $P_2 = [3 \; 3 \; 0]^T$, and $P_3 = [3 \; 2 \; 0]^T$

Find the equation of the resulting Bezier curve. Also find points on the curve for $u = 0, 0.25, 0.5$ and 1

Solution

- No. of control points $(n+1) = 4$
- $n = 3$

The Bezier polynomial is given as

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

161

$$\Rightarrow P(u) = B_{0,3} \cdot P_0 + B_{1,3} \cdot P_1 + B_{2,3} \cdot P_2 + B_{3,3} \cdot P_3 \quad \text{—(1)} \quad 0 \le u \le 1$$

evaluating the $B_{i,3}$ values using

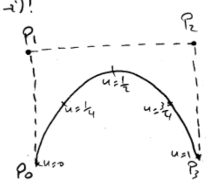
$$B_{i,n}(u) = C(n,i)\, u^i (1-u)^{n-i} = \frac{n!}{i!\,(n-i)!} u^i (1-u)^{n-i}$$

$$\Rightarrow B_{0,3} = \frac{3!}{0!\,(3-0)!} u^0 (1-u)^{3-0} = (1-u)^3$$

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

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

$$B_{3,3} = \frac{3!}{3!\,(3-3)!} u^3 (1-u)^{3-3} = u^3$$



Substitute the values of $B_{i,3}$ into equation (1), gives

$$\boxed{P(u) = P_0(1-u)^3 + 3P_1 u(1-u)^2 + 3P_2 u^2(1-u) + P_3 u^3} \quad \text{—(2)}$$

$$0 \le u \le 1$$

For $u = 0 \Rightarrow P(0) = [2 \; 2 \; 0]^T$

$u = 0.25 \Rightarrow P(0.25) = [2.156 \; 2.563 \; 0]^T$

$u = 0.5 \Rightarrow P(0.5) = [2.5 \; 2.75 \; 0]^T$

$u = 1 \Rightarrow P(1) = [3 \; 2 \; 0]^T$

162

Synthesis Curves

2- B-spline Curves

Given n+1 control points P_0, P_1, ……., P_n, the B-spline curve of degree (k-1) defined by these control points is given as

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

Where

- P(u) is any point on the curve
- P_i is a control point
- $N_{i,k}(u)$ are the B-spline basis functions of degree k
- The parameter k controls the degree (k-1) of the resulting B-spline curve and usually independent of the number of control points
- It should be noted that the range of u is not 0 to 1, but it varies with the number of control points and the degree of the curve

$0 \le u \le ((n+1) – (k-1))$

$0 \le u \le n – k + 2$

163

Synthesis Curves

2- B-spline Curves

If k = 2, we get a linear curve
If k = 3, we get quadratic
curve If k = 4, we get cubic
curve

- The B-spline basis functions are given as

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

$$N_{i,1} = \begin{cases} 1 & u_i \le u \le u_{i+1} \\ 0 & otherwise \end{cases}$$

Synthesis Curves

2- B-spline Curves

The u_i are called parametric knots or knot values. These values form a sequence of non-decreasing integers called knot vector. The point on the curve corresponding to a knot u_i is referred to as a knot point. The knot points divide a B-spline curve into curve segments.

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

Where $0 \le j \le n+k$

- The number of knots (n + k + 1) are needed to create a (k-1) degree curve defined by (n+1) control points

165

Surface Modeling

- Surface modeling is a widely used modeling technique in which objects are defined by their bounding faces.
- Surface modeling systems contain definitions of surfaces, edges, and vertices
- Complex objects such as car or airplane body can not be achieved utilizing wireframe modeling.
- Surface modeling are used in
  - calculating mass properties
  - checking for interference
  - between mating parts
  - generating cross-section views
  - generating finite elements meshes
  - generating NC tool paths for
  - continuous path machining

166

Surface Modeling

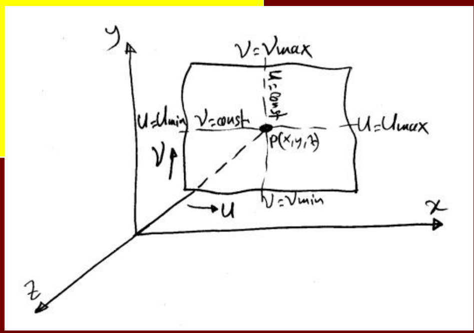
Parametric representation of surface

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

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

$$u_{\min} \le u \le u_{\max}$$

$$v_{\min} \le v \le v_{\max}$$

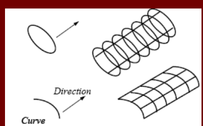


167

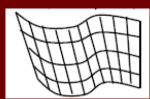
Surface Modeling

Surfaces Entities

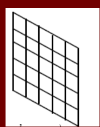
1- Analytical surface entities



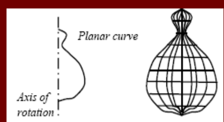
Tabulated cylinder



Ruled (lofted) surface



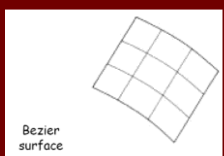
Plane surface



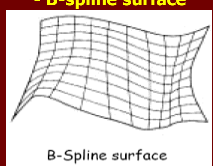
Surface of revolution

2- Synthesis surface entities

- Bezier surface



- B-spline surface



168

Surface Modeling

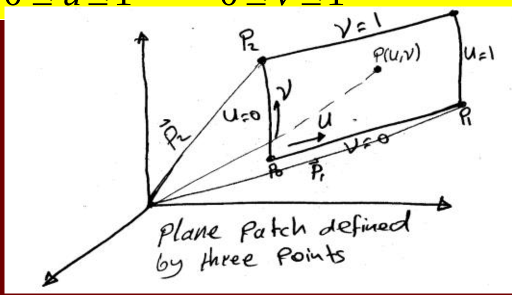
Parametric Representation of Analytical Surfaces

1- Plane Surface

The parametric equation of a plane defined by three points, P_0, P_1, and P_2

$$P(u,v) = P_0 + u(P_1 - P_0) + v(P_2 - P_0)$$

$$0 \le u \le 1 \qquad 0 \le v \le 1$$



169

Surface Modeling

Parametric Representation of Analytical Surfaces

2 Ruled Surface

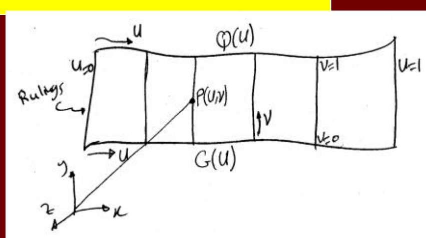
A ruled surface is generated by joining corresponding points on two space curves (rails) G(u) and Q(u) by straight lines

- The parametric equation of a ruled surface defined by two rails is given as

$$P(u,v) = (1-v)G(u) + vQ(u)$$

$$0 \le u \le 1 \quad 0 \le v \le 1$$

Holding the u value constant in the above equation produces the rulings in the v direction of the surface, while holding the v value constant yields curves in the u direction.



170

Surface Modeling

Parametric Representation of Analytical Surfaces

3 Tabulated Cylinder

A tabulated cylinder has been defined as a surface that results from translating a space planar curve along a given direction.

- The parametric equation of a tabulated cylinder is given as

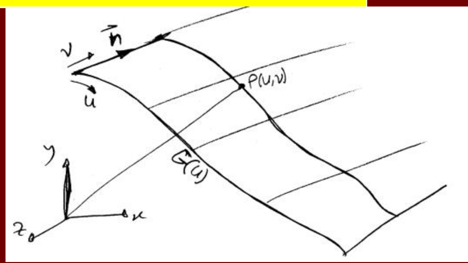
$$P(u,v) = G(u) + v\vec{n} \qquad 0 \le u \le u_{max} \qquad 0 \le v \le v_{max}$$

Where

G(u) can be any wireframe entities to form the cylinder

v is the cylinder length

n is the cylinder axis (defined by two points)

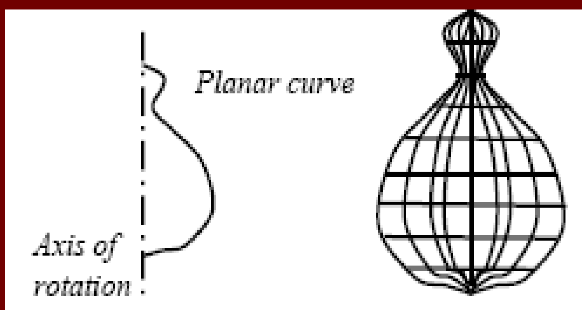


Surface Modeling

Parametric Representation of Analytical Surfaces

4- Surface of Revolution

Surface of revolution is generated by rotating a planar curve in space about an axis at a certain angle.

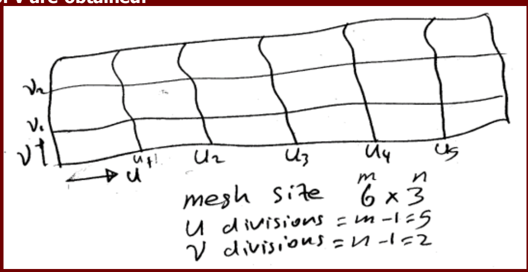


172

Surface Modeling

Mesh Generation

- Whenever the user requests the display of the surface with a mesh size m x n
  - The u range is divided equally into (m-1) divisions and m values of u are obtained.
  - The v range is divided equally into (n-1) divisions and n values of v are obtained.



173

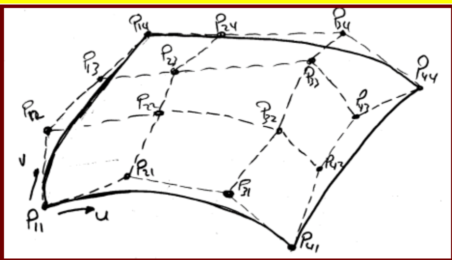
Surface Modeling

Parametric Representation of Synthesis Surfaces

1- Bezier Surface

A Bezier surface is defined by a two-dimensional set of control points $P_{i,j}$ where i is in the range of 0 to m and j is in the range of 0 to n. Thus, in this case, we have m+1 rows and n+1 columns of control points

$$p(u,v) = \sum_{i=0}^{m}\sum_{j=0}^{n} B_{m,i}(u)B_{n,j}(v)P_{i,j} \qquad \begin{array}{c} 0 \le u \le 1 \\ 0 \le v \le 1 \end{array}$$



174

Surface Modeling

Parametric Representation of Synthesis Surfaces

Where
P(u, v) is any point on the surface $P_{i,j}$ are the control points

$B_{m,i}(u)$ and $B_{n,j}$ are the i-th and j-th Bezier basis functions in the u- and v-directions

$$B_{m,i}(u) = \frac{m!}{i!(m-i)!} u^i (1-u)^{m-i}$$

$$B_{n,j}(v) = \frac{n!}{j!(n-j)!} v^j (1-v)^{n-j}$$

175

Surface Modeling

Parametric Representation of Synthesis Surfaces

1- B-spline Surface

B-spline surface defined by (m+1) x (n+1) array of control points is given by

$$p(u,v) = \sum_{i=0}^{m} \sum_{j=0}^{n} P_{ij} N_{i,k}(u) N_{j,L}(v) \qquad 0 \le u \le u_{max} \quad 0 \le v \le v_{max}$$

Where
P(u, v) is any point on the surface K is the degree in u-direction

L is the degree in v-direction

$N_{i,k}(u)$ and $N_{j,L}(v)$ are B-spline basis functions of degree K and L respectively

Solid Modeling

Solid modeling techniques provide the user with the means to create, store, and manipulate complete representations of solid objects with the potential for integration and improved automation.

Solid Representation

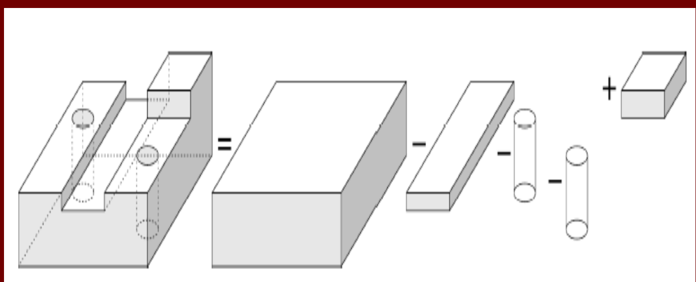
Several representation schemes are available for the creation of solid models. Some of the most popular are given:

- **Constructive Solid Geometry (CSG).**
- **Boundary Representation (B-Rep).**
- **Sweeping.**

177

1- Constructive Solid Geometry

A CSG model is based on the topological notation that a physical object can be divided into a set of primitives (basic elements or shapes) that can be combined in a certain order following a set of rules (Boolean operations) to form the object.



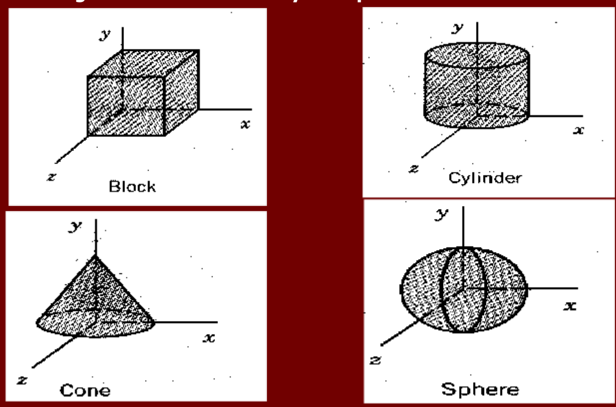
178

1- Constructive Solid Geometry

1.1 CSG Primitives

Primitives are usually translated and/or rotated to position and orient them properly applying Boolean operations.

Following are the most commonly used primitives:



179

1 Constructive Solid Geometry

1.2 Boolean Operations

Boolean operations are used to combine solid primitives to form the desired solid. The available operators are Union (U or +), intersection (∏ or I) and difference (-).

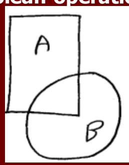
- **The Union operator (U or +):** is used to combine or add together two objects or primitives
- **The Intersection operator (∏ or I):** intersecting two primitives gives a shape equal to their common volume.
- **The Difference operator (-):** is used to subtract one object from the other and results in a shape equal to the difference in their volumes.

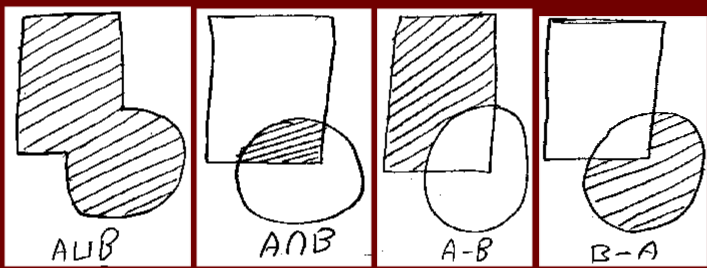
180

1- Constructive Solid Geometry

1.2 Boolean Operations

Figure below shows Boolean operations of a clock A and Cylinder B



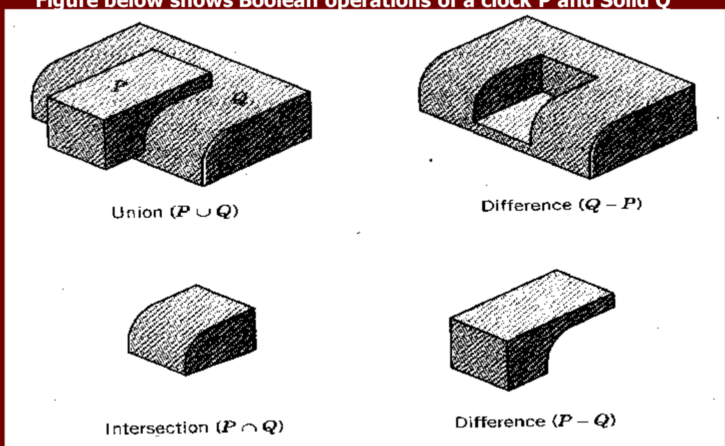


181

1- Constructive Solid Geometry

1.2 Boolean Operations

Figure below shows Boolean operations of a clock P and Solid Q

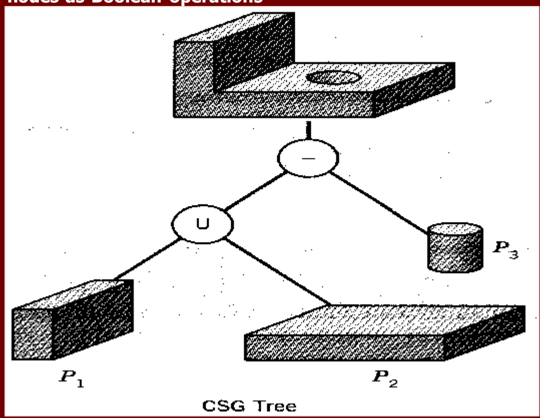


182

1- Constructive Solid Geometry

1.3 CSG Data Structure

Data structures for the CSG representation are based on the binary tree structure. The CSG tree is a binary tree with leaf nodes as primitives and interior nodes as Boolean operations

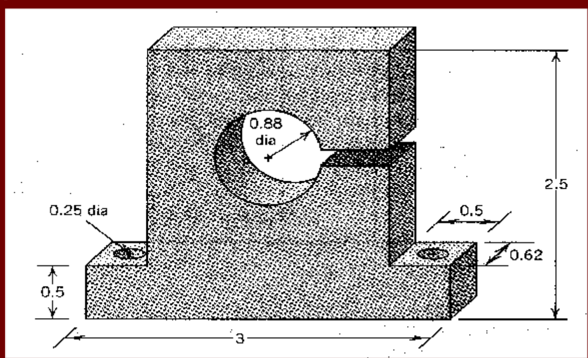


183

1- Constructive Solid Geometry

1.4 CSG Creation Process

The creation of a model in CSG can be simplified by the use of a table summarizing the operations to be performed. The following example illustrates the process of model creation used in the CSG representation.



184

CSG Table

Primitive No.	Primitive Type	Transformations $S(x,y,z)$ $T(x,y,z)$ $R(x,y,z)$	Boolean (U, D, I)	CSG Tree	Sketch
1	Block	$S(3.0,2.5,.62)$		P_1	
2/3	Block	$S(0.5,2.0,.62)$ $T(2.5,0.5,0.0)$ ‖ $S(0.5,2.0,.62)$ $T(0.0,0.5,0.0)$	D/D	SOL_2 = SOL_1 D P_3; SOL_1 = P_1 D P_2	
4	Cylinder	$S(r = 0.44, h = 0.62)$ $T(1.5,1.5,0.0)$	D	SOL_3 = SOL_2 D P_4	
5	Block	$S(0.56,0.12,0.62)$ $T(1.94,1.44,0.0)$	D	SOL_4 = SOL_3 D P_5	
6/7	Cylinder	$S(r = 0.125, h = 0.5)$ $T(0.25,0.0,0.31)$ $R(90.0,0.0,0.0)$ ‖ S(same) $T(2.75,0.0,0.31)$ R(same)	D/D	SOL_6 = SOL_5 D P_7; SOL_5 = SOL_4 D P_6	

1- Constructive Solid Geometry

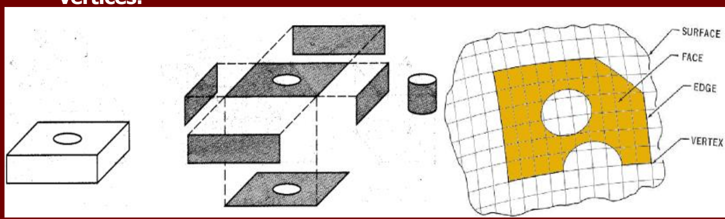
Limitations

- Inconvenient for the designer to determine simultaneously a sequence of feature creation for all design iterations
- The use of machining volume may be too restrictive
- Problem of non-unique trees. A feature can be constructed in multiple ways
- Tree complexity
- Surface finish and tolerance may be a problem

186

2- Boundary Representation (B-Rep)

- A B-Rep model or boundary model is based on the topological notation that a physical object is bounded by a set of Faces.
- These faces are regions or subsets of closed and orientable surfaces.
  - A closed surface is one that is continuous without breaks.
  - An orientable surface is one in which it is possible to distinguish two sides by using the direction of the surface normal to a point inside or outside of the solid model.
- Each face is bounded by edges and each edge is bounded by vertices.

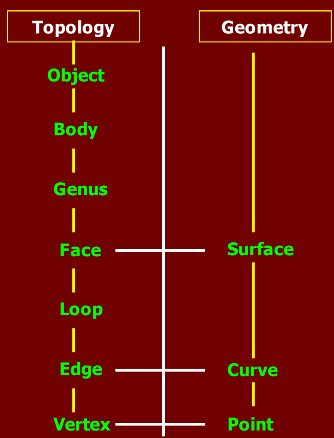


2- Boundary Representation (B-Rep)

2.1 B-Rep Data Structure

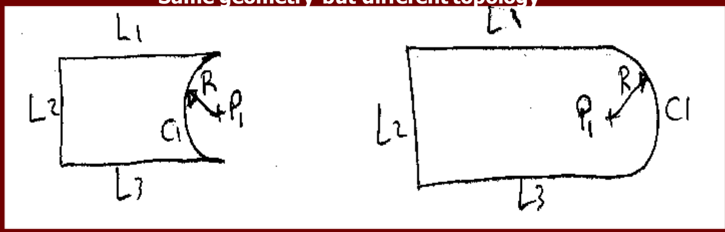
A general data structure for a boundary model should have both topological and geometrical information

- Geometry relates to the information containing shape defining parameters, such as the coordinates of the vertices
- Topology describes the connectivity among the various geometric components, that is, the relational information between the different parts of an object

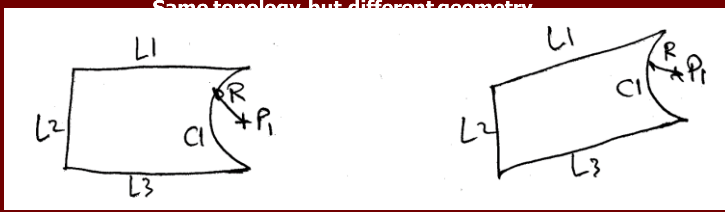


2- Boundary Representation (B-Rep)

Same geometry but different topology



Same topology but different geometry



189

2 Boundary Representation (B-Rep)

Two important questions in B-Rep

1. **What is a face, edge or a vertex?**

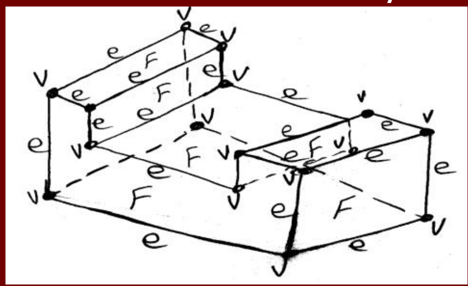
2. **How can we know that when we combine these entities we would create valid objects?**

190

2- Boundary Representation (B-Rep)

B-Rep Entities Definition

- **Vertex** is a unique point in space
- **An Edge** is a finite, non-self-intersecting, directed space curve bounded by two vertices
- **A Face** is defined as a finite connected, non-self-intersecting, region of a closed oriented surface bounded by one or more loops

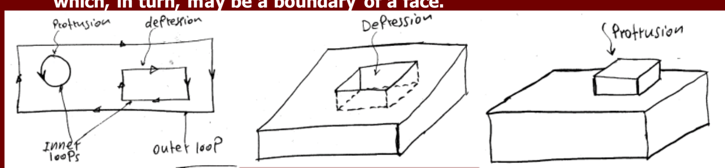


191

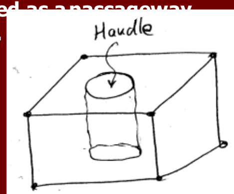
2- Boundary Representation (B-Rep)

B-Rep Entities Definition

- **A Loop** is an ordered alternating sequence of vertices and edges. A loop defines a non-self-intersecting, piecewise, closed space curve which, in turn, may be a boundary of a face.



- **A Handle (Genus or Through hole)** is defined as a passageway that passes through the object completely.



- **A Body (Shell)** is a set of faces that bound a single connected closed volume. Thus a body is an entity that has faces, edges, and vertices

192

2 Boundary Representation (B-Rep)

Validity of B-Rep

- To ensure topological validation of the boundary model, special operators are used to create and manipulate the topological entities. These are called Euler Operators
- The Euler's Law gives a quantitative relationship among faces, edges, vertices, loops, bodies or genus in solids

Euler Law

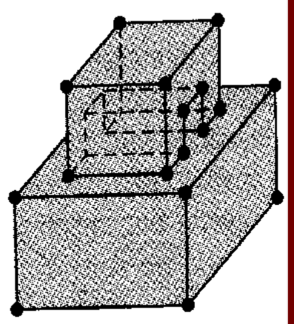
$$F - E + V - L = 2(B - G)$$

Where

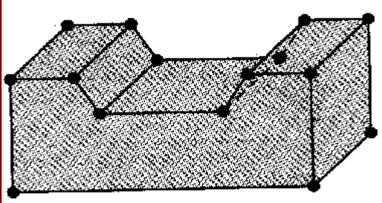
F = number of faces
E = number of edges
V = number of vertices
L = Faces inner loops
B = number of bodies
G = number of genus (handles)

193

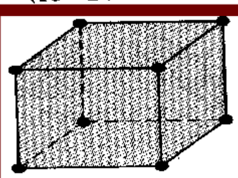
2- Boundary Representation (B-Rep)



$F - E + V - L = 2(B - G)$
$[14 - 36 + 24 - 2 = 2(1 - 1)]$



$F - L + V = 2$
$(10 - 24 + 16 = 2)$



$F - L + V = 2$
$(6 - 12 + 8 = 2)$

194

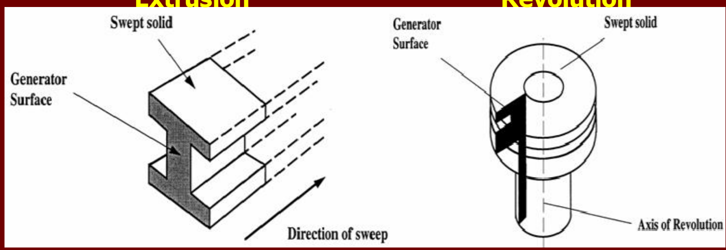
3 Sweep Representation

Solids that have a uniform thickness in a particular direction and axisymmetric solids can be created by what is called

Transitional (Extrusion) and Rotational (Revolution) Sweeping

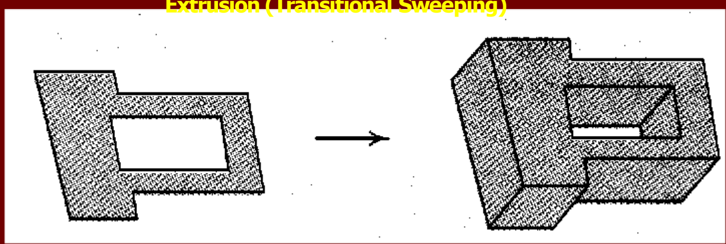
- **Sweeping requires two elements – a surface to be moved and a trajectory, analytically defined, along which the movement should occur.**

Extrusion **Revolution**

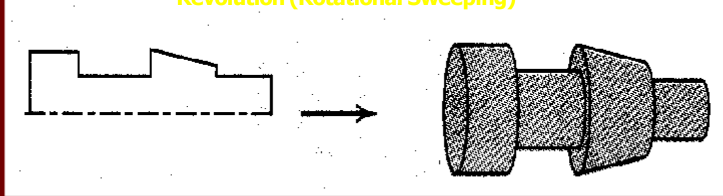


3- Sweep Representation

Extrusion (Transitional Sweeping)



Revolution (Rotational Sweeping)



UNIT 4

COMPUTER AIDED DRAFTING AND SOLID MODELLING

What is AutoCAD?

AutoCAD is a CAD (Computer Aided
• Design or Computer Aided Drafting)
software application for 2D and 3D design

199

Commands

Tool Bar
• Pull Down
•
KEY COMMANDS •
From the Key board –

200

Key Sequences

- Always look at the command line
  - At the bottom of the page
  - Always be as specific as possible

201

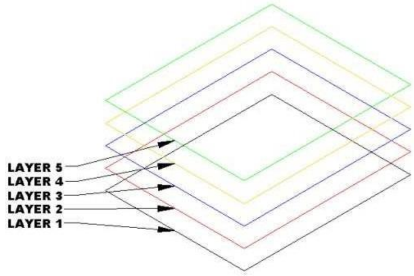
Layers

- In Auto CAD, we make individual layers…
  - For things like
    - Hidden lines
    - Center lines
    - Section lines
    - Break lines

202

Layers

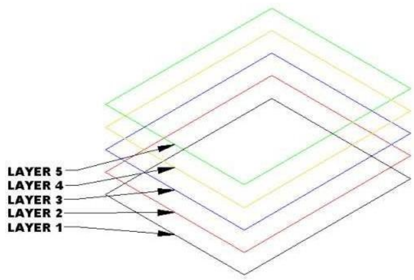
Layers are a – way of managing, tidying and also controlling the visual layout of a drawing.



203

Layers

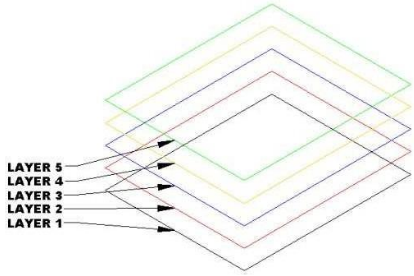
A whole section – of a drawing can be turned on or off, or simply one aspect can be controlled - text for example.



204

Layers

This is all done –
by using layers
within Autocad.



What is a Layer

A layer can be thought of as a large piece of – clear plastic, as infinitely large as the drawing area in Autocad.

What is a Layer

When drawing in Autocad, everything is – drawn on the default layer which is set current. Only the objects you are drawing are visible on the layer, the layer itself can never be seen - it is invisible.

207

What is a Layer

Layers are controlled by the **layer properties manager** button which is located on th object properties toolbar:

Each new layer is created by you, the user. – Normally, it is acceptable to have a layer for each different part of a drawing.

208

Layer property manger

209

In Layer Property manger

- Add a New Layer - Press the **New** button to create a new layer.

Delete a Layer - Press the **delete** button to delete the selected layer.

Set Current layer - Press the **current** button to set the selected layer current. All objects drawn will then be drawn on this current layer.

Show Details - Press the show details button to see more detailed information about the selected layer.

Each layer also has the following options against it:

210

Layer property Manger

- **Name** - Displays the layer name.
- **On** - Controls if the layer is on or off. Select the light bulb to turn the layer off on the drawing.
- **Freeze in all VP -** Pressing this will freeze the layer in all viewports as well as the current model view (see lesson 10 to learn about viewports)
- **Lock -** This handy feature locks a layer preventing any content of the layer from being modified.
- **Colour -** Change this to whichever colour you like. All objects drawn on the layer will display the chosen colour provided that the objects colour setting in the object properties toolbar (shown above) is set to 'ByLayer'.
- **Linetype** - Set the default linetype for all objects drawn on the layer. i.e continuous, dashed, dotted etc.
- **Lineweight** - Set the thickness a line appears .Default is no thickness. This option can be toggled on/off on the display by the LWT button above the command console.
- **Plot -** Select if the layer will be shown when the drawing is plotted (printed).
- The current layer, layer colour, linetype and lineweight can all be controlled outside of the layer properties manager via the object properties toolbar.

Drafting Settings

- Command DS
  - Changes Grid –
  - Object Snaps –
  - Polar Tracking –

Object Snaps

Midpoint
• End point •
Intersection •
Extension •
Center •
Quadrant •
Tangent •
Perpendicular
•
Parallel
• Insert
•
Node •

Object Snaps

The Object Snaps (Osnaps for short) are
• drawing aids which are used in
conjunction with other commands to help
you draw accurately.

Object Snaps

Osnaps allow you to *snap* onto a specific
- object location when you are picking a point

215

When you are drawing, take a few
- moments to consider how you will construct each part of the drawing and which Osnaps you will use before starting work. There is always more than one way to draw anything in AutoCAD but the quickest, most accurate and the most efficient way always requires the use of one or more of the Osnap tools

216

Dock the Object Snap toolbar to your
• drawing window for quick access to the
Osnaps. You will be using them all the
time, one-click access is essential. See
Object Snaps to find out how to display
the Object Snap toolbar. To dock the
toolbar, click on the toolbar title and drag
it to the edge of the drawing window.

You will begin to work on

- Handed out exercises

AutoCAD

Day 2

Modify Commands

- The modify tools (from left to right): **Erase, Copy, Mirror, Offset, Array, Move, Rotate, Scale, Stretch, Lengthen, Trim, Extend, Break at point, Break, Chamfer, Fillet, Explode**

Erase

Select this button then a drawing element
- to erase it permanently from the drawing.

Copy

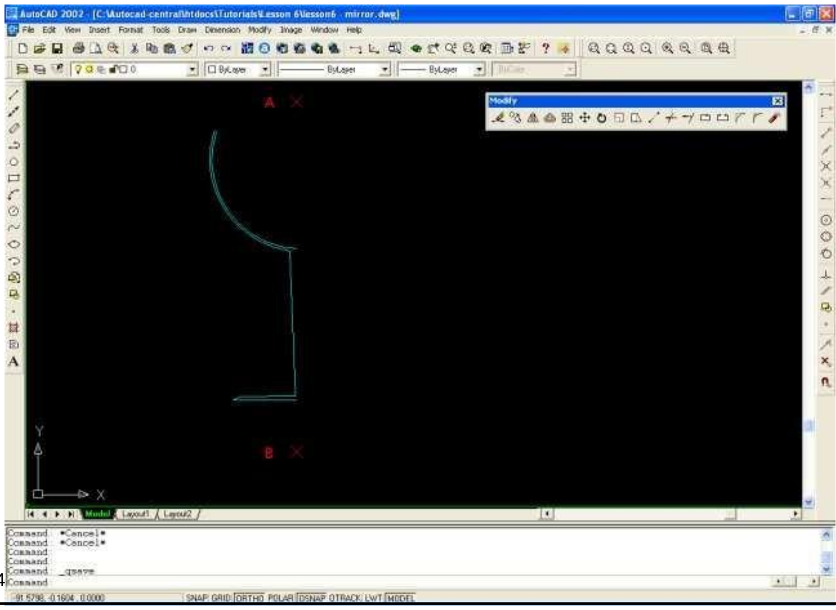
Copy - The copy command will copy any
- selected drawing elements and reposition
    where specified by the user,
        without affecting the original
        elements.

Mirror

Mirror - The mirror command will create a mirror image of any selected drawing elements along any line of symmetry specified by the user.

223

Mirror



224

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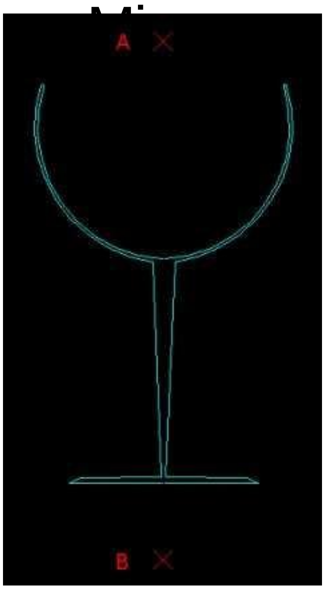


225

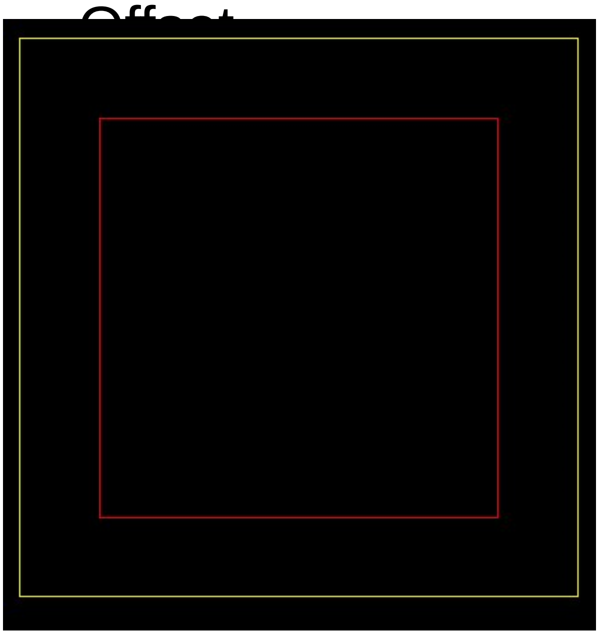
Offset

- Offset will make a copy of a line or series of selected lines by a specified distance in the direction specified.

226

IARE

Offset



227

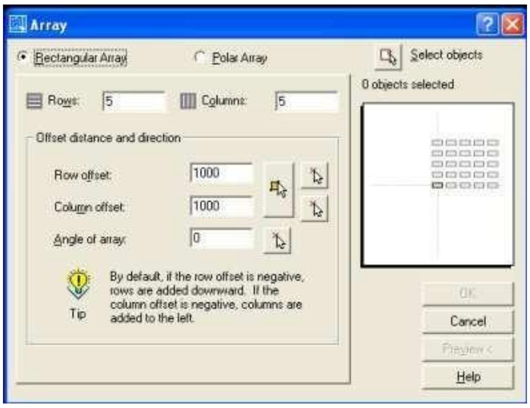
Array

The array command quickly creates

- copies of a selected object(s) to a specified spacing..

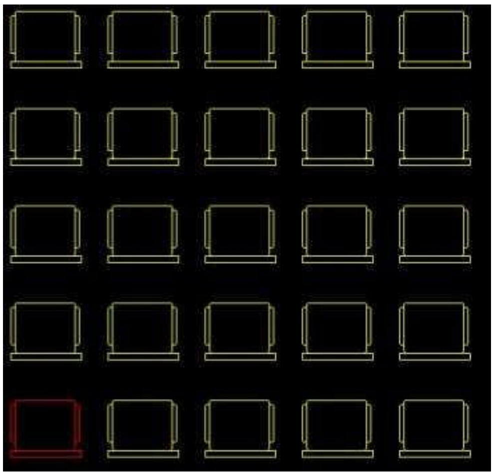
228

Rectangular Array



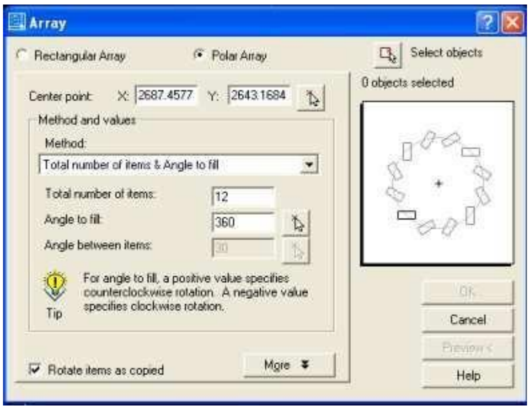
229

Rectangular Array



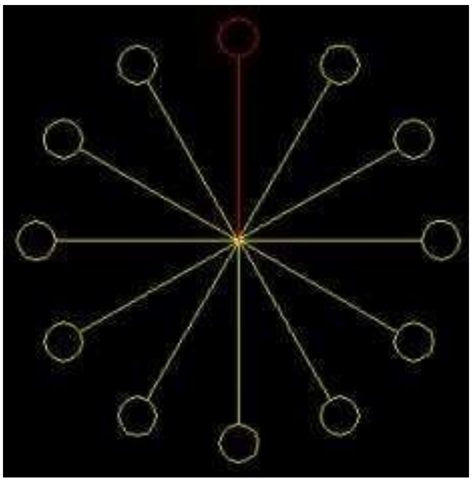
230

Polar Array



231

Polar Array



232

Move

The move command works exactly the
• same as the copy command described above, except instead of creating a copy of the selected objects, the second objects are moved.

Rotate

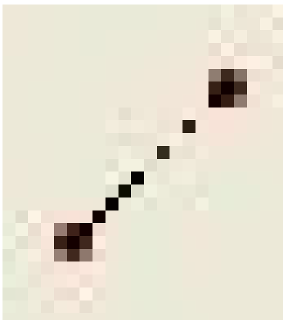
The rotate command rotates any selected
• objects about a defined point by the angle specified. By default Autocad will rotate objects anticlockwise when an angle is entered.

Scale

The scale command scales the size of a
• selected object(s) by a defined scale factor from a selected base point. The selected objects can be scaled up to increase size
or down to reduce the size.

Lengthen

The lengthen command
• will lengthen a selected line.



```
Command:
Command:
Command: _lengthen
Select an object or [DElta/Percent/Total/DYnamic]:
```

Lengthen

DE - Delta: Autocad asks for a distance to
• lengthen the line by, when the line is selected it will then be lengthened by the specified distance ONLY to the side of the line where the line was selected. i.e If when you selected the line, you selected it just to the left of centre, then the left side of the line would be lengthened.

•

Lengthen

P - Percent: Autocad asks for a percent to
• lengthen by, then asks you to select the line. Specifying 50% would reduce the size of the line by half (The same effect as scaling by a factor of 0.5). Specifying 100% would result in no change in length. 200% would double the length of the line. When specifying the percentage to Autocad only the numerical figure has to be entered and not the percent (%) symbol.

•

Lengthen

T - Total: Autocad asks for the distance

• you want the entire line to be, when you select the line it will adjust the lines length to the distance specified.

•

```
Command:
Command:
Command: _lengthen
Select an object or [DElta/Percent/Total/DYnamic]:
```


Lengthen

DY - Dynamic: Autocad adjusts the length

• of the line as the mouse is moved in the direction the line is to be lengthened. This is not an accurate technique, although is useful for quickly lengthening construction lines for example.

•

```
Command:
Command:
Command: _lengthen
Select an object or [DElta/Percent/Total/DYnamic]:
```

Auto CAD

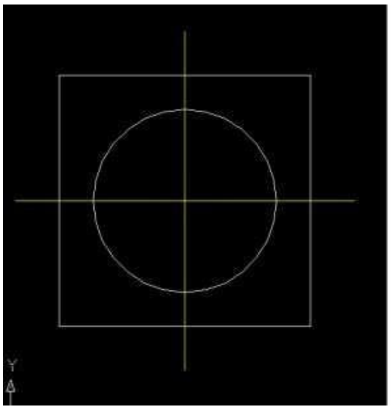
Day 3

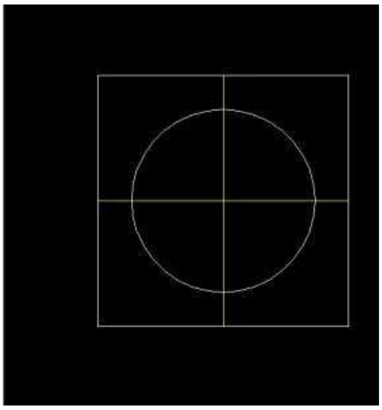
Trim

The trim command is an extremely useful

• tool which will erase all parts of an object beyond or within its intersection with another object.

Trim





243

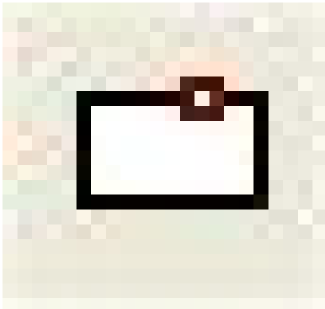
Extend

The extend command is
• similar to the trim command in how it functions, except it extends a selected line to a point of intersection of another selected object.

244

Break at Point

The break at point command enables the
- user to break an object at a specific point, creating two separate objects.



Break

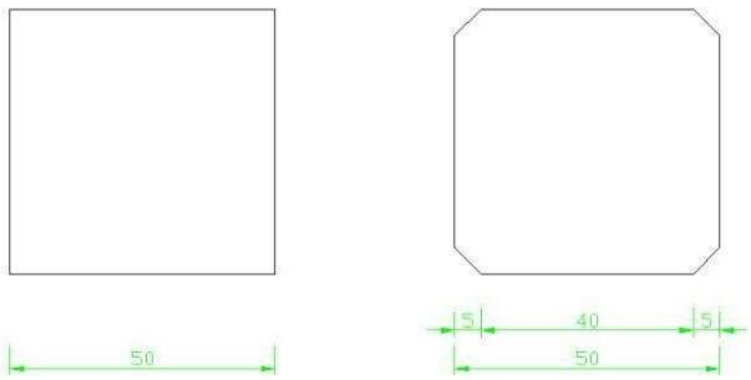
The break command is identical to the
- break at point command, except the break line isn't as neat as break at point.

Break

Chamfer

The chamfer command will chamfer the
- intersection of two lines to a specified distance.

Chamfer



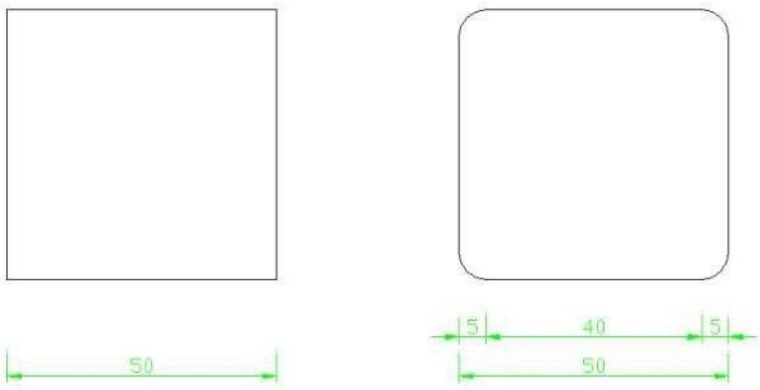
249

Fillet

The fillet command is very similar to the
• chamfer command above, except instead
of creating a straight line chamfer,
Autocad creates a radius between the
two points.

250

Fillet

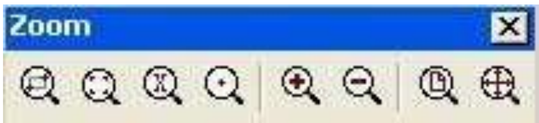


Explode

• The explode command is very straight forward. It simply breaks down an object down to its basic line entities.

ZOOM

- AutoCAD's zoom command toolbar:



Zoom real time and Pan

- Pan Button

Zoom real time and Pan

While holding the left mouse button, pull
• the mouse to the left, right, up or down.
Notice how the pan tool reflects these mouse movements on screen so we can move around the screen effortlessly.

Day 4

Auto CAD

Deficiencies of Geometric Models

Geometric models have a number of deficiencies that seriously limit their usefulness to the extent that they are really attractive only for recording the detail design of the product.

1. Microscopic data The data available in geometric models is at low, microscopic level. For instance;

   - Boundary representation models are expressed in terms of geometry (points, lines, surfaces, etc) and topology (vertices, edges, faces, etc.),
   - CSG in terms of solid primitives and set operations

- **Unfortunately, the decision-making and reasoning processes of most engineering tasks require macroscopic entities**

Deficiencies of Geometric Models

2. **Lack of design intent** A related problem to microscopic data is that geometric models cannot make the distinction between the geometry which is there to satisfy interface constraints, or to satisfy functional requirements, or for other reasons, such as manufacturability.

3. **Single-level structure** Geometric models record the geometry at a single level of abstraction in terms of precisely dimensioned geometric entities. In other words, when ordinary geometric modeling methods are used, the exact geometry of the part being designed must be known in advance and defined using exact coordinates, orientations, geometric locations, and so on.

Deficiencies of Geometric Models

4. **Tedious construction** The geometry construction methods typically supported in geometric modelers are not in line with how designers view the part.

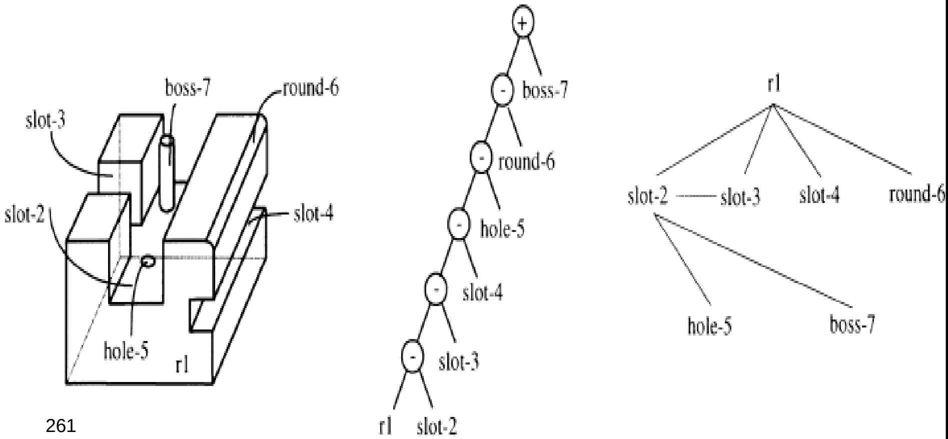
   - The primitives are very low level; locating and orienting entities with respect to each other must be done tediously by means of arbitrary points, lines, and planes.

- All problems of geometric modeling discussed in the previous slides point in the same direction:

some macroscopic entities should be available in explicit form in the model.

Feature-based Design (FBD)

Feature modeling, in brief, is an approach where high-level modeling entities termed "features" are utilized to provide all the above improvements to ordinary geometric modeling techniques.



Definition of Feature

- Features are generic shapes with which engineers associate certain attributes and knowledge useful in reasoning about the product.
- Features encapsulate the engineering significance of portions of the geometry and, as such, are important in product design, product definition, and reasoning for a variety of applications
- A specific geometric configuration formed on the surface, edge, or corner of a workpiece intended to modify outward appearance or to achieve a given function.

Feature Model

A feature model is a data structure that represents a part or an assembly mainly in terms of its features.

- Each feature in the feature model is an identifiable entity that has some explicit representation.
- The shape of a feature may be expressed in terms of dimension parameters and enumeration of geometric and topological entities and relations, or in terms of construction steps needed to produce the geometry corresponding to the feature.
- The engineering significance may involve formalizing the function the feature serves, or how it can be produced, or what actions must be taken when performing engineering analysis or evaluation, or how the feature "behaves" in various situations.

The collection of features chosen to represent a part depends on the part type and the applications that the feature model is intended to support.

Types of Features

1. **Form features** Portions of nominal geometry; recurring, stereotypical shapes.
2. **Tolerance features** Deviations from nominal form/size/location.
3. **Assembly features** Grouping of various features types to define assembly relations, such as mating conditions, part relative position and orientation, various kinds of fits, and kinematic relations.
4. **Functional features** Sets of features related to specific function; may include design intent, non-geometric parameters related to function, performance, etc.
5. **Material features** Material composition, treatment, condition, etc.

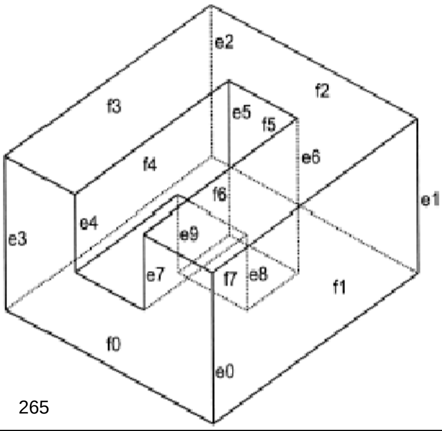
Form features, tolerance features, and assembly features are all closely related to the geometry of parts, and are hence called collectively Geometric Features.

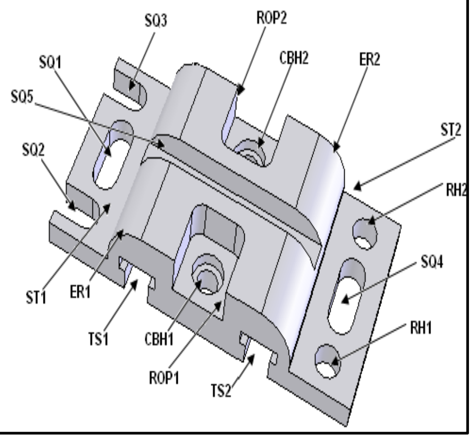
Types of Features

Features can also be broadly classified into two main categories, as follows:

Explicit features All the details of the feature are fully defined.

Implicit features Sufficient information is supplied to define the feature but the full details have to be calculated when required.

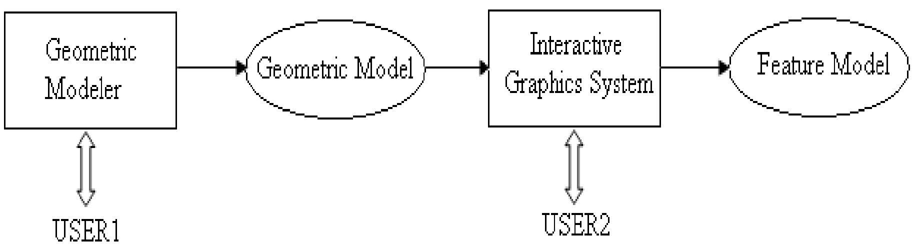




Feature Modeling Techniques

1- Interactive feature recognition

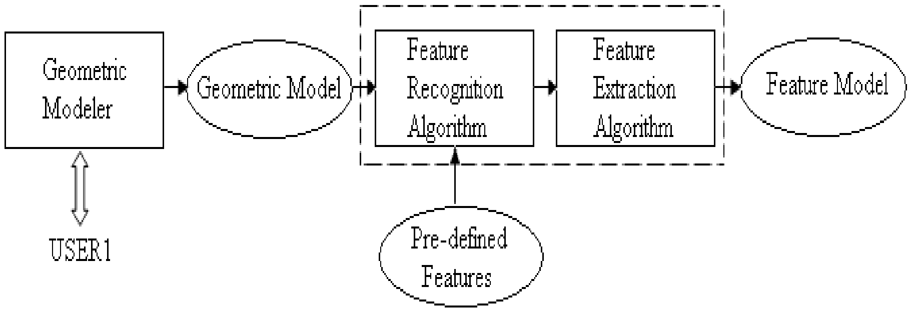
A geometric model is created first, then features are created by human users, such as by picking entities in an image of the part



Feature Modeling Techniques

2- Automatic feature recognition

A geometric model is created first, and then a computer program processes the resulting model to automatically find features

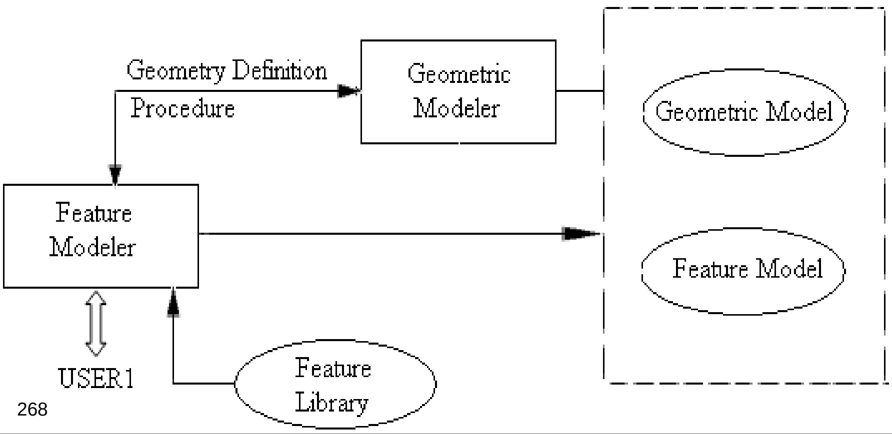


267

Feature Modeling Techniques

3- Design by features

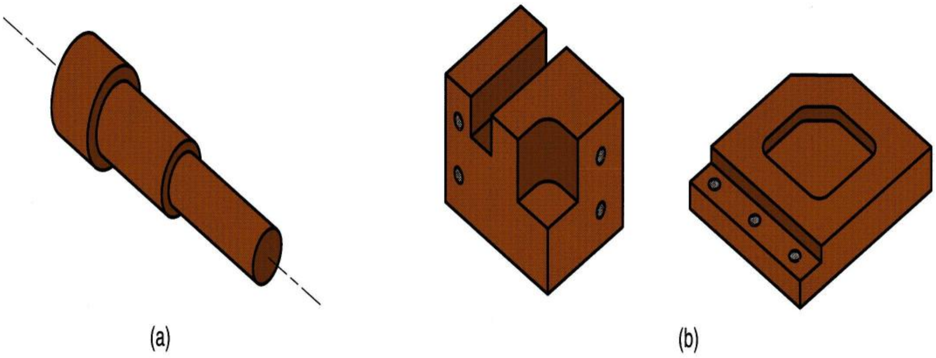
The part geometry is created directly in terms of features; geometric models are created from the features



268

Classification of AERONAUTICAL Parts

- *Rotational* - cylindrical or disk-like shape
- *Nonrotational* (also called *prismatic*) - block-like or plate-like



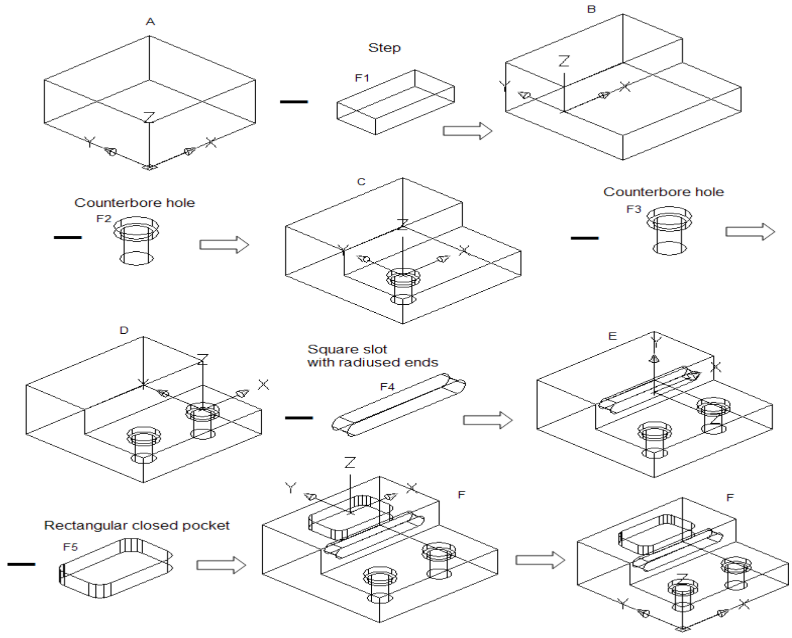
AERONAUTICAL parts are classified as: (a) rotational, or (b) nonrotational, shown here by block and flat parts

Design by feature

1- Destructive by machining features

In the destructive by machining features approach, one starts with a model of the raw stock from which a part is to be machined; the part model is created by subtracting from the stock, features corresponding to material removed by machining operations.

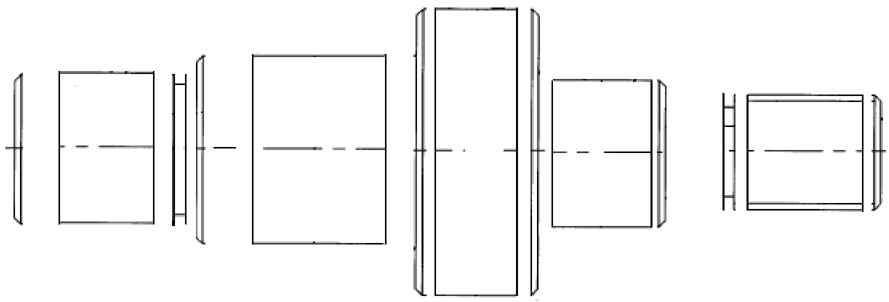
This facilitates a manufacturing plan to be concurrently developed.



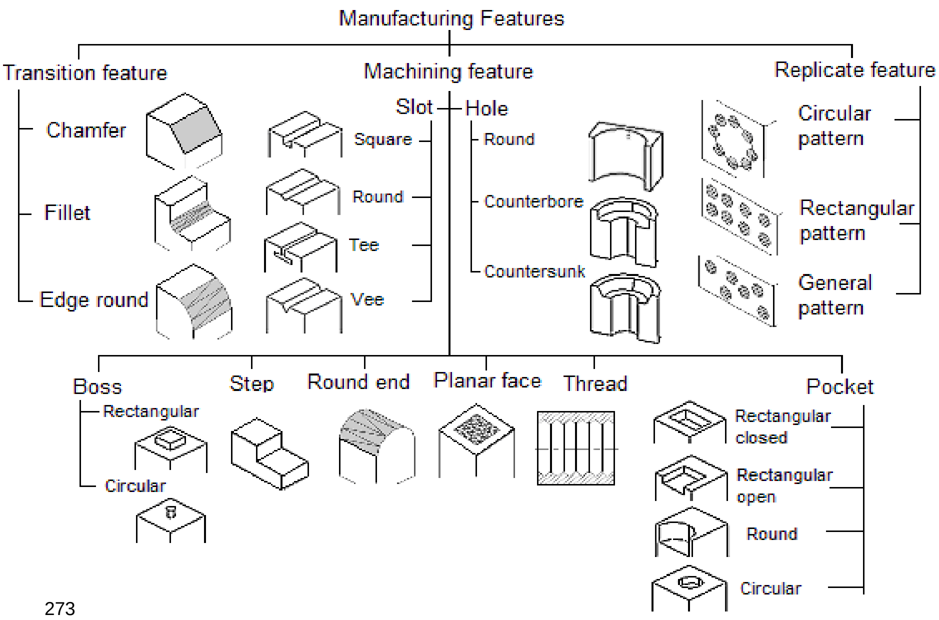
Design by feature

2- Synthesis by design features

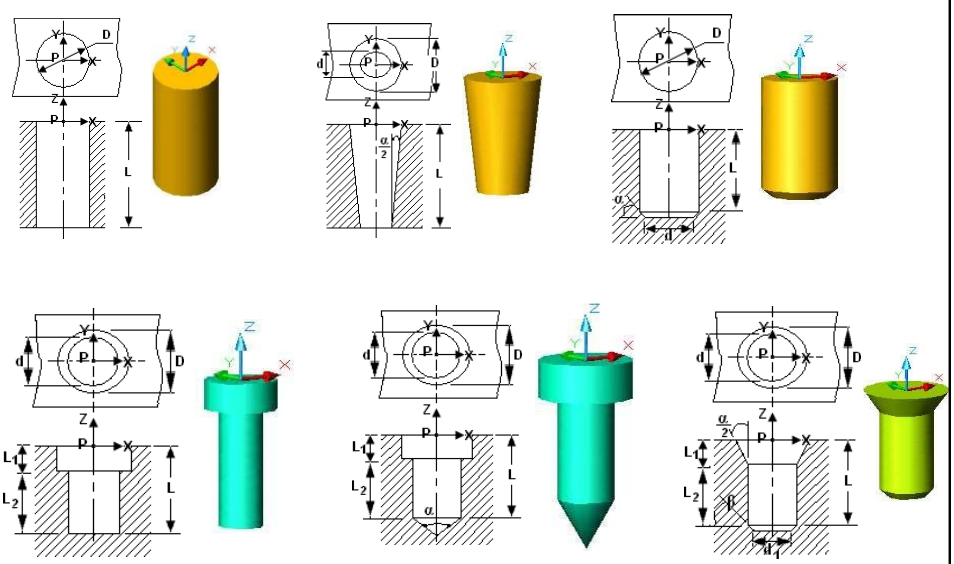
The synthesis by design features approach differs from the above in that models can be built both by adding and subtracting features; it is not necessary to start with the model of the base stock.



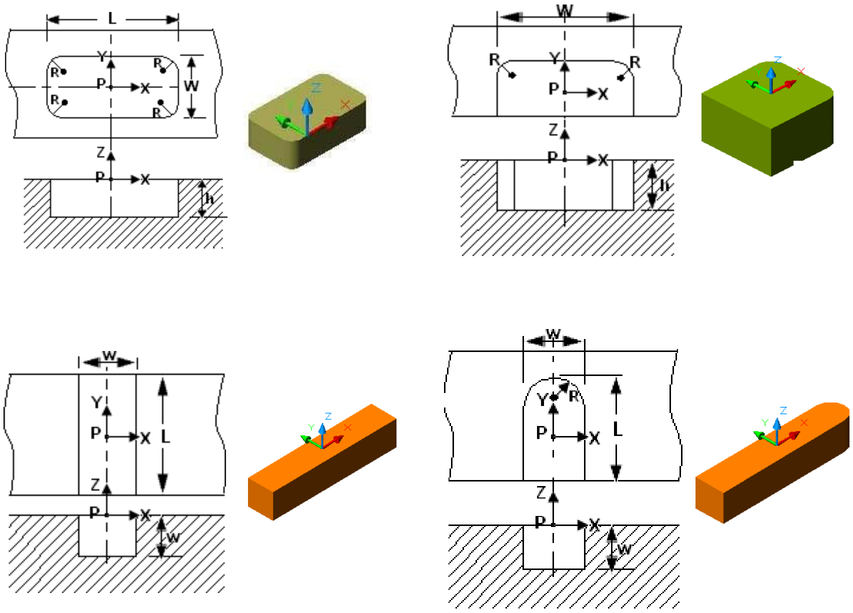
Features Library



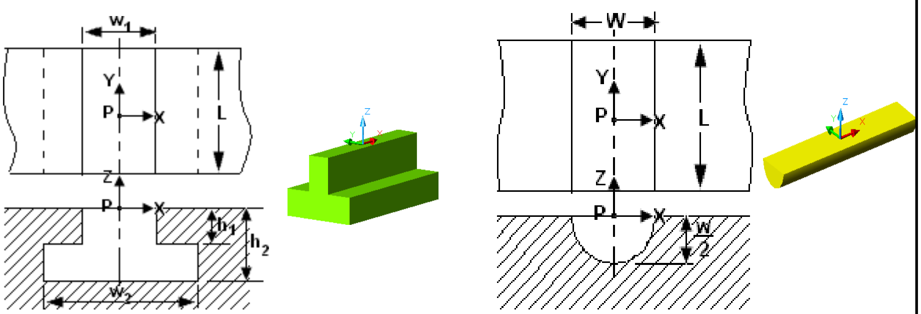
Features Library



Features Library



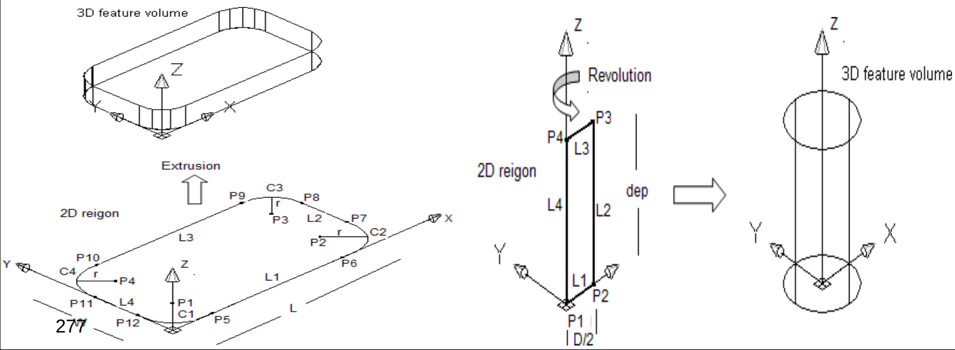
Features Library



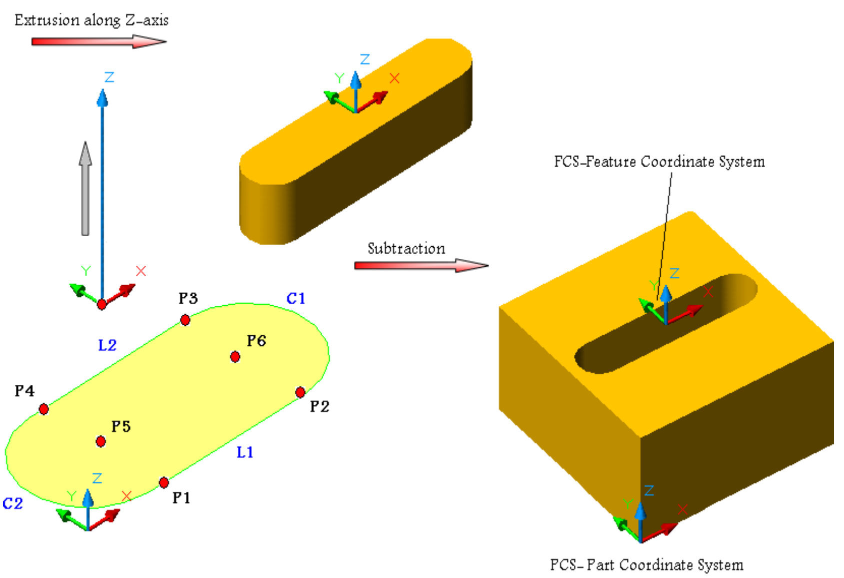
Feature Creation

Feature creation usually consists of two main stages.

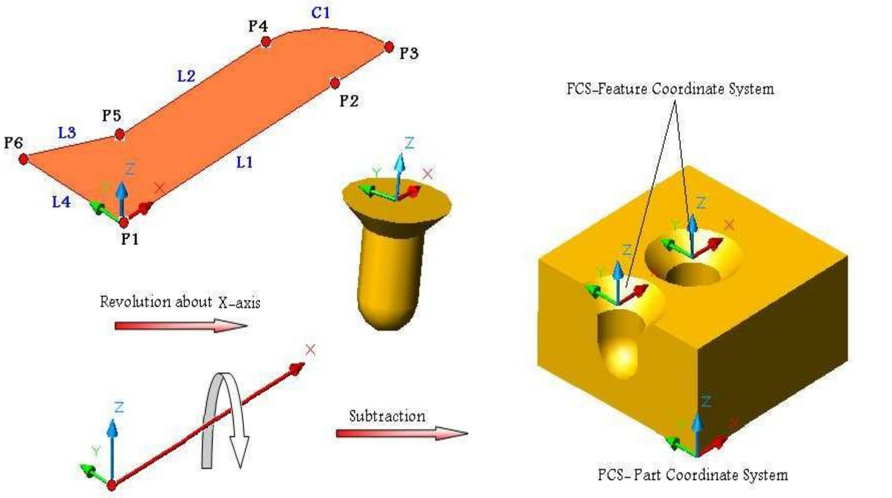
- The first stage deals with the building of a two-dimensional feature region.
- The second stage deals with the generation of three-dimensional feature volume.



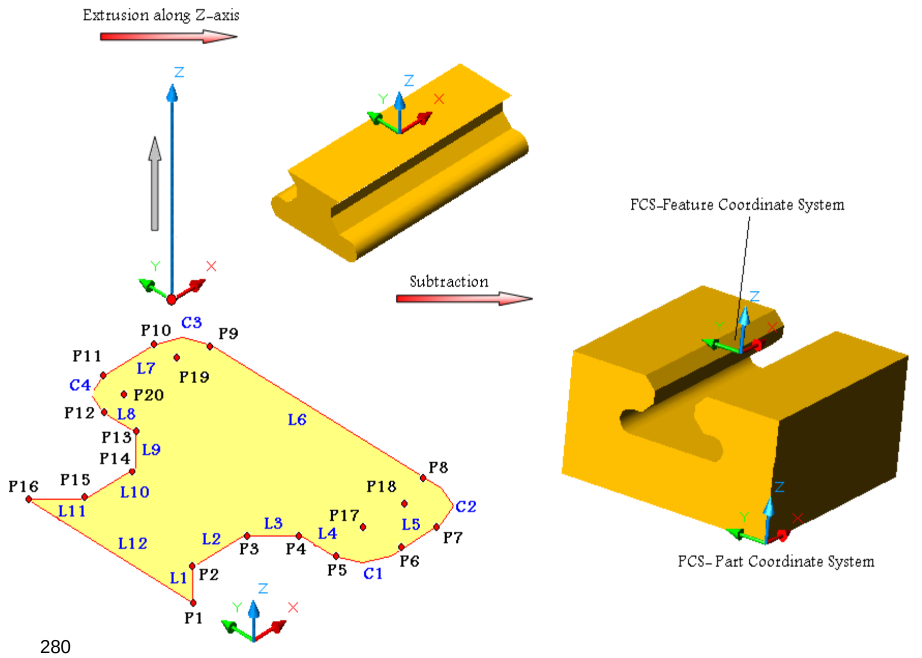
Feature Creation



Feature Creation

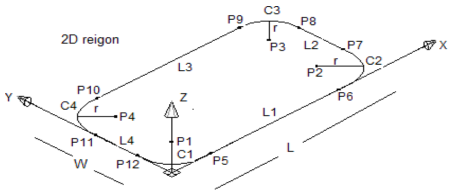


Feature Creation



Features Attachment

- Feature attachment is the process by which the user includes a new feature in the part under design
- Feature attachment consists of a number of steps.
- First, the feature to be attached is selected visually by its name and then the user provides interactively the minimal and sufficient information needed to define the feature

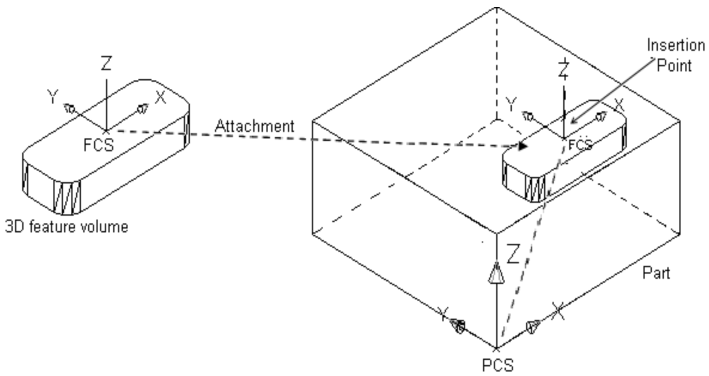


P0(L/2, W/2, h)	P1(r, r, 0)	P2(L-r, r, 0)
P3(L-r, W-r, 0)	P4(r, w-r, 0)	P5(r, 0, 0)
P6(L-r, 0, 0)	P7(L, r, 0)	P8(L, W-r, 0)
P9(L-r, W, 0)	P10(r, w, 0)	P11(0, W-r, 0)
P12(0, r, 0)	L1(P5, P6)	L2(P7, P8)
L3(P9, P10)	L4(P11, P12)	C1(P1, r, 180°, 270°)
C2(P2, r, 270°, 0°)	C3(P3, r, 0°, 90°)	C4(P4, r, 90°, 180°)

L = pocket length, W = pocket width, h = pocket depth
r = corner radius, P0 = pocket insertion point.

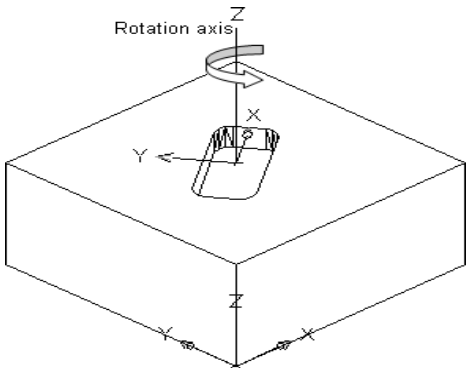
Features Attachment

- Second, after generating the feature, the feature position is fixed by placing the feature in the specified insertion point in the part



Features Attachment

- Third, the feature orientation is adjusted by specifying the part face upon which is to be attached.

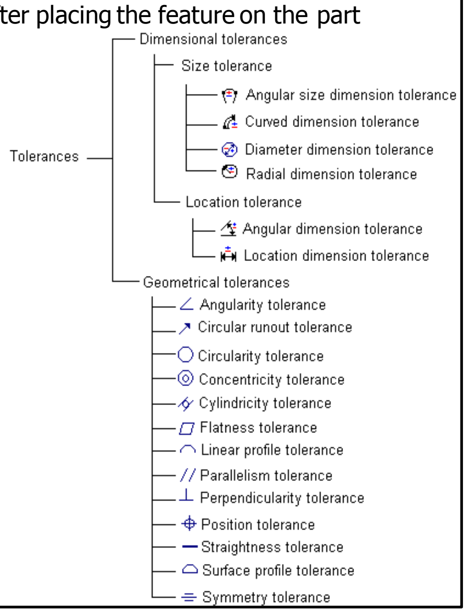


- Finally, feature Boolean operation is performed by subtracting, intersection or adding the feature to the part under design

Features Technological Attributes Attachment

1. Tolerances Attributes

- Feature tolerances can be attached right after placing the feature on the part
- Generally, two types of tolerances can be attached: dimensional and geometric tolerances.
- Each tolerance is a self-standing entity which may be applied to more than one feature, and several tolerances may apply to the same feature.



Features Technological Attributes Attachment

2. Surface Attributes

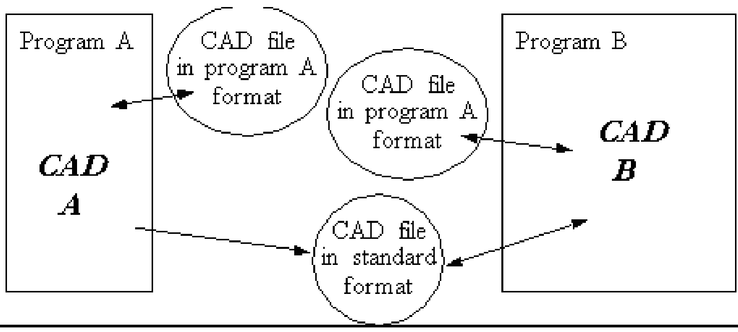
- Surface attributes specify the characteristics of a surface that are elements of the shape of a feature or a part (for example: Surface Finish).

3. Process Attributes

- A process attributes can be attached as series of actions or operations directed toward changing the feature or part properties

CAD Data Exchange

- Every CAD package stores information internally in a format that it best suited for that package. When the user is done this information is written to files on the hard drive.
- For most modern engineering applications it is necessary to be able to transfer CAD models between dissimilar computer programs.
- Standard file formats are the best method for storing and transferring CAD geometries (and other information) between dissimilar programs.



CAD Data Exchange Standards

Some types are

- **DXF - Primarily developed by Autodesk (for AutoCAD) to transfer geometry using ASCII definitions**
- **IGES - Initial Graphics Exchange Specification for product data exchange began in 1979**
- **SET - Standard d'Echange et de Transfert - Made to be more compact than IGES**
- **STEP and PDES (Standard for the Exchange of Product model data and Product Data Exchange Specification) An attempt to model other attributes of a product, in addition to geometry, such as tolerancing. This is the emerging standard, but it is not widely available yet.**
- **VDA-FS (DIN 66301) A German approach for modelling surfaces**
- **VDA-IS - A German subset of IGES for the auto industry**

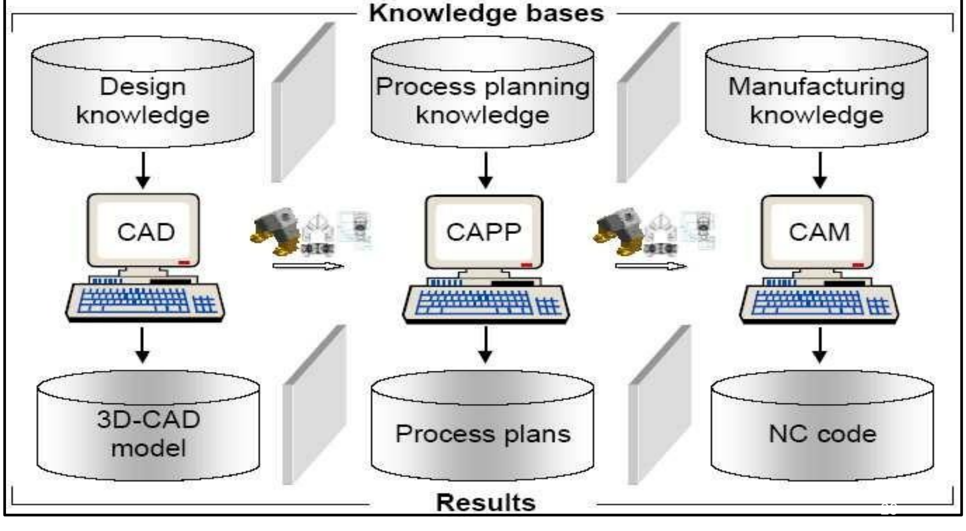

```
This is a CADDS part
being tested for IGES conversion                                  S  1
,,8HTESTIGES, 13Higes.TESTIGES, 49HCOMPUTERVISION                 S  2
CADDStation REV 4.0 GRAPHIC SYSTEM, 28HIGES                       G  1
VERSION 4.0 (06-OCT-88),32,38,6,308,14,8HTESTIGES,                G  2
1.0,1,4HINCH, 32767, 32.767, 13H891013.124852,0.000001,,          G  3
12HCENGIZ YEKER,2HNU,6,3;                                         G  4
124   1  1  0   0  0  0  0                                       1D  1
124   0  0  1   0                                                 D  2
124   2  1  0   0  0  0  0                                       1D  3
124   0  0  1   0                                                 D  4
124   3  1  0   0  0  0  0                                       1D  5
124   0  0  1   0                                                 D  6
124   4  1  0   0  0  0  0                                       1D  7
124   0  0  1   0                                                 D  8
124   5  1  0   0  0  0  0                                       1D  9
124   0  0  1   0                                                 D 10
124   6  1  0   0  0  0  0                                       1D 11
124   0  0  1   0                                                 D 12
406   7  1  0   0  0  0  0                                   10201D 13
406   0  0  1  15                                                 D 14
124   8  1  0   0  0  0  0                                   10101D 15
124   0  0  1   0                                                 D 16
108   9  1  0   0  0  0  0                                   10001D 17
108   0  0  1   1                                                 D 18
108  10  1  0   0  0  0  0                                   10001D 19
108   0  0  1   1                                                 D 20
108  11  1  0   0  0  0  0                                   10001D 21
108   0  0  1   1                                                 D 22
108  12  1  0   0  0  0  0                                   10001D 23
108   0  0  1   1                                                 D 24
410  13  1  0   0  0 15  0                                   10201D 25
410   0  0  1   0                                                 D 26
116  14  1  1   0  0  0  0                                       1D 27
116   0  0  1   0                                                 D 28
116  15  1  1   0  0  0  0                                       1D 29
116   0  0  1   0                                                 D 30
116  16  1  1   0  0  0  0                                       1D 31
116   0  0  1   0                                                 D 32
402  17  1  0   0  0  0  0                                     201D 33
402   0  0  1   4                                                 D 34
110  18  1  1   0 33  0  0                                       1D 35
110   0  0  1   0                                                 D 36
402  19  1  0   0  0  0  0                                     201D 37
402   0  0  1   4                                                 D 38
110  20  1  1   0 37  0  0                                       1D 39
110   0  0  1   0                                                 D 40
100  21  1  1   0  0  3  0                                       1D 41
```

UNIT 5

COMPUTER AIDED MANUFACTURING

Introduction to Computer Aided Manufacturing - CAM

Computer Aided Manufacturing involves the use of computer programs specifically designed to create the geometry and tool paths needed for parts to be machined. These tool paths can then be automatically processed into a program specific for the CNC machine to be used.



Definition of Numerical Control (NC)

- Numerical Control (NC) is a form of programmable automation in which the AERONAUTICAL actions of a machine tool or other equipment are controlled by a program containing coded instructions (alphanumeric data)

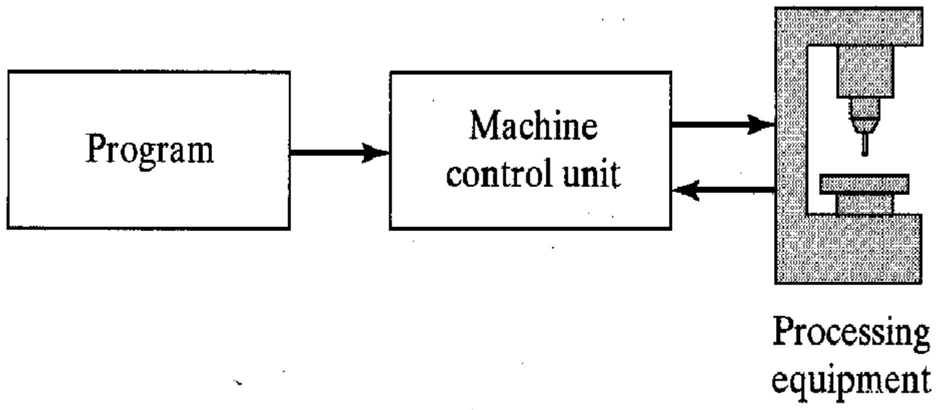
- The collection of all instructions (or program of instruction) necessary to machine a part is called an NC program, CNC program, or a part program.

- The person who prepares this program is called a part programmer.

Basic Components of NC System

- An NC system consists of three basic components:

  1. A program of instructions,
  2. A machine control unit, and
  3. Processing equipment.



Basic Components of NC System

1 Program of instruction

The program of instructions is the detailed step-by-step commands which refer to positions of a cutting tool relative to the worktable on which the workpart is fixed.

2 Machine Control Unit

It consists of a microcomputer and related control hardware that stores the program of instructions and executes it by converting each command into AERONAUTICAL actions of the processing equipment, one command at a time.

3 Processing Equipment

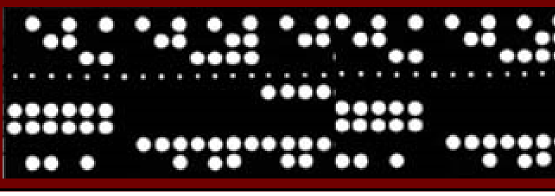
It accomplishes the processing steps to transform the starting workpiece into a completed part. Its operation is directed by the control unit, which in turn is driven by instructions contained in the part program.

NC and CNC Technology

- The NC stands for the older and original Numerical Control technology.
- The CNC stands for the newer Computerized Numerical Control technology.
- Both systems perform the same task, namely manipulation of data for the purpose of machining a part.
- In both cases, the internal design of the control system contains the logical instructions that process the data.

NC Technology

- The NC system uses a fixed logical functions, those that are built-in and permanently wired within the control unit.
- These functions can not be changed by the programmer or the machine tool operator.
- The system can interpret a part program, but it does not allow any changes to the program.
- NC system requires the use of punched tapes for input of the program instructions.



CNC Technology

- The modern CNC system uses an internal micro processor (computer).
- This computer contains memory registers storing a variety of routines that are capable of manipulating logical functions.
- The part program or the machine operator can change the program on the control itself (at the machine).

Advantages and Disadvantages of NC

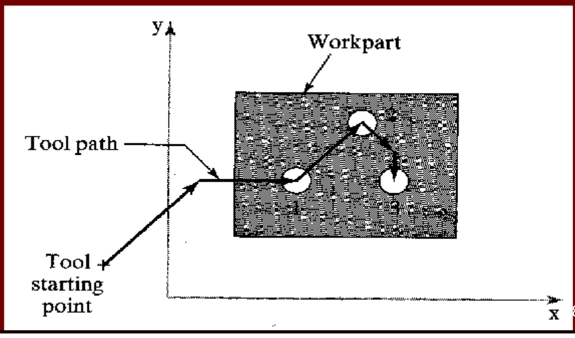
- **The advantages generally attributed to NC, with emphasis on machine tool applications, are the following:**
    1. **Non-productive time is reduced (fewer setups, less setup time, reduced workpiece handling time, and automatic tool changes).**
    2. **Greater accuracy and repeatability.**
    3. **More-complex part geometries are possible.**
    4. **Simplified tooling and work holding.**
    5. **Operator skill-level requirements are reduced.**
    6. **Inspection requirements are reduced.**
- **The disadvantages of NC include the following:**
    1. **Higher investment cost.**
    2. **Higher maintenance effort.**
    3. **Part programming.**

Motion Control Systems for NC

- **Motion control systems for NC can be divided into two types:**
    1. **Point-to-point systems.**
    2. **Continuous systems.**

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

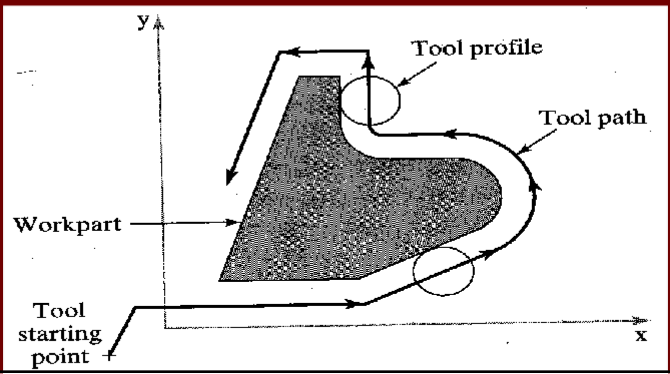
- **These systems move the worktable to a programmed location without regard for the path taken to get to that location.**
- **Once the move has been completed, some processing action is accomplished by the workhead at the location, such as drilling or punching a hole.**



Motion Control Systems for NC

(2) Continuous Path Systems

- Generally refer to systems that are capable of continuous simultaneous control of two or more axes.
- This provides control of the tool trajectory relative to the workpart.
- The tool performs the process while the worktable is moving, thus enabling the system to generate angular surfaces, 2D curves, and 3D contours.



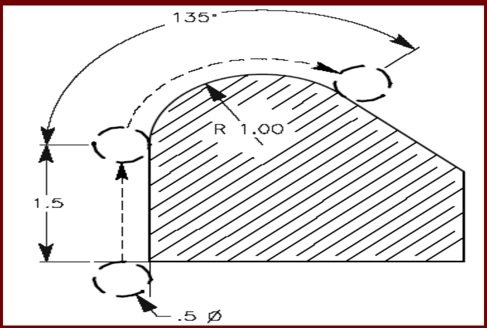
Types of Continuous paths

- **Straight-Cut**

  When continuous path control is utilized to move the tool parallel to only one of the major axes of the machine tool worktable.

- **Contouring**

  When continuous path control is used for simultaneous control of two or more axes in machining operations.

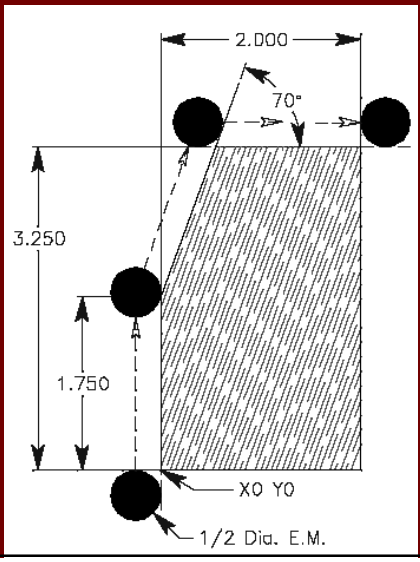


Interpolation Methods

- A number of interpolation methods are available to deal with the various problems encountered in generating a smooth continuous path in contouring.
  1. Linear interpolation.
  2. Circular interpolation.
  3. Helical interpolation.
  4. Parabolic interpolation
  5. Cubic interpolation
- Linear and Circular interpolations are almost always included in modern CNC systems.
- Helical interpolation is a common option.
- Parabolic and Cubic interpolation are less common, they are only needed by machine shops that must produce complex surface contours.

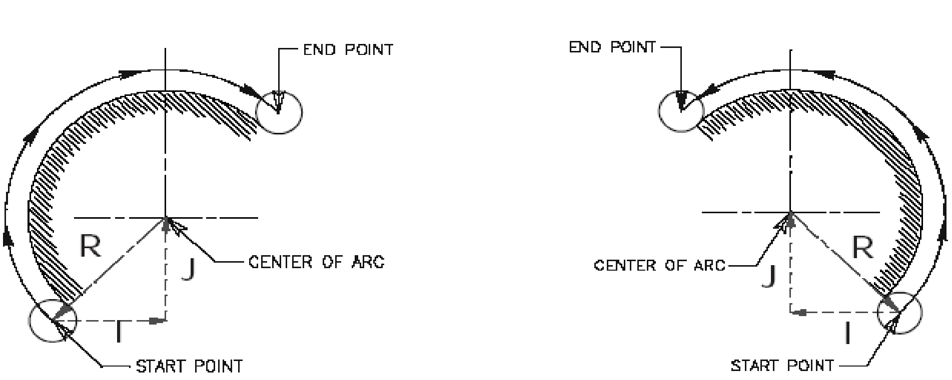
Linear Interpolation

This is the most basic and is used when a straight line path is to be generated in continuous path NC.



Circular Interpolation

- This method permits programming of a circular arc by specifying:
  1. The coordinates of the starting point.
  2. The coordinates of the end point.
  3. Either the center or radius of the arc.
  4. The direction of the cutter along the arc.



Helical Interpolation

- This method combines the circular interpolation scheme for two axes with linear movement of a third axis.

Parabolic and Cubic Interpolations

- These routines provide approximations of free form curves using higher order equations

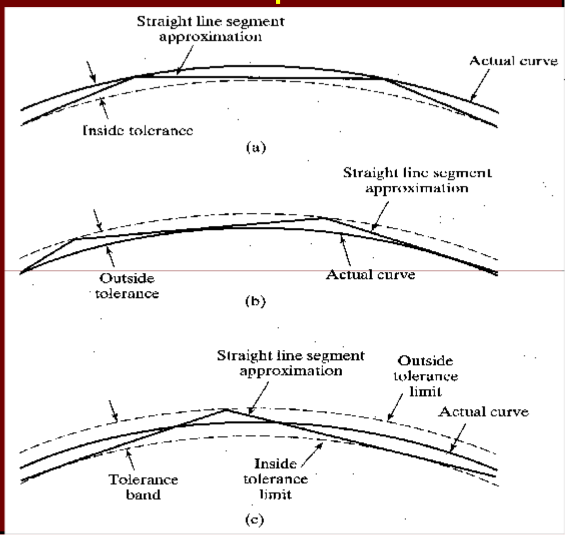
Approximation of a Curved Path in NC

- **To cut along a circular path, the circle must be divided into a series of straight line segments that approximate the curve.**
- **The tool is commanded to machine each line segment so that the machined surface closely matches the desired shape.**

(a)The tolerance is defined on only the inside of the nominal curve.

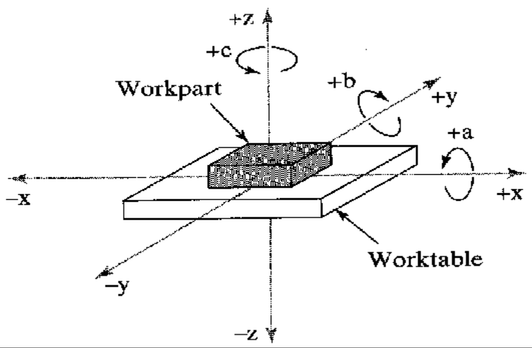
(b)The tolerance is defined on only the outside of the desired curve.

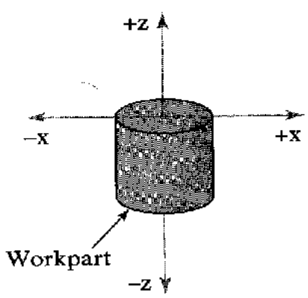
(c)The tolerance is defined on both the inside and outside of the desired curve.



NC Coordinate Systems

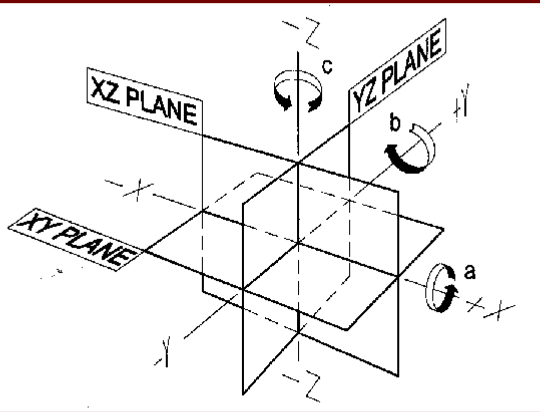
- **To program the NC processing equipment, a standard axis system must be defined by which the position of the workhead relative to the workpart can be specified.**
- **There are two axis systems used in NC, one for flat and prismatic parts and the other for rotational parts.**
- **Both axis systems are based on the Cartesian Coordinate System.**

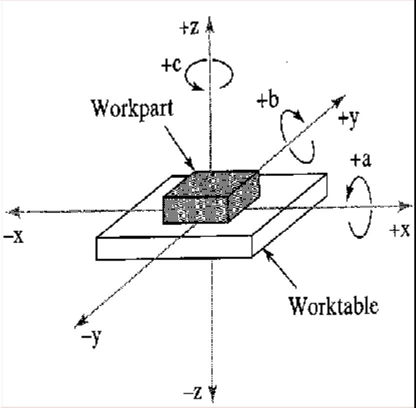




NC Coordinate Systems

- **The axis system for flat and prismatic parts consists of:**
  1. **Three linear axes (X, Y, Z) in Cartesian coordinate system.**
  2. **Three rotational axes (A, B, C)**

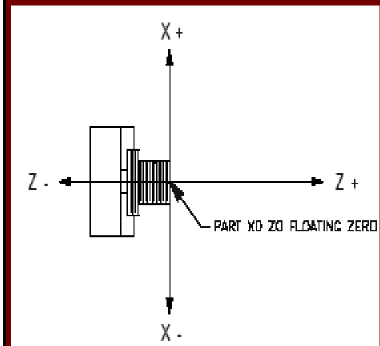


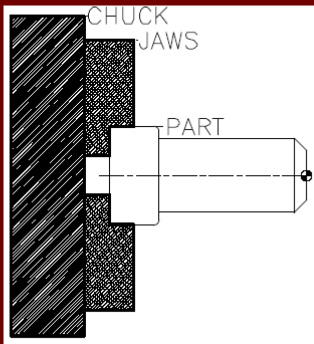


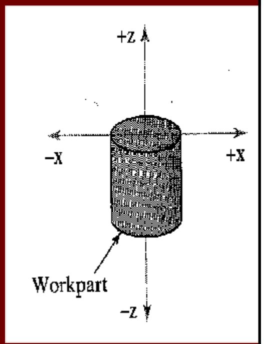
- **In most machine tool applications, the x-axes and y-axes are used to move and position the worktable to which the part is attached, and the z-axis is used to control the vertical position of the cutting tool**

NC Coordinate Systems

- **The axis system for rotational parts is shown below**



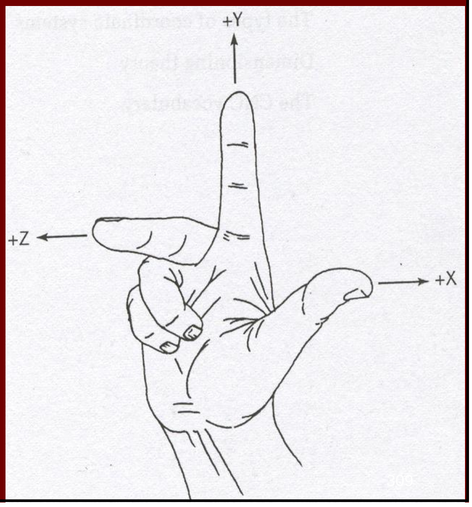




- **The path of the cutting tool relative to the rotating workpiece is defined in the x-z plane.**
- **The x-axis is the radial location of the tool.**
- **The z-axis is parallel to the axis of rotation of the part.**

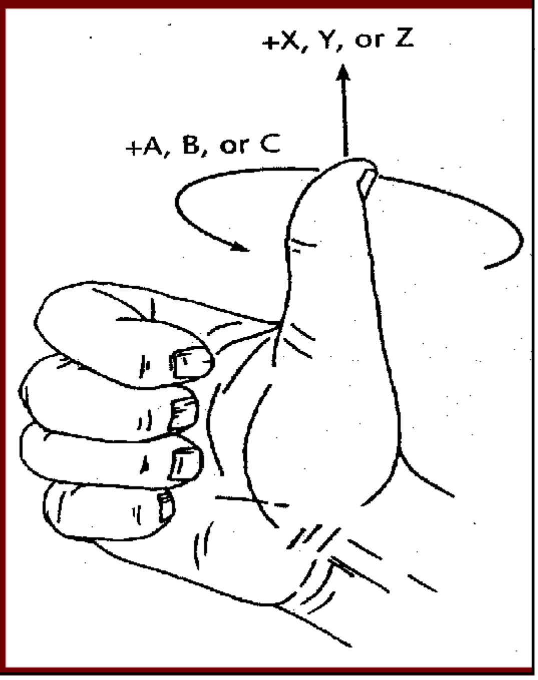
The Right-hand rule of Coordinates

- The machine coordinate system is described by the right-hand rectangular coordinate system.
- Based on this system, the right-hand rule governs how the primary axis of a machine tool should be designated.
- Hold your right hand with the thumb, forefinger, middle finger perpendicular to each other.
- The thumb represents the X-axis
- The forefinger represents the Y-axis
- The middle finger represents the Z-axis
- The other two fingers are kept closed



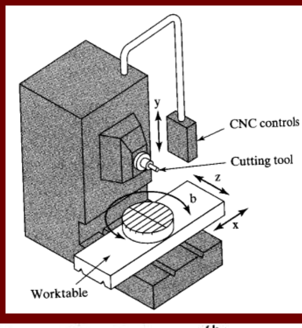
The Right-hand rule of Coordinates

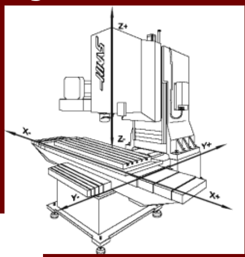
- To determine the positive direction, clockwise, about an axis, close your hand with the thumb pointing out in the positive direction.
- The thumb may represent the X, Y, or Z axis direction.
- The curl of the fingers may represent the clockwise, or positive, rotation about each axis.



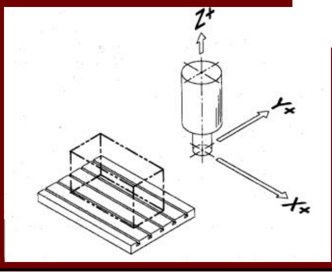
CNC Milling Machines

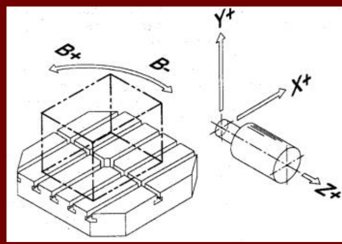
- In the area of milling systems, three most common machine tools are available:
  - ❑ CNC Vertical Machining Center – VMC
  - ❑ CNC Horizontal Machining Center – HMC
  - ❑ CNC Horizontal Boring Mill





Vertical

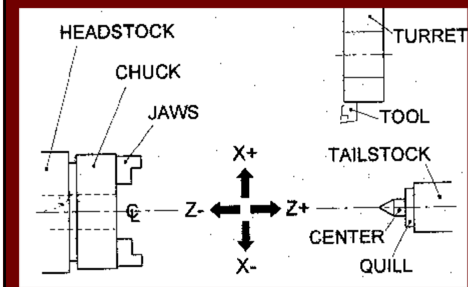




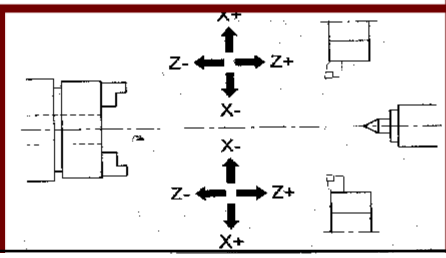
Horizontal

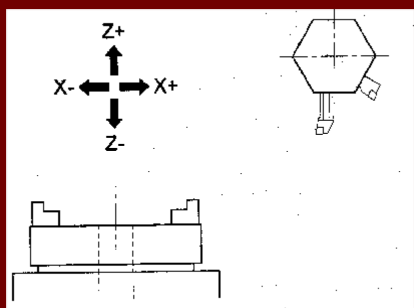
CNC Turning Machines

- In the area of turning systems, two basic types are available:
  - ❑ Vertical CNC Lathe
  - ❑ Horizontal CNC Lathe



Horizontal

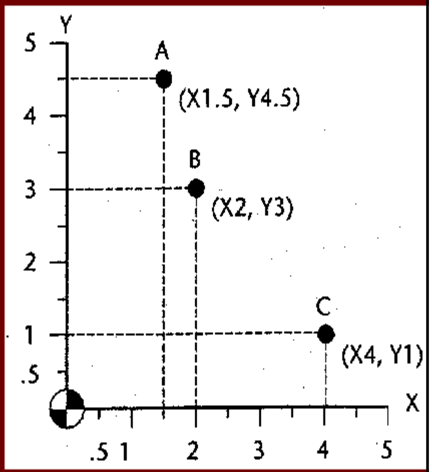




Vertical

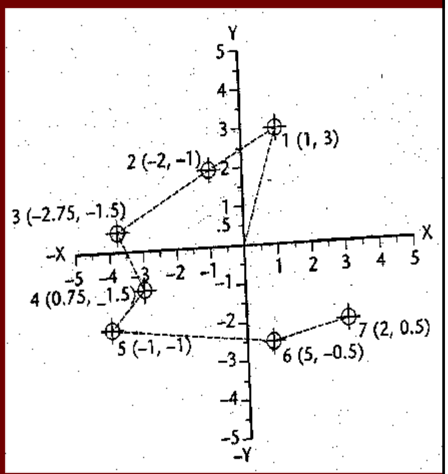
Absolute Coordinates for Milling

- **Absolute coordinates use the origin point as the reference point.**
- **This means that any point on the Cartesian graph can be plotted accurately by measuring the distance from the origin to the point, first in the X direction and then in the Y direction – then, (if applicable), in the Z direction.**
- **<u>Point A:</u> this point is 1.5 units along the X axis from the origin and 4.5 units along the Y axis from the origin. It is as (X1.5, Y4.5)**
- **<u>Point B:</u> this point is 2 units along the X axis from the origin and 3 units along the Y axis from the origin. It is as (X2.0, Y3.0)**
- **<u>Point C:</u> this point is 4 units along the X axis from the origin and 1 units along the Y axis from the origin. It is as (X4.0, Y1.0)**



Incremental Coordinates for Milling

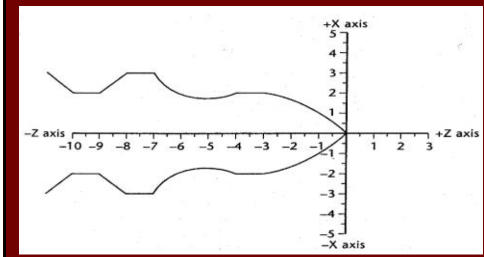
- **Incremental coordinates use the present position as the reference point for the next movement.**
- **This means that any point in the Cartesian graph can be plotted accurately by measuring the distance between points, generally starting at the origin.**
- **<u>Point 3</u> is (X-2.75, Y-1.5) units from the previous point (point 2)**
- **<u>Point 4</u> is (X0.75, Y-1.5) units from the previous point (point 3)**
- **<u>Point 5</u> is (X-1.0, Y-1.0) units from the previous point (point 4)**
- **<u>Point 6</u> is (X5.0, Y-0.5) units from the previous point (point 5)**
- **<u>Point 7</u> is (X2.0, Y0.5) units from the previous point (point 6)**

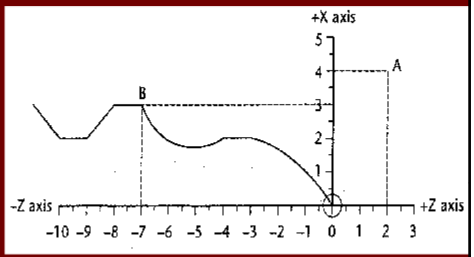


Diameter versus Radius Programming

- **Diameter programming** relates the X axis to the diameter of the workpiece. Therefore, if the workpiece has a 10 mm diameter and you want to command an absolute move to the outside, you would program X10

- **Radius programming** relates the X axis to the radius of the workpiece. Therefore, with the same size workpiece of 10 mm, you would program X5.0 to move the tool to the outside.



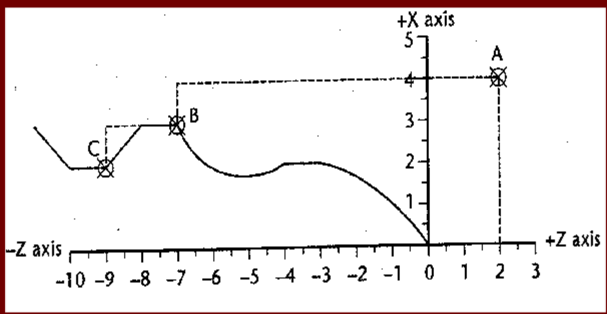


- Although many controllers can work in either mode, diameter programming is the most common and is the default with CNCez.

Absolute Coordinates for Turning

1. When plotting points using absolute coordinates, always start at the origin (X0, Z0).
2. The travel along the Z axis until you reach a point directly below the point that you are trying to plot.
3. Write down the Z value, then go up until you reach your point. Write down the X value.

Remember, travel left or right first along the Z axis and then up or down the X axis.



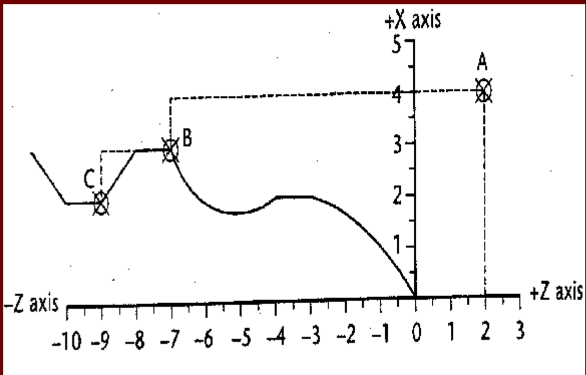
Absolute Coordinates for Turning

- **Example A: Find point A**
  1. Start at (X0, Z0).
  2. Travel right until you are below point A.
  3. Move up to point A.
     - The radial XZ coordinates for point A are (X4.0, Z2.0)
     - The diametrical XZ coordinates for point A are (X8.0, Z2.0)

Example B: Find point B

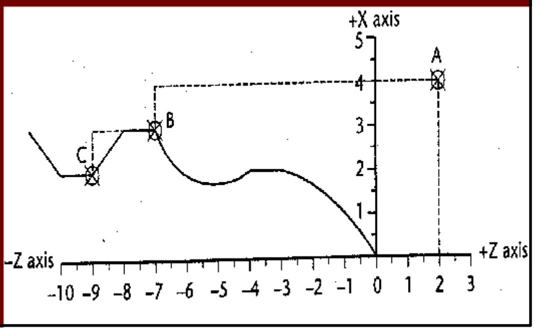
1. Start at (X0, Z0).
2. Travel along the Z axis to a point below point B.
3. Move up to point B.

- The radial XZ coordinates for point B are (X3.0, Z-7.0)
- The diametrical XZ coordinates for point B are (X6.0, Z-7.0)



Incremental Coordinates for Turning

- Incremental coordinates use each successive point to measure the next coordinate.
- Starting with the origin, each point in turn is the reference point to the next coordinate.
- **Example A: Find point A**
  1. Start at (X0, Z0), travel along the Z axis until you are below point A.
  2. Move up the X axis until you reach point A.
     - The radial XZ coordinates for point A are (X4.0, Z2.0)
     - The diametrical XZ coordinates for point A are (X8.0, Z2.0)
- **Example B: Find point B**
  1. Start at point A.
  2. Travel along the Z axis until you are below (or above) point B
  3. Move up (or down) the X axis until you are at point B
     - The radial XZ coordinates for point B are (X-1.0, Z-9.0)
     - The diametrical XZ coordinates for point B are (X-2.0, Z-9.0)



Flow of CNC Processing

- Before you can fully understand CNC, you must first understand how a manufacturing company processes a job that will be produced on a CNC machine.
- The following is an example of how a company may break down the CNC process:
  1. Obtain or develop the part drawing.
  2. Decide what machine will produce the part.
  3. Decide on the machining sequence.
  4. Choose the tooling required.
  5. Do the required calculations for the program coordinates.
  6. Calculate the speeds and feeds required.
  7. Write the NC program.
  8. Prepare setup sheets and tool lists.
  9. Send the program to the machine.
  10. Verify the program.
  11. Run the program if no changes are required.

Preparing a Program

- A program is a sequential list of machining instructions for the CNC machine to execute.
- These instructions are CNC code that contains all the information required to machine a part, as specified by the programmer.
- CNC code consists of blocks (also called lines), each of which contains an individual command for a movement or specific action.
- CNC codes are listed sequentially in numbered blocks. Each movement is made before the next one.
- A program is written as a set of instructions given in the order they are to be performed. The instructions, if given in English, might look like this:

LINE #1 = SELECT CUTTING TOOL.

LINE #2 = TURN SPINDLE ON AND SELECT THE RPM.

LINE #3 = RAPID TO THE STARTING POSITION OF THE PART.

LINE #4 = TURN COOLANT ON.

LINE #5 = CHOOSE PROPER FEED RATE AND MAKE THE CUT(S).

LINE #6 = TURN THE SPINDLE AND COOLANT OFF.

LINE #7 = RETURN TO CLEARANCE POSITION TO SELECT ANOTHER TOOL.

CNC Codes

- There are two major types of CNC codes, or letter addresses, in any program. The major codes are called G-codes and M-codes.

  - G-codes are preparatory functions, which involve actual tool moves. These include:
    - Rapid moves.
    - Feed moves.
    - Radial feed moves.
    - Dwells.
    - Roughing.
    - Profiling cycles.
  - M-codes are miscellaneous functions, which include actions necessary for machining but not those that are actual tool movement. These include:
    - Spindle on/off
    - Tool changes
    - Coolant on/off
    - Programs stops

CNC Codes

- Letter Addresses are variables used in G- and M-codes to make words. Most G-codes contain a variable, defined by the programmer, for each specific function. Each designation used in CNC programming is called a letter address.

The letters used for programming are as follows:

- N Block number
- G Preparatory function
- X X axis coordinate
- Y Y axis coordinate
- Z Z axis coordinate
- I X axis location of arc center
- J Y axis location of arc center
- K Z axis location of arc center
- S sets the spindle speed
- F assigns a feed rate
- T specifies tool to be used
- M Miscellaneous function
- U Incremental coordinate for X axis
- V Incremental coordinate for Y axis
- W Incremental coordinate for Z axis

Three Major Phases of A CNC Program

- The following shows the three major phases of a CNC program.

```
%
: 1001
N5 G90 G20              <-- Program set up
N10 M06 T2
N15 M03 S1200
N20 G00 X1.00 Y1.00
N25 Z0.125              <-- Material removal
N30 G01 Z-0.125 F5.0
N35 G01 X2.0 Y2.0
N40 G00 Z1.0
N45 X0 Y0
N50 M05
N55 M30                 <-- System shutdown
```

323

Three Major Phases of A CNC Program

1. Program Setup

The program setup contains all the instructions that prepare the machine for operation.

%	Program start flag
: 1001	Four-digit program number
N5 G90 G20	Use absolute units and inch programming
N10 M06 T2	Stop for tool change, use tool #2
N15 M03 S1200	Turn the spindle on CW to 1200 rpm

324

Three Major Phases of A CNC Program

2. Material Removal

The material removal phase deals exclusively with the actual cutting feed moves.

N20 G00 X1.0 Y1.0	Rapid move to (X1, Y1) from origin
N25 Z0.1	Rapid down to Z1.0 just above the part
N30 G01 Z-0.125 F5.0	Feed down to Z-0.125 at 5 ipm
N35 X2.0 Y2.0	Feed diagonally to X2 and Y2
N40 G00 Z1.0	Rapid up to Z1 (clear the part)
N45 X0 Y0	Rapid back home X0 Y0

3. System shutdown

The system shutdown phase contains the G- and M-codes that turn off all the options that were turned on in the setup phase.

N50 M05	Turn the spindle off
N55 M30	End of program

Using a Programming sheet

- You use the CNC program sheet to prepare the CNC program. Each row contains all the data required to write one CNC block

NC PROGRAMMING SHEET	PART NAME:	PROG BY:	
	MACHINE:	DATE:	PAGE:
	SETUP INFORMATION:		

N SEQ	G Code	X Pos'n	Y Pos'n	Z Pos'n	I J K Pos'n	F Feed	R Radius or Retract	S Speed	T Tool	M Misc
5	20, 90									
10									2	6
15								1200		3
20	0	0	0							
25				0.1						
30	1			-0.1		2				
35	1	1.5								

Some restrictions to CNC blocks

Sample block of CNC code

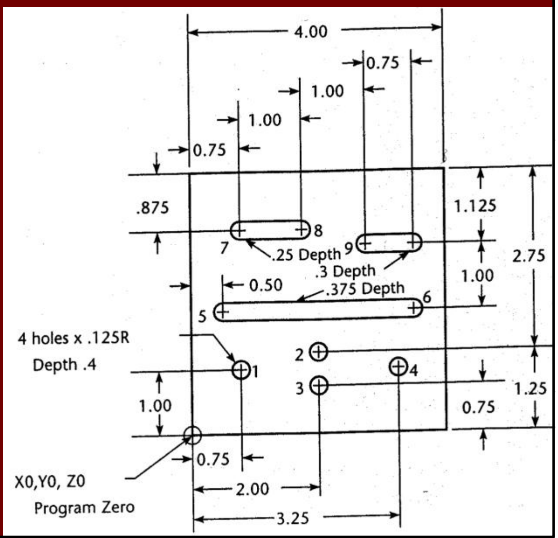
N135 G01 X1.0 Y1.0 Z0.125 F5.0

1. Each block may contain only one tool move.
2. Each block may contain any number of nontool move G-codes, provided they do not conflict with each other.
3. Each block may contain only one feed rate.
4. Each block may contain only one specified tool or spindle speed.
5. The block numbers should be sequential
6. Both the program start flag and the program number must be independent of all other commands.
7. Each block may contain only one M-code
8. The data within a block should follow the sequence shown in the above sample block
   - N-block number, G-code, any coordinates, and other required functions

Milling program zero location

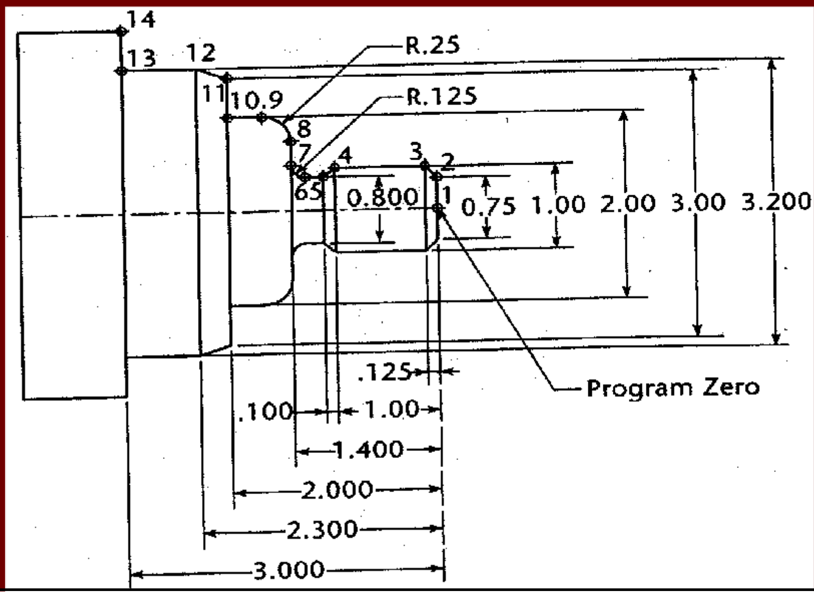
- Program zero allows you to specify a position from which to start or to work. Once program zero has been defined, all coordinates that go into a program will be referenced from it.

- Program Zero for milling is always the lower left-hand corner and top surface of the workpiece.



Lathe program zero location

- **Program Zero for lathe is always the center of the part in X and the right-hand end of the finished workpiece in Z.**



MFGE 404

Computer Integrated Manufacturing

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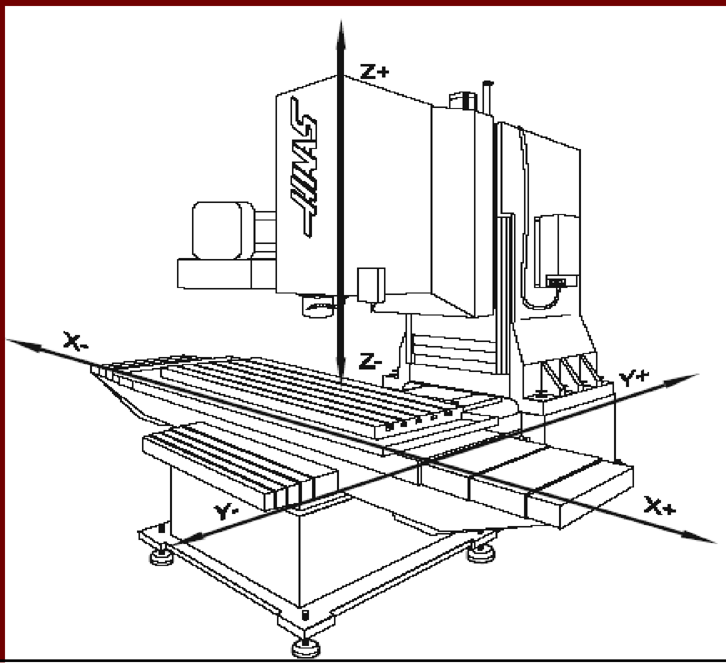
A T I L I M   U N I V E R S I T Y
Manufacturing Engineering Department

Lecture 5– Computer Aided Manufacturing - CAM

Fall 2005/2006

Dr. Saleh AMAITIK

CNC Milling Programming



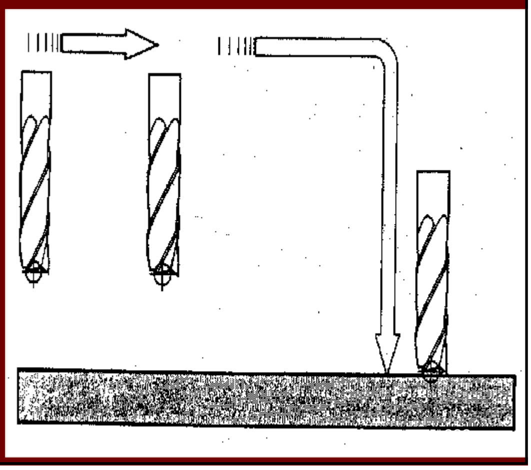
Positioning in Rapid G00

Z_ Y_ X_ G00 N_

- **The G00 command is a rapid tool move. A rapid tool move is used to move the toll linearly from position to position without cutting any material.**

- **This command is not to be used for cutting any material**

- **On most CNC machine tools, it is standard to program a G00 rapid for XY move only and the Z moves separately**

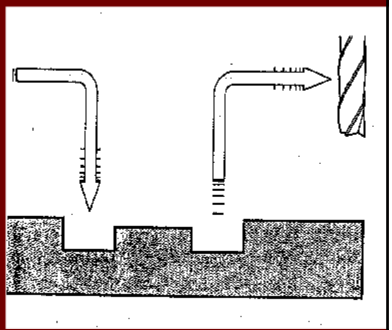


Positioning in Rapid G00

- **Depending on where the tool is located, there are two basic rules to follow for safety**

1. If the Z value represents a cutting move in the negative direction, the X and Y axes should be executed first

2. If the Z value represents a move in the positive direction, the X and Y should be executed last.



Example

Rapid to X2.5 Y4.75 — **Y4.75 X2.5 G00 N25**

Rapid down to Z0.1 — **Z0.1 N30**

Linear Interpolation G01

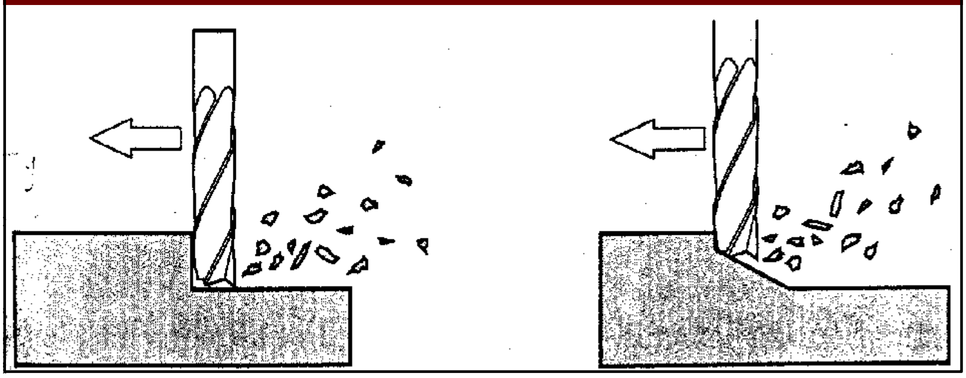
F_ Z_ Y_ X_ G01 N_

- **G01 command is specifically for the linear removal of material from a workpiece, in any combination of the X, Y, or Z axes.**
- **This G code provides for straight line (linear) motion from point to point. Motion can occur in 1, 2 or 3 axes. All axis specified will start at the same time and proceed to their destination and arrive simultaneously at the specified feed rate.**
- **Because there is contact between the cutting tool and the workpiece, it is imperative that the proper spindle speeds and feed rates be used.**

Linear Interpolation G01

Example

feed Down to Z-0.125 at ipm	F5	Z-0.125	G01	N30
feed diagonally to X3, Y2 at 10 ipm	F10	Y2	X3	N35



Circular Interpolation (CW) G02

The G02 command requires an endpoint and a radius

I, J, K specify the radius

F_	K_	J_	I_	Z_	Y_	X_	G02	N_

R specifies the radius

F_	R_	Z_	Y_	X_	G02	N_

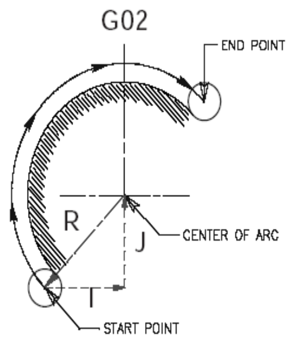
- The G02 command is used specifically for all clockwise radial moves, whether they are quadratic arcs, partial arcs, or complete circles, as long as long they lie in any one plane

Example

F20	J0	I1	Y2	X2	G02	N35
F20	R2	Y0.5	X3	G02	N45	

Circular Interpolation (CW) G02

- **Circular interpolation commands are used to move a tool along a circular arc to the commanded end position. Five pieces of information are required for executing a circular interpolation command:**



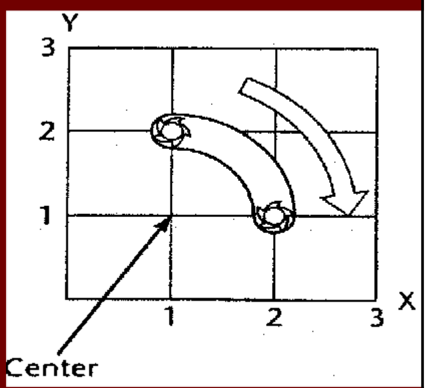
The Five pieces of information for executing a circular interpolation command.

	Item	Command	Remark
❶	Plane selection command	G17	Arc parrallel to XY-plane
	Plane selection command	G18	Arc parrallel to ZX-plane
	Plane selection command	G19	Arc parrallel to YZ-plane
❷	Arc start position coordinates	X,Y,Z	Coordinates of the start position
❸	Rotation direction	G02	Clockwise direction
		G03	Counterclockwise direction
❹	Arc end position (G90) Absolute	X,Y,Z	Coordinates of the end position on the work coordinate system
	or		
	Arc end position (G91) Incremental	X,Y,Z	Distance from start position to end position in X, Y, and Z axes, respectively
❺	I J K method (arc center coordinate)	I,J,K	Distance from start position to arc center in X, Y, and Z axes, respectively
	or		
	R method (arc radius)	R	Arc radius value

Circular Interpolation (CW) G02

- **An easy way to determine the radius values (I and J values) is by making a small chart:**

Center Point	**X1**	**Y1**
Start Point	**X1**	**Y2**
Radius	**I0**	**J-1**

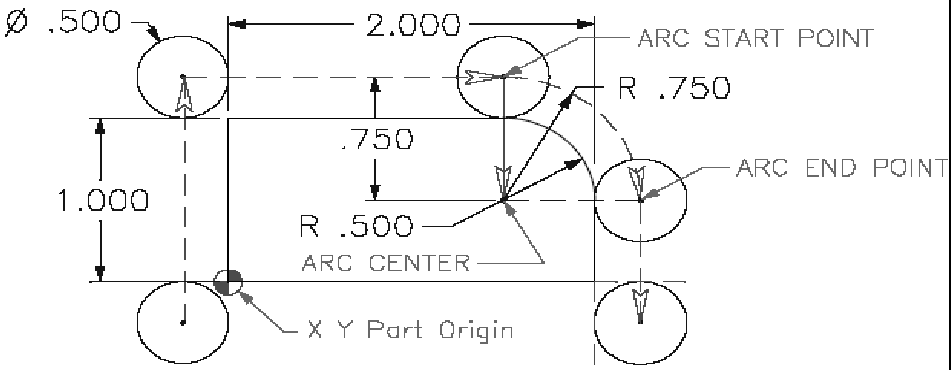


Result

J-1 F5 I0 Y1 X2 G02

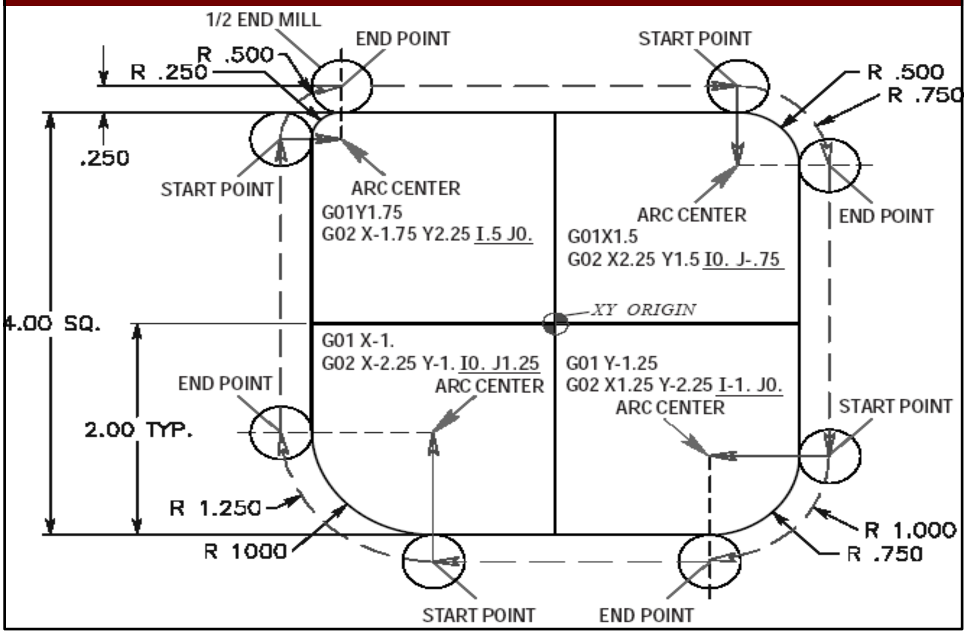
Circular Interpolation (CW) G02

Example

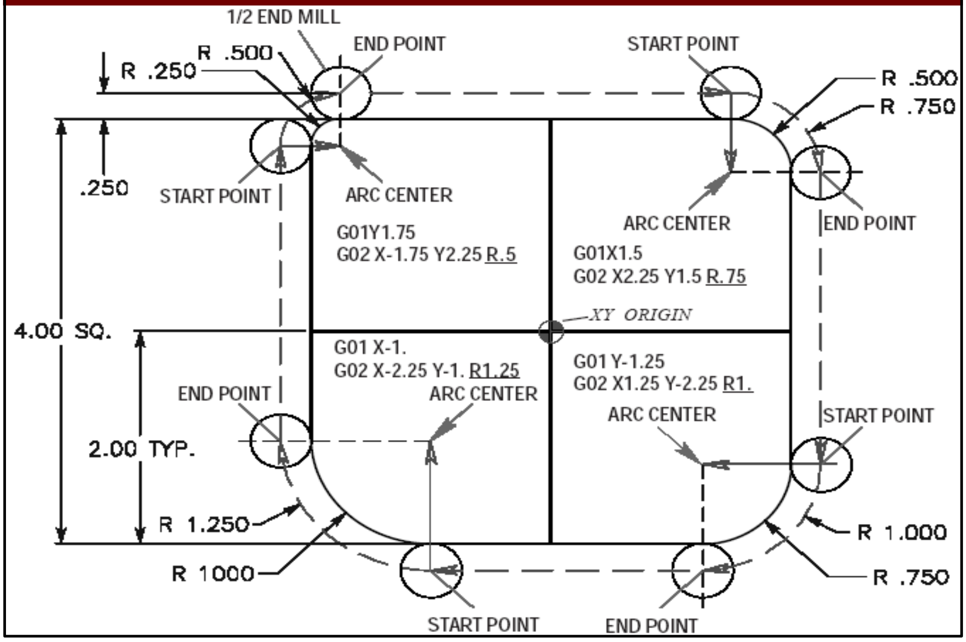


N6 G01 Y1.250 F12.
N7 X1.500 (to start point)
N8 G02 X2.250 Y.500 (I0. J-.750 or R.750)
N9 G01 Y-.25

G02 CW CIRCULAR INTERPOLATION USING "I", &"J" FOR THE X & Y AXIS



G02 CW CIRCULAR INTERPOLATION USING "R"



Circular Interpolation (CCW) G03

The G03 command requires an endpoint and a radius

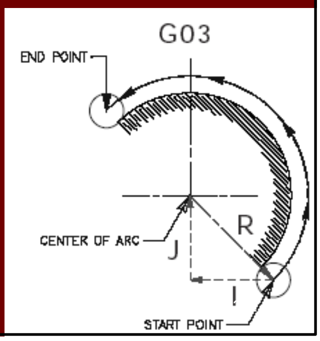
I, J, K specify the radius

F_	K_	J_	I_	Z_	Y_	X_	G03	N_

R specifies the radius

F_	R_	Z_	Y_	X_	G03	N_

- **The G03 command is specifically for all counterclockwise radial feed moves, whether they are quadratic arcs, partial arcs, or complete circles, as long as they lie in any plane.**



Example

F20 J0 I-0.5 Y3.5 X3 G03 N40

F20 R0.5 Y1 X3.5 G03 N60

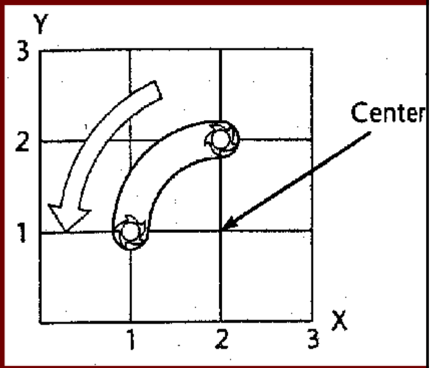
Circular Interpolation (CCW) G03

- An easy way to determine the radius values (I and J values) is by making a small chart:

Center Point	X2	Y1
Start Point	X2	Y2
Radius	I0	J-1

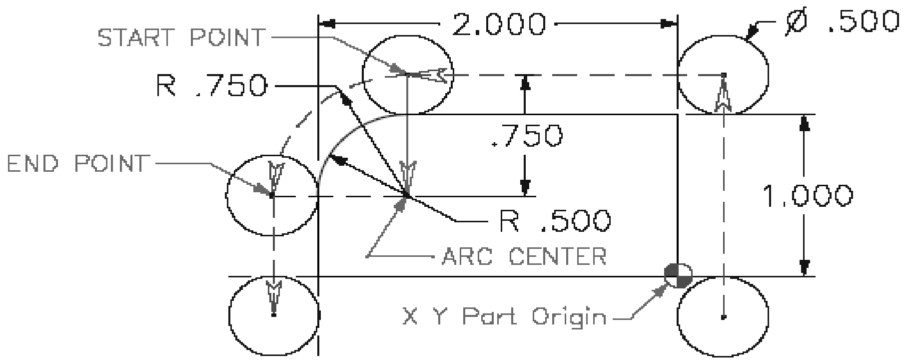
Result

J-1 F5 I0 Y1 X1 G03



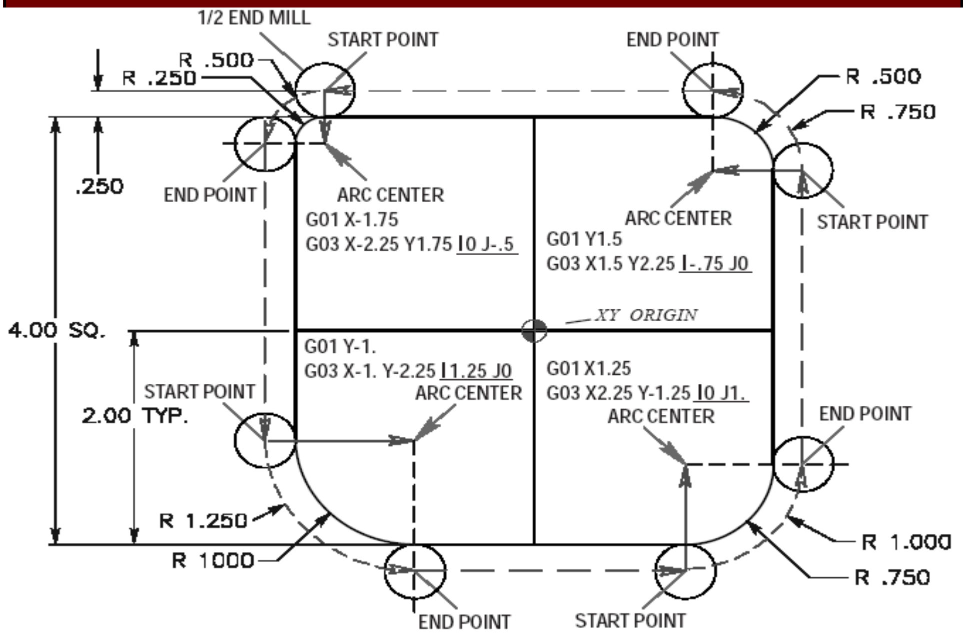
Circular Interpolation (CCW) G03

Example

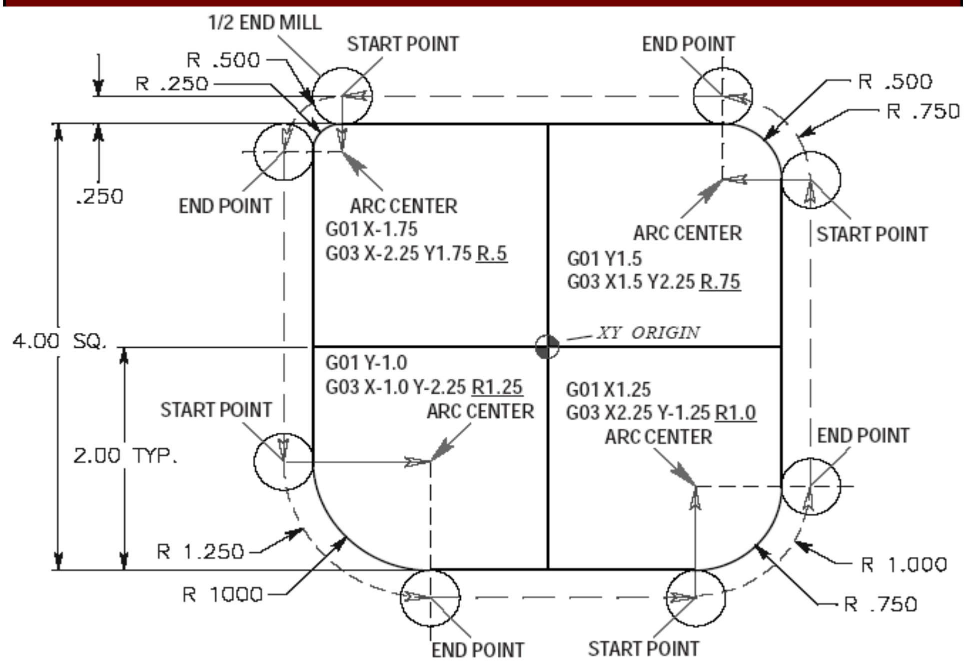


N6 G01 Y1.250 F12.
N7 X-1.500 (to start point)
N8 G03 X-2.250 Y.500 (I0. J-.750 or R.750)
N9 G01 Y-.25

G03 CCW CIRCULAR INTERPOLATION USING "I", &"J" FOR THE X & Y AXIS



G03 CCW CIRCULAR INTERPOLATION USING “R”

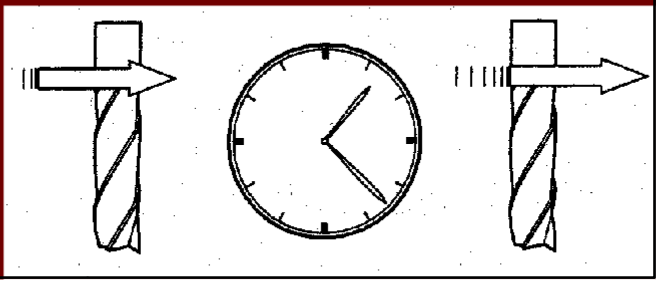


Dwell G04

P_ G04 N_

- **The G04 command is a Dwell command that halts all axis movement for a specified time, while the spindle continuous revolving at the specified rpm.**
- **A Dwell is used largely in drilling operations, which allows for the clearance of chips**
- **This command requires a specified duration, denoted by the letter P, and followed by the time in seconds.**

Example
P2 G04 N30
(Dwell for 2 seconds)



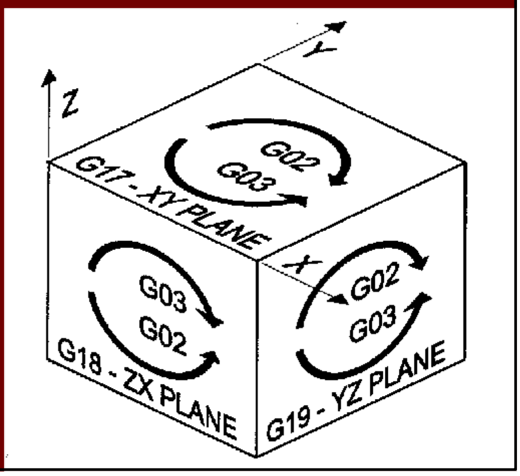
Machine Tool Planes

- **A typical CNC machining center has three axes. Any two axes form a plane. A machine plane may be defined by looking at the machine from standard operating position.**
- **For a vertical machining center, there are three standard views**

➢ **The top view (XY Plane) is selected by G17.**

➢ **The front view (XZ plane) is selected by G18.**

➢ **The right side vide (YZ plane) is selected by G19.**



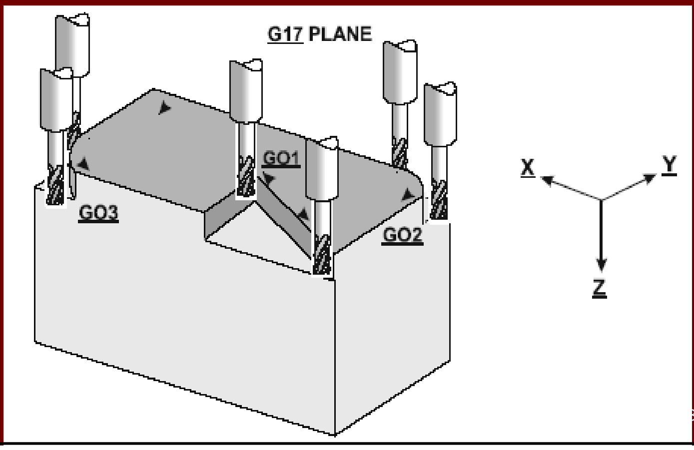
Machine Tool Planes

- For machining applications using the circular interpolation mode, with G02 or G03 commands, cutter radius offset with G41 or G42 commands and fixed cycles mode with G81 to G89 commands. The plane selection is very critical.
- For all rapid motions (programmed with G00) and all linear motions (programmed with G01), the plane selection command is not needed.
- Any plane selection change is programmed as desired, prior to actual tool path change. Plane can be changed as often as necessary in a program, but only one plane can be active at any time.
- Selection of one plane cancels any other plane, so the G17/G18/G19 commands cancel each other.

G17 XY Plane

G17 N_

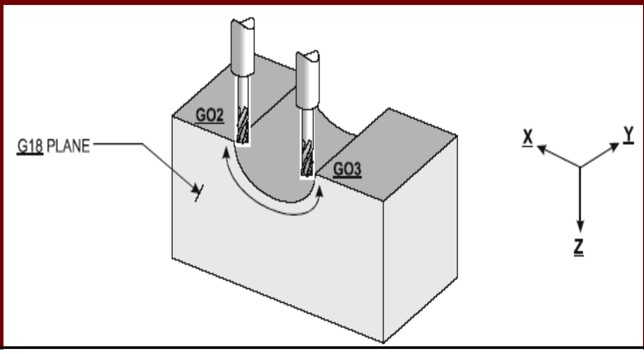
- G17 commands sets the system to default to the XY plane as the main machining plane for specifying circular interpolation moves and/or cutter compensation.
- Here the Z-axis is secondary and works perpendicular to the XY plane



G18 XZ Plane

G18 N_

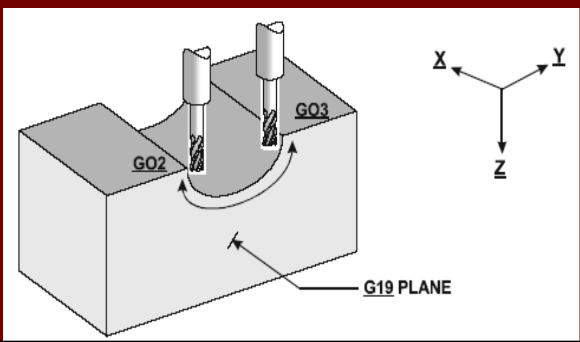
- **G18 command sets the system to the XZ plane as the main machining plane for specifying circular interpolation moves and/or cutter compensation.**
- **This command changes the default machining plane to the XZ plane, where the Y axis is secondary, and works perpendicular to the XZ plane.**
- **In this plane, it is possible to cut convex and concave arcs using G02 and G03 circular interpolation commands.**



G19 YZ Plane

G19 N_

- **G19 command sets the system to the YZ plane as the main machining plane for specifying circular interpolation moves and/or cutter compensation.**
- **This command changes the default machining plane to the YZ plane, where the X axis is secondary, and works perpendicular to the YZ plane.**
- **In this plane, it is possible to cut convex and concave arcs using G02 and G03 circular interpolation commands.**



G20 English Units (Inch Units)

G20 N_

- **G20 command defaults the system to inch data units. When you are running a program and encounter the G20 command, all coordinates are stated in inch units**

G21 SI Units (Metric Units)

G21 N_

- **G21 command defaults the system to metric data units (Millimeters). When you are running a program and encounter the G21 command, all coordinates are stated in metric (mm) units**

G90 Absolute Positioning

G90 N_

- **The G90 command defaults the system to accept all coordinates as absolute coordinates. Remember that absolute coordinates are those measured from a fixed origin (X0, Y0, Z0) and are expressed in terms of X, Y, and Z distances.**
- **This command is found at the beginning of most programs to default the system to absolute coordinates.**
- **On some machines it is possible to change between absolute and incremental coordinates within a program**

Example
Set to absolute mode and metric units **G21 G90 N5**

G91 Incremental Positioning

G91 N_

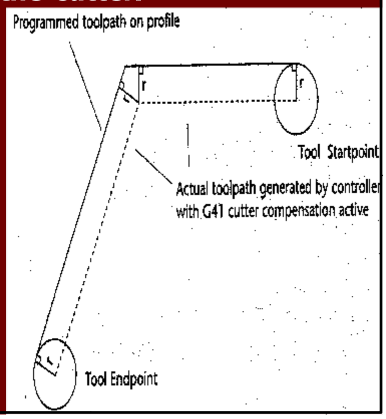
- **The G91 command defaults the system to accept all coordinates as incremental coordinates. Remember that incremental coordinates are those measured from the previous point and are expressed in terms of X, Y, and Z distances.**
- **This command is found at the beginning of some programs to default the system to incremental coordinates.**
- **On some machines it is possible to change between incremental and absolute coordinates within a program**

Example

Set to incremental mode and metric units **G21 G91 N5**

Cutter Compensation

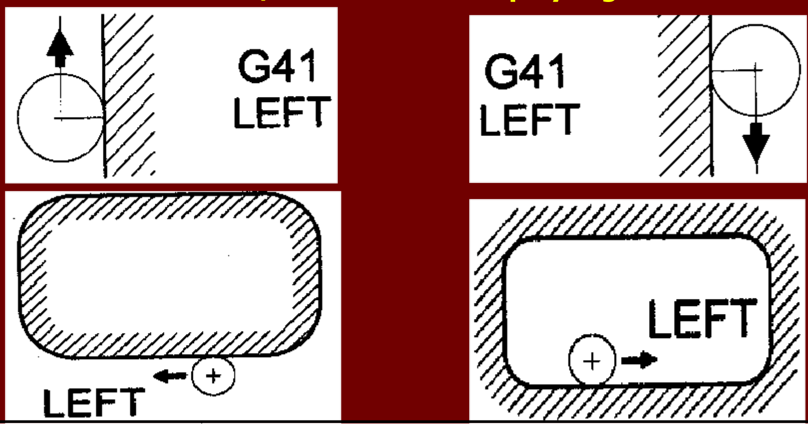
- **Cutter compensation is used to offset the center of the cutter, and shift it the distance of the radius, to the specified side of the programmed path.**
- **Complex part geometries having angled lines, lines tangent to arcs, and lines intersecting arcs involve substantial trigonometric computations to determine the center of the cutter.**
- **Cutter compensation involves programming the part geometry directly instead of the tool center.**
- **The cutter compensation commands are:**
  - **Cutter Compensation Left (G41),**
  - **Cutter Compensation Right (G42), and**
  - **Cutter Compensation Cancel (G40).**



Cutter Compensation Left G41

D_ G41 N_

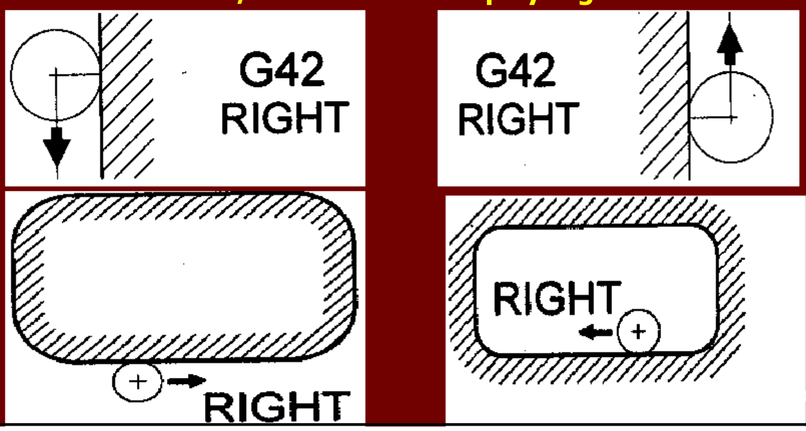
- **G41 will select cutter compensation left; that is the tool is moved to the left of the programmed path to compensate for the radius of the tool.**
- **A Dnn must also be programmed to select the correct tool size from the DIAMETER/RADIUS offset display register.**



Cutter Compensation Right G42

D_ G42 N_

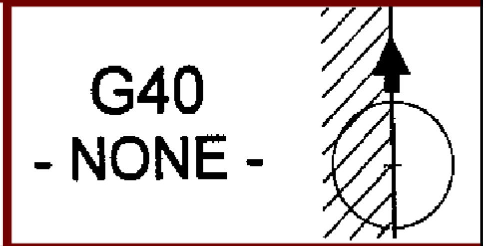
- **G42 will select cutter compensation right; that is the tool is moved to the right of the programmed path to compensate for the radius of the tool.**
- **A Dnn must also be programmed to select the correct tool size from the DIAMETER/RADIUS offset display register.**



Cutter Compensation Cancel G40

G40 N_

- **G40 will cancel the G41 or G42 cutter compensation commands.**
- **A tool using cutter compensation will change from a compensated position to an uncompensated position.**
- **Be sure to cancel cutter compensation, when you're done with each milling cut series that's using compensation.**

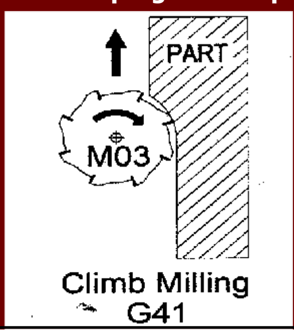


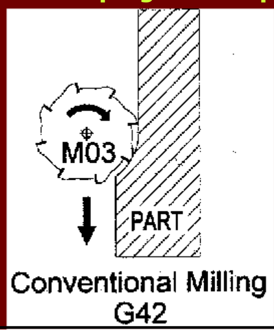
Cutter Compensation

- **Understanding cutter compensation can be simplified if one has a basic understanding of manual machining. There are two common types of cutting conditions associated with milling machines. They are CLIMB and CONVENTIONAL cutting.**

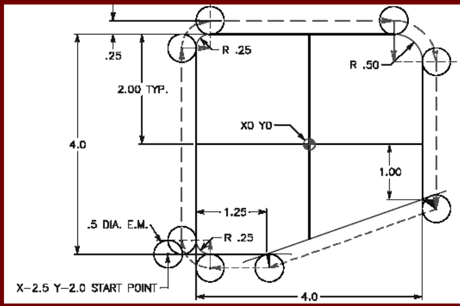
Two common rules for these types of cuts are:

- **If the programmed cutter path needs to mill CLIMB cutting, and if it's a standard right handed tool, it will then be programmed with G41 cutter LEFT of the programmed path.**
- **If the programmed cutter path needs to mill with CONVENTIONAL cutting, and it's a standard right handed tool, it will then be programmed with G42 cutter RIGHT of the programmed path.**





Cutter Compensation Example



Program without cutter compensation.

```
N104 G00 X-2.5 Y-2.0
N105 G01 Z-0.45 F50.
N106 X-2.25 F12.
N107 Y1.75
N108 G02 X-1.75 Y2.25 R0.5
N109 G01 X1.5
N110 G02 X2.25 Y1.5 R0.75
N111 G01 Y???? (Calculate point)
N112 X???? Y-2.25 (Calculate point)
N113 G01 X-1.75
N114 G02 X-2.25 Y-1.75 R0.5
N115 G01 X-2.35 Y-2.0
```

Program with cutter compensation.
Dia. value for D01 would be .500
in DIAMETER offset register #1.

```
N204 G00 X-2.35 Y-2.0
N205 G01 Z-0.45 F50.
N206 G41 X-2. D01 F12. (turn on C.C. with an X and/or Y move)
N207 Y1.75
N208 G02 X-1.75 Y2. R0.25
N209 G01 X1.5
N210 G02 X2. Y1.5 R0.5
N211 G01 Y-1.
N212 X-0.75 Y-2.
N213 X-1.75
N214 G02 X-2. Y-1.75 R0.25
N215 G40 G01 X-2.35 (turn off C.C. with an X and /or Y move)
```

Some Restrictions with Cutter Compensation

- A cutter compensation command (G41, G42 or G40) must be on the same block with an X and/or Y linear command when moving onto or off of the part using cutter compensation

```
N206 G41 X-2. D01 F12.
```

- You cannot turn on or off cutter compensation with a Z axis move.

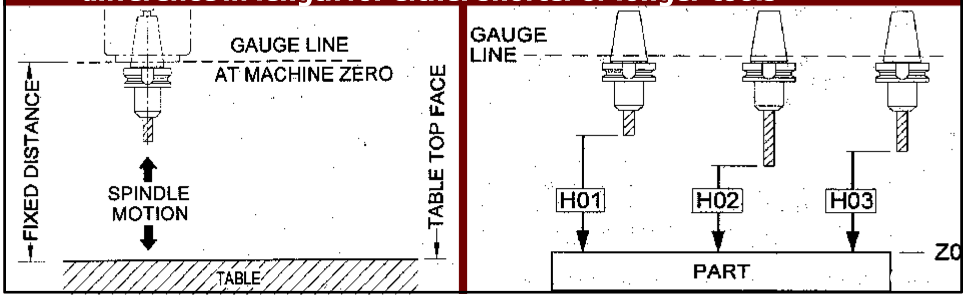
```
N215 G40 G01 X-2.35
```

- You cannot turn ON or OFF cutter compensation in a G02 or G03 circular move, it must be in a linear G00 or G01 straight line move.

```
N205 G01 Z-0.45 F50.
N206 G41 X-2. D01 F12.
N207 Y1.75
N208 G02 X-1.75 Y2. R0.
N209 G01 X1.5
```

Tool Length Compensation

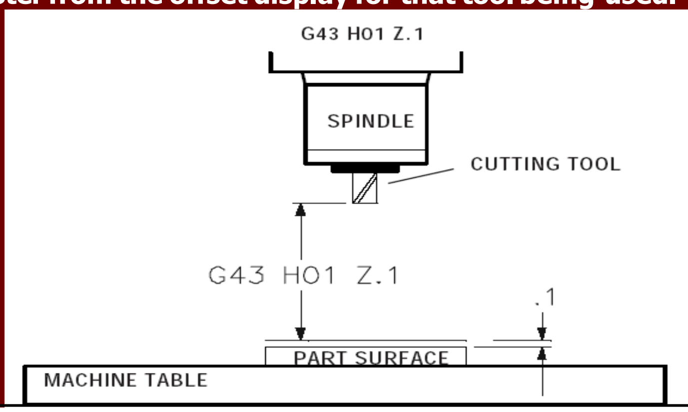
- **During the setup process, each tool point was touched-off to the part zero surface. From this position a TOOL LENGTH DISTANCE offset was recorded for that tool with the TOOL OFSET MESUR key. This TOOL LENGTH is referred to as the "Z" axis origin move to the part zero surface.**
- **It is important to realize that different tools will have varying lengths, and when tools are changed in a program, any variation in tool length will through the origin out of zero.**
- **To prevent this, the tools can now be compensated for the difference in length for either shorter or longer tools**



Tool Length Compensation (Plus) G43

H_ G43 N_

- **This code selects tool length compensation in a positive direction. That is; the tool length offsets are added to the commanded axis positions.**
- **An Hnn must be programmed to select the correct offset register from the offset display for that tool being used.**



Tool Length Compensation (Minus) G44

H_ G44 N_

- **This code selects tool length compensation in a negative direction. That is; the tool length offsets are subtracted from the commanded axis positions.**
- **A Hnn must be programmed to select the correct entry from offsets memory.**

Tool Length Compensation Cancels G49

G49 N_

- **This G code cancels tool length compensation.**

M-Codes

- **M-codes are miscellaneous functions that include actions necessary for machining but not those that are actual tool movements. That is, they are auxiliary functions**
- **Only one M code may be programmed per block of a program. All M codes are effective or cause an action to occur at the end of the block.**

Program Stop M00

M00 N_

- **The M00 code is used to stop a program. It also stops the spindle and turns off the coolant and stops interpretation lookahead processing. The program pointer will advance to the next block and stop.**
- **A cycle start will continue program operation from the next block.**

Optional Program Stop M01

M01 N_

- **The M01 code is identical to M00 except that it only stops if OPTIONAL STOP is turned on from the front panel.**
- **A cycle start will continue program operation from the next block.**

Program End M02

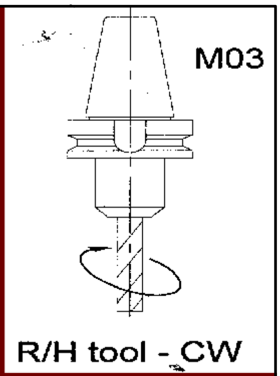
M02 N_

- **The M01 code is identical to M00 except that it only stops if OPTIONAL STOP is turned on from the front panel. A cycle start will continue program operation from the next block.**
- **This command appears on the last line of the program.**

Spindle On Clockwise M03

M03 N_

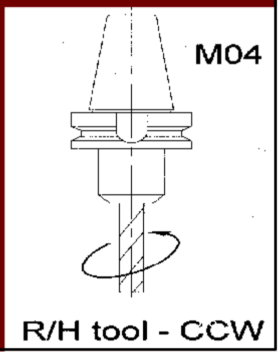
- **The M03 code will start the spindle moving is a clockwise direction at whatever speed was previously set.**



Spindle On Counterclockwise M04

M04 N_

- **The M04 code will start the spindle moving is a counterclockwise direction at whatever speed was previously set.**



Spindle Stop M05

M05 N_

- The M05 command turns the spindle off. Although other M-cods turn off all functions (for example, M00 and M01), this command is dedicated to shutting the spindle off directly.
- The M05 command appears at the end of a program.

Example
%
:1010
G20 G90 N5
T12 M06 N10
……………………………………………….
(Spindle stop) M05 N65

Tool Change M06

T_ M06 N_

- The M06 code is used to initiate a tool change. The previously selected tool (T_) is put into the spindle. If the spindle was running, it will be stopped.
- The Z-axis will automatically move up to the machine zero position and the selected tool will be put into the spindle. The Z-axis is left at machine zero.
- The T_ must be in the same block or in a previous block. The coolant pump will be turned off during a tool change.

Example
%
:1010
G20 G90 N5
(Tool change to tool #12) T12 M06 N10
……………………………………………….
M05 N65

Coolant On M07/M08

M07 N_ OR **M08 N_**

- The M07 and M08 commands switch on the coolant flow.

Coolant Off M09

M09 N_

- The M09 command shuts off the coolant flow. The coolant should be shut off prior to tool changes or when you are rapiding the tool over long distances.

Clamps On M10

M10 N_

- The M10 command turns on the automatic clamps to secure the workpiece.
- Not all CNC machines have automatic clamps, but the option exists and the actual code will vary by the machine tool make and model.
- This command is normally in the program setup section of a CNC Program.

Example

```
%
:1010
G20    G90    N5
T12    M06    N10
(clamp workpiece)    M10    N15
S1000  M03    N20
```

Clamps Off M11

M11 N_

- The M11 command releases the automatic clamps so that the workpiece may be removed and the next blank inserted.
- This command is normally in the system shutdown section of a CNC Program.

Example
%
:1010
G20 G90 N5
…………………………..
M05 N80
(Unclamp workpiece) M11 N85
M30 N90

Program End, Reset to Start M30

M30 N_

- The M30 code is used to stop a program. It also stops the spindle and turns off the coolant. The program pointer will be reset to the first block of the program and stop.

Example
%
:1012
G20 G90 N5
…………………………..
Y0 X0 N65
M05 N85
(program end; reset to start) M30 N90

Call Subprogram M98

P_ M98 N_

- The M98 function is used to call a subroutine or subprogram. Execution is halted in the main program and started on the program referenced by The letter P_ address value.
- For example,

  N15 M98 P1003 would call program:1003

Return from Subprogram M99

M99 N_

- The M99 function is used to end or terminate the subprogram and return to the main calling program.
- Execution is continued at the line immediately following the subprogram call. It is used only at the end of the subprogram

Block Skip

N_ /

- If turned on, upon execution of a CNC program and encountering a block skip "/", the program will ignore and CNC code on that block.

Example

```
%
:1012
G20   G90    N5
T03   M06   /N10
Y0    X0    G00   /N20
………………………………………..
M05   N85
      M30   N90
```

Comments

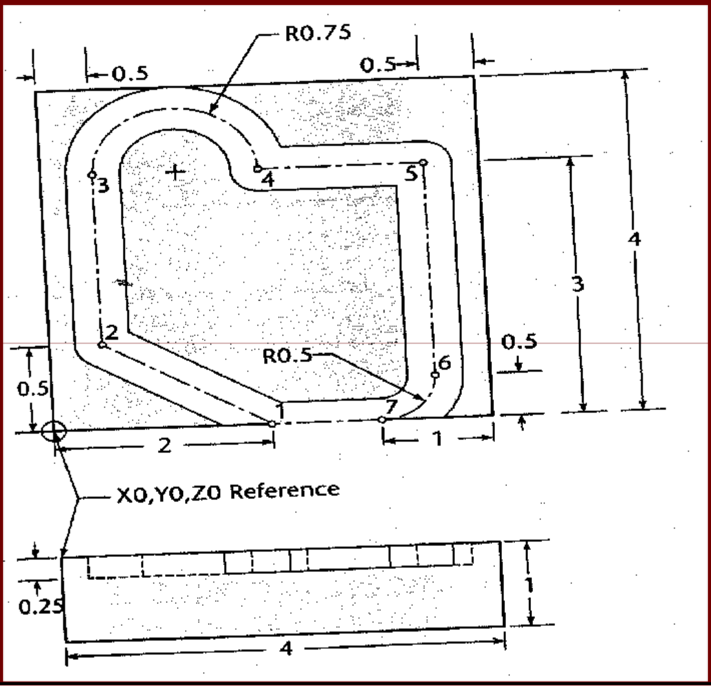
(Comment statement) N_

- Comments help the CNC machine operator to set up and run a job.
- Comments are defined by the use of round brackets. Anything between them is ignored by the controller.
- Remember that comments are just aids to help in reading and understanding a program. Their text is totally ignored even it contains valid CNC code.

Example

(Rapid to Z0.5) Z0.5 G00 N 10

Example



(program start flag)	%
(program number)	1087:
(Absolute, Inches, and compensation canceled)	N5 G90 G20 G40
(Tool change to toll #4)	N10 M06 T04
(Spindle on clockwise at 2000 rpm)	N15 M03 S2000
(Rapid to X2, Y-0.375), coolant 2 on)	N20 G00 X2 Y-0.375 M08
(Rapid down to Z-0.25)	N25 Z-0.25
(Feed move to point #1 at 15 ipm)	N30 G01 Y0 F15
(Feed move to point #2)	N35 X0.5 Y0.5
(Feed move to point #3)	N40 Y3.0
(Circular feed move to point #4)	N45 G02 X2 I0.75 J0
(Feed move to point #5)	N50 G01 X3.5
(Feed move to point #6)	N55 G01 Y0.5
(Circular feed move to point #7)	N60 G02 X3 Y0 I-0.5 J0
(Feed move to point #1)	N65 G01 X2
(Rapid to Z1)	N70 G00 Z1
(Rapid to X0, coolant off)	N75 X0 M09
(Spindle off)	N80 M05
(End of program)	N85 M30

UNIT 6

GROUP TECHNOLOGY AND CAPP

Introduction to Group Technology (GT)

- **Group Technology (GT)** is a manufacturing philosophy in which similar parts are identified and grouped together to make advantage of their similarities in design and production.
- Similar parts bare arranged into **part families**, where each part family possesses similar design and/or manufacturing characteristics.
- Grouping the production equipment into machine cells, where each cell specializes in the production of a part family, is called **cellular manufacturing**.

Implementing Group Technology (GT)

- There are two major tasks that a company must undertake when it implements Group Technology.

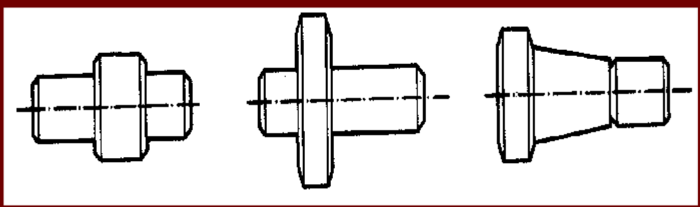
1. **Identifying the part families.** If the plant makes 10,000 different parts, reviewing all of the part drawings and grouping the parts into families is a substantial task that consumes a significant amount of time.
2. **Rearranging production machines into cells.** It is time consuming and costly to plan and accomplish this rearrangement, and the machines are not producing during the changeover.

Benefits of Group Technology (GT)

- GT promotes standardiztion of tooling, fixturing, and setups.
- Material handling is reduced because parts are moved within a machine cell rather than within the entire factory.
- Process planning and production scheduling are simplified.
- Setup times are reduced, resulting in lower manufacturing lead times

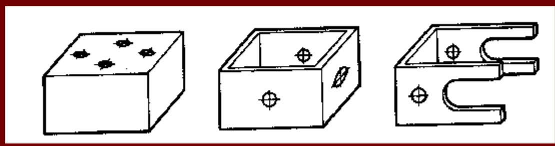
Part Families

- **A part family** is a collection of parts that are similar either because of geometric shape and size or because similar processing steps are required in their manufacture.
- The parts within a family are different, but their similarities are close enough to merit their inclusion as members of the part family.

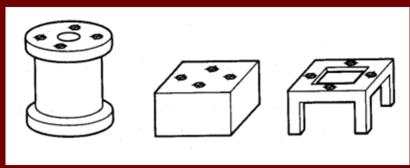


Rotational part family requiring similar turning operations

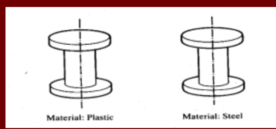
Part Families



Similar prismatic parts requiring similar milling operations

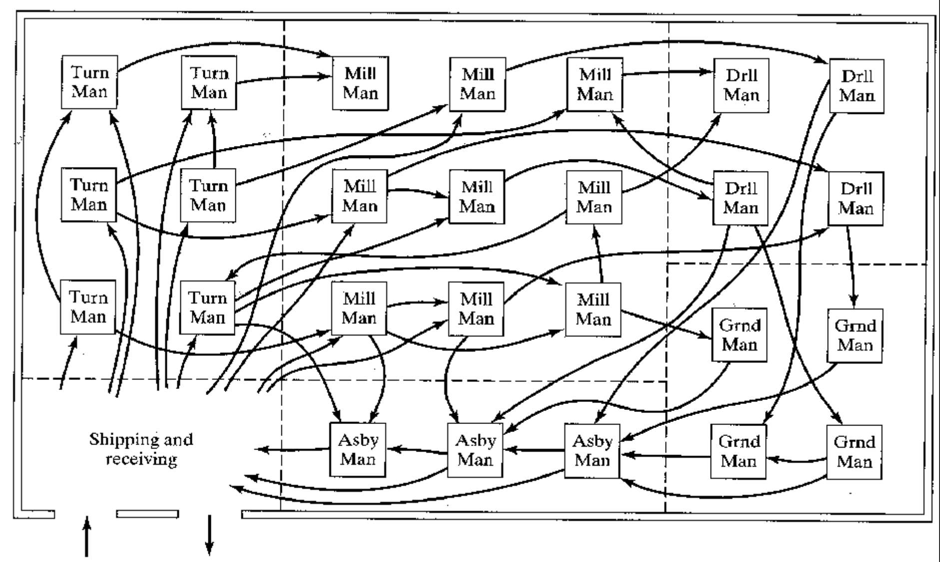


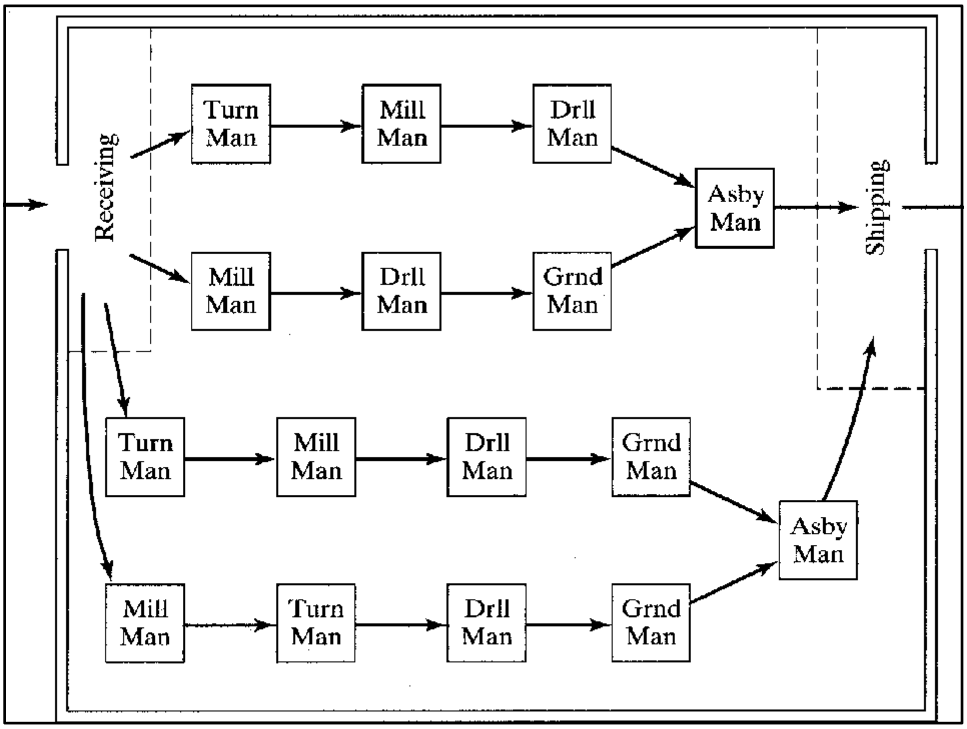
Dissimilar parts requiring similar machining operations (hole drilling, surface milling



Identical designed parts requiring completely different manufacturing processes

- **One of the important manufacturing advantages of grouping workparts into families can be explained with reference to figures below**





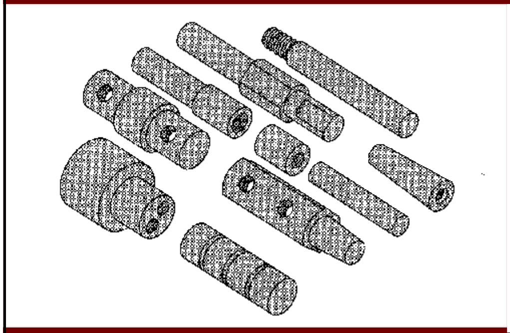
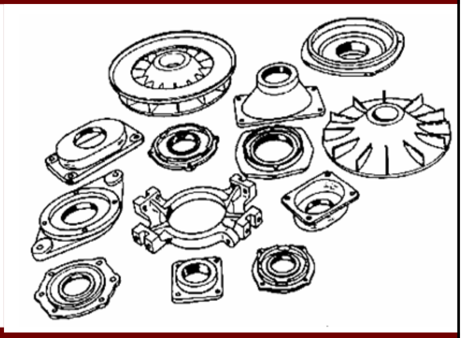
Grouping Part Families

- **There are three general methods for solving part families grouping. All the three are time consuming and involve the analysis of much of data by properly trained personnel.**

- **The three methods are:**
  1. **Visual inspection.**
  2. **Parts classification and coding.**
  3. **Production flow analysis.**

1- Visual Inspection Method

- The visual inspection method is the least sophisticated and least expensive method.
- It involves the classification of parts into families by looking at either the physical parts or their photographs and arranging them into groups having similar features.

2- Parts classification and Coding

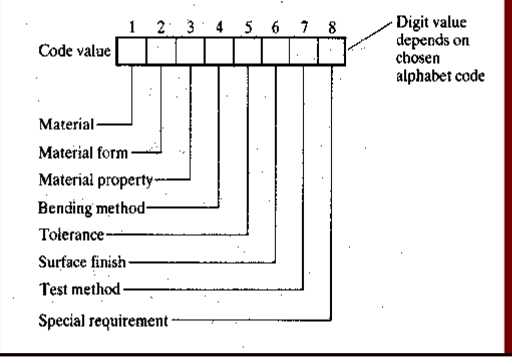
- In parts classification and coding, similarities among parts are identified, and these similarities are related in a coding system.
- Two categories of part similarities can be distinguished:
  1. Design attributes, which concerned with part characteristics such as geometry, size and material.
  2. Manufacturing attributes, which consider the sequence of processing steps required to make a part.

2- Parts classification and Coding

- **Reasons for using a classification and coding system:**
  1. **Design retrieval.** A designer faced with the task of developing a new part can use a design retrieval system to determine if a similar part already exist. A simple change in an existing part would take much less time than designing a whole new part from scratch.
  2. **Automated process planning.** The part code for a new part can be used to search for process plans for existing parts with identical or similar codes.
  3. **Machine cell design.** The part codes can be used to design machine cells capable of producing all members of a particular part family, using the composite part concept.

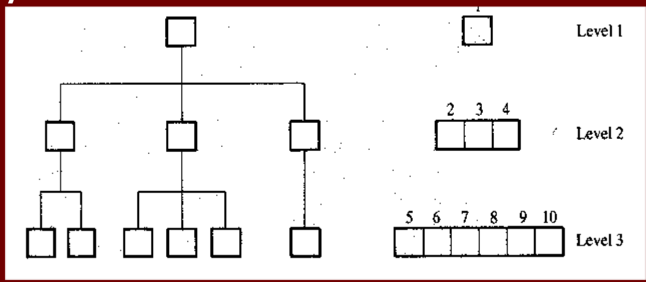
2- Parts classification and Coding

- A part coding system consists of a sequence of symbols that identify the part's design and/or manufacturing attributes.
- The symbols are usually alphanumeric, although most systems use only numbers.
- **The three basic coding structures are:**
  1. **Chain-type structure**, also known as a **polycode**, in which the interpretation of each symbol in the sequence is always the same, it does not depend on the value of the preceding symbols.

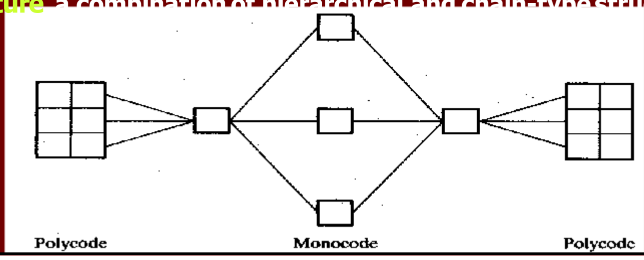


2 Parts classification and Coding

2. **Hierarchical structure**, also known as a **monocode**, in which the interpretation of each successive symbol depends on the value of the preceding symbols.



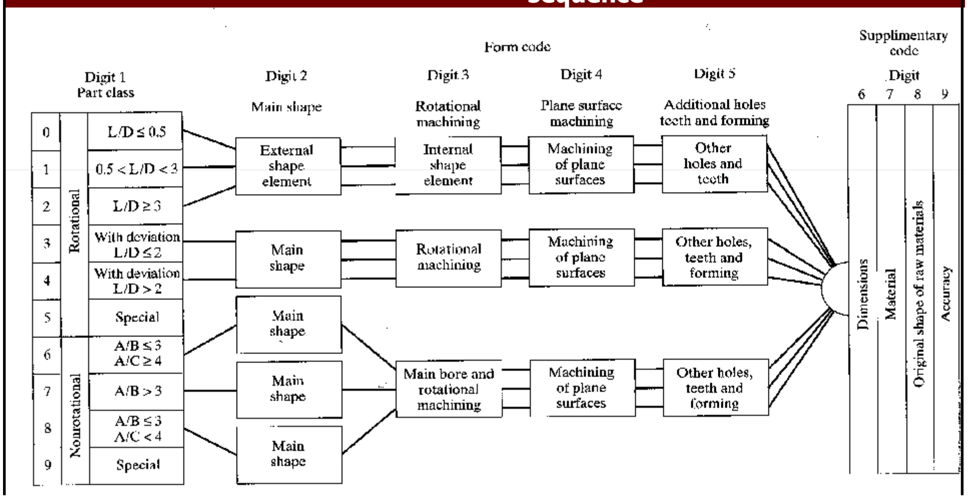
3. **Hybrid structure**, a combination of hierarchical and chain-type structures.



393

Opitz Classification and Coding System

- It is intended for machined parts and uses the following digits sequence
  - **Form Code** 1 2 3 4 5 for design attributes
  - **Supplementary Code** 6 7 8 9 for manufacturing attributes
  - **Secondary Code** A B C D for production operation type & sequence

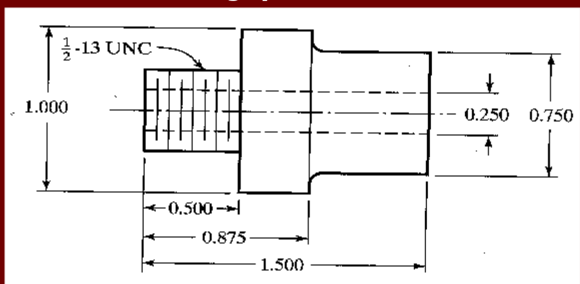


Digits (1-5) for Rotational parts in the Opitz System

	Digit 1	Digit 2	Digit 3	Digit 4	Digit 5
	Part class	External shape, external shape elements	Internal shape, internal shape elements	Plane surface machining	Auxiliary holes and gear teeth
0	Rotational parts: L/D ≤ 0.5	Smooth, no shape elements	No hole, no breakthrough	No surface machining	No auxiliary hole
1	0.5 < L/D < 3	Stepped to one end or smooth: No shape elements	Smooth or stepped to one end: No shape elements	Surface plane and/or curved in one direction, external	No gear teeth: Axial, not on pitch circle diameter
2	L/D ≥ 3	Thread	Thread	External plane surface related by graduation around the circle	Axial on pitch circle diameter
3		Functional groove	Functional groove	External groove and/or slot	Radial, not on pitch circle diameter
4		Stepped to both ends: No shape elements	Stepped to both ends: No shape elements	External spline (polygon)	Axial and/or radial and/or other direction
5		Thread	Thread	External plane surface and/or slot, external spline	Axial and/or radial on PCD and/or other directions
6		Functional groove	Functional groove	Internal plane surface and/or slot	With gear teeth: Spur gear teeth
7	Nonrotational parts	Functional cone	Functional cone	Internal spline (polygon)	Bevel gear teeth
8		Operating thread	Operating thread	Internal and external polygon, groove and/or slot	Other gear teeth
9		All others	All others	All others	All others

Example: Optiz part coding System

- **Given the rotational part design below, determine the form code in the Optiz parts classification and coding system.**



Solution

- **Length-to-diameter ratio:** L/D = 1.5 — **Digit 1 = 1**
- **External shape:** both ends stepped with screw thread on one end — **Digit 2 = 5**
- **Internal shape:** part contains a through hole — **Digit 3 = 1**
- **Plane surface machining:** none — **Digit 4 = 0**
- **Auxiliary holes, gear teeth, etc.:** none — **Digit 5 = 0**

The form code in the Optiz system is 15100

3- Production Flow Analysis (PFA)

- **Production flow analysis (PFA) is a method for identifying part families and associated machine groupings that uses the information contained on process plans rather than on part drawings.**

- **Workparts with identical or similar process plans are classified into part families. These families can then be used to form logical machine cells in a group technology layout.**

- **The procedure in production flow analysis must begin by defining the scope of the study, which means deciding on the population of parts to be analyzed.**

3- Production Flow Analysis (PFA)

- **The procedure of Production flow analysis (PFA) consists of the following steps:**

  1. **Data Collection. The minimum data needed in the analysis are the part number and operation sequence, which is obtained from process plans.**
  2. **Sortation of process plans. A sortation procedure is used to group parts with identical process plans.**
  3. **PFA Chart. The processes used for each group are then displayed in a PFA chart as shown below.**

	Parts								
Machines	A	B	C	D	E	F	G	H	I
1	1			1				1	
2					1				1
3			1		1				1
4		1				1			
5	1							1	
6			1						1
7		1				1	1		

3- Production Flow Analysis (PFA)

4. **Clustering Analysis.** From the pattern of data in the PFA chart, related groupings are identified and rearranged into a new pattern that brings together groups with similar machine sequences.

Machines	C	E	I	A	D	H	F	G	B
	Parts								
3	1	1	1						
2		1	1						
6	1		1						
1				1	1	1			
5				1		1			
7							1	1	1
4							1		1

MFGE 404

Computer Integrated Manufacturing
CIM

ATILIM UNIVERSITY

Manufacturing Engineering Department

Lecture 3– Computer Aided Process Planning - CAPP

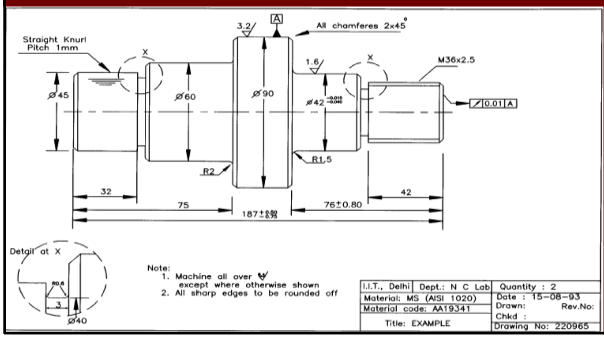
Fall 2005/2006

Defining Process planning

- **Process planning can be defined as the systematic determination of the detailed methods by which workpieces or parts can be manufactured economically and competitively from initial stages (raw material form) to finished stages (desired form).**

- **Geometrical features, dimensional sizes, tolerances, materials, and surface finishes are analyzed and evaluated to determine an appropriate sequence of processing operations.**

Final Form



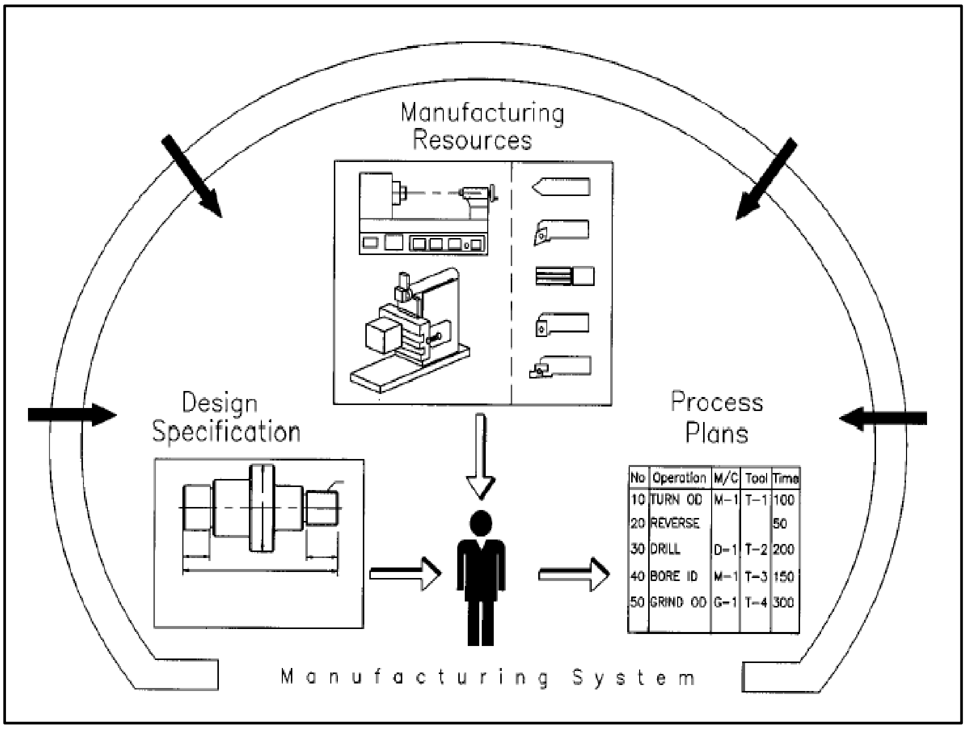
Initial Form

Defining Process planning

- In general, the inputs to process planning are
  - design data,
  - raw material data,
  - facilities data (machining data, tooling data, fixture data, etc.),
  - quality requirements data, and
  - production type data.

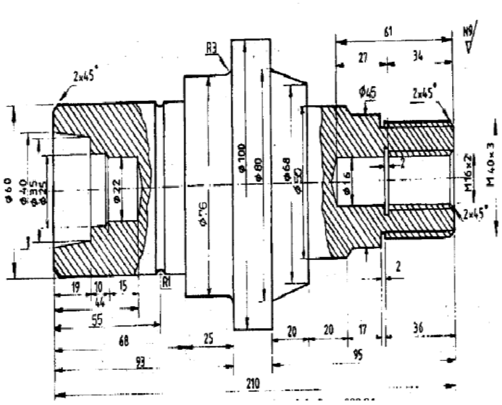
- The output of process planning is the process plan.

- The process plan is often documented into a specific format and called
  - process plan sheet,
  - process sheet,
  - operation sheet,
  - planning sheet,
  - route sheet,
  - route plan, or
  - part program.



Defining Process planning

- **A process plan is an important document for production management. The process plan can be used for**
  - Management of production,
  - Assurance of product quality,
  - Optimization of production sequencing, and
  - Determination of equipment layout on the shop floor.



PROCESS SHEET

SHEET NAME	:SHEET2	MATERIAL	:STEEL 1045
PART NAME	:SHAFT	PART NO.	:002.94
BATCH SIZE	:1	MACHINE	:MASTER 2500/NO.4
BLANK SIZE	:110x218 mm	BLANK	:ROLLED
BHN	:210		

NO.	OPERATION	LENGTH mm	DIAMETER mm	PASSES	DEPTH mm	FEED mm /r	SPEED rpm	TIME mins	POWER KW	TOOL
1	Face	55	110	2	2.000	0.32	72	4.86	0.511	16
2	R. Turn	115	100.8	2	2.300	0.32	72	10.60	0.588	1
3	R. Turn	93	76.8	4	3.000	0.32	98	12.56	1.534	2
4	R. Turn	68	60.8	4	2.000	0.32	130	6.94	1.023	1
5	F. Turn	22	100	1	0.400	0.16	98	1.57	0.023	1
6	F. Turn	25	76	1	0.400	0.16	130	1.33	0.023	2
7	F. Turn	68	60	1	0.400	0.16	130	3.45	0.023	1
8	Groove	2	60	1	1.000	0.25	54	0.30	0.035	6
9	Chamfer	2	60	1	2.000	0.25	54	0.30	0.071	9
10	Drill	44	21.5	1	n/a	0.40	320	0.36	n/a	13
11	R. Bore	19	34.2	5	1.270	0.20	175	2.69	0.322	17
12	R. Bore	10	24.2	1	1.350	0.20	235	0.28	0.069	17
13	Taper	19	40 7.5	1	2.900	0.32	235	0.29	0.371	33
14	F. Bore	10	25	1	0.250	0.08	235	0.70	0.005	17
15	F. Bore	15	22	1	0.250	0.08	235	0.97	0.005	17
16	Rechuck	-	-	-	-	-	-	1.00	-	0
17	Face	55	110	2	2.000	0.32	72	4.86	0.511	16
18	R. Turn	95	80.8	4	3.650	0.32	98	12.83	1.866	1
19	R. Turn	75	50.8	4	3.750	0.32	175	5.68	1.918	1
20	R. Turn	55	45.8	1	2.500	0.32	175	1.07	0.320	2
21	R. Turn	38	40.8	1	2.500	0.32	235	0.56	0.320	1
22	Taper	20	68 16.7	2	3.200	0.32	130	1.06	0.818	32
23	F. Turn	20	50	1	0.400	0.16	175	0.80	0.023	1
24	F. Turn	17	45	1	0.400	0.16	175	0.69	0.023	2
25	F. Turn	38	40	1	0.400	0.16	235	1.09	0.023	1
26	Groove	2	40	1	2.000	0.25	72	0.23	0.071	5
27	Thread	36	40	5	0.520	3.00	72	1.26	1.102	13
28	Chamfer	2	40	1	2.000	0.25	72	0.23	0.071	9
29	Drill	61	15.75	1	n/a	0.40	425	0.37	n/a	0
30	F. Bore	61	16	1	0.120	0.08	425	1.91	0.002	17
31	Groove	2	20	1	2.000	0.25	130	0.13	0.071	21
32	Thread	34	16	2	0.870	2.00	175	0.26	0.492	29
33	Chamfer	2	16	1	2.000	0.25	175	0.09	0.071	25

FIRST CLAMPING :clamped diameter =110mm and extended length = 124 mm
SECOND CLAMPING: clamped diameter =100mm and extended length = 104 mm

Total machining time	= 79.18 mim
Total approach time	= 2.36 mim
Total tool changing time	= 42 mim
Non-productive time	= 4 mim
Setup time	= 25 mim
Total production time	= 152.53 mim

ALL OPERATIONS ARE SUPPORTED IN 3-JAW CHUCK

Defining Process planning

- Recent research results have also demonstrated that process planning plays an important role in Computer Integrated Manufacturing – CIM

Process planning is the key link for integrating design and manufacturing

- **the process plan provides necessary information for technical and equipment preparation, such as:**
  - tools,
  - jigs and fixtures,
  - machines,
  - inspection devices,
  - raw material stocks,
  - inventory plans,
  - purchasing plans,
  - personal requirements,
  - etc.

Defining Computer Aided Process planning - CAPP

- Computer Aided Process Planning (CAPP) can be defined as the functions which use computers to assist the work of process planners.

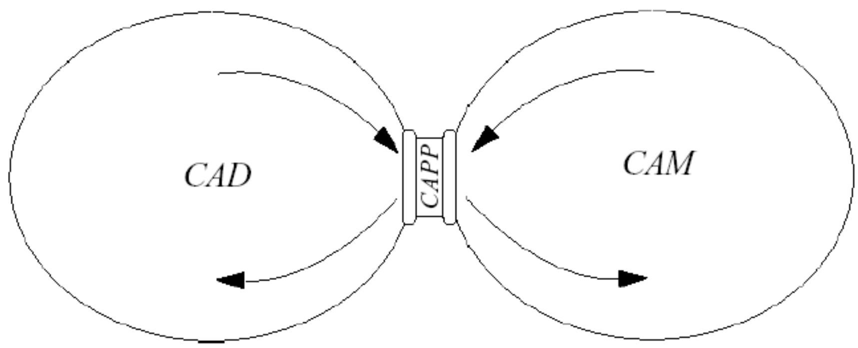
- The levels of assistance depend on the different strategies employed to implement the system.

  - **Lower level strategies** only use computers for storage and retrieval of the data for the process plans which will be constructed manually by process planners, as well as for supplying the data which will be used in the planner's new work.

  - **Higher level strategies** use computers to automatically generate process plans for some workpieces of simple geometrical shapes.

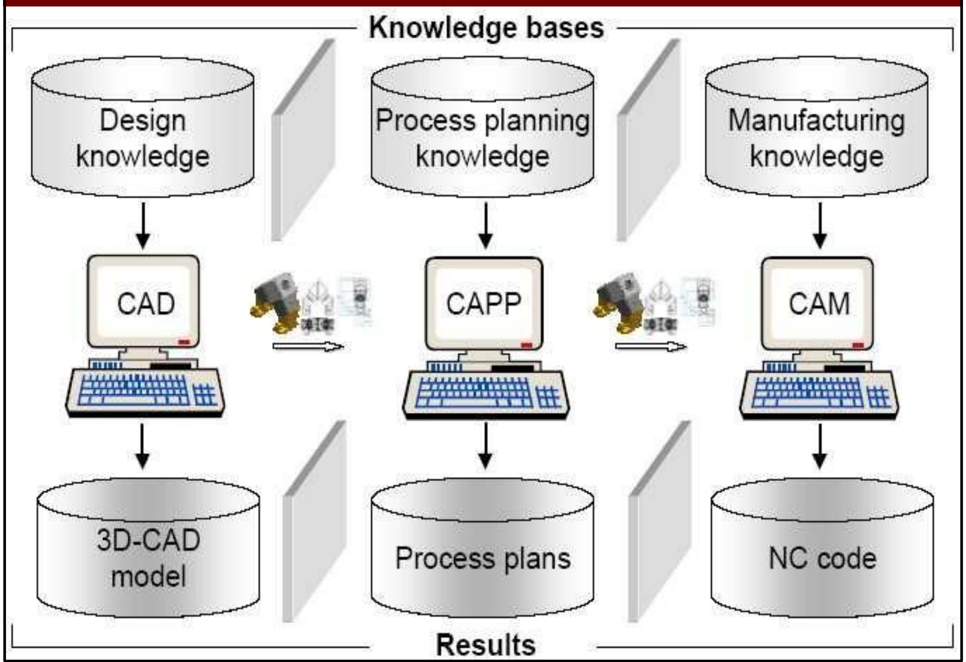
Defining Computer Aided Process planning - CAPP

CAPP a key factor in CAD/CAM integration because it is the link between CAD and CAM.



CAPP bottleneck between CAD and CAM.

Defining Computer Aided Process planning - CAPP



Benefits of CAPP

1. **Reduction in process planning time.**
2. **Reduction in the required skill of the process planner.**
3. **Reduction in costs due to efficient use of resources.**
4. **Increased productivity.**
5. **Production of accurate and consistent plans.**

Approaches of CAPP

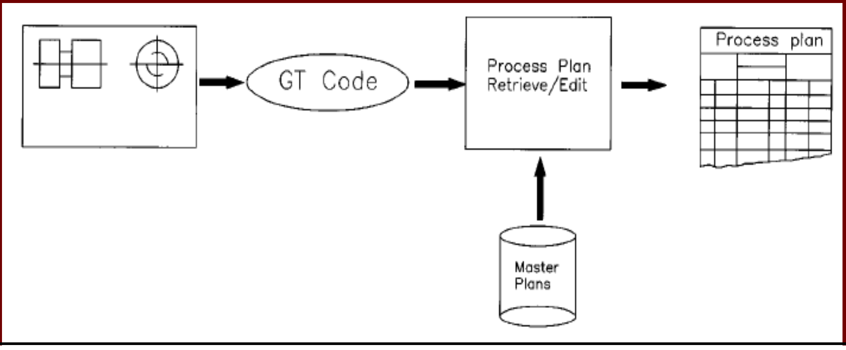
In general, three approaches to CAPP are traditionally recognized:

- the variant approach,
- the generative approach, and
- the hybrid (semi-generative) approach

The Variant approach of CAPP

- The variant approach, which is also called retrieval approach, uses a group technology (GT) code to select a generic process plan from the existing master process plans developed for each part family and then edits to suit the requirement of the part.

- Variant approach is commonly implemented with GT coding system. Here, the parts are segmented into groups based on similarity and each group has a master plan.



Advantages of Variant approach of CAPP

1. **Once a standard plan has been written, a variety of components can be planned.**

2. **Programming and installation are comparatively simple.**

3. **The system is understandable, and the planner has control of the final plan.**

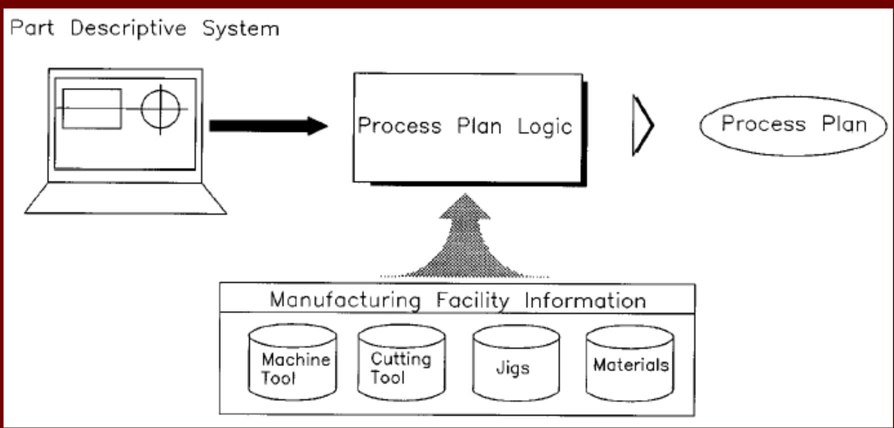
4. **It is easy to learn and easy to use.**

Disadvantages of Variant approach of CAPP

1. The components to be planned are limited to previously planned similar components.
2. Experienced process planners are still required to modify the standard plan for the specific component.
3. Details of the plan cannot be generated.
4. Variant planning cannot be used in an entirely automated manufacturing system, without additional process planning.

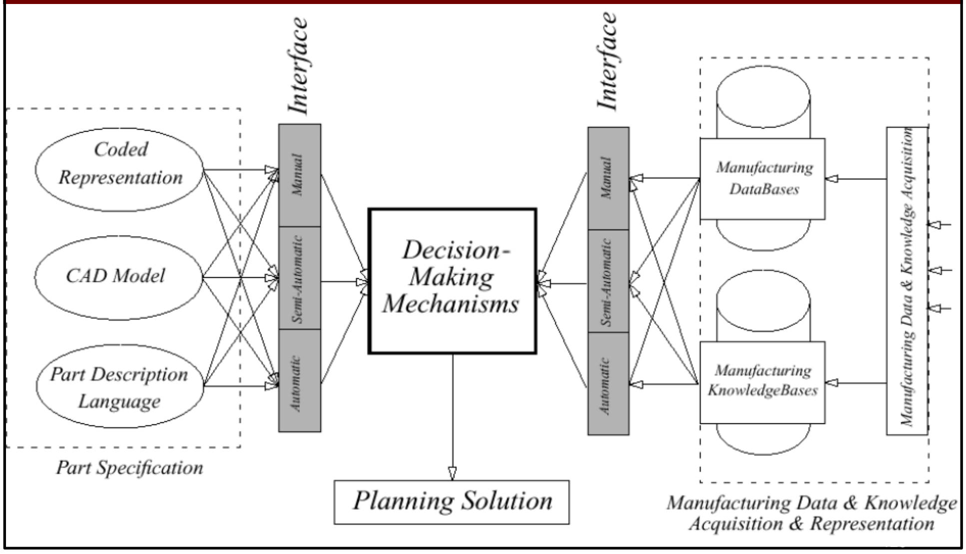
The Generative approach of CAPP

- In a generative approach, a process plan for each component is created from scratch without human intervention. These systems are designed to automatically synthesize process information to develop a process plan for a part



The Generative approach of CAPP

- Generative CAPP systems contain the logic to use manufacturing data bases, knowledge bases and suitable part description schemes to generate a process plan for a particular part.



Advantages of Generative approach of CAPP

1. **Consistent process plans can be generated rapidly.**
2. **New components can be planned as easily as existing components.**
3. **It has potential for integrating with an automated manufacturing facility to provide detailed control information.**

The Hybrid (Semi-Generative) approach of CAPP

- A hybrid planner, for example, might use a variant, GT-based approach to retrieve an existing process plan, and generative techniques for modifying this plan to suit the new part

Main Steps of CAPP Systems

- Identification of part specifications.
- Selection of blanks or stock.
- Selection of machining operations.
- Selection of machine tools.
- Selection of cutting tools.
- Calculation of cutting parameters.
- Generation of setup plans.
- Selection of work holding devices (fixtures).
- Calculation of times and costs.
- Generation of process plans

Main Steps of CAPP Systems

- Identification of part specifications.
- Selection of blanks or stock.
- Selection of machining operations.
- Selection of machine tools.
- Selection of cutting tools.
- Calculation of cutting parameters.
- Generation of setup plans (Operations Sequence).
- Selection of work holding devices (fixtures).
- Generation of process plans

Identification of Part Specifications

➢ There are many methods followed for part identification to CAPP systems.

These can be categorized as

- Non-CAD Models.
- CAD Models, and
- Feature based models.

Identification of Part Specifications

Non-CAD Models

- These modeling methods are characterized by the absence of CAD systems

  - **Group Technology (GT) Coding:** is based on GT coding for the retrieval of existing process plans

  - **Interactive/menu driven models:** which pose a series of questions (or menu) and interactively gather the part data from the user.

  - **Keywords/description language:** which can provide detailed information for CAPP system.

Identification of Part Specifications

CAD Models

- This approach is to freely design parts and then extract the features from the part based on B-rep. or CSG data.

- A combination of complex algorithms in computational geometry and artificial intelligence is used.

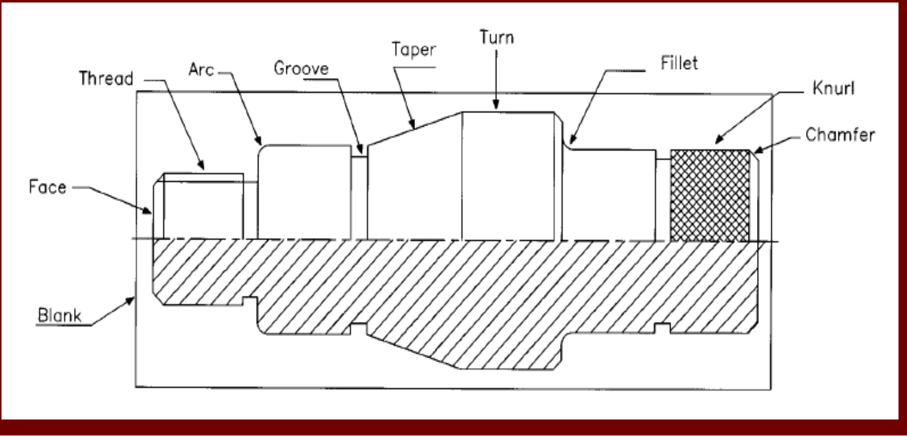
- This approach is very difficult to implement and solutions in feature extraction (recognition) have only worked for limited domains for geometry.

IF
surface, F1 is adjacent to horizontal surface, F2, and
horizontal surface F2 is adjacent to surface, F3,
F1 & F3 are 90° to F2, and
F2 with width of less than 26.2 mm
and
F1 with depth of less than 16 mm
THEN
surfaces F1, F2, F3 form a feature GROOVE

Identification of Part Specifications

Feature-based Models

- Feature-based design facilitates the designing of AERONAUTICAL parts in terms of their features.
- These models can provide automated interfaces to CAPP by modeling the part in terms of features.



Selection of blanks or stock

- This activity investigates
  - The dimensions of the part.
  - Processing requirements (e.g. heat treatment), and
  - The number of parts to be made.
- The rules can be categorized as follows:
  - Selection of material.
  - Determination of the type of blanks or stock (rod, block,..)
  - Calculations of machining allowances.

Determination of blank size or rotational parts

- **The blank size is expressed as**

$$L_b = L_f + 2a$$

$$D_b = d_L + a$$

$$a = a_d + a_e + a_t + a_{op}$$

Where

a = total allowances [mm]
a_d = thickness od defective layer [mm]
a_e = error of geometric form [mm]
a_t = tolerance of blank [mm]
a_{op} = allowances of the next operation [mm]
L_f = final part length [mm]
d_L = largest machined diameter [mm]

Selection of machining operations

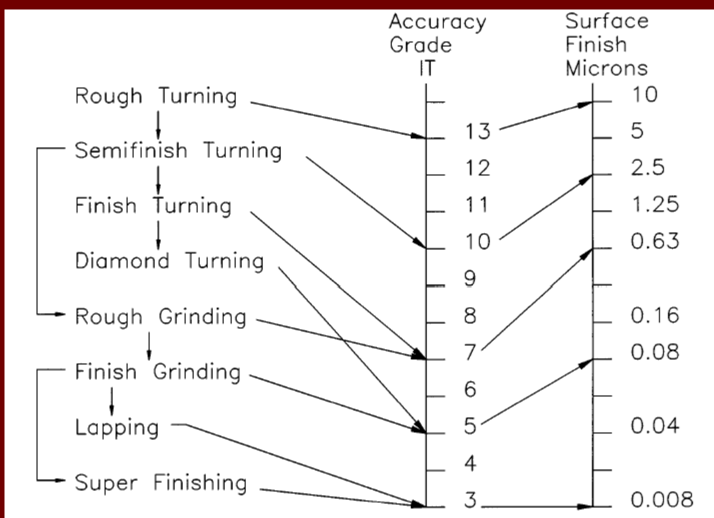
- In machining, the selection of operations is accomplished by two sets of operations namely; roughing operations and finishing operations.
- **The roughing** is to remove all material from the original raw piece surface down to the bottom or side of the feature minus the finishing allowance in multiple passes.
- **The finishing** will then remove the finish allowance to yield the final surface of the feature.
- For machining feature parameters, certain machining operations from each set will be selected.

Selection of machining operations

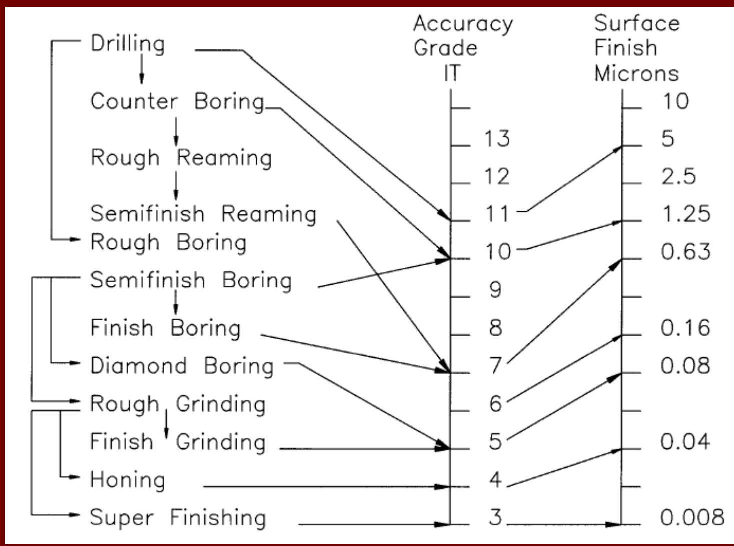
- **The operation selection can be divided into three categories:**

  1. **Operations used to produce cylindrical surfaces (external and internal) [Turning operations].**
  2. **Operations used to produce plane surfaces [Milling operations]**
  3. **Hole making operations [Drilling operations]**

Planning for Cylindrical surfaces



Planning for Hole Making Operations



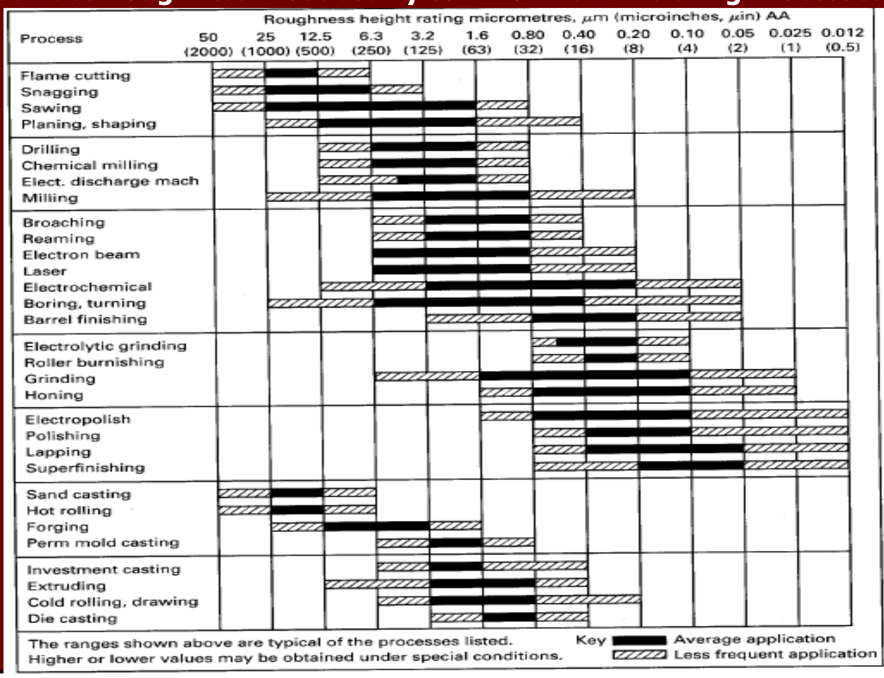
(m-6) based on ISO 286 IT Grades 1 to 14 ISO Tolerance Band "T "micrometres =

	Nominal Sizes (mm)										
over	1	3	6	10	18	30	50	80	120	180	250
inc.	3	6	10	18	30	50	80	120	180	250	315
IT Grade											
1	0.8	1	1	1.2	1.5	1.5	2	2.5	3.5	4.5	6
2	1.2	1.5	1.5	2	2.5	2.5	3	4	5	7	8
3	2	2.5	2.5	3	4	4	5	6	8	10	12
4	3	4	4	5	6	7	8	10	12	14	16
5	4	5	6	8	9	11	13	15	18	20	23
6	6	8	9	11	13	16	19	22	25	29	32
7	10	12	15	18	21	25	30	35	40	46	52
8	14	18	22	27	33	39	46	54	63	72	81
9	25	30	36	43	52	62	74	87	100	115	130
10	40	48	58	70	84	100	120	140	160	185	210
11	60	75	90	110	130	160	190	220	250	290	320
12	100	120	150	180	210	250	300	350	400	460	520
13	140	180	220	270	330	390	460	540	630	720	810
14	250	300	360	430	520	620	740	870	1000	1150	1300

Manufacturing Processes associated with ISO IT Tolerance Grade

IT Grade	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Lapping	■	■	■	■											
Honing		■	■	■											
Superfinishing			■	■	■										
Cylinderical grinding			■	■	■	■									
Diamond turning			■	■	■	■									
Plan grinding				■	■	■	■	■							
Broaching				■	■	■	■	■							
Reaming				■	■	■	■	■							
Boring, Turning					■	■	■	■	■	■	■				
Sawing								■	■	■					
Milling								■	■	■	■	■			
Planing, Shaping									■	■	■	■	■		
Extruding									■	■	■	■			
Cold Rolling, Drawing									■	■	■	■	■		
Drilling										■	■	■	■		
Die Casting											■	■	■	■	
Forging												■	■	■	■
Sand Casting													■	■	■
Hot rolling, Flame cutting													■	■	■

Surface Roughness Produced by common Manufacturing Processes



Selection of machining operations Knowledge base

IF: 1. feature type is SLOT
2. surface finish $< 30\,\mu$ inch
THEN: 1. select FINE_END_MILLING process
2. diameter of tool $<$ width of SLOT
3. width of SLOT = width of SLOT - 0.01”
4. depth of SLOT = depth of SLOT - 0.01”
5. surface finish = $200\,\mu$ inch

IF feature is a POCKET,
AND tolerance = +0.010 in,
AND finish $<=$ 94,
THEN machining_process = END_MILLING,
AND machining_direction = Z_Axis.

IF machining_process is REAMING,
THEN preparatory_process is DRILLING,
OR preparatory_process is BORING,
AND tolerance = +0.001 in,
AND finish $<$ 63.

Selection of Machine Tools

- **This step involves the selection of machine tools on which manufacturing operations can be performed.**
- **A large number of factors influence the selection of machine tools:**

1. Workpiece-related attributes

- **Kinds of features desired.**
- **The dimensions of the workpiece.**
- **Dimensional tolerances.**
- **The raw material form.**

Selection of Machine Tools

2. Machine tool – related attributes

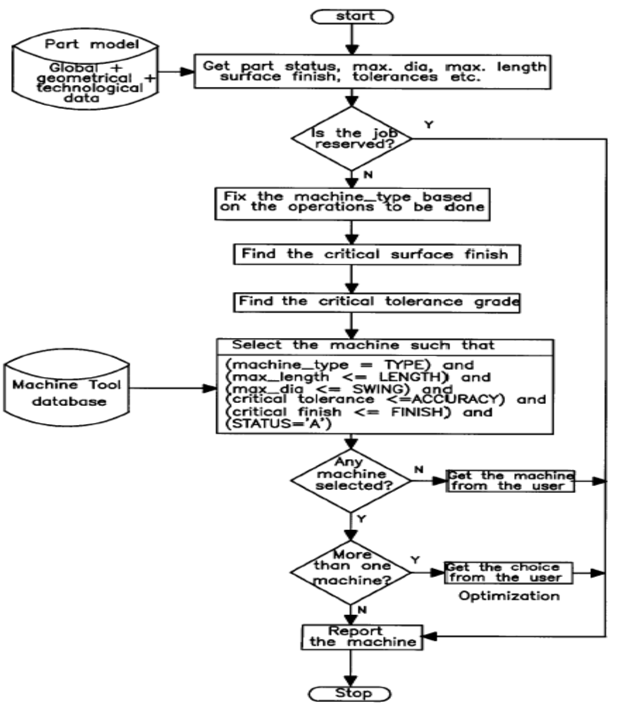
- **Process capability.**
- **Machine size.**
- **Mode of operation (e.g. manual, semiautomatic, automatic, numerically controlled)**
- **Tooling capabilities (e.g. size and type of the tool magazine) and automatic tool-changing capabilities.**

3. Production volume – related information

- **Production quantity.**
- **Order frequency.**

An expert system that embodies some of the qualitative and quantitative knowledge of machine tools can be useful in process planning

Selection of Machine Tools



Selection of Cutting Tools

- Tool selection is perhaps one of the most important functions in a process planning system because the selection of a cutting tool affects
  - the selection of machining parameters,
  - production rate,
  - cost of product, and
  - the resulting accuracy

Selection of Cutting Tools

- **Three main steps are followed in cutting tools selection:**

  1. **selection a proper cutting tool for each machining feature. The selection is based upon machining feature and its associated machining operation.**

For example,

- for square slot to be machined with an end milling operation, a flat end mill might be selected,
- for round slot to be machined with the same machining operation, a ball end mill might be used.

Selection of Cutting Tools

2. searching the cutting tools database to find standard tool dimensions that fit the machining setup.

➢ The search criteria implemented depends on the application of the cutting tool in machining the selected feature. The following are some guidelines used for this purpose:

- **Searching for the tool by a key parameter.** The search succeeds if the key parameter matches with a field in the data base. This type of search is used for the hole-making tools and form tools

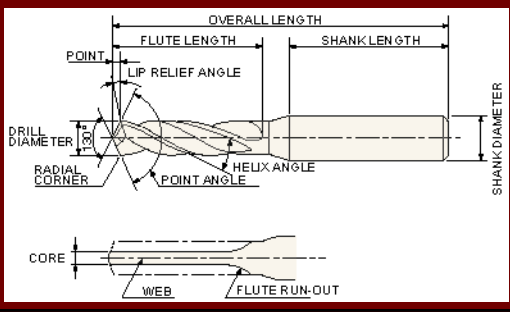
  (for example, the diameter of drills and the feature code of form grooves).

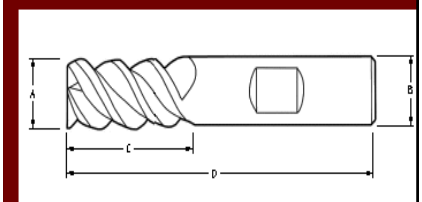
Selection of Cutting Tools

- **Searching for the tool which has a key parameter greater than or equal to the specified parameter.**

  This type of search is used while matching the cutting edge length.

- **Searching for the tool which has a key parameter less than or equal to the specified parameter.** For example, this search call is applied for grooving tools (whose width should be less than the width of the groove).

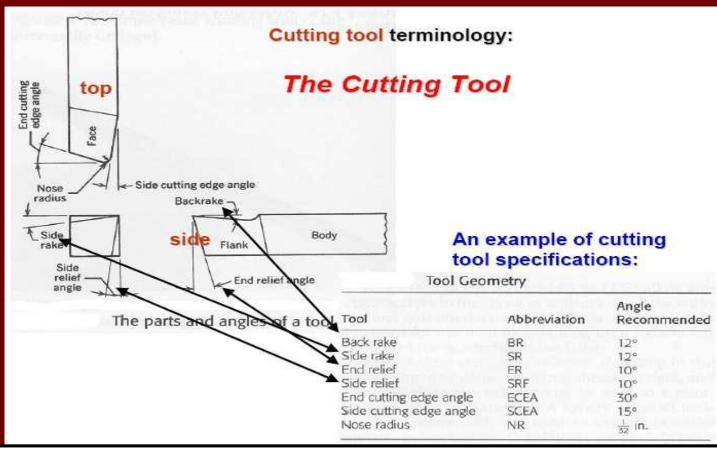




Selection of Cutting Tools

3. Selecting cutting tools geometry

- Tool geometry values are based on the recommendations collected from different machining handbooks and research outputs.
- These values can be treated as values obtained from a process planner expert on the shop floor.



Tool Geometry

Tool	Abbreviation	Angle Recommended
Back rake	BR	12°
Side rake	SR	12°
End relief	ER	10°
Side relief	SRF	10°
End cutting edge angle	ECEA	30°
Side cutting edge angle	SCEA	15°
Nose radius	NR	$\frac{1}{32}$ in.

Generation of Setup Planning (operations sequence)

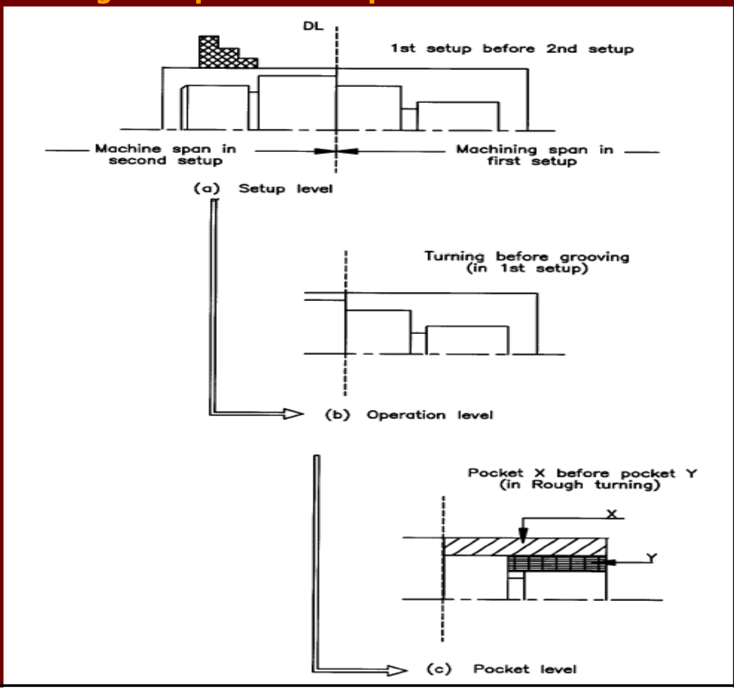
- The setup planning activity in CAPP is composed of three steps;
  - setup generation,
  - operation sequence, and
  - setup sequence.

- **The setup generation** is a procedure to group the machining operations into setups such that the manufacturing features which have common approach directions are grouped into the same setup.
- **The operation sequence** arranges the machining operations in each generated setup into order, so that the constraint of the feature precedence relationships in each setup is satisfied. In addition, the cutting tool changes among the operations are reduced to a minimum.
- **The setup sequence** is to arrange the generated setups in order so that setups with less number of machining features are machined first

Setup Planning and Operations Sequence for Rotational Parts

1. Prepare for the internal profile, if any, by removing as much internal stock as possible by a drilling operation.
2. Apply roughing operation to the external stepped profile by a turning/facing.
3. Apply finishing/semi-finishing operation to the external stepped profile.
4. Apply grooving operation to all the external grooves.
5. Thread the external threads.
6. Apply rough boring to internal stepped profile.
7. Apply finishing/semi-finishing to internal stepped profile.
8. Apply grooving operations to all internal grooves.
9. Thread all internal threads.
10. Apply part-off operation if workpiece has a free end.

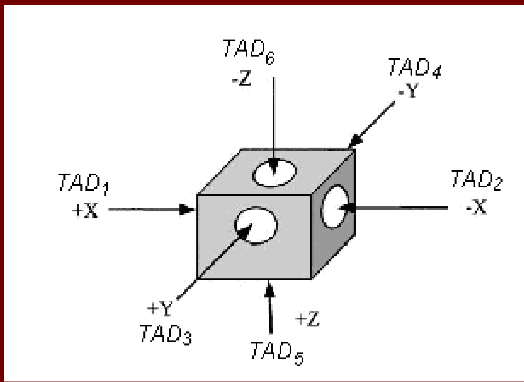
Setup Planning and Operations Sequence for Rotational Parts



Setup Planning and Operations Sequence for Prismatic Parts

Step 1 Generation of setup plans

1. Define the part coordinate system and assign Tool Access Direction (TAD) for a block shaped part machined on 3-axis milling center



2. Assign a definite TAD to every feature so that it can be assigned to a definite setup.

Setup Planning and Operations Sequence for Prismatic Parts

Step 2 Sequence of machining operation in each setup.

For every setup plan contains features

3. Sequence machining operations according to the machining features precedence.
4. Arrange machining operations according to the natural operation sequence (roughing operations prior to finishing operations).
5. Rearrange the drilling type operations according to the following sequence; center drilling + drilling + counterboring or countersinking + tapping + boring or reaming or milling.
6. Minimize the number of tool change by rearranging same type machining operations.

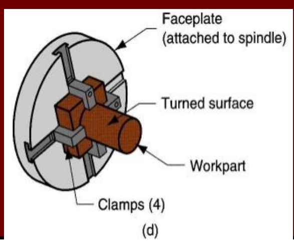
Step 3 Sequence of setups

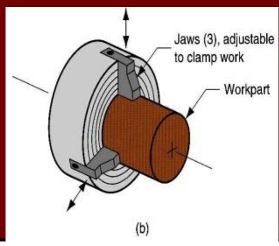
7. Sequence the setup plans so that setups with less machining features are machined first.

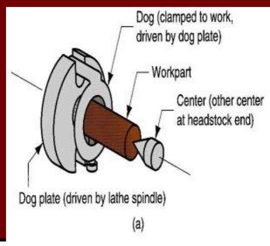
Selection of workholding devices

- **Workholding devices are used to locate and hold the workpieces to help generate machining features.**

- For rotational components, the following methods of holding are possible:
  1. **Holding between centers and using face plate and dog as driver (between centers method, BC)**
  2. **Holding between centers and using chuck as driver (chuck and center method, CC)**
  3. **Holding in chuck (chuck only method, CO)**
  4. **Clamping in special fixtures and collets.**







Selection of workholding devices

- **The following rules are employed to classify a component as short or shaft for determining the workholding method:**

(a) If $LD \leq 2$ then the part is a short component

(b) If ($LD \geq 4$) and (maximum dia. > 100) then it is a shaft

(c) If ($LD \geq 4$) and (maximum dia. ≤ 100) then it is short

(d) If ($2 < L/D < 4$) and (minimum dia. ≤ 15) then it is short

(e)If ($2 < L/D < 4$) and (minimum dia. > 15) then stiffness is to be compared. If its stiffness when

- **held between centers is greater than that when held in a chuck, then the part is considered a shaft; otherwise, it is a short component.**

Selection of workholding devices

- **After classifying the part, the following guidelines are applied to determine the work-holding method:**

- Short components are usually held in chuck (CO method).
- A component classified as a shaft is preferably machined between centers using a dog driver (BC method).
- If the shaft is a heavy component, e.g., more than 350 kg, a chuck is used to drive the shaft (CC method).
- If internal features are present on the shaft, then use of steady rest is necessary.
- The shafts with LD ratios greater than 12 are considered as non rigid and two steady rests are employed.

Calculations of Cutting Parameters

- **Having specified the workpiece material, machine tool, and cutting tool, the question is what can be controlled to reduce cost and increase production rate (Economics Criteria)**
- **The controllable variables are**
  - **Cutting speed (V)**
  - **Feed rate (f)**
  - **Depth of Cut (d)**

- In the field of machining economics the following three basic criteria are used for the selection of machining parameters:
  - The minimum production cost criterion
  - The minimum production time or the maximum production rate criterion
  - The maximum profit rate criterion

Calculations of Cutting Parameters

Machining Economics Criteria

1. **The minimum production cost criterion:** this criterion refers to producing a piece of product at the least cost, and coincides with the maximum-profit criterion. It is the criterion to be used when there is ample time available for production.

2. **The minimum production time or the maximum production rate criterion:** this maximizes the number of products produced in a unit time interval; hence it minimizes the production time per unit piece. It is the criterion to be used when an increase in physical productivity or productive efficiency is designed, neglecting the production cost needed and/or profit obtained.

3. **The maximum profit rate criterion:** this maximizes the profit in a given time interval. It is the criterion to be recommended when there is insufficient capacity for a specific time interval.

Calculations of Cutting Parameters

Mathematical Modeling for Optimization of Machining Economics

Formulation of the objective functions

- Mathematical modeling of the machining economics can be formulated as a constrained optimization model. Three objective functions are considered;
  - production cost,
  - production time, and
  - profit rate.

- The constraints set includes bounds on the parameters constraints (speed, feed and depth of cut), tool-life constraint and operation constraints (surface finish, cutting force and power)

Calculations of Cutting Parameters

1. The production cost

- The production cost per component for a machining operation is comprised of the sum of the costs of non-production cost, machining cost and tooling costs. It can be written as;

$$C_{pr} = C_1 + C_2 + C_3 + C_4$$

where

C_1 = non-productive cost. C_2 = machining cost. C_3 = tooling cost.

C_4 = tool changing cost.

- It can be written as

Where
M = total machine and operator rate.
t_m = machining time. t_l = non=productive time.
t_{ct} = tool changing time. t = tool life.
C_t = tooling cost of a cutting edge.

Calculations of Cutting Parameters

Machining time, t_m

- **For turning, boring and drilling operations;**

Where
d_m = diameter of machined surface.
l_w = length of surface or hole to be machined.
F = feed rate. V = cutting speed

- **For shaping and planing;**

Where
b_w = width of surface to be machined.
l_s = stroke length = 2lw
CR = cutting ratio

Calculations of Cutting Parameters

Machining time, t_m

- **For milling Operations**
  - slab milling
  - face milling
  - side milling

Where
a_e = depth of cut in milling.
d_t = diameter of tool.
v_f = feed speed

Calculations of Cutting Parameters

Tool life, t

- The tool life t can be written according to expanded Taylor's tool-life equation as;

Where
α, β, γ, and C are empirical constants depend on tool material.

Calculations of Cutting Parameters

Non-productive time, t_l

The non-productive time is the time taken to load and unload each component and to return the tool to the beginning of the cut.

Where
t_l = non-productive time per component.
t_{lw} = component loading time.
t_{at} = tool advancing time.
t_{rl} = tool return time.
t_{aw} = component unloading time.
t_s = setup time.
Np = number of pieces per lot.

Calculations of Cutting Parameters

- the production cost now can be written as

Where
K_0 is constant defined as follows;

- For turning, boring and drilling operations;
- For milling operations

for slab milling

for face milling

for side milling

- For shaping and planing operations

Calculations of Cutting Parameters

2 The production time

- the total production time for one component is given by;

Where
t_l = non-productive time.
t = tool life.
t_{ct} = tool changing time.
t_{pr} = total production time.
t_m = machining time.

OR

Calculations of Cutting Parameters

3- The profit rate

- The profit rate is defined as profit generated per unit time i.e.

where
P_r = profit rate.
S = the revenue per component.
C_{pr} = production cost per component.
t_{pr} = production time per component.

OR

Calculations of Cutting Parameters

Summary of the mathematical Model

Minimize

OR

Minimize

OR

Maximize

Calculations of Cutting Parameters

Summary of the mathematical Model

- **Subjected to the following constraints**

Cutting speed constraint

Feed rate constraint

Depth of cut constraint

Tool life constraint

Surface finish constraint

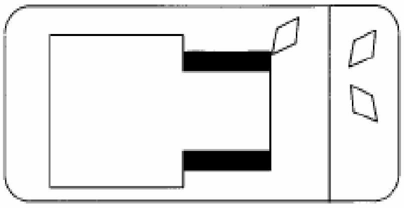
Cutting force constraint

Machining power constraint

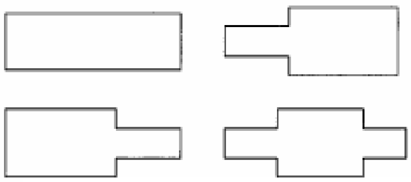
Generation of Process Plans

Operation	M/c	Tool	S	F
Facing	FC	T120	75	0.5
Turning	NCL	T200	130	1
Reverse				
Facing	FC	T120	75	0.5
* * * *				
* * *				

(a) Text Process plan



(b) Graphical Simulation



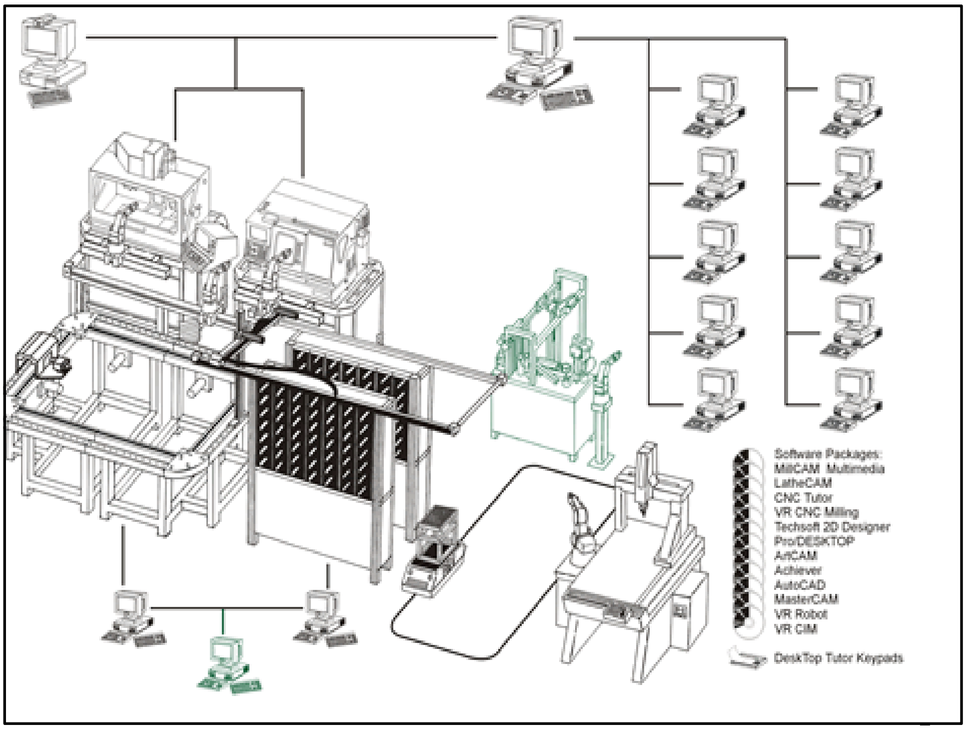
(c) Picture Process plan

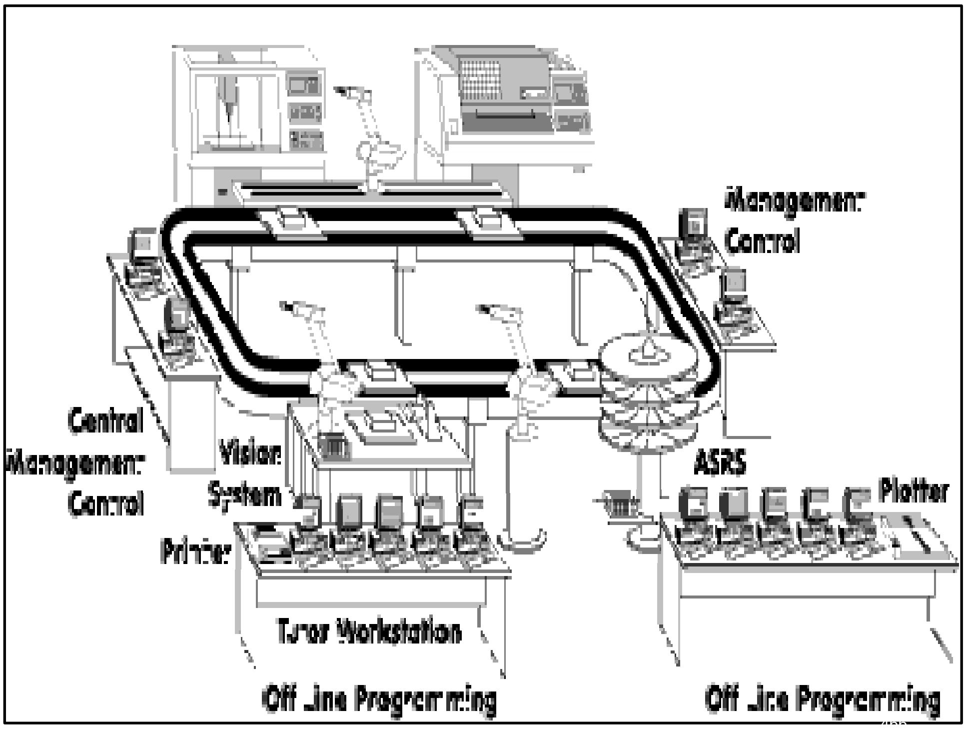
```
N01  G71
N02  G90
N03  G50  X15  Z5
N04  M03  S1200
N05  G00  X10  Z2  F120  T1
*  *  *
  *  *
```

(d) NC Part Program

UNIT 7

COMPUTER AIDED QUALITY CONTROL


Software Packages:
MillCAM Multimedia
LatheCAM
CNC Tutor
VR CNC Milling
Techsoft 2D Designer
Pro/DESKTOP
ArtCAM
Achiever
AutoCAD
MasterCAM
VR Robot
VR CIM
DeskTop Tutor Keypads


Management Control
Central Management Control
Vision System
ASRS
Plotter
Printer
Tutor Workstation
Off Line Programming
Off Line Programming

Automated Inspection

- Automated inspection can be defined as the automation of one or more of the steps involved in the inspection procedure.
- There are a number of alternative ways in which automated or semiautomated inspection can be implemented:

1. Automated presentation of parts by an automatic handling system with a human operator still performing the examination and decision steps.

2. Automated examination and decision by an automatic inspection machine, with manual loading (presentation) of parts into the machine.

3. Completely automated inspection system in which parts presentation, examination, and decision are all performed automatically.

Where and When to Inspect

- Inspection can be performed at any of several places in production:
    1. Receiving inspection, when raw materials and parts are received from suppliers.
    2. At various stages of manufacture, and
    3. Before shipment to the customer.

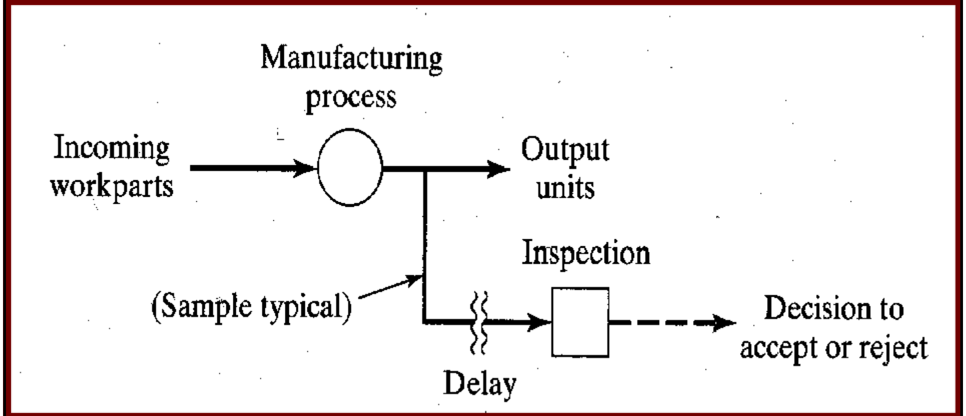
- Our principal focus is on case (2) , that is, when and where to inspect during production.

Off-Line and On-Line Inspection

- The timing of the inspection procedure in relation to the manufacturing process is an important consideration in quality control.
- Two alternative situations can be distinguished:
  1. Off-line inspection.
  2. On-line inspection.

Off-Line Inspection

- Off-line inspection is performed away from the manufacturing process, and there is generally a time delay between processing and inspection.
- Manual inspection is common.

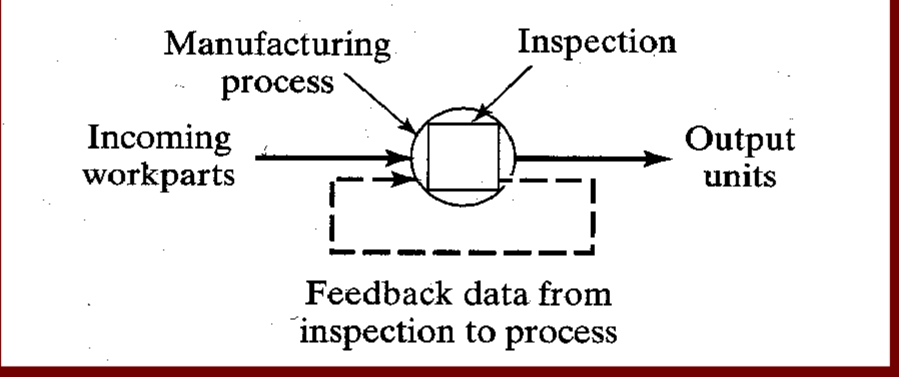


On-Line Inspection

- The alternative to off-line inspection is on-line inspection, in which the procedure is performed when the parts are made, either as
  - An integral step in the processing or assembly operation, or
  - Immediately afterward.
- Two on-line inspection procedures can be distinguished:
  - On-line/in-process.
  - On-line/post-process.

On-Line/ in-process Inspection

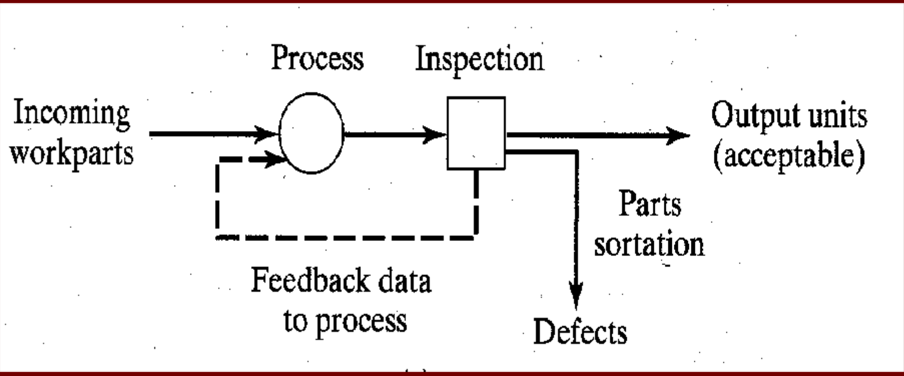
- The is achieved by performing the inspection procedure during the manufacturing operation.
- As the parts are being made, the inspection procedure is measuring or gaging the parts simultaneously.



- Technologically, automated on-line/in-process insection of the product is usually difficult and expensive to implement, As an alternative on-line/ post-process procedures are often used

On-Line/ post-process Inspection

- The measurement or gaging procedure is accomplished immediately following the production process.
- Even though it follows the process, it is still considered an on-line method because it is integrated with the manufacturing workstation, and the results of the inspection can immediately influence the production operation of the next part.



Contact vs. Non-contact Inspection Techniques

- Inspection techniques can be divided into two broad categories:
  1. Contact Inspection.
  2. Non-contact Inspection.

- In contact inspection, physical contact is made between the object and the measuring or gaging instrument.
- In non-contact inspection no physical contact is made.

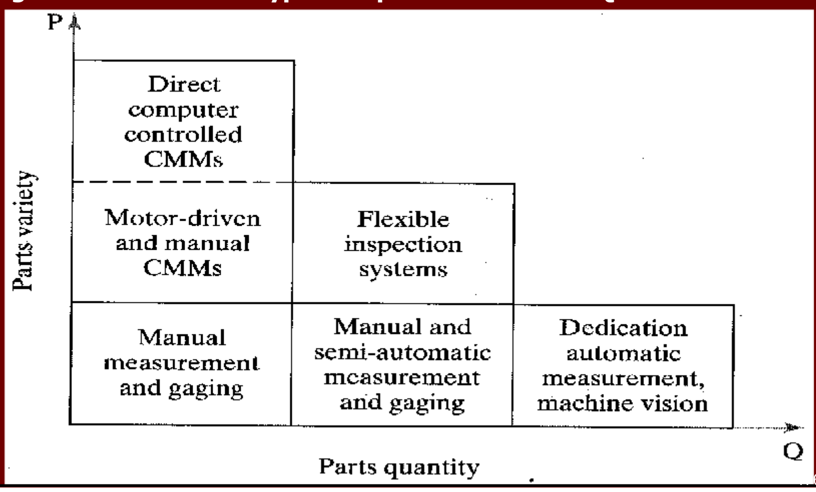
Contact Inspection Techniques

- Contact inspection involves the use of a AERONAUTICAL probe or other device that makes contact with the object being inspected.
- The purpose of the probe is to measure or gage the object in some way.
- Contact inspection is usually concerned with some physical dimension of the part.
- These techniques are widely used in the manufacturing industries, in particular the production of metal parts (metal working processes)

- The principal contact technologies are:
  - ❑ Conventional measuring and gaging instruments, manual and automated.
  - ❑ Coordinate Measuring Machines (CMMs)
  - ❑ Stylus type surface texture measuring machines.

Contact Inspection Techniques

- Conventional measuring and gaging techniques and coordinate measuring machines measure dimensions and related specifications.
- Conventional techniques and CMMs compete with each other in the measurement and inspection of part dimensions. The general application ranges for the different types are presented in the PQ chart below



Contact Inspection Techniques

- Reasons why contact inspection methods are technologically and commercially important include the following:
  1. They are the most widely used inspection technologies today.
  2. They are accurate and reliable.
  3. In many cases, they represent the only methods available to accomplish the inspection.

Non-Contact Inspection Techniques

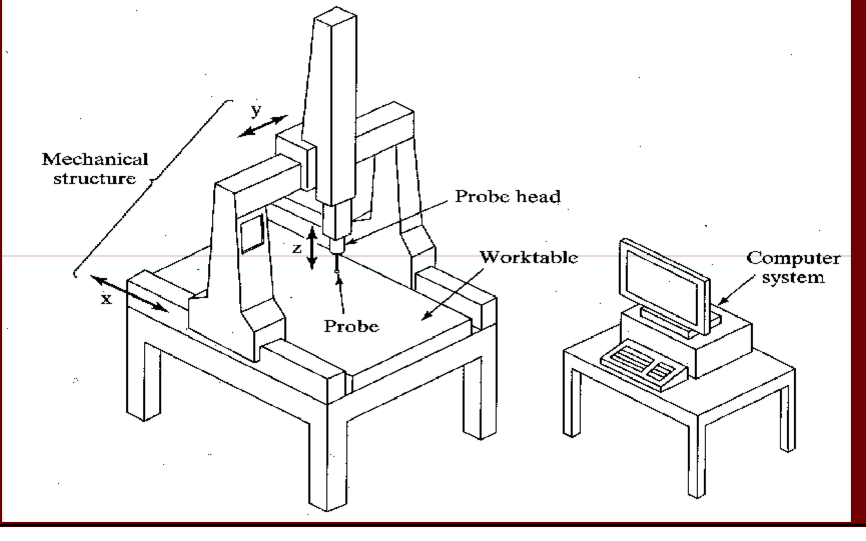
- Non-contact inspection methods utilize a sensor located at a certain distance from the object to measure or gage the desired features.
- The non-contact inspection technologies can be classified into two categories:
  1. Optical inspection
  2. Non-optical inspection
- Optical inspection technologies make use of light to accomplish the measurement or gaging cycle. The most important optical technology is machine vision.
- Non-optical inspection technologies utilize energy forms other than light to perform the inspection: these other energies include various electrical fields, radiation, and ultrasonics.

Coordinate Measuring Machines

- **Coordinate metrology is concerned with the measurement of the actual shape and dimensions of an object and comparing these with the desired shape and dimensions.**
- **In this connection, coordinate metrology consists of the evaluation of the location, orientation, dimensions, and geometry of the part or object.**
- **A Coordinate Measuring Machine (CMM) is an electromechanical system designed to perform coordinate metrology.**

Coordinate Measuring Machines

- **A CMM consists of a constant probe that can be positioned in 3D space relative to the surface of a workpart, and the x, y, and z coordinates of the probe can be accurately and precisely recorded to obtain dimensional data concerning the part geometry**

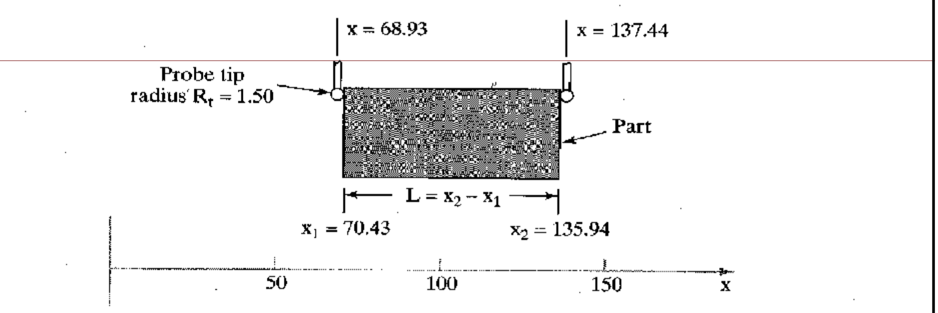


Coordinate Measuring Machines

- **To accomplish measurements in 3D, a basic CMM is composed of the following components:**
  - **Probe head and probe to contact the workpart surafec.**
  - **AERONAUTICAL structure that provides motion of the probe in three Cartesian axes and displacement transducers to measure the coordinate values of each axis.**
- **In addition, many CMM have the following components:**
  - **Drive system and control unit to move each of the three axes**
  - **Digital computer system with application software.**

EXAMPLE Dimensional Measurement with Probe Tip Compensation

The part dimension L in Figure is to be measured. The dimension is aligned with the x-axis, so it can be measured using only x-coordinate locations. When the probe is moved toward the part from the left, contact made at $x = 68.93$ is recorded (mm). When the probe is moved toward the opposite side of the part



from the right, contact made at $x = 137.44$ is recorded. The probe tip diameter is 3.00 mm. What is the dimension L?

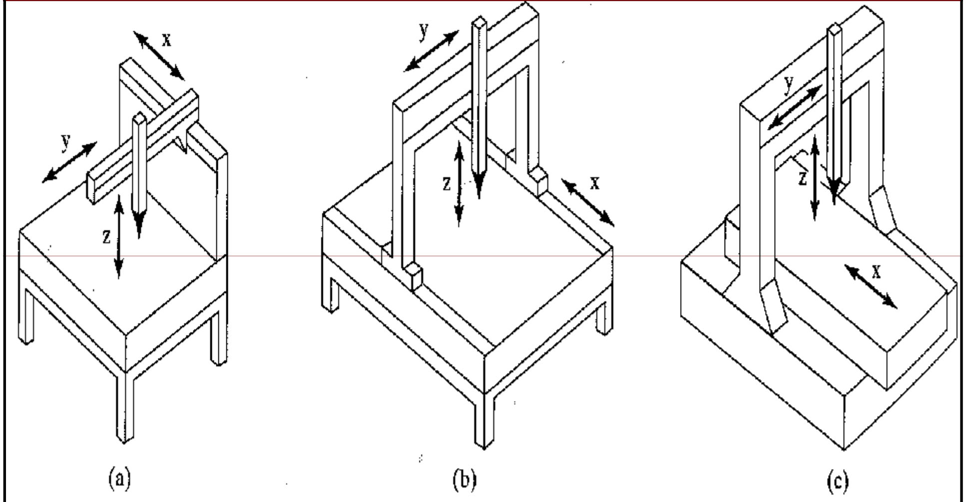
Solution: Given that the probe tip diameter $D_t = 3.00$ mm, the radius $R_t = 1.50$ mm. Each of the recorded x values must be corrected for this radius.

$$x_1 = 68.93 + 1.50 = 70.43 \text{ mm}$$

$$x_2 = 137.44 - 1.50 = 135.94 \text{ mm}$$

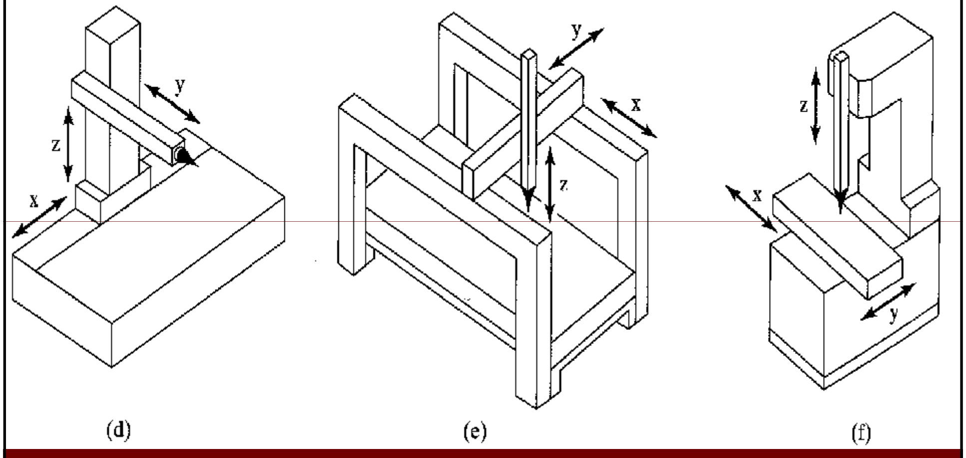
$$L = x_1 - x_2 = 135.94 - 70.43 = 65.51 \text{ mm}$$

CMM AERONAUTICAL Structure



(a) Cantilever (b) Moving bridge (c) Fixed bridge

CMM AERONAUTICAL Structure



(d) Horizontal Arm (e) Gantry (f) Column

CMM Operation and Programming

- Positioning the probe relative to the part can be accomplished in several ways, ranging from manual operation to direct computer control.
- Computer-controlled CMMs operate much like CNC machine tools, and these machines must be programmed.

CMM Controls

- The methods of operating and controlling a CMM can be classified into four main categories:
  1. Manual drive,
  2. Manual drive with computer-assisted data processing,
  3. Motor drive with computer-assisted data processing, and
  4. Direct Computer Control with computer-assisted data processing.

CMM Controls

- In manual drive CMM, the human operator physically move the probe along the machine's axes to make contact with the part and record the measurements.
- The measurements are provided by a digital readout, which the operator can record either manually or with paper print out.
- Any calculations on the data must be made by the operator.

- A CMM with manual drive and computer-assisted data processing provides some data processing and computational capability for performing the calculations required to evaluate a give part feature.
- The types of data processing and computations range from simple conversioons between units to more complicated geometry calculations, such as determining the angle between two planes.

CMM Controls

- A **motor-driven CMM with computer-assisted data processing** uses electric motors to drive the probe along the machine axes under operator control.
- A joystick or similar device is used as the means of controlling the motion.
- Motor-driven CMMs are generally equipped with data processing to accomplish the geometric computations required in feature assessment.
- A **CMM with direct computer control (DCC)** operates like a CNC machine tool. It is motorized and the movements of the coordinate axes are controlled by a dedicated computer under program control.
- The computer also performs the various data processing and calculation functions.
- As with a CNC machine tool, the DCC CMM requires part programming.

DCC CMM Programming

- There are twp principle methods of programming a DCC measuring machine:
    1. Manual leadthrough method.
    2. Off-line programming.
- In the **Manual Leadthrough** method, the operator leads the CMM probe through the various motions required in the inspection sequence, indicating the points and surfaces that are to be measured and recording these into the control memory.
- During regular operation, the CMM controller plays back the program to execute the inspection procedure.
- **Off-line Programming** is accomplished in the manner of computer-assisted NC part programming, The program is prepared off-line based on the part drawing and then downloaded to the CMM controller for execution.

Dimensions. A dimension of a part can be determined by taking the difference between the two surfaces defining the dimension. The two surfaces can be defined by a point location on each surface. In two axes (x-y), the distance L between two point locations (x_1, y_1) and (x_2, y_2) is given by

$$L = \pm\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

In three axes (x-y-z), the distance L between two point locations (x_1, y_1, z_1) and (x_2, y_2, z_2) is given by

$$L = \pm\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2}$$

See Example 23.1.

Hole location and diameter. By measuring three points around the surface of a circular hole, the "best–fit" center coordinates (a, b) of the hole and its radius R can be computed. The diameter = twice the radius. In the x-y plane, the coordinate values of the three point locations are used in the following equation for a circle to set up three equations with three unknowns:

$$(x - a)^2 + (y - b)^2 - R^2$$

where a = x-coordinate of the hole center, b = y-coordinate of the hole circle, and R = radius of the hole circle. Solving the three equations yields the values of a, b, and R. $D = 2R$. See Example 23.2.

Cylinder axis and diameter. This is similar to the preceding problem except that the calculation deals with an outside surface rather than an internal (hole) surface.

Sphere center and diameter. By measuring four points on the surface of a sphere, the best–fit center coordinates (a, b, c) and the radius R (diameter $D = 2R$) can be calculated. The coordinate values of the four point locations are used in the following equation for a sphere to set up four equations with four unknowns:

$$(x - a)^2 + (y - b)^2 + (z - c)^2 = R^2$$

where a − x-coordinate of the sphere, b − y-coordinate of the sphere, c − z-coordinate of the sphere, and R = radius of the sphere. Solving the four equations yields the values of a, b, c, and R.

Definition of a line in x-y plane. Based on a minimum of two contact points on the line, the best-fit line is determined. For example, the line might be the edge of a straight surface. The coordinate values of the two point locations are used in the following equation for a line to set up two equations with two unknowns:

$$x + Ay + B = 0$$

where A is a parameter indicating the slope of the line in the y-axis direction and B is a constant indicating the x-axis intercept. Solving the two equations yields the values of A and B, which defines the line. This form of equation can be converted into the more familiar conventional equation of a straight line, which is

$$y - mx + b$$

where slope $m = -1/A$ and y-intercept $b = -B/A$.

Angle between two lines. Based on the conventional form equations of the two lines, that is, the angle between the two lines relative to the positive x-axis is given by:

Angle between line 1 and line 2 = α-β

where $\alpha = \tan^{-1}(m_1)$, where m_1 = slope of line 1; and $\beta = \tan^{-1}(m_2)$, where m_2 = slope of line 2.

Definition of a plane. Based on a minimum of three contact points on a plane surface, the best–fit plane is determined. The coordinate values of the three point locations are used in the following equation for a plane to set up three equations with three unknowns:

$$x + Ay + Bz + C = 0$$

where A and B are parameters indicating the slopes of the plane in the y- and z-axis directions, and C is a constant indicating the x-axis intercept. Solving the three equations yields the values of A, B, and C, which defines the plane.

Flatness. By measuring more than three contact points on a supposedly plane surface, the deviation of the surface from a perfect plane can be determined.

Angle between two planes. The angle between two planes can be found by defining each of two planes using the plane definition method above and calculating the angle between them.

Parallelism between two planes. This is an extension of the previous function. If the angle between two planes is zero, then the planes are parallel. The degree to which the planes deviate from parallelism can be determined.

Angle and point of intersection between two lines. Given two lines known to intersect (e.g., two edges of a part that meet in a corner), the point of intersection and the angle between the lines can be determined based on two points measured for each line (a total of four points).

EXAMPLE Computing a Linear Dimension

The coordinates at the two ends of a certain length dimension of a machined component have been measured by a CMM. The coordinates of the first end are (23.47, 48.11, 0.25), and the coordinates of the opposite end are (73.52, 21.70, 60.38), where the units are millimeters. The given coordinates have been corrected for probe radius. Determine the length dimension that would be computed by the CMM software.

Solution: we have

$$L = \sqrt{(23.47 - 73.52)^2 + (48.11 - 21.70)^2 + (0.25 - 60.38)^2}$$

$$= \sqrt{(-50.05)^2 + (26.41)^2 + (-60.13)^2}$$

$$= \sqrt{2505.0025 + 697.4881 + 3615.6169} = \sqrt{6818.1075} = \mathbf{82.57\ mm}$$

EXAMPLE Determining the Center and Diameter of a Drilled Hole

Three point locations on the surface of a drilled hole have been measured by a CMM in the x-y axes. The three coordinates are: (34.41, 21.07), (55.19, 30.50), and (50.10, 13.18) mm. The given coordinates have been corrected for probe radius. Determine: (a) coordinates of the hole center and (b) hole diameter, as they would be computed by the CMM software.

Solution: To determine the coordinates of the hole center, we must establish three equations

$$(34.41 - a)^2 + (21.07 - b)^2 = R^2 \quad \text{(i)}$$

$$(55.19 - a)^2 + (30.50 - b)^2 = R^2 \quad \text{(ii)}$$

$$(50.10 - a)^2 + (13.18 - b)^2 = R^2 \quad \text{(iii)}$$

Expanding each of the equations, we have:

$$1184.0481 - 68.82a + a^2 + 443.9449 - 42.14b + b^2 = R^2 \quad \text{(i)}$$

$$3045.9361 - 110.38a + a^2 + 930.25 - 61b + b^2 = R^2 \quad \text{(ii)}$$

$$2510.01 - 100.2a + a^2 + 173.7124 - 26.36b + b^2 = R^2 \quad \text{(iii)}$$

Setting Eq. (i) = Eq. (ii):

$$1184.0481 - 68.82a + a^2 + 443.9449 - 42.14b + b^2 =$$
$$3045.9361 - 110.38a + a^2 + 930.25 - 61b + b^2 \quad \text{(iv)}$$

$$1627.993 - 68.82a - 42.14b = 3976.1861 - 110.38a - 61b$$

$$-2348.1931 + 41.56a + 18.86b = 0$$

$$18.86b = 2348.1931 + 41.56a$$

$$b = 124.5065 - 2.2036a \quad \text{(iv)}$$

Now setting Eq. (ii) = Eq. (iii):

$$3045.9361 - 110.38a + a^2 + 930.25 - 61b + b^2 =$$

$$2510.01 - 100.2a + a^2 + 173.7124 - 26.36b + b^2 \quad \text{(v)}$$

$$3976.1861 - 110.38a - 61b = 2683.7224 - 100.2a - 26.36b$$

$$1292.4637 - 10.18a - 34.64b = 0$$

$$10.18a = 1292.4637 - 34.64b$$

$$a = 126.9611 - 3.4027b \quad \text{(v)}$$

Substituting Eq. (iv) for b:

$$a = 126.9611 - 3.4027(124.5065 - 2.2036a)$$

$$a = 126.9611 - 423.6645 + 7.4983a$$

$$6.4983a = 296.7034 \qquad a = 45.6586 \rightarrow 45.66$$

The value of a can now be substituted into Eq. (iv):

$$b = 124.5065 - 2.2036(45.6586) \qquad b = 23.8932 \rightarrow 23.89$$

Now using the values of a and b in Eq. (i) to find R (Eqs. (ii) and (iii) could also be used), we have:

$$R^2 = (34.41 - 45.6586)^2 + (21.07 - 23.8932)^2$$

$$= (-11.2486)^2 + (-2.8232)^2 = 126.531 + 7.970 = 134.501$$

$$R = \sqrt{134.501} = 11.60 \text{ mm} \qquad D = 23.20 \text{ mm}$$

COMPUTER INTEGRATED MANUFACTURING (CIM)

UNIT 8

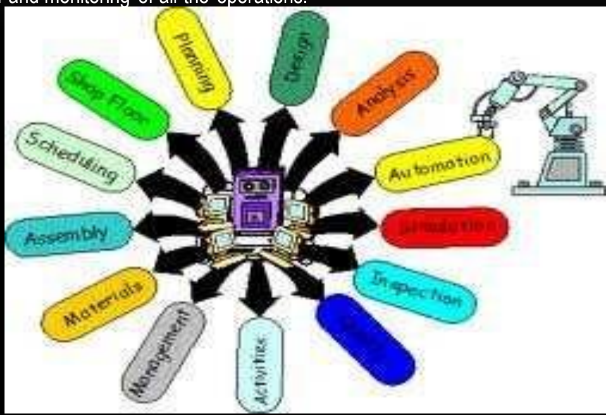
495

WHAT IS CIM?

Basically Computer Integrated Manufacturing (CIM) is the manufacturing approach of using computers to control the entire production process.

496

- In a CIM system functional areas such as design, analysis, planning, purchasing, cost accounting, inventory control, and distribution are linked through the computer with factory floor functions such as materials handling and management, providing direct control and monitoring of all the operations.



WHAT ARE THE BENEFITS OF CIM?

- CIM allows individual processes to exchange information with each other and initiate actions.
- Through the integration of computers, manufacturing can be faster and less error-prone, although the main advantage is the ability to create automated manufacturing processes.

As a method of manufacturing, three components distinguish CIM from other manufacturing methodologies:

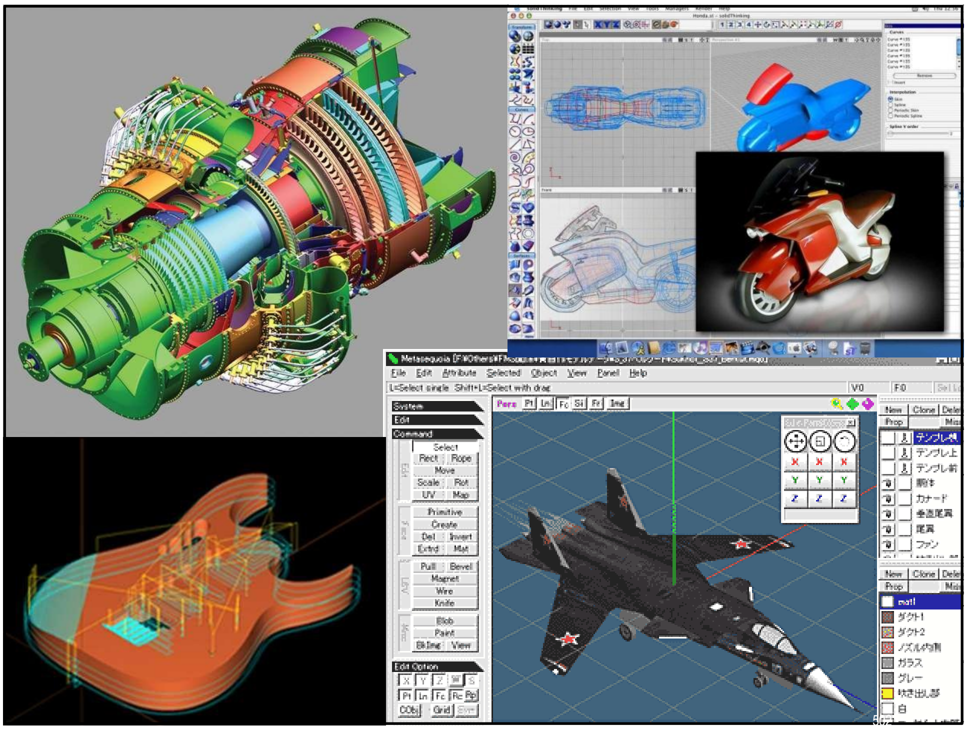
- Means for data storage, retrieval, manipulation and presentation;
- Mechanisms for sensing state and modifying processes;
- Algorithms for uniting the data processing component with the sensor/modification component.

- CIM is an example of the implementation of information and communication technologies (ICTs) in manufacturing.
- CIM implies that there are at least two computers exchanging information, e.g. the controller of an arm robot and a micro-controller of a CNC machine.

Some factors involved when considering a CIM implementation are;

- The production volume,
- The experience of the company or personnel to make the integration,
- The level of the integration into the product itself and the integration of the production processes.

CIM is most useful where a high level of ICT is used in the company or facility, such as CAD/CAM systems, the availability of process planning and its data.



COMPUTER-INTEGRATED MANUFACTURING TOPICS:

- **Key challenges;**

-Integration of components from different suppliers:

-Data integrity:

-Process control:

- **Subsystems in computer-integrated manufacturing;**

-Computer-aided techniques:

-Devices and equipment required:

-Technologies:

KEY CHALLENGES:

INTEGRATION OF COMPONENTS FROM DIFFERENT SUPPLIERS:

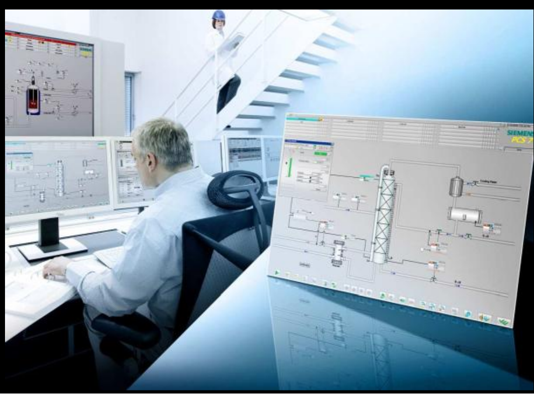
- When different machines, such as CNC, conveyors and robots, are using different communications protocols. In the case of AGVs, even differing lengths of time for charging the batteries may cause problems.

DATA INTEGRITY:

- The higher the degree of automation, the more critical is the integrity of the data used to control the machines.
- While the CIM system saves on labor of operating the machines, it requires extra human labor in ensuring that there are proper safeguards for the data signals that are used to control the machines.

PROCESS CONTROL:

- Computers may be used to assist the human operators of the manufacturing facility, but there must always be a competent engineer on hand to handle circumstances which could not be foreseen by the designers of the control software.



SUBSYSTEMS IN COMPUTER-INTEGRATED MANUFACTURING:

- A computer-integrated manufacturing system is not the same as a "lights-out" *factory*, which would run completely independent of human intervention, although it is a big step in that direction.
- Part of the system involves flexible manufacturing, where the factory can be quickly modified to produce different products, or where the volume of products can be changed quickly with the aid of computers.

Some or all of the following subsystems may be found in a CIM operation:

COMPUTER-AIDED TECHNIQUES:

- CAD (computer-aided design)
- CAE (computer-aided engineering)
- CAM (computer-aided manufacturing)
- CAPP (computer-aided process planning)
- CAQ (computer-aided quality assurance)
- PPC (production planning and control)
- ERP (enterprise resource planning)
- A business system integrated by a common database.

DEVICES AND EQUIPMENT REQUIRED:

- CNC, Computer numerical controlled machine tools
- DNC, Direct numerical control machine tools
- PLCs, Programmable logic controllers
- Robotics
- Computers
- Software
- Controllers
- Networks
- Interfacing
- Monitoring equipment

509

TECHNOLOGIES:

- FMS, (flexible manufacturing system)
- ASRS, (automated storage and retrieval system)
- AGV, (automated guided vehicle)
- Robotics
- Automated conveyance systems

510

Thank you all for listening ..

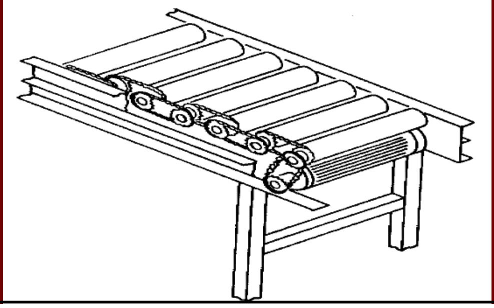
Conveyor Systems

- Conveyors are used when material must be moved in relatively large quantities between specific locations over a fixed path.
- Conveyors divided into two basic categories:
  1. Powered conveyors
  2. Non-powered conveyors.

- In powered conveyors, the power mechanism is contained in the fixed path, using belts, rotating rolls, or other devices to propel loads along the path. They are commonly used in automated material transfer systems.
- In non-powered conveyors, materials are moved either manually or by human workers who push the loads along the fixed path.

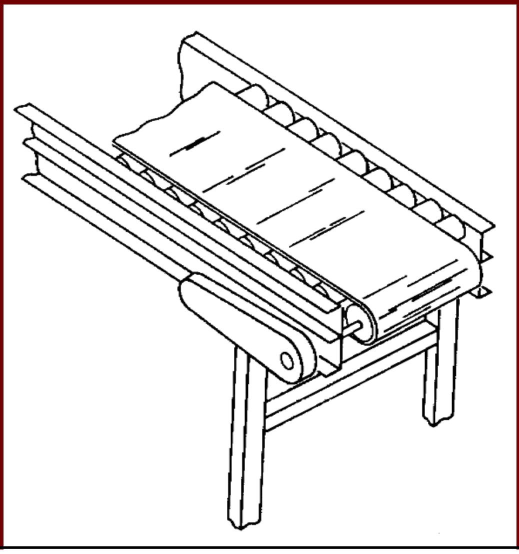
Types of Conveyors

- A variety of conveyor equipment is commercially available. The following are the major types of powered conveyors:
- In roller conveyor, the pathway consists of a series of tubes (rollers) that are perpendicular to the direction of travel.
  - The rollers are contained in a fixed frame that elevates the pathway above floor level from several inches to several feet.
  - Flat pallets carrying unit loads are moved forward as the roller rotate.
  - Roller conveyors are used in a wide variety of applications, including manufacturing, assembly, and packaging.



Types of Conveyors

2. Belt Conveyors consist of a continuous loop: Half its length is used for delivering materials , and other half is the return run.

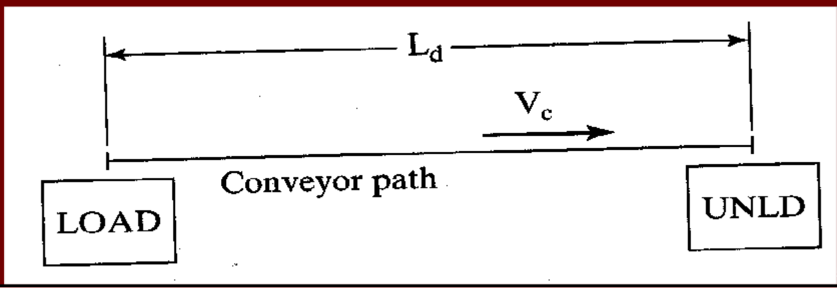


Conveyor Analysis

- Two types of conveyor operation are discussed in this course:
  1. Single direction conveyors.
  2. Continuous loop conveyors.

Single Direction Conveyors

- Consider the case of a single direction powered conveyor with one load station at the upstream end and one unload station at the downstream end



Single Direction Conveyors

- Assuming the conveyor operates at a constant speed, the time required to move materials from load station to unload station is given by:

$$T_d = \frac{L_d}{v_c}$$

- Where

  T_d = delivery time (min),

  L_d = length of conveyor between load and unload stations (m),

  v_c = conveyor velocity (m/min)

Single Direction Conveyors

- The flow rate of materials on the conveyor is determined by the rate of loading at the load station. The loading rate is limited by the reciprocal of the time required to load the materials

$$R_f = R_L = \frac{v_c}{s_c} \leq \frac{1}{T_L}$$

- R_f = material flow rate (parts/min).
- R_L = loading rate (parts/min).
- s_c = center-to-center spacing of materials on the conveyor (m/part).
- T_L = loading time (min/part).

Single Direction Conveyors

- An additional requirement for loading and unloading is that the time required to unload the conveyor must be equal or less than the loading time> That is,

$$T_U \leq T_L$$

Where T_U = Unloading time (min/part).

- If unloading requires more time than loading, then unremoved loads may accumulate at the downstream end of the conveyor
- For transporting several parts in a carrier rather than a single part.

$$R_f = \frac{n_p v_c}{s_c} \leq \frac{1}{T_L}$$

Where n_p = number of parts per carrier

s_c = center-to-center spacing of carriers on the conveyor (m/carrier)

EXAMPLE **Single Direction Conveyor**

A roller conveyor follows a pathway 35 m long between a parts production department and an assembly department. Velocity of the conveyor is 40 m/min. Parts are loaded into large tote pans, which are placed onto the conveyor at the load station in the production department. Two operators work the loading station. The first worker loads parts into tote pans, which takes 25 sec. Each tote pan holds 20 parts. Parts enter the loading station from production at a rate that is in balance with this 25-sec cycle. The second worker loads tote pans onto the conveyor, which takes only 10 sec. Determine: (a) spacing between tote pans along the conveyor, (b) maximum possible flow rate in parts/min, and (c) the minimum time required to unload the tote pan in the assembly department.

Solution: (a) Spacing between tote pans on the conveyor is determined by the loading time. It takes only 10 sec to load a tote pan onto the conveyor, but 25 sec are required to load parts into the tote pan. Therefore, the loading cycle is limited by this 25 sec. At a conveyor speed of 40 m/min, the spacing will be

$$s_c = (25/60 \text{ min})(40 \text{ m/min}) = 16.67 \text{ m}$$

(b) Flow rate is given by

$$R_f = \frac{20(40)}{16.67} = 48 \text{ parts/min}$$

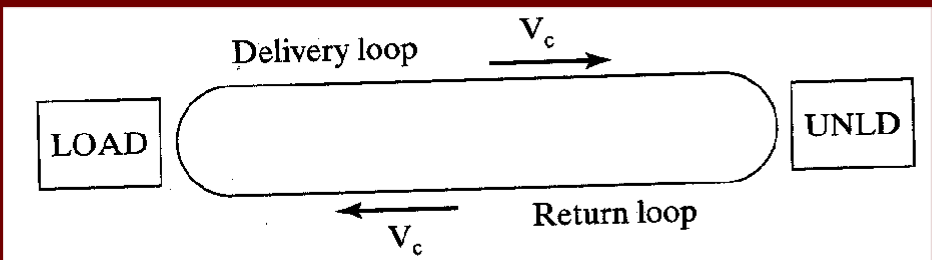
This is consistent with the parts loading rate of 20 parts in 25 sec, which is 0.8 parts/sec or 48 parts/min.

(c) The minimum allowable time to unload a tote pan must be consistent with the flow rate of tote pans on the conveyor. This flow rate is one tote pan every 25 sec, so

$$T_U \leq 25 \text{ sec}$$

Continuous Conveyors

- In continuous conveyor, the parts are moved in the carries between a load station and unload station.
- The complete loop is divided into two sections:
  - A delivery (forward) loop in which the carriers are loaded, and
  - A return loop in which the carriers travel empty.



- The length of the delivery loop is L_d, and the length of the return loop is L_e. Total length of the conveyor is therefore $L = L_d + L_e$.

Continuous Conveyors

- **The total time required to travel the complete loop is**

$$T_c = \frac{L}{v_c}$$

where T_c = total cycle time (min), and v_c = speed of the conveyor chain (m/min, ft/min)

- **The time a load spends in the forward loop is**

$$T_d = \frac{L_d}{v_c}$$

where T_d = delivery time on the forward loop (min)

Continuous Conveyors

Carriers are equally spaced along the chain at a distance s_c apart. Thus, the total number of carriers in the loop is given by:

$$n_c = \frac{L}{s_c}$$

where n_c = number of carriers, L = total length of the conveyor loop (m, ft), and s_c = center-to-center distance between carriers (m/carrier, ft/carrier). The value of n_c must be an integer, and so L and s_c must be consistent with that requirement.

Each carrier is capable of holding n_p parts on the delivery loop, and it holds no parts on the return trip. Since only those carriers on the forward loop contain parts, the maximum number of parts in the system at any one time is given by:

$$\text{Total parts in system} = \frac{n_p n_c L_d}{L}$$

As in the single direction conveyor, the maximum flow rate between load and unload stations is

$$R_f = \frac{n_p v_c}{s_c}$$

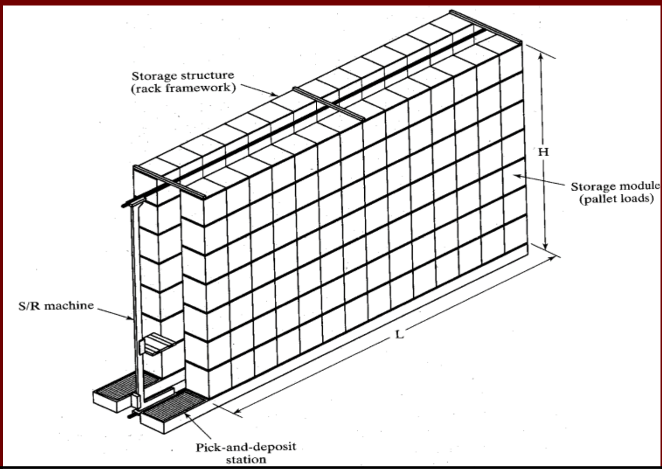
- **Where Rf = parts per minute. Again, this rate must be consistent with limitations on the time it takes to load and unload the conveyor.**

Automated Storage/Retrieval Systems

- An automated storage/retrieval system (AS/RS) can be defined as a storage system that performs storage and retrieval operations with speed and accuracy under a defined degree of automation.
- A wide range of automation is found in commercially available AS/RS systems. At the most sophisticated level, the operations are totally automated, computer controlled, and fully integrated with a factory.
- Automated storage/retrieval systems are custom designed for each application, although the designs are based on standard modular components available from each respective AS/RS supplier.

Automated Storage/Retrieval Systems

- An AS/RS consists of one or more storage aisles that are each serviced by a storage/retrieval (S/R) machine.
- The aisles have storage racks for holding the stored materials.
- The S/R machines are used to deliver material to the storage racks and to retrieve materials from the racks



Automated Storage/Retrieval Systems

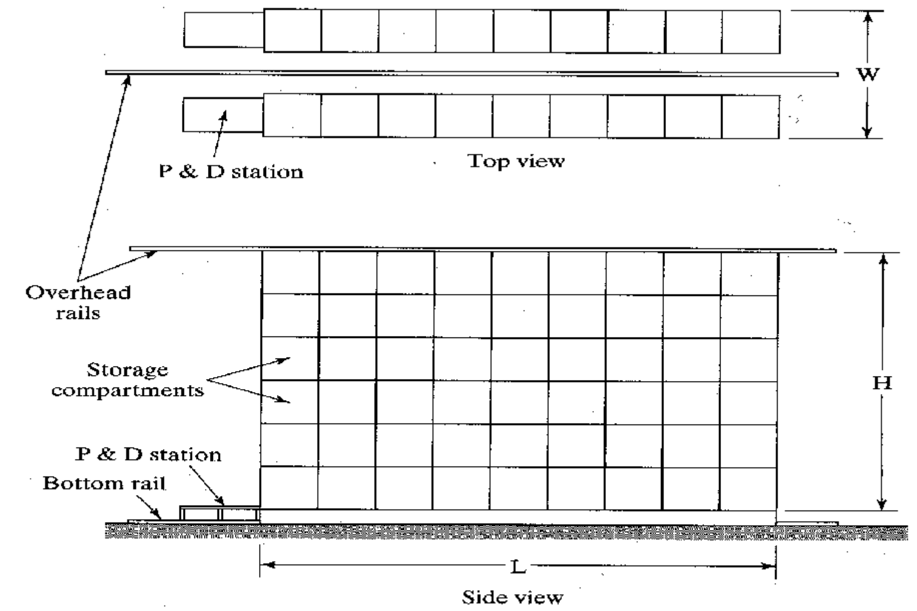
- Each AS/RS aisle has one or more input/output stations where materials are delivered into the storage system or moved out of the system.
- The input/output stations are called pickup-and-deposit (P&D) stations in AS/RS terminology.
- P&D stations can be manually operated or interfaced to some form of automated system.

Analysis of Automated Storage/Retrieval Systems

- The total storage capacity of one storage aisle depends on how many storage compartments are arranged horizontally and vertically in the aisle. This can be expressed as follows:

$$capacity \quad per \quad aisle = 2 n_y n_z$$

- Where n_y = number of load compartments along the length of the aisle, and n_z = number of load compartments that make up the height of the aisle. The constant 2 accounts for the fact that loads are contained on both sides of the aisle



Top and side views of a unit load AS/RS, with nine storage compartments horizontally ($n_y = 9$) and six compartments vertically ($n_z = 6$).

Analysis of Automated Storage/Retrieval Systems

- **If we assume a standard size compartment (to accept a standard size unit load), then the compartment dimensions facing the aisle must be larger than the unit load dimensions.**
- **Let x and y = the depth and width dimensions of a unit load, and z = the height of the unit load.**
- **The width, length, and height of the rack structure of the AS/RS aisle are related to the unit load dimensions and number of compartments as follows:**

$$W = 3(x + a)$$

$$L = n_y (y + b)$$

$$H = n_z (z + c)$$

Where

W, L, and H are the width, length and height of one aisle of the AS/RS rack structure (mm).

x, y, and z are the dimensions of the unit load (mm).

a, b, and c are allowances designed into each storage compartment to provide clearance for the unit load (mm)

EXAMPLE **Sizing an AS/RS System**

Each aisle of a four-aisle AS/RS is to contain 60 storage compartments in the length direction and 12 compartments vertically. All storage compartments will be the same size to accommodate standard size pallets of dimensions: $x = 42$ in and $y = 48$ in. The height of a unit load $z = 36$ in. Using the allowances, $a = 6$ in, $b = 8$ in, and $c = 10$ in, determine: (a) how many unit loads can be stored in the AS/RS, and (b) the width, length, and height of the AS/RS.

Solution: (a) The storage capacity is given by
Capacity per aisle = 2(60)(12) = 1440 unit loads.
With four aisles, the total capacity is:

$$\text{AS/RS capacity} = 4(1440) = 5760 \text{ unit loads}$$

(b) we can compute the dimensions of the storage rack structure:

$$W = 3(42 + 6) = 144 \text{ in} = 12 \text{ ft/aisle}$$

$$\text{Overall width of the AS/RS} = 4(12) = 48 \text{ ft}$$

$$L = 60(48 + 8) = 3360 \text{ in} = 280 \text{ ft}$$

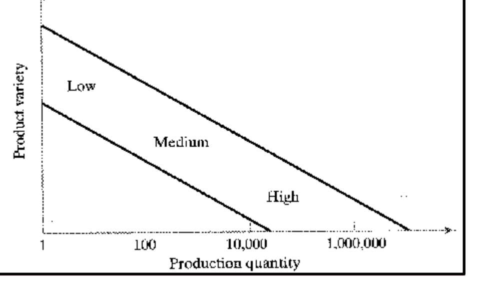
$$H = 12(36 + 10) = 552 \text{ in} = 46 \text{ ft}$$

Introduction to Flexible Manufacturing System (FMS)

- **A flexible manufacturing system (FMS) is a highly automated GT machine cell, consisting of a group or processing workstations (usually CNC machine tools), interconnected by an automated material handling and storage system, and controlled by a distributed computer system.**

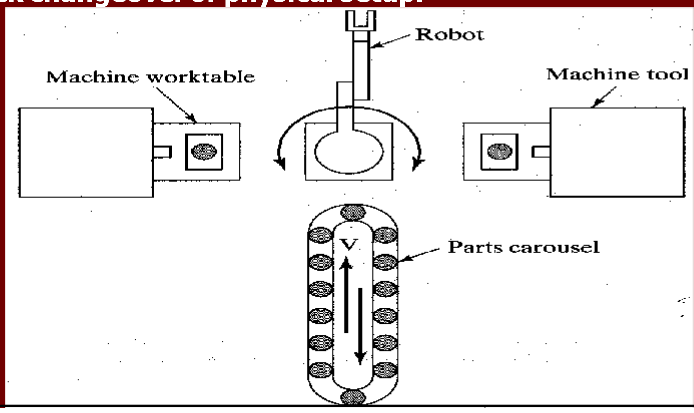
- **The reason the FMS is called flexible is that it is capable of processing a variety of different part styles simultaneously at the various workstations, and the mix of part styles and quantities of production can be adjusted in response to changing demand patterns.**

- **The FMS is most suited for the mid-variety, mid-volume production range**



What Make It Flexible?

- Three capabilities that a manufacturing system must possess to be a flexible.
  1. The ability to identify and distinguish among the different part styles processed by the system.
  2. Quick changeover of operating instructions, and
  3. Quick changeover of physical setup.



Tests of Flexibility

- To qualify as being flexible, a manufacturing system should satisfy several criteria. The following are four reasonable tests of flexibility in an automated manufacturing system:
  - **Part variety test.** Can the system process different part styles in a nonbatch mode?.
  - **Schedule change test.** Can the system readily accept changes in production schedule, and changes in either part mix or production quantity.
  - **Error recovery test.** Can the system recover quickly from equipment breakdowns, so that the production is not completely disrupted.
  - **New part test.** Can new part designs be introduced into the existing product mix with relative ease.

- If the answer to all of these questions is "YES" for a given manufacturing system, then the system can be considered flexible.

Types of Flexibility in Manufacturing

Flexibility Type	Definition	Depends on Factors Such As:
Machine flexibility	Capability to adapt a given machine (workstation) in the system to a wide range of production operations and part styles. The greater the range of operations and part styles, the greater the machine flexibility.	Setup or changeover time. Ease of machine reprogramming (ease with which part programs can be downloaded to machines). Tool storage capacity of machines. Skill and versatility of workers in the system.
Production flexibility	The range or universe of part styles that can be produced on the system.	Machine flexibility of individual stations. Range of machine flexibilities of all stations in the system.
Mix flexibility	Ability to change the product mix while maintaining the same total production quantity; that is, producing the same parts only in different proportions.	Similarity of parts in the mix. Relative work content times of parts produced. Machine flexibility.
Product flexibility	Ease with which design changes can be accommodated. Ease with which new products can be introduced.	How closely the new part design matches the existing part family. Off-line part program preparation. Machine flexibility.
Routing flexibility	Capacity to produce parts through alternative workstation sequences in response to equipment breakdowns, tool failures, and other interruptions at individual stations.	Similarity of parts in the mix. Similarity of workstations. Duplication of workstations. Cross-training of manual workers. Common tooling.
Volume flexibility	Ability to economically produce parts in high and low total quantities of production, given the fixed investment in the system.	Level of manual labor performing production. Amount invested in capital equipment.
Expansion flexibility	Ease with which the system can be expanded to increase total production quantities.	Expense of adding workstations. Ease with which layout can be expanded. Type of part handling system used. Ease with which properly trained workers can be added.

Comparison of Four Criteria of Flexibility in a Manufacturing System and the Seven Types of Flexibility

Flexibility Tests or Criteria	Type of Flexibility (Table 16.1)
1. ***Part variety test.*** Can the system process different part styles in a non-batch mode?	Machine flexibility Production flexibility
2. ***Schedule change test.*** Can the system readily accept changes in production schedule, changes in either part mix or production quantities?	Mix flexibility Volume flexibility Expansion flexibility
3. ***Error recovery test.*** Can the system recover gracefully from equipment malfunctions and breakdowns, so that production is not completely disrupted?	Routing flexibility
4. ***New part test.*** Can new part designs be introduced into the existing product mix with relative ease?	Product flexibility

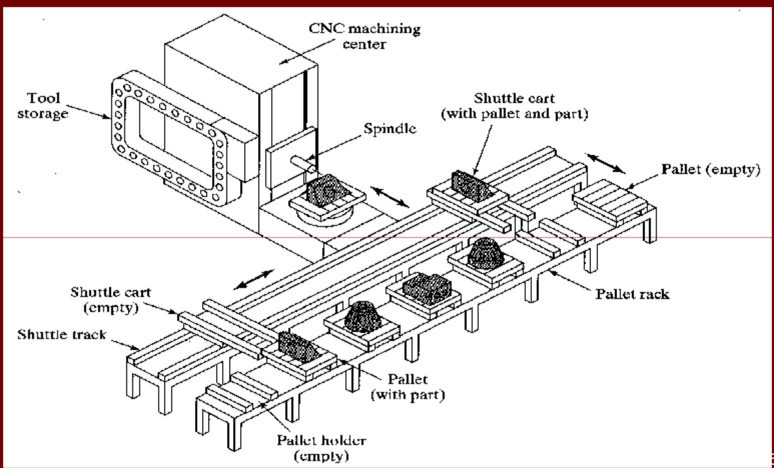
Number of Machines

- Flexible manufacturing systems can be distinguished according to the number of machines in the system. The following are typical categories:

  - Single machine cell (Type I A)
  - Flexible manufacturing cell (usually type II A, sometimes type III A)
  - Flexible manufacturing system (usually Type II A, sometimes type III A)

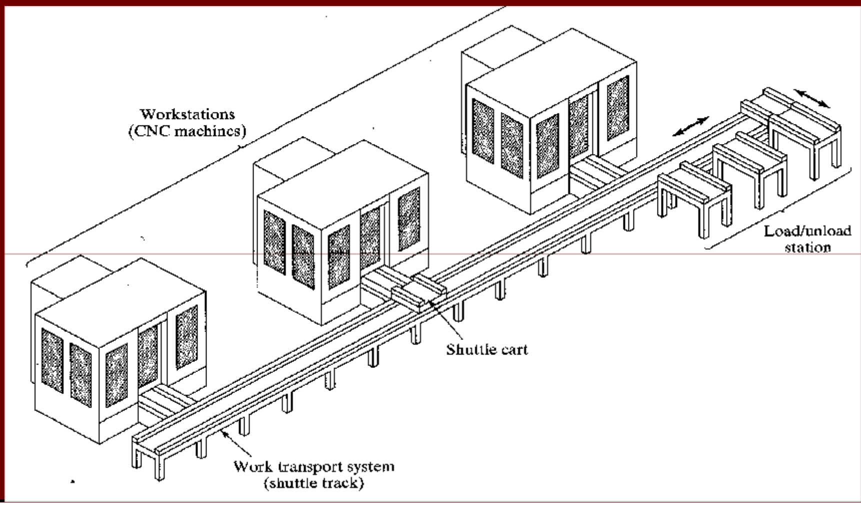
Single Machine Cell (SMC)

- A single machine cell consists of one CNC machining center combined with a parts storage system for unattended operation.
- Completed parts are periodically unloaded from the parts storage unit, and raw workparts are loaded into it



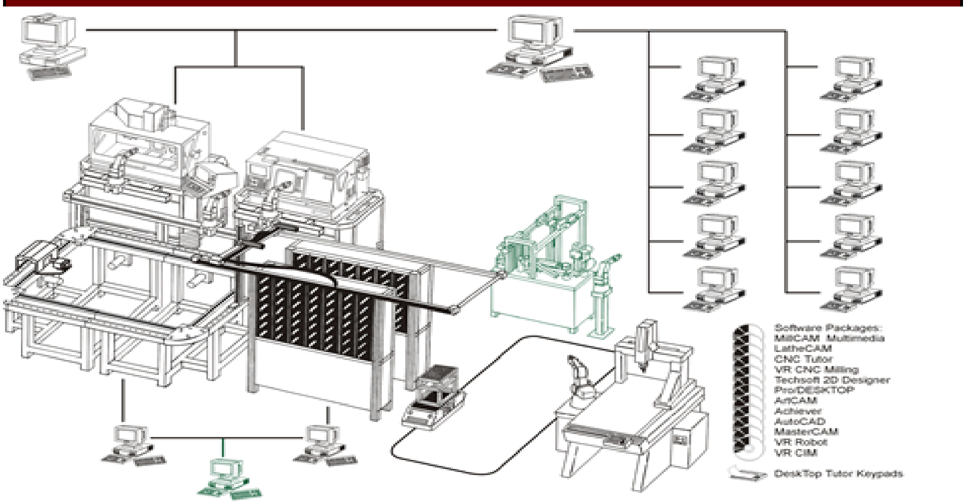
Flexible Manufacturing Cell (FMC)

- **A flexible manufacturing cell consists of two or three processing workstations (typically CNC machining centers) plus a part handling system.**
- **The part handling system is connected to a load/unload station.**

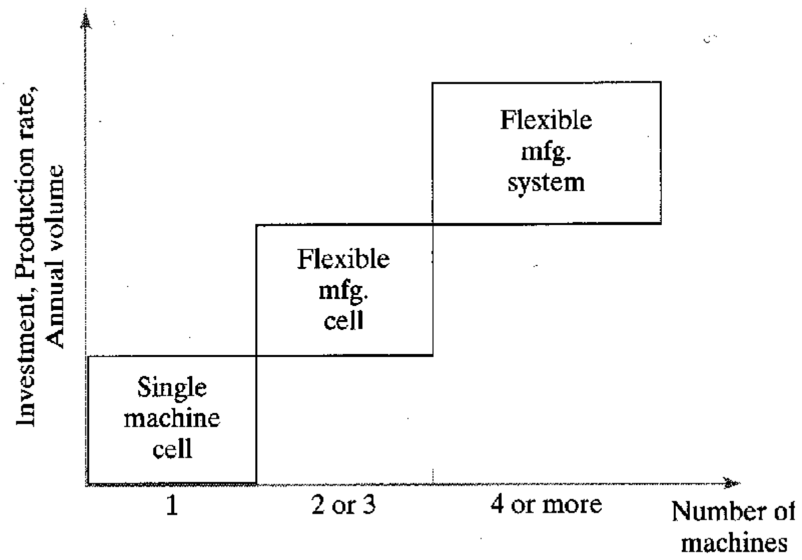


Flexible Manufacturing System (FMS)

- **A flexible manufacturing system has four or more processing workstations connected mechanically by a common part handling system and electronically by a distributed computer system.**



Some of the distinguishing characteristics of the three categories of flexible manufacturing cells and systems are summarized in figure below



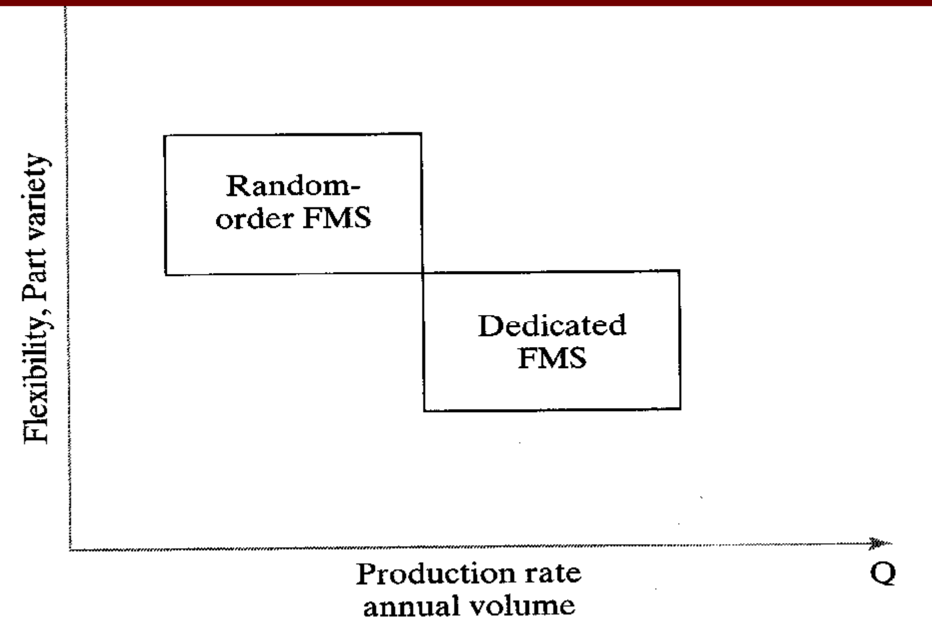
Flexibility Criteria Applied to the Three Types of Manufacturing Cells and Systems

	Flexibility Criteria (Tests of Flexibility)			
System Type	*1. Part Variety*	*2. Schedule Change*	*3. Error Recovery*	*4. New Part*
Single machine cell (SMC)	Yes, but processing is sequential, not simultaneous.	Yes	Limited recovery due to only one machine.	Yes
Flexible manufacturing cell (FMC)	Yes, simultaneous production of different parts.	Yes	Error recovery limited by fewer machines than FMS.	Yes
Flexible manufacturing system (FMS)	Yes, simultaneous production of different parts.	Yes	Machine redundancy minimizes effect of machine breakdowns.	Yes

Level of Flexibility

- Another classification of FMS is according to the level of flexibility designed into the system. Two categories are distinguished here:
    - Dedicated FMS
    - Random-order FMS
- **A dedicated FMS** is designed to produce a limited variety of part styles, and the complete universe of parts to be made on the system is known in advance.
- **A random-order FMS** is more appropriate when
    1. the part family is large,
    2. there are substantial variations in part configurations,
    3. there will be new part designs introduced into the system and engineering changes in parts currently produced, and
    4. the production schedule is subjected to change from day-to-day.

A comparison of dedicated and random-order FMS types

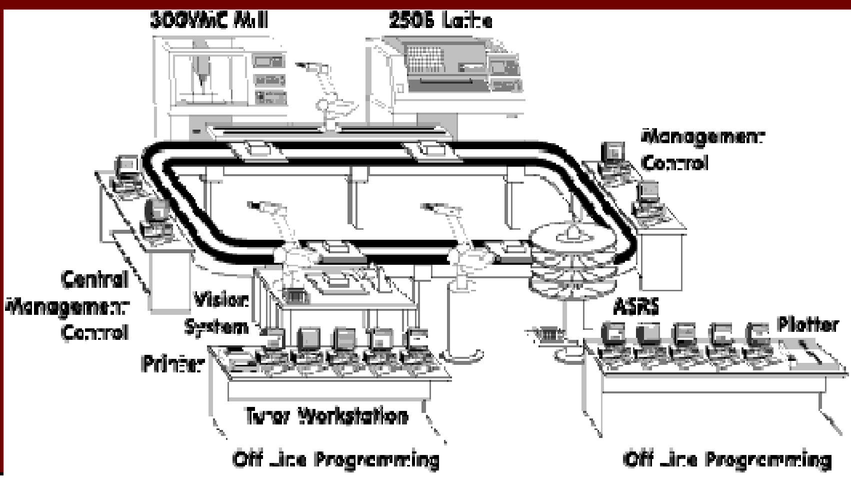


Flexibility Criteria Applied to Dedicated FMS and Random-order FMS

System Type	Flexibility Criteria (Tests of Flexibility)			
	1. Part Variety	*2. Schedule Change*	*3. Error recovery*	*4. New part*
Dedicated FMS	Limited. All parts known in advance.	Limited changes can be tolerated.	Limited by sequential processes.	No. New part introductions difficult.
Random-order FMS	Yes. Substantial part variations possible.	Frequent and significant changes possible.	Machine redundancy minimizes effect of machine breakdowns.	Yes. System designed for new part introductions.

Components of FMS

- **There are several basic components of an FMS:**
  1. **Workstations.**
  2. **Material handling and storage systems.**
  3. **Computer control system.**
  4. **People are required to manage and operate the system**



Workstations

- Following are the types of workstations typically found in an FMS:
  1. Load/Unload Stations.
  2. Machining Stations.
  3. Other processing Stations. (punching, shearing, welding, etc.)
  4. Assembly Station.
  5. Other Stations and Equipment. (Inspection, Vision, etc)

Material Handling and Storage System

- Functions of the Handling System
  1. Independent movement of workparts between stations.
  2. Handle a variety of workpart configurations.
  3. Temporary storage.
  4. Convenient access for loading and unloading workparts.
  5. Compatible with computer control.

- Material Handling Equipment

  The material handling function in an FMS is often shared between two systems:

  - Primary handling system establishes the basic layout of the FMS and is responsible for moving workparts between stations in the system. (Conveyor)

Material Handling and Storage System

2. Secondary handling system consists of transfer devices, automatic pallet changing, and similar mechanisms located at the workstations in the FMS.

- The function of the secondary handling system is to transfer work from the primary system to the machine tool or other processing station and to position the parts with sufficient accuracy and repeatability to perform the process or assembly operation.

- FMS Layout Configurations
  - The material handling system establishes the FMS layout. Most layout configurations found in today's FMS are:
    1. In-line layout
    2. Loop layout
    3. Rectangular layout

Computer Control System

- The FMS includes a distributed computer system that is interfaced to
  - the workstations,
  - Material handling system, and
  - Other hardware components.
- A typical FMS computer system consists of a central computer and microcomputers.
  - Microcomputers controlling the individual machines and other components.
  - The central computer coordinates the activities of the components to achieve smooth overall operation of the system

Human Resources

- Human are needed to manage the operations of the FMS. Functions typically performed by human includes:
  - Loading raw workparts into the system,
  - Unloading finished parts (or assemblies) from the system,
  - Changing and setting tools,
  - Equipment maintenance and repair,
  - NC part programming in a machining system, and
  - Programming and operation the computer system.