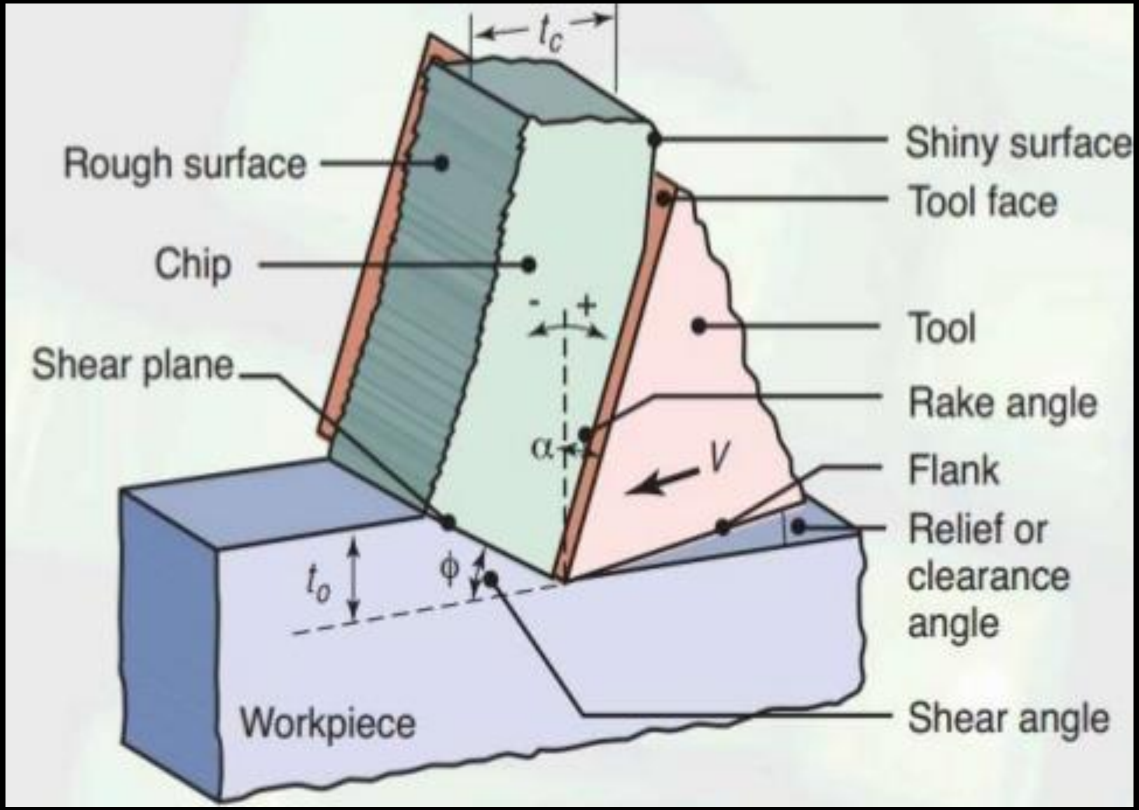
IC100

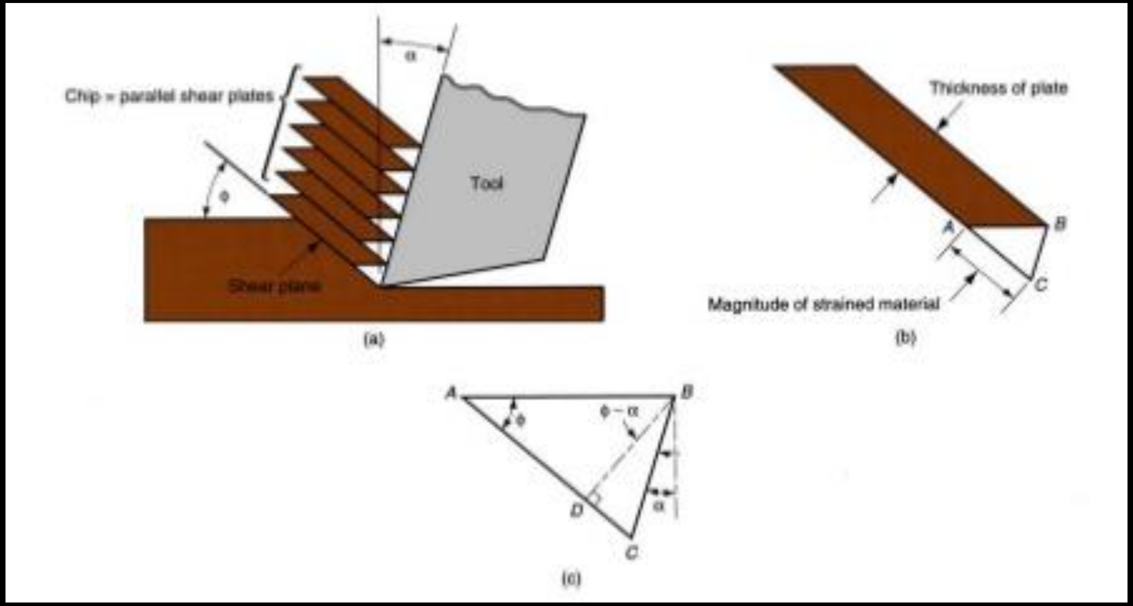
CNC Machine

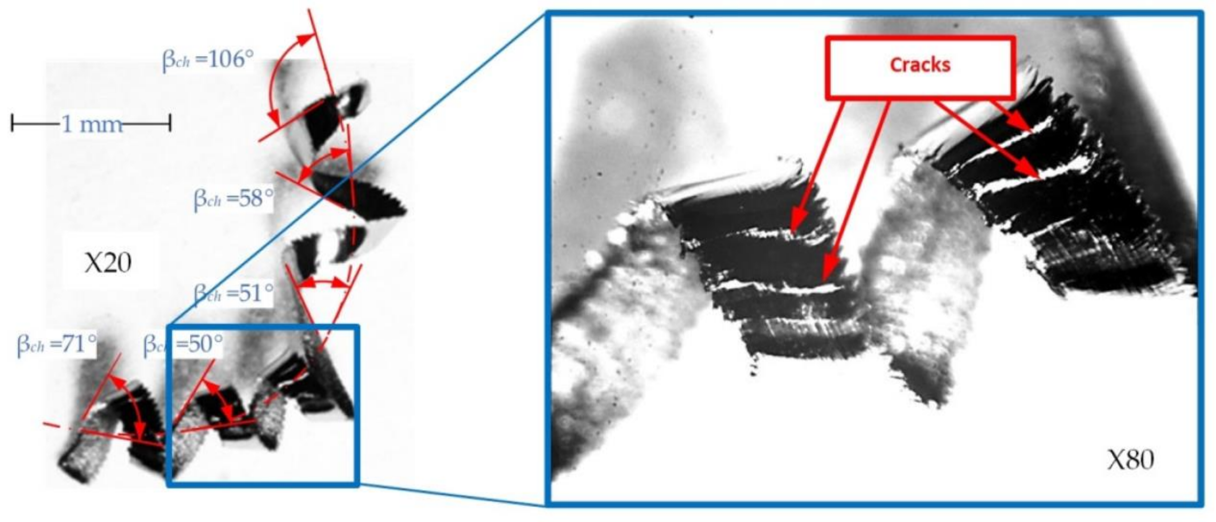
Dr. Purnendu Das (Presenter)
Dr Jose Immanuel R. (Owner)
Assistant Professor
Department of Mechanical Engineering
Indian Institute of Technology Bhilai

Principle of cutting

Principle of cutting







(a) (b)

Machining Centers - A bit of history

1949
US Air Force asks MIT to develop a "numerically controlled" machine.

1952
Prototype NC machine demonstrated (punched tape input)

1980-
CNC machines (computer used to link directly to controller)

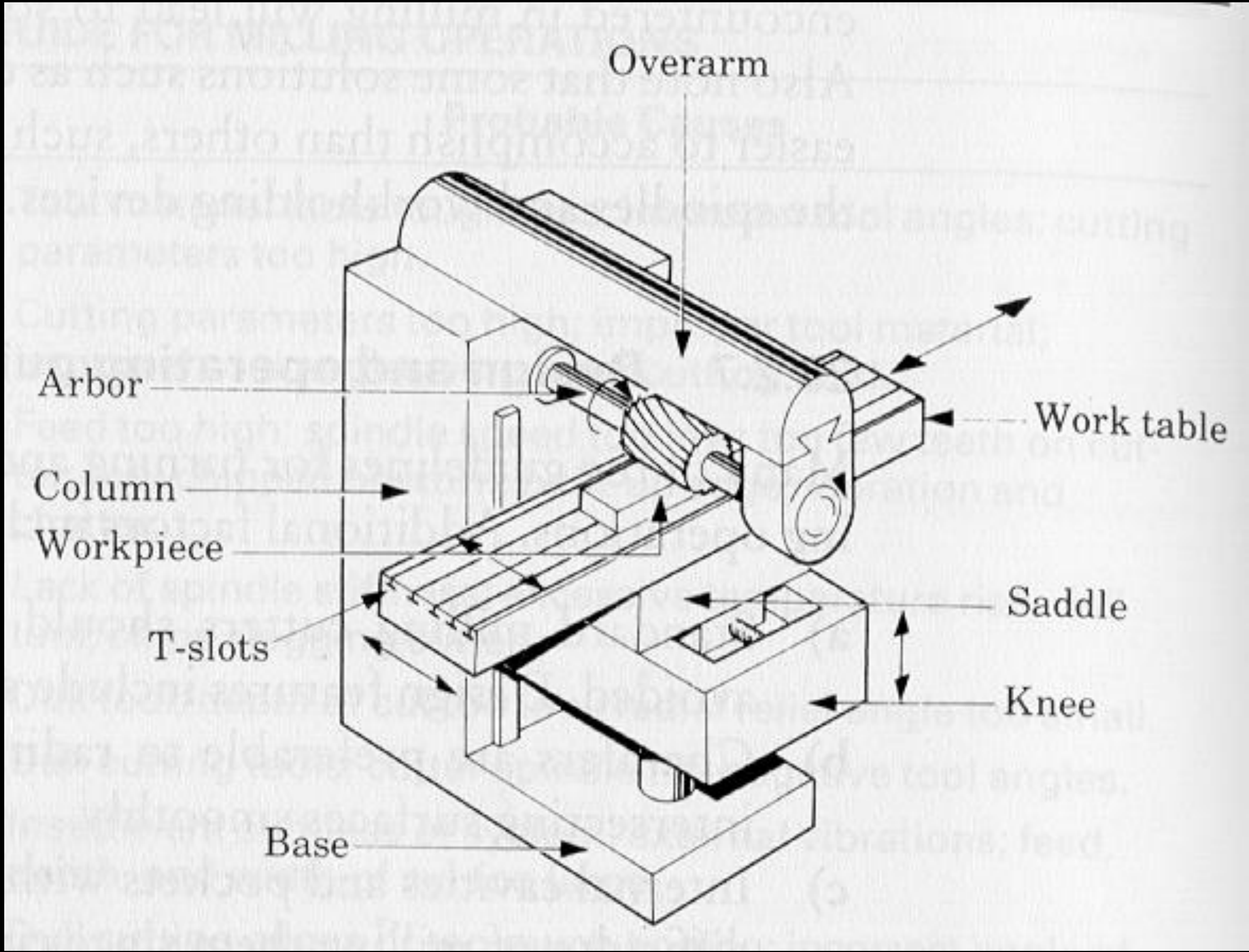
1990-
DNC: external computer “drip feeds” control programmer to machine tool controller

Conventional milling machines

Vertical milling machine

Conventional milling machines

Horizontal Milling machine architecture



How does the table move along X- Y- and Z- axes ?

Conventi

Introduction to CNC

- Numerical control (NC) is the automation of machine tools that are operated by precisely programmed commands encoded on a storage medium, as opposed to controlled manually.

- Most NC today is computer numerical control (CNC), in which computers play an integral part of the control.

- In modern CNC systems, end-to-end component design is highly automated using computer-aided design (CAD) and computer-aided manufacturing (CAM) programs.

Advantages of CNC

- CNC machines can be used continuously
- Batch production with high accuracy
- Can be updated by improving the software
- Training in the use of CNCs is available through the use of ‘virtual software’.
- Intricate detail machining
- No need to make a prototype or a model
- One person can supervise many CNC machines simultaneously – Economical and time saving

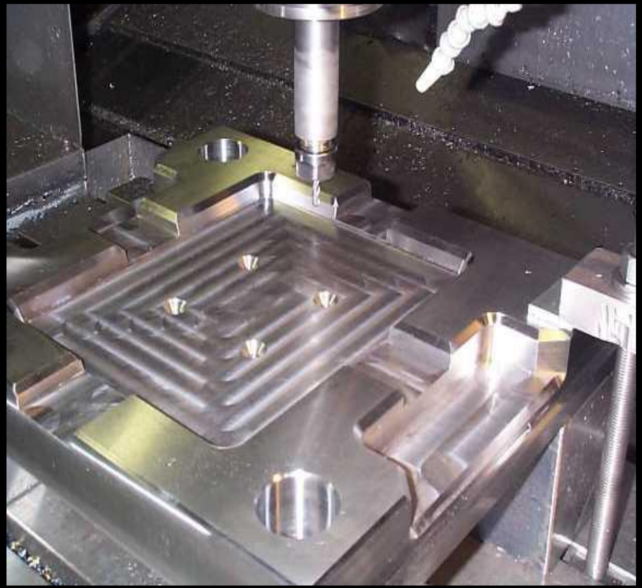
Disadvantages

- Expensive than manually operated machines

- CNC machine operator only needs basic training and skills, enough to supervise several machines. In years gone by, engineers needed years of training to operate centre lathes, milling machines and other manually operated machines. This means many of the **old skills are been lost**.

- Investment in CNC machines can lead to unemployment

Operations in CNC



CNC Milling

CNC Plasma Cutter

CNC Electric Discharge Machining

Other CNC Operations

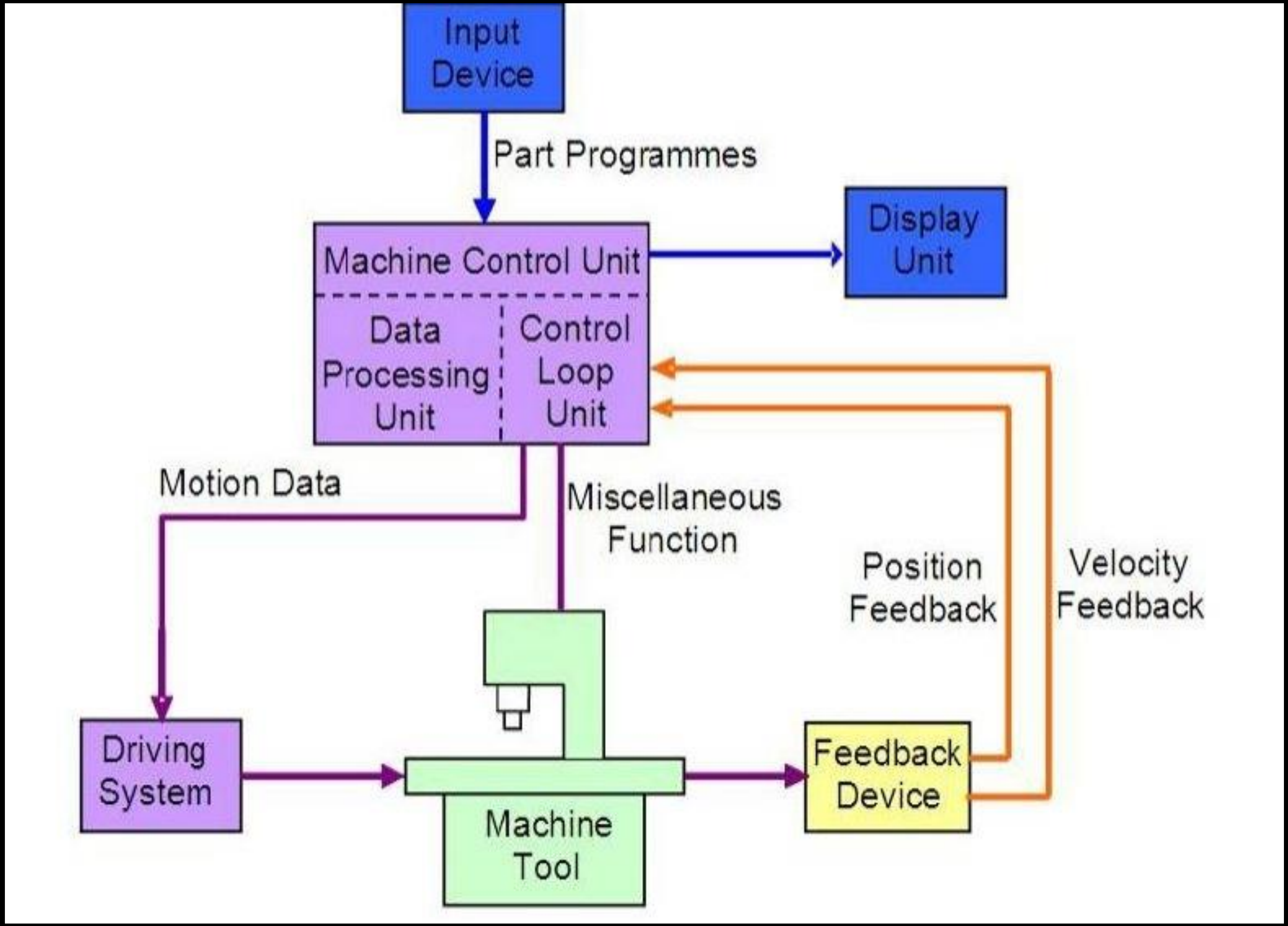
- CNC Water Jet Cutter
- Drilling
- Sheet metal works (Turret punch)
- Wire bending machines
- Surface grinders
- Cylindrical grinders

Some principle components

Elements of CNC Machine

SIX major elements:

i. Input Device
ii. Machine Control Unit
iii. Machine Tool
iv. Driving System
v. Feedback Devices
vi. Display Unit



Types

Based on ***Motion Type****:*

Point-to-Point or Continuous path

Based on ***Control Loops****:*

Open loop or Closed loop

Based on ***Power Supply:***

Electric or Hydraulic or Pneumatic

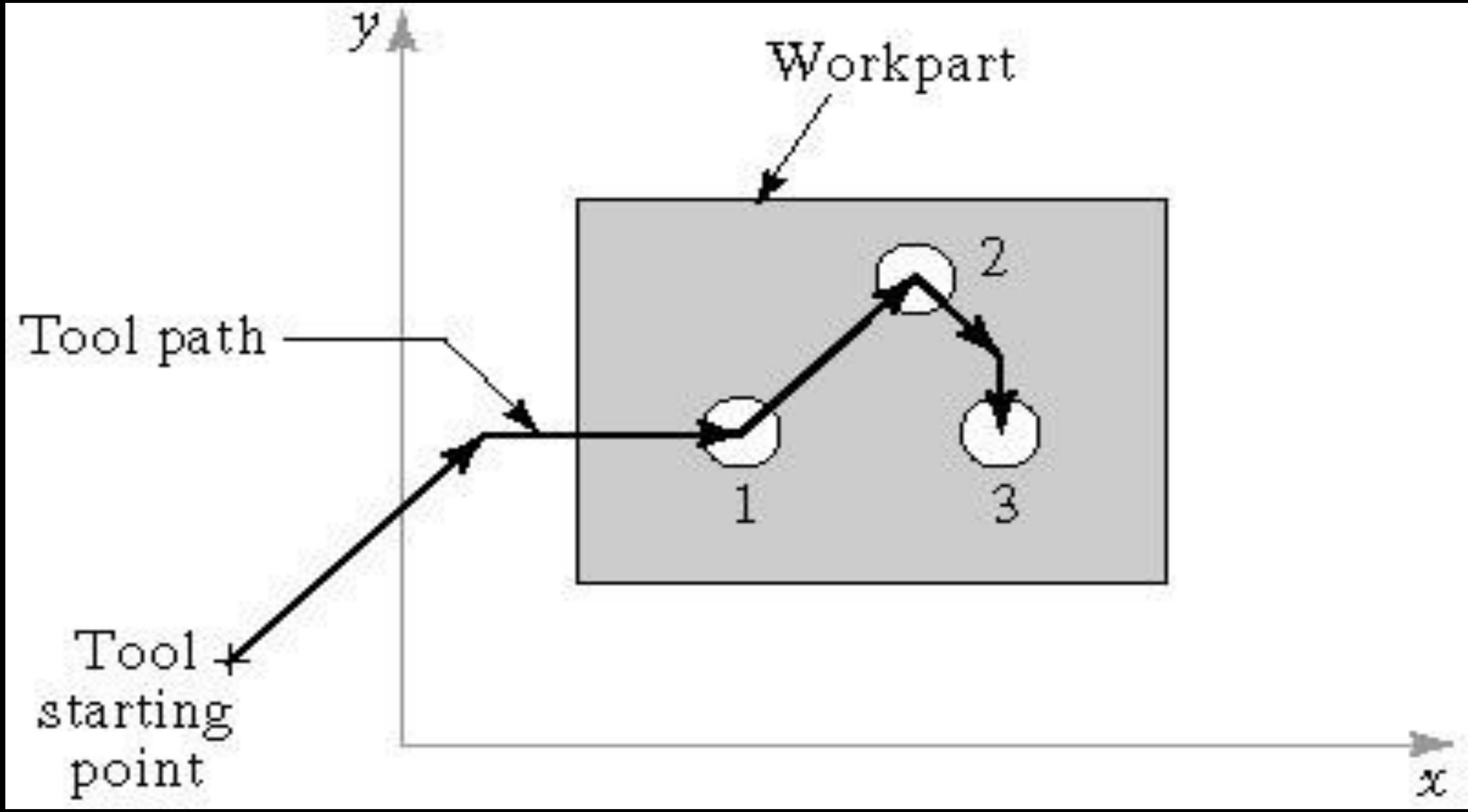
Based on ***Positioning System***

Incremental or Absolute

Motion Control Systems

1. Point-To-Point Control: CNC Drilling of Three Holes in Flat Plate

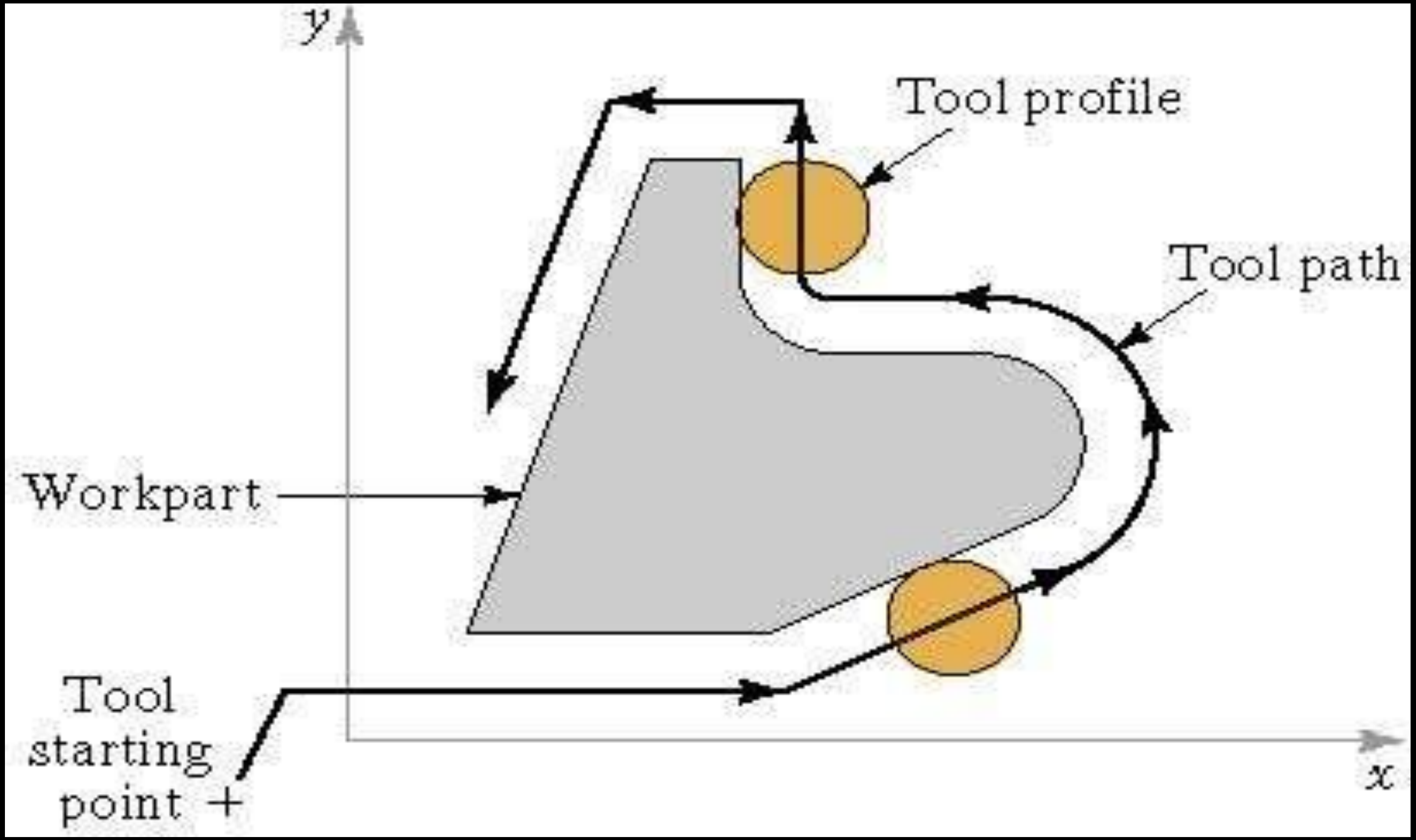
- System moves to a location and performs an operation at that location (e.g., drilling)
- Also applicable in robotics



Motion Control Systems

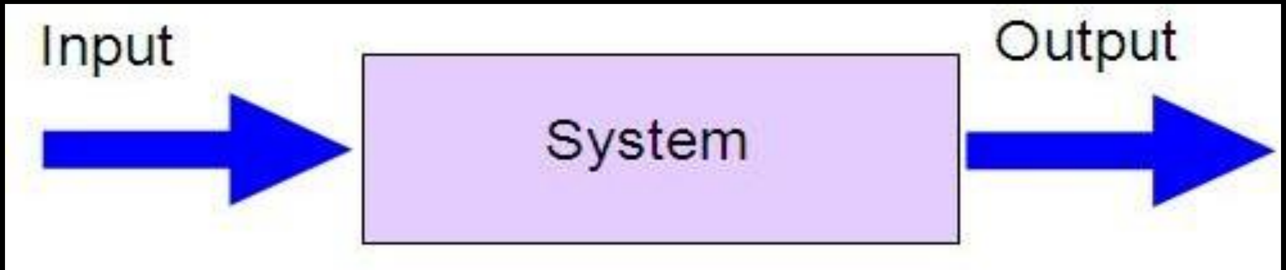
2. Continuous Path Control in CNC Profile Milling of Part Outline

- System performs an operation during movement (e.g., milling and turning) - Contouring

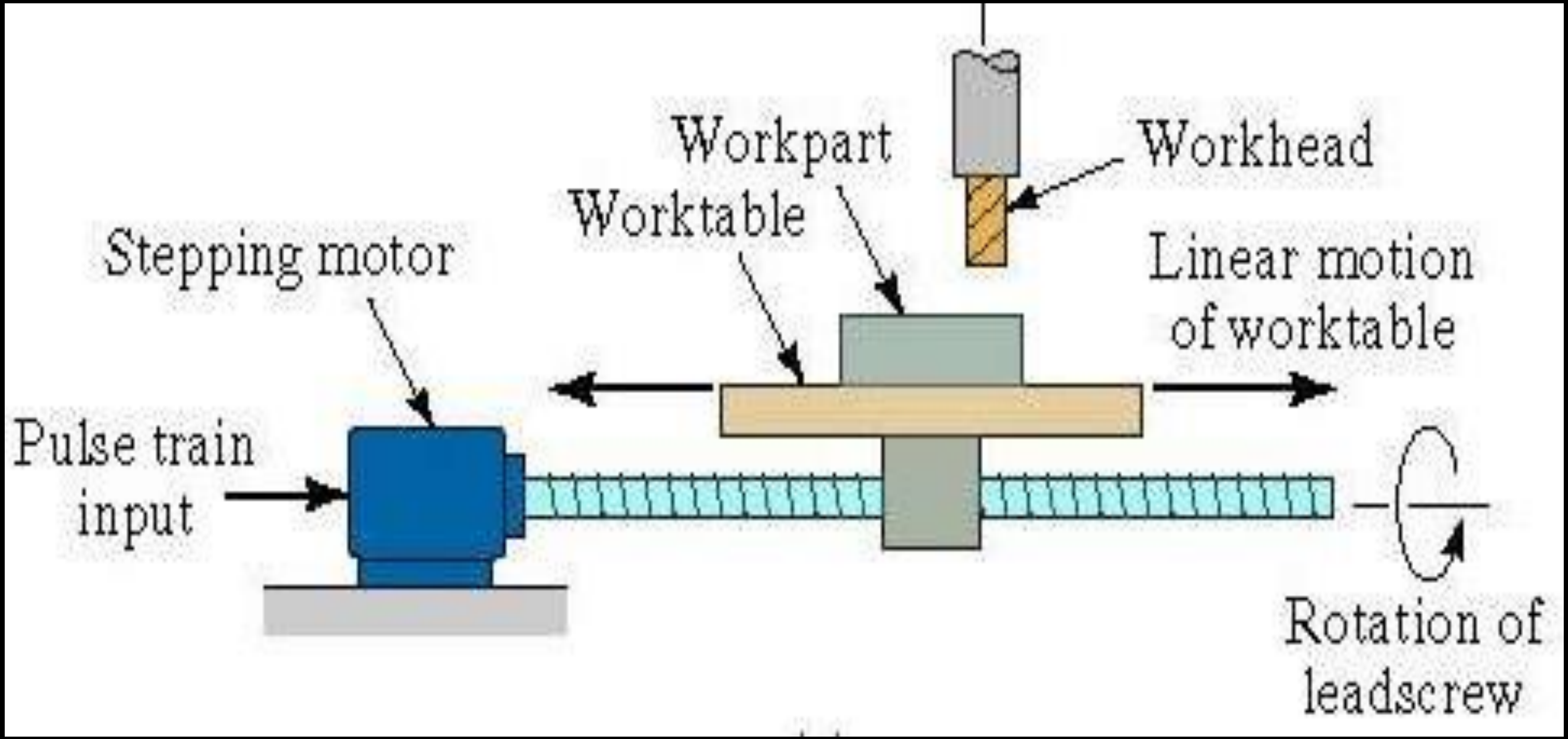


Open Loop Systems

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.

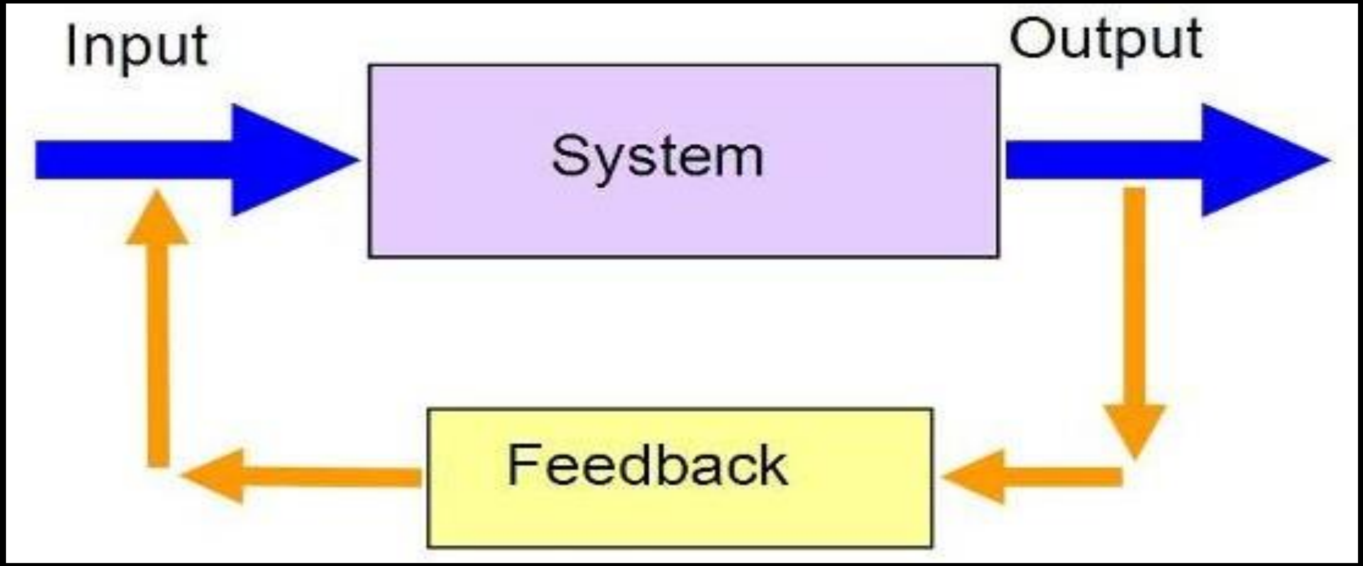


Open loop system – An example

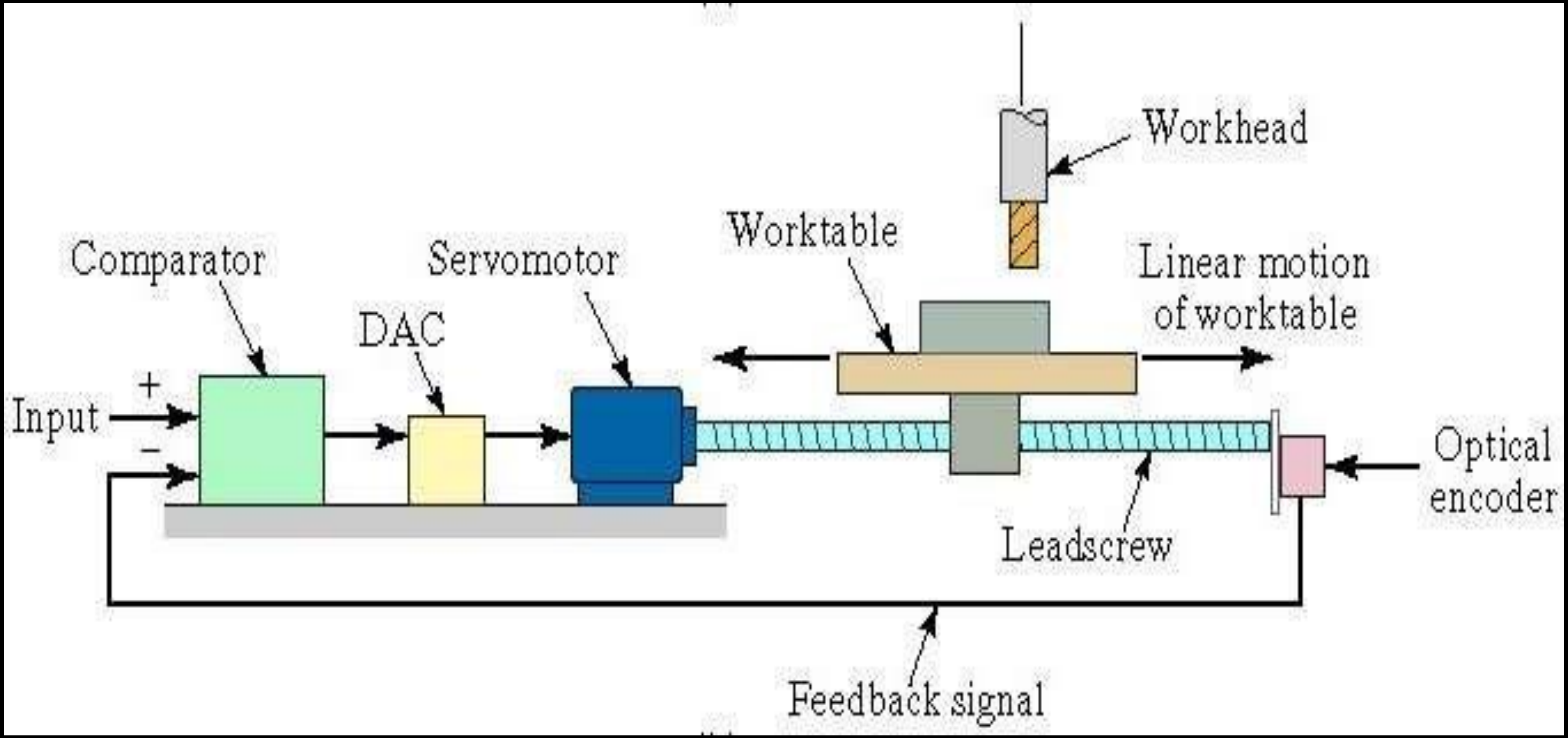


Close Loop Systems

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.

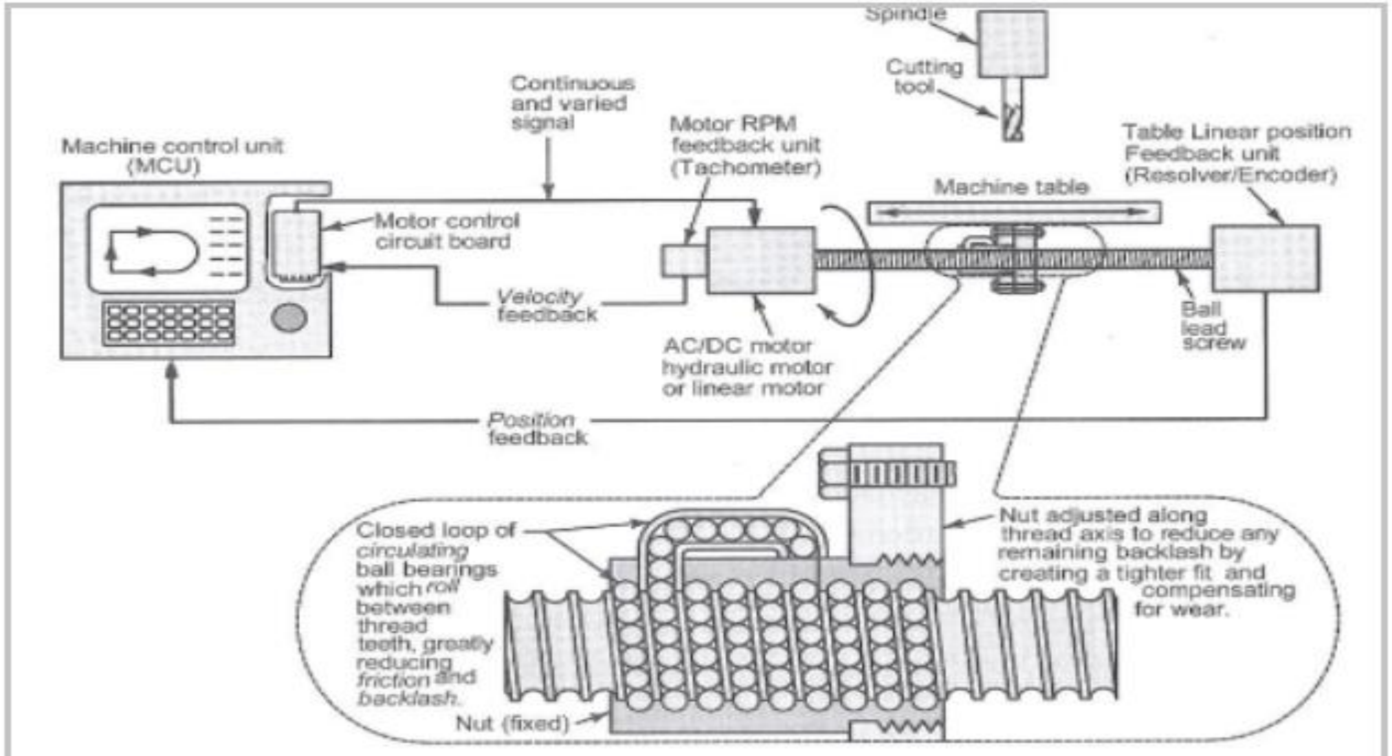


Close loop system – An example



Ball Lead Screws

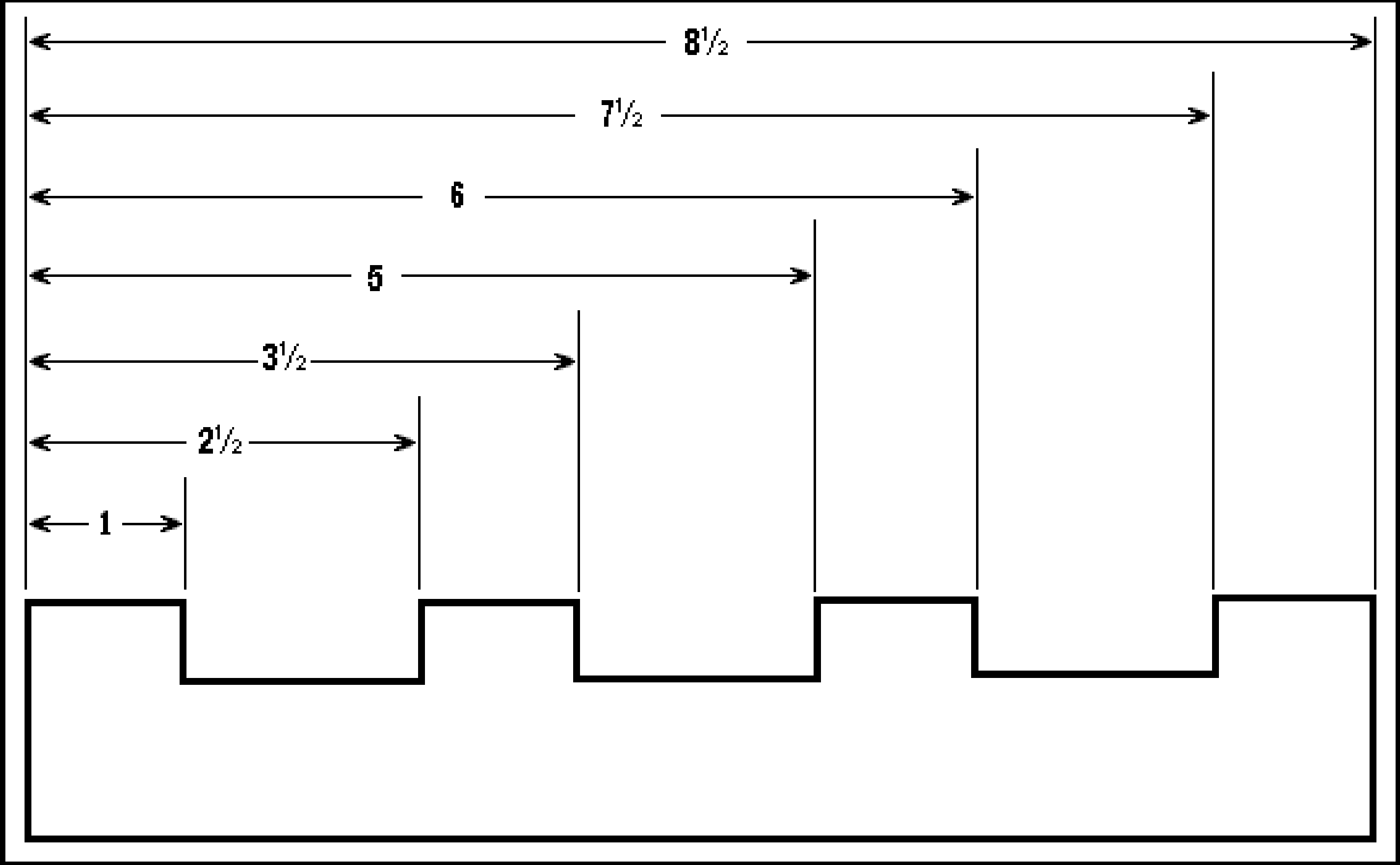
- Ball lead screw is the heart of the drive system.
- Advantages of ball lead screw are:
- Precise position and repeatability
- High Speed capability
- Less Wear
- Longer life

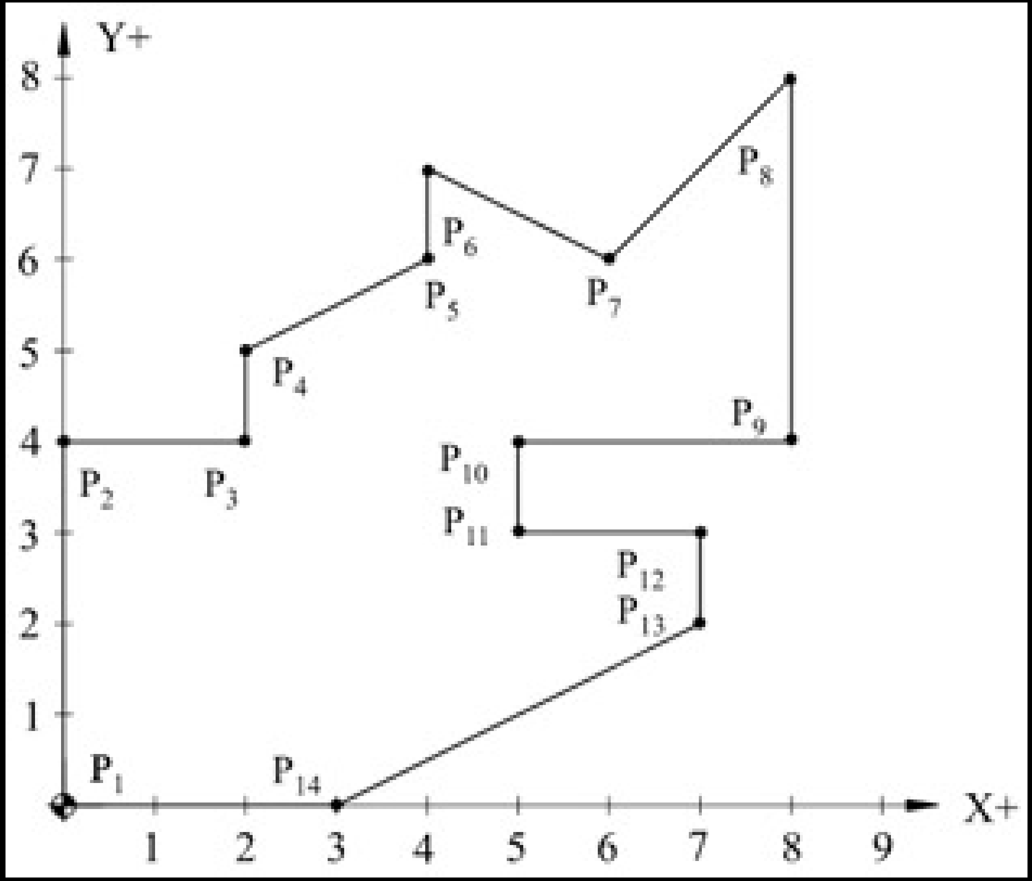


Configuration for a closed loop system that uses a ball lead screw mechanism.

PITCH Vs LEAD

Absolute and relative dimensioning





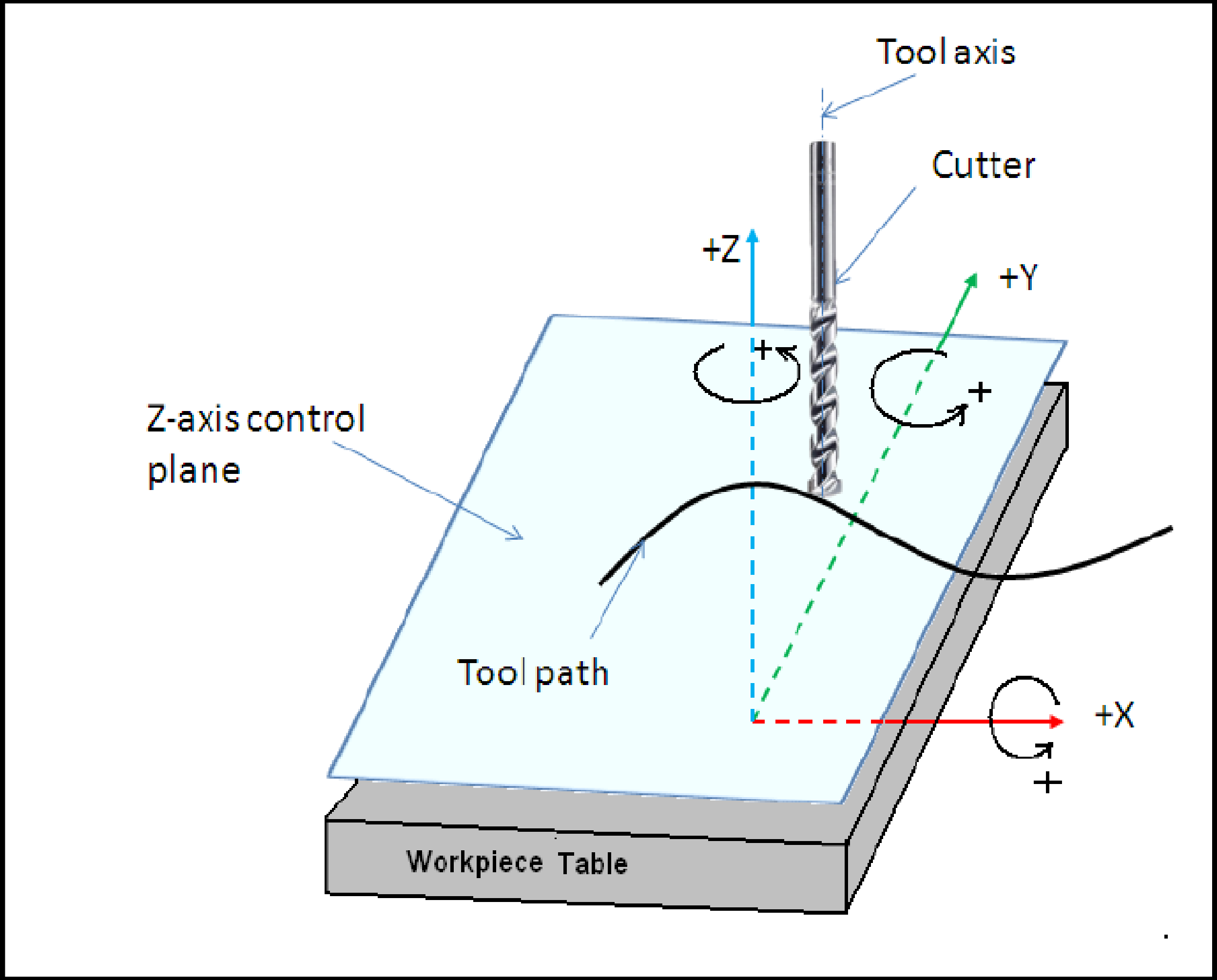
CNC Programming Basics

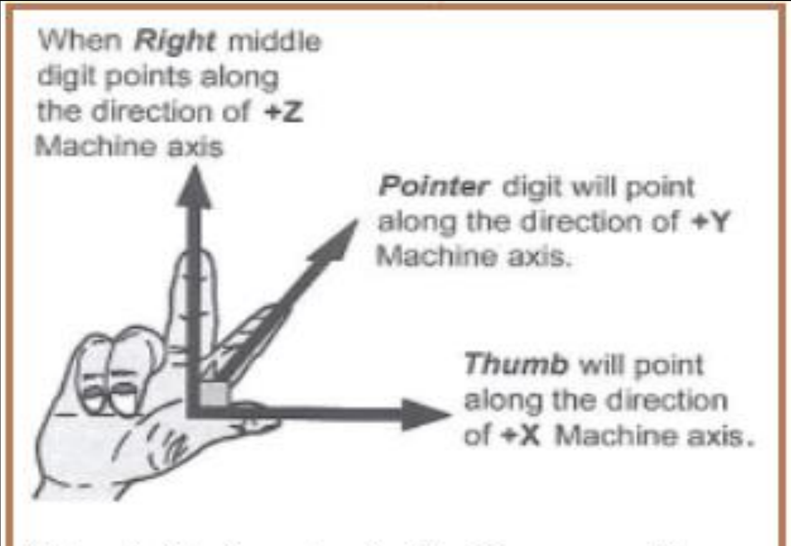
- CNC instructions are called part program commands.
- When running, a part program is interpreted one command line at a time until all lines are completed.
- Commands, which are also referred to as blocks, are made up of words which each begin with a letter address and end with a numerical value.

CNC programming – Things to know

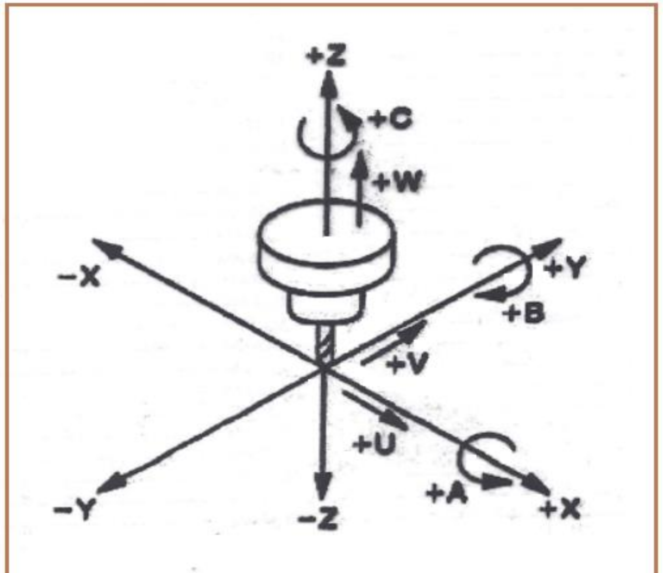
- Coordinate System
- Units, incremental or absolute positioning
- Coordinates: X,Y,Z, RX,RY,RZ
- Feed rate and spindle speed
- Coolant Control: On/Off, Flood, Mist
- Tool Control: Tool and tool parameters

Axes of CNC Machine Tool





The right-hand rule for linear motion



Machine axes of motion

From 3-axis to 5-axis machining

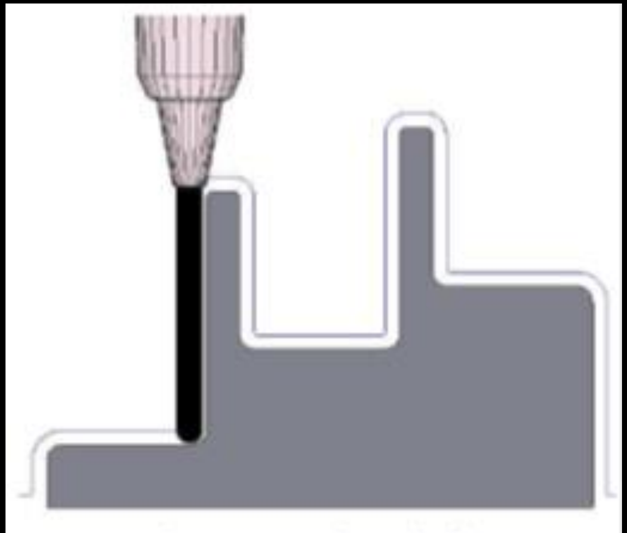


Fig. 1 3-axis toolpath.

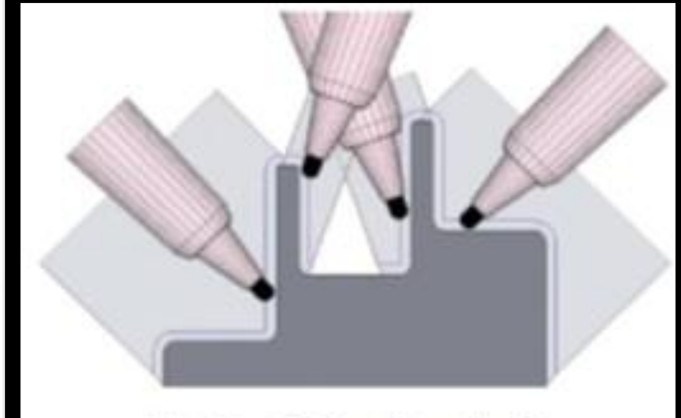


Fig.2 3+2-axis toolpath.

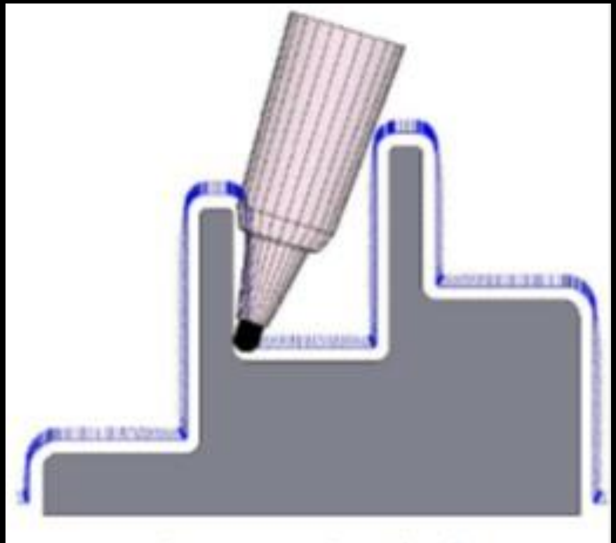
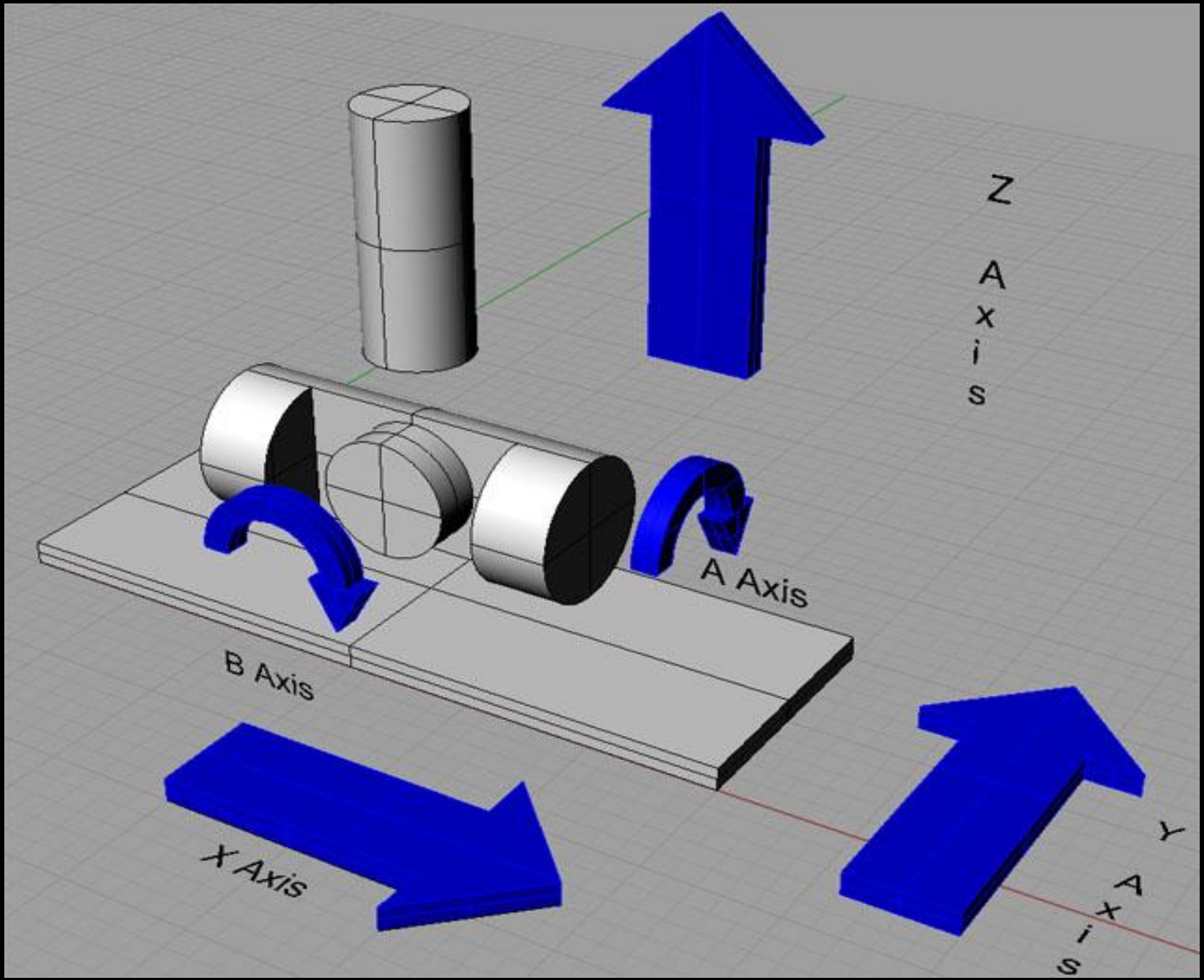


Fig.3 5-axis toolpath.

- Not sufficient for the complete finishing process for very deep part and having narrow cavities
- Results in a bad surface quality and long machining times in Case of harder material

- dozens of views need to be defined
- more tool movements
- programming is quite difficult
- sum of all views does not cover the whole geometry
- overlapping views lead to surface quality problems
- More number of lead-in and out movements

Five Axis CNC



Application

- complex three dimensional profiles
- for impellers, turbine blades, and plastic mold tools

ADVANTAGES OF 5 AXIS CNC

- to machine complex shapes in a single setup
- reduces the machinist setup time and increases production rates
- By eliminating multiple set-ups, time and errors are reduced
- the feature-to-features accuracy is improved because the same zero or datum reference frame is used throughout the manufacturing process
- since simultaneous movement is allowed along the X and Y axis, shorter and more rigid tools may be used
- higher spindle/cutting tool speeds may be achieved while reducing the load on the cutting tool
- Shorter and thicker cutters also reduce vibration when machining deep pockets or contoured features with three-axis machines.

Programming the machines – G code

- Each line of program -> **Block**

Sequence and format of words:

N3 G2 X+1.4 Y+1.4 Z+1.4 I1.4 J1.4 K1.4 F3.2 S4 T4 M2

destination coordinates

dist to center of circle

tool

sequence no

spindle speed

feed rate

preparatory function

miscellaneous function

Programming Key Letters

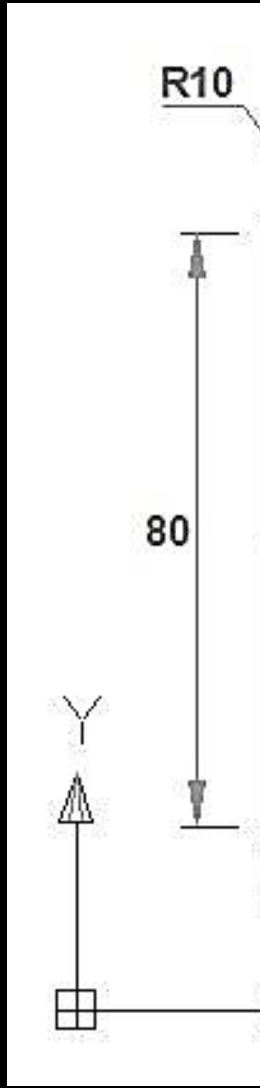
- O - Program number (Used for program identification)
- N - Sequence number (Used for line identification)
- G - Preparatory function
- X - X axis designation
- Y - Y axis designation
- Z - Z axis designation
- R - Radius designation
- F – Feed rate designation
- S - Spindle speed designation
- H -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

Some essential G-codes

- G00 Rapid traverse
- G01 Linear interpolation
- G02 Circular interpolation CW
- G03 Circular interpolation CCW
- G20 Imperial unit
- G21 Metric unit
- G90 Absolute system
- G91 Incremental system
- G94 Feed per minute
- G95 Feed per revolution

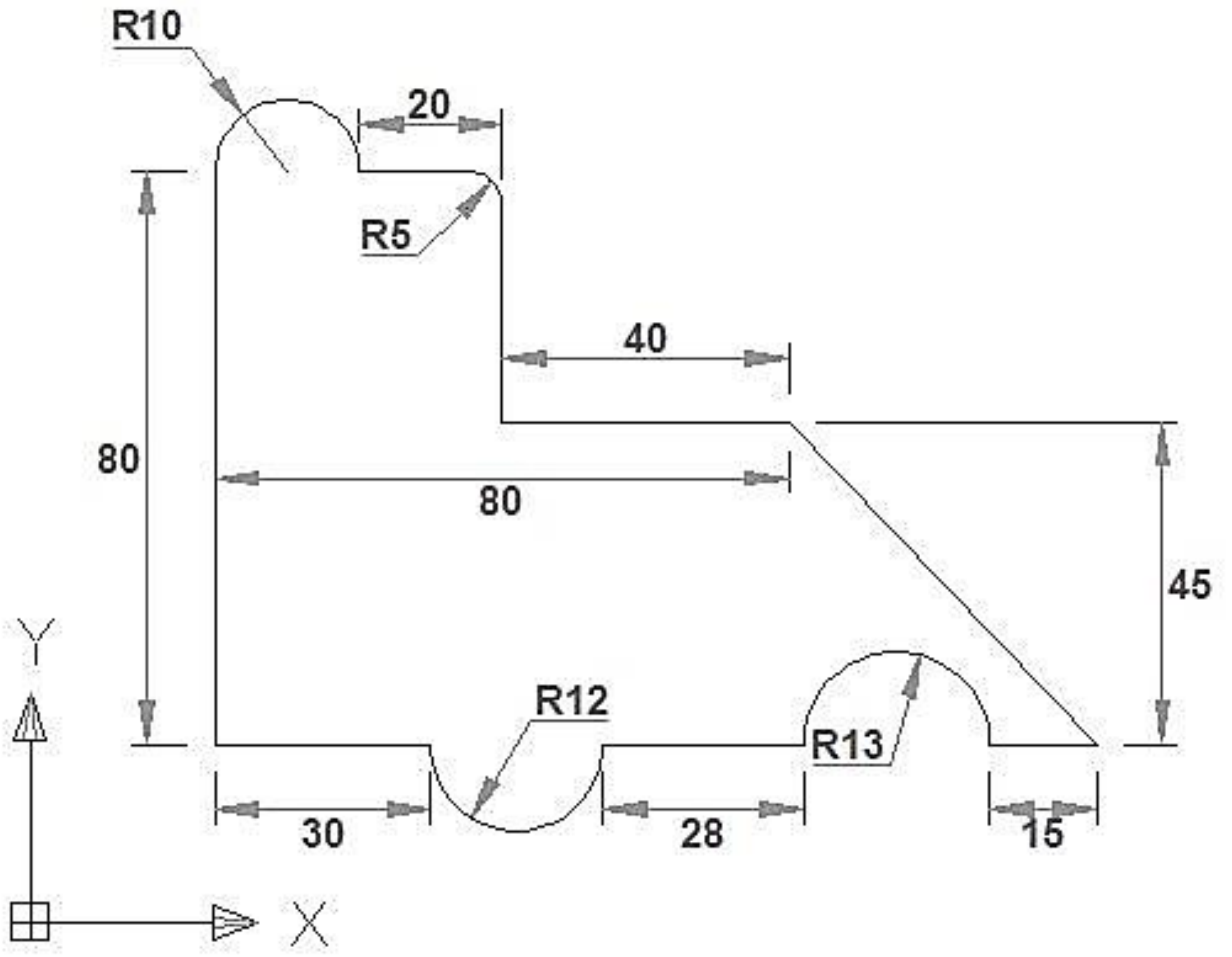
Some essential M-codes

- M00 Program Stop
- M03 Spindle on CW
- M04 Spindle on CCW
- M05 Spindle stop
- M06 ATC
- M08/M09 Coolant on/off
- M10/M11 Vice Open/close
- M30 Program stop and rewind
- M98 Sub-program call
- M99 Sub-program end and return



Example

- Feed: 30 mm/min
- Speed: 5000 rpm



Primary Machining Parameters

• Cutting Speed – (*v*)		
– Primary motion		
– Peripheral speed	m/s	ft/min
• Feed – (*f*)		
– Secondary motion		
– Turning:	mm/rev	in/rev
– Milling:	mm/tooth	in/tooth
• Depth of Cut – (*d*)		
– Penetration of tool below original work surface		
– Single parameter	mm	in
• Resulting in Material Removal Rate – (*MRR*)		
$MRR^{*} = v\,f\,d$	mm^3/s	in^3/min

where v = cutting speed; f = feed; d = depth of cut

* general model, only!

Machining Operations & Parameters

Operation Type	*Speed*	*Feed*	*Depth of Cut*
Turning: workpiece rotates single point cutting	**Surface speed (periphery) of workpiece**	**Parallel to the workpiece axis*** **(except parting/grooving)**	**Tool penetration below original work surface**
Drilling: tool rotates single pass cutting	**Surface speed (periphery) of tool**	**Parallel to the tool axis**	**Tool penetration below original work surface (depth of hole)**
Milling: tool rotates multi-point cutting	**Surface speed (periphery) of tool**	**Perpendicular to the tool axis**	**Tool penetration below original work surface**

Cut Types: Roughing & Finishing

Cut Type	*Number of Passes*	*Speed*	*Feed*	*Depth of Cut*
Roughing: removes large amounts to get close to shape	1 +	Low	High 0.4 - 1.25 mm/ .015 - .050 in/	High 2.5 - 20 mm .100 - .750 in
Finishing: achieves final dimensions, tolerances, and finish	1 - 2	High	Low 0.125 - 0.4 mm/ .005 - .015 in/	Low 0.75 - 2.0 mm .030 - .075 in

Machining Calculations: Turning

- Spindle Speed - N (rpm)
    - **v = cutting speed**
    - **D_o = outer diameter**

$$N = \frac{v}{\pi D_o}$$

- Feed Rate - f_r (mm/min -or- in/min)
    - **f = feed per rev**

$$f_r = N f$$

- Depth of Cut - d (mm -or- in)
    - **D_o = outer diameter**
    - **D_f = final diameter**

$$d = \frac{D_o - D_f}{2}$$

- Machining Time - T_m (min)
    - **L = length of cut**

$$T_m = \frac{L}{f_r}$$

- Mat'l Removal Rate - MRR (mm^3/min -or- in^3/min)*

$$MRR = v f d$$

** This approximate equation assumes that **f** has units of mm or inches – in accordance with Groover and Rufe (SME) texts.*

- Mat'l Removal Rate - MRR $$MRR = \pi D_{avg}\, d\, f\, N$$ (mm³/min -or- in³/min)*

In this equation: – in accordance with Kalpakjian, et. al. texts. $$D_{avg} = \frac{D_o + D_f}{2}$$

IENG 475: Computer-Controlled

Mat'l Removal Rate - MRR $$MRR = \frac{\pi (D_o^2 - D_f^2) f N}{4}$$ (mm³/min -or- in³/min)*

**This equation is the SDSM&T form!*

$$MRR = v\, f\, d$$

Machining Calculations: Drilling

- Spindle Speed - N (rpm)
  - v = cutting speed
  - D = tool diameter

$$N = \frac{v}{\pi D}$$

- Feed Rate - f_r (mm/min -or- in/min)
  - f = feed per rev

$$f_r = Nf$$

$$A = \pi r^2$$

- Machining Time - T_m (min)
  - Through Hole :
    - t = thickness
    - θ = tip angle

$$T_m = \frac{t + \frac{1}{2} D\left[\tan\left(90 - \frac{\theta}{2}\right)\right]}{f_r}$$

  - Blind Hole :
    - d = depth

$$T_m = \frac{d}{f_r}$$

- Mat'l Removal Rate - MRR (mm³/min -or- in³/min)

$$MRR = \frac{\pi D^2 f_r}{4}$$

Alternatively: $MRR = \frac{\pi D^2 N f}{4}$

Machining Calculations: Milling

- Spindle Speed - N (rpm)
    - **v = cutting speed**
    - **D = cutter diameter**

$$N = \frac{v}{\pi D}$$

- Feed Rate - f_r (mm/min -or- in/min)
    - **f = feed per tooth**
    - **n_t = number of teeth**

$$f_r = N\, n_t\, f$$

- Machining Time - T_m (min)
    - **Slab Milling:**
        - **L = length of cut**
        - **d = depth of cut**

$$T_m = \frac{L + \sqrt{d(D - d)}}{f_r}$$

    - **Face Milling:**
        - **w = width of cut**
        - **2nd form is multi-pass**

$$T_m = \frac{L + D}{f_r} \quad \textbf{-or-} \quad T_m = \frac{L + 2\sqrt{w(D - w)}}{f_r}$$

- Mat'l Removal Rate - MRR $MRR = w\, d\, f_r$ (mm^3/min -or- in^3/min)

Power and Energy Relationships

- Power requirements to perform machining can be computed from:

$$\boldsymbol{P_c = F_c v}$$ N-m/s (W) ft-lb/min

where: P_c = cutting power;

F_c = cutting force; and

v = cutting speed

- Customary U.S. units for power are Horsepower

(= 33000 ft-lb/min)

Power and Energy Relationships

- The Gross machine power ($\boldsymbol{P_g}$) available is:

$$\boldsymbol{P_c = P_g \bullet E}$$

where E = mechanical efficiency of machine tool

- Typical E for machine tools = ~ 80 - 90%

Note: Alternate relationships for the same -

$$P_g = \frac{P_c}{E} \qquad HP_g = \frac{HP_c}{E}$$

Unit Power in Machining

- Useful to convert power into power per unit volume rate of metal cut
- Called the *unit power*, P_u or *unit horsepower*, HP_u

$$P_u = \frac{P_c}{MRR} \quad \text{or} \quad HP_u = \frac{HP_c}{MRR}$$

where MRR = material removal rate

Specific Energy in Machining

- Unit power (***P_u***) is also known as the *specific energy* (***U***), or the power required to cut a unit volume of material:

$$U = P_u = \frac{P_c}{MRR} = \frac{F_c}{t_o w}$$

where t_0 = un-deformed chip thickness;
w = width of the chip; and
F_c = cutting force

- Units for specific energy are typically N-m/mm³ (*same as J/mm³*) or as in-lb/in³
- Table on Materials page approximates specific energy for several materials based on estimated hardness