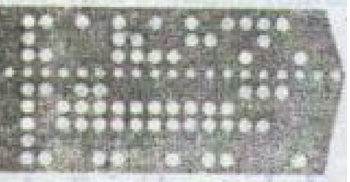
5 NUMERICAL CONTROL OF MACHINE TOOL



History of numerical control

Numerical control is nothing new. As early as 1808 weaving machines utilized metal cards with holes punched in them to control the pattern of the cloth being produced. Each needle on the machine was controlled by the presence or absence of a hole on the punched cards. The punched cards were the program for the machine to get the desired pattern.

In the late 1940, Parasons conceived a method of using punched cards containing coordinate position data to control a machine tool. Parsons envisioned the following system.

A computer would calculate the path that the tool should follow and store that information on punched cards. A reader at the machine would then read the cards. The machine control would take the data from the reader and control the motors attached to each axis. The first machine produced by Parsons and MIT (Massachusetts Institute of Technology) was demonstrated in 1952. It was a three-axis vertical spindle milling machine and vacuum tubes were used in machine control.

Up until about 1976 these machines were called NC machines. In 1976 CNC machines were produced. These machine controls utilized microprocessors to give them additional capability. The NC machines typically read one short program step (block) at a time and executed it, however, CNC machine could store whole programs. Improvements in computer technology in the late 1970s and 1980s brought the cost of numerical control machines very low.

Numerical control

Numerical control (NC) may be defined as a method of controlling the operation of a machine tool by a series of coded instructions, consisting of numbers, letters of alphabet and symbols that the machine control unit can understand. The numerical data required to produce a part is known as *part program* and is used to control the relative position of work-to-tool, tool selection, turning on cutting fluid, feeds and speeds, etc. A numerical control machine tool system consists of the following three components (fig. 5.1).

1. Program of instructions, 2. Machine control unit (MCU) and 3. Machine tool

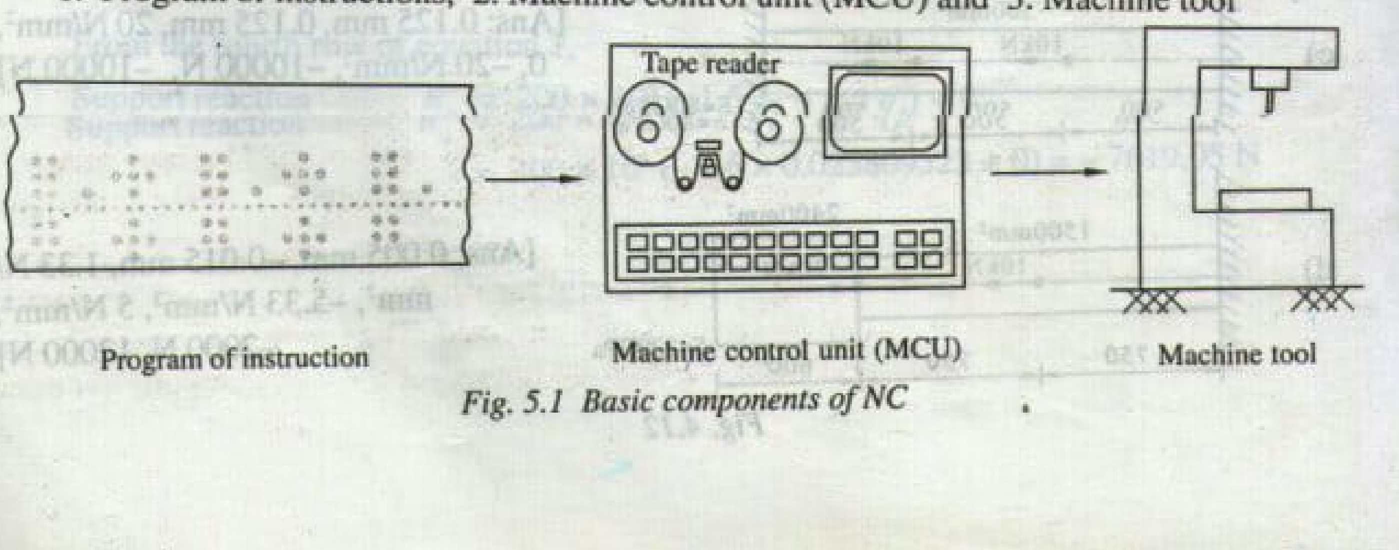


Fig. 5.1 Basic components of NC

Program of instructions: The part program (program of instructions) is the detailed step by step instructions by which the sequence of processing steps is to be performed. The programmer write the program on paper and recorded on a tape by means of tape punch. The most commonly used punched tape is 25 mm wide, 8 tracks, i.e., eight punched holes can be accommodated in one line across the width of tape. The tape is then played on a tape reader. The tape reader has the capacity of reading the punched holes either mechanically or electronically.

Machine control unit (MCU): The punched tape is played on a tape reader in the machine control unit. The controller unit interprets the program of instructions received from the tape reader and convert it into mechanical actions of machine tool, i.e., the signals are forwarded to servomotors which control the movement of the slides or spindle along X, Y and Z-axis. The controller unit controls the path to be followed by the cutting tool spindle speeds, feed rate, tool changes and several other functions of the machine tool.

Machine tool: The machine tool perform the machining operations. It consists of work table motors, spindle motors and controls. It also includes the cutting tools, fixtures and other auxiliary equipment needed in the machining operation. The machine tool has the capacity to change the tools automatically under tape command. The machine table can orient the job so that it can be machined on several surfaces as required.

NC procedure

The following steps must be accomplished to utilize the numerical control in manufacturing.

1. Process planning: In process planning, the work part drawing must be interpreted in terms of manufacturing processes to be used and to prepare route sheet. The route sheet is a listing of the sequence of operations which must be performed on the workpart.

2. Part programming: Part program is the procedure by which the sequence of processing steps to be performed on the NC Machine is planned and documented. There are two ways to program for NC. i) Manual part programming ii) Computer - assisted part programming.

The manual part programming consists of (i) calculating dimensional relationships of the tool and work piece, based on engineering drawings of the part, and (ii) the manufacturing operations to be performed and their sequence. A program sheet is then prepared, which consists of the necessary information to carry out the operation, such as cutting tools, spindle speeds, feeds, depth of cut cutting fluids, and tool or workpiece relative positions and movements.

Computer assisted part programming involves special symbolic programming languages that determine the coordinate points of corners, edges, and surfaces of the part. Thus the tedious computational work required in manual part programming is transferred to the computer.

3. Tape preparation: The program of instructions are placed on the NC tape by punching a specific pattern of holes. This is accomplished on a special typewriter tape punch machine. The typewriter keyboard operates in a similar manner as a standard typewriter. The tape punch is activated as each typewriter key is depressed. This produces a unique pattern of holes in the tape.

4. Tape verification: The typewriter tape punch also has a tape reading head. The reader is used to obtain a printed record of a punched tape. This is useful for verifying tape accuracy. If there is an error in the tape information, it can be detected and corrected. The typewriter reader is also used to duplicate tapes. The tape can also be checked by running it through computer program which plots the various tool movements.

5. Production: The final step in NC procedure is to use NC tape in production. The operator has to load new stock in the machine and play the tape in the tape reader usually found in the machine control unit. The NC system then takes over and machine the part according to the instructions on tape. When the part is completed, the operator remove the finished part from the machine and loads the next stock. Except for downtime due to re-sharpening of cutting tools or routine maintenance, the NC machine tool can function continuously.

Axes and coordinate system

In order for the part programmer to plan the sequence of positions and movements of the cutting tool relative to the workpiece, it is necessary to establish a standard axis system by which the relative positions can be specified. The machine tool motions are generally described in X-Y-Z Cartesian space. The axis of the spindle or the axis parallel to the spindle represented as Z-axis. The X-axis lies on a horizontal plane parallel to the work table. The positive or negative movement of the three axis is based on right hand rule.

Lathes or *turning center* typically use only X and Z axis as shown in fig. 5.2. The Z denotes the movement parallel to the spindle axis and controls the length of the part. The X-axis is perpendicular to the spindle and controls the diameter of the part.

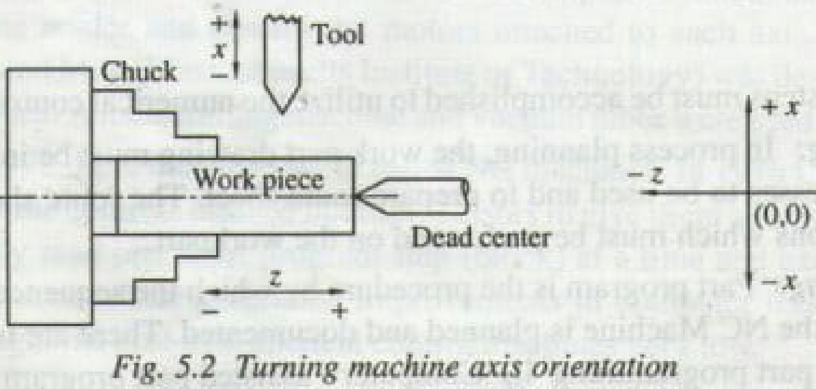


Fig. 5.2 Turning machine axis orientation

Milling machines or *machining center* use all the three axes as shown in fig. 5.3. On a vertical milling machine, the Z-axis denotes the movement parallel to the spindle axis, i.e., the up and down movement of the spindle or table. The X-axis (longest motion of the table) moves to the operator's left and right. The Y-axis moves toward and away from the operator. The Y-axis usually has the shortest travel.

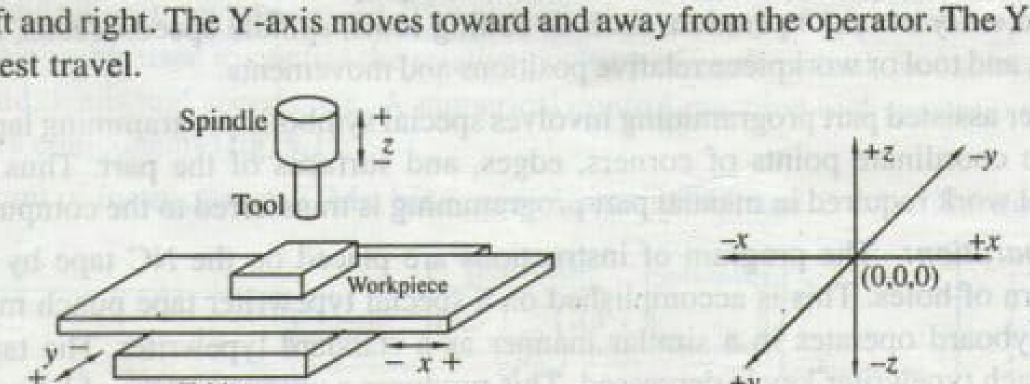


Fig. 5.3 Machining center (vertical milling machine) axis orientation

Fixed zero and floating zero (datum location): The programmer must determine the position of the tool relative to the origin of the coordinate system. NC machines have two methods of specifying the origin (zero point) 1. Fixed zero and 2. Floating zero. In fixed zero method, the origin is always located at the same position on the machine table, usually the lowest left-hand corner of the table. In floating zero method, the origin (zero point) can be set at any desired position on the machine table or on the work piece (part datum). Good programmers will choose the floating zero that is easy to access and one that will involve the least amount of dimensional calculations.

Classification of numerical control machines

Numerical control machines can be generally classified using the following categories.

1. Power drives : Hydraulic, pneumatic and electric.
2. Machine tool motion control : Point-to-point, straight cut and contouring.
3. Positioning systems : Incremental positioning and absolute positioning.
4. Control loops : Open loop and closed loop.

Power drives

The three principal power sources in NC machines are 1. Hydraulic, 2. Pneumatic, and 3. Electric.

Hydraulic : Most high-power machines are generally driven by hydraulic power. Hydraulics can deliver large forces, so that the machine slides move with more uniform speed. The disadvantages of hydraulic drives are that they tend to leak hydraulic fluid, high cost, more maintenance and require more peripherals such as pump, valve, reservoir, etc.

Pneumatic drives: Pneumatic drives are inexpensive and simple but cannot be controlled precisely. The motion in a pneumatic machine is usually non uniform in nature (with high acceleration and deceleration).

Electric drives: Electric drives are the most applicable for precision jobs. There are two major groups among electric drives. They are 1. Stepper motor and 2. Servo motor.

Stepper motor can be driven through the specified number of steps by applying discrete voltage pulses. Stepper motor movements can be very precise provided the torque load does not exceed the design limits. The operation is jerky due to acceleration and deceleration during each step and are usually of the open-loop type. Usually a step angle of 1.8 degree is very common. Thus one step of the stepper motor rotates the shaft by $1/200^{th}$ ($360/1.8 = 200$ steps) of a revolution.

Servo motors provide excellent speed regulation, high torque and high efficiency, and they are ideally suited for closed loop systems.

NC positioning system (motion control)

The three basic types of motion control used in NC systems are: 1. Point-to-point control 2. Straight cut control, and 3. Contouring or continuous path control.

Point-to-point (PTP) control: It is also called a *positioning system*. The PTP control system positions the tool from one point to another within a coordinate system. Each slide axis is controlled separately and the motion of the axes is either one axis at a time (refer fig. 5.4a) or multiple axes motion with constant velocity on each axis (refer fig. 5.4b). The control of motion is always defined by the programmed points, not by the path between them. The data for the desired position is given by coordinate values. Rapid traverse is usually a PTP operation. PTP controls are used mainly in drilling, punching and tapping.

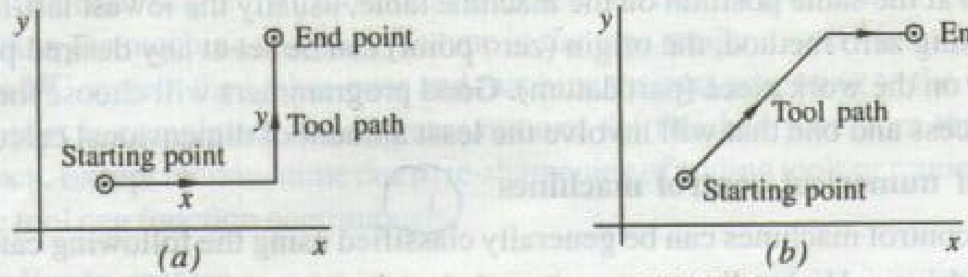


Fig. 5.4 Point-to-point control in NC

Straight cut : In straight cut motion control the machine is capable of moving the cutting tool parallel to only a single machine axis at a controlled rate suitable for machining. This type of motion is very restrictive and is less widely applied. An NC machine tool capable of performing straight cut movements is also capable of point-to-point movements. It is mainly used in straight milling operation.

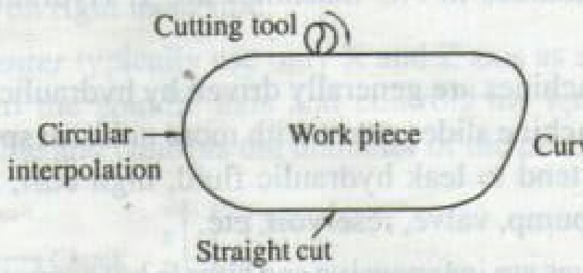
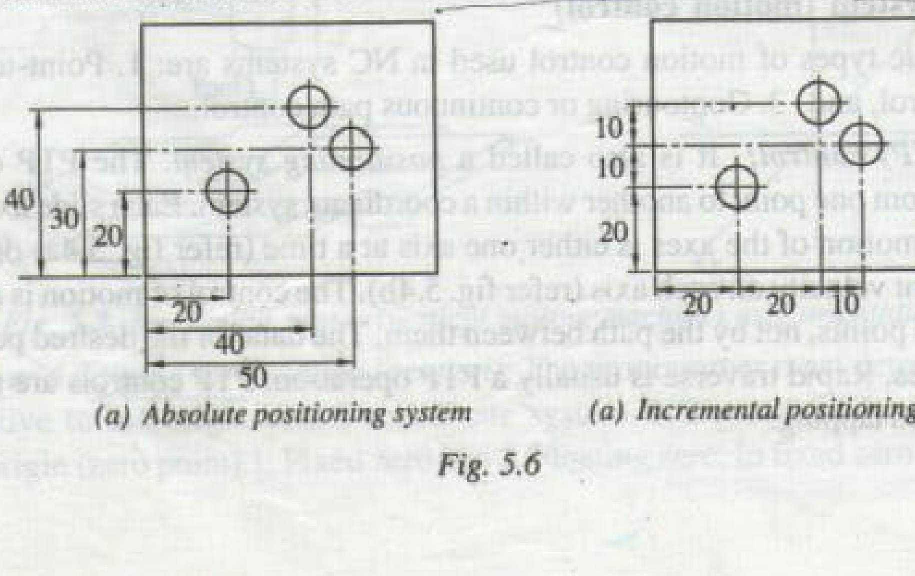


Fig. 5.5 Contouring control in NC

Contouring: A continuous path or contouring control system independently controls the speed of each slide axis and has the capability of moving two or more machine axes simultaneously. In contouring system, positioning and cutting operations are both along controlled paths but at different velocities. Because the tool cuts as it travels along a prescribed path, accurate control and synchronization of velocities and movements are important. This type of control is used for machining arcs, circles or any other form which are mathematically definable (fig. 5.5). It is mainly used on lathes, milling machines, grinding machines and welding machinery.

Absolute and incremental positioning system

Absolute programming implies that the coordinate locations are given as absolute values in the machines coordinate space. i.e., all positions are referenced relative to the same zero or reference point. All positional movements come from the same zero point at all times. Most point-to-point NC



(a) Absolute positioning system *(a) Incremental positioning system*

Fig. 5.6

machines are of an absolute type. The incremental programming implies that each move is specified as an incremental move from the previous position. An absolute and incremental measurement of a part are shown in fig. 5.6a and fig. 5.6b respectively.

Absolute positioning systems have a major advantage over incremental positioning. If the programmer makes a mistake when using absolute positioning, the mistake is isolated to the one location. When the programmer makes a positioning error using incremental positioning, all future positions are affected. Most NC machines allow the programmer to mix absolute and incremental programming.

Control-loops

Every control system, including NC systems may be designed as either an open loop or a closed-loop control system. Open loop systems provide no check or measurement to verify that a specific position has actually been reached. No feedback information is passed from the machine tool back to the controller. In an open loop system, a stepping motor is generally employed as the driving component to provide the machine-slide motion.

The program commands are converted into electric pulses or signals by the controller unit. These pulses are fed to the stepping motor. The stepping motor is an electromechanical device driven by an electrical pulse train to produce a sequence of angular movements corresponding to the number of pulses. Since there is no feedback from the slide position, the systems accuracy is solely a function of the motor's ability to step through the exact number of steps provided as its input. Fig. 5.7 shows an open-loop control system for a single axis of motion.

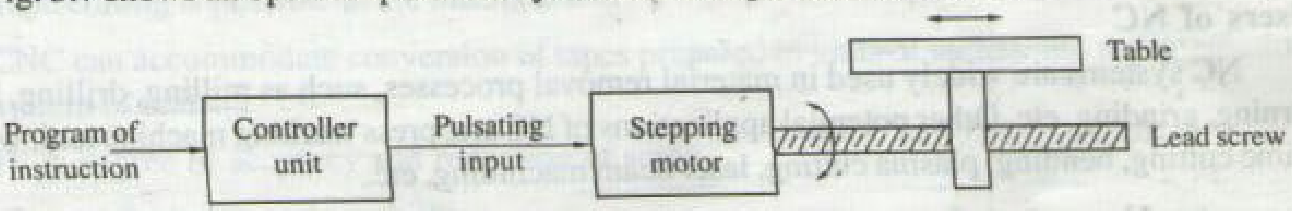


Fig. 5.7 Open-loop control in NC

One of the disadvantages of the stepping motor as the drive unit is the possible loss of one or more pulses when the motor is operating under heavy loads. This results in a loss in accuracy of table position.

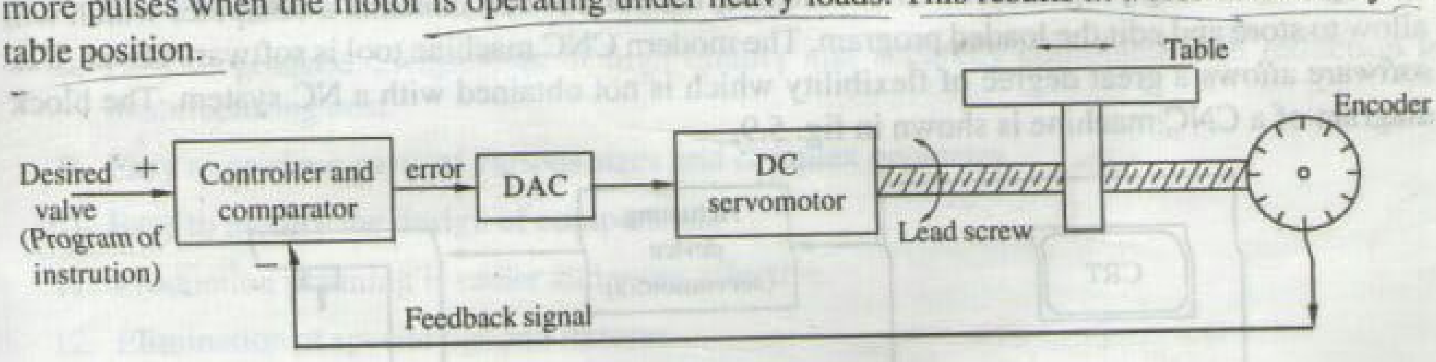


Fig. 5.8 Closed-loop control in NC

In closed loop system as shown in fig. 5.8, the slides actual position is measured by encoders and compared with the desired position. This feedback comparison provides the ability to correct any position and velocity errors. Closed loop NC systems generally use DC servomotor in the drive systems. A digital-to-analog convertor (DAC) is necessary between the comparator and the DC motor.

Advantages and disadvantages of NC

Advantages:

1. Flexibility of operation is improved, as is the ability to produce complex shapes with good dimensional accuracy.
2. Reduced non machining and lead time.
3. Reduced inventory.
4. *Reduced floor space requirements.*
5. Reduced tool costs, since templates and other fixtures are not required.
6. High productivity.
7. High product quality.
8. Longer tool life.
9. Easy to modify the design of components.
10. Consistency using the correct speeds, feeds and tooling to achieve optimum productivity.

Disadvantages:

1. Relatively high initial cost of the equipment.
2. High maintenance cost.
3. Requires skilled programmers and operators.

Users of NC

NC systems are widely used in material removal processes, such as milling, drilling, boring, turning, grinding, etc. Other potential applications of NC are, press working machine tool, welding, flame cutting, bending, plasma cutting, laser beam machining, etc.

Computer Numerical Control (CNC)

NC controls must read the program each time a part is run. They have no means of storing or editing the existing programs. In CNC machine, the control unit contains a computer which will allow to store and edit the loaded program. The modern CNC machine tool is software driven. The software allows a great degree of flexibility which is not obtained with a NC system. The block diagram of a CNC machine is shown in fig. 5.9.

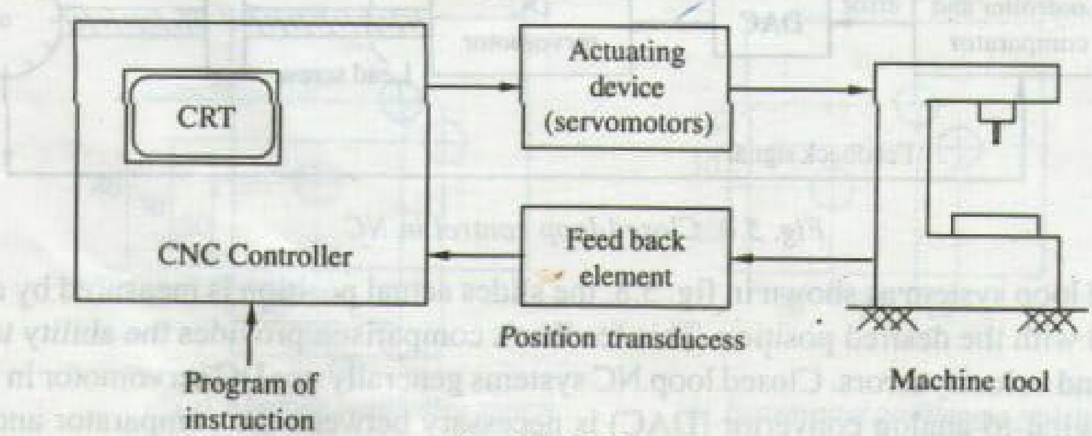


Fig. 5.9 CNC system

The function of a computer is to receive coded instructions (input data) in numerical form, process this information and produce output data that causes a machine tool to function. In CNC, the part program is loaded into the computer memory by means of a punched tape or floppy disc. Thus the tape reader or floppy drive is used only for the original loading of part program and data. The program can also be entered by typing on an editor. Cathode ray tube displays were added to CNC machines to allow the operator easy access to information. On the CRT screen, the operator can see the loaded program, tool and cutter offsets, machine positions, spindle speed, power usage, tool path simulation, etc. The tool path simulation can be used to prove the program before the program is run to eliminate programming errors that could damage tools, parts, machine or operator.

The information for each operation is fed from the control unit to the servo motors. The servo motors turn the ball screws, which in-turn drive the different axes of the machine tool. The increasing capability and speed of computers make it possible to continuously monitor the machines position and velocity while it is operating. CNC machine offers accuracy, reliability, repeatability and productivity.

Advantages and disadvantages of CNC machines

Advantages:

1. Part program tape and tape reader are used only once to enter the program into computer memory. This results in improved reliability.
2. Tape editing is possible at the machine site.
3. CNC can accommodate conversion of tapes prepared in units of inches into the international system of units.
4. High degree of accuracy and reduction of scrap.
5. Greater flexibility and capabilities.
6. Reduced non-machining time and lead time for production.
7. Faster in operation and high productivity.
8. Easy to produce components of high quality and accuracy combined with reduction in manufacturing cost.
9. Easy to produce parts of various sizes and complex geometry.
10. Easy to modify the design of components.
11. Production planning is easier and more effective.
12. Elimination of special jigs and fixtures.
13. Greater operator safety.
14. Longer tool life.
15. Operator errors are virtually eliminated due to dry run feature.
16. Reduced space requirements.
17. Less inspection required.

Disadvantages:

1. High initial cost.
2. High maintenance cost.
3. Requires skilled programmers and operators.

Direct Numerical Control (DNC)

In direct numerical control, several machines are directly controlled step by step by a central mainframe computer. In this system, the operator has access to the central computer through a remote terminal. Thus handling tapes and need for computers on each machine are eliminated. The computer is designed to provide instructions to each machine tool on demand. With DNC, the status of all machines in a manufacturing plant can be monitored and assessed from the central computer. However, DNC has the disadvantage that if the computer goes down, all the machines become inoperative.

Components of DNC system

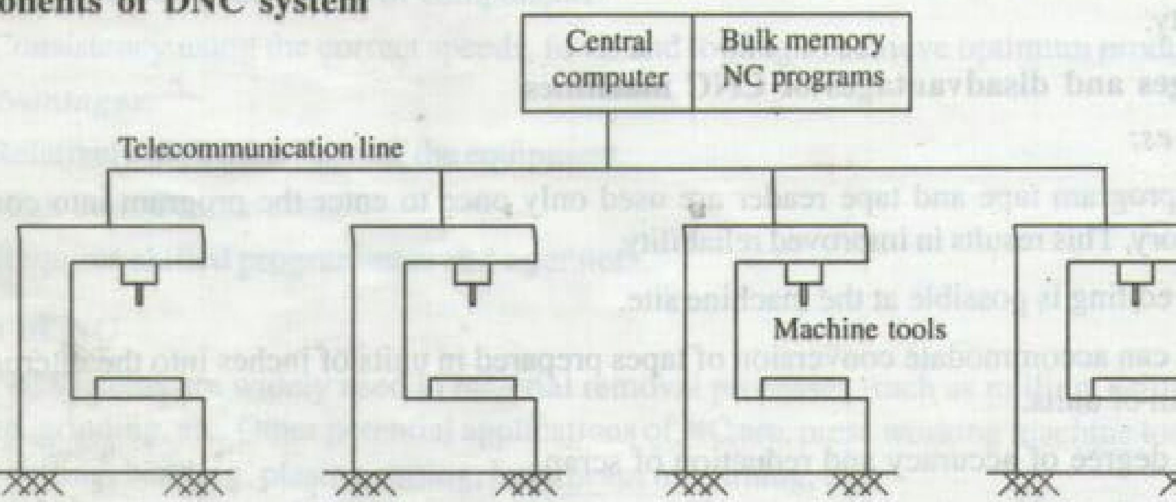


Fig. 5.10 DNC system

Fig. 5.10 illustrates the configuration of the basic DNC system. It consists of four basic components.

1. Central computer,
2. Bulk memory to store NC programs,
3. Telecommunication lines and
4. Machine tools.

The computer calls the part program instructions from the bulk storage and sends them to the individual machines as the need arises. The feature of DNC system is that the computer is servicing a large number of separate machine tools, all in real time.

A more recent DNC (Distributed Numerical Control) includes the use of central computer serving as the control system over a number of individual computer numerical control machines with onboard micro computers (fig. 5.11). This system provides large memory and computational capabilities, thus offering flexibility while overcoming the previous disadvantage of DNC. The central computer downloads complete programs to CNC machines as required. These machines may store one or more programs in their local storage, and they are thus independent of the central computer, but the distributed arrangement allows flexibility in determining the machine to carry out a particular job. DNC systems of all types often provide facilities for a reporting of machine operation data to central computers for the provision of workshop management information.

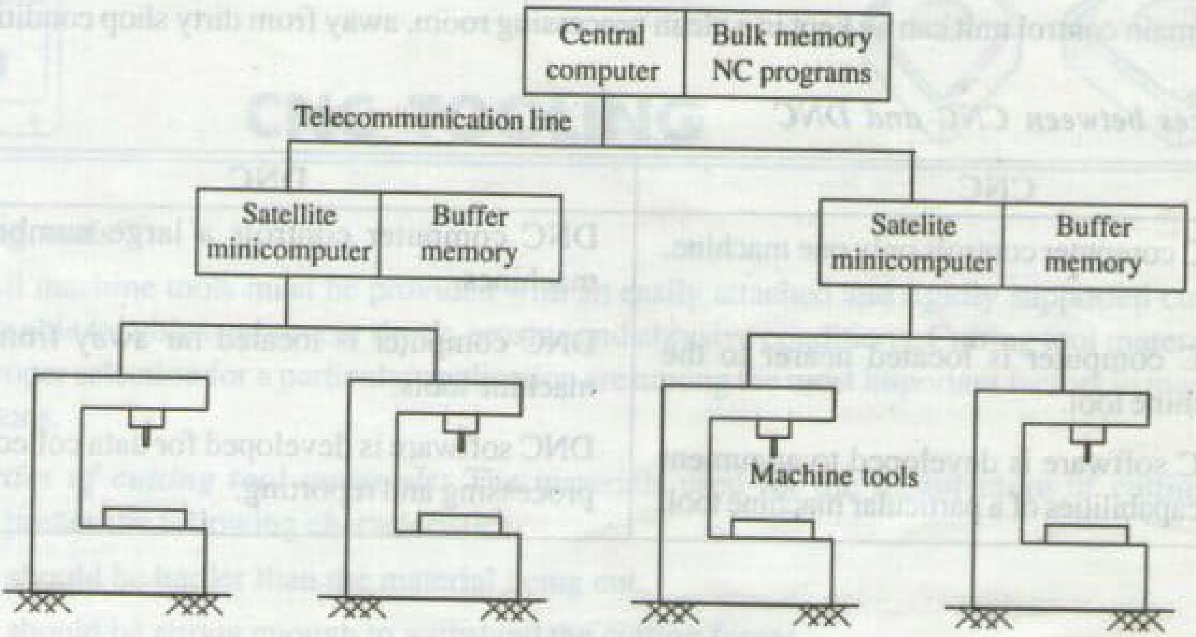


Fig. 5.11 DNC with minicomputer

Functions of DNC

The principal functions of DNC are: 1. NC without punched tape, 2. NC part program storage, 3. Data collection, processing and reporting, 4. Communications.

1. NC without punched tape: The objective of DNC is to eliminate the use of punched tape to overcome the difficulties in making corrections, and changes in the program contained on punched tape, etc.

2. NC part program storage: The program storage subsystem must be structured to satisfy the following purposes.

i) The storage subsystem must allow for new program to be entered, edited, deleted, etc.

ii) The programs must be made available for downloading to the NC machine tools.

iii) DNC software must accomplish the post processing function.

3. Data collection, processing and reporting: DNC involves a two-way transfer of data. Data are collected on production piece counts, tools usage, machine utilization, and other factors that measure the performance in the shop. These data must be processed by the DNC computer, and reports are prepared to provide management with information necessary for running the plant.

4. Communications: A communication network is required to accomplish the above functions.

Advantages of DNC

1. Elimination of punched tapes and tape readers.
2. Reduction in data input errors.
3. Greater computational capability and flexibility.

4. Greater storage capacity.
5. Continuous status monitoring and machine utilization.
6. Control of more than one machine on real time basis.
7. The main control unit can be kept in a clean processing room, away from dirty shop conditions.

Differences between CNC and DNC

CNC	DNC
1. CNC computer controls only one machine.	DNC computer controls a large number of machines.
2. CNC computer is located nearer to the machine tool.	DNC computer is located far away from the machine tools.
3. CNC software is developed to augument the capabilities of a particular machine tool.	DNC software is developed for data collection, processing and reporting.

EXERCISE - 5

1. What is numerical control?
2. Explain the principle of NC.
3. List and describe the basic components of a NC system.
4. Explain the functions of MCU of a NC machine.
5. Briefly explain the basis of designating the coordinate axes in CNC machine tools.
6. How are NC machines classified?
7. Explain the differences between point-to-point and contouring systems.
8. Explain the open loop and closed loop control systems used in NC.
9. Describe the NC procedure.
10. What are the advantages and disadvantages of numerical control?
11. List the applications of NC machines.
12. Explain the principles of CNC machines.
13. What are the advantages and disadvantages of CNC?
14. Briefly explain DNC.
15. What are the functions of DNC?
16. What are the advantages of DNC?
17. Differentiate between CNC and DNC.