UNIT 5 CNC MACHINES AND TOOL HANDLING SYSTEMS

5.1 INTRODUCTION

Numerical Control (NC)

Numerical control (NC) systems are hardware controls in which most of functions are carried out by electronic hardware based upon digital circuit technology. Numerical Control is a technique for controlling machine tools or processes using coded command instructions. These coded command instructions are interpreted and converted by NC controller into two types of signals namely; motion control signals and miscellaneous control signals.

Motion control signals are a series of electric pulse trains that are used to control the positions and the speed of the machine table and spindle, whereas miscellaneous control signals are set of ON/OFF signals to execute the spindle rotation and direction, control of coolant supply, selection of cutting tools, automatic clamping and unclamping, etc. In motion control signals, each pulse activates a motion of one basic length-unit (BLU). Figure 5.1 represents a typical NC system.

Computer Numerical Control (CNC)

CNC controls are soft-wired NC systems as control functions are controlled by software programs. Alternatively, Computer Numerical Control is the numerical control system in which dedicated, stored program microprocessors are built into the control to perform basic and advanced NC functions. Control signals in CNC systems are in the form of binary words, where each word contains fixed number of bits, 32 bits or 64 bits are commonly used, representing different axial positions. For example, BLU= 0.0001 in., this represents motion up to 429 469 in. possible motions.

Direct Numerical Control (DNC)

Direct numerical simultaneously control the operations of a group of NC machine tools using a shared computer. Programming, editing part programs and downloading part programs to NC machines are main responsibilities of the computers in a NC system. Cincinnati Milacron and General Electric first used idea of direct numerical control in the mid 60s. By 1970, about a half dozen vendors marketed their DNC systems (figure 5.2). Due to high cost of mainframe computers and introduction of CNC in 1970s,the DNC system couldn’t become popular in industry.

SAQ*

1. Define the term NC, CNC, DNC, and distributed numerical control.
2. What is BLU, and how it is related to a CNC system?

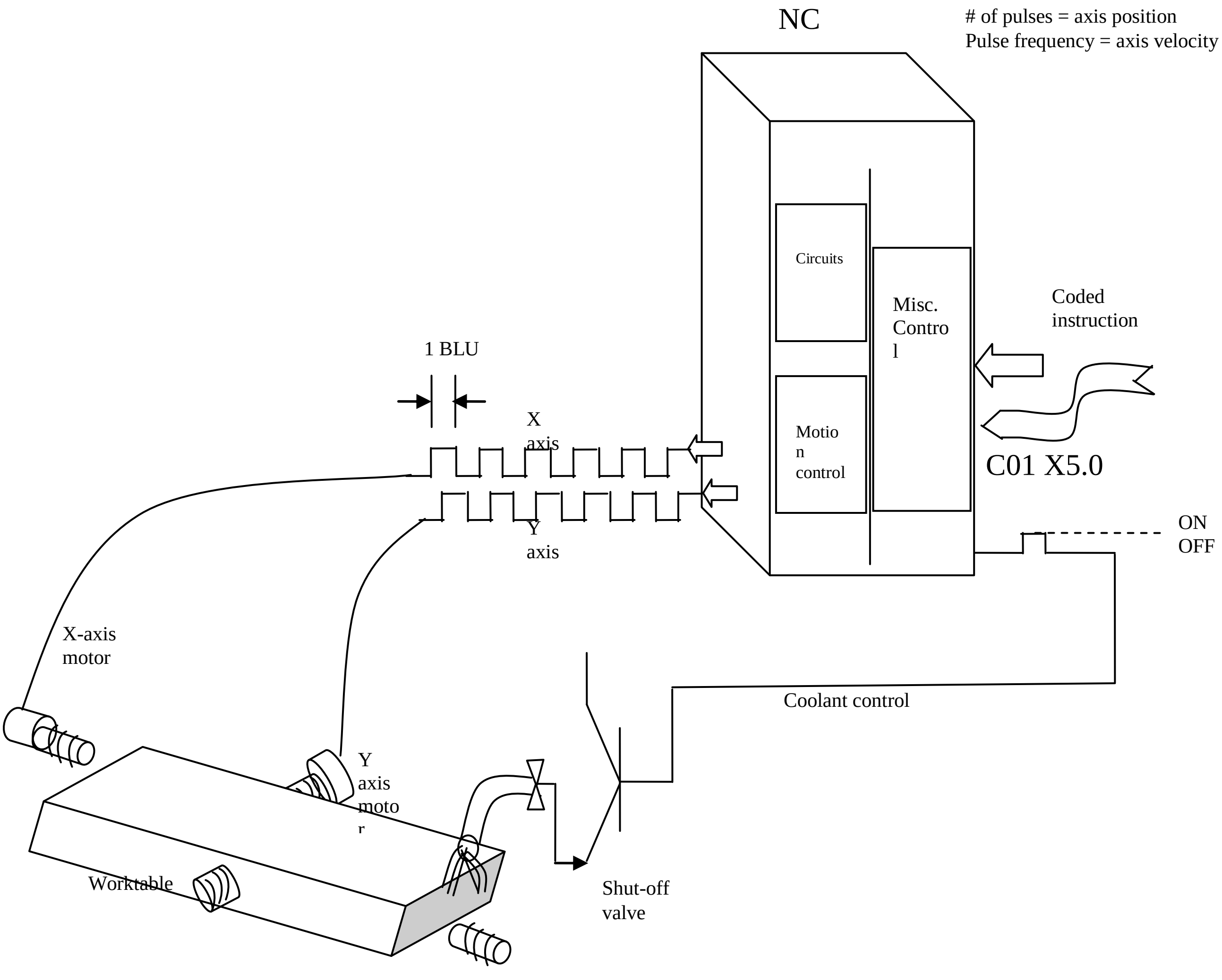


Figure 5.1 numerical control systems

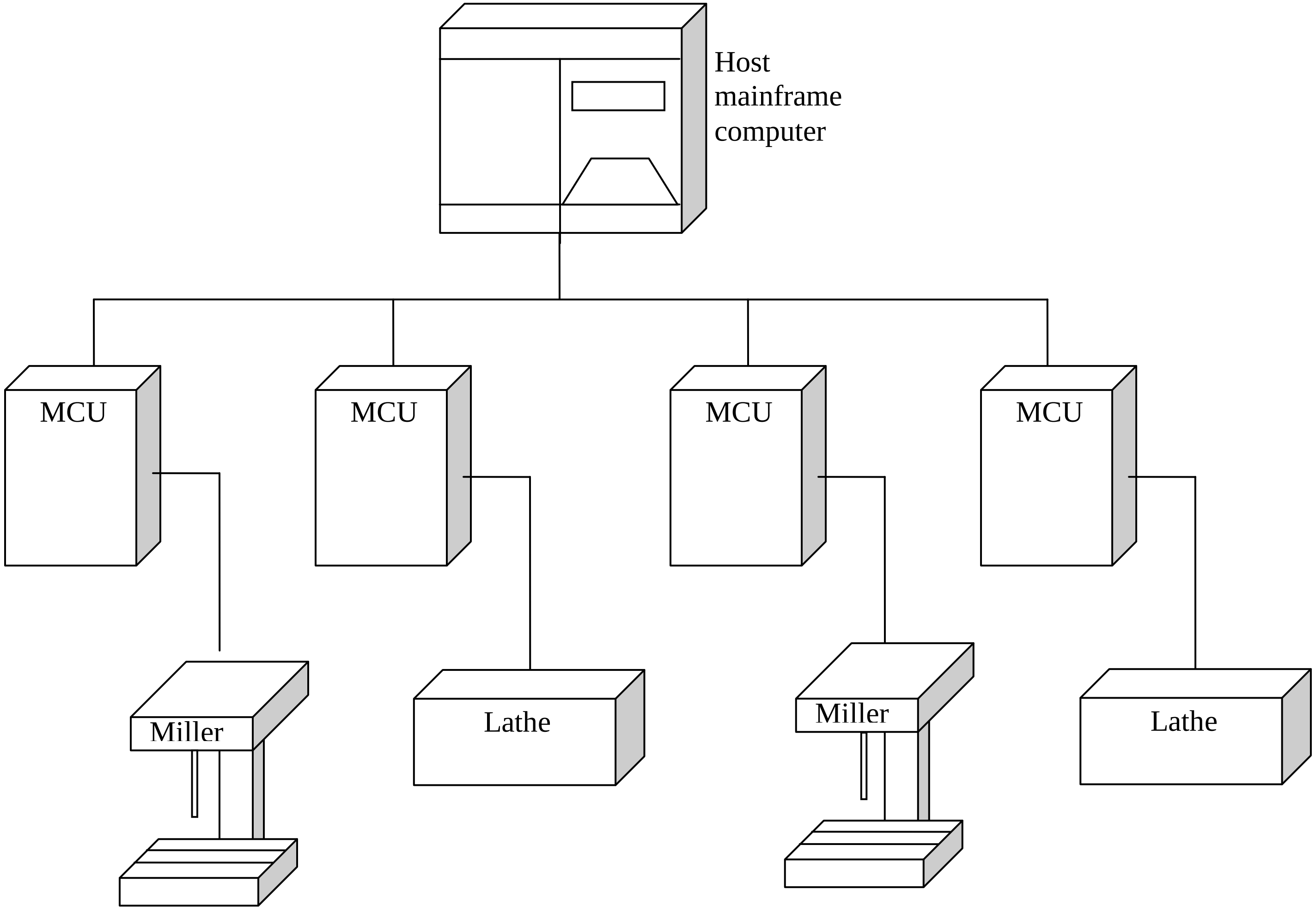


Figure 5.2 Direct Numerical control

The capacity of stored memory and enhanced intelligence of the built-in, low cost, and dedicated computer replaced the desirable features of the DNC systems. Today DNC is utilized for machines to run very large part programs by dropping feeds codes to machine through computers and thus, enabling user to use limited storage of computers.

Distributed Numerical Control (DNC)

In early 1980s, with advancement in computers and communication technologies, engineers realized that in a network of computers there must be a proper co-ordination for operations of a group of CNC machine tools. Hence, Distributive numerical control (DNC) comes into picture. Now, many CNC machines together with robots, programmable logic controllers, and other computer-based controllers have been integrated into DNC systems to make automated manufacturing systems possible. In figure 7.3, a DNC is presented.

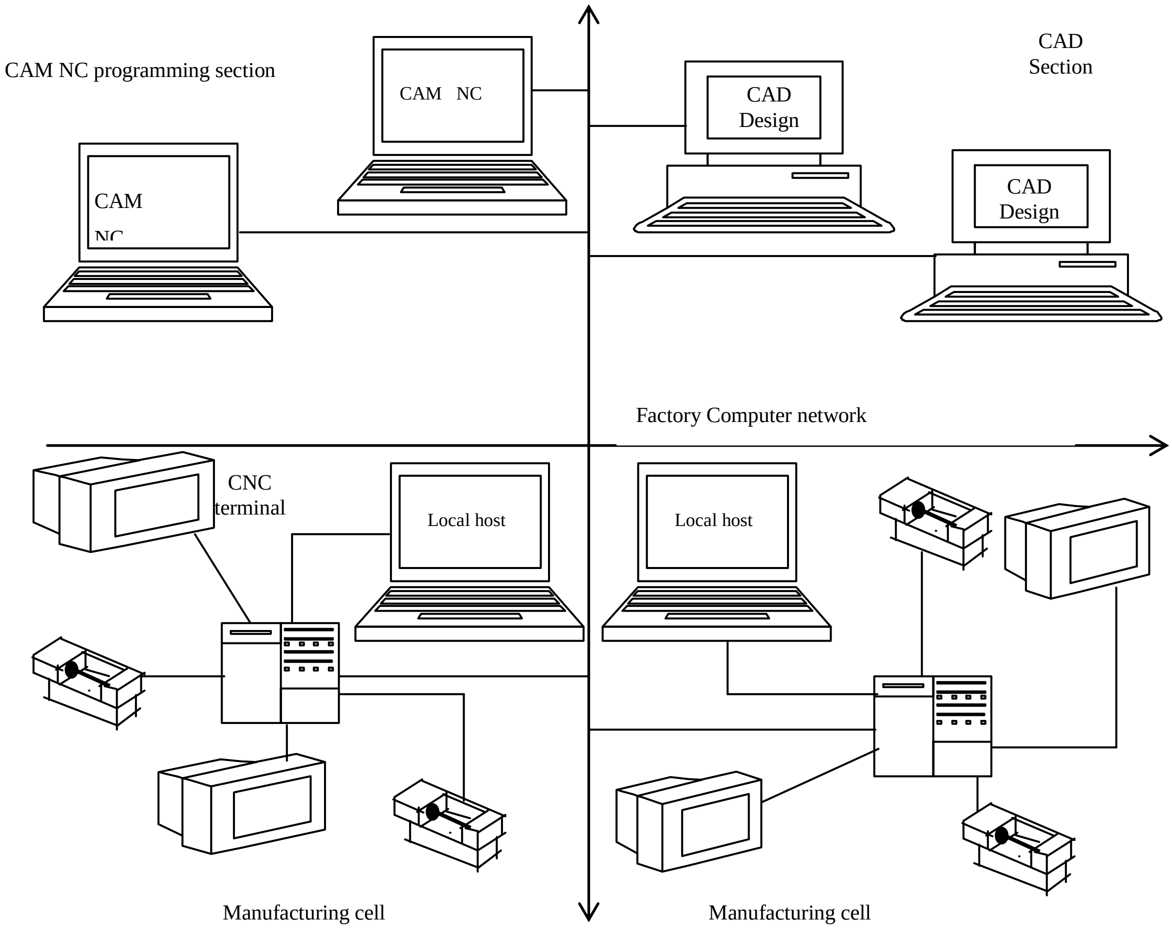


Figure 5.3: Distributed numerical control

5.2 CNC OPERATIONS

Implementing CNC operations is attributed to execution of organizational structure, which varies through out the industry. There is greater need of organization for the larger operation. Functions incorporated in CNC group are independent of group size. It depends on the allocation of those functions. Smaller operations are performed by a particular department, whereas larger one is assigned to a number of departments by dividing NC functions into smaller groups. Figure 5. 4 illustrates the various facets of CNC operations.

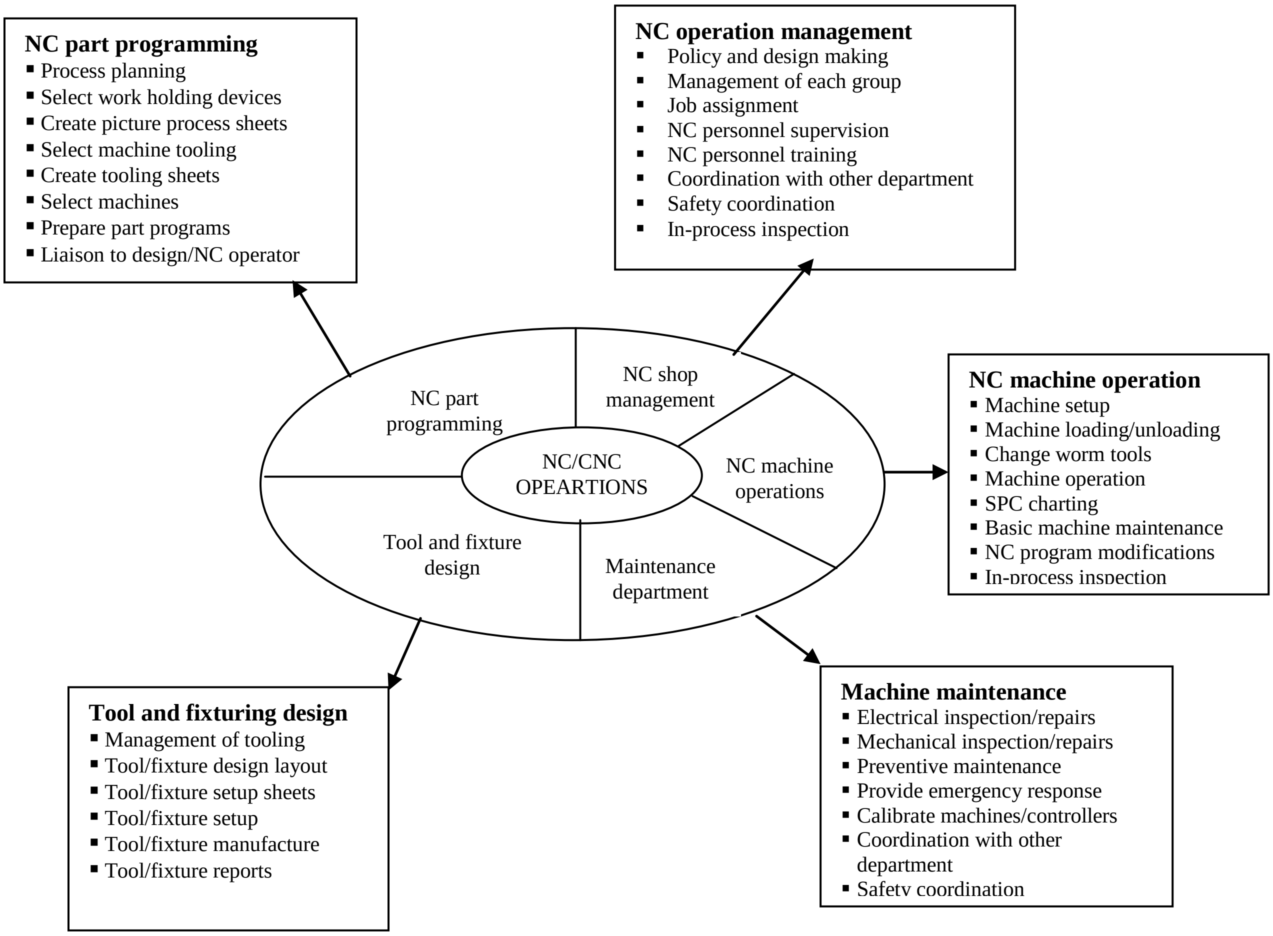


Figure 5.4 CNC operations

5.2.1 NC Shop Management

There will a separate supervisor for each of the areas discussed in figure5.4, in a larger shop and a manager to pre side over the entire department. Whereas, a smaller shop will have either a supervisor or manager administrating the entire operation.

Irrespective of the management structure, the functions are basically same as these six types:

- Policy and decision making
- Management of each group
- Job assignment
- NC personnel and training
- Coordination with other department
- Safety coordination

5.2.2 NC Part Programming

A part program consists of series of coded instructions that direct a CNC controller to cut the part along the desired profile or locations. Part programming begins with a process planning that includes all the information a CNC operator needs for producing work piece. Depending on the size of organization, process plan is simulated by a process planner or an NC programmer. The major tasks involved in part programming are; Process planning, Tool selection and tooling sheets preparation, Work holder selection and layout sheet preparation, Part program preparation, Liaison to designers and NC operators, Machine selection.

5.2.3 Tool and Fixture Design

The tool and fixture group is responsible for the design and manufacture of cutting tools some of the work holders that come with the machine tools such as chucks and vices can secure many simple parts. Some projects require the design of new fixtures that have pins, buttons, clamps, and many other devices mounted on them. The fixturing must be planned before the machining, and it is based on the quantity of parts, the expanses of the parts and their accuracy. The function of the tool and fixture design group are: Tooling and fixturing management, Tool and fixture design making, Tooling setup sheets preparation, and Tool and fixture usage report.

5.2.4 NC Machine Operation

Machine setup and machine operation are two chief tasks performed by NC machine operation. Machine setup involves:

1. Setting up of the workhold devices
2. Loading the NC program

3. Loading necessary tools
4. Measuring and entering work coordinate offset and compensation values

Apart from these a trial run is made to ensure the smooth operation of the machine. Whereas, machine operation includes:

1. Loading and unloading the workpieces
2. Machine operation monitoring for broken and worn tools
3. In-process inspection and measurement and SPC charting

In large shops, these tasks are divided into two groups and handled by two different people.

5.2.5 Machine Maintenance

Last but not the least, CNC controls and machines must have regular maintenance. This mainly comprises of changing cutting tools, calibrating controllers, lubricating moving parts, etc. In case of unexpected mechanical and electrical failure, emergency service is required.

SAQ*

1. Describe six elements of a CNC system.

5.3 CNC SYSTEM ELEMENTS

Any CNC system consists of following elements:

- Part program
- Program input device
- Machine control unit
- Drive system
- Machine tool
- Feedback system

5.3.1 Part Program

A part program is series of coded instruction that are required to the movement of the machine tools and the ON/OFF controls of auxiliary functions such as spindle rotation and coolant for producing a part. The basic commands of coded instructions are G-codes, M-codes, T-function, and F-function. Any part program, simple or complicated, is coded from these instructions. A word is the basic building unit of the part program. It always starts with an address followed by a numeric value, e.g.

G01 Linear interpolation mode

X5.0 X-dimension (5.0 in +X direction)

F15.0 Feed rate at 15 inches per minute

The coded instructions are composed of letters, numbers, and symbol and are arranged in the format of functional words and blocks, e.g.

N5 G00 X2.0 Y3.0 S1000 M3

Where N5= sequence number

G00= rapid traverse mode

X2.0= X-coordinate (2.0”)

Y3.0= Y-coordinate (3.0”)

S1000= spindle rate (1000 rpm)

M3= spindle on (Clockwise direction)

There are four methods of generating CNC part programs, namely: manual programming method, computer-assisted programming method, conversational programming method, and CAD/CAM programming method. In the manual programming method, standard G-codes, M-codes, T-function, and F-function are used to create the part program block-by-block. A computer program allows the programmer to pre-define part-geometry, tool-path movements and auxiliary functions, in computer-assisted programming method. Most modern CNC controls provide conversational programming function to allow part-programmers to interact with the control for generating part programs. CAD/CAM programming method mainly consists of three components CAD, CAM, and post processor. CAD creates part geometry; CAM uses that part geometry to generate tool paths. Finally, the post-processors convert the toolpaths to CNC part programs for particular CNC machine.

5.3.2 Program Input Device

The program input device is the mechanism used to enter the part program into the CNC control. The main components of program input devices are:

- Punch tape recorder
- Magnetic tape recorder

- Computer via RS-232-C communication
- NIC card for network communication

Figure 5.5 represents a typical program input device.

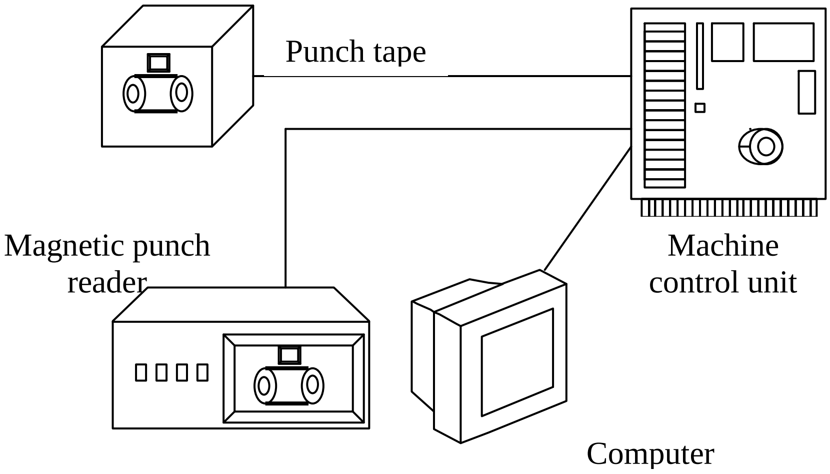


Figure 5.5: Program input device

5.3.3 Machine Control Unit

The machine control unit (MCU) is the backbone of CNC systems. Following six functions are being done by MCU:

- Read coded instructions
- Decode coded instructions
- Implement interpolations to generate axis motion commands
- Feed axis motion commands to amplifier circuits to drive axis mechanisms
- Receive the feed back signals of position and speed for each drive axis
- Implement auxiliary control functions such as coolant ON/OFF, spindle ON/OFF, and tool change

5.3.4 Drive System

Amplifier circuits, drive motors, and ball lead screws are main component of a drive systems. Control signals i.e. position and speed of each axis is fed to amplifier circuits from MCU. The control signals are augmented to actuate drive motors that in turn rotate ball lead-screws to position the machine table.

5.3.5 Machine Tool

CNC controls are used to control various types of machine tools. Irrespective of type of machine tool is to be controlled, a machine consists of one or two motion axes (X and/or Y) perpendicular to the work head and one motion axis (Z) parallel to the work head. Some machines are equipped with index tables that allow rotary motions (A, B, or C) around the linear axes (X, Y, or Z).

5.3.6 Feedback System

A feed back system is also referred to as a measuring system. It uses position and speed transducers to continuously monitor the position of the cutting tool at any particular time. The MCU uses the difference between reference signals and feedback signals for correcting position and speed errors.

SAQ*

1. Discuss importance of program input device and list any three of them.
2. What is the purpose of feedback system in a CNC system?

5.4 DATA CARRIERS AND INPUT DEVICES

5.4.1 Data Carriers for NC Part Programs

To store NC programs various forms of data carriers have been used since the years NC has evolved. Punched card, punched tape, magnetic tape, motion picture film, punched plastic tape, floppy diskette, and hard disk are various forms of data carriers. Figure5.6 shows a typical representation. Advancement in communication technology results in wide use of floppy diskette, hard disk, network server, and internet. Part program can be remotely distributed via modern communication media such as electronic mails, internet, intranet, etc.

Punched tape

Punched tape is used for practical storage of part programs. It is reliable because the data will not change, although the tape can be physically damaged. In earlier NC days, punched tapes were used extensively. Prevalence of computer disks has drastically reduced its use. But, still used as backup storage media, when the computer is down.

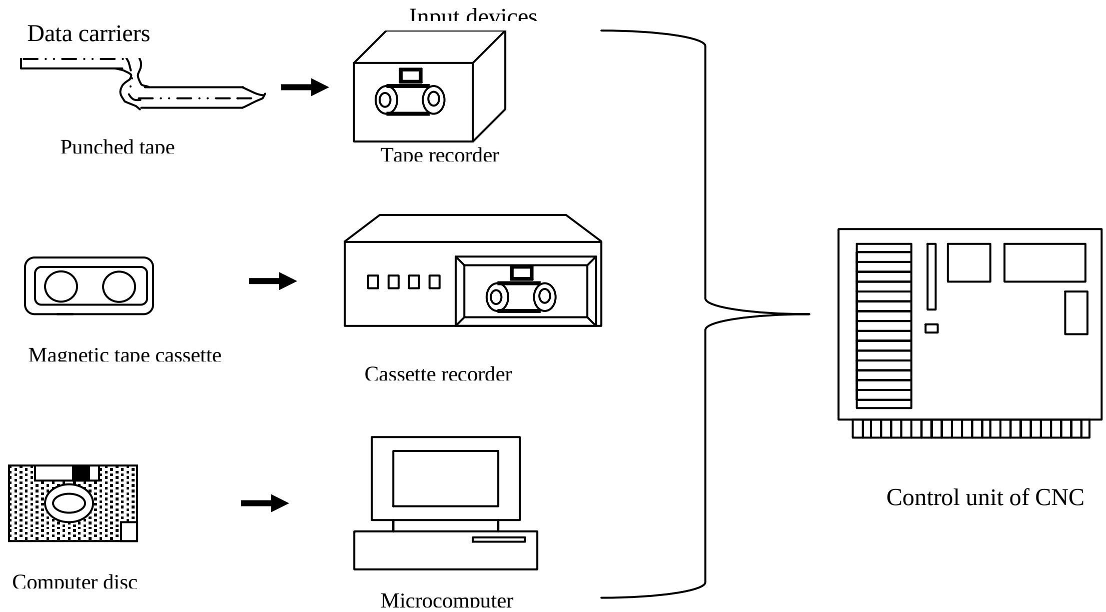


Figure 5.6 Data carriers and input devices

Magnetic Tape

Although it is least costly option for NC part program storage yet not often used due to its low speed. It is also difficult to locate the right program in the tape, and vulnerable to contamination and electromechanical fields in shop floor surroundings.

Computer Disks

In today’s milieu, computer disks are widely used to store NC part program. These disks are of two forms; floppy diskette and hard disk. It is inexpensive, can store large volume data and easy to access.

5.4.2 Input Devices for Part Program

The input device that is used must match with the data carrier. The common input devices used in industries are punched tape recorder for punched tape as data carrier, cassette recorder for magnetic type as data carrier, and computer for disks as data carrier.

5.5 CONTROL SYSTEMS OF A CNC

5.5.1 Point-to-Point System

CNC controls can be either a point-to-point or continuous path system. The point –to-point (PTP) control moves the tool to the programmed point, normally in rapid traverse, without engaging the workpiece. The PTP system is also called the positioning system because its exact tool path normally cannot be controlled. PTP tool path follow one of the three modes: axial path, 45^0 line and linear path. Figure 5.7 represents these three modes.

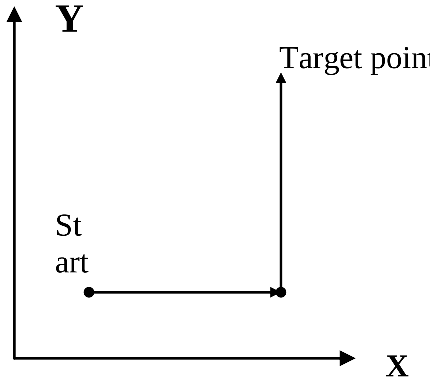


Figure 5.7 (a): Axial path

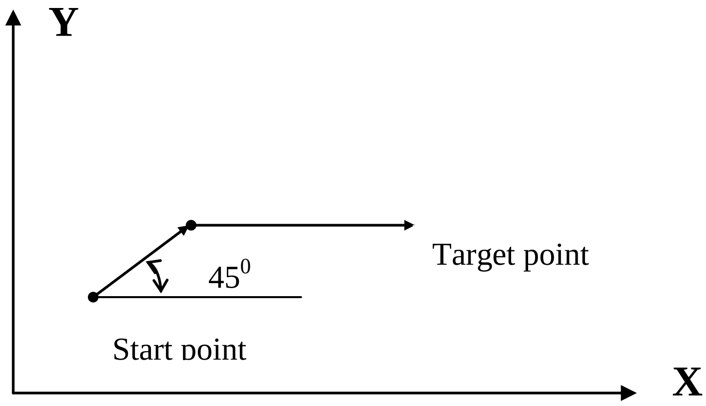


Figure 5.7 (b): 45^0 Line path

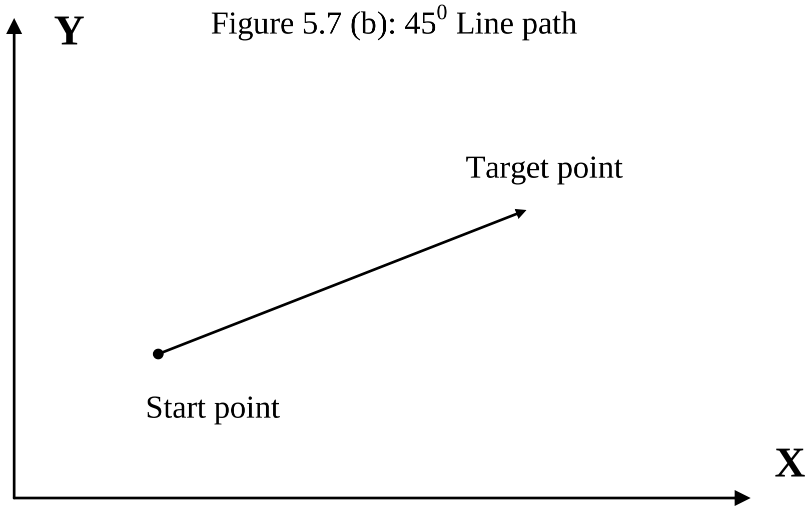


Figure 5.7 (c): Linear path

The PTP systems are typically used in drilling machines, punch presses, and spot welders, which require positioning in the XY plane in rapid traverse mode and executing machining in Z-axis direction. Figure 5.8 depicts the process.

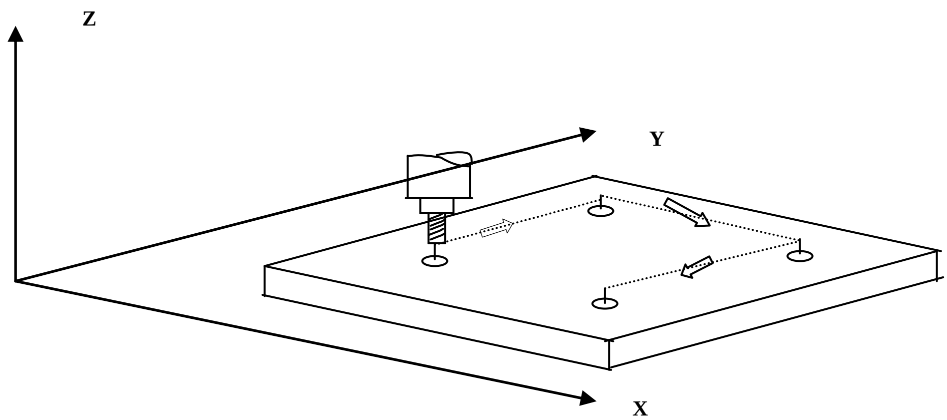


Figure 5.8: an application of a PTP control system

PTP systems are easy to maintain and less expensive.

5.5.2 Continuous Path Control Systems

This is also known as contouring system. It is capable of synchronizing two or more axial drives to produce a desired path. Contour systems are of five types, depending upon type of control. These are:

2-D contouring	It synchronizes feed only in two axes simultaneously
2 ½-D contouring	Any two of three can be controlled simultaneously
3-D contouring	Capable of synchronizing three axes simultaneously
4-axis machining	Apart from 3 regular axis, 4^{th} axis is rotary axis
5-axis machining	It incorporates 3 regular and 2 rotary axis

5.5.3 CNC Drive Systems

The structure of CNC control can be either an open loop or closed loop system. The main difference between the two systems depends on whether or not the system has a feed back loop to insure the accuracy of the system performance.

Open Loop

Open loop is characterized by no feed back system in the drive system. MCU provides control to the drive motors. It is being assumed by the system that the machine table will reach the target position. There is no way from the MCU to know the actual performance of the system. Figure5.9 shows a block diagram of an open loop CNC drive system.

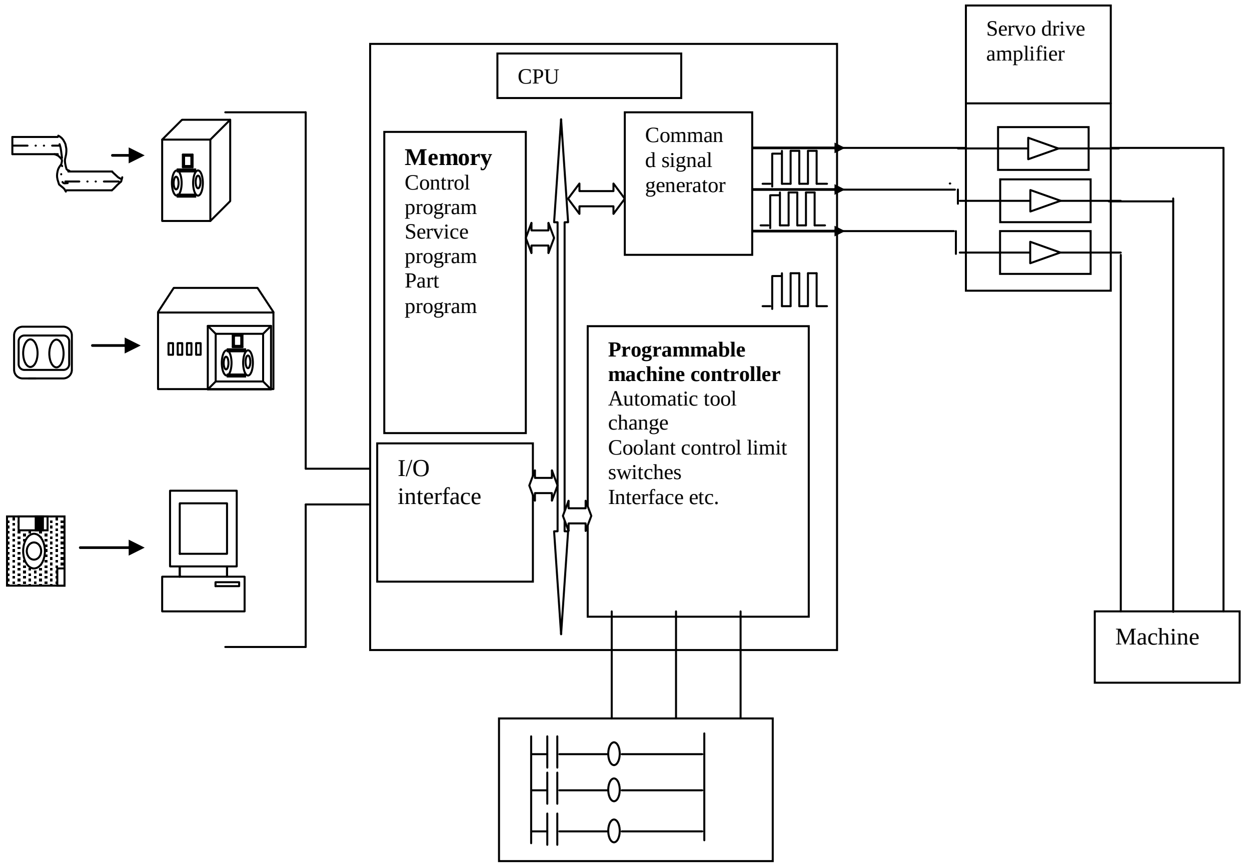


Figure 5.9 Open loop CNC drive systems

PTP system usually uses open loop drive systems, where cutting tool doesn't engage with workpiece during positioning. They can also be used in light-loaded cutting machines. Although they are economical but are vulnerable to load resistances during positioning.

Closed Loop

With closed loop drive systems, feedback sub systems are used to monitor the actual output and correct any discrepancy between the desired and the actual system performance. Feedback subsystems are of two types:

1. *Analog feedback system*: Variations in physical systems such as position and velocity are being measured as voltage levels in analog feedback system. Tachometers are typically used to measure the velocity, whereas the resolvers are used to measure position. There are two feedback loops in CNC drive systems; position loop and velocity loop as shown in figure5.10 The position

loop is the outer loop, which consists of comparator, an amplifier circuit, a velocity loop, a resolver, and a resolver interface.

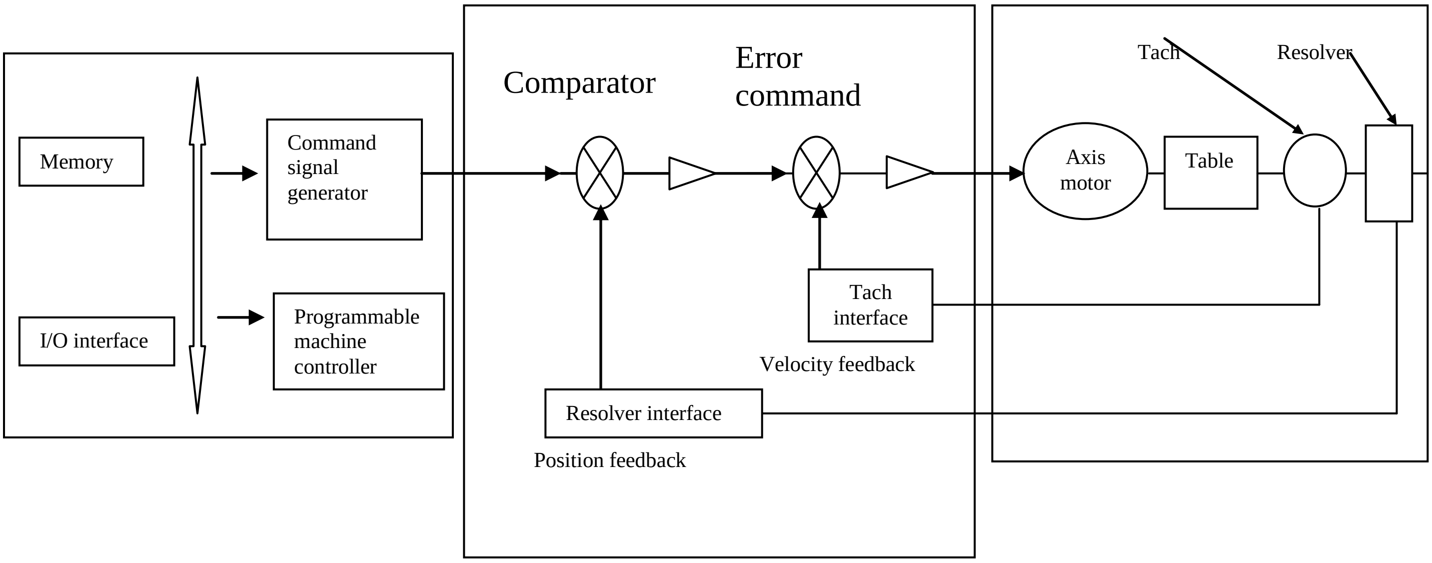


Figure 5.10 Analog closed loop CNC drive

2. *Digital feedback system*: A digital feedback system uses a digital position transducer to measure the position. Encoders are popular digital position transducers. Comparator and amplifier are replaced by up-down counter and digital-to-analog converter.

SAQ*

1. Discuss point-to-point and continuous path control systems.
2. Differentiate between a closed loop analog and digital system?

5.5 CNC INTERPOLATIONS

Interpolations are done to execute contouring tool paths. It produces a series of intermediate data points between given coordinate positions and computes the axial velocity of an individual axis along the contour path. Now a day's all CNC controls are equipped with linear and circular interpolations, some provides helical interpolation, and a very few provides parabolic and cubic interpolations.

1. *Linear interpolation*: This moves tool from start point to the target point along a straight line. It can be implemented in a 2-D plane or 3-D space. the programming command should indicate X, Y, Z coordinates of target point, and feed rate.
2. *Circular interpolation*: It is programmed to cut circular arcs in three principal planes; namely XY, YZ, ZX. Direction, target position, arc radius, cutting plane, and feed rate must be specified in the program.
3. *Helical interpolation*: Helical interpolation combines the two-axis circular interpolation with a linear interpolation in third axis.
4. *Parabolic interpolation*: It uses three non-collinear points to approximate curves that are of free forms. It reduces the number of programmed points by as much as 50 times the number required by the linear interpolation mode. It is mainly used in mold and die making.
5. *Cubic interpolation*: Cubic interpolation approximates the surfaces defined by third-order geometry. It involves the motion of three axes to machine complex shapes such as automobile sheet metal dies.

5.6 TYPES OF CNC MACHINES

In every aspects of manufacturing CNC machines are used. It can be mainly classified in eight classes.

1. *Mills and Machining centers*
2. *Lathes and Turning centers*
3. *EDM Machines*
4. *Grinding machines*
5. *Cutting Machines*
6. *Fabrication Machines*
7. *Welding Machines*
8. *Coordinate Measuring Machines*

5.6 ADVANTAGES AND LIMITATIONS

1. *Advantages*
    - Reduces product cost
    - Improved product quality

- Facilitate production planning and control
- Increased productivity
- Greater flexibility

2. *Limitations*
    - High initial investment
    - High maintenance
    - For low production it is costlier process

SAQ*

1. Enumerate advantages and limitations of CNC system.

5.7 TOOL HANDLING SYSTEMS

For successful operation of any system a comprehensive tool management is required. It can be defined as the capability of having the correct tools on the appropriate machines at the right time while maintaing acceptable utilization of manufacturing resources. It should be ensured that tooling never causes delay in production. In a typical machining system, actual cutting time represents a value between 5 and 20% average machine utilization time. Automating tool handling and management system results in a number of benefits, such as: increase in machine productivity, elimination of emergency tools and purchase of incorrect tools, and improvement in product delivery time.

5.7.1 Components of Tool Handling Systems

Tool magazine and automatic tool changer

A tool magazine and tool changer is placed on machine. Figure 5.11 shows some frequently used types of tool magazine. The operational aspect of a tool changer is shown in figure 5.12.

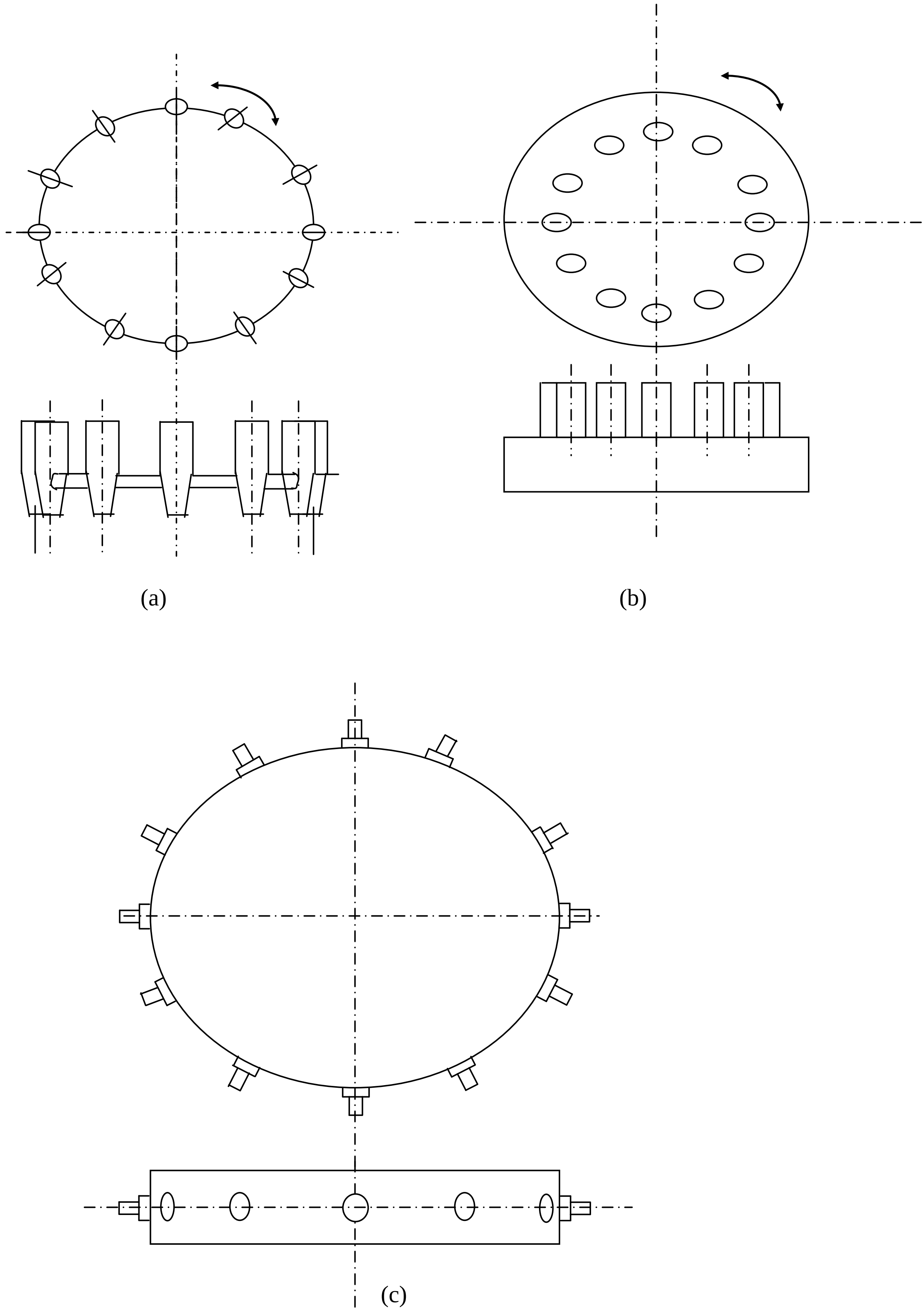


Figure 5.11 Types of tool magazines: (a) disk, (b) drum, (c) turret.

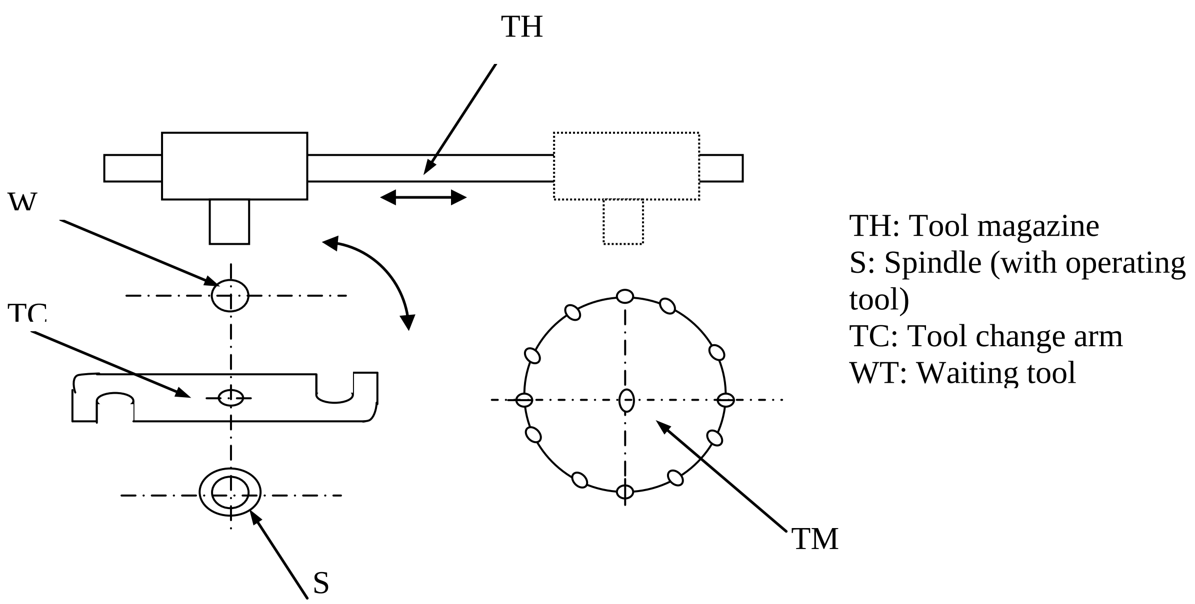
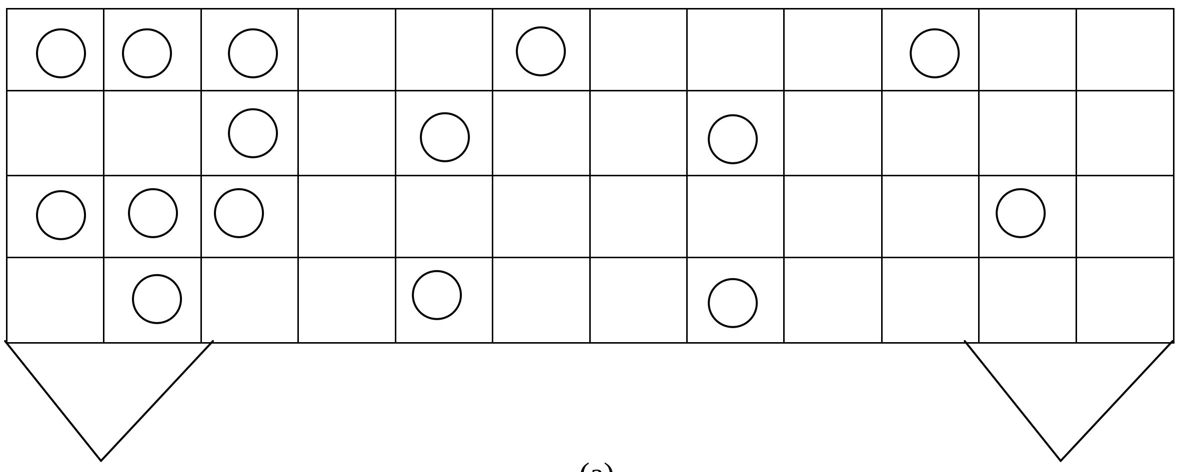


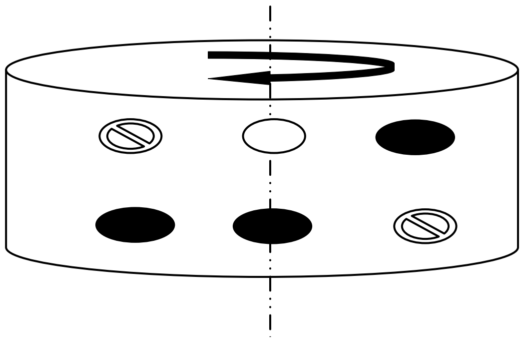
Figure 5.12 Tool changer

Tool Storage and Support System

It is concerned with preparing tools for the production in time. The functions performed in the tool storage system are tool identification, tool storage, and tool presetting. Additional support executed in the tool storage and support system includes buildup tool assemblies returned from the machines and tear down of tool assemblies. Two types of typically used stockers are rack stocker and disk stocker (figure 5.13).



(a)



(b)

Figure 5.13 Tool stockers (a) rack stockers, (b) disk stockers

Tool Handling

The tool handling system transfers tools from the tool storage and tool room to the individual tool magazines on each machine. Depending on tool changeover requirements, one tool handling system can serve several machines. A tool handling system equipped with an automated guided vehicle (AGV) reduces or elimiantes setup time and increases machine utilization. Figure 5.14 depicts an AGV mounted robot loading a tool magazine with tools.

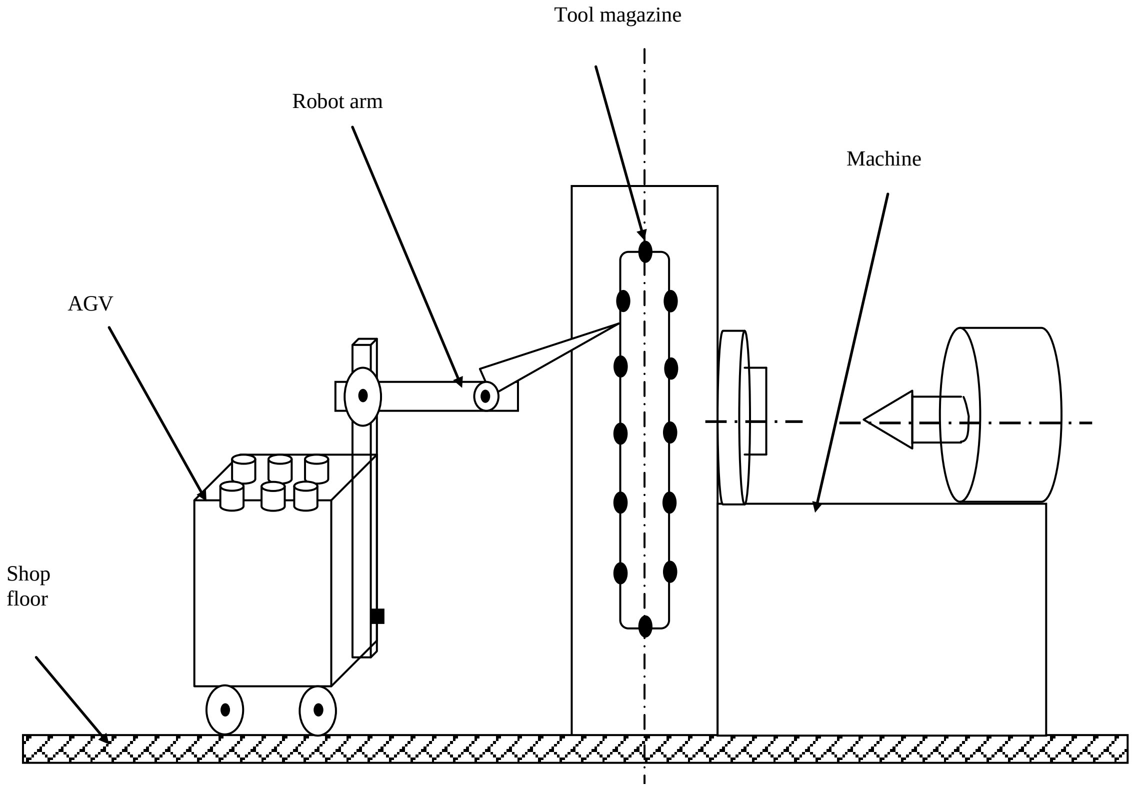


Figure 5.14 Loading of tool magazine

SAQ*

1. Give an application of disk, drum, and turret.
2. Briefly discuss Tool handling system.

5.8 SUMMARY

This text has presented what the authors feel are important concepts in CNC. Role of CNC machines in CIM environment and its recent trends and advances are discussed from a pragmatic perspective. It should be obvious that some technologies are maturing to the point that the coming decades will be an exciting era in manufacturing. However, much has been learned, and sufficient technology is available to allow a careful progression towards achieving CIM.

5.9 KEYWORDS

Numerical Control, Computer Numerical control, Direct Numerical Control, Distributive Numerical Control, Tool Handling System.

5.10 ANSWER TO SAQ

Refer in the text.

5.11 REFERENCES

1. Mason, F. (1986). " Computerized cutting-tool management", *American Machinist and Automated Manufacturing*, May, pp. 105-120.
2. Chang, T., C., Wysk, R., A., Wang, H-.,P. " Computer-Aided Manufacturing".