Computer Numeric Control

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d Semester

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Computer Numeric Control

A system in which actions are controlled by the direct insertion of numerical data at some point. The system must automatically interpret at least some portion of this data.
Computer Numerical Control (CNC) Machine
Advantages and Disadvantages of CNC

Advantages:
- High Repeatability and Precision e.g. Aircraft parts.
- Volume of production is very high.
- Complex contours/surfaces can be easily machined.
- Flexibility in job change, automatic tool settings, less scrap.
- More safe, higher productivity, better quality.
- Less paper work, faster prototype production, reduction in lead times.

Disadvantages:
- Costly setup, skilled operators.
- Computer programming knowledge required.
- Maintenance is difficult.
Open Loop Systems

Open loop systems have no access to the real time data about the performance of the system and therefore no immediate corrective action can be taken in case of system disturbance.

Block Diagram of an Open Loop System.
Open loop system
Close Loop Systems

In a close loop system, feed back devices closely monitor the output and any disturbance will be corrected in the first instance. Therefore high system accuracy is achievable.

Block Diagram of a Close Loop System
Close loop system
Three measures of precision:

1. **Control resolution**: Distance separating two adjacent addressable points in the axis movement.

2. **Accuracy**: Maximum possible error that can occur between the desired target point and the actual position taken by the system.

3. **Repeatability**: Defined as $\pm 3\sigma$ of the mechanical error distribution associated with the axis.
Plot showing measures of precision

- Accuracy: $\frac{CR}{2} + 3\sigma$
- Control resolution: $CR$
- Repeatability: $\pm 3\sigma$
- Addressable points
- Desired position
- Distribution of mechanical errors

Linear axis
Motion Control Systems

1. Point-To-Point Control in CNC:

   Drilling of Three Holes in Flat Plate

   ➢ System moves to a location and performs an operation at that location (e.g., drilling)
   ➢ Also applicable in robotics
2. Continuous path control in CNC

Profile Milling of Part Outline

- Also called contouring systems in machining
- System performs an operation during movement (e.g., milling and turning)
Elements of a CNC system

- Input Device
- Central Processing Unit/ Machine Control Unit
- Machine Tool
- Driving System
- Feedback Devices
- Display Unit
Input Devices

- Floppy Disk Drive
- USB Flash Drive
- Serial Communication
- Ethernet communication
- Conversational Programming
Central Processing Unit/ Machine Control Unit

- The CPU is the heart of a CNC system.
- It accepts the information stored in the memory as part program.

- This data is decoded and transformed into specific position control and velocity signals.

- It also oversees the movement of the control axis or spindle and whenever this does not match with the programmed values, a corrective action is taken.
Machine Tool

- Most are made from high speed steel (HSS), tungsten carbide or ceramics.

- Tools are designed to direct waste away from the material.

- Some tools need coolant such as oil to protect the tool and work.
Driving System

- The requirement is that the driving system has to response accurately according to the programmed instructions.
- The motor is coupled either directly or through a gear box to the machine lead screw to move the machine slide or the spindle.

Three types of electrical motors are commonly used:
1. DC Servo motor
2. AC Servo motor
3. Stepping motor as explained ahead.
1. DC Servo Motor

➢ The principle of operation is based on the rotation of an armature winding in a permanently energized magnetic field.

➢ The armature winding is connected to a commutator, which is a cylinder of insulated copper segments mounted on the shaft.

➢ DC current is passed to the commutator through carbon brushes, which are connected to the machine terminals.
2. AC Servo Motor

- In an AC servomotor, the rotor is a permanent magnet while the stator is equipped with 3-phase windings.

- The speed of the rotor is equal to the rotational frequency of the magnetic field of the stator, which is regulated by the frequency converter.
3. Stepping Motor

- The stepper motor is known by its property to convert a train of input pulses (typically square wave pulses) into a precisely defined increment in the shaft position.
- Each pulse moves the shaft through a fixed angle.
- Multiple "toothed" electromagnets arranged around a central gear-shaped piece of iron.
- The electromagnets are energized by an external driver circuit or a micro controller. In that way, the motor can be turned by a precise angle.
What does Stepper means?

- To make the motor shaft turn, first, one electromagnet is given power, which magnetically attracts the gear's teeth.
- When the gear's teeth are aligned to the first electromagnet, they are slightly offset from the next electromagnet.
- This means that when the next electromagnet is turned on and the first is turned off, the gear rotates slightly to align with the next one.
- From there the process is repeated. Each of those rotations is called a "step", with an integer number of steps making a full rotation.
However, stepping motors are not commonly used in machine tools due to the following drawbacks:
- slow speed,
- low torque,
- low resolution
- easy to slip in case of overload.
Open Loop Positioning Systems
Stepper Motor calculations

- It uses a stepper motor to rotate the lead screw. A stepper motor is driven by series of electrical pulses generated by MCU.
- For each pulse the motor rotates a fraction of revolution called Step Angle, it is given by

\[ \alpha = \frac{360}{n_s} \text{ (Degrees/Pulse)} \]

Where, \( n_s \) = Number of step angles for the motor (an integer).
- If \( n_p \) is the pulses received by the motor then angle through which motor rotates is

\[ A_m = n_p \times \alpha \]
Stepper Motor calculations

- Lead Screw is connected to the motor shaft through a gear box.
- Angle of the lead screw rotation taking the gear ratio into account is given by
  \[ \theta = n_p \times \alpha / r_g \]

  \( r_g \) = Gear ratio
  \( = A_m / A = N_m / N \)

  \( N_m \) = RPM of motor, \( N \) = RPM of lead Screw

  The linear movement of worktable is given by
  \[ x = pA / 360 \text{ (mm,inch)} \]

  \( p \) = pitch of lead screw
Stepper Motor calculations

- Total number of pulses required to achieve a specified x-position increment is calculated by:

\[ n_p = \frac{360 \times r_g \times x}{p \times \alpha} = \frac{n_s \times x \times r_g}{p} \]

Where, \( n_s = \frac{360}{\alpha} \)

Control pulses are transmitted from pulse generator at a certain frequency which drives the work table at the corresponding velocity.

The rotational speed of lead screw depends on the frequency of the pulse train

\[ N = \frac{60 \times f_p}{n_s \times r_g} \]

Equation (1)

\( N = \text{RPM of lead screw}, \ f_p = \text{frequency of pulse train (Hz, Pulses/sec)} \)
The table travel speed in the direction of lead screw axis is determined by:

\[ V_t = f_r = N \times p \]  

Equation (2)

Where, 

- \( V_t \) = Table travel speed (mm/min)  
- \( f_r \) = Table feed rate (mm/min)  
- \( p \) = Lead screw pitch (mm/rev)  

The required pulse train frequency to drive the table at a specified linear travel rate by combining equations (1) and (2):

\[ f_p = \frac{f_r \times n_z \times r_g}{60 \times p} \]
Ball Lead Screws

- Ball lead screw is the heart of the drive system.
- Advantages of ball lead screw are:
  - Precise position and repeatability
  - High Speed capability
  - Less Wear
  - Longer life

![Diagram of a closed loop system that uses a ball lead screw mechanism.](image)
Feedback Devices

Two types of feedback devices normally used are:

1. Positional Feed Back Devices
   1.1 Linear Transducers - a device mounted on the machine table to measure the actual displacement of the slide in such a way that backlash of screws; motors etc would not cause any error in the feedback data.
1.2 Rotary Encoders: a device to measure the angular displacement. It cannot measure linear displacement directly so that error may occur due to the backlash of screw and motor etc.
2. Velocity Feedback Device

- The actual speed of the motor can be measured in terms of voltage generated from a tachometer mounted at the end of the motor shaft.

- The voltage generated by the DC tachometer is compared with the command voltage corresponding to the desired speed.

- The difference of the voltages is used to actuate the motor to eliminate the error.
Display Unit

- Interface between the machine and the operator.

The Display Unit displays:
- position of the machine slide
- spindle RPM
- feed rate
- part programs
- graphics simulation of the tool path.
Interpolation Methods

1. Linear interpolation
   Straight line between two points in space

2. Circular interpolation
   Circular arc defined by starting point, end point, centre or radius, and direction.

3. Helical interpolation
   Circular plus linear motion

4. Parabolic and cubic interpolation
   Free form curves using higher order equations
Circular Interpolation

Approximation of a curved path in NC by a series of straight line segments, where tolerance is defined on only the outside of the nominal curve.
Circular Interpolation

Approximation of a curved path in NC by a series of straight line segments, where tolerance is defined on both the inside and outside of the nominal curve.
Circular Interpolation

Approximation of a curved path in NC by a series of straight line segments, where tolerance is defined on only the inside of the nominal curve.
Machine axes

Machine axes are established according to the industry standard report EIA RS - 267A

The right-hand rule for linear motion
Axes configuration

- X axes moves from right to left as you face the machine
- Y axes move toward and away from you
- The Z axes is the spindle movement up and down spindle.
- A move toward work is $Z(-Z)$
- A move away from work is $Z(+Z)$
Dimensioning Systems

Absolute Coordinate System

Incremental Coordinate System
CNC Programming

- Programming consists of a series of instructions in the form of letter codes

Preparatory Codes:

- **G codes**: Initial machining setup and establishing operating conditions
- **N codes**: Specify program line number to executed by the MCU
- **Axis Codes**: $X, Y, Z$ - Used to specify motion of the slide along $X$, $Y$, $Z$ direction
- **Feed and Speed Codes**: $F$ and $S$ - Specify feed and spindle speed
- **Tool codes**: $T$ – specify tool number

Miscellaneous codes – **M codes**: For coolant control and other activities
Programming Key Letters

O - Program number (Used for program identification)
N - Sequence number (Used for line identification)
G - Preparatory function
X - X axis designation
Y - Y axis designation
Z - Z axis designation
R - Radius designation
F – Feed rate designation
S - Spindle speed designation
H - Tool length offset designation
D - Tool radius offset designation
T - Tool Designation
M - Miscellaneous function
Table of Important G Codes

G codes are instructions describing machine tool movement

G00: Rapid Transverse
G01: Linear Interpolation
G02: Circular Interpolation, CW
G03: Circular Interpolation, CCW
G20/G70: Inch units
G21/G71: Metric Units
G40: Cutter compensation cancel
G41: Cutter compensation left
G42: Cutter compensation right
G43: Tool length compensation (plus)
G44: Tool length compensation (minus)
G49: Tool length compensation cancel
G80: Cancel canned cycles
G81: Drilling cycle
G82: Counter boring cycle
G83: Deep hole drilling cycle
G90: Absolute positioning
G91: Incremental positioning
M Codes are instructions describing miscellaneous functions like calling the tool, spindle rotation, coolant on/off etc.,

<table>
<thead>
<tr>
<th>M Code</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>M00</td>
<td>Program Stop</td>
</tr>
<tr>
<td>M01</td>
<td>Optional Stop</td>
</tr>
<tr>
<td>M02</td>
<td>Program End</td>
</tr>
<tr>
<td>M03</td>
<td>Spindle Forward</td>
</tr>
<tr>
<td>M04</td>
<td>Spindle Reverse</td>
</tr>
<tr>
<td>M05</td>
<td>Spindle Stop</td>
</tr>
<tr>
<td>M06</td>
<td>Automatic Tool change</td>
</tr>
<tr>
<td>M08</td>
<td>Coolant On</td>
</tr>
<tr>
<td>M09</td>
<td>Coolant Off</td>
</tr>
<tr>
<td>M10</td>
<td>Vice / Chuck Open</td>
</tr>
<tr>
<td>M11</td>
<td>Vice / Chuck Close</td>
</tr>
<tr>
<td>M30</td>
<td>Program Stop &amp; Rewind</td>
</tr>
<tr>
<td>M38</td>
<td>Door Open</td>
</tr>
<tr>
<td>M39</td>
<td>Door Close</td>
</tr>
<tr>
<td>M98</td>
<td>Sub program Call</td>
</tr>
<tr>
<td>M99</td>
<td>Subprogram Exit</td>
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</tbody>
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Programming Example
CNC Turning operation

N5 M12
N10 T0101
N15 G0 X100 Z50
N20 M3 S600
N25 M8
N30 G1 X50 Z0 F600
N40 Y-30 F200
N50 X80 Y-20 F150
N60 G0 X100 Z50
N70 T0100
N80 M5
N90 M9
N100 M13
N110 M30
Programming Example
CNC multi step Turning operation
<table>
<thead>
<tr>
<th>Line</th>
<th>Code</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>N1</td>
<td>T0101</td>
<td>Tool no 1 with offset no 1 FANUC Control</td>
</tr>
<tr>
<td>N2</td>
<td>G97 S500 M03</td>
<td>Spindle rotation clockwise with 500 RPM</td>
</tr>
<tr>
<td>N4</td>
<td>G01 X25 G95 F0.3</td>
<td>Feed</td>
</tr>
<tr>
<td>N5</td>
<td>G01 Z-7.5</td>
<td>P1</td>
</tr>
<tr>
<td>N6</td>
<td>G01 X40 Z-15</td>
<td>P2</td>
</tr>
<tr>
<td>N7</td>
<td>G01 Z-25</td>
<td>P3</td>
</tr>
<tr>
<td>N8</td>
<td>G01 X60 Z-35</td>
<td>P4</td>
</tr>
<tr>
<td>N9</td>
<td>G40 G00 X200 Z100</td>
<td>Tool nose radius compensation cancel</td>
</tr>
</tbody>
</table>
CNC milling example

N5 G90 G71
N10 T1 M6
N15 G92 X-100 Y86 Z95
N20 G0 X0 Y0 S2500 M3
N25 Z12.5
N30 G1 Z-12.5 F150
N35 X-20 Y30
N40 G2 X10 Y100 R80
N45 G1 X140 Y60
N50 G2 X150 Y0 R50
N55 G1 X0 Y0
N60 G0 Z12.5
N65 G91 G28 Z0 M5
N70 G91 G28 X0 Y0
N75 M30
Programming Example

N2 G17 G71 G90 G94 G54
N4 T1 L90
N6 G00 Z5 D5 M3 S500 X20 Y90
N8 G01 Z-2 F50
N10 G02 X60 Y50 I0 J-40
N12 G03 X80 Y50 I20 J0
N14 G00 Z100
N16 M02
N1 T16 M06
N2 G90 G54 G00 X0.5 Y-0.5
N3 S1450 M03
N4 G43 H16 Z1. M08
N5 G81 G99 Z-0.375 R0.1 F9. N6 X1.5
N7 Y-1.5
N8 X0.5
N9 G80 G00 Z1. M09
N10 G53 G49 Z0. M05
N11 M30
THANK YOU