Lecture notes

On

Computer Aided Design /Computer Aided Manufacturing

B.TechVII Semester-IARE-R16

Prepared by:
Mr. M.Sunil Kumar, Assistant Professor
Dr. K. Raghu Rammohan Reddy, Professor

INSTITUTEOFAERONAUTICAL ENGINEERING

(AUTON0MOUS)

DUNDIGAL, HYDERABAD-500043

UNIT -I

FUNDAMENATAL CONCEPTS IN CAD

INTRODUCTION

- In engineering practice, CAD/CAM has been utilized in different ways by different people.

- Some utilize it to produce drawings and document designs.

- Others may employ it as a visual tool by generating shaded images and animated displays.

- A third group may perform engineering analysis of some sort on geometric models such as finite element analysis.

- A fourth group may use it to perform process planning an generate NC part programs. In order to establish the scope and definition of CAD/CAM in an engineering environment and identify existing and future related tools, a study of a typical product cycle is necessary. Figure 1.1 shows a flowchart of such a cycle.
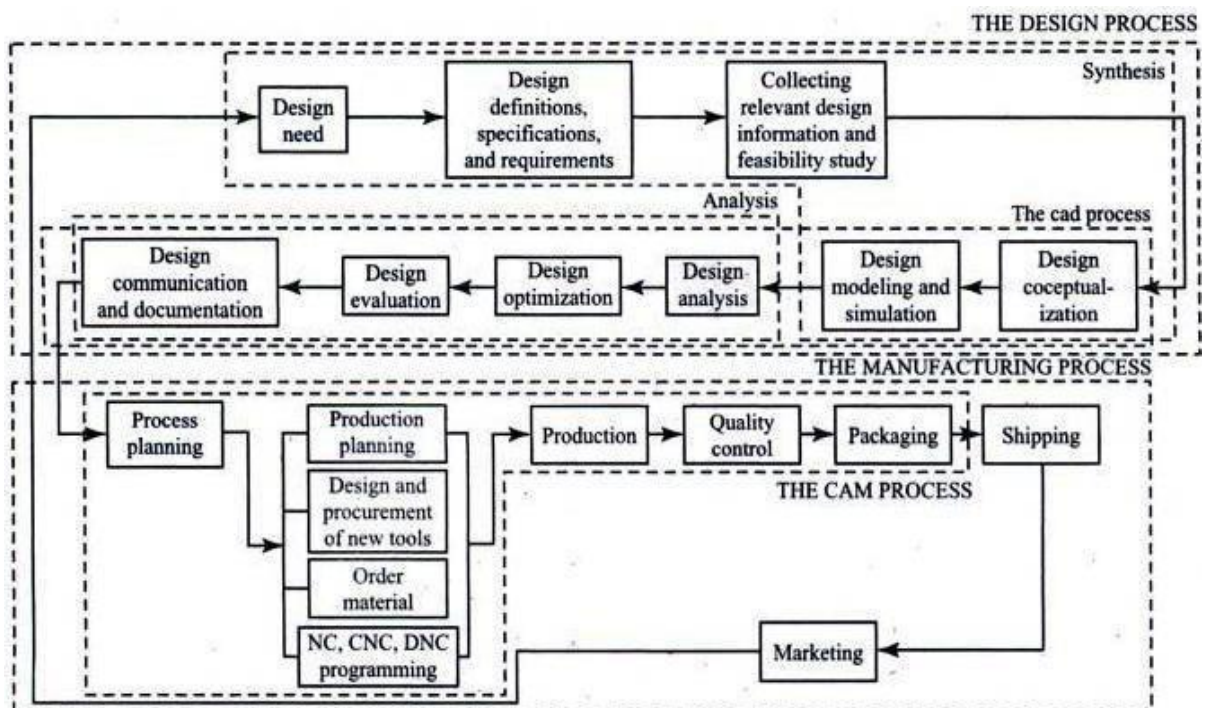

Fig. 1.1 Typical Product Cycle

- CAD tools can be defined as the intersection of three sets: geometrical modeling, computer graphics and the design tools.

- Figure 1.2 shows such definition. As can be perceived from this figure, the abstracted concepts of geometric modeling and computer graphics must be applied innovatively to serve the design process.

- Based on implementation in a design environment, CAD tools can be defined as the design tools (analysis codes, heuristic procedures, design practices, etc.) being improved by computer hardware and software throughout its various phases to achieve the design goal efficiently and competitively as shown in Fig.1.2.
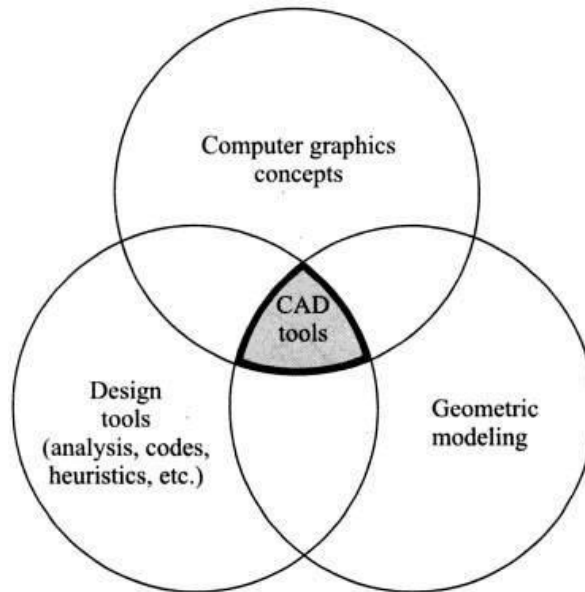

Fig. 1.2 Definition of CAD tools based on their Constituents

- Designers will always require tools that provide them with fast and reliable solutions to design situations that involve iterations and testing's of more than one alternative.

- CAD tools can vary from geometric tools, such as manipulations of graphics entities and interference checking, on one extreme, to customized applications programs, such as developing analysis and optimization routines, on the other extreme.

- In between these two extremes, typical tools currently available include tolerance analysis, mass property calculations and finite element modeling and analysis.
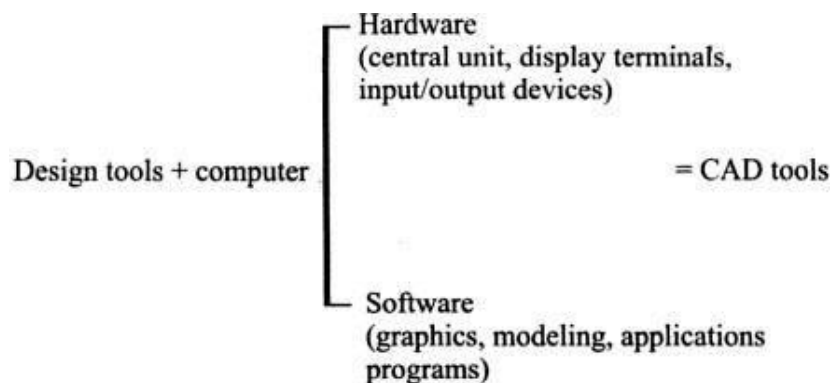

Fig. 1.3 Definition of CAD tools based on their implementation in a design environment

- CAD tools, as defined above, resemble guidance to the user of CAD technology.

- The definition should not and is not intended to, represent a restriction on utilizing it in engineering design and applications. The principal purposes of this definition are the following:

    1. To extend the utilization of current CAD/CAM systems beyond just drafting and visualization.
    2. To customize current CAD/CAM systems to meet special design and analysis needs.
    3. To influence the development of the next generation of CAD/CAM systems to better serve the design and manufacturing processes.

Reasons for Implementing a CAD System

1. To increase in the productivity of the designer

The CAD improves the productivity of the designer to visualize the product and its components, parts and reduces time required in synthesizing, analyzing and documenting the design.

2. To improve the quality of design

- CAD system permits a more detailed engineering analysis and a large no. of design alternatives can be investigated.
- The design errors are also reduced because of the greater accuracy provided bysystem.

3. To improve communication indesign

The use of a CAD system provides better engineering drawings, more standardization in drawing, better documentation of design, few drawing errors.

4. To create a data base for manufacturing

In the process of creating the documentation for the product design, much of the required data base to manufacture the product can be created.

5. Improves the efficiency of design

It improves the efficiency of design process and the wastages at the design stage can be reduced.
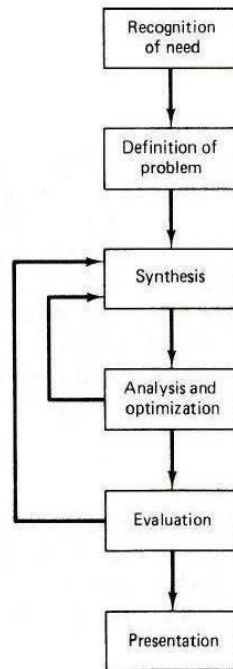
Conventional Design Process

Fig. 1.4. Conventional Design process

There are six steps involved in the conventional design process as discussed below:

1. **Recognition of need**

   - The first step in the designing process is to recognize necessity of that particulardesign.
   - The condition under which the part is going to operate and the operation of part in that particularenvironment.
   - The real problem is identified by knowing the history and difficulties faced insystem.

2. **Definition ofproblem**

   - The design involves type of shape of part, its space requirement, the material restrictions and the condition under which the part has to operate.
   - The basic purpose of design process has to be known before starting thedesign.
   - A problem may be design of a simple part or complexpart.
   - It may be problem on optimizing certainparameters.

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3. **Synthesis of design**

- In this, it may be necessary to prepare a rough drawing of designpart.

- The type of loading conditions imposed on theparts.

- The type of shapes which the part section can require and approximate dimension at which the different forces are located has to be provided on the sketch ofpart.

- The stresses to which the part is likely to be subjected must be analyzed and relevant formulas should beprepared.

- A mathematical model of design may be prepared to synthesize the parts ofdesign.

4. **Analysis andoptimization**

- The design can be analyzed for the type of loading condition as well as the geometric shape of thepart.

- In the first stage it will be necessary to check the design of the part for safestresses.

- If it is not satisfactory, then the dimensions of the part can be recalculated.

- The part can further be optimized for acquiring minimum dimensions, weight, volume, efficiency of the material andcost.

- The optimization depends on the definition of the problem and importance of aparameter.

- It may be sometimes necessary to optimize the part for certain operating parameters like efficiency, torque,etc.

5. **Evaluation**

- It is concerned with measuring the design against the specifications established in the problem definitionphase.

- The evaluation often requires the fabrication and testing of model to assess operating performance, quality andreliability.

6. **Presentation**

- The design of component must be presented along with necessary drawings in an attractive format.
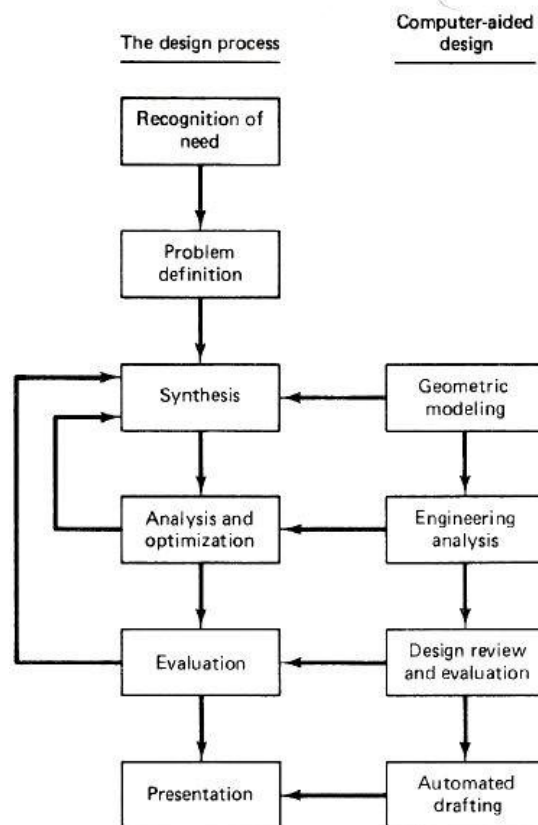
1.4 Conventional Design vs CAD

Fig. 1.5 Computer Aided Design

1. Geometric modeling

- Geometric modeling is concerned with the computer compatible mathematical description of the geometry of anobject.
- The mathematical description allows the image of the object to be displayed and manipulated on a graphics terminal through signals from the CPU of CADsystem.
- The software that provides geometric modeling capabilities must be designed for efficient use both by the computer and humandesigner.
- The basic form uses wire frames to represent theobject.
- The most advanced method of geometric modeling is solid modeling in threedimensions.

2. Engineering Analysis

- The analysis may involve stress-strain calculations, heat transfer computationetc.
- The analysis of mass properties is the analysis feature of CAD system that has probably the widestapplication.

- It provides properties of solid object being analyzed, such as surface area, weight, volume, center of gravity and moment ofinertia.
- The most powerful analysis feature of CAD system is the finite elementmethod.

3. Design Review &Analysis

- A procedure for design review is interferencechecking.
- This involves the analysis of an assembled structure in which there is a risk that the components of the assembly may occupy samespace.
- Most interesting evaluation features available on some CAD systems is kinematics.
- The available kinematics packages provide the capabilities to animate the motion of simple designed mechanisms such as hinged components andlinkages.

4. AutomatedDrafting

- This feature includes automatic dimensioning, generation of cross-hatched areas, scaling of the drawing and the capability to develop sectional views and enlarged views of particular partdetails.

Benefits of CAD

- Improved engineeringproductivity
- Reduced manpowerrequired
- More efficientoperation
- Customer modification are easier tomake
- Low wastages
- Improved accuracy ofdesign
- Better design can beevolved
- Saving of materials and machining time byoptimization
- Colors can be used to customize theproduct

Limitations of CAD

- The system requires large memory andspeed.
- The size of the software package islarge.
- It requires highly skilled personal to perform thework.
- It has hugeinvestment.

CAD/CAM Systems Evaluation Criteria

- The various types of CAD/CAM systems are Mainframe-Based Systems, Minicomputer-Based Systems, Microcomputer-Based Systems and Workstation BasedSystems.

- The implementation of these types by various vendors, software developers and hardware manufacturers result in a wide variety of systems, thus making the selection process of one rather difficult. CAD/CAM selection committees find themselves developing long lists of guidelines to screen availablechoices.

- These lists typically begin with cost criteria and end with sample models or benchmarks chosen to test system performance and capabilities. In between comes other factors such as compatibility requirements with in-house existing computers, prospective departments that plan to use the systems and credibility of CAD/CAM systems'suppliers.

- In contrast to many selection guidelines that may vary sharply from one organization to another, the technical evaluation criteria are largely the same. They are usually based on and are limited by the existing CAD/CAM theory and technology. These criteria can be listed asfollows.

System Considerations

(i) Hardware

Each workstation is connected to a central computer, called the server, which has enough large disk and memory to store users' files and applications programs as well as executing these programs.

(ii) Software

Three major contributing factors are the type of operating system the software runs under, the type of user interface (syntax) and the quality of documentation.

(iii) Maintenance

Repair of hardware components and software updates comprise the majority of typical maintenance contracts. The annual cost of these contracts is substantial (about 5 to 10 percent of the initial system cost) and should be considered in deciding on the cost of a system in addition to the initial capitalinvestment.

(iv) Vendor Support andService

Vendor support typically includes training, field services and technical support. Most vendors provide training courses, sometimes on-site if necessary.

Geometric Modeling Capabilities

(i) Representation Techniques

The geometric modeling module of a CAD/CAM system is its heart. The applications module of the system is directly related to and limited by the various representations it supports. Wireframes, surfaces and solids are the three types of modelingavailable.

(ii) Coordinate Systems and Inputs

In order to provide the designer with the proper flexibility to generate geometric models, various types of coordinate systems and coordinate inputs ought to be provided. Coordinate inputs can take the form of cartesian (x, y, z), cylindrical (r, θ, z) and spherical (θ, φ, z).

(iii) ModelingEntities

The fact that a system supports a representation scheme is not enough. It is important to know the specific entities provided by the scheme. The ease to generate, verify and edit these entities should be considered duringevaluation.

(iv) Geometric Editing andManipulation

It is essential to ensure that these geometric functions exist for the three types of representations. Editing functions include intersection, trimming and projection and manipulations include translation, rotation, copy, mirror, offset, scaling and changing attributes.

(v) Graphics StandardsSupport

If geometric models' databases are to be transferred from one system to another, both systems must support exchangestandards.

Design Documentation

(i) Generation of Engineering Drawings

After a geometric model is created, standard drafting practices are usually applied to it to generate the engineering drawings or the blueprints. Various views (usually top, front and right side) are generated in the proper drawing layout. Then dimensions are added, hidden lines are eliminated and/or dashed, tolerances are specified, general notes and labels are added, etc.

Applications

(i) Assemblies or ModelMerging

Generating assemblies and assembly drawings from individual parts is an essential process.

(ii) Design Applications

There are design packages available to perform applications such as mass property calculations, tolerance analysis, finite element modeling and analysis, injection modeling analysis and mechanism analysis and simulation.

(iii) ManufacturingApplications

The common packages available are tool path generation and verification, NC part programming, postprocessing, computer aided process planning, group technology, CIM applications and robot simulation.

(iv) Programming LanguagesSupported

It is vital to look into the various levels of programming languages a system supports. Attention should be paid to the syntax of graphics commands when they are used inside and outside the programming languages. If this syntax changes significantly between the two cases, user confusion and panic should be expected.

CAD Hardware

The hardware of CAD system consists of following:

- CPU
- Secondarymemory
- Workstation
- Inputunit
- Outputunit
- Graphics displayterminal

1. Central Processing Unit(CPU)

The CPU is the brain of the entire system.

Functions of CPU

• To receive information from the work station and display the output on the CRTscreen.

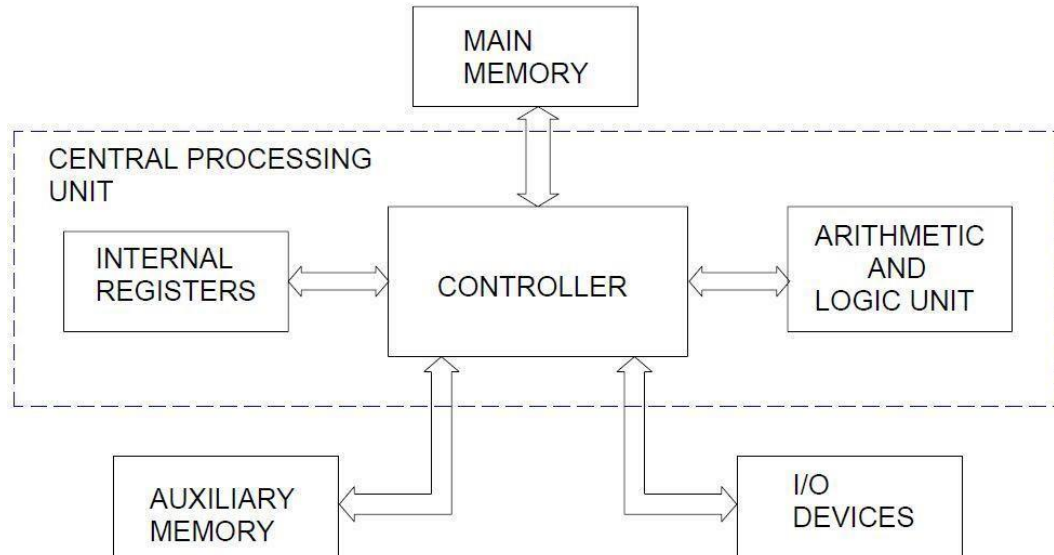• To read the data stored in the secondary memory storageunit.

Fig. 1.6 Components of CPU

Functions of secondary memory

> • To store files related to engineeringdrawing
>
> • To store programs required to give instruction to output devices likeplotters.
>
> • To store CADsoftware
>
> • The secondary storage unit consists of magnetic tapes anddiscs.
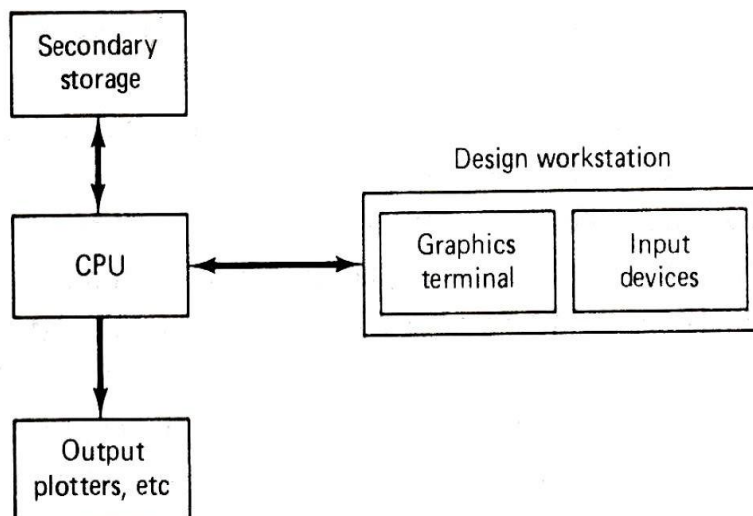
2. WorkStation

Fig. 1.7 Design Workstation

• The work station is a visible part of the CAD system which provides interaction between the operator and thesystem.

• Among these advantages offered by work station are their availability, portability, the availability to dedicate them to a single task without affecting other users and their consistency of timeresponse.

• A work station can be defined as a station of work with its own computing power to support major software packages, multitasking capabilities demanded by increased usage, complex tasks and networking potential with other computingenvironments.

3. InputDevices

- o A no. of input devices is available. These devices are used to input two possible types of information: text andgraphics.
- o Text-input devices and the alphanumerickeyboards.
- o There are two classes of graphics input devices: Locating devices and image inputdevices.
- o Locating devices, or locators, provide a position or location on thescreen.
- o These include light pens, mouse, digitizing tablets, joysticks, trackballs, thumbwheels, touchscreen andtouchpads.
- o Locating devices typically operate by controlling the position of a cursor on screen. Thus, they are also referred to as cursor-controldevices.

I. Scanners

- • Scanners comprise other class of graphics-inputdevice.
- • There are four relevant parameters to measure the performance of graphics input devices. These are resolution, accuracy, repeatability andlinearity.
- • Some may be more significant to some devices thanothers.

II. Keyboards

- • Keyboards are typically employed to create/edit programs or to perform word processingfunctions.
- • CAD/CAM systems, information entered through keyboards should be displayed back to the user on a screen forverification.

III. DigitizingTablets

- • A digitizing tablet is considered to be a locating as well as pointing device. It is a small, low-resolution digitizing board often usedin

conjunction with a graphics display.

- The tablet is a flat surface over which a stylus can be moved by the user.
- A tablet's typical resolution is 200 dots perinch
- The tablet operation is based on sensitizing its surface area to be able to track the pointing element motion on thesurface.
- Several sensing methods and technologies are used in tablets. The most common sensing technology is electromagnetic, where the pointing element generates an out of phase magnetic field sensed by wire grid in tabletsurface.
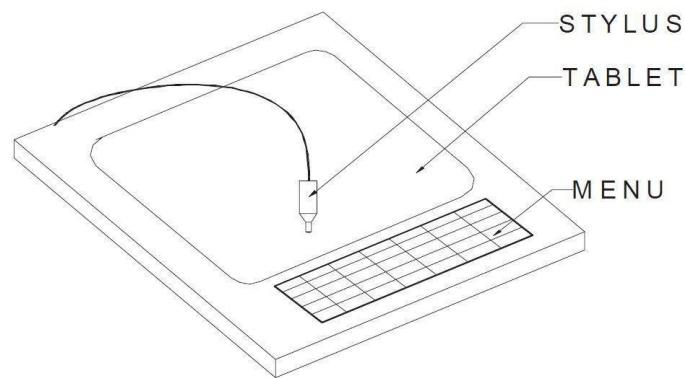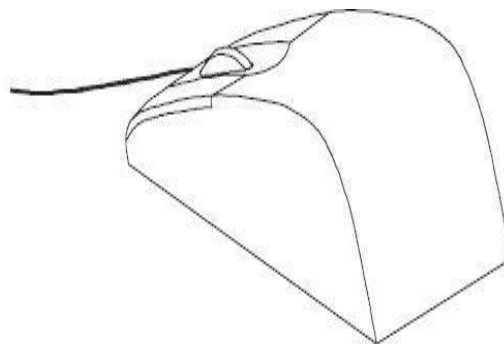

Fig. 1.8 Digitizer

IV. Mouse

Fig. 1.9 Mouse

- •Therearetwobasictypesofmouseavailablemechanicaland optical.
- The mechanical mouse has roller in order to record the mouse motion in X and Ydirections.

- In optical mouse, movements over the surface are measured by a light beam modulationtechnique.
- The light source is located at the bottom and the mouse must be in contact with the surface for screen cursor to follow itsmovement.
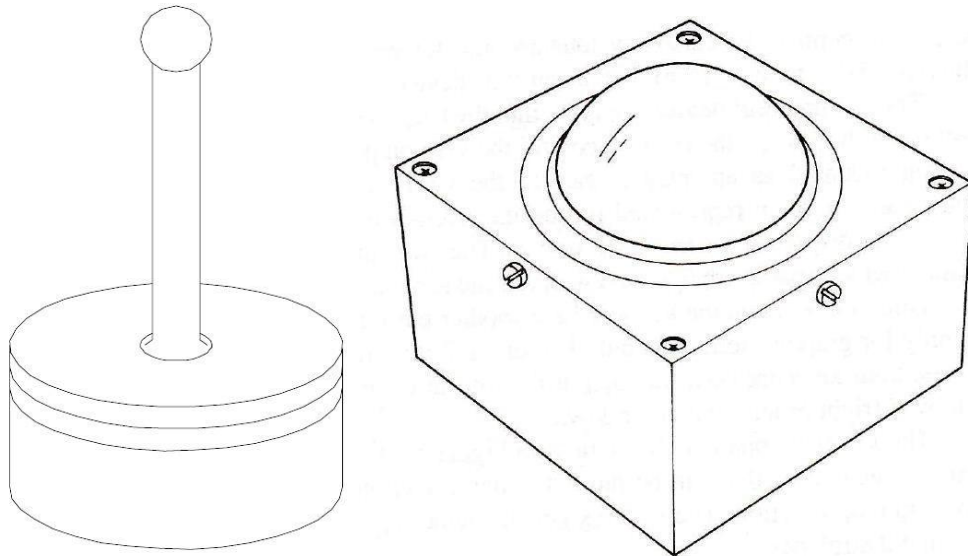
V. Joy sticks &Trackballs

Fig. 1.10 Joy stick& Track ball

- The joystick works by pushing its stick backwards or forward or to left or right. The extreme positions of these directions correspond to the four corners of thescreen.
- A trackball is similar in principal to a joystick but allows more precise fingertip control. The ball rotates freely within itsmount.
- Both the joystick and trackball are used to navigate the screen display cursor. The user of a trackball can learn quickly how to adjust to any nonlinearity in itsperformance.

CLASSIFICATION OF HARDWARE CONFIGURATIONS

The classification hardware configuration is as follows:

      (a)   Mainframe-basedsystems

      (b)   Minicomputer-basedsystems

      (c)   Microcomputer-basedsystems

   (d)   Workstation-basedsystems

Mainframe-based Systems

Mainframe-based CAD/CAM systems are used in large organizations for handling massive amounts of data and a multitude of concurrent activities of remote separate software applications. Mainframes often host hundreds of remote workstations operating and communicating over a vast network (sometimes covering thousands of kilometers and crossing international boundaries).

Below Figure shows a schematic of the mainframe-based CAD system components and details of a workstation. The computer environment is divided into:

•   The userenvironment
•   The systemenvironment

The user environment signifies the components and the area which the user can access. These components include primarily workstations and peripherals. The mainframe can support as many workstations as possible to avoid degradation of the response time between the users and the system. A typical workstation consists of input and output devices. The input devices may include cursor control devices for graphics input and text input devices. The cursor can be controlled via a light pen, joystick, mouse, electronic pen with a digital tablet, thumbwheel, or trackball. Text input can be input through a keyboard, which may have programmed function keys. Output devices consist of a graphics display with a hardcopy printer to provide convenient raster plots of full screencontents.
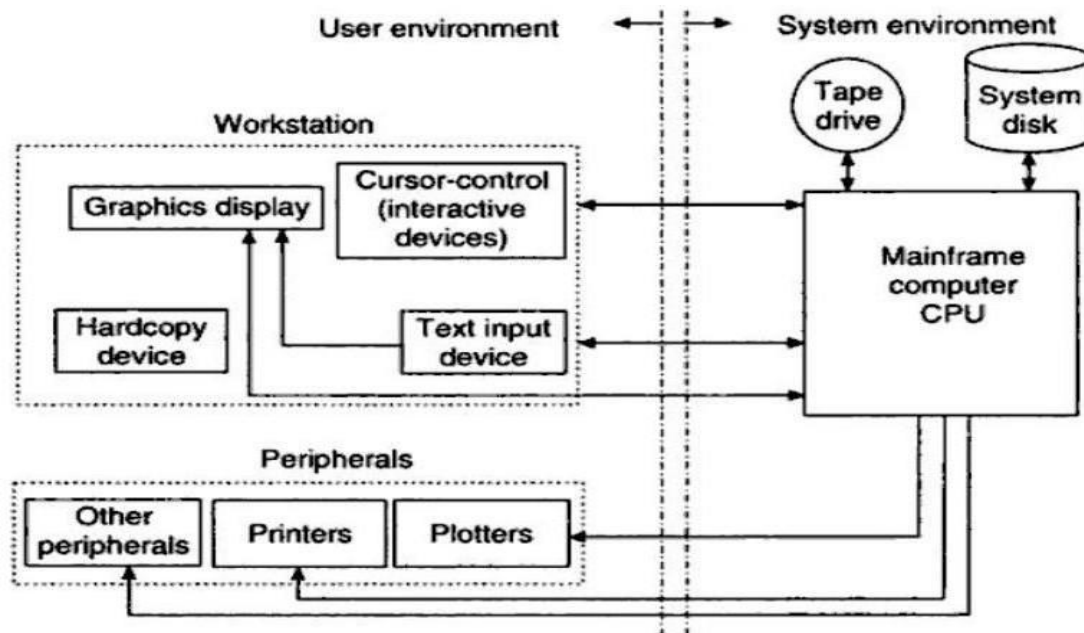
Minicomputer-based Systems

The development of VLSI (very large scale integrated) circuits has changed the basic principles of computer architecture and has directly led to the proliferation of minicomputers. Early versions on minis were 16-bit word, slow and limited-storage computers.
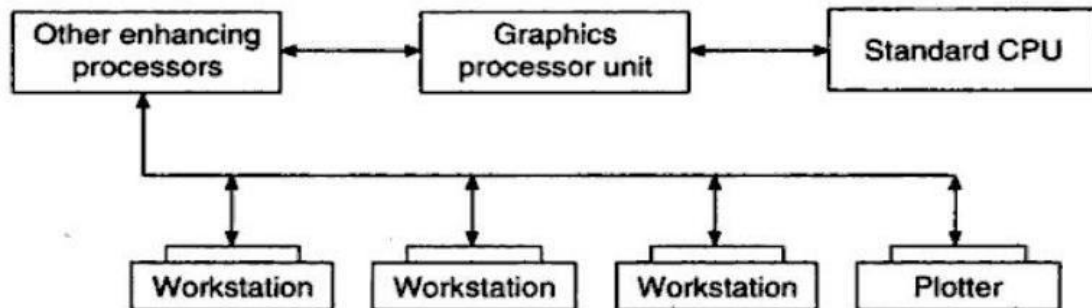
The DEC (Digital Equipment Corporation) PDP series offers a typical example.In the late 1970s, the arrival of super 32-bit word and virtual memory operating systems, boosted CAD/CAM applications and facilitated decentralization from mainframes. Minicomputers have enabled the rapid growth of the CAD/CAM industry. The 32-bit minicomputer is capable of handling complex geometric software and large quantities of data. The schematic of minicomputer is shown in abovefigure.

Microcomputer-based Systems

The advent of the IBM Personal Computer (PC) provided the first significant impetus for CAD on micros. Two main factors are responsible for the popularity and fast emergence of micro-based CAD systems. First, the speed, size, and accuracy problems are being reduced. Microcomputers of a 32-bit word length are available with enough memory size, disk storage, and speed for CAD/CAM applications. Second, various application programs have matured and cover most, if not all user needs.
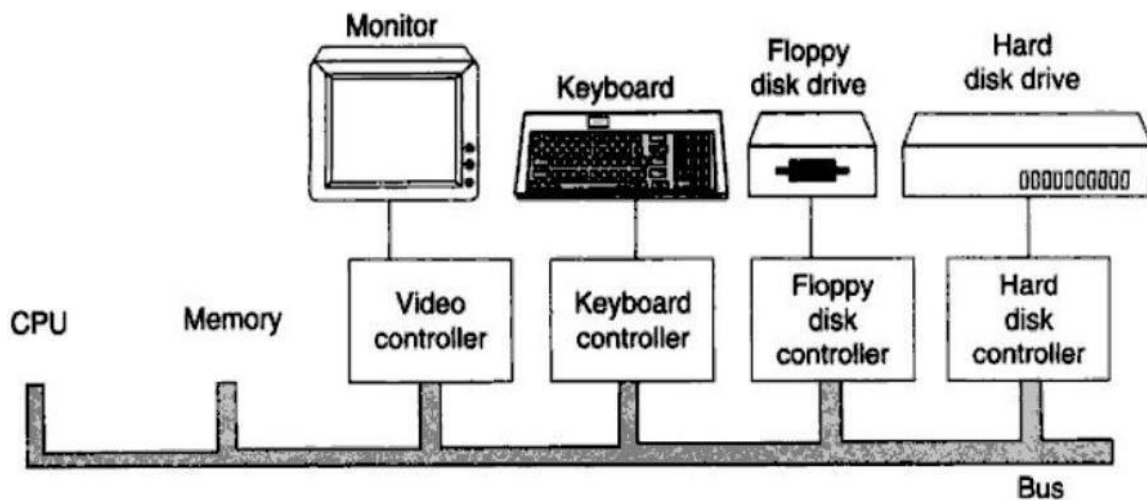
Workstation-based Systems

Graphics terminals attached to mainframes, minis, or PCs do not qualify as workstations. These terminals may be referred to as work stations* (two words). A workstation can be defined as a 'work station' with its own computing power to support major software packages, multitasking capabilities demanded by increased usage and complex tasks, and networking potential with other computing environments. The workstation concept seems to form (he basis of the present generation of CAD/CAMsystems.
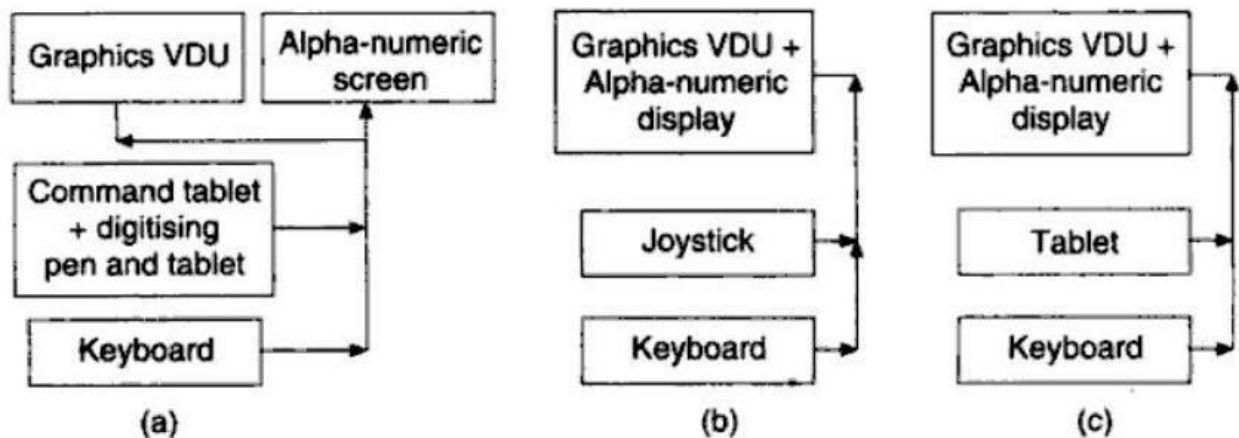
The basic elements of a CAD workstation are:

- A graphics screen called the VISUAL DISPLAY UNIT(VDU)
- An ALPHA-NUMERIC DISPLAY (word and numberscreen)
- A workstationPROCESSOR
- An electronic COMMANDTABLET
- A MENU facility
- A CURSOR CONTROLdevice
- AKEYBOARD
- A PRINTER/PLOTTERdevice

GRAPHICAL DISPLAYS

The graphical display enables the user to view images and to communicate with the displayed images by adding, deleting, blanking and moving graphics entities on the display screen. Various display technologies are now available based on the concept of converting the computer electrical signals into visible images at high speed. The graphics display can be divided into two types based on the scan technology used to control the electron beam when generating graphics on the screen. Theseare:

- Randomscan
- Rasterscan

In random scan, graphics can be generated by drawing vectors or line segments on the screen in a random order, which is controlled, by the user input and the software. The principle of random scan is illustrated in below figure.
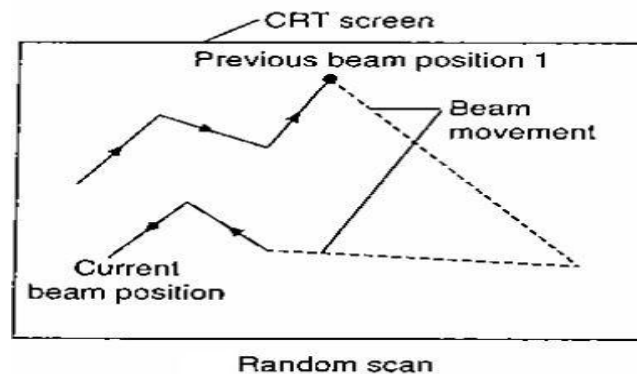
Random scan

In raster scan, the screen is canned from left to right, top to bottom, all the time to generate graphics. The principle of random scan is illustrated in below figure.

Raster scan
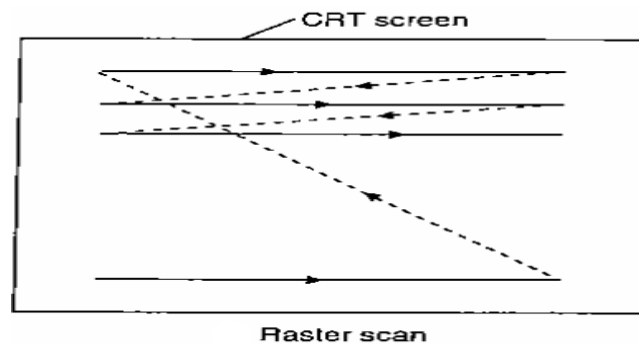
The graphic display technologies include:
- CRT (cathode raytube)
- Liquid crystaldisplay
- Plasma paneldisplay

The CRT is basically an evacuated glass tube in which a beam of electrons is fired from an electron gun onto a phosphor-coated screen, resulting in an illuminated trace being displayed on the screen.
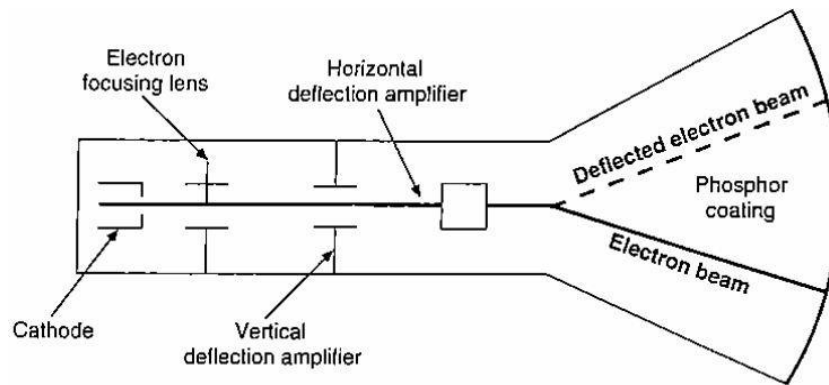
Schematic of a CRT.

Various types of CRT displays are broadly categorized into:

- Direct view storage tube(DVST)
- Vectorrefresh
- Rasterrefresh

The **DVST** (Direct View Storage Tube) has the standard CRT electron gun and deflection system for location of the beam onto the screen. The picture is stored as a charge in the phosphor mesh located behind the screen surface. Once displayed, the picture remains on the screen until it is explicitly erased. Therefore, complex pictures can be drawn without flicker at high resolution. One cannot alter a DVST picture except by erasing the entire screen and drawing it again. The inability to erase and edit individual areas of the drawing is a major drawback of the DVST system. Colored pictures are not usually available with a DVST. This can be a distinct disadvantage, particularly for three-dimensional drawings. Animation is also difficult to achieve, a factor that effectively disallows such vital facilities as tool-path simulation, and dynamic analysis of mechanisms.
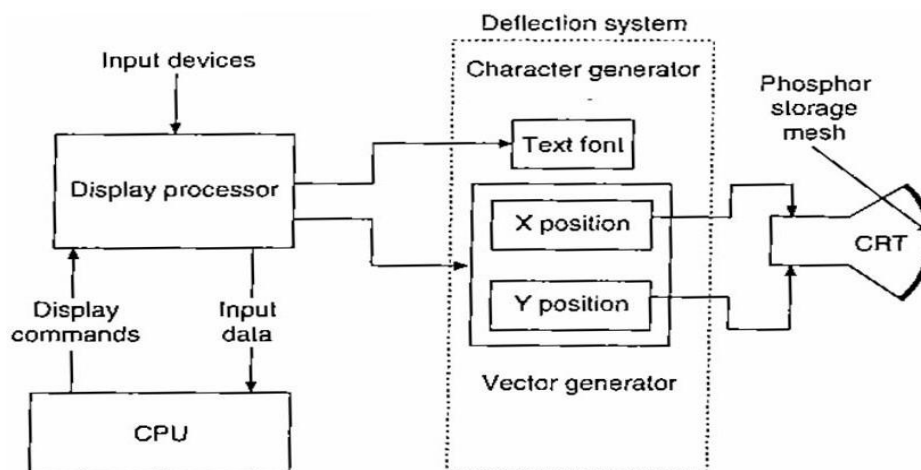
Direct view storage tube.

In **vector refresh display,** the deflection system of the CRT is controlled and driven by the vector and character generators and digital-to-analog converters. The refresh buffer stores the display file that contains points, lines, characters, and other attributes of the picture to be drawn. These commands are interpreted and processed by the display processor. The electron beam accordingly excites the phosphor that glows for a short period. In order to maintain a steady flicker-free image, the screen must be refreshed or re-drawn at least 30 or 60 times per second. Vector refresh displays are particularly noted for their bright, clear image, and high drawing speed. The refresh operation is well-suited to fast moving animation of the screen display in either 2D or 3D. The chief disadvantages of vector refresh displays are their high cost, and their tendency to flicker on complex drawings if the refresh rate becomes less than the flicker threshold of the eye. Color displays are possible, but again are only available at highcost.
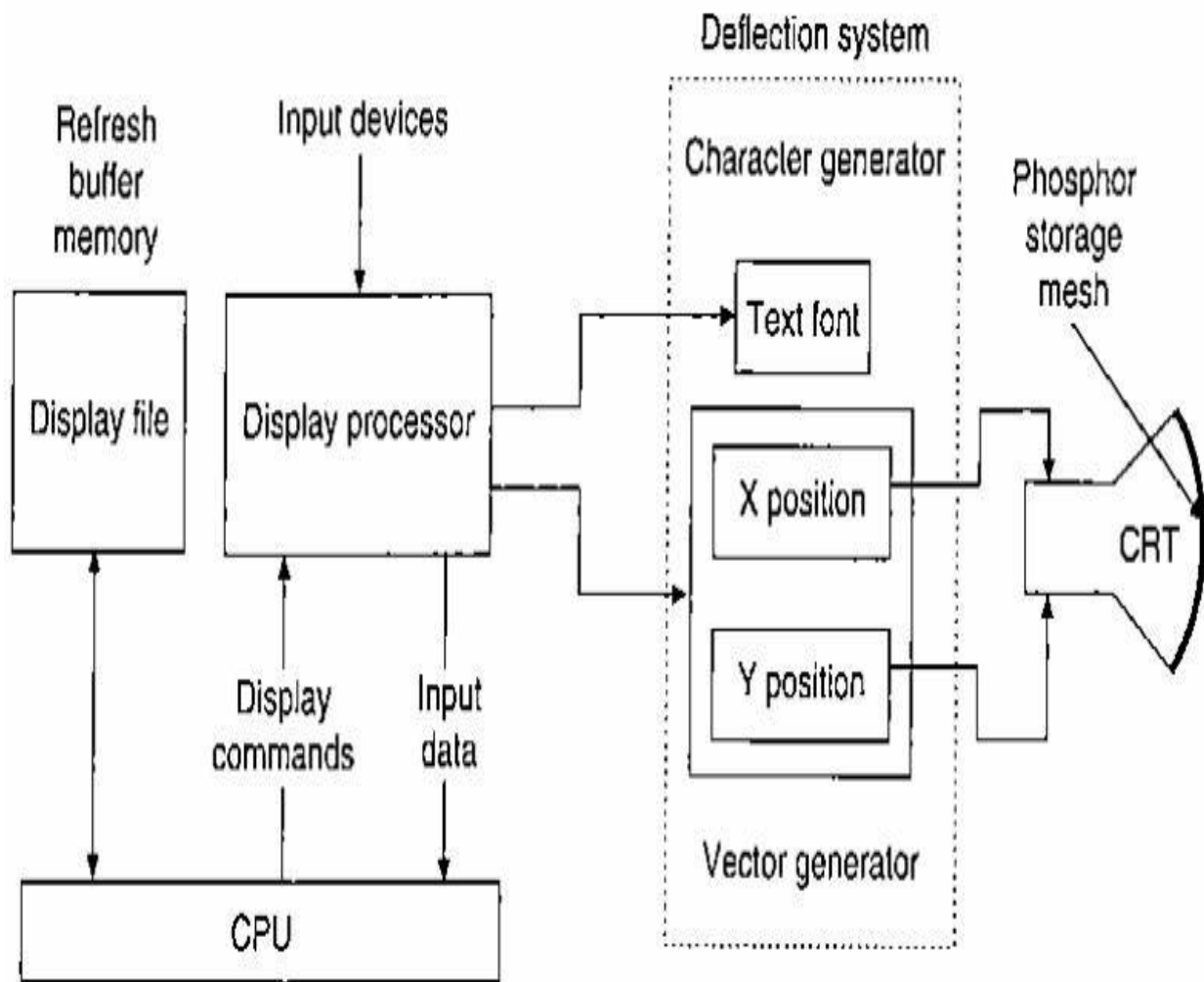
Vector refresh display.

Raster refresh display works on the principle of a domestic television set. In raster display, the display screen area is divided horizontally and vertically into a matrix of small elements called picture elements (pixels). A pixel is the smallest addressable area on a screen as shown in Figure 2.25. A n N x M resolution defines a screen with N rows and M columns. Each row defines a scan line. A typical resolution of a raster display is 1280 X 1204. The pixels are controlled by the electron beam as it sweeps across the screen from one side to the other. The beam always starts its sweep from the top left-hand corner of the screen, regardless of what has been drawn, finishes on a horizontal line to the right, moves down one row of pixels, returns, and starts again from the left. The display is completed when the beam has reached the bottom right of the screen. It then refreshes by commencing the whole procedure again at the top left. Each refresh operation takes about 0.02 seconds. Images are displayed by converting geometric in format ion into pixel values, which arc then converted into electron beam deflection through the display processor and the deflectionsystem.

In a **color raster display**, there are three electron guns, one for each of the primary colors, red, green and blue. The electron guns are frequently arranged in a triangular pattern corresponding to a similar triangular pattern of red, green and blue phosphor dots on the face of the CRT. In order to ensure that the individual electron guns excite the correct phosphor dots (e.g., the red gun excites only the red phosphor dot), a perforated metal grid is placed between the electron guns and the face of the CRT. The perforations in the shadow mask are arranged in the same triangular pattern as the phosphor dots.

Colour raster refresh display
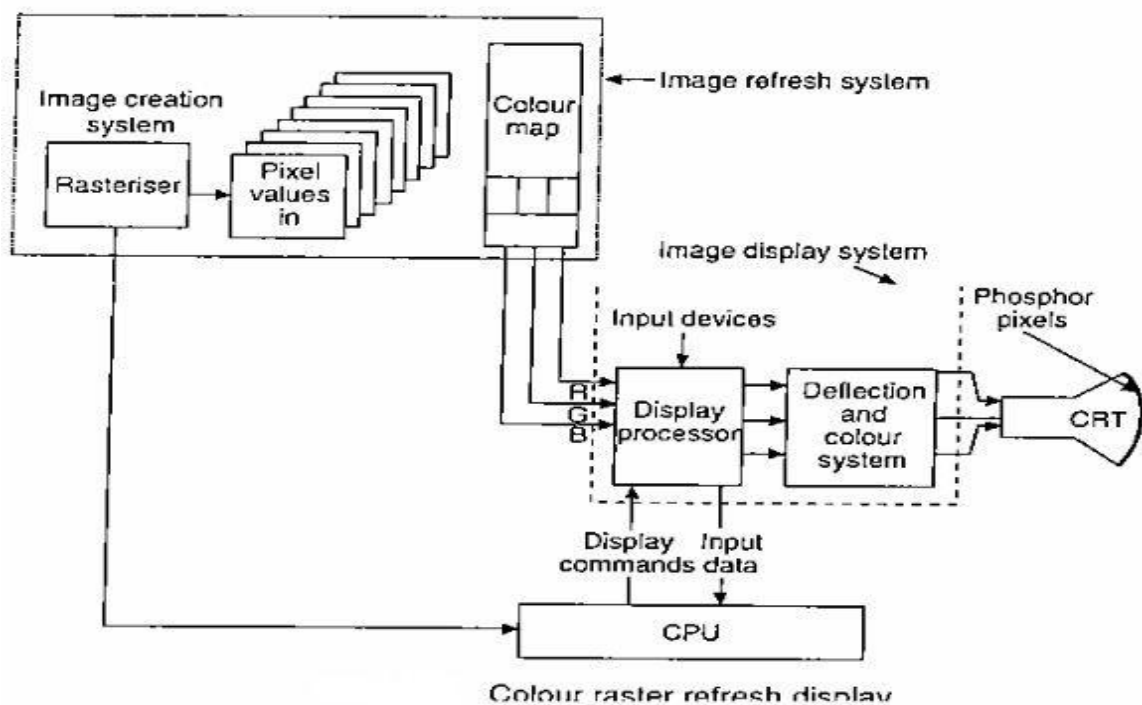
The distance between perforations is called the pitch. The color guns are arranged so that the individual beams converge and intersect at the shadow mask. Upon passing through [he hole in the shadow mask, the red beam, for example, is prevented or masked from intersecting either the green or blue phosphor dot; it can only intersect the red phosphor dot. By varying the strength of the electron beam for each individual primary color, different shades (intensities) are obtained. These primary color shades are combined into a number of colors for each pixel.

In a **liquid crystal display** transmitted or blocked, depending upon the orientation of molecules in the liquid crystal. The polarizing characteristics of certain organic compounds are used to modify the characteristics of the incident light. The basic principles of polarized light are shown in below figure. In figure (a) non-coherent light is passed through the first (left) polarizer. The resulting transmitted light is polarized in the *x-y* plane. Since the polarizing axis of the second polarizer is also aligned with the *x-y* plane, the light continues through the second polarizer. In figure (b) the polarizing axis of the second polarizer is rotated 90° to that of first. Consequently, the plane polarized light that passed through the first polarizer is absorbed by thesecond.

(a) Light transmitted

(b) Light absorbed

Polarisation of light.
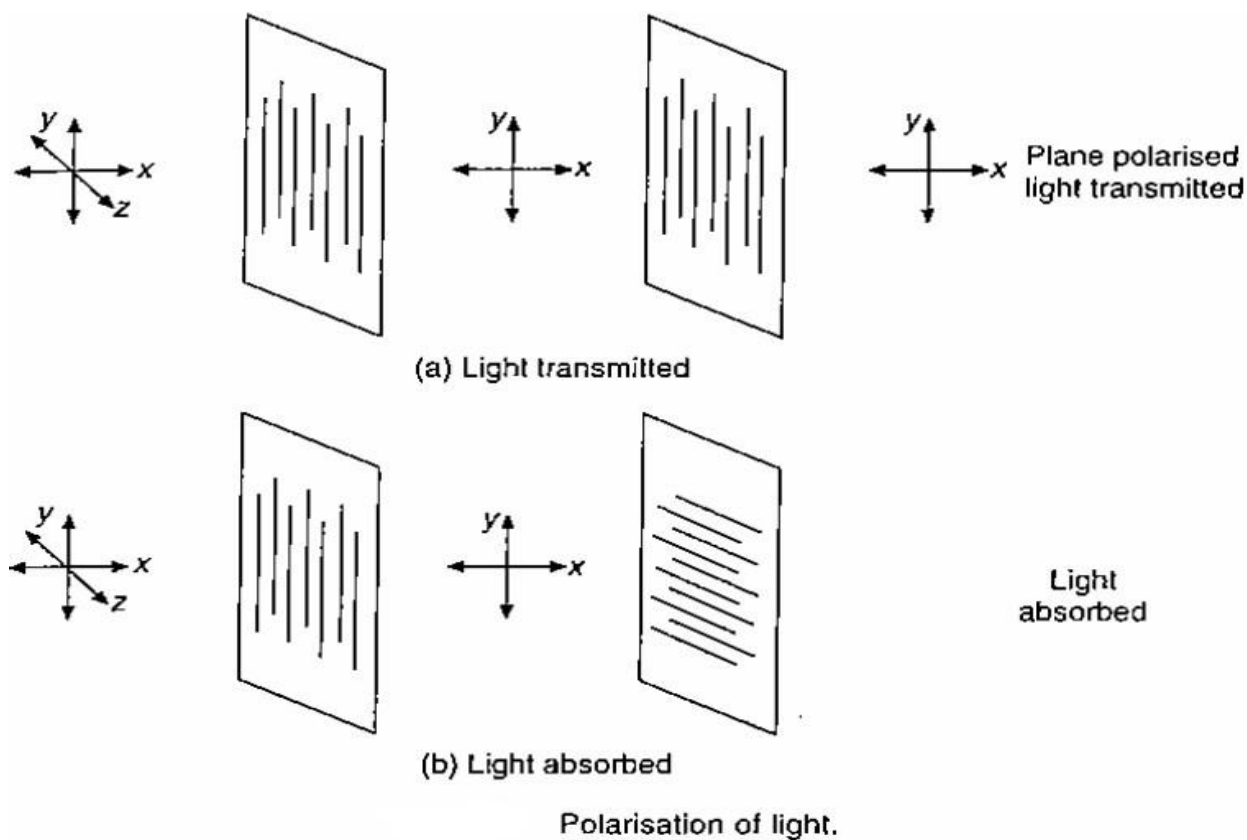
Color liquid crystal displays use colored filters or phosphors with twisted nematic technology or use guest-host (dye) technology. Guest-host liquid crystal displays combine dichromic-dye guest molecules with the host liquid crystal molecules. The spectral characteristics of different guest molecules are used to produce different colors. The application of an electric field realigns the orientation of both the guest and host molecules, lo allow transmission of light. A typical guest-host trans missive liquid crystal display is shown in below figure.

Guest-host liquid crystal display.
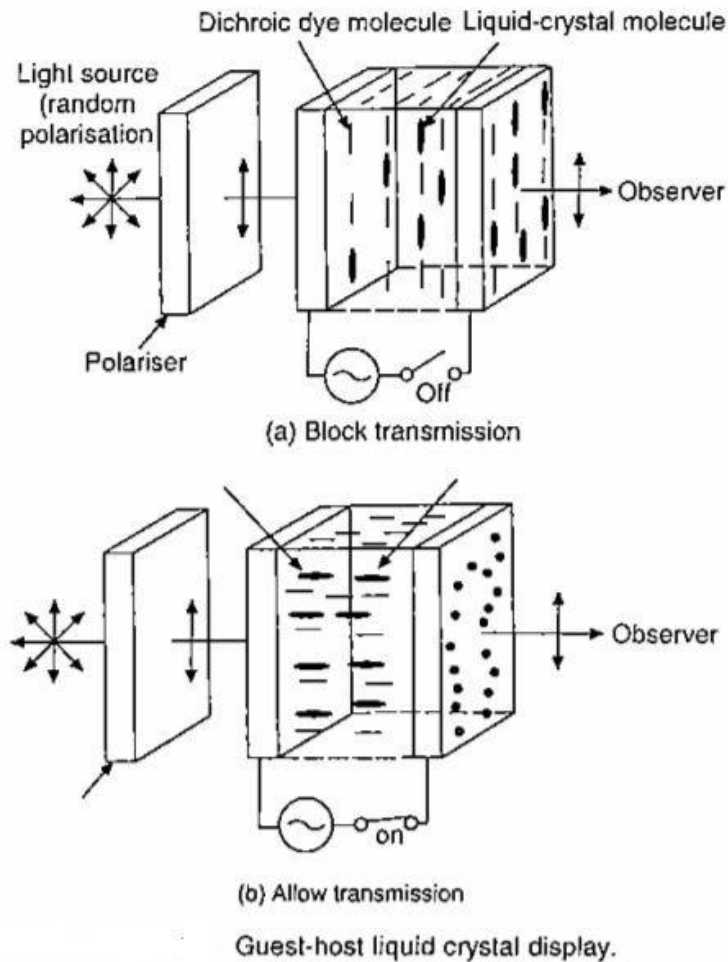
The plasma display contains a gas at low pressure sandwiched between horizontal and vertical grids of fine wires. A tower voltage will not start aglow but will maintain a glow once it is started. Normally, the wires have this low voltage between them. To see a pixel, the voltage is increased momentarily on the wires that intersect the desired point. To extinguish a pixel, the voltage on the corresponding wires is reduced until the glow cannot bemaintained.

Plasma displays can be AC or DC or hybrid AC/DC activated. AC and DC plasma

displays are shown in below Figure. The DC-activated display consists of a dielectric spacer plate, which contains the gas cavities sandwiched between plates containing the row-column conductors. The electric field is applied directly to the gas. A DC-activated plasma display requires continuous refreshing.

In the AC-activated plasma display, a dielectric layer is placed between the conductors and the gas. Thus, the only coupling between the gas and the conductors is capacitive. Hence, an AC-voltage is required to dissociate the gas. AC-activated plasma displays have bistable memory; thus, the necessity to continuously refresh the display is eliminated. Bistable memory is obtained by using a low AC voltage to keep alive voltage. The characteristic capacitive coupling provides enough voltage to maintain the activity in the conducting pixels, but not enough to activate non-conducting pixels.

A hybrid AC/DC plasma display uses DC voltage lo prime the gas and make it more easily activated by the AC voltage. The principal advantage of the hybrid AC/DC plasma display is reduced drivercircuitry

(a) AC-activated   (b) DC-aclivated
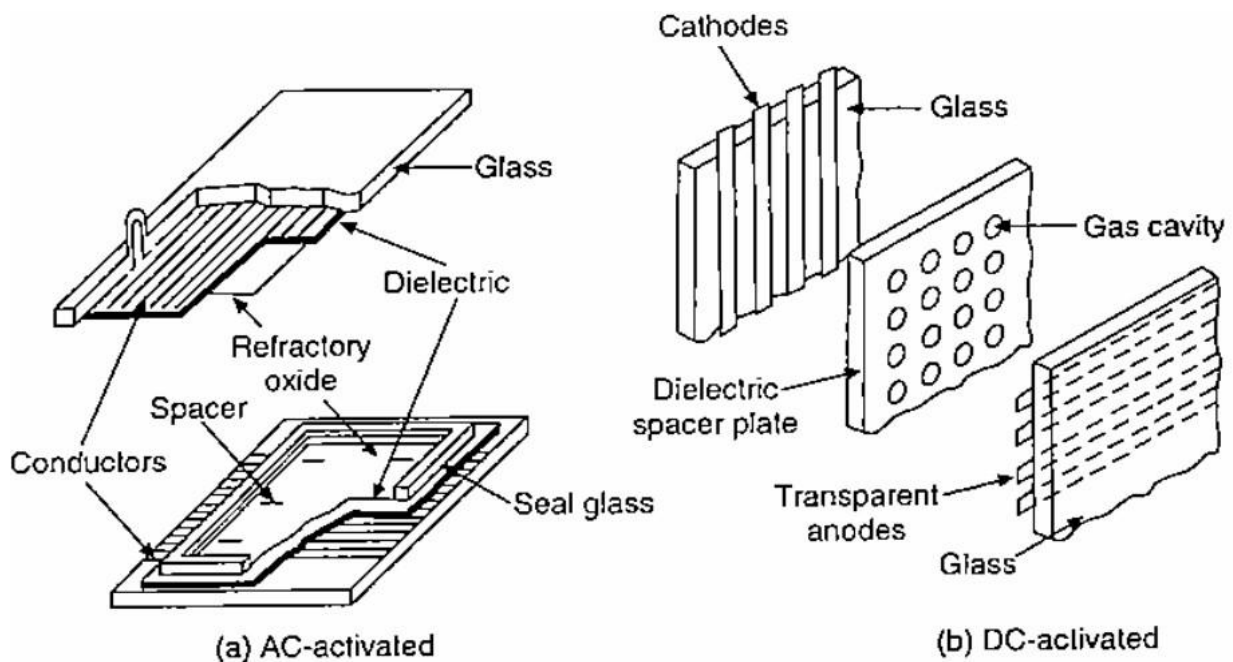
Basic structure of gas discharge plasma displays.

HARDCOPY PRINTERS AND PLOTTERS

Printers and plotters are used to create check plots for offline editing and producing final drawings and documentation on paper. Printers usually provide hard copies of text as well as graphics.

Printers are classified as follows on the basis of three principal technologies used for their operation:

- Impact dot matrixprinter
- Ink jetprinter
- Laserprinter

Impact dot matrix printer: This is an electromechanical device, which creates images on paper from thousands of tiny dots when thin wires create an impact on an ink ribbon. The working principle of dot matrix printer is shown in Figure. Text characters and graphics elements are not displayed as separate items. The complete display is built up from reciprocating horizontal sweeps of the printing head as the paper winds around a rotating drum. Thus, the hard copy is constructed from dots in a similar manner to a raster screen display, with the resulting appearance being much the same. The resolutions that are available vary but range from 60 dots per inch lo 240 dots per inch. Their cost is comparatively low, but a major disadvantage is their noise because of the impact of the pins on the paper. For example, the letter ˋA' is printed with 24 overlapping needles shown in Figure.
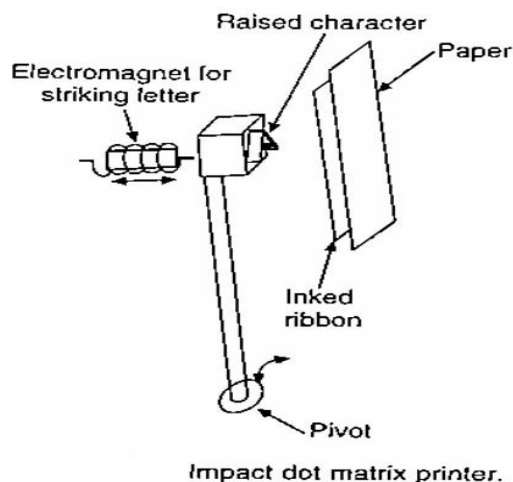
Impact dot matrix printer.
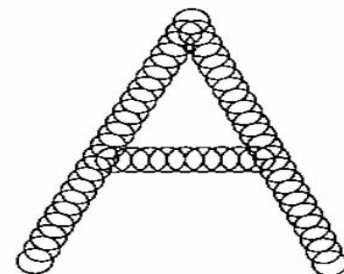
The letter 'A' printed with 24 overlapping needies.

Ink jet printer: This is a raster scan device. The basic principle is lo shoot tiny droplets of ink onto a medium. There are two types of ink jet printers, continuous flow and drop-on-demand. The continuous flow ink jet produces a stream of droplets by spraying ink out of the nozzle. The stream of ink from the nozzle is broken up into droplets by ultrasonic waves. If ink is desired on the medium, selected droplets are electrostatically charged. Deflection plates are then used to direct the droplet onto the medium. If not, the droplet is deflected into a gutter, from which the ink is returned to (he reservoir. Paper and transparency film are typical media. This system is shown in Figure.

A drop-on-demand printer fires ink at the medium only if a dot is required at a particular location. Here, ink from a reservoir is supplied to a nozzle under pressure. The ink is fired on demand by applying an electric voltage to a piezoelectric crystal as the head makes a pass across the medium. When a voltage is applied, the piezoelectric crystal expands, decreasing the volume of the ink chamber. These causes a drop of ink lo squirt out of the nozzle. Release of the voltage causes the piezoelectric crystal lo contract, decreasing the volume of the reservoir and sucking the link back onto the nozzle. The resolution of ink jet printers is determined by the size of the droplet and hence by the size of the nozzle. Because of the extremely small nozzle size required, nozzle clogging, ink contamination and air bubbles in the ink can be significant problems.

Continuous
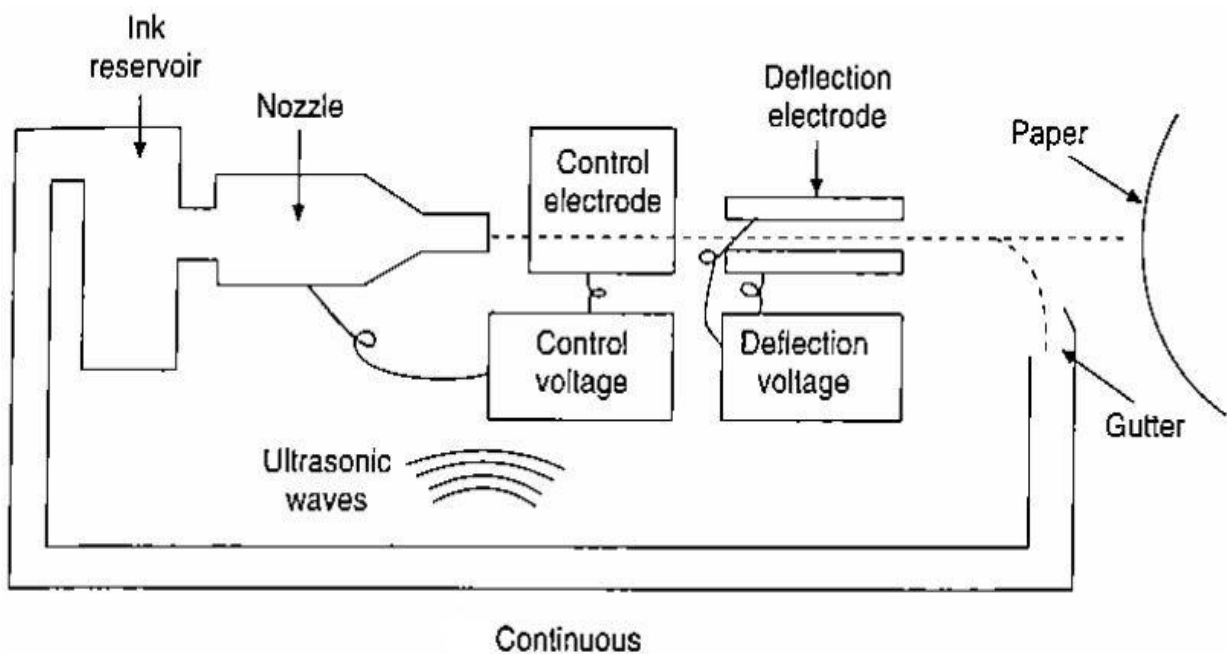
Laser printer: This is essentially an electrostatic plain paper copier with the difference that the drum surface is written by a laser beam. The working principle of a laser printer is illustrated in below figure.The heart of the printer is a rotating precision drum. At the start of each page cycle, it is charged up to about 1000 volts and coated with a photosensitive material. Then light from a laser is scanned along the length of the drum much like the electron beam in a CRT only instead of achieving the horizontal deflection using a voltage, a rotating octagonal mirror is used to scan the length of the drum. The light beam is modulated to produce a pattern of light and dark spots. The spots where the beam hits lose theirelectricalcharge.Afteralineofdotshasbeenpainted,thedrumrotatesafractionofa

degree to allow the next line to be painted. Eventually, the first line of dots reaches the toner, a reservoir of an electroslatically sensitive black powder. The toner is attracted to those dots that are still charged, thus forming a visual image of that line. A little later in the transport path, the toner-coated drum is pressed against the paper, thus transferring the black powder to the paper. The paper is then passed through heated rollers to bind the toner to the paper permanently, fixing the image. Later in its rotation, the drum is discharged and scraped clean of any residual toner, preparing it for being charged and coated again for the next page.

Operation of a laser printer.
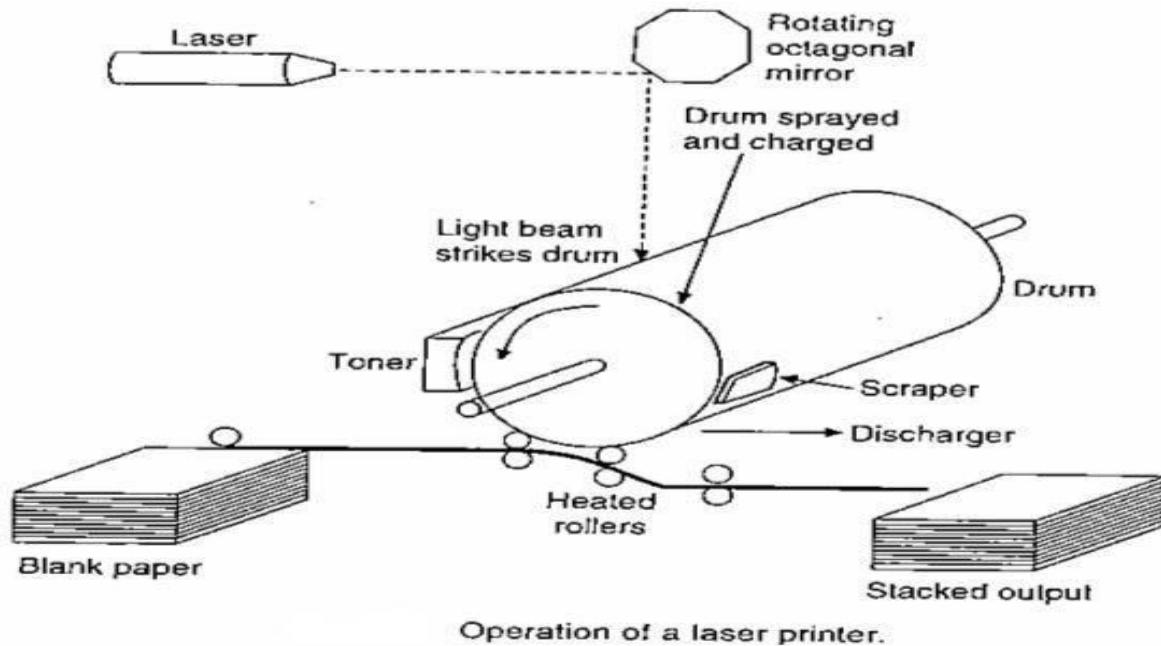
Plotter: This is a widely accepted output device for CAD/CAM applications. A large range (A0-A4) of plotters of varying sizes and prices are available. The accuracies achievable are very high and the plots can be made on all types of media such as paper, tracing paper and acetate film. There are three common types of conventional pen plotters: flatbed, drum and pinch roller. Pens may be-of wet ink, Ballpoint or felt-tip type. The basic mechanisms are shown in below Figure.

In a moving-arm flatbed plotter, the medium is fixed in position on the bed of the plotter. Two-dimensional motion of the plotting head is obtained by the movement of an arm suspended across the width of the plotter bed. This provides motion in one direction. Motion in the second direction is obtained by moving the plotting head along the suspended arm.

A moving head flatbed head plotter uses a plotting tool carriage suspended above the bed by magnetic forces that are counter-balanced by an air bearing. This arrangement provides nearly frictionless movement. Movement of the head in two dimensions is controlled electromagnetically by using the Sawyer motor principle.

In the drum plotter the paper is attached to a drum that rotates back and forth, thereby providing movement in one axis. The pen mechanism moves in the transverse direction to provide movement along the other axis.
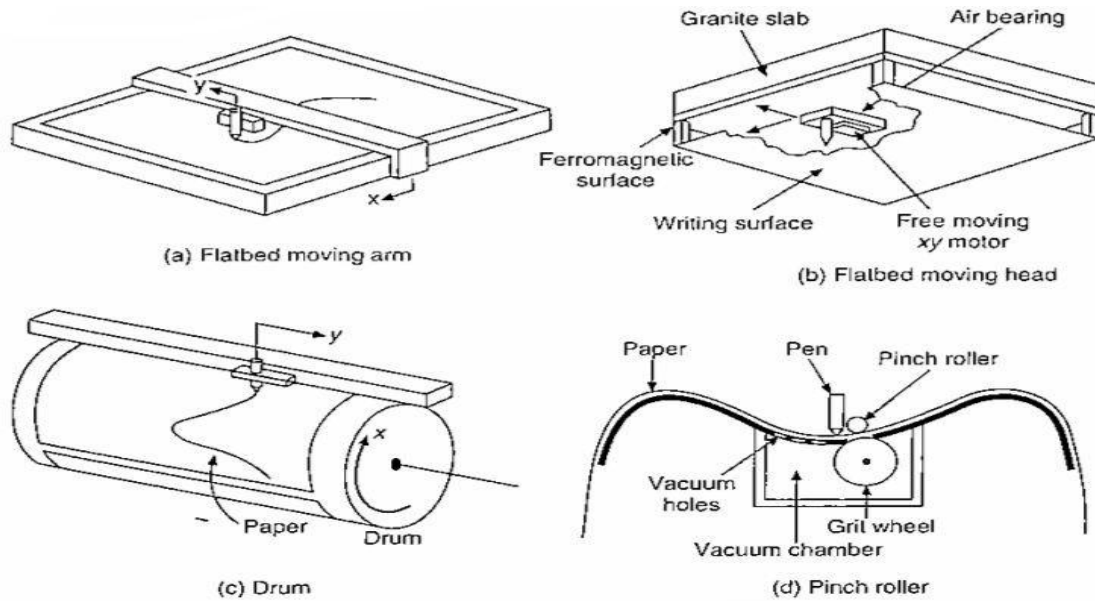
schematic diagrams of pen and ink plotters

ROLE OF COMPUTER IN MANUFACTURING

- Coordinate measuring machine(CMM)
- Rapidprototyping
- Standardization andLocalization
- Conceptualmodeling
- FMS (ASRS, AGV,CONVEYERS)
- CIM (Business data processingsystem)
- JIT, Kanban system
- Inspection
- Robots
- Machinevision
- Coefficient of thermalexpansion
- Bill of material(MRP)
- PLM (product lifecycle management)
- Supply chainmanagement
- Feed rotes, D.C, M/Cspeed
- Scheduling ofparts
- Digitalmanufacturing

UNIT-II

GEOMETRIC MODELING AND DRAFTING SYSTEMS

INTRODUCTION
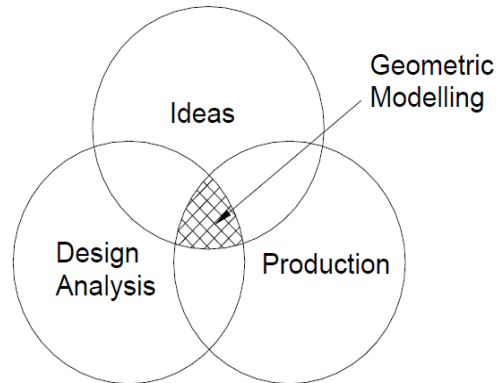
Geometric modeling is a branch of applied mathematical and computational geometry that studies methods and algorithms for mathematical description of shapes

The shapes studied in Geometric modeling are mostly 2-Dimensional or 3-Dimensional although many of its tools and principles can be applied to sets of any finite dimension. Most Geometric modeling is done with computer and computer based applications. 2-Dimensions models are important in computer typography (The art and technique of arranging type in order to make language visible) and technical drawings. 3-Dimensional models are central to CAD and CAD many applied technical fields. Such as civil, mechanical, architecture, geology, medical image processing.

NEED OF GEOMETRIC MODELING

For manufacturing automobile engine it require around 10,000 drawings models in various departments with different styles. Once models are prepared using any CAD software, these models can be used in almost all departments of the organization which includes-

1. Designing the parts and assemblies and then performing tolerance analysis of the assemblies
2. Preparation of production drawings of individual parts, subassemblies, assemblies, tooling andjig-fixtures
3. Making structural, thermal and kineticanalysis
4. Considering volume of parts and after extracting material properties from material library, cost estimation can be easilydone

5. Process plans are also prepared for all thecomponents

6. Using CAM software's, we can model as input for CNCprogramming

7. Programming the movement of the components from one station to another is possible using various material devices such as robots, conveyors, automated guidedvehicles

8. Using coordinate measuring machine (CMM) dimensional and geometric accuracies are checked by extracting various dimensions and parametric from the modelsonly

9. Other supporting activities such as material requirement and procurement, preparation of bill of materials, manufacturing resource requirement, planning and scheduling,analysis

With competitions products $_{etc}$ are also possible once geometric models are available thus for all these activities, geometric models becomes the central that will be manipulate at all these storages. While modeling, geometric models are prepared in such a way that the other modules such as CAM, CAE, Mechanism systems are able to use this information in the most optimal and efficientway.

REQUIREMENTS OF GEOMETRIC MODELING

The requirement of geometric modeling is manifold. The conceptual design is the basis of the generation of geometric model. The choice of the geometric model depends on the mechanical functions to be performed by it. A valid geometric model is created by CAD system and its model database is stored. The database of geometric modeling is used for engineering analysis and for design optimization. Design testing and evaluation may necessitate changing the geometric model before finalizing it. When the final designis achieved, it is documented and used for subsequent manufacturing applications, quality and costanalysis.

Good geometric model is designed based in the following important guidelines-

1. Modeling method must be easy touse

2. Completeness of partrepresentation

3. Representation should be able to represent a useful set of geometricobjects

4. Model should not create any ambiguity (The ability to express more than one interpretation) to users. A given representation should correspond to one and only one solid

5. To represent the solid normally there should only unique way. With this one can compare two identical solidrepresentations

6. A geometric model must be very accurate. There should not be anyapproximation

7. Geometric modeling should not create any invalid or impossiblemodels

8. The various transformations such as move, rotation, scale $_{etc}$ and manipulations such as union, intersect, subtract $_{etc}$ should able to be performed on geometricmodel

9. A good representation should be compact enough for saving space and allow for efficient algorithms to determine desired physical characteristics

10. Geometric model should have shading and rendering (Generation an image for a model by means of a computer program) capability to give realistic effect to themodel

GEOMETRIC MODELS

The geometric models are broadly classified on the basis of geometric construction into the following categories
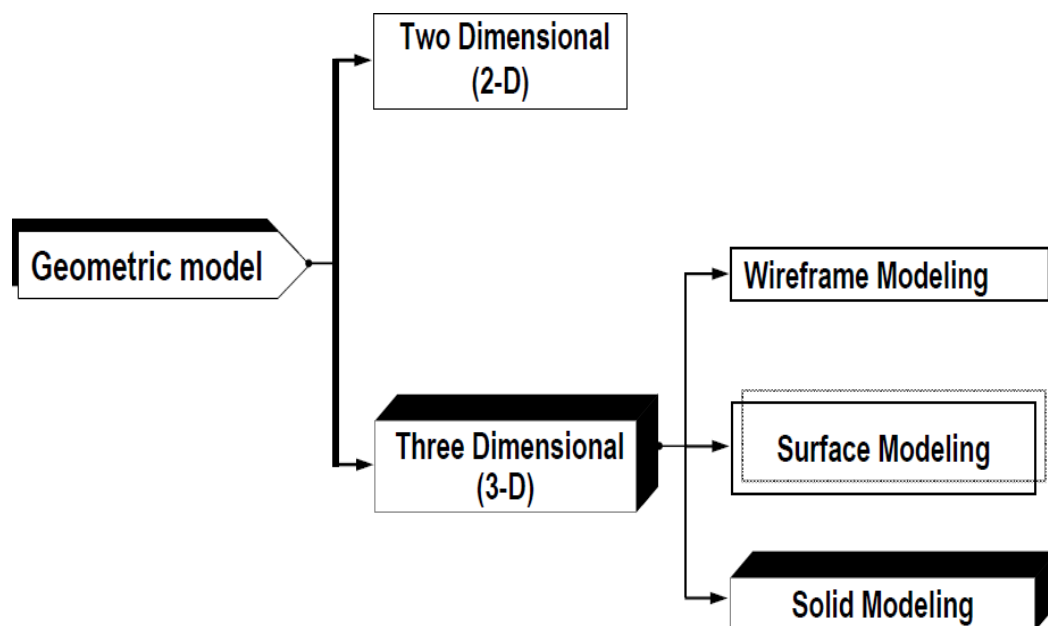
1. Two Dimensional(2D)
2. Three Dimensional(3D)

Two Dimensional (2D)

The 2D modeling includes the construction of geometrical faces, plane drawings, 2D views (Top, Front, Right, and Light views) of objects. Presently, the application of 2D model is limited to drafting, sheet metal manufacturing, Spot welding, Laser cutting $_{etc.}$

Three dimensional (3D)

The 3D modeling is widely used for engineering applications. It provides all the information required for animation, design analysis and manufacturing. The 3D objects are shown in below figure.

(a) LINE MODEL (b) SURFACE MODEL

(c) VOLUME MODEL
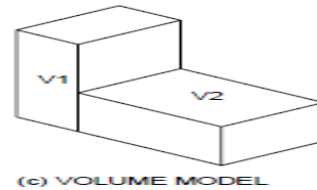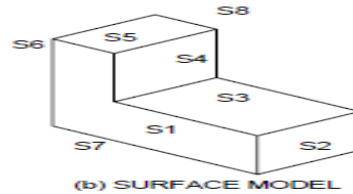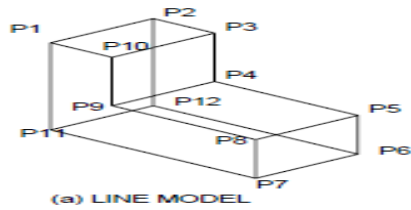
The 3D models are further sub-divided into **three** groups:

1. Wireframe modeling
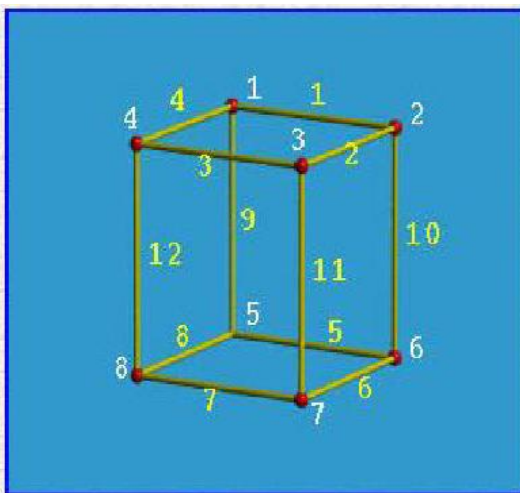
	Edge Table	
Edge #	Start Vertex	End Vertex
1	1	2
2	2	3
3	3	4
4	4	1
5	5	6
6	6	7
7	7	8
8	8	5
9	1	5
10	2	6
11	3	7
12	4	8

Vertex Table			
Vertex #	x	y	z
1	1	1	1
2	1	-1	1
3	-1	-1	1
4	-1	1	1
5	1	1	-1
6	1	-1	-1
7	-1	-1	-1
8	-1	1	-1

Wireframe modeling is the oldest and simplest methods of geometric modeling which can be used to store model mathematically in the computer memory. It contains information about the locations of all the points (vertices) and edges in space coordinates. Various wireframe entities are points, lines, planer arcs, circle, curves $_{etc.}$ Each vertex is defined by x, y, z coordinates. Edges are defined by a pair of vertices and faces are defined as three or more edges. Thus wireframe is a collection of edges, there is no skin defining the area between the edges. This is the lowest level of modeling and has serious limitations. But it some applications such as tool path simulation it is very convenient to use wireframe models.

Advantages of wireframe models:

1. It is simple methods and requires less memoryspace
2. It forms the basis for surface and solidmodeling
3. Manipulations in the model can be done easily andquickly

Disadvantages:

1. One of the serious limitation in the ambiguity of orientation and viewingplane
2. Cannot model complex curvesurfaces
3. Does not represent an actual solid (no surface and volume)
4. Physical properties such as mass, surface area, volume, centre of gravity etc are not possible tocalculate
5. Wireframe models has no knowledge of surface faces, therefore it will not detect interface between two matting components and this is serious drawback especially in component assembly, kinematic analysis, NC tool and robot armsimulation

2. Surface modeling
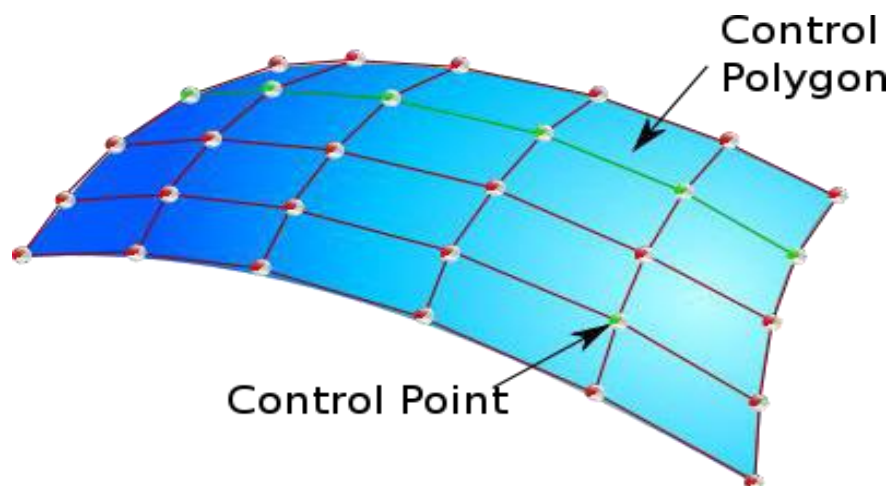
Surface modeling is the next stage of wireframe modeling. In wireframe modeling models are unable to represent complex surfaces of objects like car, ship, aeroplane, wings, castings etc. only a surface profile of these objects. A surface model represents the skin of an object. These skins have no thickness or material type. Surface models define the surface properties, as well as the edges of objects. These are often capable of clearly representing the solid from the manufacturing. However, no information regarding the interior of the solid model would be available which could be relevant for generating the NC cutter data. Further the calculation of properties such as mass and inertia $_{etc}$ would be difficult. Surface modeling facilities would be available as part of the modeling technique and would be used when such surface is present in the product for design. For example this method is used mode for specific non-analytical surfaces, called sculptures surfaces such as those used for modeling the car bodies and ship-hulls. There are a number of mathematical techniques available for handling these surfaces such as Bezier andB-splines.

Advantages:

1. Eliminates much ambiguity and non-uniqueness present in wireframe models by hiding lines notseen

2. Renders the model for better visualization and presentation, objects appear morerealistic

3. Provides the surface geometry for CAM, NCmachine

4. Provides the geometry needed by the manufacturing engineer for mould and diedesign

5. This can be used to design and analysis complex free-formed surfaces of ship hulls, aeroplane fuselages andbodies

6. Surface properties such as roughness, color and reflectivity can be assigned and demonstrated

Disadvantages:

1. Provides no information about the inside of anobject

2. Curved surfaces need a fine mesh to beaccurate

3. Provides wrong results if mesh is toocoarse

4. Complicated computation, depending on the number ofsurfaces

3. Solid modeling

Solid modeling is the most powerful of 3D modeling technique. This includes vertices (nodes), edges, surfaces, weight and volume. This model consisting of the complete description of the solid in a certain form is the most ideal representation, as all the information requires at every stage of product cycle can be obtained with technique. Defining an object with a solid model is the easiest of the available three modeling techniques. The model is a complete and unambiguous representation of a precisely enclosed and filled volume. Solid model contain bath geometric and available to represent the solid, but geometry two techniques are very famous, these are constructive solid geometry (CSG) and boundary representation(B-rep)

Advantages:

1. Mass properties such as area, volume, weight, centre of gravity and moment of inertia can be determinedquickly

2. It allows the design engineer to develop and evaluate alternative concepts for parts and assemblies while the design is still a theoreticalmodel.

3. Solid models arenon-ambiguous

4. Easily exported to different FEM programs foranalysis

5. It can be used in newly manufacturing techniques; CIM, CAM, design for manufacturing (DFM)

6. 2D standard drawings, assembly drawings and exploded drawings are generated from the model

Disadvantage:

1. More intensive computation than wireframe and surfacemodeling
2. Requires more powerful computers (faster with the morememory)

DIFFERENCE AMONG WIREFRAME, SURFACE AND SOLID MODELING

Parameter	Wireframe model	Surface model	Solid model
1. Computer memory	Less	Moderate	Large
2. Entities used	Points, line, circle, arc, ellipse, synthetic curves, such as Bezier, hermite, B-spline etc.	Plane, revolve, ruled, tabulated, free form surfaces	Solid primitives as cone, cube, wedge, cylinder, sphere etc
3. Input data required	More	Moderate	Less
4. Automatic orthographic, perspective, isometric view generation	Impossible	Impossible	Easily possible
5. NC code generation	Not possible	Automatic possible	Automatic possible
6. Interference between matting parts	Not possible to detect	Can detect	Can detect
7. Rendering and shadow effect	Not possible	possible	possible
8. Cross sectioning	Not possible done manually	Not possible	Possible done automatically
9. Elimination of hidden lines	Done manually	May be possible	Possible
10. Calculation of physical properties such as volume, surface area, center of gravity,M.I etc	Not possible	Possible to calculate some properties	Possible to calculate all properties required for analysis
11. Design parameters optimization	Not possible	Not possible	Possible
12. Generation of assembly and detail drawings from model and vice versa	Not possible	Not possible	Possible
13. CAD/CAM/CAE modules	Drafting	Drafting, design	Drafting, design, manufacturing, analysis, assembly, mechanism, optimization

MODELING FACILITIES

The total modeling facilities that one would look for in any system can be broadly categorized as follows:

- The geometric modelingfeatures
- The editing or manipulationfeatures
- The display controlfacilities
- The draftingfacility
- The programmingfacility
- The analysisfeatures
- The connectingfeatures

Geometric Modeling Features

The various geometric modeling and construction facilities that one should expect to have in any good system are as follows:

1. Various features to aid geometric construction methods, such as Cartesian and polar coordinates, absolute and incremental dimensions, various types of units, grip, snap, object snap, layer$_{etc}$

2. All 2D analytical features, such as points, lines, arcs, circles, coins, splines, fillets, chamfers $_{etc}$. In each of these features, various constructional features including interactive and dynamic draggingfacilities

3. Majority of the 3D wireframe modeling facilities includes 3D lines, 3D faces, ruled surfaces, linear sweep from 2D topology with any sweep direction, rotational sweep and tapered sweep. General sweep with twist. Rotational about an axis or radial offset for generating helical or spiralshapes

4. Solid modeling with various basic primitives such as block, cylinder, sphere, cone, prism, torus, pyramid, quadrilateral, along with the ability to apply the Boolean operation on any solid that can be constructed using the other techniques available in the modeler

5. Skinning around regular and arbitrary surface. Profiles (cross-sections), both analytical and arbitrary places across any 3Dcurve

6. Sculptured surfaces of the various types like Bezier, Coons and other freeform surfaces

7. Comprehensive range of transformation facilities for interactively assembling the various solid models generated by the modeler with features such as surfaces filling and trimming

Editing or Manipulation Features

These set of facilities refer to the way the geometric data, once created, would be used to advantage for further modeling. Using these facilities, it would be possible to use the geometry created earlier to complete the modeling, thus improving the productivity of the designer. The facilities designed in this category are:

1. Transformation such as move, copy, rotate, scale, elongate or compress, mirror or to any arbitrary coordinateframe
2. The editing features used to alter the already drawn geometric entities, such as stretching, trimming or trimming to any intersection, delete or erase, undo orredo
3. Symbols in drawing refer to often-repeated together set in number of drawings, which may consist of a number of geometric entities that are grouped together and stored as a symbol. This symbol can be recalled at any scale, at any angle or exploded if necessary to treat all of them as separate entities. Symbols can also be of parametric type so that a large variation in symbols can be done without mucheffort
4. Some of editing facilities are : resizing, relocating and duplicating, filleting and chamfering, windowing, clipping and zooming, exploding, mirroring, lengthening and shortening, renaming named objects, editingsolid

Display Control Facilities

In this range of features are all the facilities needed for interacting with the modeling system so as to obtain the necessary feedback at the right time during the modeling stage. The facilities required are:

Window – to identify a set of entities for any possible display or editing function

Zoom – to change the scale of display of the image selected in the screen

Pan – to move the image on screen without changing the scale at which the drawing is displayed on the screen

Hidden – to remove hidden lines or hidden surfaces for viewing the geometry in proper form

Shading – to show the 3D view of the image on screen complete with the light source location and the resulting light and shade as it appears on the image

Animation – is the display of a number of images in sequence to imitate the actual motion of the part

*Clippin*g – helps in discarding the part of the geometry outside the viewing window, such that all the transformations that are to be carries out for zooming and panning of the image on the screen are applied only on the necessary geometry. This improves the response of the system.

Some other facilities that are required are: *isometric views, sectioning, orthographic views, perspective views*

Drafting Features

These facilities refer to the way the model developed can be utilized for purpose of transmitting the information in hard copy form for other applications, such as par prints onto the shop floor or maintenance manuals for the equipment. A really large range of facilities are required in this particular category and it is sometimes treated as a separate module in the modeling system

The ability to get various types of lines drawn and provide ample notes in the form of text addition at various locations in the drawing. The text handling capability in terms of font changing and different methods of text presentation should be available.

A large number of types of views should be obtained from the solid model of the geometry stored in the database. The types of views required may be as for display functions, such as perspective views, orthographic views (Shown in below figure), isolated views and axonometric views.
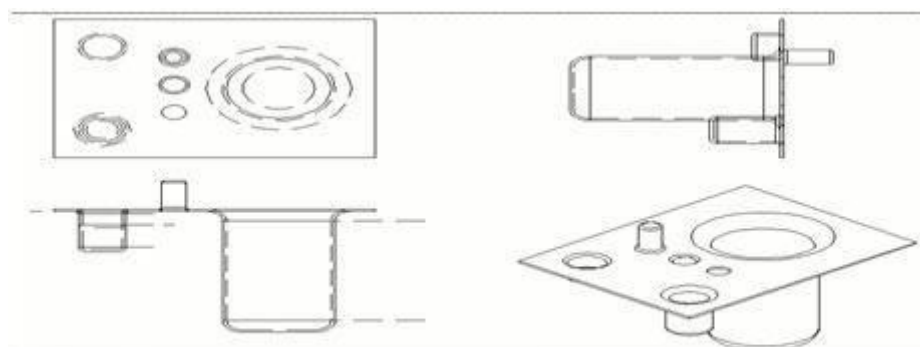
Orthographic views from a Geometric model

It is necessary that the views being shown should be sectioned to get a better appreciation of the model. For this purpose, the section planes may be simple or complex orientations. After sectioning the system should have the automatic ability to show the sectioning details (Shown in below figure) in the form of typical crosshatching depending

upon the standard practice.
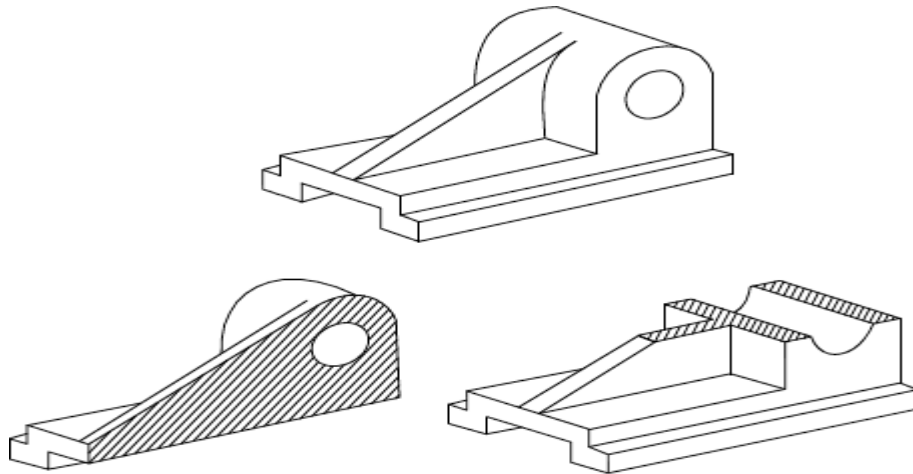
Programming Facility

Programming ability (MACRO programming) within a CAD system is going to be a very useful feature. It is well known that not all kinds of facilities would be available in any general-purpose CAD system. Therefore, it is necessary that the CAD system would have to be customized for a given range of application process specific to the company. For this purpose, if a programming facility exists in a CAD system, it is possible to program specifically for an application, making use of all the features available in the system for either modeling or for any specific application based on the information generated during the modeling. Some such examples are the GRIP in unigraphics and GLUE in CAM-X. The availability of such a program helps the user to input the least amount of information for any required design, if the application programs are written well using the programming language.

Analysis And Optimization Features

In this range, the kind of analysis facilities that are require to e carried on the product models being generated should be considered. The simplest kind to the most sophisticated features may be available under this category. The simplest facilities may be calculated perimeter, area, volume, mass, centre of gravity, moment of inertia, radius of gyration $_{etc}$.

Besides these simple features of analysis, a general-purpose analysis that is normally carried is the Finite Element Analysis (FEA). The geometric model created as above could be conveniently passed onto the FEA through an intermediate processor called a Finite Element Methods (FEM), which converts the geometric data into the finite element mesh and calculates all the data required for the analysis and then transmits it to the FEA program. Examples are the SUPERTAB for GEOMOD and the GFEM for the unigraphics.

Another important feature essential in the modeling system used by the mechanical engineering industries is the assembly facility with the associated interference checking. By this, products individually modeled can be assembly joints are analyzed. This would be further used along with animation facility, if present, to see the performance of the assembly in service. Along with the assembly facility, the other facility needed is the ability to explode an assembly (Show in above figure) for the creation of technical illustrations for the user and maintenance manual preparation.
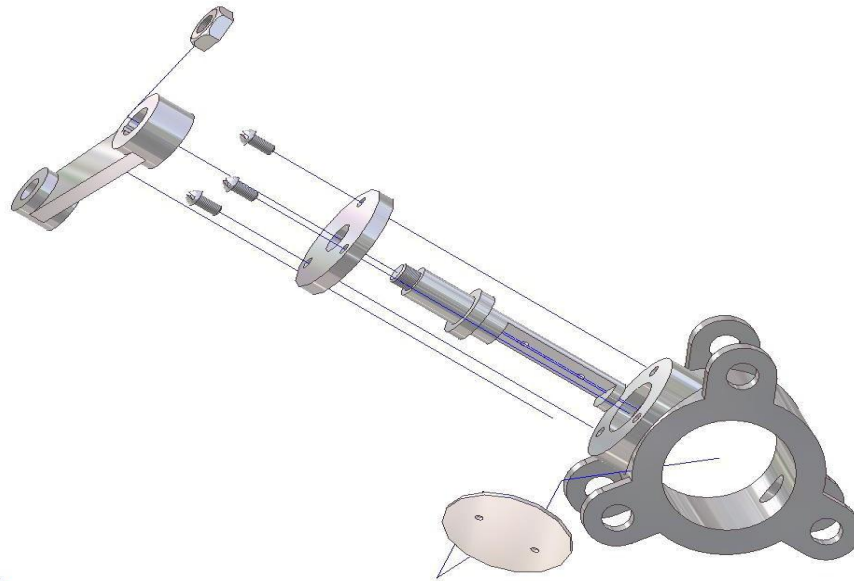
Connecting Features

Modeling is only the start of the complete process of a product evolution and as such the data generated is used directly by the other systems. It is therefore, necessary that the internal data format in which the data is stores by the modeling system should be well documented and should also have very good connectivity (data interfacing) with other allied modules. Identically, an integrated data base structure would be useful where in all the various modules share the common database. This would only be possible if all the modules are developed at a single developer as in the case of ProEngineer or Unigrapchis for CAD/CAMintegration.

GEOMETRIC CONSTRUCTION METHODS

The three-dimensional construction methods are:

- Wireframemodeling
- Surfacemodeling
- Solid modeling
- Extrusion

- Sweeping
- Featuremodeling
- Lofting
- Tweaking

Wireframe Modeling

Wireframe modeling uses geometric primitives for the construction of models. The geometric primitives are points, lines, arcs and circles, conies, cubic curve, Bezier curve and B-spline curve.

(a) Line   (b) Circle   (c) Arc   (d) Ellipse
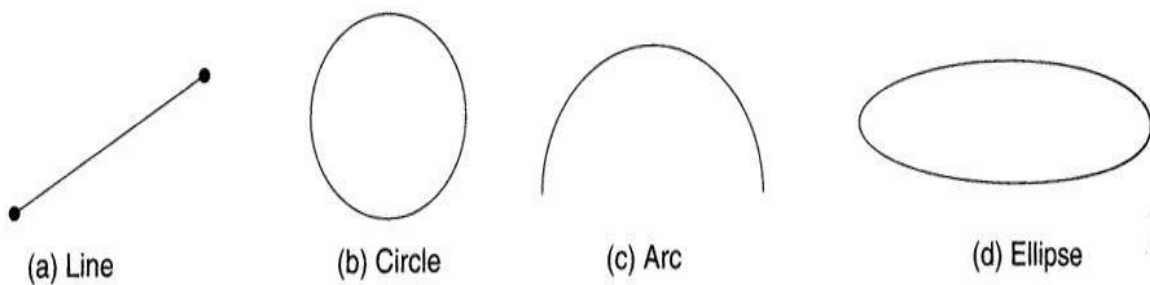
Wireframe primitives.

Surface Modeling

Surface models are generated by using surface primitives such as plane surface, ruled surface, surface of revolution, tabulated cylinder, fillet surface, offset surface, Bezier surface, B-spline surface and coons patch.

(a) Plane surface

(b) Ruled surface

(c) Axis of revolution specified

(d) Cubic surface

(e) Tabulated cylinder

(f) Cubic surface
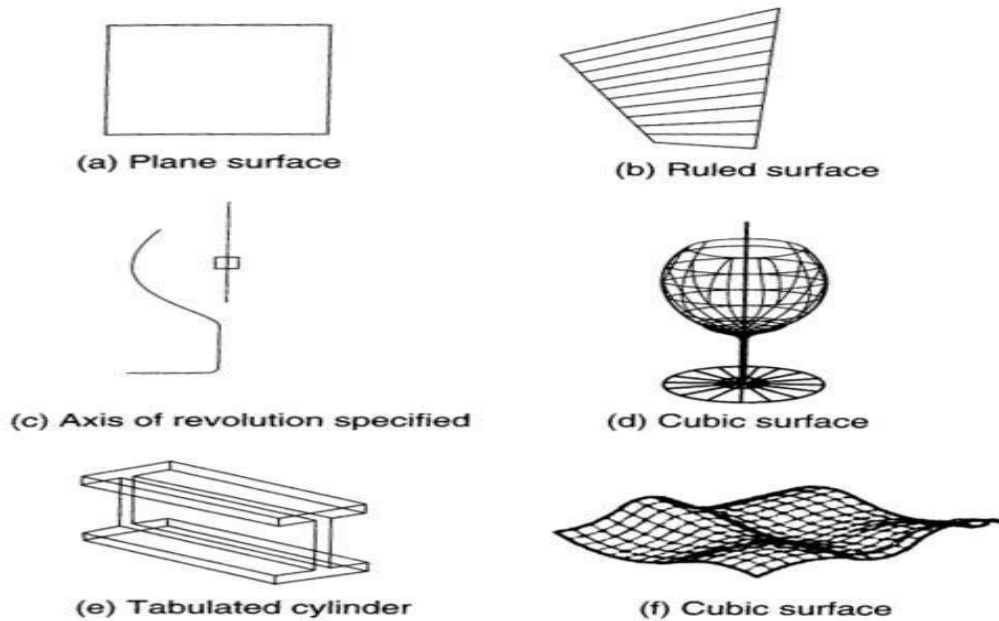
Surface entities.

Solid Modeling

Solid models are constructed by the boundary representation (B-rep) method or by constructive solid geometry (CSG). The solid entities of CSG modeling are box, cone, sphere, cylinder, prism, wedge and torus. CSG modeling constructs solid models through Boolean operations (union, subtraction and intersection) on solidentities.

(a) Box   (b) Cone   (c) Cylinder

(d) Sphere   (e) Wedge   (f) Torus

Solid primitives.
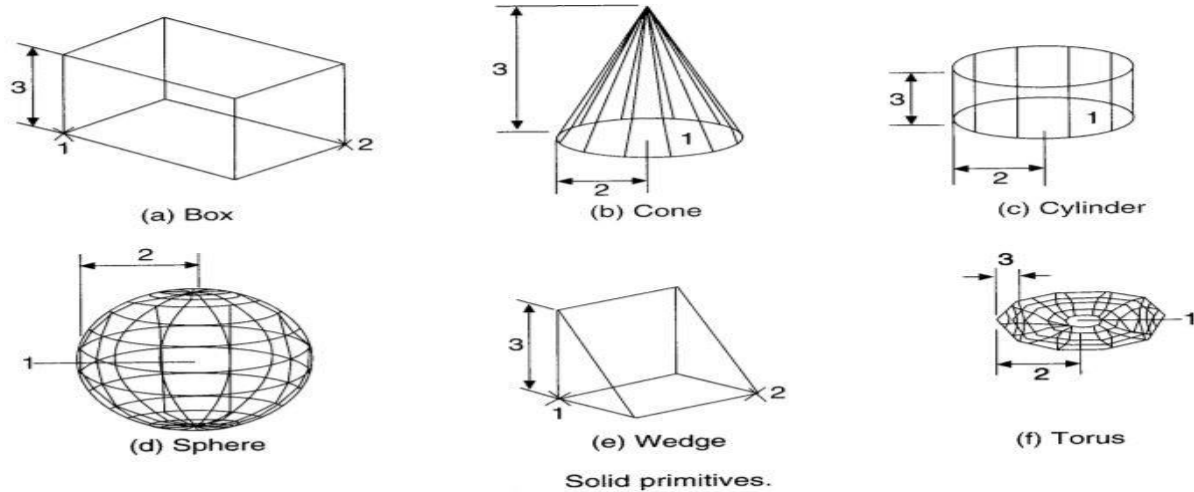
Extrusion

In extrusion, a three-dimensional solid is created by extruding the face in a direction perpendicular to it as shown in below figure.
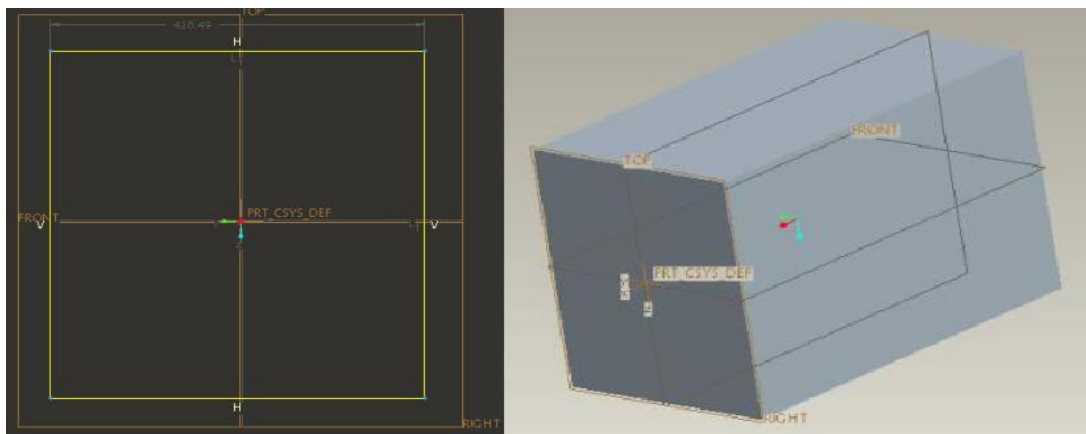
Sweeping

Sweeping is based on the notation of moving a point, curve, or a surface along a given path. A sweep may be linear or non-linear. The linear sweep may involve extrusion or revolving.

Face is defined   Axis is defined   Swept object
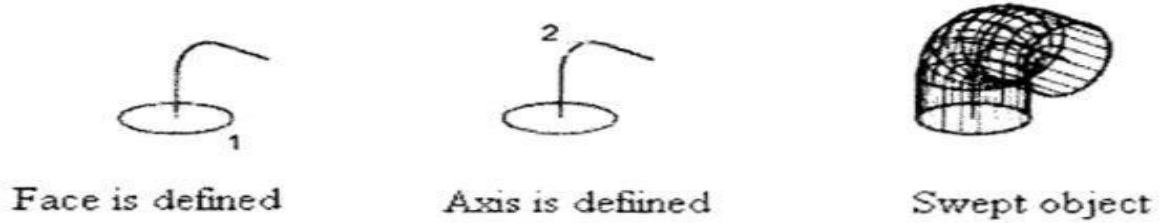
Feature Modeling

This creates solid models from a shape by an operation. The shape is a two-dimensional sketch for example, ribs, bosses, cuts and holes. The operation may involve extrusion, sweeping, revolving etc. Feature modeling is shown in below Figure.

Step 1: Create sketch   Step 2: Extrude the sketch   Step 3: Add a rib
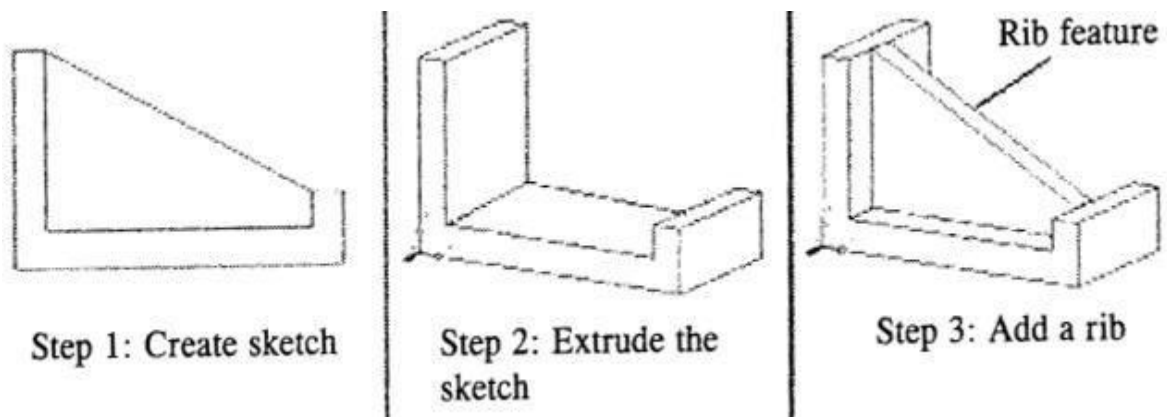
Filleting

Filleting implies the rounding of a corner to eliminate its sharpness. The fillet radius is the radius of the arc that connects filleted objects. Changing the fillet radius affects subsequent fillets. If you set the fillet radius to 0, filleted objects are trimmed or extended until they intersect, but no arc is created. Filleting is shown in belowFigure.

Two lines before fillet   Two lines filleted with radius   Two lines filleted with zero radius

Polyline arc segment
Polyline line segment

Polyline selected for filleting

Fillet arc

Result-fillet arc replaces arc segment

Filleting.
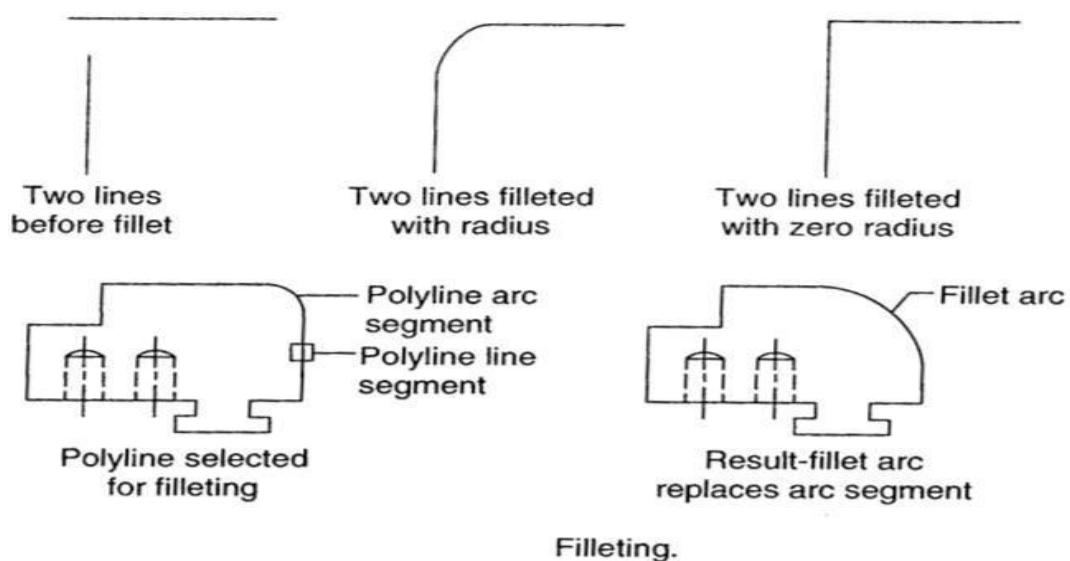
Tweaking

Tweaking uses several features to deform or alter (tweak) the surface of the part. Tweaking is not applicable to CSG solid models, splitting sketch drafts is shown in below Figure. This is because the CSG models retain the geometry and topology modeled from the primitives. The tweak menu lists the following options:

1. Draft
2. Local Push
3. Radius Dome
4. Section Dome
5. Offset
6. Replace
7. Ear
8. Lip
9. Patch
10. Spinal Bend
11. Free Form
12. Draft Offset
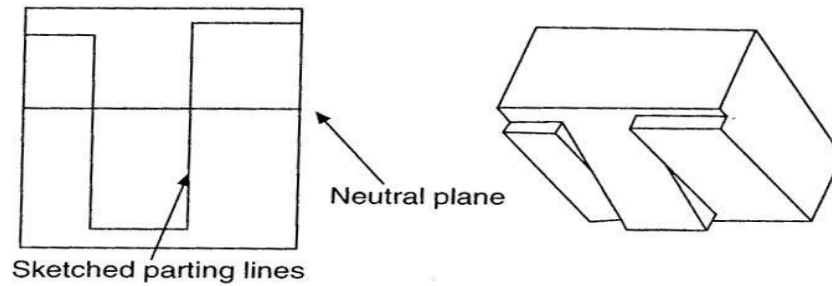
Lofting

Lofting is used to create a model with a variant cross-section along a linear/non-linear axis. The lofting procedure is illustrated in below figure.

Lofting.
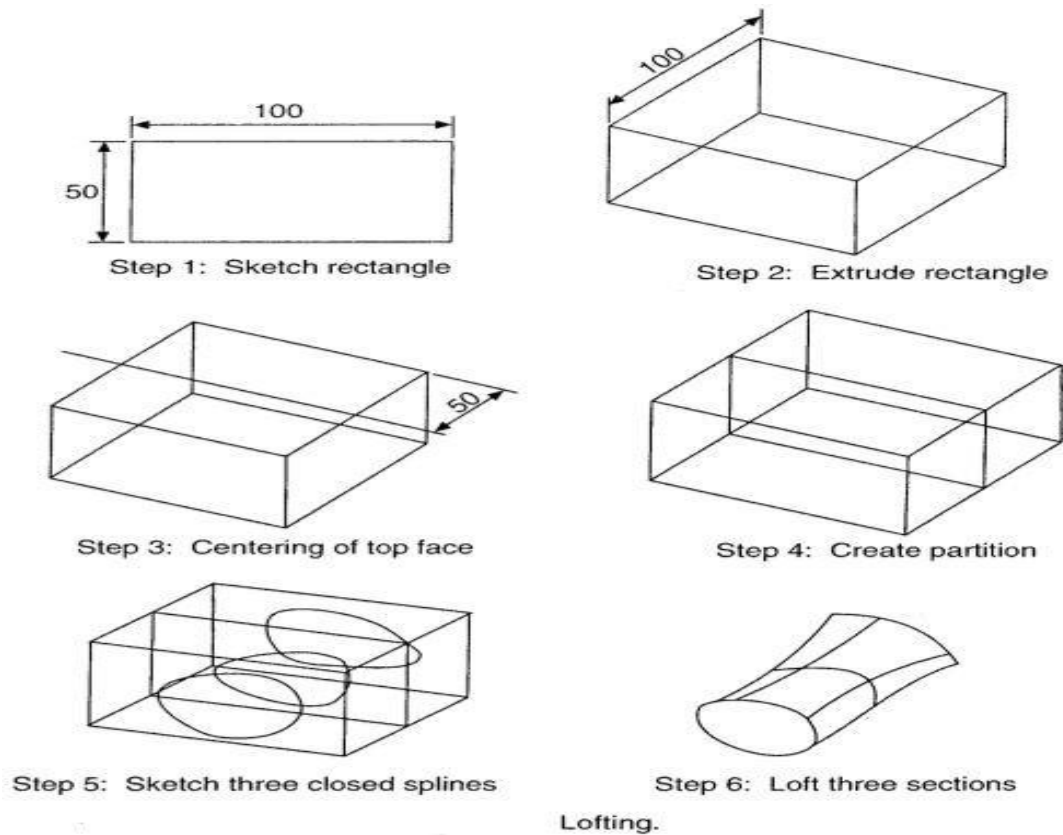
CURVATURE CONTINUITY

Mathematically, synthetic curves represented the problem of constructing a smooth curve that passes through given data points. Therefore the typical form of these curves is a polynomial. Various continuity requirements can be specified at the data points to impose various degrees of smoothness upon the resulting curve. The order of continuity becomes important when a complex curve is modeled by several curve segments pieced together end-to-end.
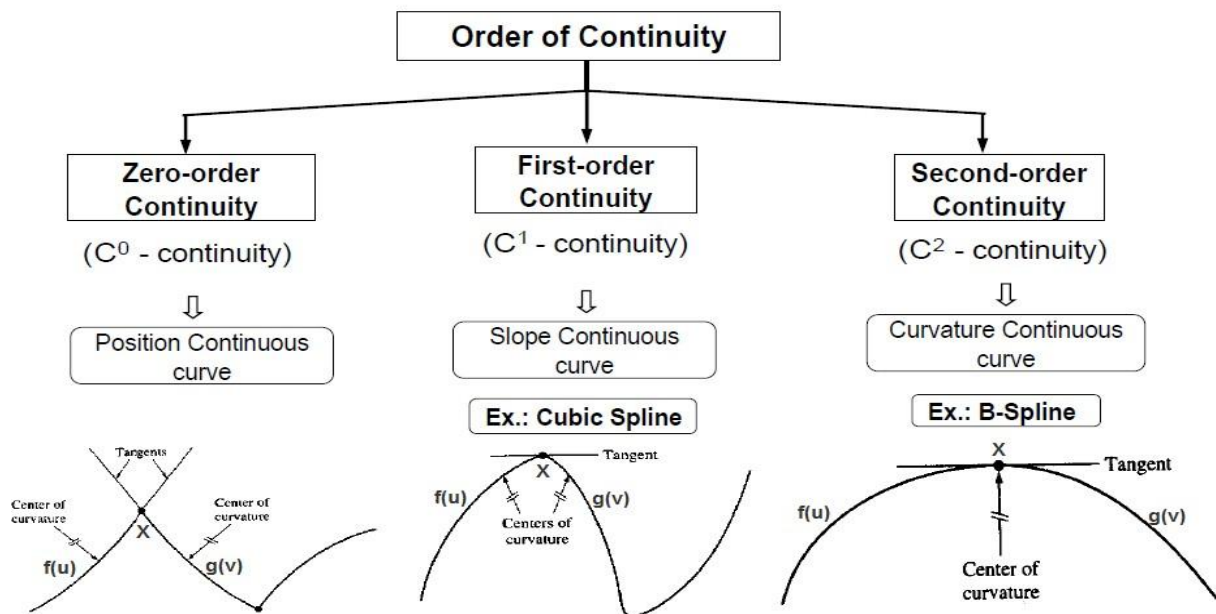
Two boundary curve segments shown in above figure are meeting at a vertex X. let these two curves be described as $\mathbf{f}(u)$ and $\mathbf{g}(v)$. Where u and v are values in intervals [a, b] and [m, n] respectively. The problem is: how these curves join together in a 'smooth'way.

Consider the 'endpoint' of curve $\mathbf{f}(u)$ and the 'start point' of curve $\mathbf{g}(m)$. If $\mathbf{f}(b)$ and $\mathbf{g}(m)$ are equal as shown in above figure a, say curves $\mathbf{f}()$ and $\mathbf{g}()$ are $\mathbf{C^0}$continuity at $\mathbf{f}(b) = \mathbf{g}(m)$.

If for all i<=k, the i-th derivatives at $\mathbf{f}(b)$ and $\mathbf{g}(m)$ are equal, say that the curves are $\mathbf{C^k}$continuity at point $\mathbf{f}(b) = \mathbf{g}(m)$. Intuitively,

- $\mathbf{C^0}$continuity (point/ position continuity) – Continuity of end point only (or) continuity of position
- $\mathbf{C^1}$continuity (tangent continuity) – Tangent continuity or first derivate ifposition
- $\mathbf{C^2}$continuity (curvature continuity) – Hydrodynamic character, light reflection curvature continuity (or) second derivative ofposition

Bezier Curve

A Bezier curve is defined by a set of data points. The curve may interpolate or extrapolate the data points. Some CAD systems offer both options; others offer the interpolation version only. In both cases, the data points are used to control the shape of the resulting curves.

Bezier curves and surfaces are credited to P. Bezier of the French car firm Regie Renault, who developed (about 1962) and used them in his software system called UNISURF, which designers used to define the outer panels of several Renault cars. These curves, known as Bezier curves, were also independently developed by P. DeCasteljau of the French car company Citroen (about 1959), which used them as part of its CAD system. The Bezier UNISURF system was soon published in the literature; this is the reason that the curves now bear Beziersname.

As its mathematics show, the major characteristics of the Bezier curve are:

1. The shape of the Bezier curve is controlled by its defining points. Tangent vectors are not used in the curve development as is the case with the cubic spline. This allows the designer a much better feel for the relationship between input (points) and output(curve).

2. The order or the degree of Bezier curve is variable and is related to the number of points defining it. n + 1 points define an n^{th}degree curve, which permits higher-order continuity. This is not the case for cubic splines, where the degree is always cubic for a splinesegment.

The data points of a Bezier curve are called control points. They form the vertices of what is called the control or characteristic polygon, which uniquely defines the curve shape as shown in Figure 6.30. Only the first and the last control points or vertices of the polygon actually lie on the curve. The other vertices define the order, derivatives, and shape of the curve. The curve is also always tangent to the first and last polygon segments. In addition, the curve shape tends to follow the polygonshape.

These three observations should enable the user to sketch or predict the curve shape once its control points are given as illustrated in below Figure. The figure shows that the order of defining the control points changes the polygon definition, which changes the resulting curve shape. The arrow shown on each curve shows its parameterizationdirection.

P_k Control points (vertices)
- - - - Characteristic polygon
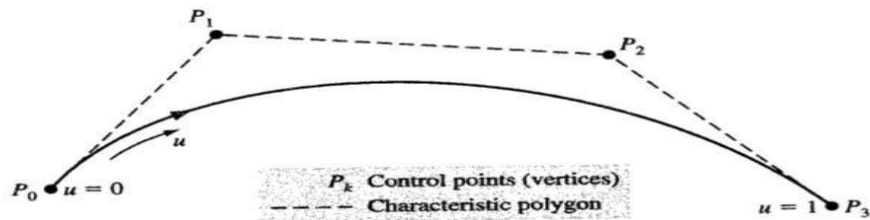
Mathematically, for n + 1 control points, the Bezier curve is defined by the following polynomial of degree n:

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

Where P(u) is a point on the curve and P_j is a control point. $B_{i,n}$ is the Bernstein polynomials. Thus, the Bezier curve has a Bernstein basis. The Bernstein polynomial serves as the blending or basis function for the Bezier curve and is given by

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

Where C(n, i) is the binomial coefficient

$$C(n, i) = \frac{n!}{i!(n-i)!} \qquad \longrightarrow 3$$

Utilizing above two Equations 2 and 3 and observing that C(n, 0) = C(n, n) = 1, Equation 1 can be expanded to give:

$$\mathbf{P}(u) = \mathbf{P}_0(1-u)^n + \mathbf{P}_1 C(n, 1)u(1-u)^{n-1} + \mathbf{P}_2 C(n, 2)u^2(1-u)^{n-2}$$
$$+ \cdots + \mathbf{P}_{n-1} C(n, n-1)u^{n-1}(1-u) + \mathbf{P}_n u^n, \qquad 0 \le u \le 1 \qquad \longrightarrow 4$$

Following are the important **characteristics** of a **Bezier curve**:

1. *The degree of a Bezier curve defined by n + 1 control points is n:* In each basis function, the exponent of U is i + (n - i) ~ n. Therefore, the degree of the curve isn.

2. *P (u) passes through P_0 and P_n:* The curve passes though the first and the last control points.

3. *Non-negativity:* All basis functions arenon-negative.

4. *Bezier curves are tangent to their first and lastlegs*

5. *Partition of unity:* The sum of the basic functions at a fixed u is 1. It is not difficult to verify that the basic functions are the coefficients in the binomial expansion of the expression $1 = [u + (1 - u)]^n$. Hence, their sum is one. Moreover, since they are non-negative,weconcludethatthevalueofanybasisfunctionisintherangeof0and1.

Since all basis functions are in the range of 0 and 1 and add to one, they can be considered as weights in the computation of a weighted average. More precisely, we could say "to compute **P**(u), one takes the weight $B_{n,i}$ (u) for control point **P$_i$**and sum themtogether."

6. *Convex hull property:* This means that the Bezier curve defined by the given n + 1 control points lays completely in the convex hull of the given control points. The convex hull of a set of points is the smallest convex set that contains all points. In below Figure, the convex hull of the 11 control points is shown. Note that not all control points are on the boundary of the convex hull. For example, control points 3, 4, 5, 8 and 9 are in the interior. The curve, except for the first two end points, lies completely in the convex hull. This property is important because we are guaranteed that the generated curve will be in an understood and computable region and will not go outside ofit.

Illusration of convex hull property
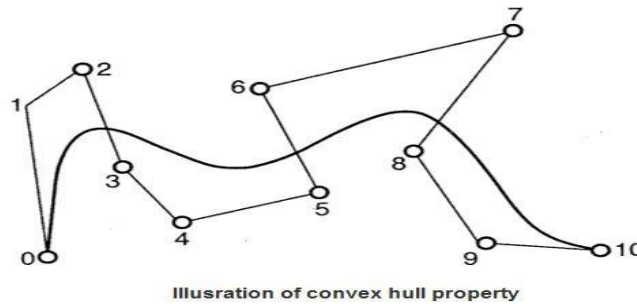
7. *Variation diminishing property:* If the curve is in a plane, this means that no straight line intersects a Bezier curve more times than it intersects the characteristics polygon. Line 1 intersects the curve three times and the polyline seven times; line 2 intersects the curve and its polyline twice; the line 3-intersects the curve four times and the polyline seven times. You can draw other straight lines to verify this property. So, what is the meaning of this characteristic? It tells us that the complexity (i.e., turning and twisting) of the curve is no more complex than the characteristic polygon. In other words, the characteristic polygon twists and turns more frequently than the Bezier curve does, because an arbitrary line hits the control polyline more often than it hits thecurve.

Complexity of characteristic polygon.
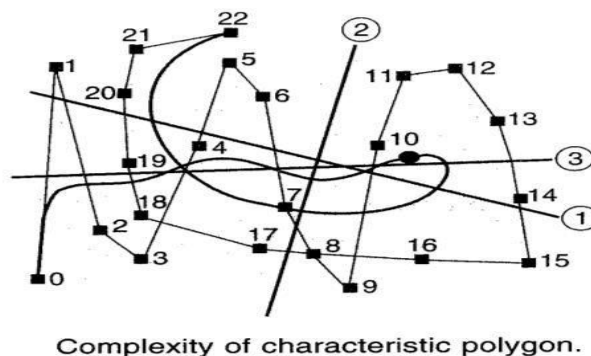
8. *Affine invariance:* If an affine transformation is applied to a Bezier curve, the result can be constructed from the affine images of its control points. This is a nice property. When we want to apply a geometric or even affine transformation to a Bezier curve, this property states that we can apply the transformation to control points, which is quite easy, and once the transformed control points are obtained the transformed Bezier curve is the one defined by these new points. Therefore, we do not have to transform the curve.

9. *Moving control points:* Changing the position of a control point will change the shape of the defined Bezier curve. Suppose a control point P_k is moved to a new position $P_k + v$, where vector **v** gives both the direction and length of this move.
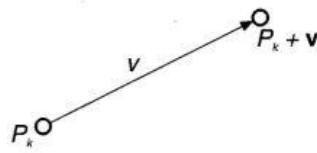
Effect of control point.
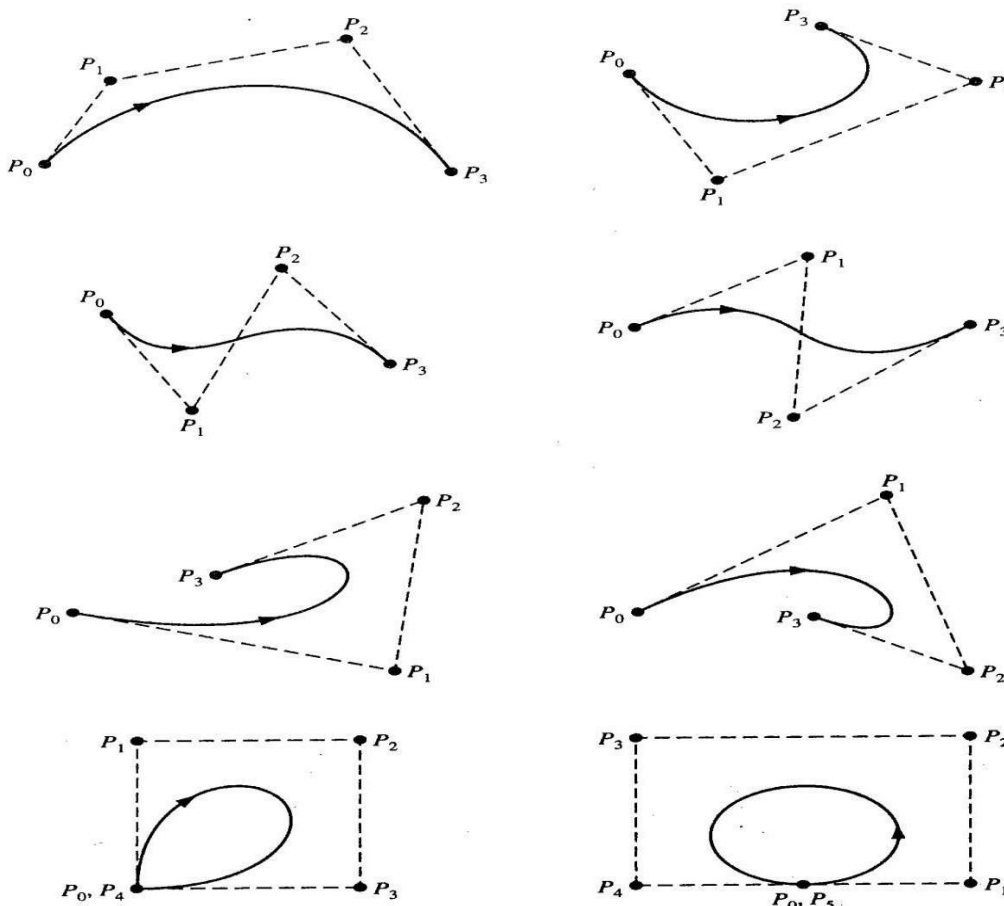
Cubic Bezier curve for various control points.

Wireframe Modeling

```
                                    → Point
                                    → Lines
            Analytic Entities /     → Arcs
            Curves                  → Circles
                                    
Wireframe entities                  → Conics    → Ellipse
                                                 → Parabolas
<Geometric Primitives>                           → Hyperbolas

            Synthetic Curves → Cubic spline
                             → Bezier curves
                             → B-spline
                             → NURBS (Non-Uniform Rational B-spline)
```
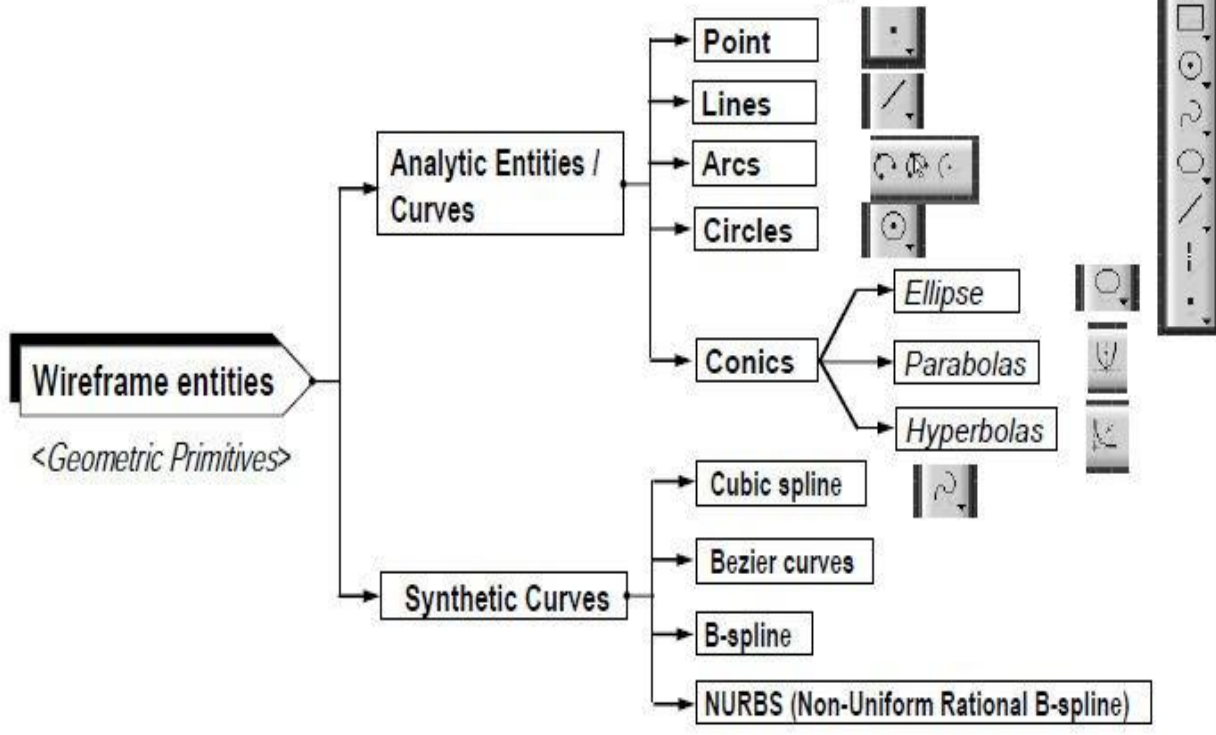
Analytic Curve	Synthetic Curve
- are described by analytic equations	- are described by a set of data points (i.e. control points)

Surface Modeling

Surface entities

Analytic Surface Entities
- Plane surface
- Ruled surface/ Lofted surface
- Surface of revolution
- Tabulated cylindrical surface

Synthetic Surface Entities
- Bi-cubic Hermite spline surface
- B-Spline surface
- Bezier surface or patch
- Coons patch
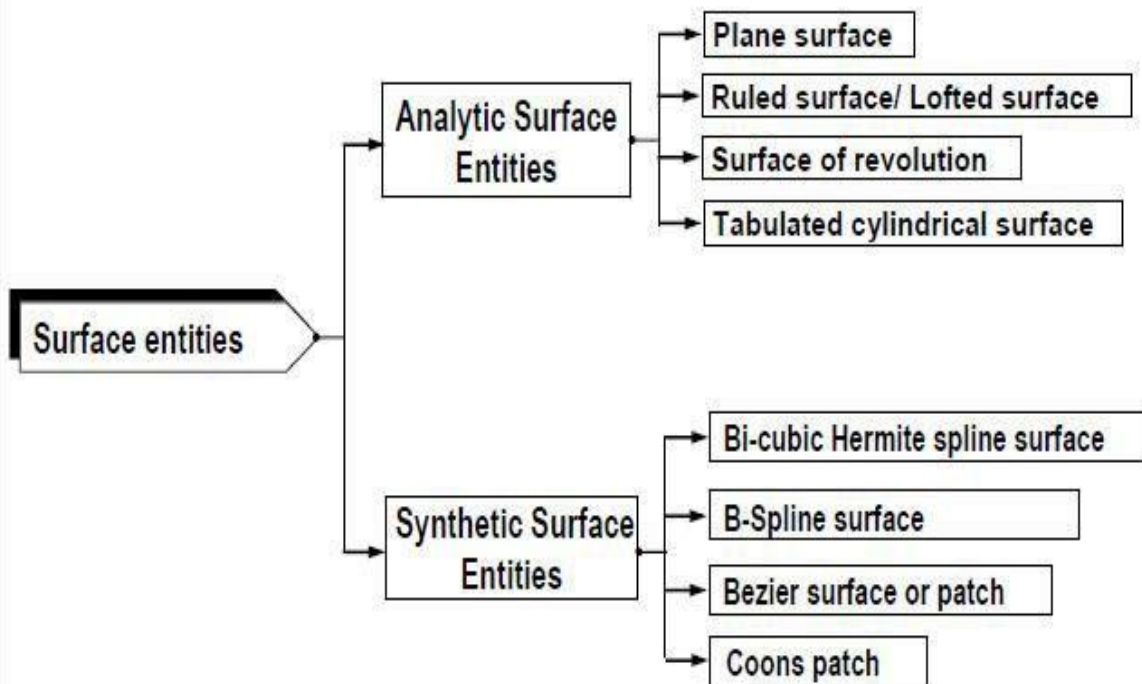
Curve segment : is the fundamental building block for curve entities

Surface patch : is the fundamental building block for surfaces

UNIT -III

COMPUTER AIDED MANUFACTURING

The total modelling facilities that one would look for in any system can be broadly categorized as follows:

The geometric modelling features.

- ✓ The editing or manipulationfeatures.
- ✓ The display controlfacilities.
- ✓ The draftingfeatures.
- ✓ The programmingfacility.
- ✓ The analysisfeatures.
- ✓ The connectingfeatures

A. Geometric ModellingFeatures

The various geometric modelling and construction facilities that one should expect to have in any good system are as follows:

1. Various features to aid geometric construction methods, such as Cartesian and polar coordinates, absolute and incremental dimensions, various types of units, grid, snap, object snap, layer,etc.

2. All 2D analytical features, such as points, lines, arcs, circles, conics, splines, fillets, chamfers, etc. In each of these features, various constructional features including interactive and dynamic draggingfacilities.

3. Majority of the 3D wireframe modelling facilities including 3D lines, 3D faces, ruled surfaces, linear sweep from 2D topology with any sweep direction, rotational sweep, and tapered sweep. General sweep with twist. Revolving about an axis with axis or radial offset for generating helical or spiralshapes.

4. Solid modelling with various basic primitives such as block, cylinder, sphere, cone, prism, torus, pyramid, quadrilateral, along with the ability to apply the boolean operators on any solid that can be constructed using the other techniques available in the modeler.

5. Skinning around regular and arbitrary surfaces. Profiles (cross-sections),both analytical and arbitrary placed across any 3Dcurve.

6. Sculptured surfaces of the various types like Bezier, Coons and other free form surfaces.

7. Comprehensive range of transformation facilities for interactively assembling the various solid models generated by the modeler with features such as surface filleting andtrimming.

B. Editing or ManipulationFeatures

1. Transformations such as move, copy, rotate, scale, elongate or compress, b mirror or to any arbitrary coordinateframe.

2. The editing features used to alter the already drawn geometric entities, such as stretching, trimming or trimming to any intersection, delete or erase, undo orredo.

3. Symbols in drawing refer to often-repeated set in a number of drawings, which may consist of a number of geometric entities that are grouped together and stored as a symbol. This symbol can be recalled at any scale, at any angle or exploded if necessary to treat all of them as separateentities.

C. Display ControlFacilities

In this range of features are all the facilities needed for interacting with the modelling system so as to obtain the necessary feedback at the right time during the niodelling stage. The facilities required are:

1. **Window** - to identify a set of entities for any possible display or editing function.

2. **Zoom** - to change the scale of display of the image selected on thescreen.

3. **Pan** - to move the image on screen without changing the scale at which the drawing is displayed on thescreen.

4. **Hidden** - to remove hidden lines or hidden surfaces for viewing the geometry in properform

5. **Shading** - to show the 3D view of the image on screen complete with the light source location and the resultant light and shade as it appears on theimage.

Fig. 3.29 Elimination of hidden lines in display
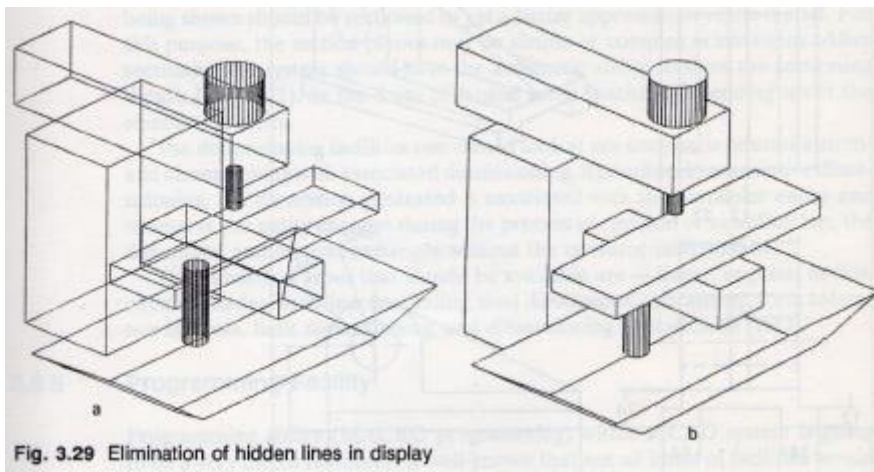
D. DraftingFeatures

These facilities refer to the way the model developed can be utilized for the purpose of transmitting the information in hard copy form for other applications, such as part prints onto the shop floor, or maintenance manuals for the equipment. A really large range of facilities are required in this particular category, and it is sometimes treated as a separate module in the modelingsystem.

A large number of types of views should be obtained from the solid model of the geometry stored in the data base. The types of views required may be , as for display functions, such as perspective views, orthographic views (Fig.), isometric views, and axonometricviews.
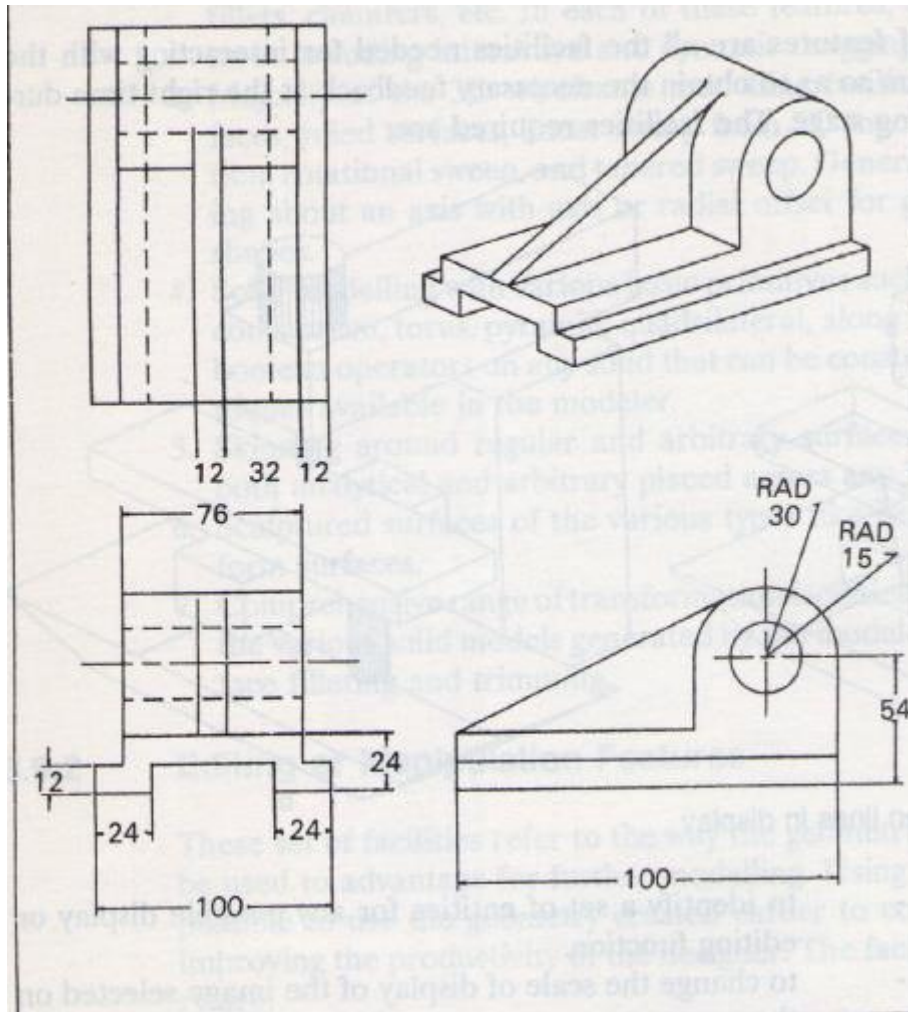
E. ProgrammingFacility

Programming ability (MACRO programming) within a CAD system is going to be a very useful feature. It is well-known that not all kinds of facilities would be available in any general purpose CAD system. Therefore, it is necessary that the CAD system would have to be customised for a given range of application processes specific to the company. For this purpose, if a programming facility exists in a CAD system, it is possible to program specifically for an application, making use of all the features available in the system for either modelling or for any specific application based on the information generated during the modelling. Some such examples are, the GRIP in Unigraphics and GLUE in CAM-X. The availability of such a program helps the user to input the least amount of information for any required design, if the application programs are written well using the programminglanguage.

F. **AnalysisFeatures**

In this range, the kind of analysis facilities that are required to be carried on the product models being generated should be considered. The simplest kind to the most sophisticated features may be available under this category. The simplest facilities may be calculating perimeter, area, volume, mass, centre gravity, moment of inertia, radius of gyration, etc.

G. **ConnectingFeatures**

Modelling is only the start of the complete process of a product evolution, and as such the data generated is used directly by the other systems. It is, therefore, necessary that the internal data format in which the data is stored by the modelling system should be well documented and should also have very good connectivity (data interfacing) with other allied modules. Ideally, an integrated data base structure would be useful wherein all the various modules share the common data base. However, this would only be possible if all the modules are developed at a single developer as in the case of Computer vision or Unigraphics for CAD/CAM integration.

Numerical Control

Many of the achievements in computer-aided design and manufacturing have a common origin in numerical control (abbreviated NC). The conceptual framework established during the development of numerical control is still undergoing further refinement and enhancement in today's CAD/CAM technology.

Numerical control can be defined as a form of programmable automation in which the process is controlled by numbers, letters, and symbols. In NC, the numbers form a program of instructions designed for a particular work part or job. When the job changes, the program of instructions is changed. This capability to change the program for each new job is what gives NC its flexibility. It is much easier to write new programs than to make major changes in the productionequipment.

NC technology has been applied to a wide variety of operations, including drafting, assembly, inspection, sheet metal press working, and spot welding. However, numerical control finds its principal applications in metal machining processes. The machined work parts are designed in various sizes and shapes, and most machined parts produced in industry today are made in small to medium-size batches. To produce each part, a sequence of drilling operations may be required, or a series of turning or milling operations. The suitability of NC for these kinds of jobs is the reason for the tremendous growth of numerical control in the metalworking industry over the last 25 years.

BASIC COMPONENTS OF AN NC SYSTEM

An operational numerical control system consists of the following three basic components:

1. Program ofinstructions

2. Controller unit, also called a machine control unit(MCU)

3. Machine tool or other controlled process

FIGURE 7.1 Three basic components of a numerical control system: (a) program of instruction; (b) controller unit; (c) machine tool.
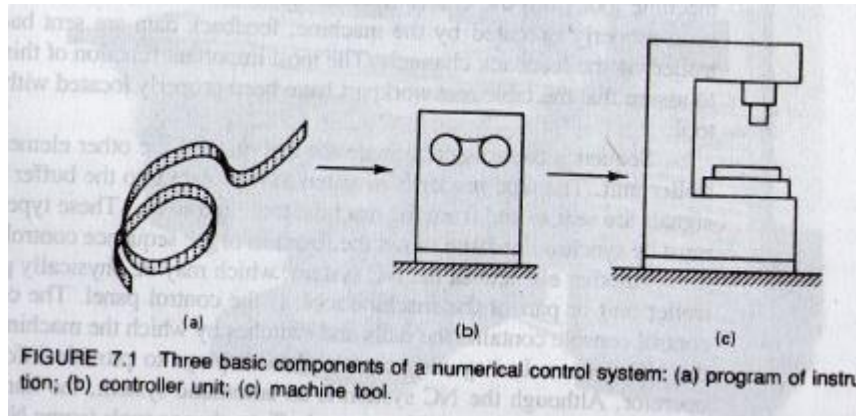
Program of instructions

The program of instructions is the detailed step-by-step set of directions which tell the machine tool what to do. It is coded in numerical or symbolic form on some type of input medium that can be interpreted by the controller unit. The most common input medium today is l-in.-wide punched tape. Over the years, other forms of input media have been used, including punched cards, magnetic tape, and even 35-mm motion picture film.

There are two other methods of input to the NC system which should be mentioned. The first is by manual entry of instructional data to the controller unit. This method is called manual data input, abbreviated MDI, and is appropriate only or relatively simple jobs where the order will not be repeated.

The second other method of input is by means of a direct link with a computer. This is called direct numerical control, or DNC.

The program of instructions is prepared by someone called a part programmer. The programmer's job is to provide a set of detailed instructions by which the sequence of processing steps is to be performed. For a machining operation, the processing steps involve the relative movement between the cutting tool and the workpiece.

Controller unit

The second basic component of the NC system is the controller unit. This consist of the electronics and hardware that read and interpret the program of instruction and convert it into mechanical actions of the machine tool. The typical elements of a conventional NC controller unit include the tape reader, a data buffer, signal output channels to the machine tool, feedback channels from the machine tool, and the sequence controls to coordinate the overall operation of the foregoing elements. It should be noted that nearly all modern NC systems today are sold with microcomputer as the controller unit. This type of NC is called computer numerical control (CNC

The tape reader is an electromechanical device for winding and reading the punched tape containing the program of instructions. The data contained on the tape are read into the data buffer. The purpose of this device is to store the input instructions in logical blocks of information. A block of information usually represents one complete step in the sequence of processing elements. Another element of the NC system, which may be physically part of the controller unit or part of the machine tool, is the control panel. The control panel or control console contains the dials and switches by which the machine operator runs the NC system.

Machine tool or other controlled process

The third basic component of an NC system is the machine tool or other controlled process. It is the part of the NC system which performs useful work. In the most common example of an NC system, one designed to perform machining operations, the machine tool consists of the worktable and spindle as well as the motors and controls necessary to drive them. It also includes the cutting tools, work fixtures, and other auxiliary equipment needed in the machiningoperation.

THE NC PROCEDURE

To utilize numerical control in manufacturing, the following steps must be accomplished;

1. **Process planning.**

The engineering drawing of the work part must be interpreted in terms of the manufacturing processes to be used. This step is referred to as process planning and it is concerned with the preparation of a route sheet. The route sheet is a listing of the sequence of operations which must be performed on the work part. It is called a route sheet because it also lists the machines through which the part must be routed in order to accomplish the sequence of operations.

2. **Partprogramming.**

A part programmer plans the process for the portions of the job to be accomplished by NC. Part programmers are knowledgeable about the machining process and they have been trained to program for numerical control. They are responsible for planning the sequence of machining steps to be performed by NC and to document these in a special format. There are two ways to program for NC:

- **Manual partprogramming**

- **Computer-assisted part programming**

In **manual part programming**, the machining instructions are prepared on a form called a part program manuscript. The manuscript is a listing of the relative cutter/workpiece positions which must be followed to machine the part. In **computer-assisted part programming**, much of the tedious computational work required in manual part programming is transferred to the computer. This is especially appropriate for complex work-piece geometries and jobs with many machiningsteps

3. **Tapepreparation.**

A punched tape is prepared from the part programmer's NC process plan. In **manual part**

programming, the punched tape is prepared directly from the part program manuscript on a typewriter like device equipped with tape punching capability. In **computer-assisted part programming**, the computer interprets the list of part programming instructions, performs the necessary calculations to convert this into a detailed set of machine tool motion commands, and then controls a tape punch device to prepare the tape for the specific NC machine.

4. **Tapeverification.**

After the punched tape has been prepared, a method is usually provided for checking the accuracy of the tape. Sometimes the tape is checked by running it through a computer program which plots the various tool movements (or table movements) on paper..In this way, major errors in the tape can be discovered. The **"acid test"** of the tape involves trying it out on the machine tool to make the part. A foam or plastic material is sometimes uses thistryout

5. **Production**

The final step in the NC procedure is to use the NC in production. This involves ordering the raw work parts, specifying and preparing tooling and any special fixturing that may be required, and setting up the machine tool for the job. The machine tool operator's function during product to load the raw work part in the machine and establish the starting position of cutting tool relative to the workpiece. The NC system then takes over machines the part according to the instructions on tape.

NC COORDINATE SYSTEMS

Two axes, x and y, are defined in the plane of the table, as shown in Fig. The z axis is perpendicular to this plane and movement in the z direction is controlled by the vertical motion of the spindle. The positive and negative directions of motion of tool relative to table along these axes. NC drill presses are classified as either two-axis or three-axis machine depending on whether or not they have the capability to control the z axis.
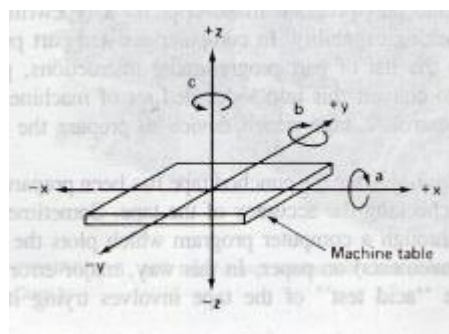
For turning operations, two axes are normally all that are required to command the movement of the tool relative to the rotating workpiece. The z axis is the axis of rotation of the workpart,

and x axis defines the radial location of the cutting tool.
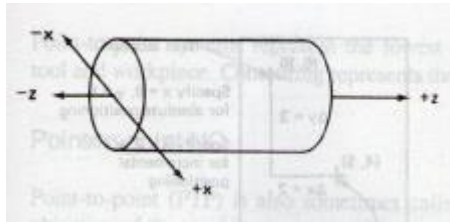
The purpose of the coordinate system is to provide a means of locating the tool in relation to the workpiece. Depending on the NC machine, the part programmer may have several different options available for specifying this location.

Fixed zero and floating zero

NC machines have either of two methods for specifying the zero point-

The first possibility is for the machine to have a **fixed zero**. In this case, the origin is always located at the same position on the machine table. Usually, that position is the southwest corner (lower left-hand corner) of the table and all tool locations will be defined by positive x and y coordinates.

The second and more common feature on modern NC machines allows the machine operator to set the zero point at any position on the machine table. This feature is called **floating zero**. The part programmer is the one who decides where the zero point should be located. The decision is based on part programming convenience.

Absolute positioning and incremental positioning

Another option sometimes available to the part programmer is to use either absolute system of tool positioning or an incremental system. Absolute positioning means that the tool locations are always defined in relation to the zero point.

If a hole is to be drilled at a spot that is 8 in. above the x axis and 6 in. to the right of the y axis, the coordinate location of the hole Would be specified as x = +6.000 and y = +8.000.

By contrast, incremental positioning means that the next tool location must be defined with reference to the previous tool location. If in our driling example, suppose that the previous hole had been drilled at an absolute position of x = +4.000 and y = +5.000. Accordingly, the incremental position instructions would be specified as x = +2.000 and y = +3.000 in order to move the drill to the desired spot.

FIGURE 7.6 Absolute versus incremental positioning.
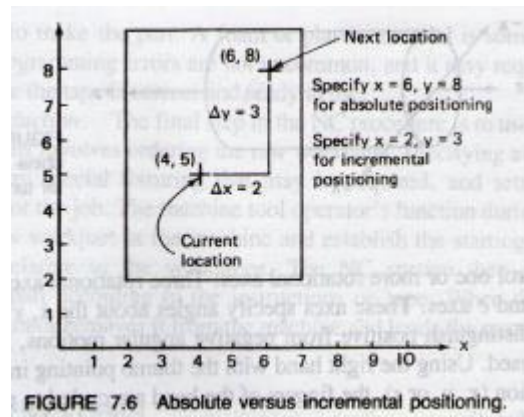
NC MOTION CONTROL SYSTEMS

In order to accomplish the machining process, the cutting tool and workpiece must be moved relative to each other. In NC, there are three basic types of motion control systems:

1. Point-to-point
2. Straightcut
3. Contouring

1. Point-to-pointNC

Point-to-point (PTP) is also sometimes called a **positioning system**. In PTP, the objective of the machine tool control system is to move the cutting tool to a predefined location. The speed or path by which this movement is accomplished is not important in point-to-point NC. Once the tool reaches the desired location, the machining operation is performed at that position.
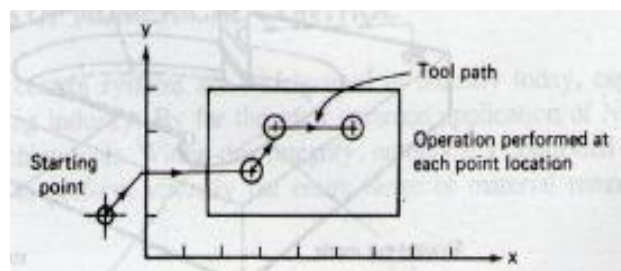
2. Straight-cutNC

Straight-cut control systems are capable of moving the cutting tool parallel to one of themajor axes at a controlled rate suitable for machining. It is therefore appropriate for performing milling operations to fabricate workpieces of rectangular configurations. With this type of NC system it is not possible to combine movements in more than a single axis direction.
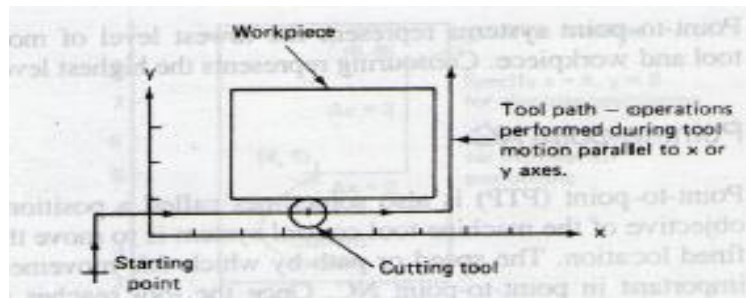
3. Contouring NC

Contouring is the most complex, the most flexible, and the most expensive types machine tool control. It is capable of performing both PTP and straight-cut operations. In addition, the distinguishing feature of contouring NC systems is their capacity for simultaneous control of more than one axis movement of the machine tool. The path of the cutter is continuously controlled to generate the desired geometry of the workpiece. For this reason, contouring systems are also called **continuous-path NCsystems**.
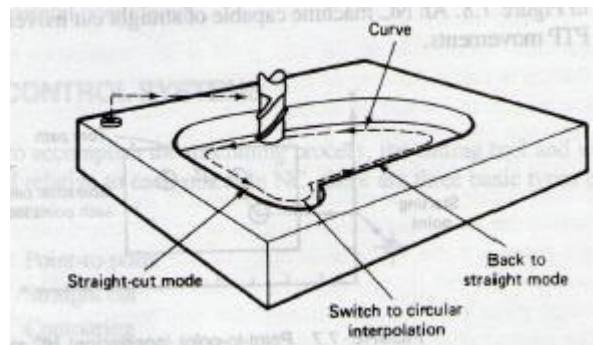
In order to machine a curved path in a numerical control contouring system the direction of the feed rate must continuously be changed so as to follow the path. This is accomplished by breaking the curved path into very short straight-line segments that approximate the curve.
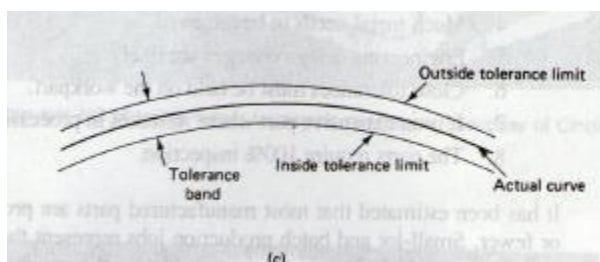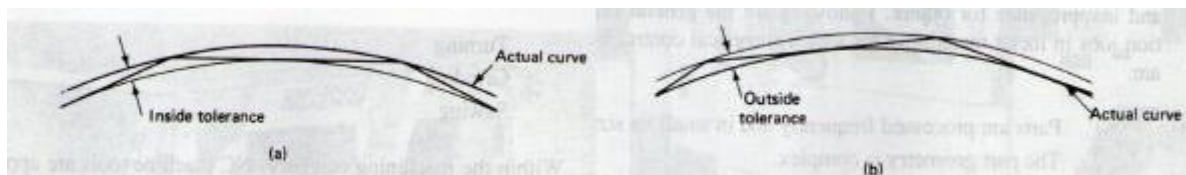
APPLICATIONS OF NUMERICAL CONTROL:

Numerical control systems are widely used in industry today, especially in the metalworking industry. By far the most common application of NC is for metal cutting machine tools. Within this category, numerically controlled equipment has been built to perform virtually the entire range of material removal processes,including:

- Milling
- Drilling and relatedprocesses
- Boring
- Turning
- Grinding

NC machine tools are appropriate for certain jobs and inappropriate for others. Following are the general **characteristics of production jobs in metal machining** for which numerical control would be most appropriate;

1. Parts are processed frequently and in small lotsizes.
2. The part geometry iscomplex.
3. Many operations must be performed on the part in itsprocessing
4. Much metal needs to be removed.
5. Engineering design changes arelikely.
6. Close tolerances must be held on theworkpart.
7. It is an expensive part where mistakes in processing would becostly.
8. The parts require 100%inspection.

Advantages of NC

1. <u>Reduced nonproductive time</u>. Numerical control has little or no effect on the basic metal cutting (or other manufacturing) process. However, NC can increase the proportion of time the machine is engaged in the acutal process. It accomplishes this by means of fewer setups, less time in setting up, reduced workpiece handling time, automatic tool changes on some machines, and soon.

2. <u>Reduced fixturing.</u> NC requires fixtures which are simpler and less costly to fabricate because the positioning is done by the NC tape rather thanthe

3. <u>Reduced manufacturing lead time.</u> Because jobs can be set up more quickly with NC and fewer setups are generally required with NC, the lead time to deliver a job to the customer isreduced.

4. <u>Greater manufacturing flexibility.</u> With numerical control it is less difficult to adapt to engineering design changes, alterations of the production schedule changeovers in jobs for rush orders, and so on.

5. <u>Improved quality control.</u> NC is ideal for complicated workparte where the chances of human mistakes are high. Numerical control produces parts with greater accuracy, reduced scrap, and lower inspectionrequirements.

6. <u>Reduced inventory.</u> Owing to fewer setups and shorter lead times with numerical control, the amount of inventory carried by the company isreduced.

7. <u>Reduced floor space requirements</u>. Since one NC machining center can often accomplish the production of several conventional machines, the amount of floor space required in an NC shop is usually less than in a conventionalshop.

Disadvantages of NC

1. <u>Higher investment cost</u>. Numerical control machine tools represent a more sophisticated and complex technology. This technology costs more to buy than its non-NCcounterpart.

2. <u>Higher maintenance cost.</u> Because NC is a more complex technology and because NC machines are used harder, the maintenance problem becomes moreacute.

3. <u>Finding and/or training NC personnel</u>. Certain aspects of numerical control shop operations require a higher skill level than conventional operations Part programmers and NC maintenance personnel are two skill areas where available personnel are in short supply. The problems of finding, hiring, and training these people must be considered a disadvantage to the NCshop.

NC part programming

Numerical control part programming is the procedure by which the sequence of processing steps to be performed on the NC machine is planned and documented. It involves the preparation of a punched tape (or other input medium) used to transmit the processing instructions to the machine tool.

It is appropriate to begin the discussion of NC part programming by examining the way in which the punched tape is coded. Coding of the punched tape is concerned with the basic symbols used to communicate a complex set of instructions to the NC machine tool. In numerical control, the punched tape must be generated whether the part programming is done manually or with the assistance of some computer package. With either method of part programming, the tape is the net result of the programming effort.

THE PUNCHED TAPE IN NC

The part program is converted into a sequence of machine tool actions by means of, the input medium, which contains the program, and the controller unit, which interprets the input medium. The controller unit and the input medium must be compatible. That is, the input medium uses coded symbols which represent the part program, and the controller unit must be capable of reading thosesymbols.

The most common input medium is punched tape. The tape has been standardized so that tape punchers are manufactured to prepare the NC tapes, and tape readers (part of the controller unit) can be
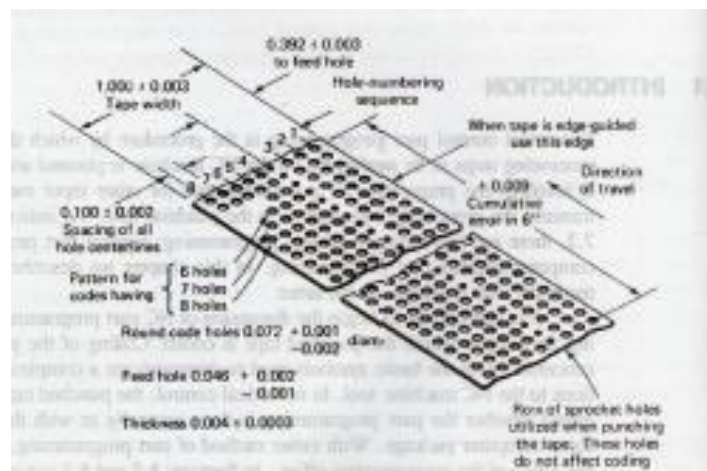
manufactured to read the tapes. The punched tape used for NC is 1 in. wide. there are eight regular columns of holes running in the lengthwise direction of the tape. There is also a ninth column of holes between the third and fourth regular columns. However, these are smaller and are used as sprocket holes for feeding thetape.

There are two basic methods of preparing the punched tape;

* The first method is associated with manual part programming and involves the use of a typewriter like device. The operator types directly from the part programmer's handwritten list of coded instructions. This produces a typed copy of the program as well as the punchedtape.

- The second method is used with computer-assisted part programming. By this approach, the tape is prepared directly by the computer using a device called a tape punch.

By either method of preparation, the punched tape is ready for use. During production on a conventional NC machine, the tape is fed through the tape reader once for each workpiece. It is advanced through the tape reader one instruction at a time. While the machine tool is performing one instruction, the next instruction is being read into the controller unit's data buffer. This makes the operation of the NC system more efficient. After the last instruction ha$ been read into the controller, the tape is rewound back to the start of the program to be ready for the next workpart.

A binary digit is called a bit. It has a value of 0 or 1 depending on the absence or presence of a hole in a certain row and column position on the tape. (Columns of hole positions run lengthwise along the tape. Row position run across the tape.) Out of a row of bits, a character is made. A character is a combination of bits which represents a letter, number, or other symbol. A word is a collection of characters used to form part of an instruction. Typical NC words are x position, y position, cutting speed, and soon.

NC words

Following is a list of the different types of words in the formation of a block.

- SEQUENCE NUMBER (n-words): This is used to identify theblock.
- PREPARATORY WORD (g-words): This word is used to prepare the controller for instructions that are tofollow.
- COORDINATES (x-, y-, and z-words): These give the coordinate positions of the tool.
- FEED RATE (f-word): This specifies the feed in a machiningoperation.
- CUTTING SPEED (s-word): This specifies the cutting speed of the process, the rate & which the spindlerotates.
- TOOL SELECTION (t-word): This word would be needed only for machines with a too turret or automatic toolchanger.
- MISCELLANEOUS FUNCTION (m-word): The m-word is used to specify certain miscellaneous or auxiliary functions which may be available on the machinetool.

MANUAL PART PROGRAMMING

To prepare a part program using the manual method, the programmer writes the machining instructions on a special form called a part programming manuscript. The instructions must be prepared in a very precise manner because the typist prepares the NC tape directly from the manuscript. Manuscripts come in various forms, depending on the machine tool and tape format to be used. Manual programming jobs can be divided into two categories: point-to-point jobs and contouring jobs. Except for complex workparts with many holes to be drilled, manual programming is ideally suited for point-to-point applications. On the other hand, except for the simplest milling and turning jobs, manual programming can. Become quite time consuming for applications requiring continuous-path control of thetool.
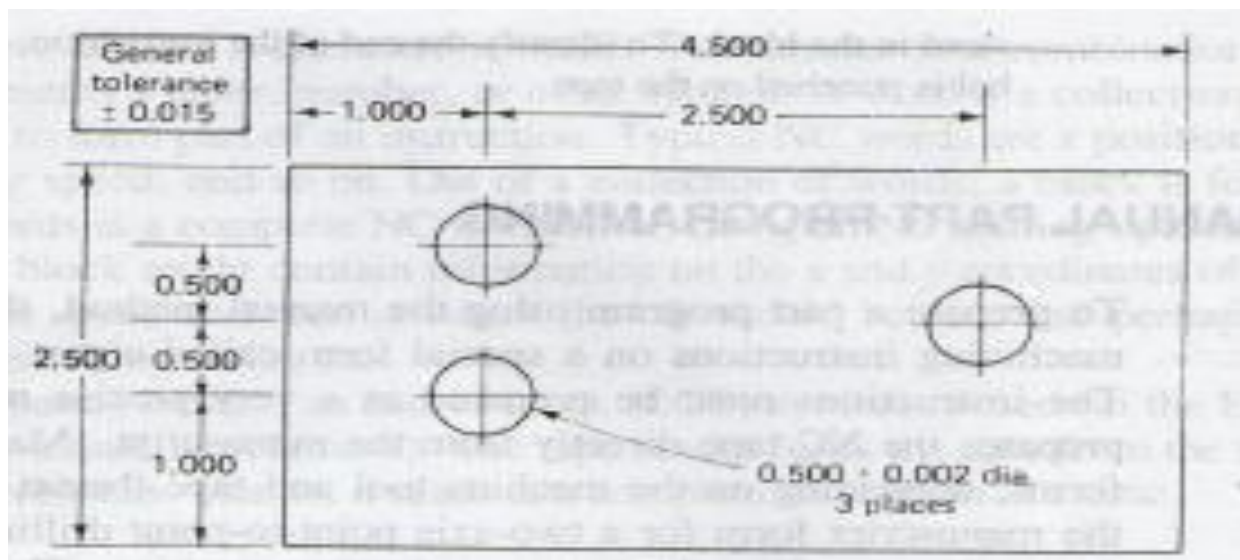
NC part programming manuscript
Two axis point-to-point drill press
tab sequential format

Part No. __EXAMPLE #.2__   Date __4/4/79__

Part Name __HOLE PLATE__   Prepared by __MPG__

Seq. No.	Tab EOB	x-COORD	Tab EOB	y-COORD	Tab EOB	Feed	Tab EOB	Speed	Tab EOB	m-WORD	Tab EOB	Comments
00 RWS	TAB	0.0	TAB	0.0	EOB							ZERO
01	TAB	1.0	TAB	2.0	TAB	3.55	TAB	592	TAB	13	EOB	DRILL 1
02	TAB		TAB	1.0	EOB							DRILL 2
03	TAB	3.5	TAB	1.5	EOB							DRILL 3
04	TAB	-1.0	TAB	3.0	TAB		TAB		TAB	06	EOB	TOOL CHG
05	TAB	3.5	TAB	1.5	TAB	3.82	TAB	382	TAB	13	EOB	REAM 3
06	TAB	1.0	TAB	1.0	EOB							REAM 2
07	TAB		TAB	2.0	EOB							REAM 1
08	TAB	-1.0	TAB	3.0	TAB		TAB		TAB	06	EOB	TOOL CHG
09	TAB		TAB		TAB		TAB		TAB	30	EOB	REWIND CHG PART

COMPUTER-ASSISTED PART PROGRAMMING

Many part programming language systems have been developed to perform automatically most of the calculations which the programmer would otherwise be forced todo. This saves time and result in a more accurate and more efficient part program.
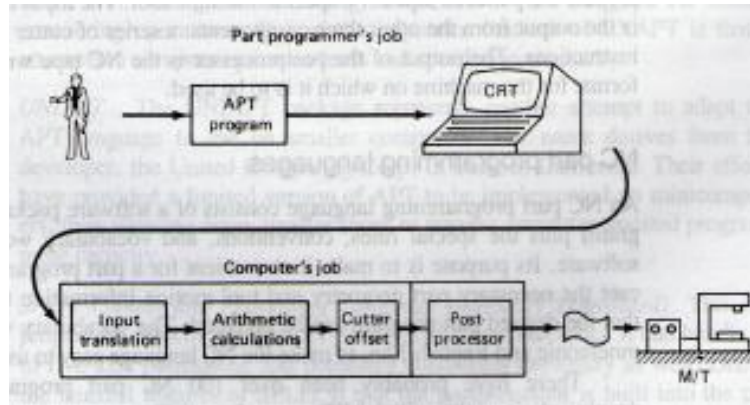
Part programmer's job

The computer's job in computer-assisted part programming consists of the following steps:

1. **Input translation**- The part programmer enters the program written in the APT or other language. The input translation component converts the coded instructions contained in the program into computer-usable form, preparatory to further processing.

2. **Arithmetic Calculations**- The arithmetic calculations unit of the system consists of a comprehensive set of subroutines for solving the mathematics required to generate the part surface. These subroutines are called by the various part programming language statements. The arithmetic unit is really the fundamental element in the part programming package. This unit frees the programmer from the time-consuming geometry and trigonometry calculations, to concentrate on the workpartprocessing.

3. **Cutter offset** - The purpose of the cutter offset computations is to offset the tool path from the desired part surface by the radius of the cutter. This means that the part programmer can define the exact part outline in the geometry statements. Thanks to the cutter offset calculation provided by the programming system, the programmer need not be concerned with thistask.

4. **Post processor**- The postprocessor is a separate computer program that has been written to prepare the punched tape for a specific machine tool. The input to the postprocessor is the output from the other three components: a series of cutter locations and other instructions. The output of the postprocessor is the NCtape written in the correct format for the machine on which it is to beused.

NC part programming languages

An NC part programming language consists of a software package (computer program) plus the special rules, conventions, and vocabulary words for using that software. Its purpose is to make it convenient for a part programmer to communicate the necessary part geometry and tool motion information to the computer so that the desired part program can be prepared. The following NC languages in current use;

- APT (Automatically ProgrammedTools)
- ADAPT (Adaptation of APT)
- EXAPT (Extended subset ofAPT)
- UNIAPT
- SPLIT (Sundstrand Processing Language InternallyTranslated)

THE APT LANGUAGE

APT is not only an NC language; it is also the computer program that per forms the calculations to generate cutter positions based on APT statements. APT is a three-dimensional system that can be used to control up to five axes. APT can be used to control a variety of different machining operations. There are over 400 words in the APT vocabulary. There are four types of statements in the APT language:

1. **Geometry statements.** These define the geometric elements that comprise the workpart. They are also sometimes called definitionstatements.
2. **Motion statements**. These are used to describe the path taken by the cuttingtool.
3. **Postprocessor statements.** These apply to the specific machine tool and control system. They are used to specify feeds and speeds and to actuate other features of themachine.
4. **Auxiliary statements**. These are miscellaneous statements used to identify the part, tool, tolerances, and soon.

Geometry statements

To program in APT, the workpart geometry must first be defined. The tool is subsequently directed to move to the various point locations and along surfaces of the workpart which have been defined by these geometry statements. The definition of the workpart elements must precede the motion statements.

The general form of an APT geometry statement is this:

symbol = geometry type/descriptive data

Example:-

Forpoint	P1 =POINT/5.0,4.0,0.0
Line	L3 = LINE/P3,P4
	Or
	L4 = LINE/P5, PARLEL, L3
Plane	PL1 = PLANE/PI, P4, P5
	OR
	PL2 = PLANE/P2, PARLEL, PL1
Circle	Cl = CIRCLE/CENTER, PI, RADIUS, 5.0

Example:

PO   = POINT/0,-1.0,0

P1   = POINT/6.0, 1.125,0

P2   = POINT/0, 0,0

P3   = POINT/6.0, 0, 0

P4   = POINT/1.75, 4.5,0

LI   = LINE/P2, P3

C1   = CIRCLE/CENTER, P1, RADIUS, 1.125

L2   = LINE/P4, LEFT, TANTO,C1

L3   = LINE/P2, P4

PL1   = PLANE/P2, P3,P4
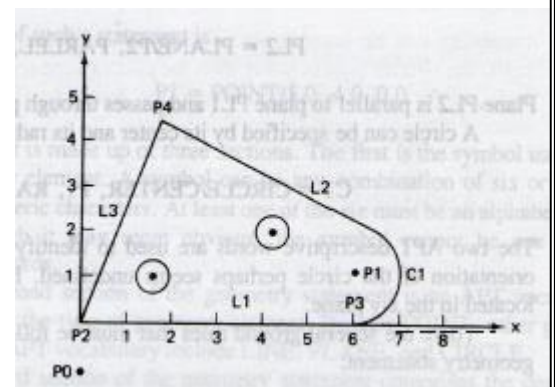
Motion statements

APT motion statements have a general format, just as the geometry statements do. The general form of a motion statement is

motion command/descriptive data

Example of a motion statement is

GOTO/P1

FROM/TARG

FROM/-2.0, -2.0, 0.0

The GODLTA command specifies an incremental move for thetool.For   example, the statement

GODLTA/2.0, 7.0, 0.0

Example:
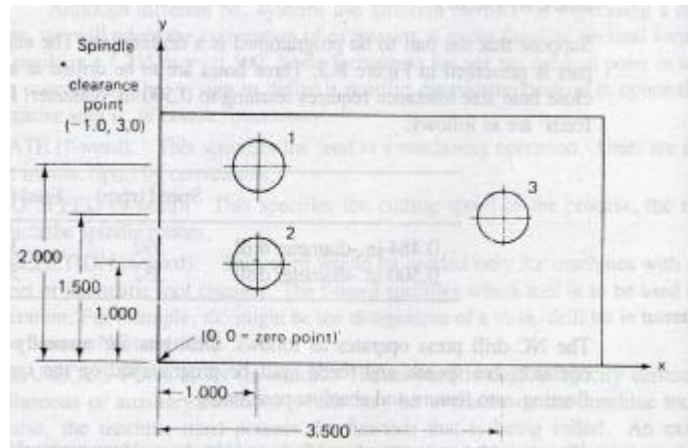
P1   = POINT/1.0.2.0,0

P2   = POINT/1.0. 1.0,0

P3 = POINT/3.5, 1.5,0

P0   = POINT/- 1.0, 3.0, 2.0

FROM/P0

GOTO/P1

GODLTA/0,0,-1.0

GODLTA/0,0,+1.0

GOTO/P2

GODLTA/0,0,-1.0

GODLTA/0,0,+1.0

GOTO/P3

GODLTA/0,0,-1.0

GODLTA/0,0,+1.0

GOTO/P0

This is not a complete APT program because it does not contain the necessary auxiliary and postprocessor statements. However, the statement sequence demonstrates how geometry and motion statements can be combined to command the tool through a series of machining steps.

CONTOURING MOTIONS.

Contouring commands are somewhat more complicated because the tool's position must be continuously controlled throughout the To accomplish this control, the tool is directed along two intersecting surfaces. These surfaces have very specific names in APT ;

1. **Drive surface.** This is the surface that guides the side of thecutter.
2. **Part surface.** This is the surface on which the bottom of the cutter rides. The "part surface" may or may not be an actual surface of theworkpart.
3. **Check surface.** This is the surface that stops the movement of the tool in its current direction. In a sense, it checks the forward movement of thetool.
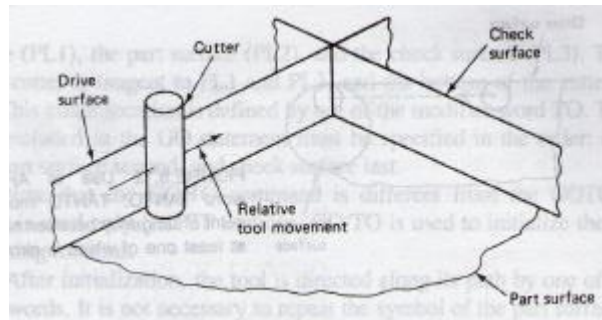
The APT contour motion statement commands the cutter to move along the drive and part surfaces and the movement ends when the tool is at the check surface. There are six motion command words:

GOLFT	GOFWD	GOUP
GORGT	GOBACK	GODOWN
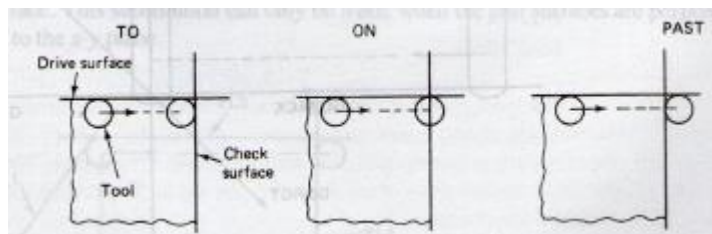
Postprocessor statements

To write a complete part program, statements must be written that control fie operation of the spindle, the feed, and other features of the machine tool. These are called postprocessor statements. Some of the common postprocessor statementsare:

COOLNT/

END

FEDRAT7

MACHIN/

RAPID

SPINDL/

TURRET/

Auxiliary statements

The complete APT program must also contain various other statements, called auxiliary statements. These are used for cutter size definition, part identification, and so on. The following APT words used in auxiliary statements are:

CLPRNT	INTOL/
CUTTER	OUTTOL/
FINI	PARTNO

Advantages of CAD/CAM in NC Programming:

1. **Savings in geometry definition**- Since the part geometry data have already been created during design using the CAD/CAM graphics system, the part programmer is not required to redefine the geometry of the part. This can be a time-consuming procedure in conventional APTprogramming.

2. **Immediate visual verification**- The graphics terminal provides a display of the tool path for immediate verification by the part programmer. Most programming errors can be detected by the user and corrected at the time the error is made. With conventional APT or other NC language, there is a delay between writing the program and the verification/correctionprocess.

3. **Use of automatic programming routines**- For common part programming situations such as profiling and pocketing, the use of automatic MACRO-type routines yields a significant reduction in part programmingtime.

4. **One-of-a-kind jobs**- Because the part programming time is significantly reduced when using a CAD/CAM system, numerical control becomes an economically attractive method for producing one-of-a-kind jobs. Without CAD/CAM, the time required to prepare the part program represents a significant obstacle which often precludes the use of NC for one/offproduction.

5. **Integration with other related functions**- There is the obvious opportunity to integrate the product design function with part programming. Other opportunities for functional integration within manufacturing also exist. These include tool design, process planning, and preparation of operator and setup instructions, grouping of parts into families for programming convenience, and soon.

MANUAL DATA INPUT

Manual data input (MDI) involves the entry of part programming data through a CRT display at the machine site; hence the use of punched tape is avoided. The programming process is usually carried out by the machine operator. NC systems equipped with MDI capability possess a computer (microcomputer) as the control unit.

The great advantage of MDI is its simplicity. It represents a relatively easy way for a small shop to make the transition to numerical control. There is a minimum of change in normal shop procedures needed to use NC systems featuring manual data input. Since no punched tape is employed with MDI, the shop is spared the expense of tape punching equipment normally associated with NC.

one of the biggest disadvantages of manual data input is that the machine tool itself is not productive while programming is being accomplished. In essence, a very expensive piece of equipment is being utilized to prepare the part program. The more complicated the program, the more time is taken when the machine is not cutting metal.

Computer Controls in NC

Use of the digital computer has also permitted substantial improvement to be made in the controls for NC. There are three NC-related control:

1. **Computer numerical control (CNC)** - Computer NC involves the replacement of the conventional hard-wired NC controller unit by a small computer (minicomputer or microcomputer). The small computer is used to perform some or all of the basic ,NC functions by programs stored in its read/write memory. One of the distinguishing features of CNC is that one computer is used to control one machinetool.

2. **Direct numerical control (DNC)** - DNC involves the use of a larger computer to control a number of separate NC machinetools.

3. **Adaptive control** - It does not require a digital computer for implementation. Adaptive control machining denotes a control system that measures one or more process variables (such as cutting force, temperature, horse power, etc.) and manipulates feed and/or speed in order to compensate for undesirable changes in the process variables. Its objective is to optimize the initial adaptive control projects relied on analog controls rather than digital computers, Today, these systems employ microprocessor technology to implement the adaptive controlstrategy.

PROBLEMS WITH CONVENTIONAL NC

1. **Part programming mistakes** - In preparing the punched tape, part programming mistakes are common. The mistakes can be either syntax or numerical errors, and it is not uncommon for three or more passes to be required before the NC tape is correct. Another related problem in part programming is to achieve the best sequence of processing steps. This is mainly a problem in manual partprogramming.

2. **Non-optimal speeds and feeds** - n conventional numerical control, the control system does not provide the opportunity to make changes in speeds and feeds during the cuttingprocess.

3. **Punched tape** - Paper tape is especially fragile, and its susceptibility to wear and tear causes it to be unreliable NC component for repeated use in theshop.

4. **Tape Reader** – The tape reader that interprets the punched tape is generally acknowledge among NC users to be the least reliable hardware component of the machine.

5. **Controller** – The conventional NC controller unit is hard-wired. This means that its control features cannot be easily altered to incorporate improvements into theunit.

6. **Management Information** – the conventional NC system is not equipped to provide timely information on operational performance tomanagement.

COMPUTER NUMERICAL CONTROL

Computer numerical control is an NC system that utilizes a dedicated, stored program computer to perform some or all of the basic numerical control function. Because of the trend toward downsizing in computers, most of the CNC system sold today use a microcomputer-based controller unit

The external appearance of a CNC machine is very similar to that of a conventional NC machine. Part programs are initially entered in a similar manner. Punched tape readers are still the common device to input the part program into the system. However, with conventional numerical control, the punched tape is cycled through the reader for every work piece in the batch. With CNC, the programis entered once and then stored in the computer memory. Thus the tape reader used only for the original loading of the part program and data. Compared to regular NC, CNC offers additional flexibility and computational capability. New system options can be incorporated into the CNC controller simply by reprogramming the unit. Because of this reprogramming capacity, both in terms of part programs and system control options, CNC is often referred to by the term "soft-wire" NC.
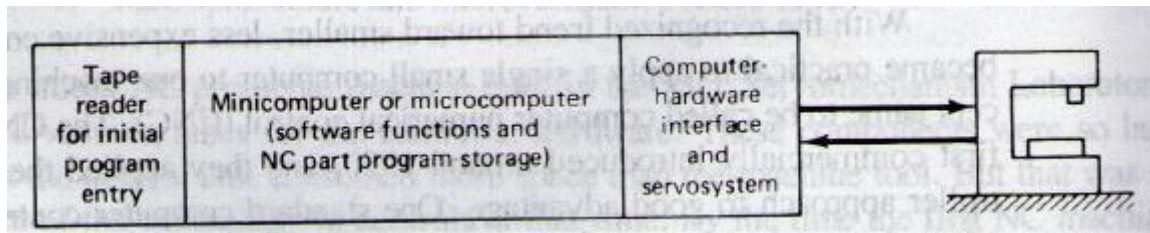
Functions of CNC

The principal functions of CNC are:

1. Machine toolcontrol
2. In-processcompensation
3. Improved programming and operatingfeatures
4. Diagnostics

➢ **MACHINE TOOL CONROL-** The primary function of the CNC system is control of the machine tool. This involves conversion of the part program instructions into machine tool motions through the computer interface and servosystem. Some of the control functions, such as circular interpolation, can be accomplished more efficiently with hard wired circuits than with the computer. This fact has lead to the development of two alternative controller designs inCNC:

1. HybridCNC
2. StraightCNC

In the hybrid CNC system, the controller consists of the soft-wired computer plus hard-wired logic circuits. The hard-wired components perform those functions which they do best, such as feed rate generation and circular interpolation. The computer performs the remaining control functions plus other duties not normally associated with a conventional hard-wired controller. There are several reasons for the popularity of the hybrid CNC configuration. As mentioned previously, certain NC functions can be performed more efficiently with the hard-wired circuits.
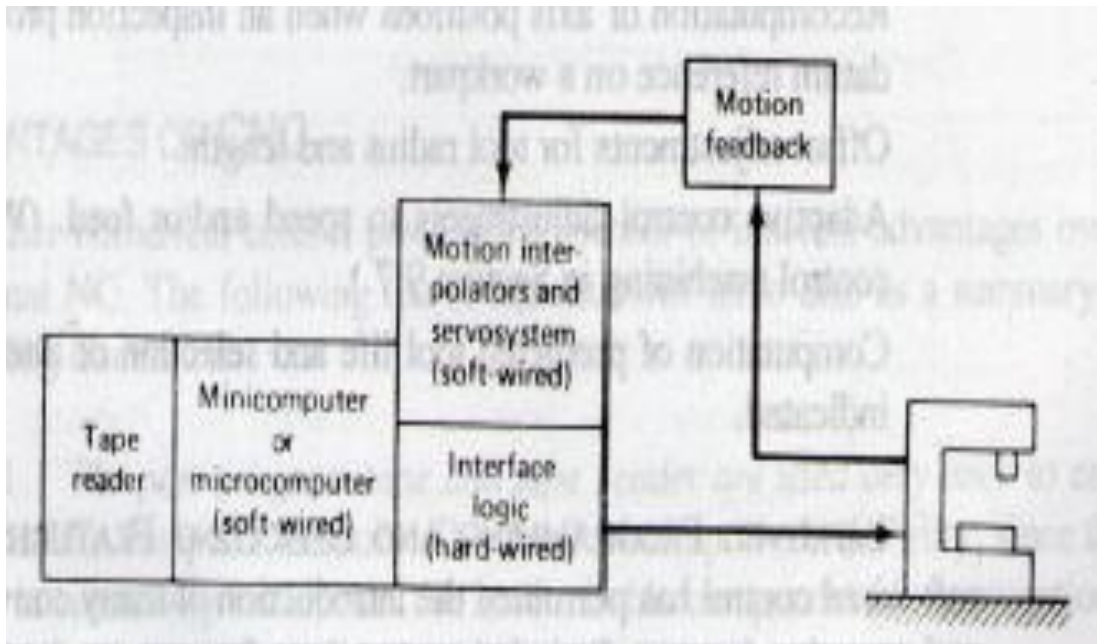
The **straight CNC system** uses a computer to perform all the NC functions. The only hard-wired elements are those required to interface the computer with the machine tool and the operator's console. Interpolation, tool position feedback, and all other functions are performed by computersoftware.
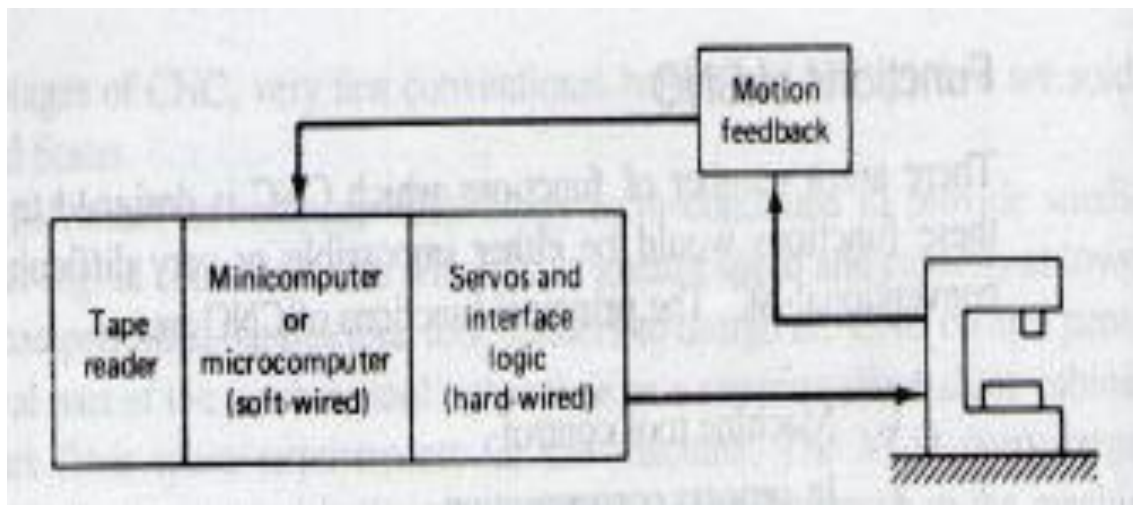
- ➢ **IN-PROCES COMPENSATION**- A function closely related to machine tool control is in-process compensation. This involves the dynamic correction of the machine tool motions for changes or errors which occur duringprocessing.

- ➢ **IMPROVED PROGRAMING and OPERATING FEATURE** - The flexibility of soft-wired control has permitted the introduction of many convenient programming and operatingfeatures.

- ➢ **DIAGNOSTICS**- NC machine tools are complex and expensive systems. The complexityincreasestheriskofcomponentfailureswhichleadtosystemdowntime.

It also requires that the maintenance personnel be trained to a higher level of proficiency in order to make repairs. The higher cost of NC provides a motivation to avoid downtime as much as possible. CNC machines are often equipped with a diagnostics capability to assist in maintaining and repairing the system.

Advantages of CNC

1. The part program tape and tape reader are used only once to enter the program into computermemory.
2. Tape editing at the machine site. The NC tape can be corrected and even optimized (e.g., tool path, speeds, and feeds) during tape tryout at the site of the machinetool.
3. Metric conversion- CNC can accommodate conversion of tape prepared in Units of inches into the International System of units.
4. Greater flexibility- One of the more significant advantages of CNC over conventional NC is itsflexibility.
5. User-written programs - One of the possibilities not originally anticipated for CNC was the generation of specialized programs by theuser.
6. Total manufacturing system- CNC is more compatible with the use of a computerized factory-wide manufacturingsystem.

DIRECT NUMERICAL CONTROL

Direct numerical control can be defined as a manufacturing system in which number of machines is controlled by a computer through direct connection and in real time. The tape reader is omitted in DNC, thus relieving the system of its least reliable component. Instead of using the tape reader, the part program is transmitted to the machine tool directly from the computer memory. In principle, one larger computer can be used to control more than 100 separate machines. The DNC computer is designed to provide instructions to each machine, tool on demand. When the machine needs control commands, they are communicated to it immediately.

Components of a DNC system

1. Centralcomputer
2. Bulk memory, which stores the NC partprograms
3. Telecommunicationlines
4. Machinetools
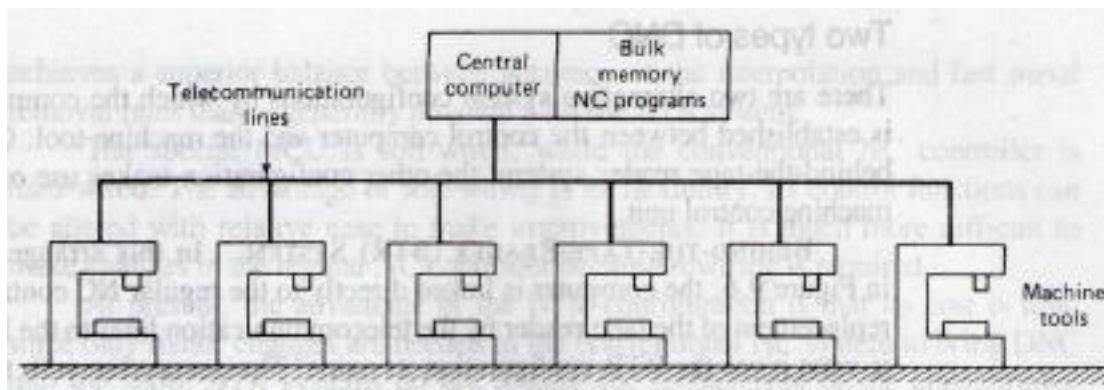
Functions of DNC

The principal functions of DNC are:

1. NC without punchedtape
2. NC part programstorage
3. Data collection, processing, andreporting
4. Communications

> NC WITHOUT PUNCHED Tape. One of the original objectives in direct mmerical control was to eliminate the use of punched tape. Several of the problems. with conventional NC discussed in Section 9.2 are related to the use of mnched tape (the relatively unreliable tape reader, the fragile nature of paper tape, the difficulties in making corrections and changes in the program contained on punched tape, etc.). There is also the expense associated with the equipment that produces the punched tape. All of these costs and inconveniences can be eliminated with the DNCapproach.

> NC Part Program Storage. A second important function of the DNC system is concerned with storing the part programs. The program storage subsystem must be structured to satisfy several purposes. First, the programs must be made available for downloading to the NC machine tools. Second, the subsystem must allow for new programs to be entered, old programs to be deleted, and existing programs to be edited as the need arises. Third, the DNC software must accomplish the post processingfunction.

> Data Collection, Processing, and Reporting. The two previous functions for DNC both concerned the direct link from the central computer to the machine tools in the factory. Another important function of DNC involves the opposite link,, the transfer of data from the machine tools back to the central computer. DNC involves a two-way transfer ofdata.

> COMMUNICATIONS. A communications network is required to accomplish the previous three functions of DNC. Communication among the various subsystems is a function that is central to the operation of any DNCsystem.

Advantages of DNC

1. Elimination of punched tapes and tapereaders
2. Greater computational capability andflexibility
3. Convenient storage of NC part programs in computerfiles
4. Programs stored asCLFILE
5. Reporting of shopperformance
6. Establishes the framework for the evolution of the future computer automatedfactory

ADAPTIVE CONTROL MACHINING SYSTEMS

For a machining operation, the term adaptive control denotes a control system that measures certain output process variables and uses these to control speed and/or feed. Some of the process variables that have been used in adaptive control machining systems include spindle deflection or force, torque, cutting temperature, vibration amplitude, and horsepower. In other words, nearly allthemetal   cutting variables that can be measured have been tried in experimental adaptive control systems. The motivation for developing an adaptive machining system lies in trying to operate the process more efficiently. The typical measures of performance in machining have been metal removal rate and cost per volume of metal removed.

Two types of adaptive control

1. Adaptive control optimization (ACO)- In this form of adaptive control, an index of performance is specified for the system. This performance index is a measure of overall process performance, such as production rate or cost per volume of metal removed. The objective of the adaptive controller is to optimize the index of performance by manipulating speed and/or feed in theoperation.

   Most adaptive control optimization systems attempt to maximize the ratio of work material removal rate to tool wear rate.

   $$IP = a \text{ function of } (MRP/TWR)$$

   where MRR = material removal rate

   TWR = tool wear rate

2. Adaptive control constraint (ACC) - The production AC systems utilize constraint limits imposed on certain measured process variables. Accordingly, these are called adaptive control constraint (ACC) systems. The objective in these systems is to manipulate feed and speed so that these measured process variables are maintained at or below their constraint limit values.

Benefits of adaptive control machining

There are obviously many machining situations for which it cannot be justified. Adaptive control has been successfully applied in such machining processes as milling, drilling, tapping, grinding, and boring. It has also been applied in turning, but with only limited success. Following are some of the benefits gained from adaptive control in the successful applications.

1. Increased productionrates
2. Increased toollife
3. Greater partprotection
4. Less operatorintervention
5. Easier partprogramming

UNIT – IV

Group Technology, CAPPAND CAQC

INTRODUCTION:

Group technology (abbreviated GT) is a manufacturing philosophy in which similar parts are identified and grouped together to take advantage of their similarities in manufacturing and design. Similar parts are arranged into part families. For example, a plant producing 10,000 different part numbers may be able to group the vast majority of these parts into 50 or 60 distinct families. Each family would possess similar design and manufacturing characteristics. Hence, the processing of each member of a given family would be similar, and this results in manufacturing efficiencies. These efficiencies are achieved in the form of reduced setup times, lower in-process inventories, better scheduling, improved tool control, and the use of standardized process plans. In some plants where GT has been implemented, the production equipment is arranged info machine groups, or cells, in order to facilitate work flow and partshandling.

Parts classification and coding is concerned with identifying the similarities among parts and relating these similarities to a coding system. Part similarities are of two types: design attributes (such as geometric shape and size), and manufacturing attributes (the sequence of processing steps required to make the part).

Whereas a parts classification and coding system is required in a design retrieval system, it can also be used in computer-aided process planning (CAPP). Computer-aided process planning involves the automatic generation of a process plan (or route sheet) to manufacture the part. The process routing is developed by recognizing the specific attributes of the part in question and relating these attributes, to the corresponding manufacturing operations.

Group technology and parts classification and coding are based on the concept of a part family.

PART FAMILIES

A part family is a collection of parts which 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 identification as members of the part family.
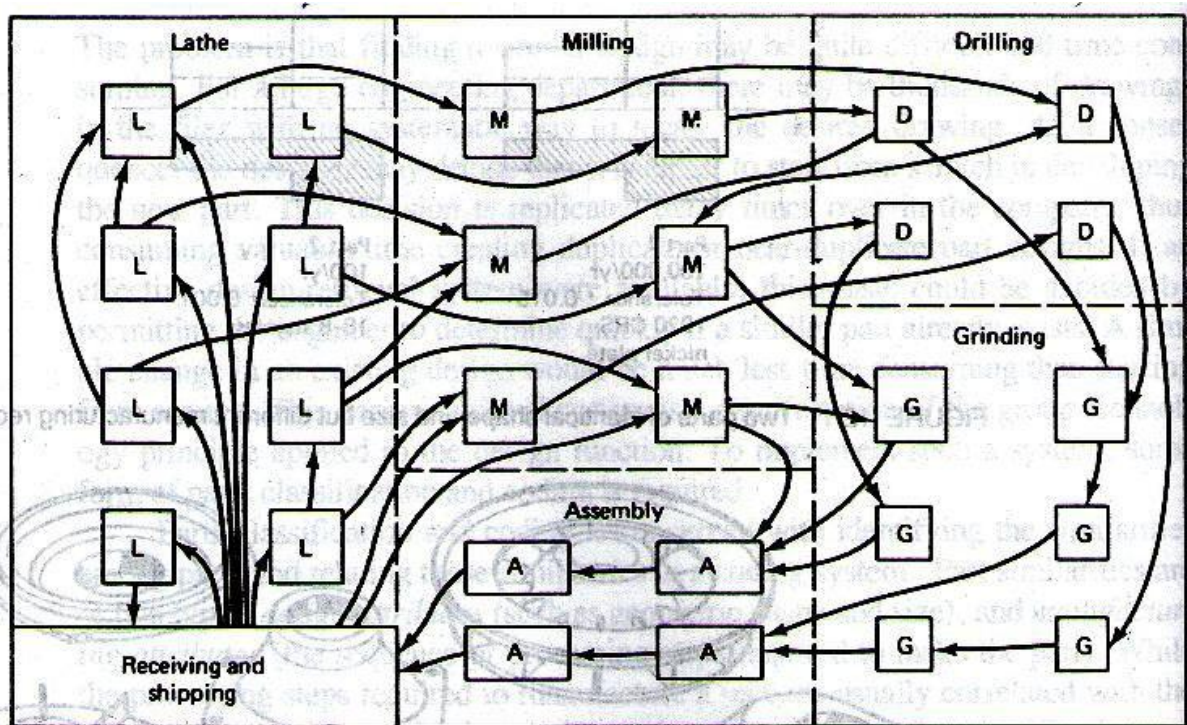
Process-type layout.

The part family concept is central to design-retrieval systems and most current computer-aided process planning schemes. Another important manufacturing advantage derived from grouping work part into families. The machines arranged into cells. Each cell is organized to specializedin the manufacturing of a particular part family. Advantages are gained in tha form of reduced workpiece handling, lower setup times, less in-process inventory, less floor space, and shorter lead times. Some of the manufacturing cells can be designed to form production flow lines, with conveyors used to transport work parts between machines in thecell.

The biggest single obstacle in changing over to group technology from a traditional production shop is the problem of grouping parts into families.
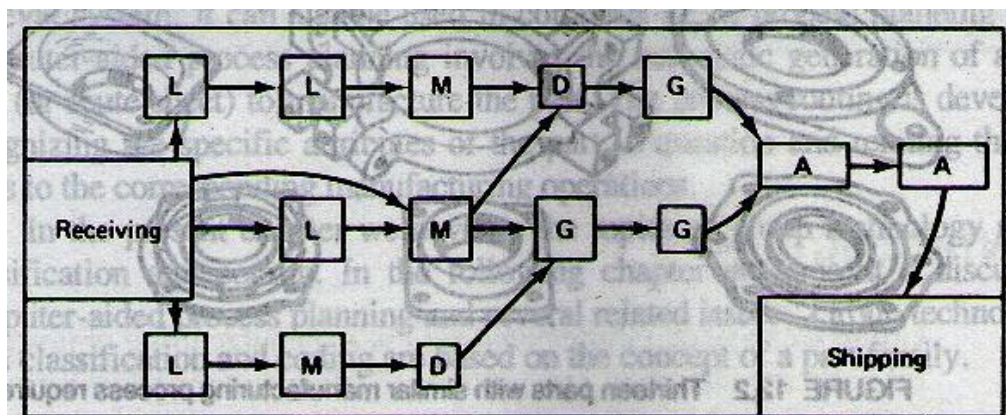
Group technology layout.

There are three general methods for solving this problem. All three methods are time consuming and involve the analysis of much data by properly trained personnel. The three methods are:

1. **Visual inspection** - 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 photographs and arranging them into similar groupings. This method is generally considered to be the least accurate of thethree.

2. **Production flow analysis (PFA)** - PFA is a method of identifying part families and associated machine tool groupings by analyzing the route sheets for parts produced in a given shop. It groups together the parts that have similar operation sequences and machine routings. The disadvantage of PFA is that it accepts the validity of existing route sheets, with no consideration given to whether these process plans are logical orconsistent.

3. **Parts classification and coding system** - It is the most time consuming and complicated of the three methods. However, it is the most frequently applied method and is generally recognized to be the most powerful of thethree.

PARTS CLASSIFICATION AND CODING

This method of grouping parts into families involves an examination of the individual design and/or manufacturing attributes of each part. For example, parts produced in the shop during a certain given time period could be examined to identify part family categories. The trouble with any sampling procedure is the risk that the sample may be unrepresentative of the entire population. However, this risk may be worth taking, when compared to the relatively enormous task of coding all the company's parts.

Design systems versus manufacturing systems

Parts classification and coding systems divide themselves into one of three general categories:

1. Systems based on part design attributes- This category are useful for design retrieval and to promote designstandardization.

2. Systems based on part manufacturing attributes –This category are used for computer-aided process planning, tool design, and other production-relatedfunctions.

3. Systems based on both design and manufacturing attributes – This category represents an attempt to combine the functions and advantages of the other two systems into a single classificationscheme.

Coding system structure|

A parts coding scheme consists of a sequence of symbols that identify the part's design and/or manufacturing attributes. The symbols in the code can be all numeric, all alphabetic, or a combination of both types. However, most of the common classification and coding systems use number digits only. There are three basic code structure used in group technology applications:

1. **Hierarchical structure** - The interpretation of each succeeding symbol depends on the value of the preceding symbols. Other names commonly used for this structure are monocodeand iree structure. The hierarchical code provides a relatively compact structure which conveys much information about the part in a limited number ofdigits.

2. **Chain-type structure** - In the chain-type structure, the interpretation of each symbol in the sequence is fixed and does not depend on the value of preceding digits. Another name commonly given to this structure is polycode. The problem associated with polycodes is that they tend to be relativelylong.

3. **Hybrid structure**, a combination of hierarchical and chain-type structures - The hybrid structure is an attempt to achieve the best features of monocodes and polycodes. Hybrid codes are typically constructed as a series of short polycodes. Within each of these shorter chains, the digits are independent, but one or more symbols in the complete code number are used to classify the part population into groups, as in the hierarchical structure. This hybrid coding seems to best serve the needs of both design andproduction.

To illustrate the difference between the hierarchical structure and the chain- type structure, consider a two-digit code, such as 15 or 25. Suppose that the first digit stands for the general part shape. The symbol 1 means round workpart and 2 means flat rectangular geometry. In a hierarchical code structure, the interpretation of the second digit would depend on the value of the first digit. If preceded by 1, the 5 might indicate some length/diameter ratio, and if preceded by 2.the 5 might be interpreted to specify some overall length. In the chain-type code structure, the symbol 5 would be interpreted the same way regardless of the value of the first digit. For example, it might indicate overall part length, or whether the part is rotational or rectangular.

THREE PARTS CLASSIFICATION AND CODING SYSTEMS

Inyong Ham [8] recommends that the following factors be considered in selecting a parts coding and classification system:

Objective.

The prospective user should first define the objective for the system.

Will it be used for design retrieval or part-family manufacturing orboth?

Scope and application.

What departments in the company will use the system? What specific requirements do these departments have?

What kinds of information must be coded? How wide a range of products must be coded?

How complex are the parts, shapes, processes, tooling, and so forth?

Costs and time.

The company must consider the costs of installation, training, and maintenance for their parts classification and coding system. Will there be consulting fees, and how much?

How much time will be required to install the system and train the staff to operate and maintain it?

How long will it be before the benefits of the system are realized?

Adapability to other systems.

Can the classification and coding system be readily adapted to the existing company computer systems and databases?

Can it be readily integrated with other existing company procedures, such as process planning, NC programming, and productionscheduling?

Management problems.

It is important that all involved management personnel be informed and supportive of the system. Also, will there be any problems with the union?

Will cooperation and support for the system be obtained from the various departments involved?

➢ Three parts classification and coding systems which are widely recognized among people familiar withGT:

1. **Opitz system** - This parts classification and coding system was developed by H. Opitz of the University of Aachen in West Germany. The Opitz coding system uses the following digit sequence:

<p style="text-align:center">12345 6789 ABCD</p>

The basic code consists of nine digits, which can be extended by adding four more digits. The first nine digits are intended to convey both design and manufacturing data. The general interpretation of the nine digits is indicated. The first five digits, 12345, are called the "form code'" and describe the primary design attributes of the part. The next four digits.6789, constitute the supple mentary code." It indicates some of the attributes that would be ot use to manuiacturing (dimensions, work material, starting raw workpiece shape and accuracy). The extra four digits, ABCD, are referred to as the "secondary code" and are intended to identify the production operation type and sequence. The secondary code can be designed by the firm to serve its own particularneeds.

Basic structure of the Opitz system.
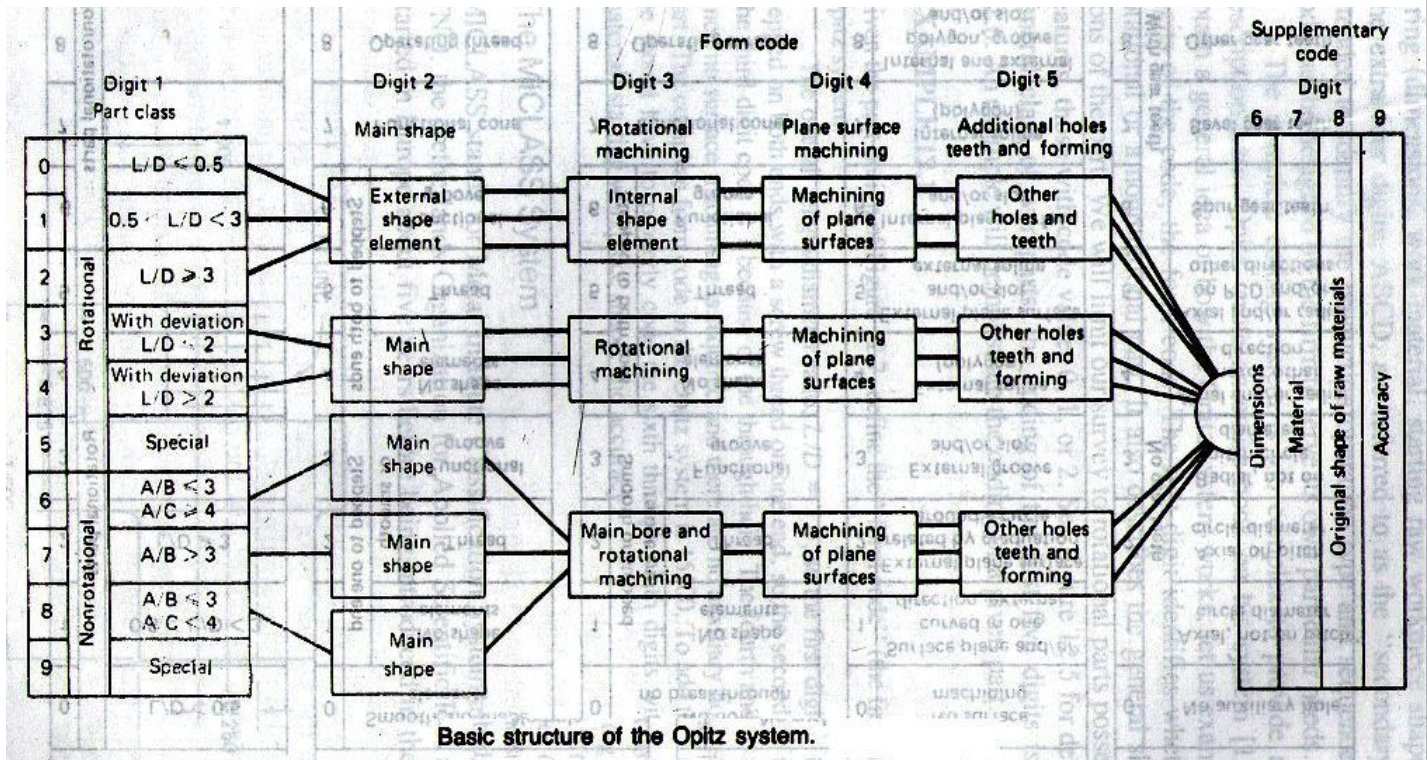
2. **The MICLASS system** - MICLASS stands for Metal Institute Classification System was developed by TNO, the Netherlands Organization for Applied ScientificResearch.
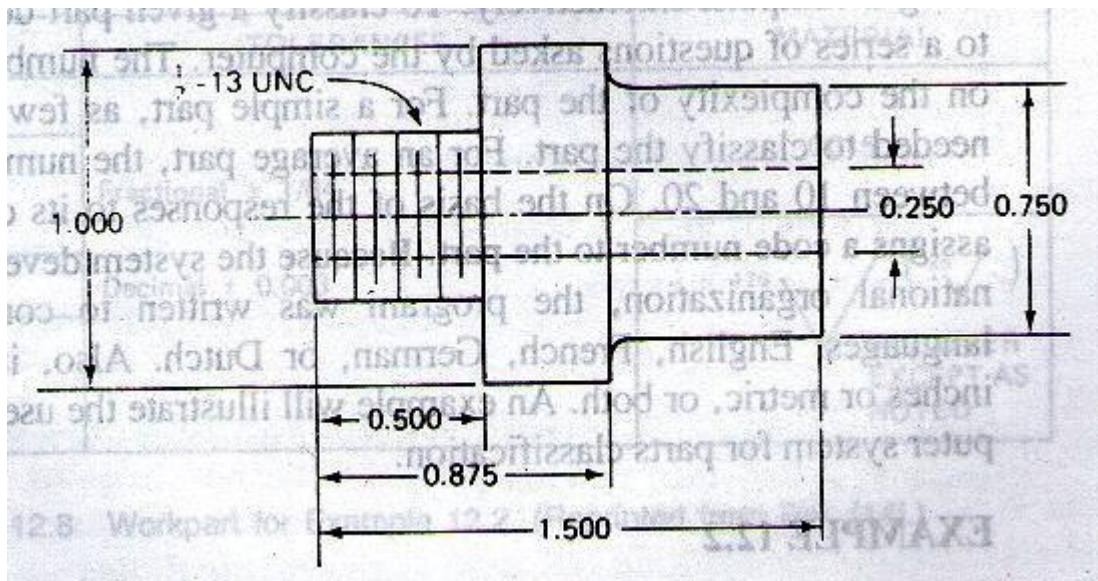
The MICLASS system was developed to help automate and standardize a number of design, production, and management functions. These include:

- Standardization of engineeringdrawings
- Retrieval of drawings according to classificationnumber
- Standardization of processrouting
- Automated processplanning
- Selection of parts for processing on particular groups of machinetools

- Machine tool investmentanalysis

The MICLASS classification number can range from 12 to 30 digits. The first 12 digits are a universal code that can be applied to any part. Up to 18 additional digits can be used to code data that are specific to the particular company or industry. For example, lot size, piece time, cost data, and operation sequence might be included in the 18 supplementary digits.

The workpart attributes coded in the first 12 digits of the MICLASS number are as follows:

1stdigit	Mainshape
2nd and3rd digits	Shape elements
4thdigit	Position of shapeelements
5th and6thdigits	Maindimensions
7thdigit	Dimension ratio
8thdigit	Auxiliarydimension
9th and10thdigits	Tolerance codes
11th and12thdigits	Materialcodes

One of the unique features of the MICLASS system is that parts can be coded using a computer interactively. To classify a given part design, the user responds to a series of questions asked by the computer. The number of questions depends on the complexity of the part. For a simple part, as few as seven questions are needed to classify the part. For an average part, the number of questions ranges between 10 and 20. On the basis of the responses to its questions, the computer assigns a code number to the part

3. **CODE system** - The CODE system is a parts classification and coding system developed and marketed by Manufacturing Data Systems, Inc. (MDSI), of Ann Arbor, Michigan. Its most universal application is in design engineering for retrieval of part design data, but it also has applications in manufacturing process planning, purchasing, tool design, and inventory control.

The CODE number has eight digits. For each digit there are 16 possible values (zero through 9 and A through F) which are used to describe the part's design and manufacturing characteristics. The initial digit position indicates the basic geometry of the part and is called the Major Division of the CODE system. This digit would be used to specify whether the shape was a cylinder, flat piece, block, or other. The interpretation of the remaining seven digits depends on the value of the first digit, but these remaining digits form a chain-typestructure.

The second and third digits provide additional information concerning the basic geometry and

principal manufacturing process for the part. Digits 4, 5, and 6 specify secondary manufacturing processes such as threads, grooves, slots, and so forth. Digits 7 and 8 are used to indicate the overall size of the part (e.g., diameter and length for a turned part) by classifying it into one of 16 size ranges for each of two dimensions.

PRODUCTION FLOW ANALYSIS (PFA)

It is another methodology in GT. In this analysis, grouping of parts is done in terms of the manufacturing sequence. For this, the route sheets of components are examined and the grouping is made on the basis of the facilities used and not on the sequence of operations. The defects of this analysis are that it is based on thee exist in method of manufacture which may change after sometime, secondly it assumes that the route sheets have been correctly prepared which is often questionable; and lastly, since this analysis is based on the existing practice within a company, it cannot be universallyapplied.

PFA is carried out in three stages, namely, Factory Flow Analysis, Group Analysis and Line Analysis. These analyses help in arranging facilities and groups of components so as to minimize movement and improve the utilization of facilities. For example, group analysis is carried out as follows:

1. Examine the route sheet of all the components to be manufactured in theshop.
2. Prepare a matrix showing the operation numbers and the components number and fill it to show which component requires whichoperations.
3. While grouping parts, any particular part should be included only in one group. For facility grouping, one machine type should be only in one group. Such operations as are incompatible should be in different groups. For example, if a machined part needs heat treatment or painting, then while grouping parts, for machining, painting or heat-treatment facilities should be considered as separategroups.
4. If an operation is required by only one or very few components, or if some operation is required by all (or nearly all) the components, then these operations should not be taken note of while deciding the groups, e.g. operations 2,8 and9.

Operation	Components							
	1	2	3	4	5	6	7	8
1	X	X		X	X		X	
2	X	X	X	X	X	X	X	X
3			X	X	X		X	
.								
8			X					
9	X	X	X	X	X	X	X	X

Fig a - Matrix : operations - components

This matrix is rearranged (Fig b) by excluding operation numbers 2,8 and 9; and putting together components which need the same operations.

Components 1,2,4 and 5 are formed into a single group by excluding operation 1 on component 8.

Components 8,3,6 and 7 are formed into another group. Thus, the final grouping would be (Fig c):

Operation	Components							
	1	2	4	5	8	3	6	7
1	X	X	X	X	(X)			
3			X	X		X		X
4					X	X	X	X
5	X		X	X				
6					X		X	X
7						X	X	

Fig b – Rearranged Matrix

Operation	Components							
	1	2	4	5	8	3	6	7
1	X	X	X	X				
2	X	X	X	X				
5	X		X					
	X9							

3						X		X
4					X	X	X	X
6					X		X	X
7						X	X	

Fig c – Grouping based on production flow analysis

BENEFITS OF GROUP TECHNOLOGY

Although group technology is expected to be an important principle in future production plants, it has not yet achieved the widespread application which might be expected. There are several reasons for this.

- There is the problem of rearranging the machines in the plant into GT cells. Many companies have been inhibited from adopting group technology because of the expense and disruption associated with this transition to GT machinecells.

- There is the problem of identifying part families among the many components produced in the plant. Usually associated with this problem is the expense of parts classification and coding. Not only is this procedure expensive, but it also requires a considerable investment in time and personnel resources. Managers often feel that these limited resources can better be allocated to other projects than group technology with its uncertain futurebenefits.

- It is common for companies to encounter a general resistance among its operating personnel when changeover to a new system iscontemplated.

When these problems are solved and group technology is applied, the company will typically realize benefits in the following areas:

1. **Product design benefits** - In the area of product design, improvements and benefits are derived from the use of a parts classification and coding system, together with a computerized design retrieval system. When a new part design is required, the engineer or draftsman can devote a few minutes to figure the code of the required part. Then the existing part designs that match the code can be retrieved to see if one of them will serve the function desired. The few minutes spent searching the design file with the aid of the coding system may save several hours of the designer's time. If the exact part design cannot be found, perhaps a small alteration of the existing design will satisfy the function. Use of the automated design-retrieval system helps to eliminate design duplication and proliferation of new partdesigns.

   Other benefits of GT in design are that it improves cost estimating procedures and helps to promote design standardization. Design features such as inside corner radii, chamfers, and tolerances are more likely to become standardized with group technology.

2. **Tooling and setups -** In tooling, an effort is made to design group jigs and fixtures that will accommodate every member of a parts family. Workholding devices are designed to use special adapters which convert the general fixture into one that can accept each part family member. The machine tools in a GT cell do not require drastic changeovers in setup because of the similarity in the workparts processed on them. Hence, setup time issaved.

3. **Materials handling -** Another advantage in manufacturing is a reduction in the workpart move and waiting time. The group technology machine layouts lend themselves to efficient flow of materials through the shop. The contrast is sharpest when the flow line cell design is compared to the conventional process-typelayout

4. **Production and inventory control -** Production scheduling is simplified with group technology. In effect, grouping of machines into cells reduces the number of production centers that must be scheduled. Grouping of part's into families reduces the complexity and size of the parts scheduling problem. And for those workparts that cannot be processed through any of the machine cells, more attention can be devoted to the control of these parts. Because of the reduced setups and more efficient materials handling with machine cells, production lead times, work-in-process, and late deliveries can all be reduced. Estimates on what can be expected are provided by DeVries et al.:

   - 70% reduction in productiontimes
   - 62% reduction in work-in-processinventories
   - 82% reduction in overdueorders

5. **Employee satisfaction** - The machine cell often allows parts to be processed from raw material to finished state by a small group of workers. The workers are able to visualize their contributions to the firm more clearly. This tends to cultivate an improved worker attitude and a higher level of job satisfaction. Another employee-related benefit of GT is that more attention tends to be given to product quality. Workpart quality is more easily traced to a particular machine cell in group technology. Consequently, workers are more responsible for the quality of work they accomplish. Traceability of part defects is sometimes very difficult in a conventional process-type layout, and quality control suffers as aresult.

6. **Process planning Procedures** - The time and cost of the process planning function can be reduced through standardization associated with group technology. A new part design is identified by its code number as belonging to a certain parts family, for which the general process routing is known. The logic of this procedure can be written into computer software to form a computer-automated process planningsystem.

COMPUTER AIDED PROCESS PLANNING

INTRODUCTION

Before the role of computer aided process planning (CAPP) is discussed, it is worthwhile understanding the role of process planning in the product cycle. Once the design of the product has been evolved from customers' views, its manufacture necessitates careful planning and scheduling of the various processes of manufacture so that the product is made to right specifications and delivered at the right time at a minimal cost. This cycle (Fig. A) from concept to design, planning, production, quality control and feedback to design goes on in which one can easily understand the crucial role of planning. In job/ batch manufacture, as an enormous amount of data is needed for planning as well as other activities, data bases are required and the flow of information should be fast for a high performance of the total manufacturing system.

CAPP System
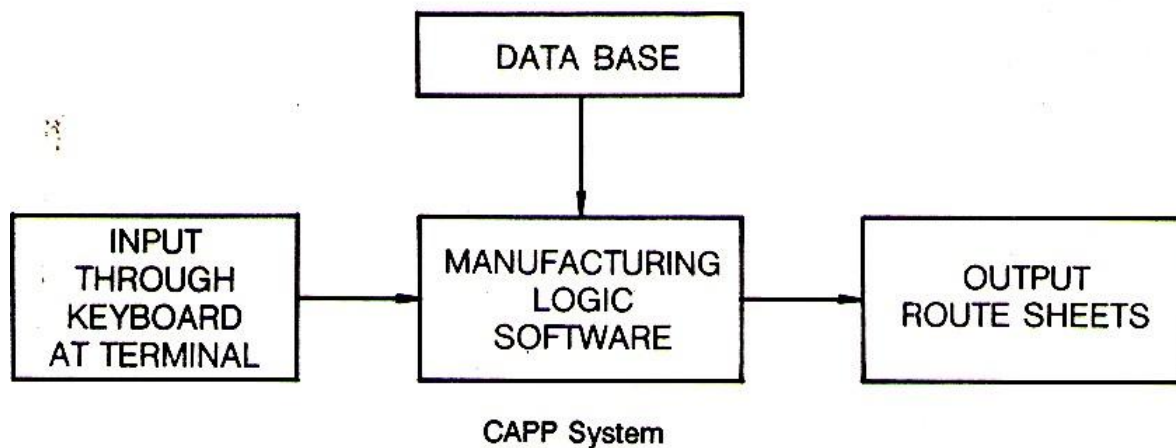
WHAT IS PROCESS PLANNING

This activity deals with determining the machine tools and thesequenceof manufacturing operations involved in the manufacture of the components/products. Route sheets are used for documentation of such activity. A process planner is expected to plan the process, determine the machining conditions and set the time standards for the component in question. He is to be familiar with the shop practice and equipmentcapabilities.

Every process planner would try to follow the best procedure based on his experience. Thus, it is possible that the routings would not be the same if different engineers are involved and it would also not be surprising if the same engineer may put up different routings for the same component if done at different occasions over a period of time. Such situations generally happen in large variety manufacture when documentation is difficult to retrieve. These problems occur because no process standardization exists. This proves that conventional process planning can never be optimal.

For process planning to be done in a rational and consistent manner leading to optimal routing, the

manual routine work needs to be eliminated. Instead, use should be made of modern computer software facilities, which on inputing specifications of the component will not only output the routings fast and correctly but be amenable to efficient storage and communication. This is Computer Aided Process Planning.

COMPUTER AIDED PROCESS PLANNING

Process planning can be considered under the two broad classes, retrieval and generative.

- Retrieval, or variant, process planning is based on Group Technology approach. Standard process plans for part families are made and stored using the code system. When a process plan of a component is required, it can be speedily retrieved and edited, if necessary. In this system, a proper file organization is to be maintained and the coding used enables efficient retrieval.

- The other type is the generative, in which individual process plans are made for each component. In this, retrieval is not involved. As the component features are input in the required way, the system itself prepares the process plan. The logic used enables rationality and consistency in the process plansobtained.

It is difficult to name all the packages available so far for process planning. A

few have been listed alone with their sources.

- o CAP (Lockheed
- o ACUDATA/UNIVATION (Allis Chalmers),
- o AUTAP (Aachen University,Berlin),
- o AUTOPLAN(Metcut),
- o APPAS (PurdueUniversity),
- o CAPP(CAM-I),
- o CIMS/PRO(Japan),
- o COBAPP(Philips),
- o COMCAPPV(MDSI),
- o DCLASS (University ofUtah),
- o GETRUN(GE),
- o GENPLAN(Lockheed),
- o MIPLAN (MetalInst.),
- o XPS-1(CAM-I),
- o CAPSY(Univ.ofBerlin),
- o LOCAM (LoganAssociates)

Retrieval Type CAPP System

In this system, separate files for part family, machine routing and operation sequence are created and stored. Algorithm is available which enables the user to identify the family to which the component belongs whenhe/she enters the part code number. On completion of the search, standard routing is retrieved from the machine routing file and then the standard operation sheet is retrieved from the operation reference file. These are edited to take care of any variation which a particular component may have from the art family. Other application software are also used to finally obtain the process plan in proper format with all the required details

Retrieval type CAPP System
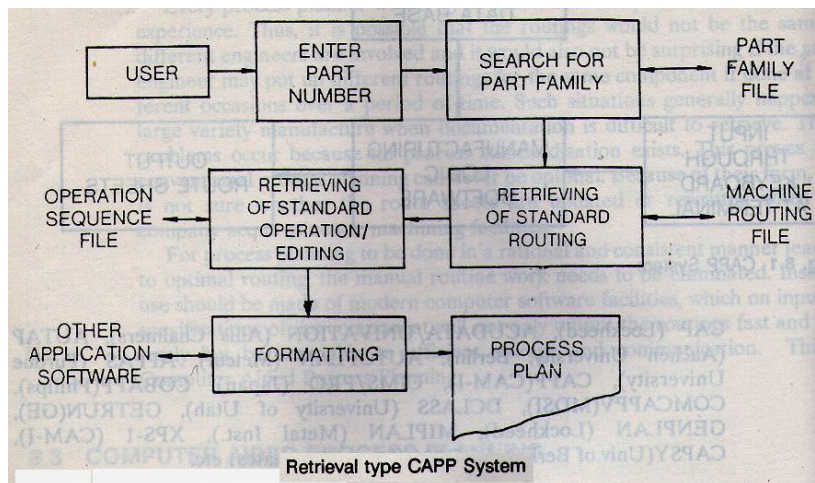
Generative CAPP System

As mentioned earlier, this differs from the variant type in that in this case the process plan is made from scratch. No standard plans exist and as such no retrieval is involved in this case. The software in the system is capable of taking technical and logical decisions (based on stored information pertaining to capabilities of machine tool available) when the user inputs description of the part in proper coded form and thus outputs the process plan. It builds up optimal processed sequence based on part description provided on the machinecapabilities.

Generative Process Planning System
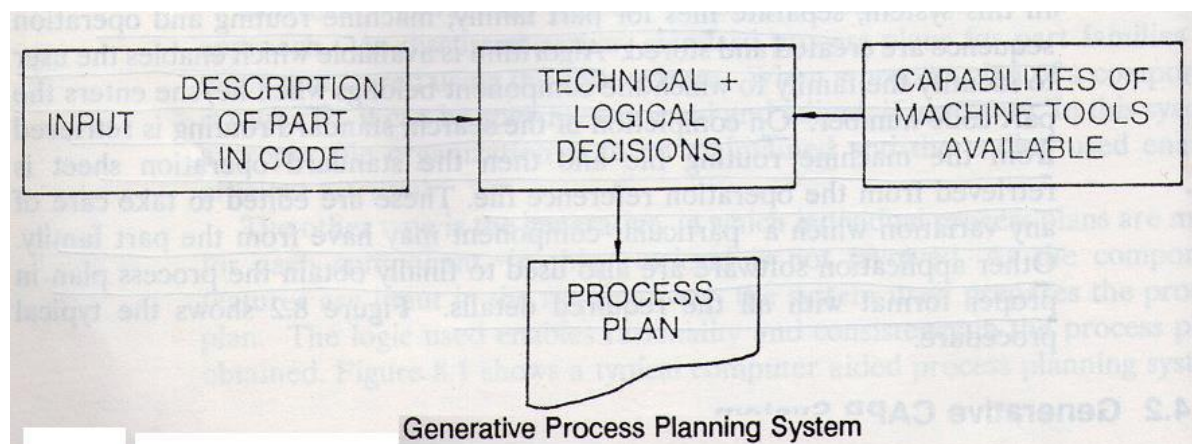
UNIT – V

COMPUTER INTEGRATED MANUFACTURING SYSTEMS

INTRODUCTION

The quality control (QC) function has traditionally been performed using manual inspection methods and statistical sampling procedures.

- **Manual inspection** is generally a time-consuming procedure which involves precise, yet monotonous work. If often requires that parts be removed from the vicinity of the production machines to a separate inspection area. This causes delays and often constitutes a bottleneck in the manufacturingschedule.

- Inherent in the use of **statistical sampling** procedures is acknowledgment of the risk that some defective parts will slip through. Indeed, statistical quality control attempts to guarantee that a certain expected or average fraction defect rate will be generated during the production/inspection process. The nature of traditional statistical QC procedures is that something less than 100% good quality must betolerated.

- There is another aspect of the traditional QC inspection process which detracts from its usefulness. It is often performed after the fact. The measurements are taken and the quality is determined after the parts are already made. If the parts are defective, they must be scrapped or reworked at a cost which is often greater than their original cost tomanufacture.

All of these various factors are driving the quality control function toward what we are calling computer-aided quality control (CAQC). Other terms that have been applied to describe this movement are "computer-aided inspection" (CAI) and "computer-aided testing" (CAT).

The objectives of computer-aided quality control are ambitious, yet straight forward. They are:

1. To improve productquality
2. To increase productivity in the inspectionprocess
3. To increase productivity and reduce lead times inmanufacturing

The strategy for achieving these objectives is basically to automate the inspection process through the application of computers combined with advanced sensor technology. Wherever technically possible and economically feasible, inspection will be done on a 100% basis rather thansampling.
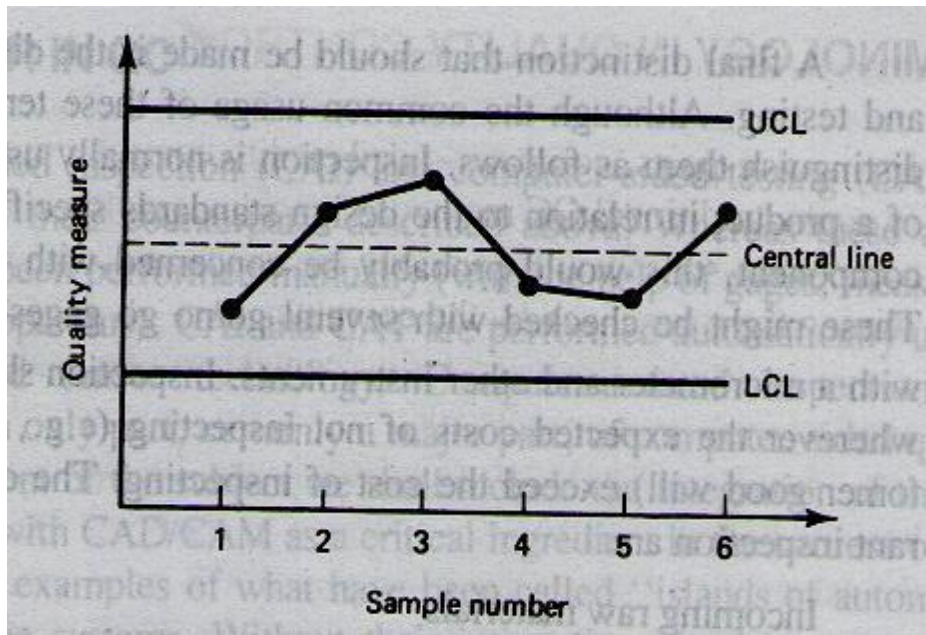
TERMINOLOGY IN QUALITY CONTROL

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

Quality assurance (QA) is concerned with those activities which will maximize the probability that the product and its components will be manufactured within the design specifications. These activities should start in the product design area, where the designer can make decisions among alternatives that might have quality consequences. QA activities continue in manufacturing planning, where decisions relative to production equipment, tooling, methods, and motivation of employees will all have an influence onquality.

Quality control is concerned with those activities related to inspection of product and component quality, detection of poor quality, and corrective action necessary to eliminate poor quality. These activities also involve the planning of inspection procedures and the specification of the gages and measuring instruments needed to perform theinspections.

StatisticalQCisgenerallydividedintotwocategories:**acceptancesampling**and **control charts**.

- Acceptance sampling is a procedure in which a sample is drawn from a batch of parts in order to assess the quality level of the batch and to determine whether the batch should be accepted or rejected. Acceptance sampling is based on the statistical notion that the quality of a random sample drawn from a larger population will be representative of the quality of thatpopulation.

- Control charts are used to keep a record over time of certain measured data collected from a process. A company would use control charts to monitor its own production processes. The central line indicates the expected quality level of the process. The upper and lower control limits (UCL and LCL) are statistical measures of the variation in the process which would be tolerated without concluding that the process has erred. when these limits are exceeded, it usually means that something has changed the process, and an investigation should be initiated to determine thecause

- ✓ Both acceptance sampling and control charts can be applied to two situations in quality control: fraction defects and measuredvariables.

    - In the **fraction-defect** case, the objective is to determine what proportion of the sample (and the population from which it came) are defective. This is often accomplished by a go/no go gage, which can quickly determine whether a part is within specification ornot.

    - In the **measured-variable** case, the object is to determine the value of the quality characteristic of interest (e.g., dimension, resistance, hardness, etc.). This requires the use of a measuring instrument of some kind (e.g., micrometer, ohmeter, hardness tester, etc.) and is normally a more time-consuming manual process than the go/no gocase.

- ✓ **Inspection** is normally used to examine a component of a product in relation to the design standards specified for it. For a mechanical component, this would probably be concerned with the dimensions of the part. These might be checked with several go/no go gages or they might be measured with a micro meter and other instruments. The situations that warrant inspectionare:

    - Incoming rawmaterials
    - At various stages during manufacturing (e.g., when the parts are moved from one production department toanother)
    - At the completion of processing on theparts
    - Before shipping the final assembled product to thecustomer

Testing, on the other hand, is normally associated with the functional aspects of the item, and it is often directed at the final product rather than its components. In this usage, testing consists of the observation of the final product during operation under actual or simulated conditions. If the product passes the test, it is deemed suitable for sale. Several categories of tests used for final productevaluation:

- Simple functional tests under normal or simulated normal operatingconditions
- Functional tests in which the product is tested under extreme (usually adverse conditions)
- Fatigue or wear tests to determine how long the product will function until Failure.
- Overload tests to determine the level of safety factor built into theproduct
- Environmental testing to determine how well the product will perform under different environments (e.g., humidity,temperature)

THE COMPUTER IN QC

CAI and CAT are performed automatically using the latest computer and sensor technology. Computer-assisted inspection and testing methods form only part, certainly a major part, of computer-aided quality control. In our treatment of the subject we shall include the integration of the quality control function with CAD/CAM as a critical ingredient in the success ofCAQC.

The implications of the use of computer-aided quality control are important. The automated methods of CAQC will result in significant changes from the traditional concepts and methods. The following list will summarize the important effects likely to result from CAQC.

1. With CAI and CAT, inspection and testing will typically be accomplished on a 100% basis rather than by the sampling procedures normally used in traditional QC.

2. Inspection during production will be integrated into the manufacturing process rather than requiring that the parts be taken to some inspection area. This will help to reduce the elapsed time to complete the parts. On line will have to be accomplished in much less time than with current manualtechniques.

3. The use of noncontact sensors will become much more widely used with computer-aided inspection. With contact inspection devices, the part must usually be stopped and often repositioned to allow the inspection device to be applied properly. With noncontact sensor devices, the part can often be inspected "on the fly." Thesedevices,

driven by the high-speed data processing capability of the computer, can complete the inspection in a small fraction of a second.

4. The on-line noncontact sensors will be utilized as the measurement component of computerized feedback control systems. These systems will be capable of making adjustments to the process variables based on analysis of the data collected by the sensors. Data would be plotted. This would not only allow out of tolerance conditions to be identified, but gradual shifts in the process could also be uncovered and corrective action taken. By regulating the process in this manner, parts will be made much closer to the desired nominal dimension rather than merely within tolerance. Quality feedback control systems will help to reduce scrap losses and improve productquality.

5. With computer-aided inspection technology, it may no longer be necessary to settle for less thanperfection.

6. Robots will be used increasingly in future inspectionapplications

7. There will also be applications for the computer in quality assurance as well as QC. The CAD/CAM data base will be used to derive these various qualityapplications,

8. There will be CAI and CAT take its place, manual inspection activity will be reduced. Quality control personnel will have to become more computer-wise and technologically sophisticated to operate the more complex inspection and testing equipment and to manage the information that will result from these more automated methods.

CONTACT INSPECTION METHODS

The contact methods usually involve the use of coordinate measuring machines (CMM). Most of these machines today are either controlled by NC or computers. The coordinate measuring machine (CMM) is the most prominent example of the equipment used for contact inspection of workparts. It consists of a table which holds the part in a fixed, registered position and a movable head which holds a sensing probe. The probe can be moved in three directions, corresponding to the x, y, and z coordinates. During operation, the probe is brought into contact with the part surface to be measured and the three coordinate positions are indicated to a high level ofaccuracy.

Today's coordinate measuring machines are computer controlled. The operation of the machine is similar to an NC machine tool in which the movement of the measuring probe is either tape controlled or computer controlled. Programs and coordinate data can be

downloaded from a central computer, much in the manner of direct numerical control. Also similar to DNC is the capability to transmit data from the CMM back up to the host computer.
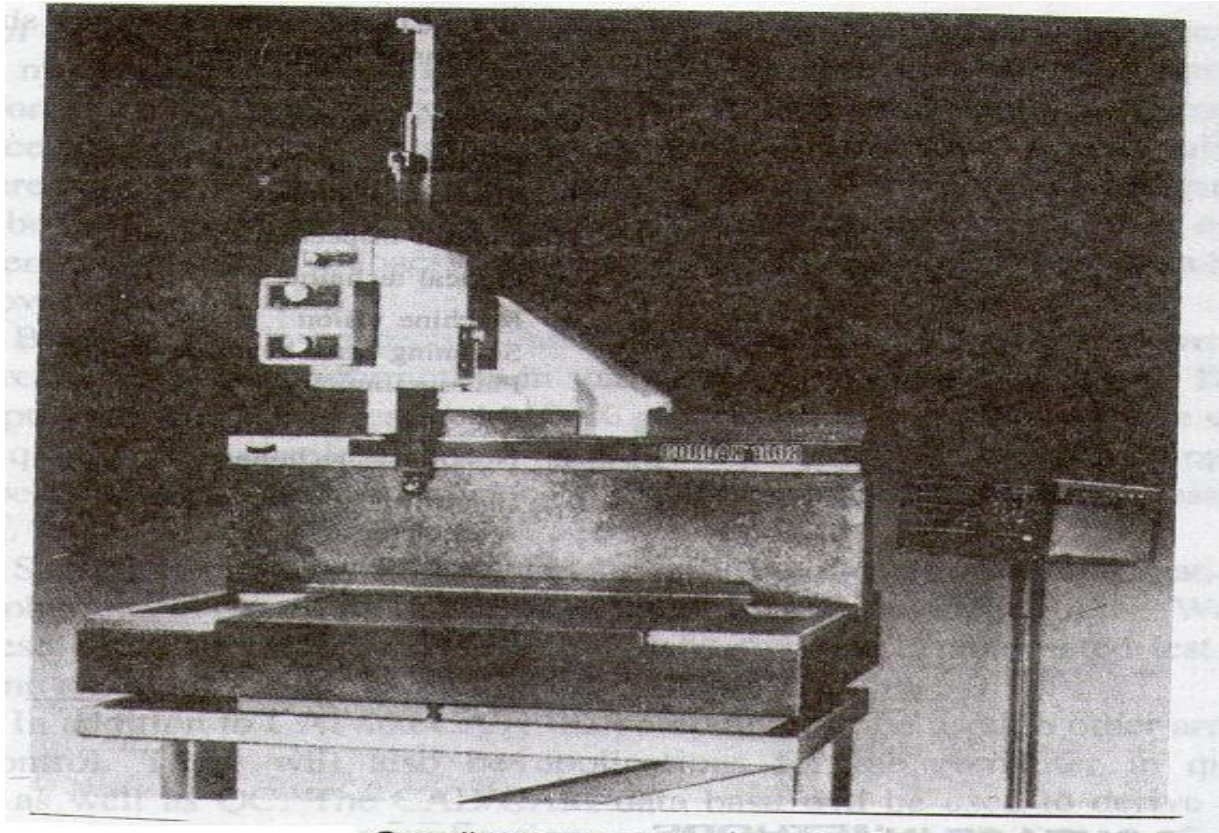
Coordinate measuring machine.

Savings in inspection time by using coordinate measuring machines are significant. Typically, between 5 and 10% of the time is required on a CMM compared to traditional manual inspection methods. Other advantages include consistency in the inspection process from one part to the next which cannot be matched by manual inspection, and reductions in production delays to get approval of the first workpiece in abatch.

The coordinate measuring machine is physically located away from the production machine, usually in a separate area of the shop. Accordingly, the parts must be transported from the production area to the CMM. In fact, if inspection is required at several different stages of production, several moves will be involved. One possible approach to overcome this problem is to use inspection probes mounted in the spindle of the machine tool. These inspection probes are contact sensing devices that operate with the machine tool much like the coordinate measuringmachine.

NONCONTACT INSPECTION METHODS

The noncontact methods are divided into two categories for our purposes:

1. Optical
    a. Machinevision
    b. Scanning laser beamdevices
    c. Photogrammetry

2. NonOptical
    a. Electric Field techniques
    b. Radiation techniques
    c. Ultrasonic

NONCONTACT INSPECTION METHODS- OPTICAL

The advantages of noncontact inspection are:

1. It usually eliminates the need to reposition the workpart.
2. Noncontact inspection is usually much faster than contactinspection.
3. It eliminates mechanical wear encountered with the contacting inspection probe because it eliminates the probe.
4. It reduces potential danger to people, who must touch a hazardous material if contact inspection isused.
5. It removes the possibility of damage to the surface of a part which migh result during contactinspection.

<u>Machine vision</u>

Other names given to these systems include microprocessor-based television and computer vision. The typical machine vision system consists of a TV camera, a digital computer, and an interface between them that functions as a preprocessor. The combination of system hardware and software digitizes the picture and analyzes the image by comparing it with data stored in memory. The data are often in the form of a limited number of models of the objects which are to be inspected. There are several limitations of machinevision;

- The first limitation is concerned with the problem of dividing the picture into picture elements. This is very similar to the problem encountered in the development of graphics terminals for computer-aideddesign.

- A second limitation is that the object in front of the camera must be capable of being divided into areas of contrasting lightness anddarkness.
- Third limitations is on the capability of machine vision systems recognize the object in the viewingarea.

Machine vision inspection problems can be divided into two categories:

1. <u>Noncontact gaging of dimensions</u> - Noncontact gaging in machine vision involves the inspection of part size and other features where it is not necessary to process the image of the entire part out line, only those portions that must be examined for dimensional accuracy. During setup for an inspection, a parts-training program is used to view the workpart of interest on a TV monitor. With the image in fixed position on the screen, the operator manipulates a cursor to define the edges of interest and to apply an appropriate scale factor to establish the correct units ofmeasure.

2. <u>Inspection based on pattern recognition of object features</u> - It is based on pattern recognition techniques. In this category, the attributes of the object to be inspected are typically more subjective and in some respects more complicated than part dimensions. The machine vision pattern recognition process can be conceptualized as involving a comparison of features (for example, area, perimeter, and so on) between the object being inspected and the model of the object stored in computermemory.

<u>Scanning laser beam devices</u>

The scanning laser beam device relies on the measurement of time rather than light, although a light sensor is required in its operation. The schematic diagram of its operation is pictured in Figure. A laser is used to project a continuous thin beam of light. A rotating mirror deflects the beam so that it sweeps across the object to be measured. The light sensor is located at the focal point of the lens system to detect the interruption of the light beam as it is blocked by the object. The time lapse corresponding to the interruption of the light beam is measured to determine the desired dimension of the part. Typically, a microprocessor is programmed to make the conversion of the time lapse into a dimensional value and to perform other functions, such as signaling an automatic parts-rejection mechanism to eject a defective part from theline.
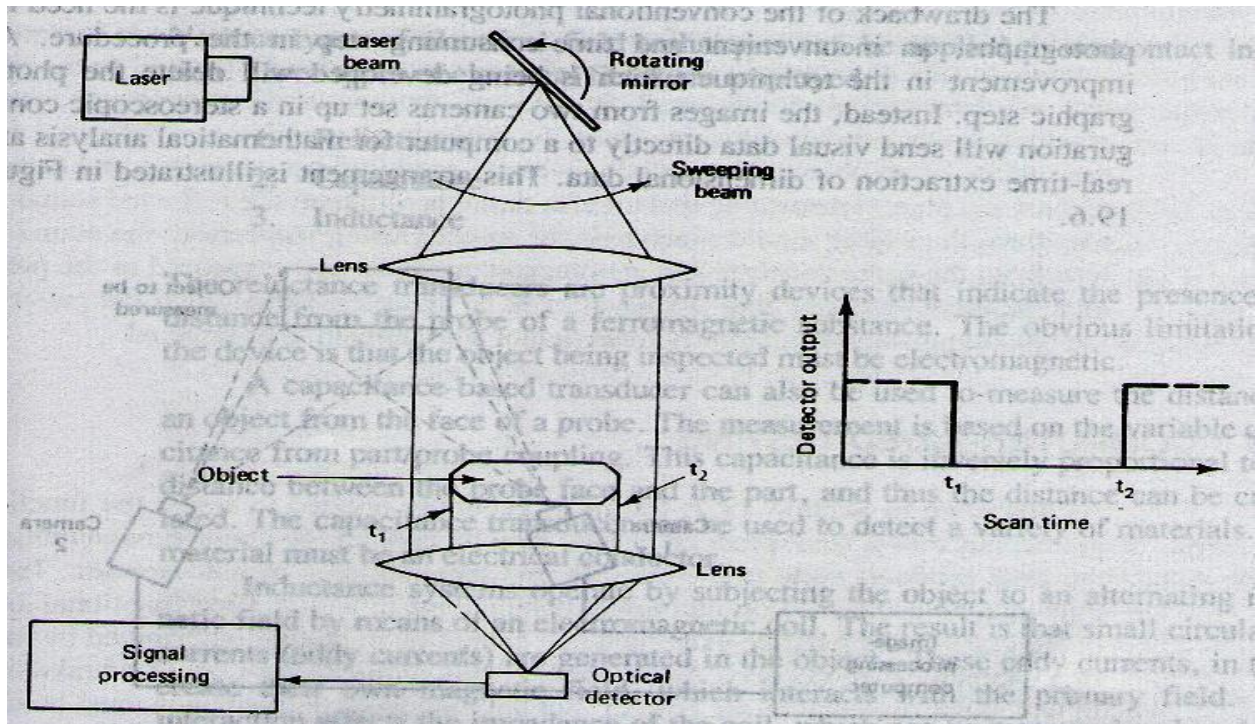
Photogrammetry

Photogrammetry involves the extraction of three-dimensional data from a pair of photographs taken at different angles. The two photographs can be combined much in the way that a stereoscope uses a pair of photographs to form a three-dimensional image for the viewer.

In the measurement process used for inspection, the two photographs are read by a device called a mono comparator to establish coordinates and positions of objects. These data are then computer-analyzed to extricate the desired information.

The drawback of the conventional photogrammetry technique is the need for photographs, an inconvenient and time-consuming step in the procedure. An improvement in the technique which is being developed will delete the photo graphic step. Instead, the images froiri two cameras set up in a stereoscopic configuration will send visual data directly to a computer for mathematical analysis and real-time extraction of dimensional data. This arrangement is illustrated in Figure.

Object to be measured

Camera 1

Camera 2

Image-processing computer
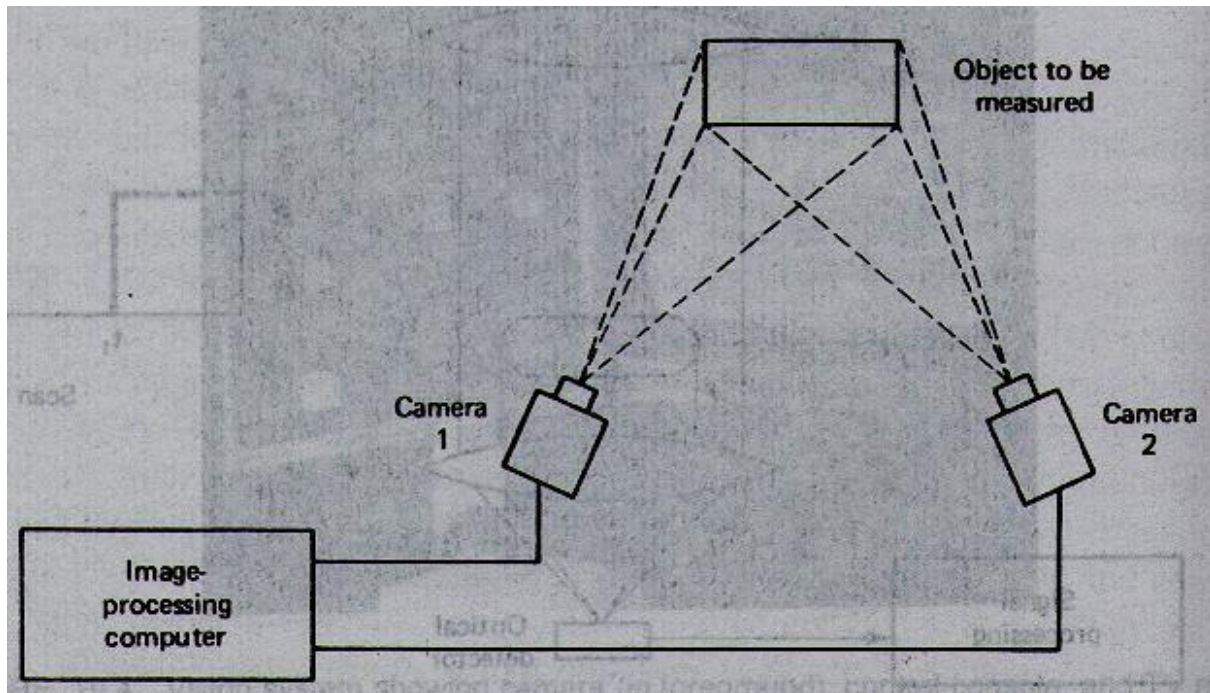
NONCONTACT INSPECTION METHODS

NONOPTICAL

In addition to noncontact inspection methods based on optical systems, non-optical approaches can also be used. We will describe three general types which are quite representative of the current technology in this area. The three general types are:

1. Electrical fieldtechniques
2. Radiationtechniques
3. Ultrasonic

Electrical field techniques

Various types of electrical field techniques can be applied to noncontact inspection. Three types of electrical fields are employed:

1. <u>Reluctance</u> - The reluctance transducers are proximity devices that indicate the presence and distance from the probe of a ferromagnetic substance. The obvious limitation of the device is that the object being inspected must beelectromagnetic.

2. <u>Capacitance</u> - A capacitance-based transducer can also be used to measure the distance of an object from the face of a probe. The measurement is based on the variable capacitance from part/probe coupling. This capacitance is inversely proportionaltothedistancebetweentheprobefaceandthepart,andthusthe

distance can be calculated. The capacitance transducer can be used to detect a variety of materials. The material must be an electrical conductor

3. <u>Inductance</u> - Inductance systems operate by subjecting the object to an alternating magnetic field by means of an electromagnetic coil. The result is that small circulating currents (eddy currents) are generated in the object. These eddy currents, in turn, create their own magnetic field, which interacts with the primary field. This interaction affects the impedance of the coil, which an be measured and analyzed to determine certain characteristics about theobject

Radiation Techniques

X-ray radiation techniques are employed for purposes of noncontact inspection in the metals and metalworking industry. The amount of radiation absorbed by a material can be used to measure its thickness and other quality characteristics. In a typical application in a rolling mill, an X-ray scanning unit measure the thickness of the plates or strips going through the rolls so that the proper adjustments can be made in the rollers. X-ray techniques are also used to inspect weld quality in fabricated steel and aluminum pressure vessels and pipes. In this case the radiation can be used to detect flaws and voids in the weld.

Ultrasonics

Ultrasonic in inspection work involves the use of very high frequency (above 20,000 Hz) sound waves to indicate quality. A principal application is in nondestructive testing of materials. Ultrasonic techniques can also be applied to the problem of determining dimensional features of workparts. One approach, called acoustical phase monitoring, involves the analysis of sound waves reflected from the surface of an object. The sound waves are produced by an emitter and directed against the object. Assuming that all else remains constant, the reflected sound pattern from the object should always be the same. During inspection, the sound pattern from the part is analyzed by a computer program and compared to the pattern of a standard part, one that is known to be of acceptable quality. If the pattern of the test part differs significantly from that of the standard, it isrejected.
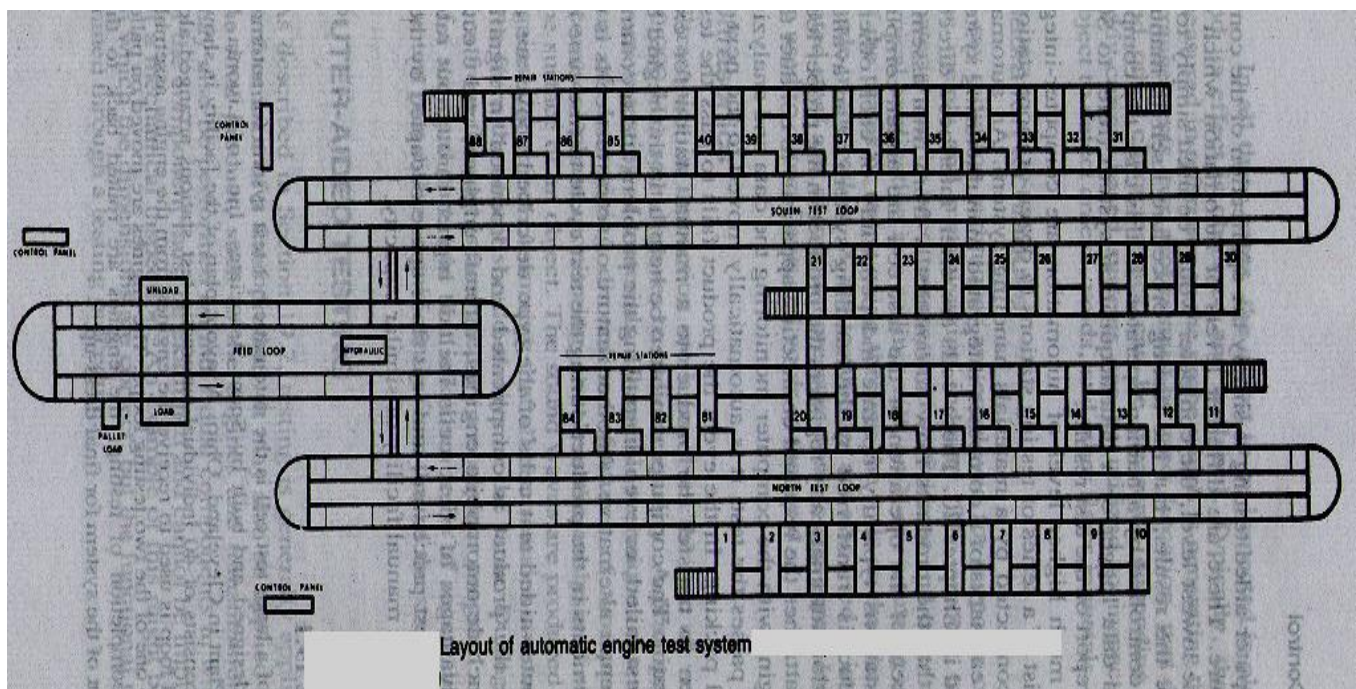
COMPUTER-AIDED TESTING

Testing is generally applied to assess the functional performance of a final product. It may also be applied for major subassemblies of the final product, such as the engines and transmissions of automobiles. Testing may also be performed on individual components in

which some functional aspect of the component must be examined and cannot be implicitly determined by means of a mechanical inspection. An example of this might be the case of a brake lining in which the dimensions are correct, but the functional performance must be determined through a testing procedure.

Computer-aided testing is simply the application of the computer in the testing procedure. There are different levels of automation which can be found CAT. At the lowest level, the computer would be used simply to monitor the test and analyze the results, but the testing procedure itself is manually set up, initiated, and controlled by a human operator. In this case the computer receives the data from a data logger or a data acquisition system and prepares a report of the test results

Computer-aided test cells are applied in situations where the product is complicated and produced in significant quantities; Examples include automobile engines, aircraft engines, and electronic integrated circuits. Advantages of these cells include higher throughput rates, greater consistency in the test procedure, and less floor space occupied by the automated cell As compared to a manual facility of similarcapacity.

Layout of automatic engine test system

INTEGRATION OF CAQC WITH CAD/CAM

Although many important benefits result from the use of computer-aided quality control, additional benefits can be obtained by integrating CAQC with CAD/CAM.

- The design department creates the product definition and the manufacturing department makes use of and supplements this definition to develop the

Manufacturing plan. It is important to add the QC connection to the CAD/CAM framework.

- The quality control department must use the same CAD/CAM data base to perform its function. These quality standards are all contained in the CAD/CAM data base, available for QC touse.

- One way in which the data base can be used is to develop the NC programs to operate the tape-controlled or computer-controlled coordinate measuring machines. These programs can be generatedautomatically.

- These programs would then be down loaded to the CMM through a DNC link from the central computer to the controller unit for the CMM. The same sort of downloading process is possible for some of the noncontact inspectionmethods.

- Another way in which a common data base is helpful to QC is when engineering changes are made to the product. It is helpful for any changes to be recorded in a common data file for all departments, including QC, touse.

- Another area where CAD/CAM benefits the QC function is in computer production monitoring. The types of production records that are generated during computer monitoring are sometimes useful to the quality control department in tracing the cause of poor quality in a particular production lot.