2

NC & CNC Machine Tools

Contents

2.1 NC Controls

- Numerical control (NC) is the technique of giving instructions to a machine in the form of a code which consists of numbers, letters of the alphabet, punctuation marks and certain other symbols. Controlling a machine tool by means of a prepared program is known as numerical control.
- NC equipment has been defined by the Electronic Industries Association (EIA) as:
- "A system in which actions are controlled by the direct insertion of numerical data at some point. The system must automatically interpret at least some portion of this data".
- Instructions are supplied to the machine as blocks of information. A block of information commands sufficient to enable the machine to carry out one individual machining operation. Each block is given a sequence number for identification.
- A set of instructions forms an NC program. When the instructions are organized in a logical manner they direct the machine tool to carry out a specific task. It is thus termed as part program.
- In a typical NC system, the numerical data which is required for producing a part is maintained on a punched tape and is called the part program. The part program is arranged in the form of blocks of information, where each block contains the numerical data required to produce one segment of the work piece. The punched tape is moved forward by one block each time the cutting of a segment is completed.
- Preparing the part program for a NC machine tool requires a part programmer. The part programmer must possess knowledge and experience of tools, cutting fluids, machinability data and fixture design techniques.
- Part programmers must be familiar with the function of NC machine tools and machining processes and have to decide on the optimal sequence of operations. Part programs are written manually or by using a computer-aided language, such as automated program tool (APT).

2.2 Types of CNC

Computer numerical control is applied to a variety of machines. Most of these find ready application in aircraft, automobile and general engineering industry. Some of them are listed below:

1. Machining Centre
    - Horizontal
    - Vertical
    - Universal
2. CNC Turning Centres
3. CNC Milling/Drilling Machines, Plane Milling Machines
4. Gear Hobbing Machines
5. Gear Shaping Machines
6. Wire Cut EDM/EDM
7. Tube Bending
8. Electron Beam Welding
9. Laser/Arc/Plasma Cutting
10. Co-ordinate Measuring Machines
11. Grinding Machines
    - Surface Grinder
    - Cylindrical Grinder

- Centreless Grinder

12. Tool and Cutter Grinder
13. CNC Boring and Jig Boring Machines
14. Press Brakes
15. CNC Transfer Lines, SPM's
16. Electrochemical Milling Machines
17. Abrasive Water Jet Cutting Machines
18. Flow Forming Machines
19. Roll Forming Machines
20. Turret Punch Press

2.3 Evolution of Controllers

The hardware technology in NC controls has changed dramatically over the years. At least seven generations of controller hardware can be identified.

1. Vacuum tubes (1952)
2. Electromechanical relays (1955)
3. Discrete semiconductors (1960)
4. Integrated circuits (1965)
5. Direct numerical control (1968)
6. Computer numerical control (1970)
7. Microprocessors and microcomputers (1975)

- The initial NC prototype machine built in the MIT Servomechanism Laboratories used vacuum tubes for the controller hardware.
- These components were so large that the control unit consumed more space than the machine tool. But that was the state of the technology in controls at that time. By the time the first NC machines were sold to the commercial market several years later, electromechanical relays were substituted for the vacuum tubes.
- The problem with these relay-based controls was their large size and poor reliability. Even the relatively simple point-to- point logic required several large cabinets filled with relays. The relays were susceptible to wear, and controls requiring a large number of these components were inherently unreliable.
- The use of transistors based on discrete semiconductor technology formed the next generation of NC controllers. The use of transistors helped to reduce the number of electromechanical relays required.
- Accordingly, this increased the reliability because the use of transistors avoided the wear problem. It also contributed to a downsizing of the controller cabinet and allowed systems designers to build more complex circuitry into the NC controller.
- Features such as circular interpolation became practical with these controls.
- Size and reliability still remained as problems with NC controls which used discrete semiconductors. Also, the electronics were sensitive to heat, and fans or air conditioners were required in the cabinets to operate under factory conditions.
- Around 1965, integrated circuits were introduced for use in NC controls. This type of electronic hardware brought significant improvements in size and reliability. The number of separate components could be reduced by 90%.

- There were corresponding savings in cost to the user. The trend toward LSI (large-scale integrated) circuits has allowed more control features to be packaged into smaller control cabinets. Among these features are circular and hyperbolic interpolation routines, inch-to-metric conversions, and vector feed rate computations.
- The next development in NC control marked the introduction of digital computers in NC controller technology. This constituted a fundamental change in NC evolution. All of the previous controls were made up of hard-wired components.
- The functions that were performed by these control systems could not be easily changed, due to the fixed nature of the hard-wired design. Digital computers, on the other hand, are based on a different approach. In this new approach, the control functions were programmed into the computer memory and could be changed by altering the program.
- DNC was the first of the computer control systems to be introduced, around 1968. In the evolution of computer technology, the computers of that era were quite large and expensive, and the only feasible approach seemed to be to use one large computer to control a number of machine tools on a time-shared basis.
- The advantage of DNC was that it established a direct control link between the computer and the machine tool, hence eliminating the necessity for using punched tape input. The tape and tape reader were turning out to be the least reliable components in the conventional NC systems.
- With the recognized trend toward smaller, less expensive computers, it soon became practical to apply a single small computer to one machine tool. This concept came to be called computer numerical control (CNC).
- The CNC systems were first commercially introduced around 1970, and they applied the soft-wired controller approach to good advantage.
- One standard computer control unit could be adapted to various types of machine tools by programming the control functions into the computer memory for that particular machine. Today, because of the advantages of CNC, very few conventional hard-wired NC systems are sold in the United States.
- Advances in computer technology have continued to provide smaller and smaller digital control devices which have greater speed and capacity at lower cost.
- This has permitted the machine tool builders to design the CNC control panel as an integral part of the machine tool rather than as a separate stand-alone cabinet. This reduces floor space requirements for the machine. The VLSI (very large scale integrated) circuits used in these controllers are advantageous to the machine tool designer and to the machine user.
- Fewer components in the controller means it is easier and less expensive for the machine tool builder to fabricate. Fewer circuit boards, which are readily replaced, reduce the burden on the user for maintenance and repair.

2.4 Advantages & Disadvantages of NC,CNC & DNC Machines

2.4.1 Advantages of NC machines

1. Increased Productivity.
2. Reduce tool Fixture storage cost.
3. Faster setup time.

4. Reduce part inventory.
5. Flexibility the speeds changes in design.
6. Better accuracy of parts.
7. Reduction in part handling.
8. Better uniformity of parts.
9. Better quality control.
10. Improvement in manufacturing control\

2.4.2 Disadvantages of NC machines

1. Increase in electrical maintenance.
2. High initial investment.
3. Operating cost per hour is higher than traditional machine tool.
4. Retraining of existing personal.

2.4.3 Advantages of CNC machines

1. Reduced Lead Time:- Time between the receipt of a drawing by an engineer & manufacturer getting ready to start a production on soft floor is called lead time.
2. Elimination of operator error:- The programme is checked before it goes to the machine so no error will occur in the job.
3. Operator Activity:- Operator doesn't require special skill for machining & single operator can operator more than one machine.
4. Lower Labor Cost:- One operator can run two or more machines resulting in reduced labor cost.
5. Smaller batches:- Periodic machining of small batches is found to be economical & bring about rapid stock turnover. Large storage facilities for work piece is not require.
6. Longer tool life:- Tools can be used at optimum speeds and feeds because of these functions are controlled by the part programming.
7. Elimination of jig & fixtures:- Standard locating fixtures are not used on CNC machine and cost of special jig & fixtures is frequently eliminated.
8. Flexibility in Change of Component Design:- The modification or changes in component design can be readily accommodated by reprogramming and altering the concerned instruction.
9. Reduced Inspection:- Normally it is necessary to inspect the first component only.
10. Less Scrap:- Since operators error are eliminated, since the tools are operating under controlled optimum condition the incidence of breakage should be very small.
11. Accurate Costing & Scheduling:- In CNC time taken in machining is predictable and result in greater accuracy in estimating and more consistency in costing.

2.4.4 Disadvantages of CNC machines

1. Higher Investment Cost:- CNC machine represents a more sophisticated and complex technology. High machines utilization is essential in order to get reasonable returns on investment

2. Higher Maintenance Cost:- Because of CNC is complex maintenance problem becomes more difficult.
3. Costlier CNC Personnel:- Certain aspect of CNC machine operator requires a higher skill level them conventional operation. Part programming & maintenance required skill are in short supply.
4. Planned Support Facility:- Since most of the preparatory work for CNC operation is done away from the machine planned support facilities will be essential. i.e part programming, tape preparation & tool presetting.

2.4.5 Advantages of DNC machines

1. It eliminates punched tapes & tape reader which are the weakest component in the NC system.
2. Large memory of DNC allows it to storage a large amount of part programme for subsequent use. It also relatives the memories of NC control unit.
3. Same part programme can be run on the different machine at the same time without duplicating it at individual machine.
4. Central DNC Computer can keep close control over the complete machine shop.
5. Individual machine performance report can be obtained on demand.
6. DNC uses a control Computer, which can be easily isolated from the machine shop & kept in suitable environment.
7. The data related to manufacturing can be centrally maintained & updated, there by effectively managing the inventory & scheduling.

2.4.6 Disadvantages of DNC machine

1. In the event of failure of central DNC computer, the complete activities of the machine shop will come to standstill.
2. DNC is expensive and it's use is justified where high automation is required

2.5 Components of NC/CNC System

Following are the basic components of an operational numerical control system:

1. Programme of instructions
2. Controller Unit also called Machine Control Unit (MCU)
3. Machine tool or other controlled equipment

2.5.1 Programme of instructions

- The programme of instructions is the detailed step by step set of directions which tell the machine tool what to do and in what sequence. The part programme is written in coded form and contains all the information needed for machining the component.
- The part programme is fed to the machine control unit through some input medium. Various types of input media are:

a. Punched cards

b. Magnetic tapes and floppy disks

c. Paper tape

2.5.1.1 Punched Cards

- Punched cards were once widely used as a medium for data input in all numerical control systems. A typical punched card used in IBM systems has 80 columns and each 'column has numbers which identify the punching position.
- There are 12 punch positions or rows in each card designated as 12, 11 and 0 to 9. For any numeric and alphabet to be punched on the card, a code is used and rectangular blocks are punched on the card at one or more places.
- Normally, one card is used for encoding each instruction or for storing each master record. However, if the instruction data is too large to fit on one card, a set of two or more cards may be used. A punched card with the hole corresponding to all the characters and numbers is shown in Figure 2.1.

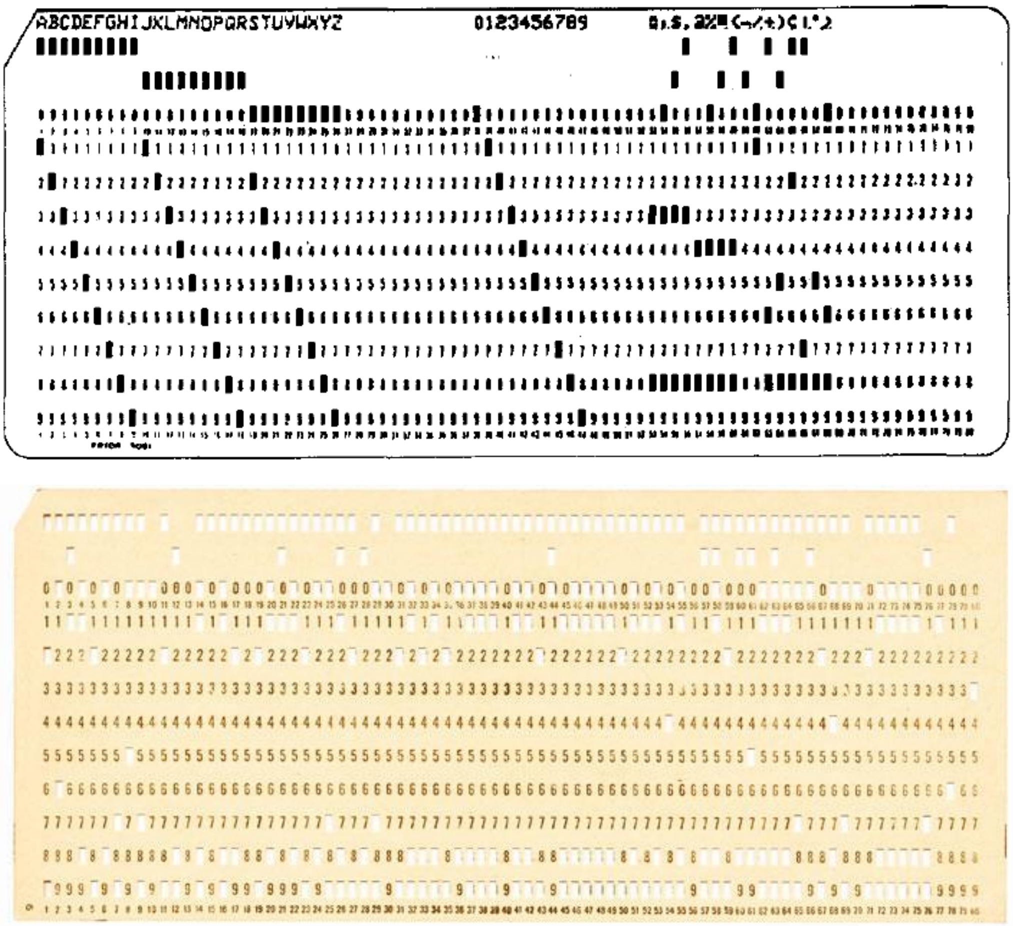


Fig.2.1 – Representation of alphabetic and numerical information on a computer card

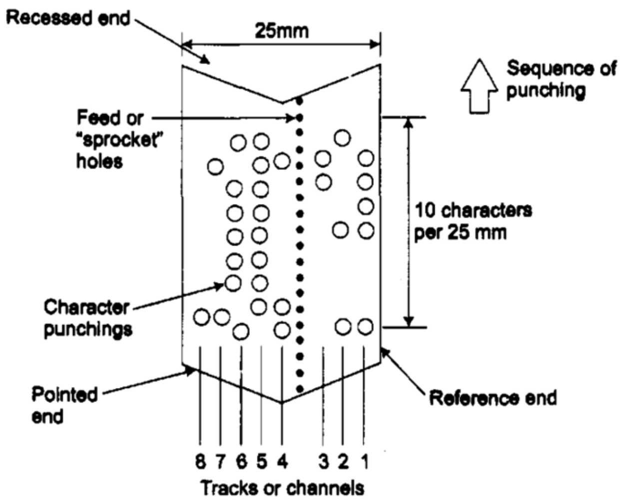
2.5.1.2 Magnetic Tape and Disk

- Magnetic tapes and disks are widely used for data storage as well as data input to NC systems. The data is stored in the coded form by means of magnetized spots on magnetic medium in both cases.
- The magnetic tapes and magnetic disks are re-usable media. The data once stored can be erased and new data saved on the magnetic tape or disk. Magnetic tape used in numerical control systems is identical to the tape used in common home tape recorder.

- The width of the tape is 6 mm or 25 mm. Magnetic disks or floppy disks are circular disks and consist of a material which can be magnetized. The disk is enclosed in a square protective sleeve. The data is stored in concentric tracks arranged on the surface of the disk.
- The commonly used sizes of magnetic disks are 5.25 inch diameter and 3.5 inch diameter. The magnetic disk is a random access device which means that any piece of data recorded on the diskcan be accessed at random.
- The data transfer rate in case of magnetic disks is much faster than magnetic tape. The magnetic tapes and disks can store more data compared to other input media. But the data stored on magnetic tapes and disks can be corrupted if these are brought into magnetic fields.

2.5.1.3 Punched Tape

- Punched tape is widely used for feeding the programme to numerical control systems. There are various types of paper tapes used in NC system but the standard format for tape size and configuration, issued by Electronic Industries Association of USA (EIA) and International Standards Organization (ISO), are universally accepted. A standard tape is 25 mm wide.
- The punched tape has capacity for storing 10 characters per 25 mm length. A punched tape is shown in Figure 2.2. There are 8 tracks on the tape, which are used for punching the information in coded form. The edge adjacent to track 1 is called reference edge.
- A row of small holes between track 3 and track 4 is used for feeding the tape into the tape reader. The information required to machine the component is punched on the tape by a tape punching device.



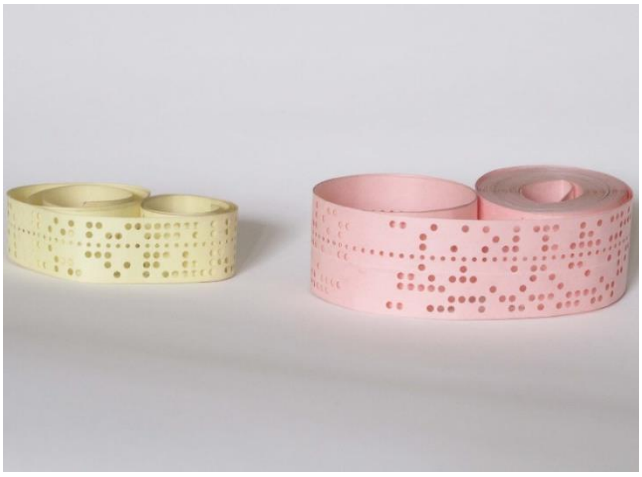


Fig.2.2 – 25 mm wide punched card

2.5.2 Machine control unit

- The second basic component of the NC system is the controller unit. This consists of the electronics and hardware that read and interpret the program of instructions and convert it into mechanical actions of the machine tool.
- The typical elements of a conventional NC controller unit are discussed below.

Programme Reader

- Programme reader is a device used to read the coded instructions from the programme of instructions. Programme readers are classified on the basis of programme input medium as

a. Card Readers

- Card readers are those devices which read the information punched into a card, converting the presence or absence of a hole into an electric signal representing a binary 0 or 1.
- The punched cards are placedinto a hopper and when the command to read is given, a lever pushes a card from the bottom of stack. Generally, the card is moved lengthwise over a row of 80 reed brushes.
- These brushes read the information punched along the bottom row of the card. If a hole is punched in a particular row, a brush makes electrical contact through the hole in the card generating a signal which is used by the computer.
- The next row is then read, and this process continues until all rows have been read, after which the next card is moved intoposition on the brushes. Faster card readers use photoelectric cells under the 12 punch positions along a column and an illuminating source above the card.
- As each column on the card is passed over the 12 photoelectric cells, whether or not a given position is punched is determined by the presence or absence of electric signal from the corresponding photocell. Card readers operate at speeds ranging from 12 to 1000 cards per minute.

b. Punched Tape Readers

- When a punched tape is passed through a punched-tape reader, electric connections are either close or open depending on whether there is a hole punched at a particular track or not.
- The coded instructions on the tape are transformed into their electrical analogues which are utilized for controlling the various machine tool functions. The punched tape readers commonly used are:

i. Mechanical (Electro-mechanical)
ii. Photo electrical
iii. Pneumatic

i. Mechanical Tape Reader

- The principle of a simple mechanical device for reading the punched tape is shown in Figure 2.3. If there is no hole in the tape the contacts remain open but when a hole is present in the tape, its presence is detected by a probe and bending of flexible strip causes the contacts to close.
- The presence of holes in the tape causes the switches to close. The switch is in ON position (hole) or OFF position (no hole) accordingly.

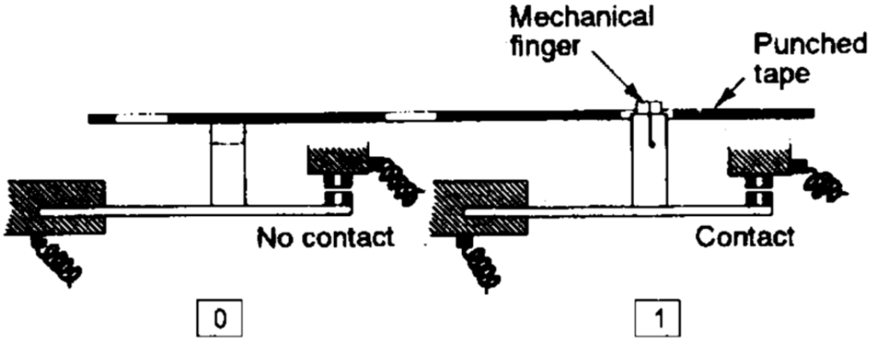


Fig.2.3 – Principle of the mechanical tape reader

ii. Optical or Photo-electrical Reader

- The operation of an optical photo electric tape reader is based upon the principle that if a beam of light falls on a photoelectric cell, the latter generates an electric signal.
- The schematic diagram of a photoelectric tape reader is shown in Figure 2.4. The punched tape is fed between a light source and a series of photo-cells. Whenever a hole is present in the tape, light from the light source passes through the hole and energizes the corresponding photo-cell which converts the light energy into electrical energy to produce a pulse i.e. ON position.
- The pulse is amplified and processed into a form suited to the control circuit. When there is no hole, the light from the light source does not reach the photo-cell, hence no signal is produced and the position is recorded as OFF.

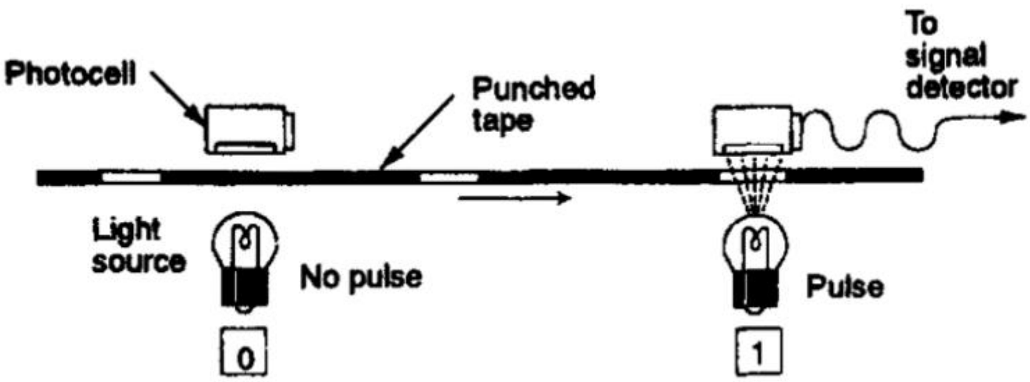


Fig.2.4 – Principle of the optical tape reader

iii. Pneumatic Tape Readers

- A pneumatic tape reader is shown in Figure 2.5. The tape is fed between a series of air jets (8 No.), covering the complete pattern of holes which is possible to be punched in a block of information on the tape and tape support plate.
- The compressed air jets are directed through specially designed tubes which have two openings. The first opening called, main outlet, is near the tape and second opening is connected to a signal detector.
- If there is no hole in the tape, the tape covers the main outlet and the free escape of air is restricted and a back pressure is developed in the supply tube. This back pressure is sensed by the signal detector and position is recorded as '0' i.e. OFF.
- But if a punched hole in the tape comes in front of the main outlet, the air is allowed to escape freely and no back pressure is built up in the supply tube. This loss of back pressure is detected by the signal detector and position is recorded as '1' i.e. ON. The support plate prevents the tape from being blown away by the compressed air coming from main outlet.

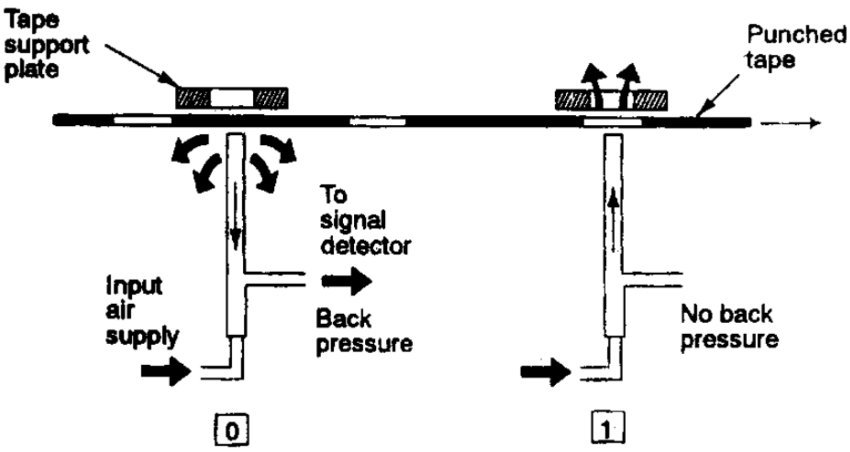


Fig.2.5 – Principle of the pneumatic tape reader

2.5.3 Machine tool

- The third part of the numerical control system is the machine tool itself. In a numerically controlled machine all the movements of the tool and the machine table are done automatically with the help of electric motors.

- For example, in case of a CNC lathe the longitudinal and transverse movements of the tool are controlled by two motors fitted on the machine i.e. one for longitudinal movement and the other for transverse movement of the tool.
- In addition, the speed of the spindle motor is also controlled by the part programme. The machine may have a tool magazine, so that tool changing is done automatically.
- Also the other functions like machine ON/OFF, coolant ON/OFF, etc are controlled through the part programme. The motors used for controlling the speed, feed and depth of cut are either servomotors or stepper motors which enable the user to select any desired speeds and feeds.

2.6 Numerical Control Procedure

1. Process planning

- This step is referred to as process planning and it concerned with preparation of route sheet.
- Route sheet is a listing of sequence of operations along with required machining data like speeds, feeds, depth of cut tools used etc.
- 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 operation.

2. Part programming

- Part programming have knowledge about the machining process and they have been trained to programme for numerically controlled machine tools.
- They are responsible for planning the sequence of operation performed by NC.
- There are two ways to develop programme for numerical control machine.

1.Manual part programming.

2.Computer assisted part programming.

- In manual part programming the machining instruction are prepared on a form called a part programme menu script.
- It is a listing of relative cutter/workpiece position which must be followed to machine the workpiece.
- In computer assisted part programming much of the tedious computational work required is manual part programming is transferred to the computer.
- This is especially suitable for complex workpiece geometrics and jobs with many machining steps.
- Use of computer will save the part programming time.

3. Tape preparation

- A punched tape is prepared from the part programmer's process plan.
- In manual part programming the punched tape is prepared directly from the part programme menu script.
- In computer assisted part programming, the computer interprets the list of part programming instructions performs the necessary calculation to convert this into a detailed set of machine tool, motion commands and then controls a tape punching device to prepare the tape for specific NC machine

4. **Tape verification**

- After the punched tape has been prepared some method is usually provided for checking the accuracy of the tape.
- Sometimes the tape is checked by running it through a computer programme which plots the various tool movement on paper.
- In this way major errors in tape can be checked.
- Acid test of tape involve trying out on the machine tool to make a part.
- Foam or plastic material is sometimes used for this tryout.
- Programming errors are not uncommon and it may require two or three attempts before the tape is supposed to be correct and ready to use.

5. **Production**

- Final step in the NC procedure is to use the part programme in production.
- This involve ordering the raw material, specifying and preparing the tooling.
- The operator function during production is to load the raw material and establish the starting position of the cutting tool relative to workpiece.
- When machining of part is completed the operator remove it from machine and load the next part.

2.7 Classification of Nc Systems

The classification of NC machine tool systems can be done in three ways

- According to the type of machine: Point-to-point, straight-cut and continuous path
- According to the programming method: Absolute and incremental
- According to the type of control system: Open-loop and closed-loop

Point-to-Point

- Point-to-point machines move only in straight lines. They are limited to drilling, reaming, boring, etc. and straight milling cuts parallel to a machine axis.
- When making an axis move, all affected drive motors run at the same speed. When one axis motor has moved the instructed amount, it stops while the other motor continues until its axis has reached its programmed location. The point-to-point positioning NC system is illustrated in Figure 2.7.

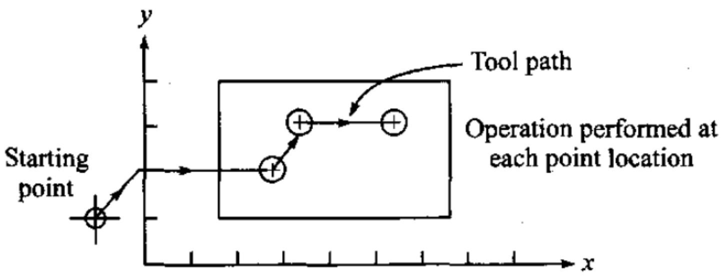


Fig.2.7 – Point-to-point (positioning) NC system

- The simplest example of a point-to-point (PTP) NC machine tool is a drilling machine. In a drilling machine, the work piece is moved along the axes of motion until the center of the hole to be drilled is exactly beneath the drill.

- Then the drill is automatically moved towards the work piece, the hole is drilled and the drill moves out in a rapid traverse feed. The work piece moves to a new point and the above sequence of actions are repeated.

Straight-cut NC

- Straight-cut control systems are capable of moving the cutting tool parallel to one of the major axes at a controlled rate suitable for machining.
- It is, therefore, appropriate for performing milling operation to fabricate work pieces of rectangular configurations. With this type of NC system it is not possible to combine movements in more than a single axis direction.
- Therefore, angular cuts on the work piece would not be possible. An example of straight-cut operation is shown in Figure 2.8. An NC machine capable of straight-cut movements is also capable of PTP movement.

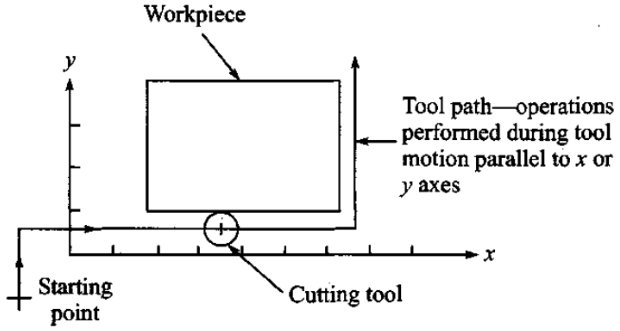


Fig.2.8 – Point-to-point (positioning) NC system

Continuous Path

- continuous path machine has the ability to move its drive motors at varying rates of speed while positioning the machine which facilitates cutting of arc segments and angles.
- The most common type of continuous path operations are milling and lathe operations. In continuous path machine, the tool is cutting while the axes of motion are moving, as for example, in a milling machine.
- All axes of motion might move simultaneously, each at a different velocity. When a non-linear path is required, the axial velocity changes, even within the segment. For example, cutting a circular contour requires a sine rate change in one axis, while the velocity of the other axis is changed at a cosine rate.
- In contouring machines, the position of the cutting tool at the end of each segment together with the ratio between the axial velocities determines the desired contour of the part and at the same time the resultant feed also affects the surface finish. Figure 2.9 shows continuous path NC system for 2D operations.

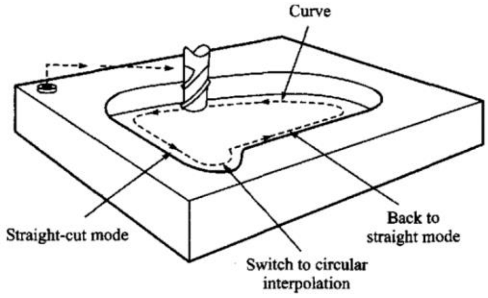


Fig.2.9 – Contouring (continuous path) NC system for two-dimensional operations

Absolute Programming

- Absolute positioning is another type of programming system. In this system, the tool locations are always defined in relation to point zero.
- The position commands are given as absolute distances from the reference point. The reference point can be defined outside the work piece or at a corner of the work piece.
- The reference point or point zero could be fixed or floating. When the point zero is fixed, the origin is always located at the same position on the machine table.
- All locations must be defined by positive x and y coordinates relative to that fixed origin.
- When the point zero is floating, the operation can set the point zero at any position on the machine table. This point zero is decided based on part programming convenience.

Advantages of absolute programming

- In cases of interruptions that force the operator to stop the machine, the cutting tool automatically returns to previous position. Since it always moves to the absolute coordinate called for and the machining proceeds from the same block where it was interrupted.
- Possibility of easily changing the dimensional data in the part program whenever required.
- When describing contours and positions, it is always preferable to employ absolute dimensioning, because the first incorrect dimensioning of an individual point has no effect on the remaining dimensions and the absolute system is easier to check for errors.

Incremental Programming

- Incremental positioning is a programming system used to define the position of the tool in NC machines. In an incremental system, the next tool location must be defined with reference to the previous tool location. The dimensional data applied to the system will be a distance increment measured from the preceding point at which the axis of motion was present.

Advantages of incremental programming

- If manual programming is used with incremental systems the inspection of the part program, before punching the tape is easy. Since the end point, when machining a part is identical to the starting point, the sum of the position, commands (for each axis separately) must be zero. A non-zero sum indicates that an error exists.
- The performance of the incremental system can be checked by a closed-loop tape. The last position command on the tape the table to return to the initial position.
- Mirror-image programming is facilitated with the incremental systems.
- Incremental dimension programming is advantageous for certain individual partial contours in a work piece are repeated several times, and the associated program sections can be employed several times without a coordinate shift.

Open-loop and Closed-loop System

- In NC system, every control system may be designed as an open or a closed-loop control. The term loop control means that there is no feedback in the total system and the action of the controller has no information about the effect of the total system and the command signals that it produces. The controller produces commands for actions of the motions of the NC machine tool.
- The open-loop NC systems are of digital type and use stepping motors for driving the slides. A stepping motor is a device whose output shaft rotates through by a fixed angle in response to an

input pulse. The stepping motors are the simplest way for converting electrical pulses into proportional movement. Each pulse drives the stepping motor by a fraction of one revolution called the step angle.

- Since there is no feedback from the slide position, the system accuracy is solely dependent on the ability of the motor and accuracy of the mechanical parts.
- The closed-loop control measures the actual position and velocity of the axis and compares them with the help of a comparator. The comparator is a device that compares the output signal with the signal received from the feedback device. The difference between the actual and the desired values is the error. The control system is designed in such a way as to eliminate or reduce to a minimum, the error, namely the system is of a negative feedback type.
- In NC system both the input to the control loop and the feedback signals may be a sequence of pulses. Each pulse representing one BLU, i.e., 0.01 mm.
- The digital comparator correlates the two sequences and gives, by means of a digital-to-analog converter (DAC), a signal representing the position error of the system and the output of DC drives the DC motor. A closed loop system uses position sensors attached to the machine table to measure its position relative to the input value for the axis.

2.8 Axis Designation In NC/CNC Machines

- Most of the machines have two or more slide ways, disposed at right angles to each other, along which the slides are displaced. Each slide can be fitted with a control system and for the purpose of giving commands to the control system the axis have to be identified.
- The basis of axis identification is the 3-dimensional Cartesian co-ordinate system and the three axis of movement are identified as X, Y and Z axis.
- The possible linear and rotary movements of machine slides/work piece are shown in Figure 2.10. Rotary movements about X, Y and Z axis are designated as A, B and C respectively.
- The main axis of movement and the direction of movement along these axis is identified as follows:

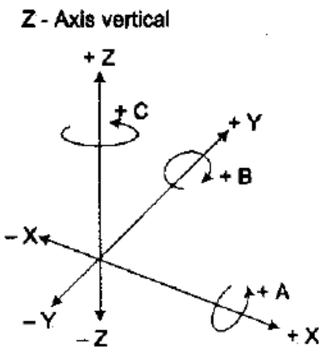


Fig.2.10 – Possible linear and rotary movements of machine parts

- X-axis: The X-axis is always horizontal and is always parallel to the work holding surface. If the Z-axis is vertical, as in vertical milling machine, positive X-axis (+X) movement is identified as being to the right, when looking from the spindle towards its supporting column.
- If Z-axis is also horizontal as in turning centres, positive X-axis motion is to the right, when looking from the spindle towards the work piece.
- Z-axis: The Z-axis of motion is always the axis of the main spindle of the machine. It does not matter whether the spindle carries the workpiece or the cutting tool.

- If there are several spindles on a machine, one spindle is selected as the principal spindle and its axis is then considered to be Z-axis.
- On vertical machining centres, the Z-axis is vertical and on horizontal machining centres and turning centres, the Z-axis is horizontal. Positive Z movement (+ Z) is in the direction that increases the distance between the workpiece and the tool.
- Convention of designating the Z-axis on milling, drilling and turning machines is shown in Figure 2.11.
- Y-axis: The Y-axis is always at right angles to both the X-axis and Z-axis. Positive Y-axis movement (+ Y) is always such as to complete the standard 3-dimensional co-ordinate system

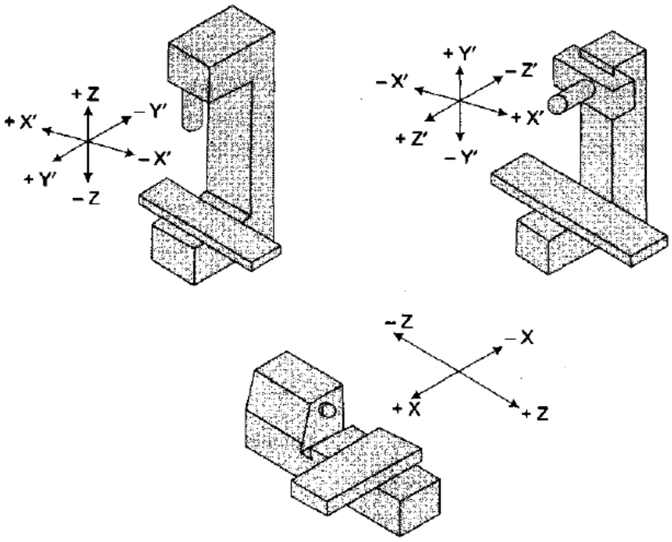


Fig.2.11 – Axis Designation

- Rotary axis: The rotary motion about the X, Y and Z-axis are identified by A, B, C respectively. Clockwise rotation is designated positive movement and counter-clockwise rotation as negative movement. Positive rotation is identified looking in + X, + Y and +Z directions respectively

2.9 Constructional Details of CNC Machines

- The basic design of a conventional machine tool is not suitable for CNC machines. Many design changes are required for CNC machines as compared to the conventional machines, due to a number of additional requirements which CNC machines are expected to meet.
- The manual hand wheel controls in the conventional machines are replaced by axis drive motors in CNC machines. If the axis drive motors have to operate against heavy loads due to friction at the sliding surfaces or due to inertia of moving components or due to some other factors, the motors will have to develop high power output which in turn will ask for motors of large size. In order to limit the size of drive motors and avoid
- other related problems, the design of CNC machine should be such as to minimize the friction between the sliding surfaces.
- Higher cutting speeds and feeds and improved tooling used in CNC machines subject the machine tool to high multidirectional forces. Also the set-up time and the change-over time between the jobs are considerably reduced in CNC machines and most of the time of the machines is spent in actually cutting the material.

- Higher percentage of cutting time will results in faster wear of slideways, guideways, lead screw and gears, etc. The higher percentage of cutting time means higher rates of metal removal requiring an efficient system for removal of swarf from the machining area. In addition, safety of the operator working on the machine is very important in CNC machines.
- In order to take care of above and many other factors, there is a need for special consideration to be given to the design of CNC machine tools in the following areas:
  1. Machine structure
  2. Slideways
  3. Spindle mounting
  4. Drive units
  5. Elements of transmission and positioning slides
  6. Location of transducers
  7. Tool and work holding devices
  8. Swarf removal
  9. Safety

1. Machine structure

The design and construction of CNC machine should be such that it meets the following main objectives:

a. High precision and repeatability

b. Reliability

c. Efficiency

- To meet the requirements of high precision, repeatability and high efficiency, the numerically controlled machine tools should have a structure that is correctly designed to withstand normal weight distribution.
- The higher cutting speeds and feeds in CNC machines result in rapid acceleration and deceleration of the slides and the machines are subjected to fluctuating and variable forces during the machining operations. The machine structure should not bend due to the heavy cutting forces.
- All the parts of the machine structure should remain in relative relationship regardless of the magnitude and direction of the stresses developed due to these forces. Another source of inaccuracy in the CNC machines is the thermal distortion of the machine structure.
- The design of machine tool structures should be such that the thermal distortion is minimum. The machine tool should be protected from external heat sources and the internal heat sources e,g., head-stock motor should be placed centrally so that thermal effects are equally distributed.
- The machine tool should be provided with an efficient and foolproof lubrication and cooling system. Also the machine structure design should be such that removal of swarf is easy and the chips, etc. do not fall on the sideways.

2. Slide ways

- In the conventional machine tools, there is a direct metal to metal contact between the slide way and the moving slides.

- Since the slide movements are very slow and machine utilization is also low, this arrangement is adequate for conventional machine tools. However, the demand on slide ways is much more in CNC machines because of rapid movements and higher machine utilization.
- The conventional type of arrangement with metal to metal contact does not meet the requirements of numerically controlled machine tools. The design of slide way in a CNC machine tools should:
  a. Reduce friction
  b. Reduce Wear
  c. Satisfy the requirements of movement of the slides
  d. Improve smoothness of the drive
- To meet these requirements in CNC machine tool slide ways, the techniques used include hydrostatic slideways, linear bearings with balls, rollers or needles and surface coatings.

3. Spindle

- At the high cutting speeds and high material removal rates, the spindle carrying the work piece or the tool are subject to deflection and thrust forces.
- To ensure increased stability and minimize torsional strain, the machine spindle is designed to be short and stiff and the final drive to the spindle is located as near to the front bearing as possible. The rotational accuracy of the spindle is dependent on the quality and design of bearings used.
- The ball or roller bearings are suitable for high speeds and high loads because of low friction, lower wear rate and lesser liability to incorrect adjustment and ease of replacement when necessary. For efficient service and accuracy the bearings should be of high quality.
- The vibrations and noise in the spindle can be reduced by using toothed belts and accurate and balanced gears. Adequate supply of lubricants should be ensured to the spindle bearings.

4. Drive units

a. Drive motors are required to perform the following functions:

b. To drive the main spindle (Spindle drive)

c. To drive the saddles or carriage (Axis drive)

In addition there may be some more motors in the CNC machine for services such as coolant pumps, swarf removal, etc.

Spindle Drive

- In CNC machines, large variation in cutting speed is required. The cutting speed may vary from 10 meters per minute to 1000 meters per minute or more. The cutting speeds are provided by rotation of the main spindle with the help of an electrical motor through suitable gear mechanism.
- The multi-change gear boxes with fixed speed ratios used in conventional machine tools are not suitable for CNC machine tools. To obtain optimum cutting speeds and feeds, the drive mechanism should be such asto provide infinitely variable speeds between the upper and the lower limits.
- The infinitely variable speed systems used in CNC machines employ either electrical motors (A. C. or D. C.) or fluid motors

Axis Drive

- All the axis in a CNC machine are controlled by servomotors. The movement along the different axis is required either to move the cutting tool or the work material to the desired positions.

- In order to accomplish accurate control of position and velocity, stepper motors are used for axis drive. The principal of working of a stepper motor is that on receiving a signal i.e. pulse, from the control unit, the motor spindle will rotate through a specified angle called step. T
- he step size depends on the design of the motor and lies between 1.8 degree and, 7.5 degree, which means that one rotation of the spindle can be divided into 200 parts. If a single pulse is received from the control system the motor spindle will rotate by one step.
- The control unit generates pulses corresponding to the programmed value of movement required of the tool or work. The rate of movement of tool or work is controlled by the speed at which the pulses are received by the stepper motor.
- The distance travelled by the carriage is calculated by the known value of lead of the axis lead screw and by counting the number of pulses. The rate at which pulses are sent to the stepper motor is accurately governed by the control system.
- Hence there is no need of providing positional or velocity feedback system. The use of stepper motor considerably simplifies the system as feedback devices are not used. The cost of the machine tool is also less. However stepper motors are suitable only for light duty machines due to low power-output.

5. **Elements of motion transmission**

- The conventional machines use lead screw for motion transmission purposes. The lead screw with acme-threads is not suitable for CNC machines due to high friction between the lead screw and the nut and poor power transmission efficiency and inaccuracy due to backlash.
- These problems have been overcome with the use of recirculating ball screw and nut arrangement. Here again, the approach is to replace sliding friction by rolling friction. The connection between the screw and the nut is through an endless stream of recirculating steel balls.
- The screw thread is, actually, a hardened and ground ball race in which the steel balls, in the nut, circulate. The balls rotate between the screw and the nut and at some point the balls are returned to start of the thread in the nut. The rigidity of the drive system and positioning accuracy can be further improved by pre-loading the nut assembly. A recirculating ball screw is shown in Figure 2.12.

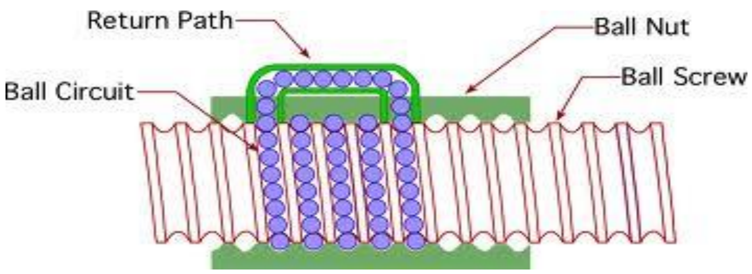


Fig.2.12 – Recirculating ball screw and nut

The advantages of using ball screw and nut assembly are:

a. High Efficiency: As compared to conventional lead screw the efficiency of ball screw and nut assembly is very high (over 90%). The power requirement for the ball screw arrangement is also less due to reduced friction.

b. Wear and Life: The recirculating rollers reduce wear to a minimum and the ball screw, therefore, has longer life without loss of accuracy.

c. Reversibility: The ball screw and nut assembly is reversible which makes it possible to back drive the unit i.e., by applying axial force to either nut or screw, the unconstrained member can be made to rotate.

d. No Stick-Slip: Stick-slip is the phenomenon which occurs when small movements between two lubricated elements are required. The lubricating medium tries to cause the mating elements to stick to each other to resist motion and results in a jerky motion as the mating elements try to stick and then slip during their relative movement. Since the sliding metal to metal contact is substituted by rolling contact, the stick-slip phenomenon is eliminated in the ball screw and nut assembly.

6. Location of transducers/control elements

- In CNC machines the control of all machine functions is totally transferred to a computerized control system. The control unit should be situated so that it is convenient for the operator to operate the machine from the central place. The facilities which a control unit should offer are:
  a. Indicate the current status and position of various machine tool features and give feedback.
  b. Allow manual or semi-manual control of machine tool elements.
  c. Enable machine tool to be programmed.
- The control unit part for allowing manual control and programming of the machine may be housed on the machine structure itself or a separate control panel may be installed near the machine or it may be mounted on a swing arm to allow it to be adjusted according to the position of the operator.
- The facilities for indication of present status of the machine features and to give feedback have to be provided at suitable place on the machine tool itself so that actual movement of slides, etc. can be monitored and feedback to the control system. To monitor the position of the slides, two types of transducers are used i.e., linear transducers and rotary transducers.

The linear transducers should be positioned:

i. near to the sliding surface and lead screw

ii. In an accessible position for maintenance purposes.

Rotary transducers should be located:

i. at the driving end of lead screw

ii. at the free end of the lead screw

On the nut if a fixed screw and rotating nut system is used.

7. Tool and work holding devices

- The cutting time in CNC machine ranges from 70 to 80%, the tooling required for these machine tools needs to be specially designed. The requirements of tool and work holding devices and cutting tools for CNC machines are discussed in the Chapter on "Tooling for CNC Machines"

8. Swarf removal

- CNC machines are designed to work at optimum cutting conditions with the improved cutting tools on a continuous operation basis. Since the cutting time is much more in CNC machines, the volume of swarf generated is also more.
- Unless the swarf is quickly and efficiently removed from the cutting zone, it can affect the cutting process and the quality of the finished product. Also the swarf cannot be allowed to accumulate at the machine tool because it may hamper the access to the machine tool.

- In addition some auxiliary functions like automatic component loading or automatic tool change may also be affected by accumulation of swarf.
    - To avoid these problems an efficient swarf control system should be provided wjth the CNC machine tools with some mechanism to remove the swarf from the cutter and cutting zone and for the disposal of swarf from the machine tool area itself.

9. Safety of operator

- Safety of operator is very important aspect which cannot be overlooked. To ensure safe working conditions the CNC machine tools are provided with metallic or plastic guards. Where it is not possible to provide effective guards, proximity protection is provided by pressure mats or light barriers.
- Perimeter Guards: The overall guards or perimeter guards serve as an enclosure for the machine tool. The perimeter guards protect the operator against flying swarf and from any accident by hitting against the moving components when the machine is working.
- The access to the machine is provided through large sliding doors for setting up the machine and for loading/unloading of the work piece. The doors have various types of inter-lock switches fitted on them. If the door is opened when the machine is working, the control unit will flash a warning signal, or activate an auditory signal like a buzzer.
- On some machines the power to the machine may be cut off if the doors are kept open beyond a certain period of time. During set-up period, the warning signal can be cancelled by the operator. The guards are fitted with transparent windows so that the machining area is visible from the operator side.
- Pressure Mats: The pressure mats are used on milling, drilling or grinding machines where the machine table can move to the either side of the machine.
- Since the tables move at a rapid rate, it may cause some accident if the operator is standing too close to the machine. The pressure mats are placed around the machine and if someone crosses the mat, a warning signal is generated.
- Light Barrier: Light barriers are also provided on milling, drilling and grinding machines. The light barrier consists of a light source, usually infra-red, sending a beam to light sensitive cell.
- If anything obstructs the light beam, a warning signal is generated. The light barriers are placed around the machine. They can be made inactive by the operator, if required.

2.10 NC/CNC Tooling

- The special design features of CNC machines have resulted in use of higher cutting speeds and feeds, leading to considerable saving in the cycle time.
- To fully exploit the higher metal removal rates of the CNC machines, the tooling used should be able to withstand the higher cutting forces in the process and help to reduce the down time to a minimum possible. The tooling used on CNC machines should be:

a. Rigid to withstand high metal removal rates

b. Capable of being pre-set and re-set in the shortest possible time to keep the down time to minimum.

c. Accurate enough to produce repetitive accuracy on the job. In conventional machines, the cutting tool cuts metal for about 25% of the total machining time whereas the CNC machine tools are expected to cut metal for 70 to 80% of the time. Since CNC machines are very costly, the down time on these machines has to be reduced to a minimum. The tooling for CNC machine tools includes the cutting tools, and tool and work holding device.

2.11 Fundamentals of Part Programming

- Part programme is an important component of the CNC system. The shape of the manufactured components will depend on how correctly the programme has been prepared.
- Part programme is a set of instructions which instructs the machine tool about the processing steps to be performed for the manufacture of a component.
- Part programming is the procedure by which the sequence of processing steps and other related data, to be performed on the CNC machine is planned and documented. The part programme is then transferred to one of the input media, which is used to instruct the CNC machine.

NC Words

- The combination of binary digits (bits) in a row on the tape denotes a character. A NC word is a collection of characters used to form an instruction.
- Typical NC-words are X-position, Y-position, feed rate, etc. A collection of NC-words is called a block and a block of words is a complete NC instruction.
- Following are the NC-words used in the formation of blocks. All the NC words may not be used on every CNC machine.
  a. Sequence Number (N-Word)
  b. Preparatory Function (G-Words)
  c. Coordinates (X-, Y- and Z-Words)
  d. Feed Function (F- Word)
  e. Spindle Speed Function (S- Word)
  f. Tool Selection Function (T-Word)
  g. Miscellaneous Function (M-Word)
  h. End of Block (EOB)

Programming Formats

Format is the method of writing the words in a block of instruction. The following are the three programme formats being used for part programming:

a. Fixed block format
b. Tab sequential format
c. Word address format

The numerical control systems are designed to understand and work with one type of programme format but control systems which can understand and work with more than one type of format are also being used in CNC machines.

a. Fixed Block Format

- In the fixed block format, instructions are always given in the same sequence. All instructions must be given in every block, including those instructions which remain unchanged from the preceding blocks. For example, if some coordinate values (i.e. x, y or z coordinates) remain constant from one block to next block these values have to be specified in the next block also.

- In this system, only data is provided in the programme and the identifying address letters are not given, but the data must be input in a specified sequence and characters within each word must be of the same length.

b. Tab Sequential Format

- In this programme format, instructions in a block are always given in the same sequence as in case of fixed block format and each word is separated by the TAB character.
- If the word remains same in the succeeding block, the word need not be repeated but TAB is required to maintain the sequence of words. Since the words are written in a set order, the address letters are not required.

c. Word Address Format

- In the word address format, each data is preceded and identified by its address letter. For example, X identifies the x-coordinate, F identifies the feed rate and so on. If a word remains unchanged, it neednot be repeated in the next block. A typical instruction block in word address format will be as follows:

  N010 X0000 Y0000 F 200 S 0800 T 010.01 M 30 EOB

N	-	Sequence number
G	-	Preparatory function
X	-	X-coordinate
Y	-	Y-coordinate
F	-	Feed rate
S	-	Spindle speed
T	-	Tool number
M	-	Miscellaneous function
EOB	-	End of block

2.12 Computer-Aided Part Programming

- The manual part programming is a time consuming process and needs an expert part programmer who should have through knowledge of the various machining processes, materials, speeds and feeds, part programming codes and capabilities of various machine tools, etc. Manual part programming is a labour oriented task and needs skilled programmers.
- Also, if a person is expert in programming one machine, he will not be able to develop part programme for another machine, since the format or the type of information required by the two machines may be different. With the modern NC/CNC machines where more than three axes are to be controlled it may not be possible to develop part programmes by manual programming methods.
- All these problems have been overcome and part programming has been considerably simplified with the use of computer aided part programming, where the computer generates the part programme required to machine the component.
- The process of generating part programmes in computer aided part programming is partly done by part programmer and partly by the computer.
- The part programmer's job in the computer aided part programming is first to define the geometry of the component from the component drawing.

- The geometry or shape of the component is split into simple elements like points, lines, arcs, full circles, distances and directions and these elements are assigned specific numbers to identify their position.
- The geometry of elements of the component is defined using simple abbreviated English like terms having specific meaning which is understood by the computer and control system. The instructions to define a point and straight line may be written as:
- PI/0, 0 (co-ordinates of point PI are (0, 0))
- L1/P2, P4 (line L1 passes through points P2 and P4)
- The programmer may be able to see the geometric construction on the video display unit depending upon the system capabilities.
- The second part of the programmer's job is to give additional information regarding the machining sequences, type of operation, tool sizes, etc. From the geometry of the component, the system generates the data required to machine the component.
- This data is called cutter location (CL) data. The data generated up to this point is independent of the machine and can be used on any machine capable of doing the required operations. The data does not contain G or M codes.
- The cutter location data is then post-processed in the computer to translate it into a form which a particular machine control system can understand. The post-processing involves addition of G Codes, M codes and other machine dependent information in the required format.
- The part programme at this stage is machine dependent and can be used for a specific machine only.
- The advantages of using computer-aided part programming are:
  a. Part programming is considerably simplified.
  b. The part programmes generated are accurate and efficient.
  c. All arithmetic calculations are done by the computer, resulting in saving in time and elimination of errors.
  d. The part programming for different machines can be done by a single person, which can then be post processed for specific machines.
  e. Such system can deal with many axes for simultaneous movement.
  f. If new machines are added, only a post processor may be needed to integrate the new machines with the existing system.

2.13 Subroutines, Do-Loops, Canned Cycle

2.13.1 Subroutines

- Subroutine also called subprogram are a powerful time saving technique.
- The subroutine provide the capability of programming certain fixed sequence or frequently repeated patterns.
- Subroutines are in fact independent programmes with all the features of a usual part programme.
- Subroutines are stored in the memory under separates programme number.

- Whenever a particular feature is required within the programme the associated subroutine is called for execution.
- The subroutine may be called any time and repeated any numbers of time.
- After execution of subroutines the control return to main programme. To describe and use a subroutine, the following information is required in the form of codes and symbols.
  - Identification (start) of subroutine.
  - End of subroutine.
  - A mean of calling a subroutine.
- Here we will use letter L followed by a number i.e L221, to identify the start of a subroutine.
- L221 means start of subroutines No. 221, Miscellaneous code M17 will indicate the end of subroutine.
- The subroutine can be called anywhere in the main programme by just giving the subroutine number preceded by letter L.

2.13.2 Do-loops

- The ability to write the programme with loops enable the programmer to instruct the control unit to jump back to an earlier part of the programme and execute the intervening programme blocks a specified numbers of time.
- The DO-LOOPS statement is given in the main programme itself and it is necessary to give following information on the form of symbols or codes.
  - Start the Loop.
  - Number of repeats of the Loop.
  - End of the Loop.
- DO-LOOPS is used for repetitive programming in cases such as Turning & Milling operation where it is not possible to remove the entire material in the single pass and more than one cut have to be taken to machine the component to require size or where uniform repetition is required like cutting uniformly spaced grooves in a shaft or drilling of a pattern of hole in plate.

2.13.3 Canned cycle

- Canned Cycle or fixed cycle may be defined as a set of instruction, inbuilt or stored in the system memory, to perform a fixed sequence of operation.
- The Canned Cycles may be brought into action with a single command and as such reduce the programming time and effort.
- Canned Cycles are used for repetitive and commonly used machining operation.
- The Canned Cycles are stored under G-code address. G 81 to G 89 are reserved for fixed Canned Cycles and G 80 is used to cancel the Canned Cycles.

2.14 APT

- APT stands for automatically programmed tools. This is the most widely used and most comprehensive part programming language available.

- APT is a three-dimensional system which can be used to control up to five axes. In programming using APT, it is assumed that the workpiece remains stationary and cutting tool does all the moving. The APT part programme consists of four types of statements
  a. Geometry statements: These are also called definition statements and are used to define geometric elements like point, circle, arc, plane, etc.
  b. Motion statements: The motion statements are used to define the cutter path.
  c. Post processor statements: These statements are applicable to specific machine tools and are used to define machining parameters like feed, speed, coolant on/ off, etc.
  d. Auxiliary statements: These are miscellaneous statements used to identify the part, tools, tolerances, etc.

2.15 Referances

B. S. Pabla, M. Adithan "CNC Machines" 3rd ed. New Age International Publishers.

Lalit Narayan "CAD/CAM " Prentice Hall of India Private Limited