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NPTEL ONLINE
CERTIFICATION COURSES

AUTOMATION IN PRODUCTION SYSTEMS AND MANAGEMENT

Fundamentals of NC Technology-I

PROF PRADIP KUMAR RAY

DEPARTMENT OF INDUSTRIAL AND SYSTEMS ENGINEERING

IIT KHARAGPUR

Fundamentals of NC Technology-I

- **Lecture-1:** Historical Perspectives and Application of Numerical Control (NC) Technology
- **Lecture-2:** Basic Concepts of an NC System
- **Lecture-3:** NC Coordinate System, NC Motion Control System
- **Lecture-4:** Features of CNC, Configuration of CNC Machine Control System
- **Lecture-5:** Numerical Examples

Fundamentals of NC Technology-I

- ✓ **Historical Perspectives and Application of Numerical Control (NC) Technology**

Introduction to Concept and Application of Numerical Control (NC) Technology

- Numerical control (NC) is a form of programmable automation in which the mechanical actions of a machine tool or other equipment are controlled by a program containing coded alphanumeric data.
- Alphanumeric data represent relative positions between a workhead and a workpart as well as other instructions needed to operate the machine.
- Workhead is a cutting tool or other processing apparatus, and the workpart is the object being processed.

Introduction to Concept and Application of Numerical Control (NC) Technology

- When the current job is completed, the program of instructions can be changed to process a new job.
- The capability to change the program makes NC suitable for low and medium production.
- It is much easier to write new programs than to make major alterations in the processing equipment.

Introduction to Concept and Application of Numerical Control (NC) Technology

Numerical control can be applied to a wide variety of processes.

1. Machine tool applications, such as drilling, milling, turning and other metal working.
2. Nonmachine tool applications, such as assembly, drafting, and inspection.
3. The concept for NC dates from the late 1940s. The first NC machine was developed in 1952.

Fundamentals of NC Technology

❑ Basic Components of an NC System:

An NC system consists of three basic components:

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

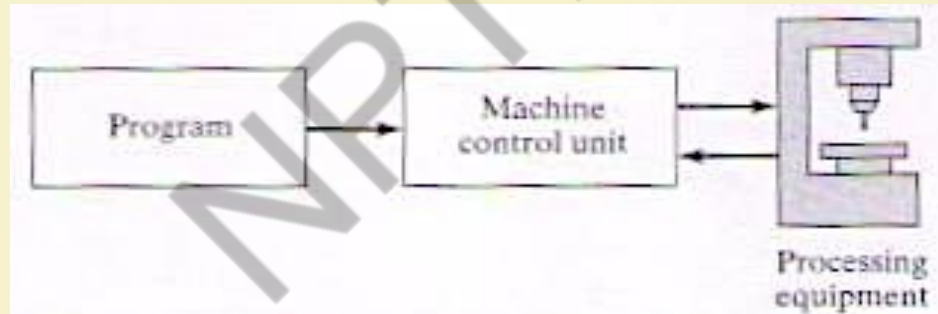


Figure 7.1 Basic components of an NC system.

Fundamentals of NC Technology

- The part program is the set of detailed step-by-step commands that direct the actions of the processing equipment.
- In machine tool applications, the person who prepares the program is called a part programmer.
- The individual commands refer to positions of a cutting tool relative to the worktable on which the workpart is fixtured.
- Additional instructions are usually included, such as spindle speed, feed rate, cutting tool selection, and other functions.

Fundamentals of NC Technology

- The program is coded on a suitable medium for submission to the machine control unit.
- For many years, the common medium was 1-inch wide punched tape, using a standard format that could be interpreted by the machine control unit. Today, punched tape has largely been replaced by newer storage technologies in modern machine shops.
- These technologies include magnetic tape, diskettes, and electronic transfer of part programs from a computer.

Fundamentals of NC Technology

- In modern NC technology, the machine control unit (MCU) is a micro computer and related hardware that stores the program of instructions and executes it by converting each command into mechanical actions of the processing equipment, one command at a time.
- The related hardware of the MCU includes components to interface with the processing equipment and feedback control elements.
- The MCU also includes one or more reading devices for entering part programs into memory. Software residing in the MCU includes control system software, calculation algorithms, and translation software to convert the NC part program into a usable format for the MCU.

Fundamentals of NC Technology

- Because the MCU is a computer, the term computer numerical control (CNC) is used to distinguish this type of NC from its technological predecessors that were based entirely on hard-wired electronics. Today, virtually all new MCUs are based on computer technology; hence, when we refer to NC in this chapter and elsewhere, we mean CNC.
- The third basic component of an NC system is the processing equipment that performs the actual productive work (e.g., machining)

Fundamentals of NC Technology

- It accomplishes the processing steps to transform the starting workpiece into a completed part. Its operation is directed by the MCU, which in turn is driven by instructions contained in the part program.
- In the most common example of NC, machining, the processing equipment consists of the worktable and spindle as well as the motors and controls to drive them.

Advantages and Disadvantages of NC

- Because the MCU is a computer, the term computer numerical control (CNC) NC yields many advantages over manual production methods.
- However, NC involves more sophisticated technology than conventional production methods, and there are costs that must be considered to apply the technology effectively.

Advantages:

- Nonproductive time is reduced.
- Greater accuracy and repeatability.
- Lower scrap rates.
- Inspection requirements are reduced.

Advantages and Disadvantages of NC

- More complex part geometrics are possible.
- Engineering changes can be accommodated more gracefully.
- Simpler fixtures are needed.
- Shorter manufacturing lead times.
- Reduced parts inventory.
- Less floor space required.
- Operator skill-level requirements are reduced.

Advantages and Disadvantages of NC

Disadvantages:

- Higher investment cost.
- Higher maintenance effort.
- Part programming.
- Higher utilization of NC equipment.

List of Reference Textbooks

- Groover, M P, Automation, Production Systems, and Computer Integrated Manufacturing, Third Edition, Pearson Prentice Hall, Upper Saddle River.
- Groover, M P and Zimmers, E W Jr, CAD/CAM: Computer-aided Design and Manufacturing, Prentice-Hall of India Private Ltd.
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Fundamentals of NC Technology-I

- ✓ Basic Concepts of an NC System

Basic Concepts of an NC System

- Numerical control (NC) is a term used to describe the control of the various functions of a machine by the use of numeric data.
- The term was first coined at the Massachusetts Institute of Technology (MIT), where the first successful NC machine was demonstrated under a subcontract from the Parsons Corporation of Traverse City, Michigan, funded by the U.S. Air Force.
- Numerical control is now applied to a wide range of machines including welding, riveting, bending, hole-making, and drafting machines.
- However, the vast majority of NC machines in use today are metal-cutting machine tools.

Metal-Cutting Machines

- The metal-cutting operation (also called machining) is one of the most important manufacturing processes in industry today.
- In addition to being a primary manufacturing process, it is used as a finishing operation after other processes such as casting or forging because of its ability to achieve very high dimensional accuracy and close surface finish.
- The nature of the metal-cutting process involves removal of excess material from a raw workpiece using a cutting tool, thus changing the shape of the workpiece.
- By controlling how the excess material is removed, we can control what the final shape of the workpiece will be.

Metal-Cutting Machines

- Material removal is achieved by forcing a sharp cutting edge (the cutting tool or simply tool for short) into the workpiece and causing relative motion between the tool and the workpiece.
- Thus, the material to be removed is in effect peeled off the raw workpiece.
- In the metal-cutting context, the material removed is called a chip.
- Metals are hard and therefore high forces are required, first to feed the tool into the workpiece and then to force relative motion between the tool and the workpiece so as to remove chips.

Metal-Cutting Machines

- Power-driven machines (also called machine tools) are used which are capable of generating the high forces required and causing the relative motion between the cutting tool and the workpiece at a sufficiently high rate (called the cutting speed) to achieve a reasonable material removal rate.
- Relative motion between the cutting tool and the workpiece can be achieved by keeping the workpiece stationary and moving the tool or by keeping the tool stationary and moving the workpiece.

Metal-Cutting Machines

- The main function of a machine tool is to control the workpiece-cutting tool positional relationship in such a way as to achieve a desired geometric shape of the workpiece with sufficient dimensional accuracy.
- Actual machine tool movements are made up of one or more degrees of freedom.
- By combining these degrees of freedom and controlling their relationships to one another, it is possible to produce various geometric shapes such as cylinders or flat surfaces.
- In using a machine tool to carry out a machining operation, we need to be able to accomplish the following basic machining functions:

Metal-Cutting Machines

1. Determining the location on the workpiece where machining is to be done.
 2. Controlling the path followed during the motion of the tool or workpiece.
 3. Controlling the rate at which the path is traversed.
 4. Controlling the rate at which the tool is fed into the workpiece.
- The first two functions are crucial in ensuring that a component of the correct shape is produced.

Numerically Controlled Machines

- An NC machine is functionally the same as a conventional machine.
- The difference between NC machines and conventional machines is in the way in which the various machine functions and slide movements are controlled.
- With NC machines, functions such as positioning the tool, turning the spindle on and off, setting cutting speeds or feed rates, and turning coolant on and off are removed from the realm of the machine operator and turned over to a machine control unit (MCU) associated with the NC machine.
- The MCU issues commands in the form of numeric data to motors controlling the individual machine functions.

Numerically Controlled Machines

- The MCU can be used too control the direction and rate of slide motion, spindle rotation, tool changes, coolant, and so forth.
- The following figure shows a photograph of a NC lathe.

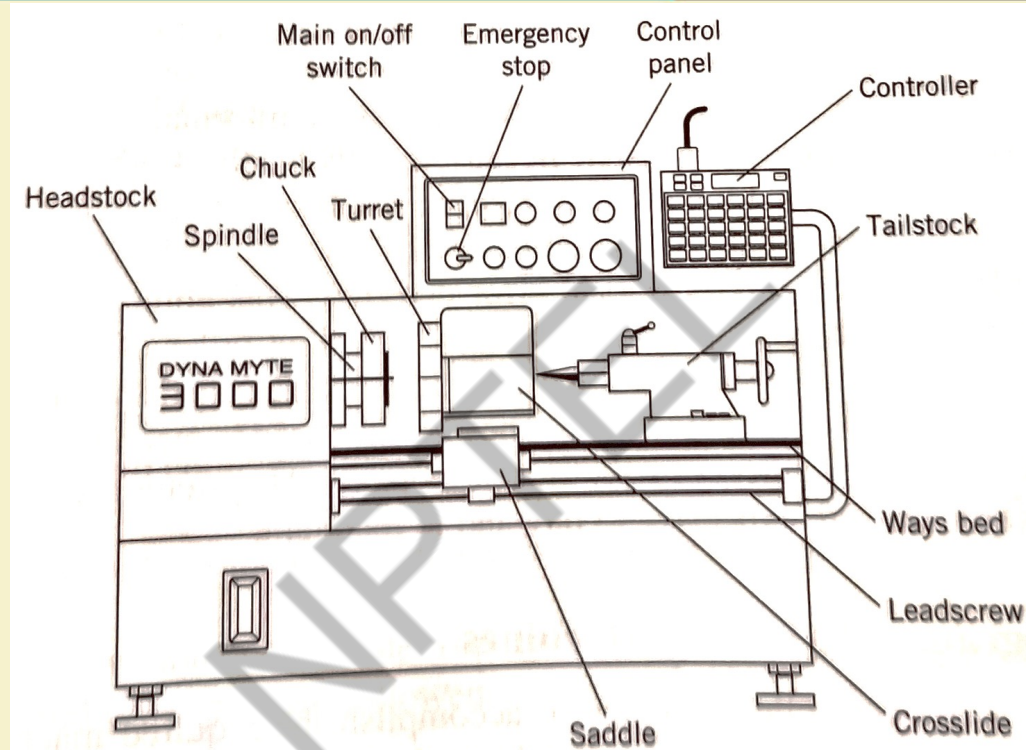


Figure 1. A Typical NC Lathe

Types of NC Control Systems

- Two basic types of control systems are used with NC machines.
- The earliest form of control was open-loop control, and this was followed by closed-loop control.

❑ Open-Loop Control

- This type of control system is used with a special motor called a stepper motor.
- With this type of control, signals in the form of current pulses are sent from the MCU to the individual motor being controlled.

Types of NC Control Systems

- Each pulse results in a finite predetermined amount of revolution of the motor.
- To cause a specified amount of movement, the control system determines how many current pulses are required and sends precisely that number to the motor.
- Thus, the control does not need to monitor specifically where the motor is located; it is assumed that the required motion is achieved if the correct number of pulses is sent.
- The control system needs only to keep track of how many revolutions (or parts thereof) the motor has gone through, to know the motor's position.

Types of NC Control Systems

- With NC machines, it is possible to design the motor to produce a movement of as little as one-thousandth of an inch for each pulse, resulting in precise control of position.
- Open-loop control systems are less costly, less complex, and easier to maintain and they are popular with smaller NC machines.
- However, with this type of control system, there is no way to correct any errors that might occur during operation because there is no feedback to the controller.
- Also, in general, stepper motor cannot generate the same amount of torque as other types of motors and therefore these systems are not suitable for use with large machines that require greater power.

Types of NC Control Systems

❑ Closed-Loop Control

- Conventional various-speed direct current (DC) motors (also called servos) are used with this type of control system.
- DC motors have the important advantage of being able to generate very high levels of torque, and they can, in essence, be reversed instantly.
- However, they cannot be caused to move in very precise amount as stepper motors can.
- In order to keep track of the position of the motor, a separate position sensor, called a resolver, has to be fitted and the position information so determined is fed back as a signal to the controller.

Types of NC Control Systems

- Because of this feedback, the system forms a closed loop.
- The positional information from the resolver is compared with the target position and any errors are determined.
- Because DC motors can be reversed instantly, it is possible to correct any positional error detected.
- This ability to correct errors enables closed-loop control systems to achieve up to an order of magnitude better accuracy than open-loop systems.

Types of NC Control Systems

- Closed-loop systems are generally used in the larger accuracy is desired, regardless of size.
- They are also used in machines where greater accuracy is desired, regardless of size.
- Closed-loop control systems are more complex, however, and thus more expensive to buy and to maintain.

Motion and Coordinate System Nomenclature for NC Machines

❑ z-axis

- This is the most important axis for machining and it is always aligned with the spindle that imparts cutting power.
- This spindle might rotate the workpiece as in a lathe, or it might rotate a tool as in a milling machine.
- If no such spindle exists on a specific machine, the z-axis is perpendicular to the workholding surface.
- Positive motion in z tends to increase the separation between the workpiece and the tool.

Motion and Coordinate System Nomenclature for NC Machines

□ x-axis

- The x-axis is the principal axis of motion in which the moving element (tool or workpiece) is positioned.
- It is parallel to the workholding surface and is arranged to be horizontal if possible.
- On machines with rotating workpieces, it is radial and parallel to the cross-slide.

Motion and Coordinate System Nomenclature for NC Machines

□ x-axis

- On machines with rotating tools,
 - If the z-axis is horizontal, the positive x motion is to the right when looking from the spindle to the workpiece.
 - If the z-axis is vertical, the positive x motion is to the right when looking from the spindle to the column.
- On machines with nonrotating workpieces and nonrotating tools, the x-axis is parallel to and directed toward the principal cutting direction.

Motion and Coordinate System Nomenclature for NC Machines

☐ y-axis

- Once the z- and x-axes are established, the y-axis must be in such a direction as to complete a right-handed Cartesian coordinate system.

☐ Supplementary Linear Motions

- On some machines, there are secondary linear motions parallel to the primary x, y and z motions.
- Such supplementary motions are designated U, V, and W respectively.

Motion and Coordinate System Nomenclature for NC Machines

□ Rotary motions

- Motions A, B, and C are rotary motions about axes respectively parallel to the x-, y-, and z-axes.
- A positive rotary motion is in a direction that would cause a right-handed screw to advance in the positive direction of the axis of rotation.

Motion and Coordinate System Nomenclature for NC Machines

❑ Spindle Rotation

- Counter clockwise spindle rotation is considered positive.
- It is the rotation that would cause a right-handed screw to recede from the workpiece.

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- Groover, M P, Automation, Production Systems, and Computer Integrated Manufacturing, Third Edition, Pearson Prentice Hall, Upper Saddle River.
- Groover, M P and Zimmers, E W Jr, CAD/CAM: Computer-aided Design and Manufacturing, Prentice-Hall of India Private Ltd.
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Fundamentals of NC Technology-I

- ✓ NC Coordinate System,
- ✓ NC Motion Control System

NC Coordinate Systems

- To program the NC processing equipment, a part programmer must define a standard axis system by which the positions of the workhead relative to the workpart can be specified.
- There are two axis systems used in NC, one for flat and prismatic workparts and the other for rotational parts.
- Both axis systems are based on the Cartesian coordinate system.
- In most machine tool applications, the x- and y- axes are used to move and position the worktable to which the part is attached, and the z- axis is used to control the vertical position of the cutting tool.

NC Coordinate Systems

- Such a positioning scheme is adequate for simple NC applications such as drilling and punching of flat sheet metal.
- The a-, b-, and c- rotational axes specify angular positions about the x-, y-, and z-axes, respectively.
- To distinguish positive from negative angles, the right hand rule is used: Using the right hand with the thumb pointing in the positive linear axis direction (+x, +y, or +z), the fingers of the hand are curled in the positive rotational direction.

NC Coordinate Systems

The rotational axes can be used for one or both of the following:

1. Orientation of the workpart to present different surfaces for machining or
2. Orientation of the tool or workhead at some angle relative to the part.

These additional axes permit machining of complex workpart geometrics. Machine tools with rotational axis capability generally have either four or five axes: three linear axes plus one or two rotational axes. Most NC machine tool systems do not require all six axes.

NC Coordinate Systems

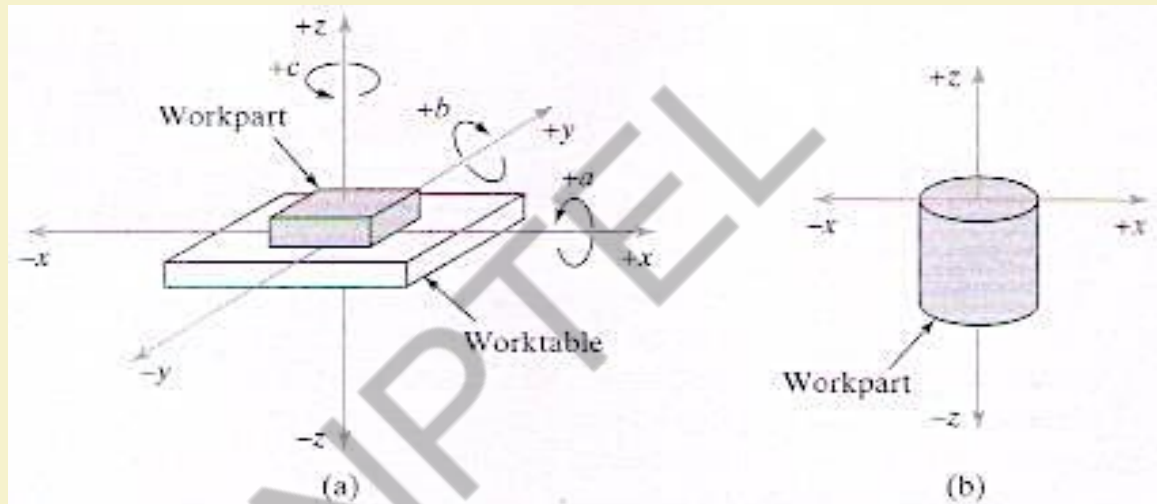


Figure 7.2 Coordinate systems used in NC (a) for flat and prismatic work and (b) for rotational work. (On most turning machines, the z -axis is horizontal rather than vertical as we have shown it.)

NC Coordinate Systems

- These systems are associated with NC lathes and turning centers.
- Although the work rotates, this is not one of the controlled axes on most turning machines. Consequently, the y-axis is not used. The path of the cutting tool relative to the rotating work piece is defined in the x-z plane, where the x-axis is the radial location of the tool, and the z-axis is parallel to the axis of rotation of the part.
- The part programmer must decide where the origin of the coordinate axis system should be located.

NC Coordinate Systems

- This decision is usually based on programming convenience. For example, the origin might be located at one of the corners of the part. If the workpart is symmetrical, the zero point might be most conveniently defined at the center of symmetry.
- Wherever the location, this zero point is communicated to the machine tool operator.

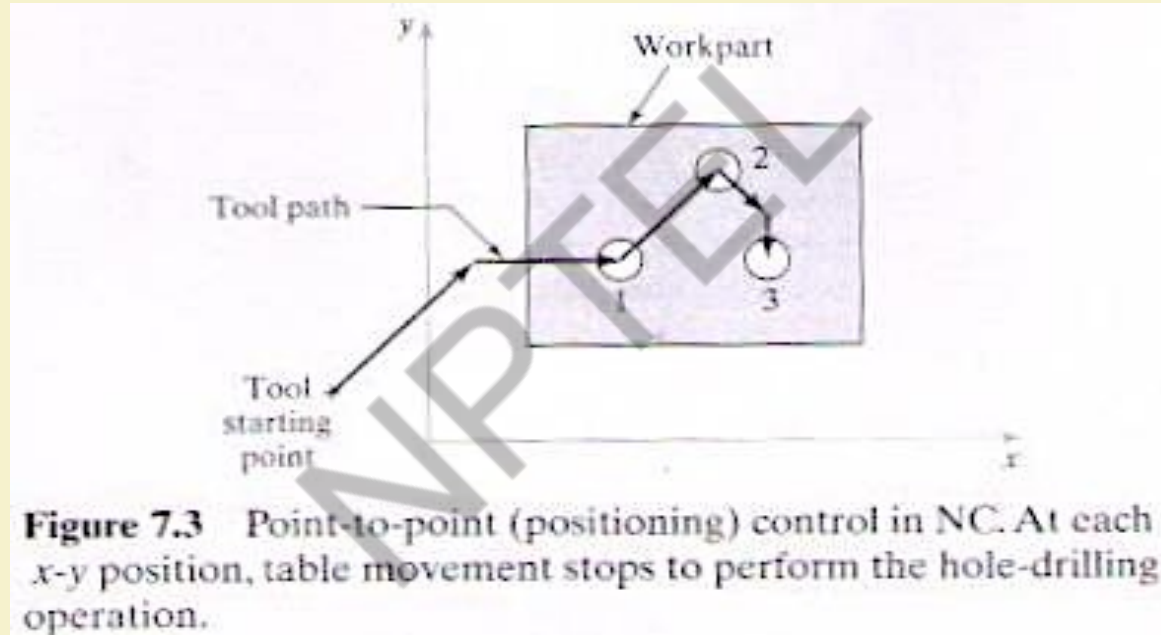
NC Coordinate Systems

- At the beginning of the job, the operator must move the cutting tool under manual control to some target point on the worktable, where the tool can be easily and accurately positioned. The target point has been previously referenced to the origin of the coordinate axis system by the part programmer. When the tool has been accurately positioned at the target point, the operator indicates to the MCU where the origin is located for subsequent tool movements.

Motion Control Systems

- Some NC processes are performed at discrete locations on the workpart (e.g. drilling and spot welding).
- Others are carried out while the workhead is moving (e.g. turning, milling, and continuous arc welding).
- If the workhead is moving, it may be necessary to follow a straight line path or a circular or other curvilinear path.
- Point-to-Point Versus Continuous Path Control

Motion Control Systems



Motion Control Systems

- Point-to-point systems, also called positioning systems, move the worktable to a programmed location without regard for the path taken to get to that location. Once the move has been completed, some processing action is accomplished by the workhead at the location, such as drilling or punching a hole.
- Continuous path systems are motion control systems capable of continuous simultaneous control of two or more axes.
- In this case, the tool performs the process while the worktable is moving, thus enabling the system to generate angular surfaces, two-dimensional curves, or three dimensional contours in the workpart.

Motion Control Systems

- This control mode is required in many milling and turning operations.
- When continuous path control is utilized to move the tool parallel to only one of the major axes of the machine tool worktable, this is called straight-cut NC. When continuous path control is used for simultaneous control of two or more axes in machining operations, the term contouring is used.

Motion Control Systems

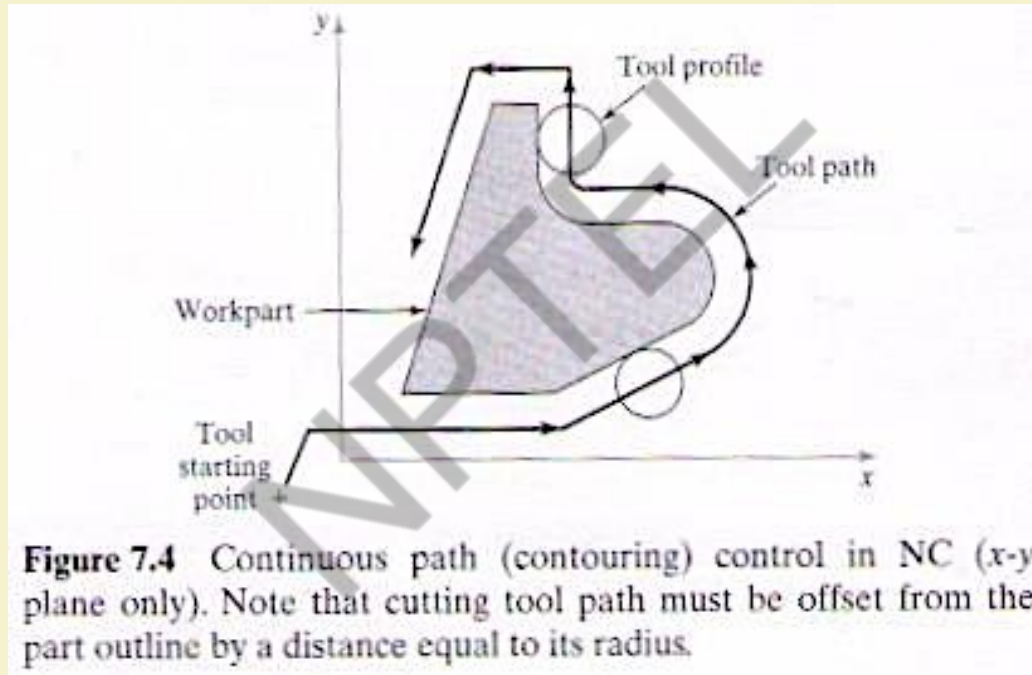


Figure 7.4 Continuous path (contouring) control in NC (x-y plane only). Note that cutting tool path must be offset from the part outline by a distance equal to its radius.

Motion Control Systems

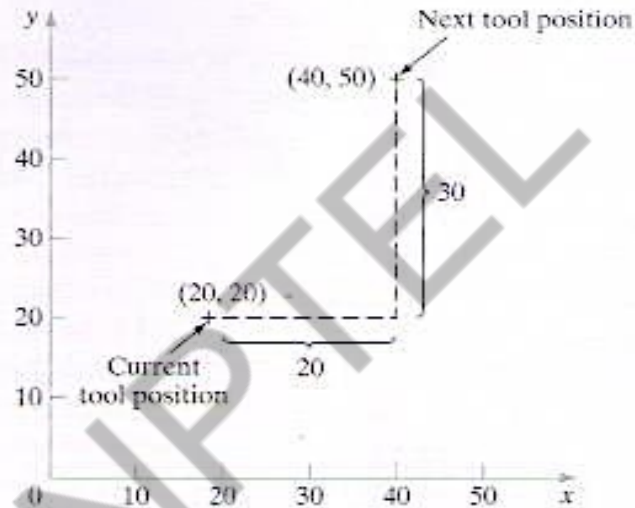


Figure 7.6 Absolute versus incremental positioning. The workhead is presently at point $(20, 20)$ and is to be moved to point $(40, 50)$. In absolute positioning, the move is specified by $x = 40, y = 50$; whereas in incremental positioning, the move is specified by $x = 20, y = 30$.

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Fundamentals of NC Technology-I

- ✓ Features of CNC,
- ✓ Configuration of CNC Machine Control System

Computer Numerical Control

- Since the introduction of NC in 1952, there have been dramatic advances in digital computer technology. The physical size and cost of a digital computer have been significantly reduced at the same time that its computational capabilities have been substantially increased.
- It was logical for the makers of NC equipment to incorporate these advances in computer technology into their products, starting with large mainframe computers in the 1960s and followed by minicomputers in the 1970s and microcomputers in the 1980s.

Computer Numerical Control

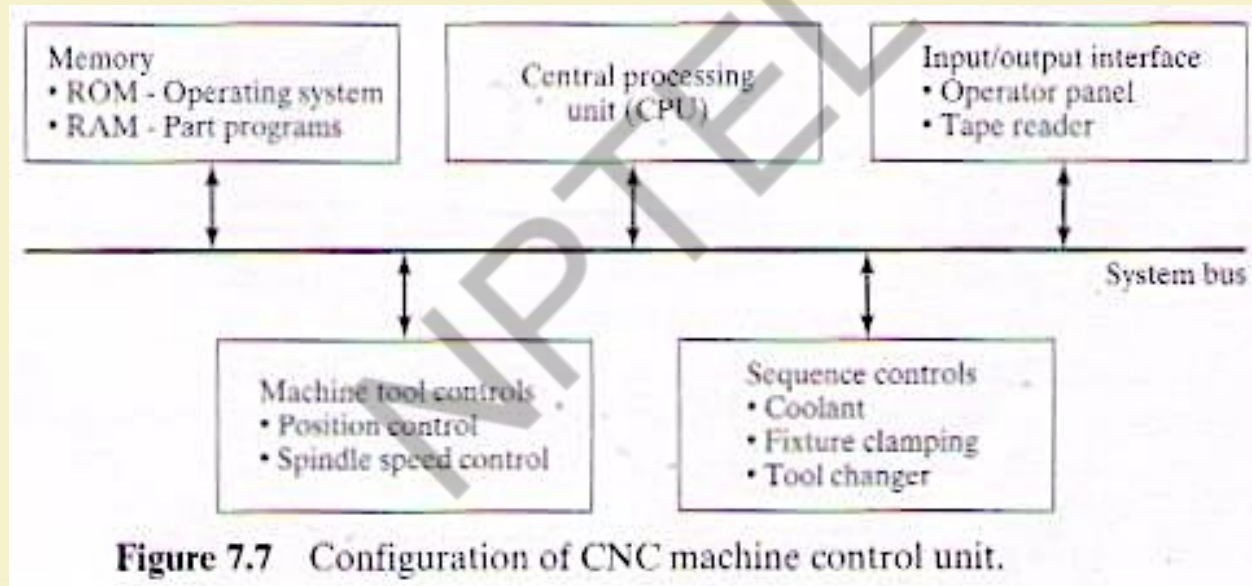
- Today, NC means computer numerical control. Computer numerical control (CNC) is defined as an NC system whose MCU is based on a dedicated microcomputer rather than on a hard-wired controller.
- The latest computer controllers for CNC feature high-speed processors, large memories, solid-state flash memory, improved servos, and bus architectures.

Features of CNC

- Storage of more than one part program.
- Various forms of program input.
- Program editing at the machine tool.
- Fixed cycles and programming subroutines.
- Interpolation.
- Positioning features for setup.
- Cutter length and size compensation.
- Acceleration and deceleration calculations.
- Communications interface
- Diagnostics

The Machine Control Unit for CNC

- The MCU is the hardware that distinguishes CNC from conventional NC.



The Machine Control Unit for CNC

- The MCU consists of the following components and subsystems:
 1. Central processing unit
 2. Memory
 3. I/O interface
 4. Controls for machine tool axes and spindle speed, and
 5. Sequence controls for other machine tool functions
- These subsystems are interconnected by means of a system bus, which communicates data and signals among the components of the network.

Central Processing Unit

- The central processing unit (CPU) is the brain of the MCU. It manages the other components in the MCU based on software contained in main memory.
- The CPU can be divided into three sections:
 - i. Control section
 - ii. Arithmetic logic unit, and
 - iii. Immediate access memory.
- The control section retrieves commands and data from memory and generates signals to activate other components in the MCU.

Central Processing Unit

- It sequences, coordinates, and regulates all of the activities of the MCU computer.
- The arithmetic-logic unit (ALU) consists of the circuitry to perform various calculations (addition, subtraction, multiplication), counting, and logical functions required by software residing in memory.
- The immediate access memory provides a temporary storage for data being processed by the CPU. It is connected to main memory by means of the system data bus.



Memory

- The immediate access memory in the CPU is not intended for storing CNC software. A much greater storage capacity is required for the various programs and data needed to operate the CNC system.
- CNC memory can be divided into two categories:
 - a. Main memory, and
 - b. Secondary memory
- Main memory (also known as Primary storage) consists of ROM (read-only memory) and RAM (random access memory) devices.

Memory

- Operating system software and machine interface programs are generally stored in ROM. These programs are usually installed by the manufacturer of the MCU.
- Numerical control part programs are stored in RAM devices. Current programs in RAM can be erased and replaced by new programs as jobs are changed.
- High-capacity secondary memory (also called auxiliary storage or secondary storage) devices are used to store large programs and data files, which are transferred to main memory as needed.

Input/output Interface

- The I/O interface provides communication between the various components of the CNC system, other computer systems, and the machine operator.
- The I/O interface transmits and receives data and signals to and from external devices.
- The operator control panel is the basic interface by which the machine operator communicates to the CNC system.
- This is used to enter commands related to part program editing, MCU operating mode (e.g., program control vs manual control), speeds and feeds cutting fluid pump on/off, and similar functions. Either an alphanumeric keypad or keyboard is usually included in the operator control panel.

Input/output Interface

- The I/O interface also includes a display (CRT or LED) for communication of data and information from the MCU to the machine operator.
- Also included in the I/O interface are one or more means of entering the part program into storage.
- Programs can also be entered manually by the machine operator or stored at a central computer site and transmitted via local area network (LAN) to the CNC system.
- A suitable device must be included in the I/O interface to allow input of the program into MCU memory.

Controls for Machine Tool Axes and Spindle Speed

- These are hardware components that control the position and velocity (feed rate) of each machine axis as well as the rotational speed of the machine tool spindle.
- The control signals generated by MCU must be converted to a form and power level suited to the particular position control system used to drive the machine axes.
- Positioning systems can be classified as open loop or closed loop, and different hardware components are required in each case.
- Depending on the type of machine tool, the spindle is used to drive either (1) the workpiece or (2) a rotating cutter.

Controls for Machine Tool Axes and Spindle Speed

- Turning exemplifies the first case, whereas milling and drilling exemplify the second.
- Spindle speed is a programmed parameter for most CNC machine tools. Spindle speed control components in the MCU usually consist of a drive control circuit and a feedback sensor interface.
- The particular hardware components depend on the type of spindle drive.

Sequence Controls for Other Machine Tool Functions

- In addition to control of table position, feed rate, and spindle speed, several additional functions are accomplished under part program control.
- These auxiliary functions are generally on/off (binary) actuations, interlocks, and discrete numerical data.
- To avoid overloading the CPU, a programmable logic controller is sometimes used to manage the I/O interface for these auxiliary functions.
- Personal Computers and the MCU.

CNC Software

- The computer in CNC operates by means of software.
- There are three types of software programs used in CNC systems:
 - a. Operating system software,
 - b. Machine interface software, and
 - c. Application software.
- The principal function of the operating system software is to interpret the NC part programs and generate the corresponding control signals to drive the machine tool axes.

CNC Software

- Machine interface software is used to operate the communication link between the CPU and the machine tool to accomplish the CNC auxiliary functions.
- Finally, the application software consists of the NC part programs that are written for machining (or other) applications in the user's plant.

CNC Software

TABLE 7.2 Examples of CNC Auxiliary Functions Often Implemented by a Programmable Logic Controller in the MCU

<i>CNC Auxiliary Function</i>	<i>Type or Classification</i>
Coolant control	On/off output from MCU to pump
Tool changer and tool storage unit	Discrete numerical data (possible values limited to capacity of tool storage unit)
Fixture clamping device	On/off output from MCU to clamp actuator
Emergency warning or stop	On/off input to MCU from sensor; on/off output to display and alarm
Robot for part loading/unloading	Interlock to sequence loading and unloading operation; I/O signals between MCU and robot
Counters (e.g., piece counts)	Discrete numerical data (possible values limited to number of parts that can be produced in a given time period, such as a shift)

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✓ Numerical Examples

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Machine Tool Applications

- Machining is a manufacturing process in which the geometry of the work is produced by removing excess material.
- There are four common types of machining operations: (a) turning, (b) drilling, (c) milling, and (d) grinding, shown in Figure 7.9.
- Each of the machining operations is carried out at a certain combination of speed, feed, and depth of cut, collectively called the cutting conditions.
- The cutting speed is the velocity of the milling cutter relative to the work surface, m/min (ft/min).

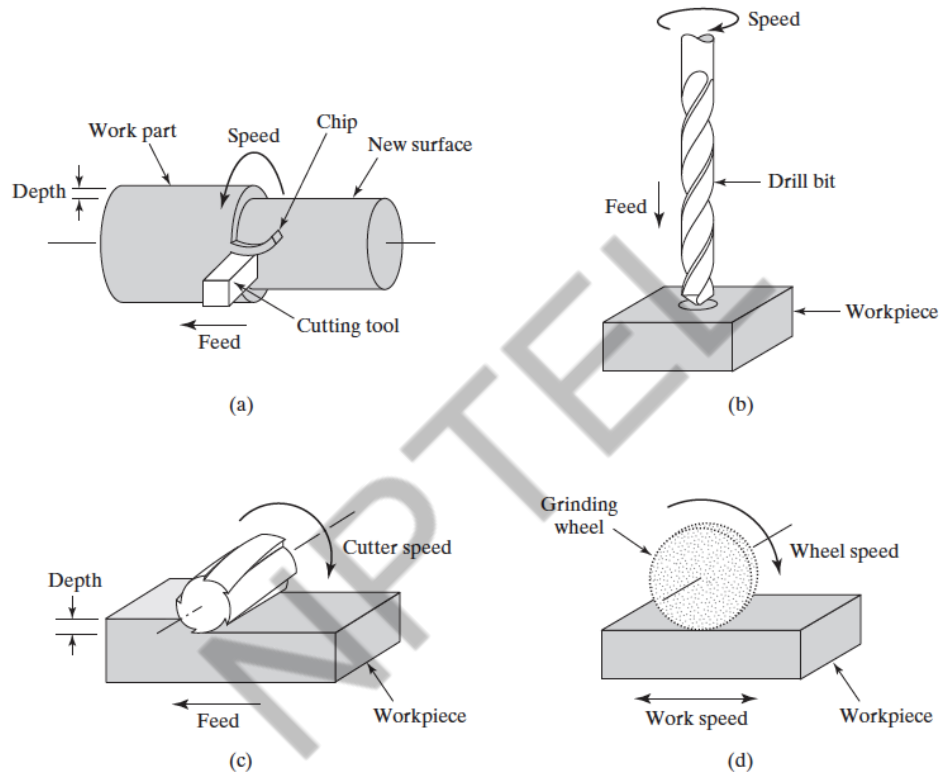


Figure 7.9 The four common machining operations are (a) turning, (b) drilling, (c) peripheral milling, and (d) surface grinding.

Machine Tool Applications

- This is usually programmed into the machine as a spindle rotation speed, rev/min.
- Cutting speed can be converted into spindle rotation speed by means of the equation $N = \frac{v}{\pi D}$
- where N = spindle rotation speed, rev/min; v = cutting speed, m/min (ft/min); and D = milling cutter diameter, m (ft). In milling, the feed usually means the size of the chip formed by each tooth in the milling cutter, often referred to as the chip load per tooth.
- This must normally be programmed into the NC machine as the feed rate (the travel rate of the machine tool table).

Machine Tool Applications

- The following is a list of the common material-removal CNC machine tools along with their typical features:
- **NC lathe**, either horizontal or vertical axis. Turning requires two-axis, continuous path control, either to produce a straight cylindrical geometry (straight turning) or to create a profile (contour turning).
- **NC boring mill**, horizontal or vertical spindle. Boring is similar to turning, except that an internal cylinder is created instead of an external cylinder. The operation requires continuous path, two-axis control.

Machine Tool Applications

- **NC drill press.** This machine uses point-to-point control of a work head (spindle containing the drill bit) and two axis (x–y) control of a worktable. Some NC drill presses have turrets containing six or eight drill bits. The turret position is programmed under NC control, allowing different drill bits to be applied to the same work part during the machine cycle without requiring the machine operator to manually change the tool.

Machine Tool Applications

- **NC milling machine.** A milling machine requires continuous path control to perform straight cut or contouring. Figure 7.10 illustrates the features of a CNC four-axis milling machine.
- **NC cylindrical grinder.** This machine operates like a turning machine, except that the tool is a grinding wheel. It has continuous path two-axis control, similar to an NC lathe.

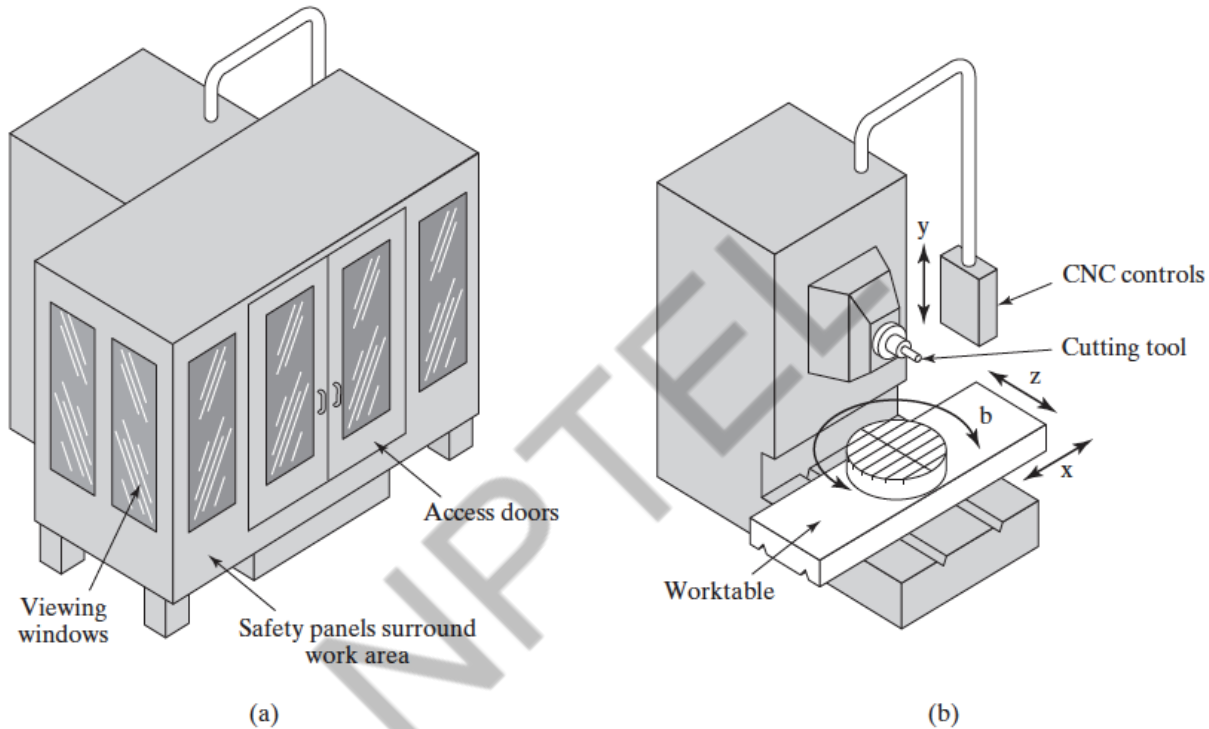


Figure 7.10 (a) Four-axis CNC horizontal milling machine with safety panels installed and (b) with safety panels removed to show typical axis configuration for the horizontal spindle.

NC Application Characteristics

- Over many years of machine shop practice, the following part characteristics have been identified as most suited to the application of NC:
- **Batch production.** NC is most appropriate for parts produced in small or medium lot sizes (batch sizes ranging from one unit up to several hundred units). Dedicated automation would not be economical for these quantities because of the high fixed cost. Manual production would require many separate machine setups and would result in higher labour cost, longer lead time, and higher scrap rate.

NC Application Characteristics

- **Repeat orders.** Batches of the same parts are produced at random or periodic intervals. Once the NC part program has been prepared, parts can be economically produced in subsequent batches using the same part program.
- **Complex part geometry.** The part geometry includes complex curved surfaces such as those found on airfoils and turbine blades. Mathematically defined surfaces such as circles and helixes can also be accomplished with NC. Some of these geometries would be difficult if not impossible to achieve accurately using conventional machine tools.

NC Application Characteristics

- **Much metal needs to be removed from the work part.** This condition is often associated with a complex part geometry. The volume and weight of the final machined part is a relatively small fraction of the starting block. Such parts are common in the aircraft industry to fabricate large structural sections with low weights.
- **Many separate machining operations on the part.** This applies to parts consisting of many machined features requiring different cutting tools, such as drilled and/or tapped holes, slots, flats, and so on. If these operations were machined by a series of manual operations, many setups would be needed. The number of setups can be reduced significantly using NC.

NC Application Characteristics

- **The part is expensive.** This factor is often a consequence of one or more of preceding factors 3, 4, and 5. It can also result from using a high-cost starting work material. When the part is expensive, and mistakes in processing would be costly, the use of NC helps to reduce rework and scrap losses.
- Although these characteristics pertain mainly to machining, they are adaptable to other production applications as well.

NC for Other Metalworking Processes

- **Punch presses for sheet metal hole punching.** The two-axis NC operation is similar to that of a drill press except that holes are produced by punching rather than drilling. Different hole sizes and shapes are implemented using a tool turret.
- **Presses for sheet metal bending.** Instead of cutting sheet metal, these systems bend sheet metal according to programmed commands.
- **Welding machines.** Both spot welding and continuous arc welding machines are available with automatic controls based on NC.

NC for Other Metalworking Processes

- **Thermal cutting machines**, such as oxy-fuel cutting, laser cutting, and plasma arc cutting. The stock is usually flat; thus, two-axis control is adequate. Some laser cutting machines can cut holes in preformed sheet metal stock, requiring four- or five-axis control.
- **Tube bending and wire bending machines.** Automatic tube and wire bending machines are programmed to control the location (along the length of the stock) and the angle of the bend. Important tube bending applications include frames for bicycles and motorcycles. Wire bending applications include springs and paper clips.

NC for Other Metalworking Processes

- **Wire EDM.** Electric discharge wire cutting operates in a manner similar to a band saw, except that the saw is a small diameter wire that uses sparks to cut metal stock that is positioned by an x-y positioning table.

Other NC Applications

- **Rapid prototyping and additive manufacturing.** These include a number of processes that add material, one thin layer at a time, to construct a part.
- **Water jet cutters and abrasive water jet cutters.** These machines are used to cut various materials, including metals and nonmetals (e.g., plastic, cloth), by means of a fine, high-pressure, high-velocity stream of water.
- **Component placement machines.** This equipment is used to position components on an x–y plane, usually a printed circuit board.
- **Coordinate measuring machines.** A coordinate measuring machine (CMM) is an inspection machine used for measuring or checking dimensions of a part.

Advantages of NC

- Non-productive time is reduced
- Greater accuracy and repeatability
- Lower scrap rates
- Inspection requirements are reduced
- More complex part geometries are possible
- Engineering changes can be accommodated more gracefully
- Simpler fixtures
- Shorter manufacturing lead times
- Reduced parts inventory
- Less floor space
- Operator skill requirements are reduced

Disadvantages of NC

- Higher investment cost
- Higher maintenance effort
- Part programming
- Higher utilization of NC equipment

Analysis of Positioning Systems

- An NC positioning system converts the coordinate axis values in the NC part program into relative positions of the tool and work part during processing.
- Consider the simple positioning system shown in Figure 7.11. The system consists of a cutting tool and a worktable on which a work part is fixtured.
- The table is designed to move the part relative to the tool.
- The worktable moves linearly by means of a rotating leadscrew or ball screw, which is driven by a stepper motor or servomotor.

Analysis of Positioning Systems

- To provide x–y capability, the system shown would be piggybacked on top of a second axis perpendicular to the first.
- The screw has a certain pitch p , mm/thread (in/thread). Thus, the table moves a distance equal to the pitch for each revolution.
-
- The velocity of the worktable, which corresponds to the feed rate in a machining operation, is determined by the rotational speed of the screw.
- Two types of control systems are used in positioning systems: (a) open loop and (b) closed loop, as shown in Figure 7.12.

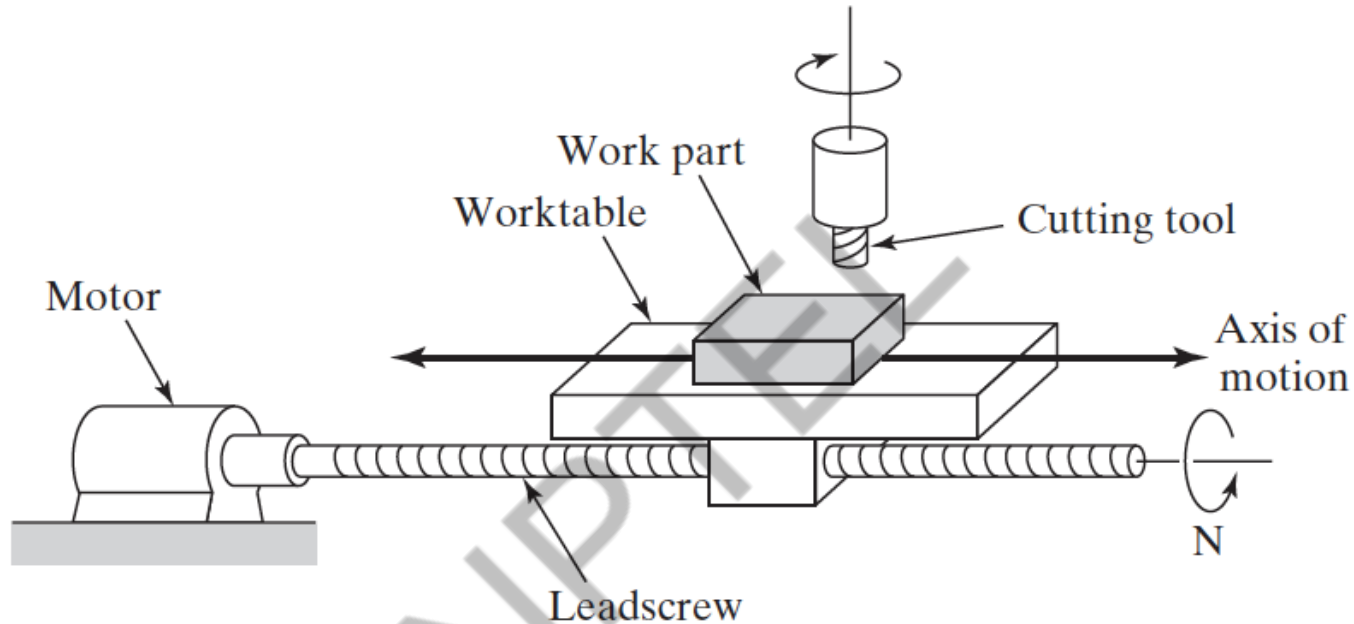


Figure 7.11 Motor and leadscrew arrangement in an NC positioning system.

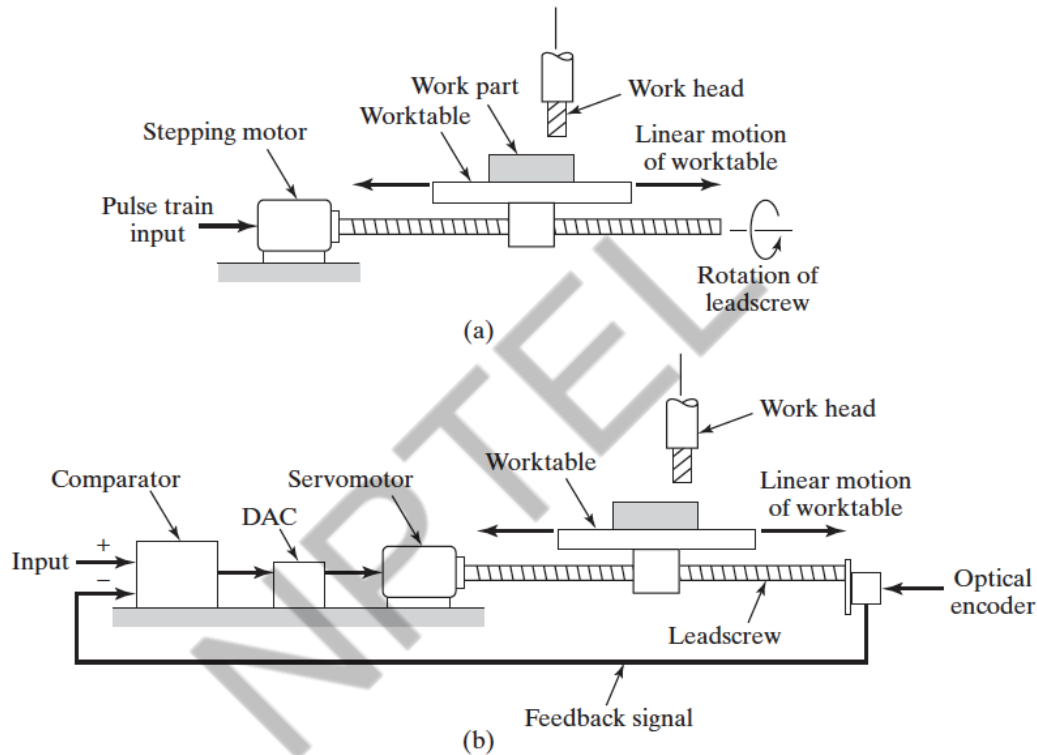


Figure 7.12 Two types of motion control in NC: (a) open loop and (b) closed loop.

Thank You!!

