LECTURE # 7

TOPIC OF DISCUSSION

NUMERIC CONTROL (NC) SYSTEMS

NUMERIC CONTROL (NC)

- Numeric control is a form of programmable automation in which the process is controlled by numbers, letters, and symbols
- A program of instruction is formed by numbers in NC for a particular workpart or job. The program of instruction is changed with change of job
- It is much easier to write a new prgram than to change the production machinery
- Its applications includes assembling, inspection, sheetmetal press working, spot welding and principally in machining processes

COMPONENTS OF NC SYSTEM

- An operational Numeric Control System consists of three basic components

1. ***Program of Instruction***
2. ***Controller Unit or Machine Control Unit***
3. ***Machine Tool or other controlled process***

COMPONENTS OF NC SYSTEM

1. Program of Instruction

- Program of instruction is the step-by-step directions which tell the machine tool what to do
- It is coded in numerical or symbolic form on some type of input medium that can be interpreted by the controller unit
- The most common input medium today is 1 in wide punched tape
- There are two other methods of input to the NC
  a) 1st is by manual entry of instructional data to the controller unit and called manual data input
  b) 2nd method of input is by means of direct link with a computer called DNC or direct numeric control

COMPONENTS OF NC SYSTEM

2. Controller Unit

- This consists of electronics and hardware that read and interpret the program of instructions and convert it into mechanical actions of the machine tool
- It consists of tape reader, a data buffer, signal output channels to the machine tool, feedback channels from the machine tool, and sequence controls to coordinate the overall operation of the foregoing elements
  - Tape reader is an electromechanical device for winding and reading the punched tape containing the program of instruction
  - The data contained on tape reader are read into data buffer
  - Signal output channels are connected to the servomotors and other controls in the machine tool
  - Through these channels instructions are sent to machine tool from control unit

COMPONENTS OF NC SYSTEM

3. Machine Tool or Other Controlled Processes

- The machine tool consists of worktable and spindle as well as the motors and controls necessary to drive them
- It also includes cutting tools, work fixtures, and other equipments needed to perform machining
- Machining centre is capable to perform a veriety of different operations like drilling, tapping, reaming, milling, and boring
- Variety of operations means variety of cutting tools are required
- The tools are kept into tool drum or other holding device
- When tape calls a particular tool, the drum rotates to position the tool for insertion into spindle
- Another capability of machine centre is workpiece positioning. The machine table can orient the job so that it can be machined on several surfaces as per requirement

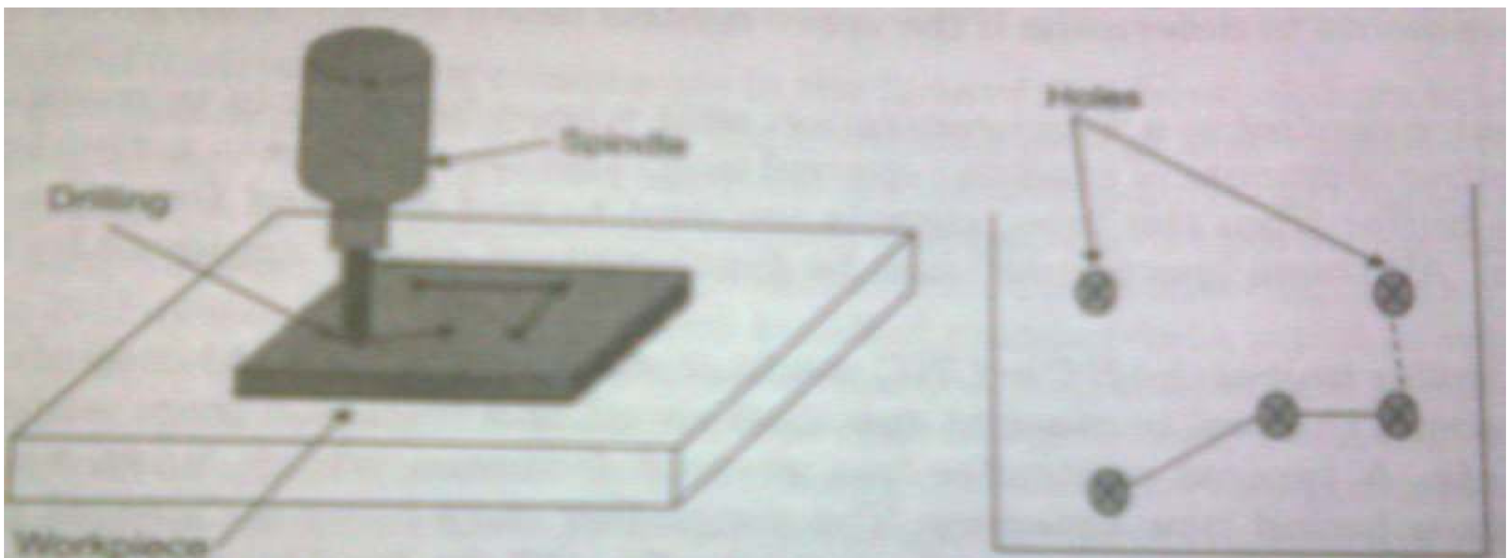
NC MOTION CONTROL SYSTEM

- In NC basically there are three types on motion control system

1. ***Point-to-point (PTP)***
2. ***Straight cut***
3. ***Contouring***

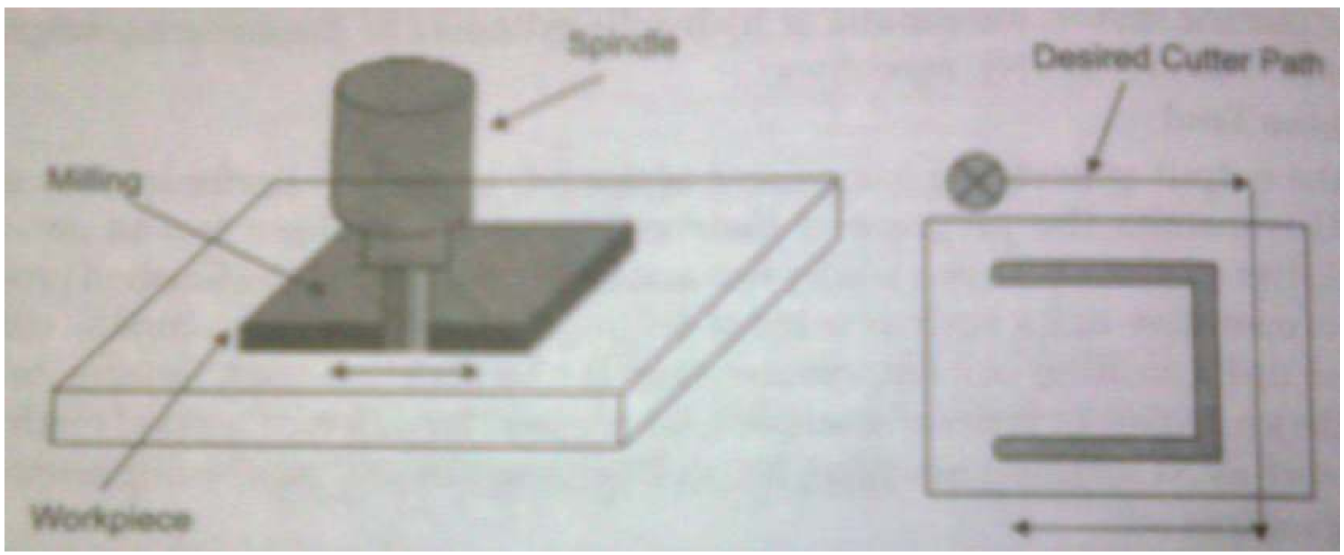
COMPONENTS OF NC SYSTEM

- **Point-to-point NC**
  - In PTP, the objective of the machine tool control system is to move the cutting tool to predefined location
  - The speed or path by which this movement is accomplished is not important in point-to-point NC
  - Once the tool reaches the desired location, the machining operation is performed at that position



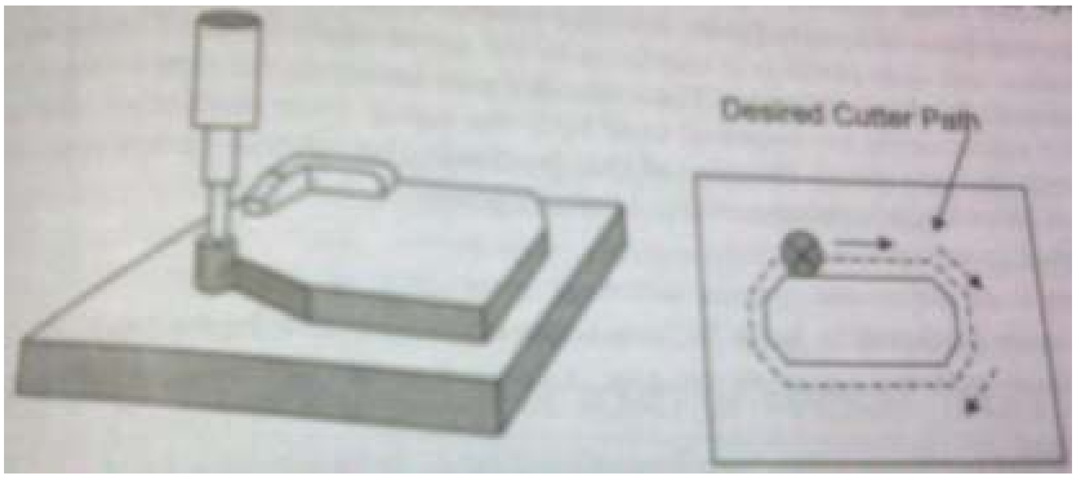
COMPONENTS OF NC SYSTEM

- **Straight-cut NC**
  - Striaght-cut NC 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 operations to fabricate workpieces of rectangular configurations



COMPONENTS OF NC SYSTEM

- **Contouring NC**
  - Contouring is complex, the most flexible, and the most expensive type of machine tool control
  - It performs both PTP and straight cut operations
  - Straight surfaces, circular paths, conical shapes or most any other mathematically definable form are possible under contouring control



NC MACHINE TOOL CONTROL SYSTEM

- There are two types of system to check and control the positions of operative units. These are

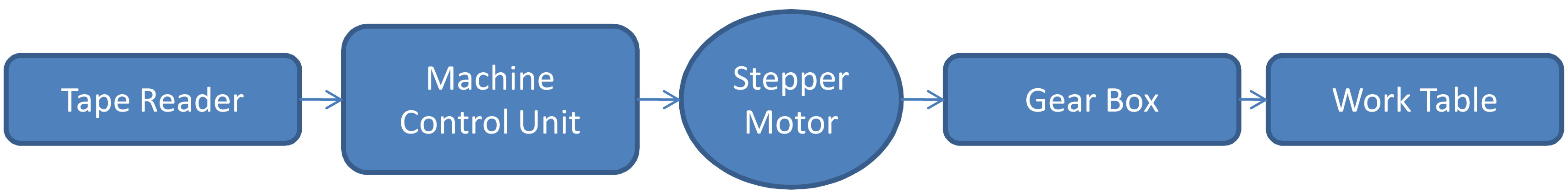
(a) Open loop control system

(b) Closed loop control system

NC MACHINE TOOL CONTROL SYSTEM

(a) Open loop control system

- In open loop system there is no provision of feedback signal to be compared with the input
- Neither slider movement is corrected nor its velocity monitored
- In this system the tape reader decodes the information punched on the tape and converts it into electrical pulses



NC MACHINE TOOL CONTROL SYSTEM

- The signal in the form of current pulses are sent from MCU to stepper motor
- To generate specific amount of movement, the control system determines how many current pulses are required and sent precisely to the motor
- Each pulse causes the motor to rotate a fraction of one revolution, called the step angle. The possible step angle must be consistent with the following relationship

$$\alpha = \frac{360}{n_s}$$

- Where, α = step angle (degrees), and n_s = the number of step angles for the motor

NC MACHINE TOOL CONTROL SYSTEM

- The angle through which the motor shaft rotates is given by

$$A_m = n_p \alpha$$

- Where A_m = angle of motor shaft rotation (degrees), n_p = number of pulses received by the motor α = step angle (degrees/pulse)
- The motor shaft is generally connected to the leadscrew through a gear box, which reduces the angular rotation of the leadscrew. The angle of the leadscrew rotation must take the gear ratio into account as follows

$$A = \frac{n_p \alpha}{r_g}$$

- Where, A = angle of leadscrew rotation (degrees) and r_g = gear ratio defined as the number of turns of the motor for each single turn of the leadscrew that is

$$r_g = \frac{A_m}{A} = \frac{N_m}{N}$$

- Where N_m = rotational speed of the motor (rev/min) , N = rotational speed of leadscrew (rev/min)

NC MACHINE TOOL CONTROL SYSTEM

- The linear movement of the worktable is given by the number of full and partial rotations of the leadscrew multiplied by its pitch

$$x = \frac{pA}{360}$$

where x = x-axis position relative to the starting position (mm.inch), p = pitch of the leadscrew (mm/rev, in/rev), A/360 = number of leadscrew revolutions

- The number of pulses required to achieve a specified x-position increment in a point-to-point system can be found by combining the two preceding equations as follows;

$$n_p = \frac{360 x r_g}{p\alpha} \; or \; \frac{n_s x r_g}{p}$$

- The rotational speed of the leadscrew depends upon the frequency of pulse train as follows

$$N = \frac{60 f_p}{n_s r_g}$$

Where N = leadscrrew rotational speed, f_p = pulse train frequency (Hz), n_s = steps per revolution or pulses per revolution

- The table travel speed in the direction of leadscrew axis is determined by the rotational speed as follows;

$$v_t = f_r = Np$$

v_t = table travel speed (mm/min, in/min), f_r = table feed rate (mm/min, in/min)

NC MACHINE TOOL CONTROL SYSTEM

- The required pulse train frequency to drive the table at a specified linear rate can be obtained by

$$f_p = \frac{v_t n_s r_g}{60p} \; or \; \frac{f_r n_s r_g}{60p}$$

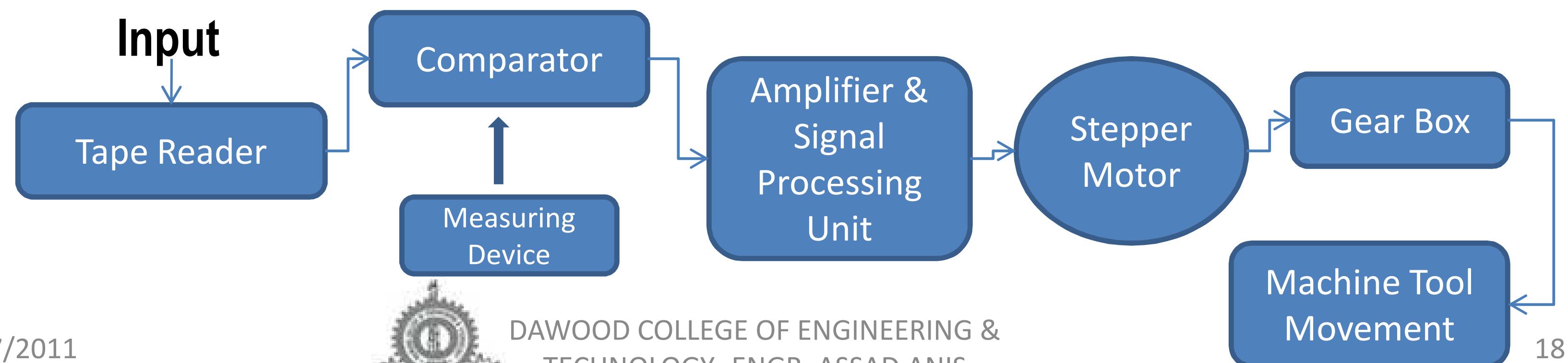
- The open loop systems are having following advantages
  - These are less costly
  - These are less complex
  - These are easier to maintain and are popular with smaller NC machines
- Major disadvantage is of this system is that there is no way to correct any error that might occur during operation because there is no feedback to the controller

NC MACHINE TOOL CONTROL SYSTEM

- ***PROBLEM:*** The worktable of a positioning system is driven by a leadscrew whose pitch = 6 mm. The leadscrew is connected to the output shaft of a stepping motor through a gearbox whose ratio is 5:1 (5 turns of the motor to one turn of the leadscrew). The stepping motor has 48 step angles. The table must move a distance of 250 mm from its present position at a linear velocity = 500 mm/min. Determine (a) how many pulses are required to move the table the specified distance and (b) the required motor speed and pulse rate to achieve the desired table velocity
- ***SOLUTION:***
- (a) $x = 250$ mm , $A = 360x/p = 360(250)/6 = 15000$ Deg
- Each step angle is $\alpha = 360/48 = 7.5$ Deg
- The number of pulses to move the table 250 mm is
- $n_r = 360xr_g/p\ \alpha = Ar_g/\ \alpha = 15000(5)/7.5 = 10{,}000$ pulses
- (b) The rotational speed of the leadscrew corresponding to a table speed of 500 mm/min can be determined by
- $N = v_t/p = 500/6 = 83.33$ rev/min
- $N_m = r_g N = 5(83.33) = 416.667$ rev/min
- The applied pulse rate to drive the table is given as
- $f_p = v_t n_s r_g/60p = 500(48)(5)/60(6) = 333.333$ Hz

(b) Closed loop control system

- In this kind of system the feedback signal is compared with input information & slide position is regulated by the servo control unit
- The servo motors are used with this kind of system. The controller unit instructs the servo motor to make whatever adjustments are required until both the signal from controller unit and one from servo unit are equal
  - Higher accuracy is achieved
  - There is an automatic compensation for error
  - It is more preferred in large NC machines because of higher load
  - These are complex, more expensive to buy and maintain



NC MACHINE TOOL CONTROL SYSTEM

- The equations that define the operation of a closed-loop NC positioning system are similar to those for an open-loop system. In the basic optical encoder, the angle between slots in the disk must satisfy the following requirement

$$\alpha = \frac{360}{n_s}$$

- Where α = angle between slots (degrees/slot), and ns = the number of slots in the disk.
- For a certain angular rotation of the encoder shaft, the number of pulses sensed by the encoder is given by

$$n_p = \frac{A_e}{\alpha}$$

- Where np = pulse count emitted by the encoder, Ae = angle of rotation of the encoder shaft (degrees) and α = angle between slots which converts to degrees per pulse
- The pulse count can be used to determine the linear x-axis position of the worktable by factoring in the leadscrew pitch and the gear reduction between the encoder shaft and the leadscrew

$$x = \frac{p n_p}{n_s r_{ge}}$$

NC MACHINE TOOL CONTROL SYSTEM

- Where p = leadscrew pitch (mm/rev, in/rev), and r_{ge} = gear reduction between the encoder and the leadscrew, defined as the number of turns of the encoder shaft for each single turn of the leadscrew. That is

$$r_{ge} = \frac{A_e}{A} = \frac{N_e}{N}$$

- Where A_e = encoder shaft angle (degrees), A= leadscrew angle (degrees), Ne = rotational speed of encoder shaft (rev/min), N = rotational speed of leadscrew (rev/min)
- The velocity of the worktable, which is normally the feed rate in the machining operation, is obtained from the frequency of the pulse train as follows

$$v_t = f_r = \frac{60 p f_p}{n_s r_{ge}}$$

- Where vt = worktable velocity (mm/min, in/min), fr = feed rate (mm/min, in/min), frequency of the pulse train emitted by the optical encoder (Hz, pulses/sec) and constant 60 converts worktable velocity and feed rate from mm /sec (in/sec) to mm/min (in/min).

NC MACHINE TOOL CONTROL SYSTEM

- **PROBLEM:** An NC operates by closed-loop positioning. The system consists of a servomotor, leadscrew, and optical encoder. The leadscrew has a pitch = 6 mmand is coupled to the motor shaft with a gear ratio of 5:1 (5 turns of the drive motor for each turn of the leadscrew). The optical encoder generates 48 pulses/rev of its output shaft. The encoder output shaft is coupled to the leadscrew with a 4:1 reduction (4 turns of the encoder shaft for each turn of the leadscrew). The table has been programmed to move a distance of 250 mm at a feed rate = 500 mm/min. Determine a) how many pulses should be received by the control system to verify that the table has moved exactly 250 mm b) the pulse rate of the encoder and c) the drive motor speed that corresponds to the specified feed rate

  SOLUTION:
- a) $n_p = x n_s r_{ge}/p$ = 250(48)(4)/6 = 8000 pulses
- b) The pulse rate corresponding to 500 mm/min can be obtained by $f_p = f_r n_s r_{ge}/60p$
- = 500(48)(4)/60(6) = 266.667 Hz
- c) Motor speed = table velocity (feed rate) /leadscrew pitch corrected for gear ratio = $N_m = r_g f_r/p$
- = 5(500)/6 = 416.667 rev/min

NC MACHINE TOOL CONTROL SYSTEM

- **Precision in NC Positioning**
- Three measures of precision can be defined for NC positioning system

  1. Control Resolution 2. Accuracy 3. Repeatibility

- Control resolution (CR) refers to the control system ability to divide the total range of the axis movement into closely space points distinguished by MCU
- CR is defined as the distance separating two adjacent addressable points in axis movement
- CR must be as small as possible but there are limitations of

  1. electromechanical components of positioning 2. number of bits used by controller to define the axis coordinate location

- CR for an open loop sysyem = $CR_1 = \frac{P}{n_s r_g}$, CR_1 = CR of electromechanical components
- CR for closed loop system = $CR_1 = \frac{P}{n_s r_g r_{ge}}$
- $CR_2 = \frac{L}{2^B - 1}$, CR_2 = control resolution of number of bits used by MCU

NC MACHINE TOOL CONTROL SYSTEM

- L = axis range, B = no. of bits in storage register for axis, 2^B = no. of control points into which axis range can be divided
- CR = max (CR_1, CR_2), generally $CR_2 \leq CR_1$
- Accuracy of any given axis of positioning system is the max. Possible error that can occur betwen the desired target point and the actual position taken by the system
- Accuracy = $\frac{CR}{2} + 3\sigma$, Accuracy = $\pm$ 0.01 for 250 mm of table travel
- Repeatibility refers to capability of a positioning system to return to a given addressable point that has been previously programmed
- Repeatibility = $\pm\ 3\sigma$
- **PROBLEM:** Suppose the mechanical inaccuracies in the open-loop positioning sysem are described by normal distribution with standard deviation = 0.005 mm. The range of worktable axis is 1000 mm and there are 16 bits in the binary register used by the digital controller to store the programmed position. Other relevant parameters are, pitch p = 6 mm gear ratio between motor shaft and leadscrew r_g = 5 and number of step angles in the stepping motor n_s = 48. Determine (a) the control resolution (b) accuracy (c) the repeatibility

NC MACHINE TOOL CONTROL SYSTEM

- **SOLUTION**
- Control Resolution = CR_1 = $CR_1 = \frac{p}{n_s r_g}$ = 6/48(5) = 0.025 mm
- CR_2 = $\frac{L}{2^B - 1}$ = $1000/2^{16} - 1$ = 0.01526 mm
- CR = max (0.025, 0.01526) = 0.025 mm
- (b) accuracy = 0.5(0.025) +3(0.005) = 0.0275 mm
- (c) repeatibility = ± 3 (0.005) = ± 0.015 mm

APPLICATIONS OF NC SYSTEM

- Milling
- Drilling
- Boring
- Turning
- Grinding
- Sawing
- Press working
- Welding machines
- Inspection machines
- Automatic Drafting
- Assembly machines
- Tube bending
- Flame cutting
- Plasma arc cutting
- Laser beam processes
- Cloth cutting
- Automatic riveting
- Wire-wrap machines

ADVANTAGES OF NC SYSTEM

- NC machines are capable of producing the parts in less time i.e. Less part handling time, less setup time and less tool changing time. Thus it reduces the non productive time
- It requires simple and less costly jigs and fixtures
- It provides better quality control because parts are produced with great accuracy
- The Inspection time required is very less
- There are less chances of operator error because operator invlovement is reduced to minimum

DISADVANTAGES OF NC SYSTEM

- Higher Investment Cost
  - ❖ NC Contril machine tools represents a more sophisticated and complex technology
  - ❖ This technology costs more to buy
- Higher Maintenance Cost
  - ❖ NC is more complex technology and because NC machines are used harder, the maontenance problems become more acute
- Finding and/or training personnel
  - ❖ Certain aspects of numerical control shop operation require higher skill level than conventional operations
  - ❖ Problems of finding, hiring, and training these people must be considered a disadvantage