Module-VI(half part)
Course: Manufacturing processes
Instructor: Prof. Alok Kumar Das

Topics to be covered: CNC machine operation, 3D printing and scanning, Robots in manufacturing process

No of classes: 03

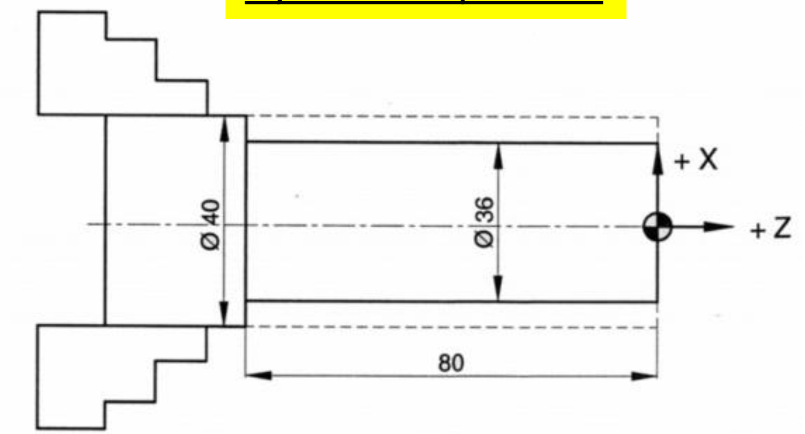
What is NC and CNC machines? Why these machines are needed?

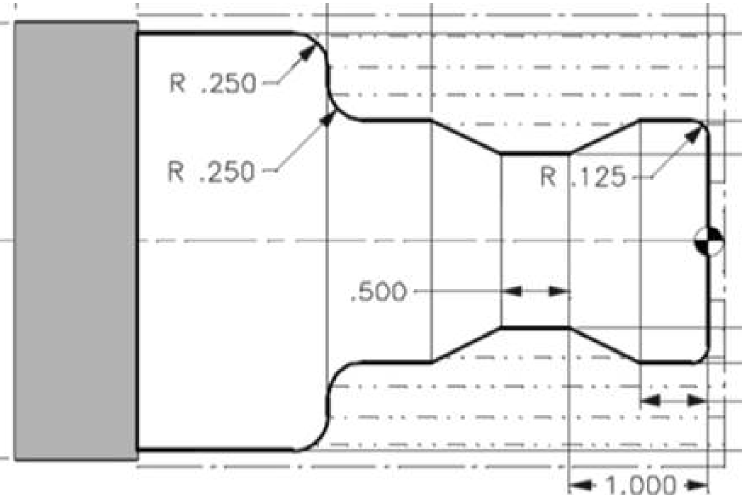
NC: **N**umerical **C**ontrol

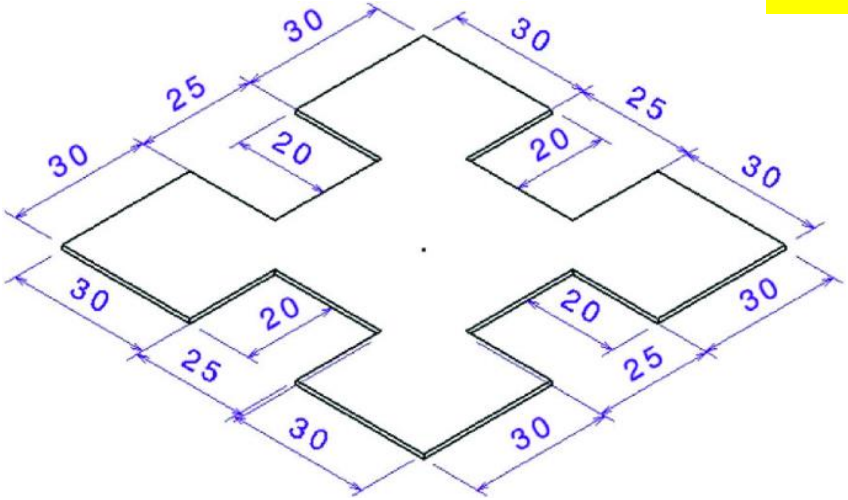
CNC: **C**omputer **N**umerical **C**ontrol

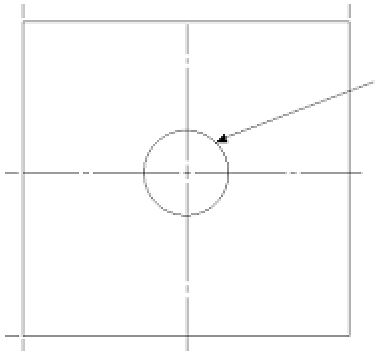
2D profiles

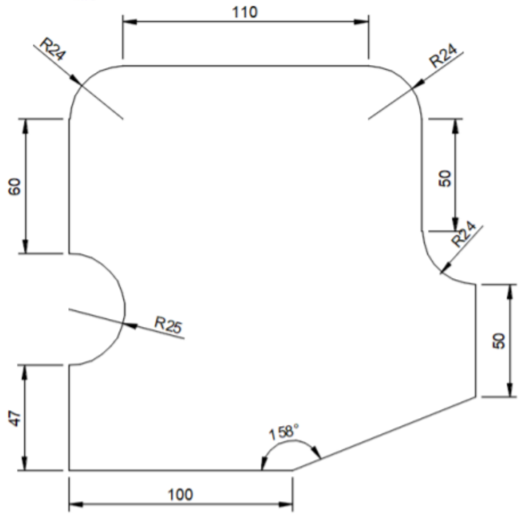
Cylindrical profiles











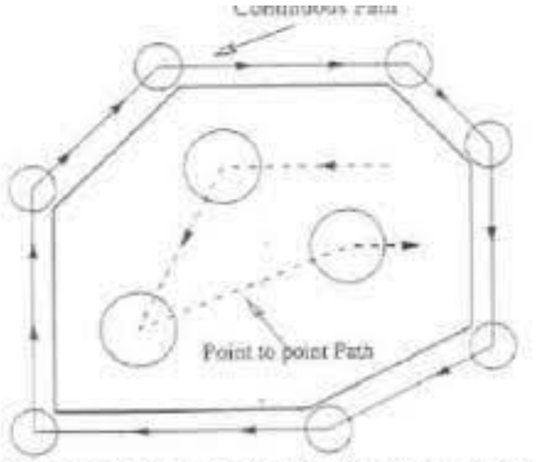
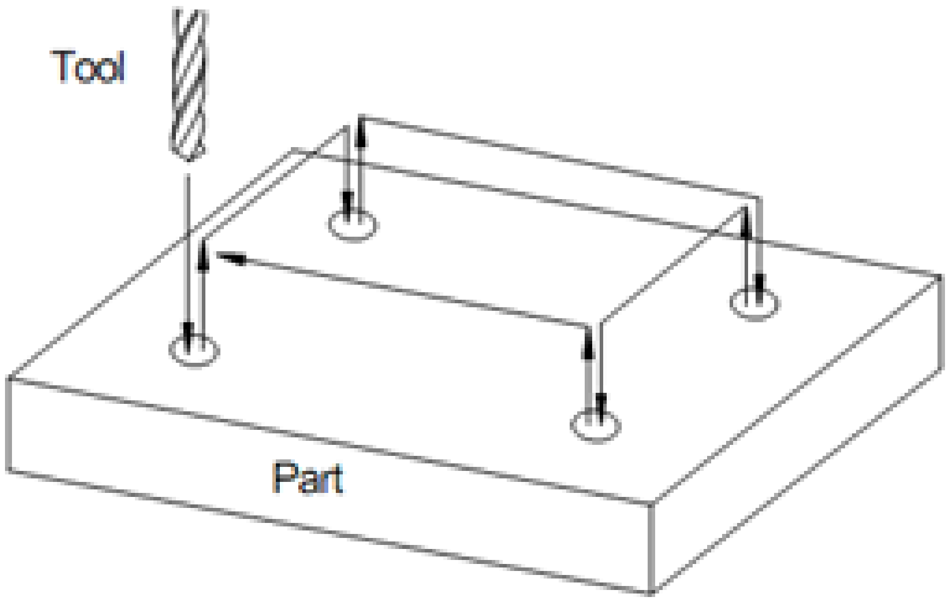


Fig. 15.15 Point-to-point and continuous path.

Classification of CNC machines based on:

- Types of cutter movement
- Type of control-open loop and close loop
- Number of axes- 2,3,4,5 ....axes machines etc.

- **Based on the tool motion : Point-to-point & Contouring or continuous systems**
  - **Point-to-point systems :** drilling, boring and tapping machines, spot welding, die-sinking EDM, brazing etc.



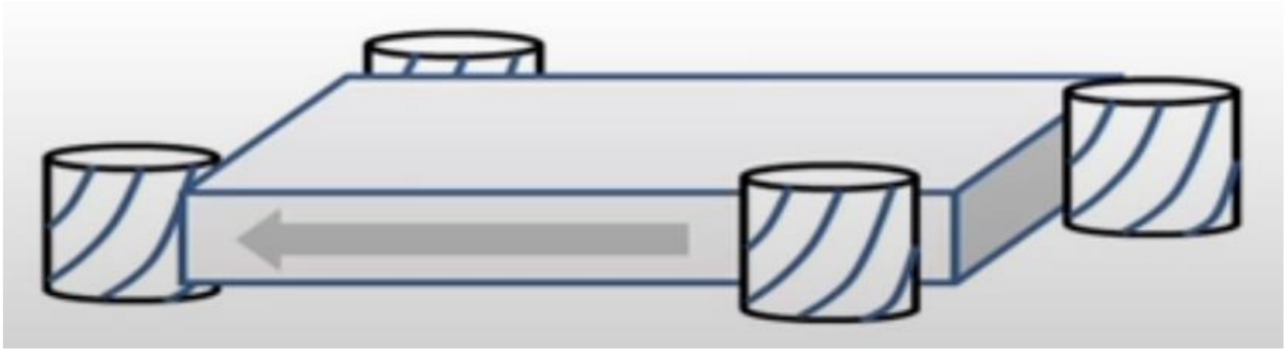
Features:

- The control system does not require an interpolator
- cutter moves from one point to another and carries out operation
- Distance between these points is covered with max. possible velocity.

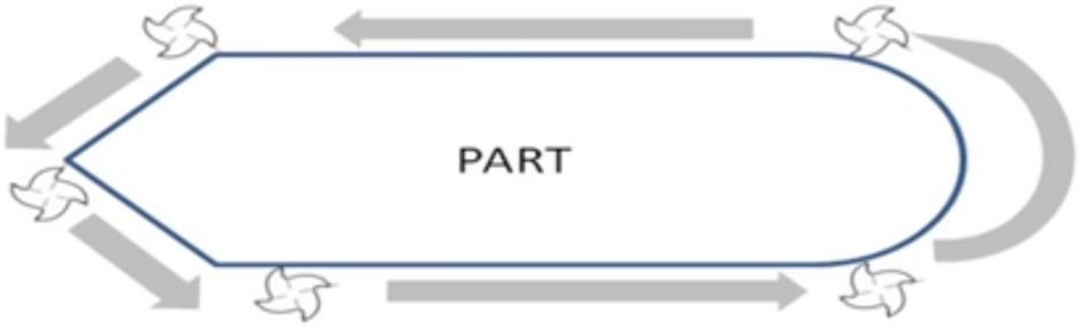
- Contouring or continuous systems: 1) linear cut, 2) linear and circular cut

Example: milling and lathe operations

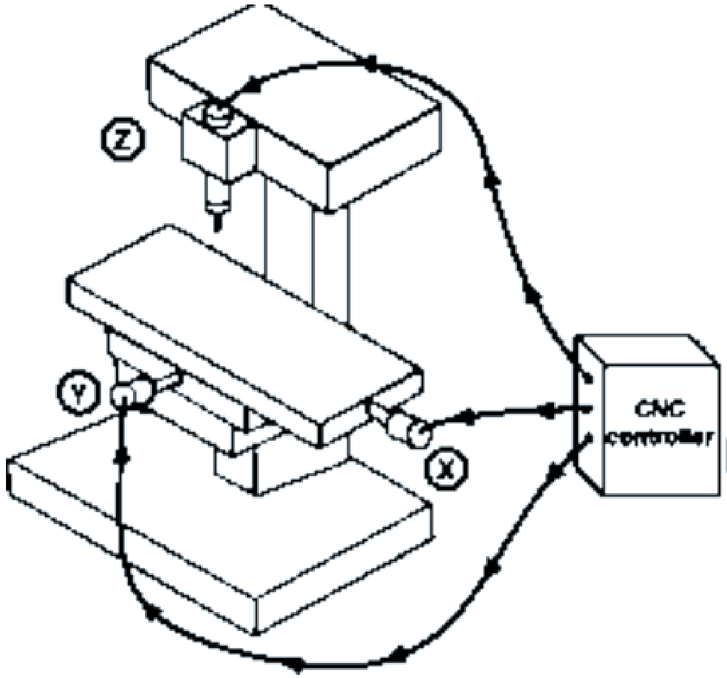
1) linear cut



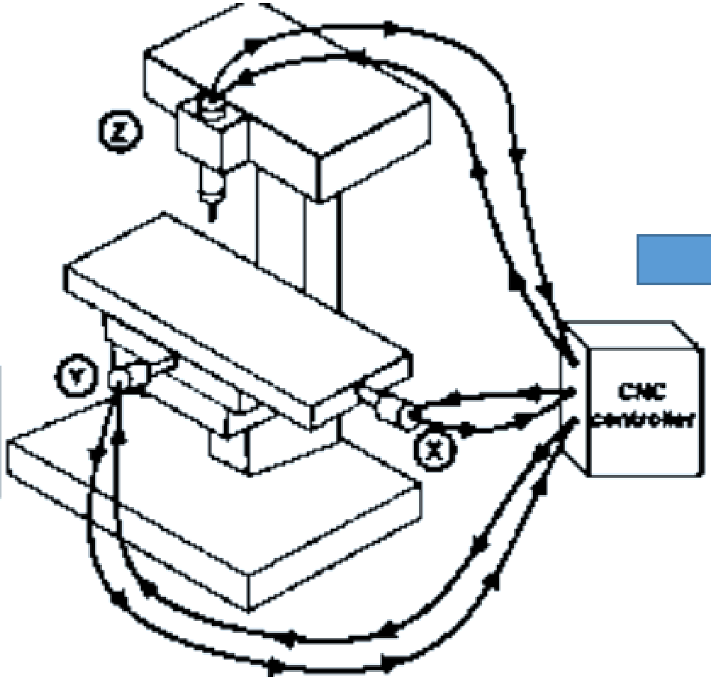
2) linear and circular cut



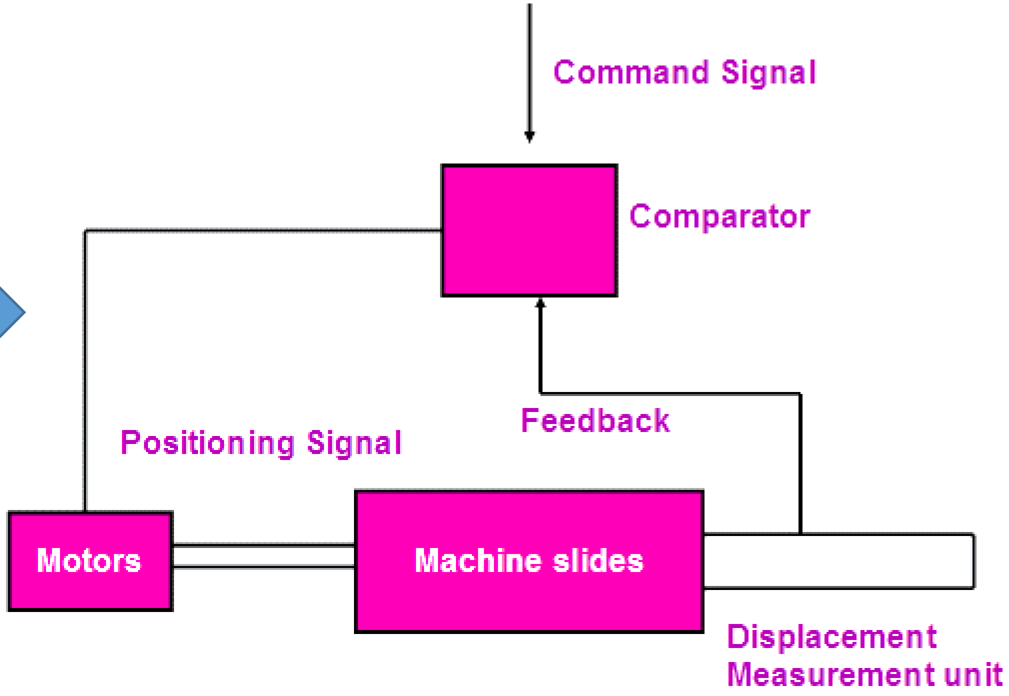
- Open loop and Close loop control

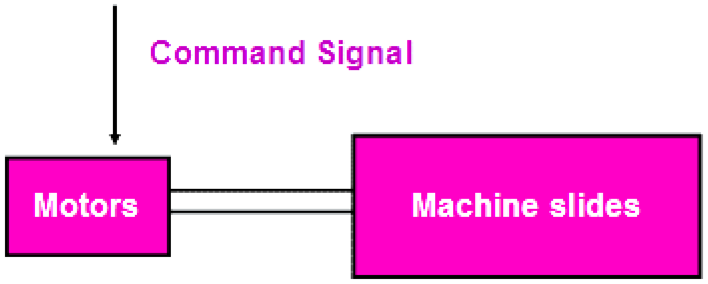


Open loop



Close loop





- Major Components of a CNC System
  - **Part program:**
  - **Program input device:**
  - **Machine Control Unit:**
  - **Drive System:**
  - **Machine Tool:**
  - **Feed Back System:**

1. CNC Part Programming fundamentals:

Machining involves an important aspect of relative movement between cutting tool and workpiece. In machine tools this is accomplished by either moving the tool with respect to workpiece or vice versa. In order to define relative motion of two objects, reference directions are required to be defined. These reference directions depend on type of machine tool and are defined by considering an imaginary coordinate system on the machine tool.

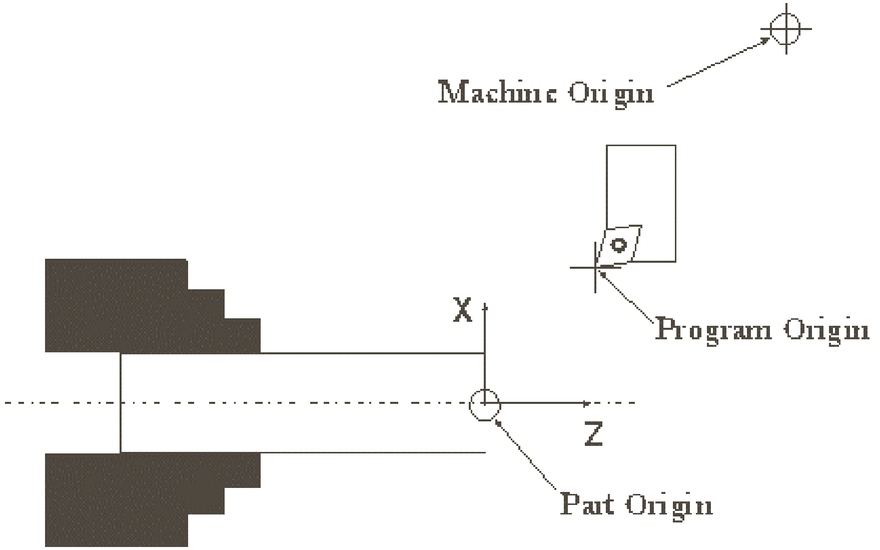
A program defining motion of tool / workpiece in this coordinate system is known as a part program. Lathe and Milling machines are taken for case study but other machine tools like CNC grinding, CNC Hobbing, CNC filament winding machine, etc. can also be dealt with in the same manner.

1.1) Reference Points in CNC machines

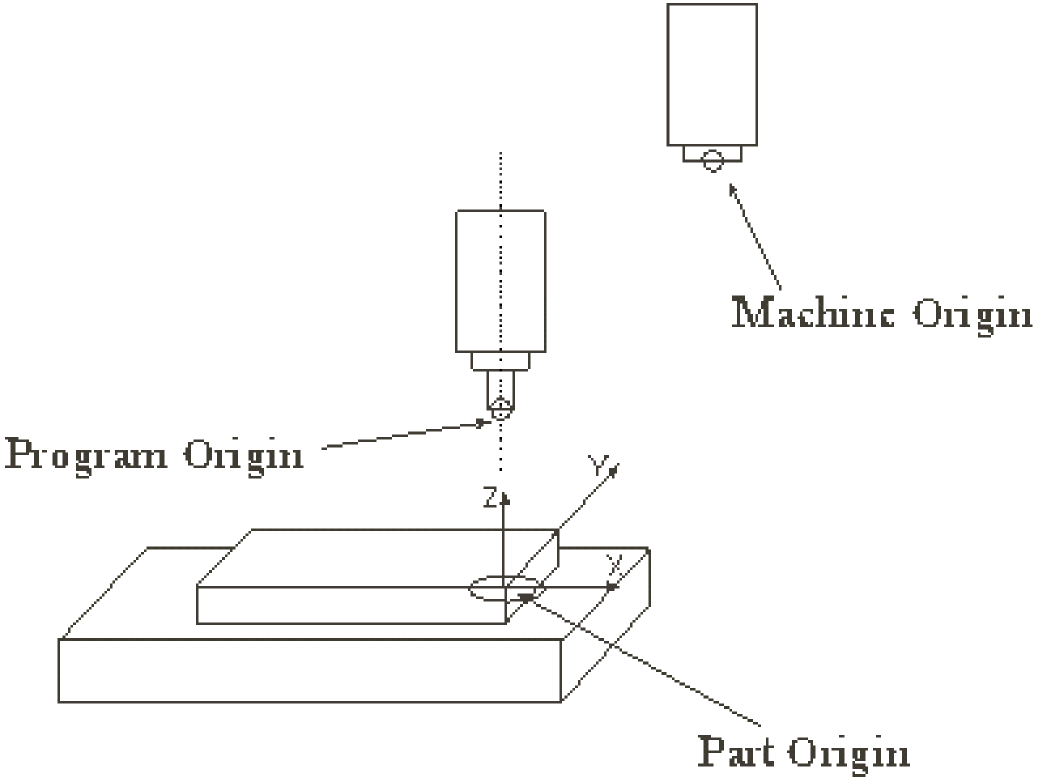
a) Machine Origin

b) Program Origin

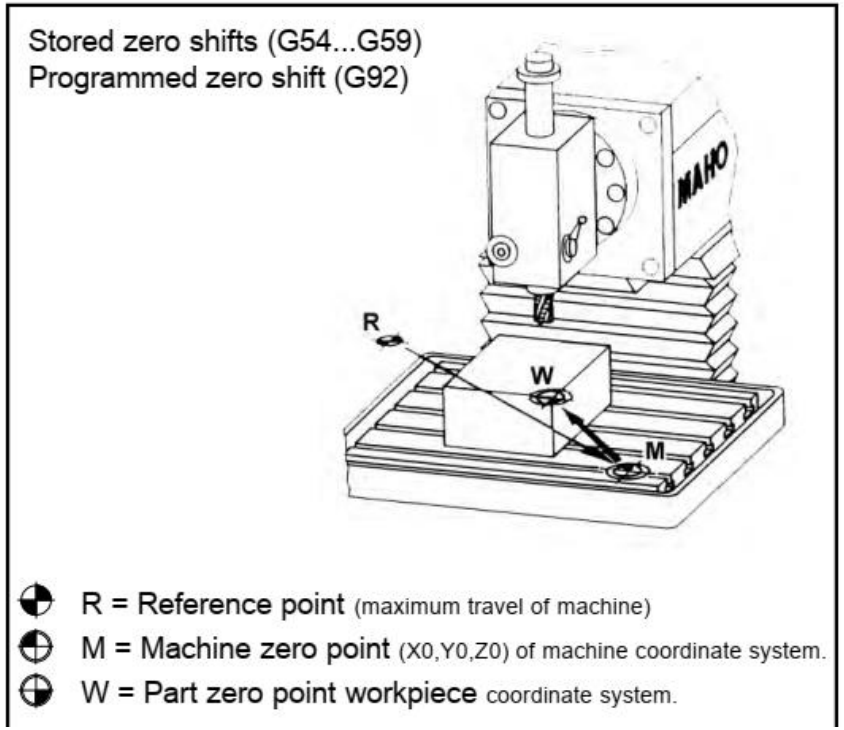
c) Part Origin



Reference points and axis on a lathe



Reference points and axis on a Milling Machine



1.2) Axis Designation

An object in space can have six degrees of freedom with respect to an imaginary Cartesian coordinate system. Three of them are liner movements and other three are rotary. Machining of simple part does not require all degrees of freedom. With the increase in degrees of freedom, complexity of hardware and programming increases. Number of degree of freedom defines axis of machine.

Axes interpolation means simultaneous movement of two or more different axes to generate required contour. For typical lathe machine degree of freedom is 2 and so it called 2 axis machines. For typical milling machine degree of freedom is $2\frac{1}{2}$, which means that two axes can be interpolated at a time and third remains independent.

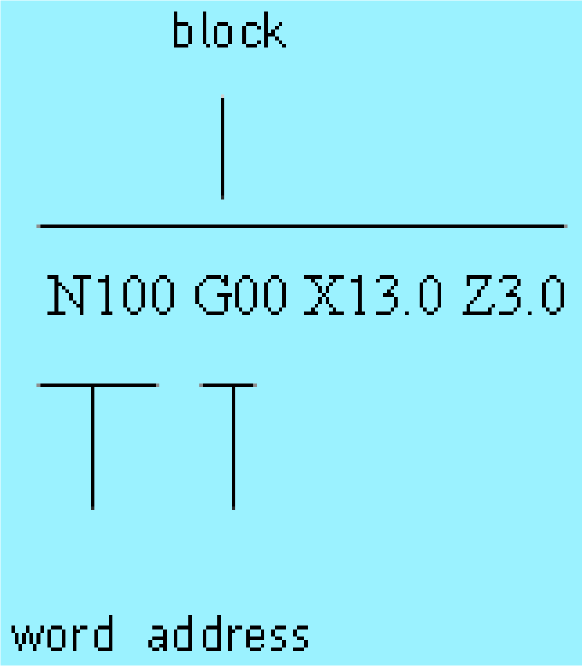
1.3) Setting up of Origin

In case of CNC machine tool rotation of the reference axis is not possible. Origin can set by selecting three reference planes X, Y and Z. Planes can be set by touching tool on the surfaces of the workpiece and setting that surfaces as X=x, Y=y and Z=z.

1.4) Coding Systems

The programmer and the operator must use a coding system to represent information, which the controller can interpret and execute.

2) CNC Code Syntax



3) Types of CNC codes

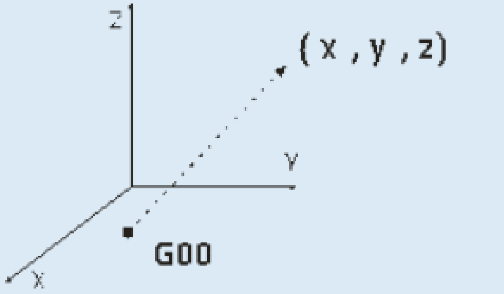
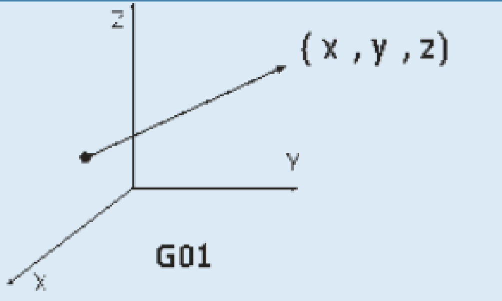
(3.1) Preparatory codes

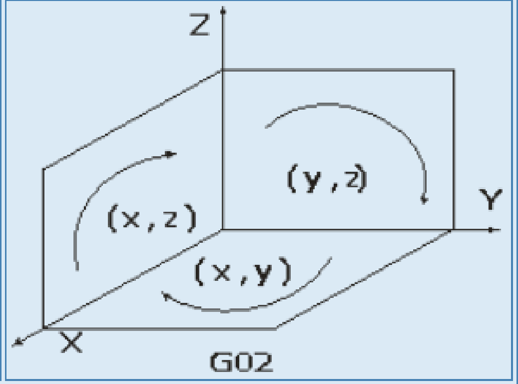
The term "preparatory" in NC means that it "prepares" the control system to be ready for implementing the information that follows in the next block of instructions. A preparatory function is designated in a program by the word address G followed by two digits. Preparatory functions are also called G-codes and they specify the control mode of the operation.

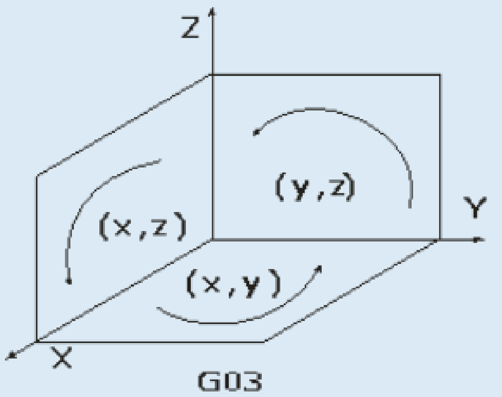
(3.2) Miscellaneous codes

Miscellaneous functions use the address letter M followed by two digits. They perform a group of instructions such as coolant on/off, spindle on/off, tool change, program stop, or program end. They are often referred to as machine functions or M-functions. Some of the M codes are given below.

M00 Unconditional stop
M02 End of program
M03 Spindle clockwise
M04 Spindle counter clockwise
M05 Spindle stop
M06 Tool change

<table>
<tr><th>Command group</th><th>G-code</th><th>Function and Command Statement</th><th>Illustration</th></tr>
<tr><td rowspan="4">Tool motion</td><td>G00</td><td>Rapid traverse
G00 Xx Yy Zz</td><td>
</td></tr>
<tr><td>G01</td><td>Linear interpolation
G01 Xx Yy Zz Ff</td><td>
</td></tr>
<tr><td>G02</td><td>Circular Interpolation in clock-wise direction

G02 Xx Yy Ii Jj
G02 Xx Zz Ii Kk
G02 Yy Zz Jj Kk</td><td>
</td></tr>
<tr><td>G03</td><td>Circular interpolation in counter-clockwise direction

G03 Xx Yy Ii Jj
G03 Xx Zz Ii Kk
G03 Yy Zz Jj Kk</td><td>
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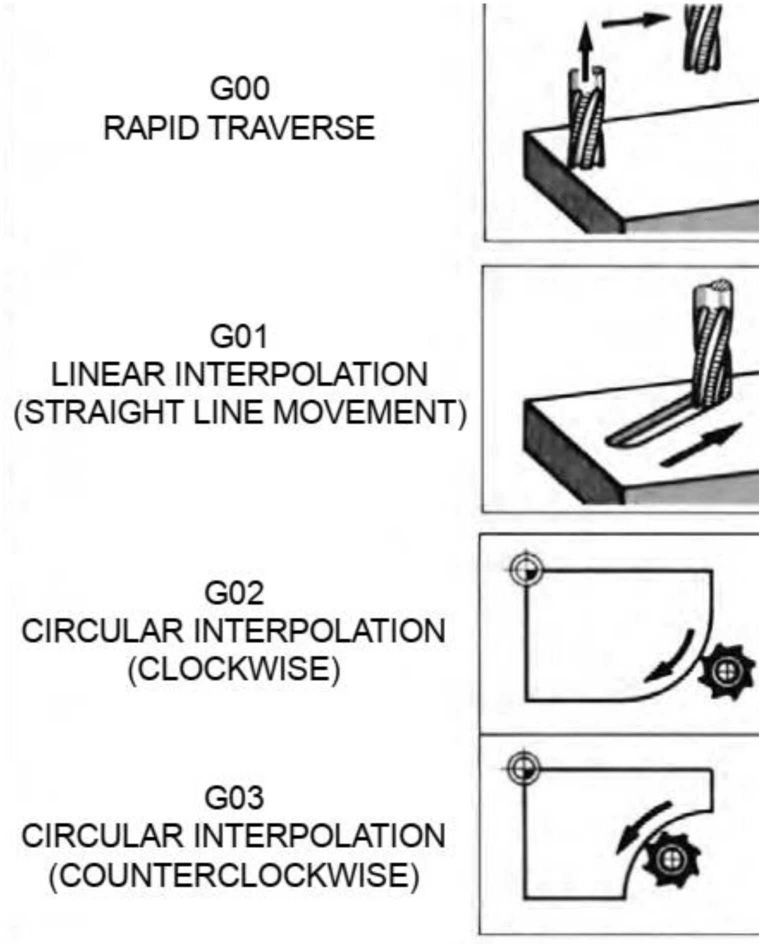
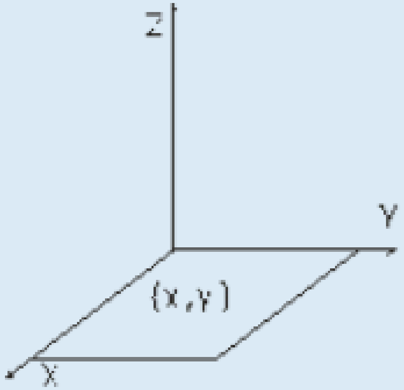
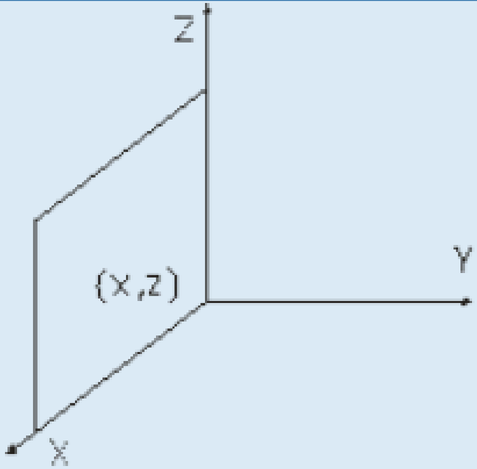
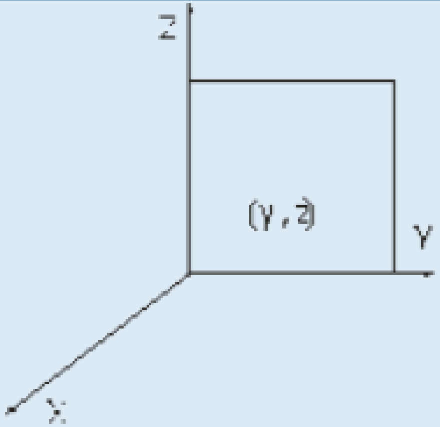
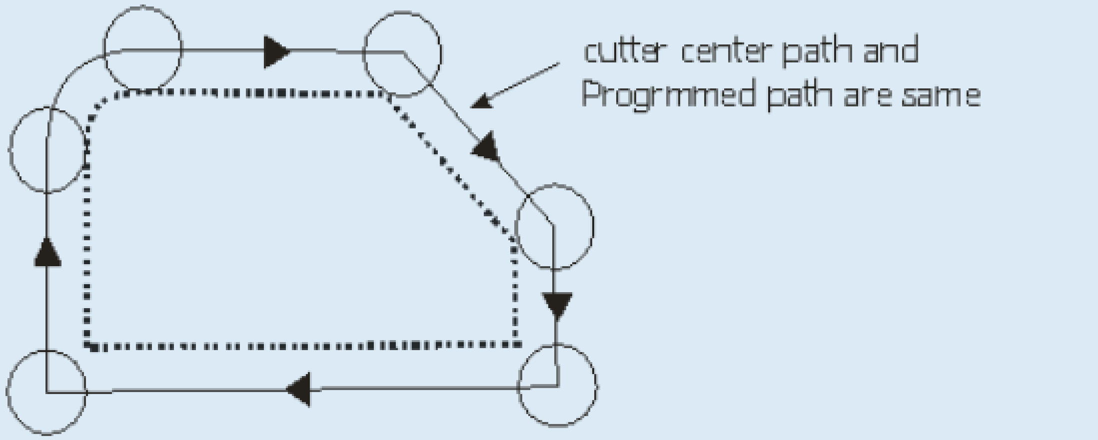
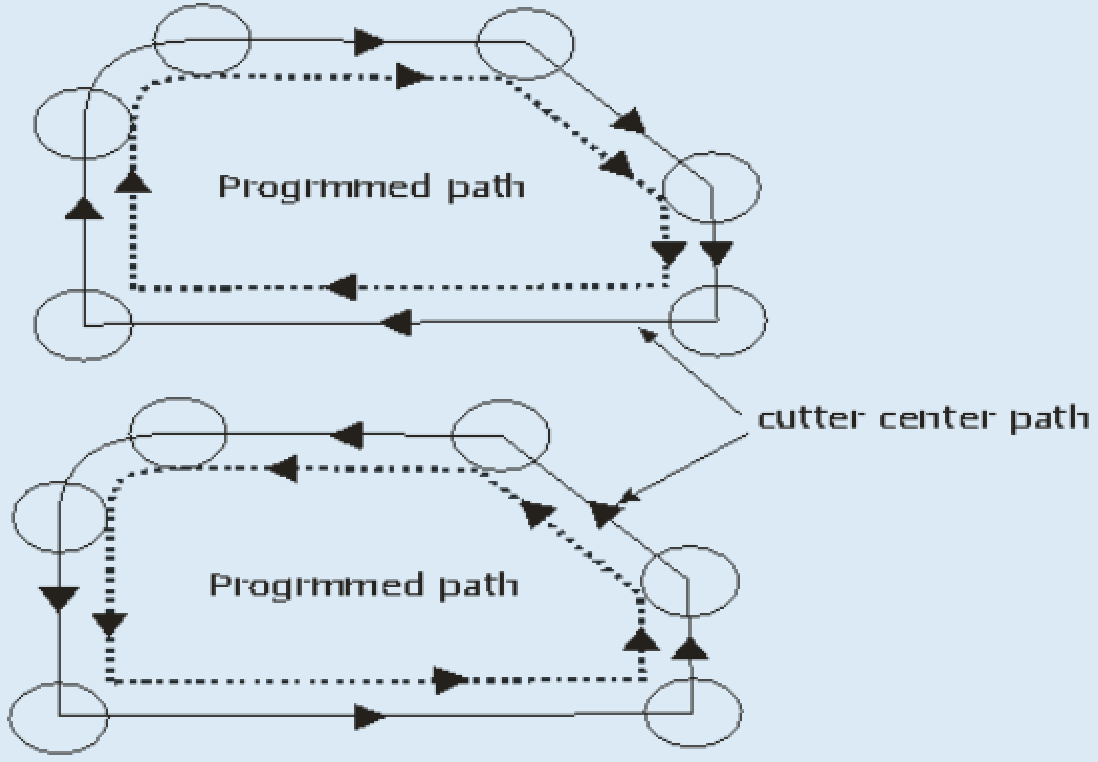
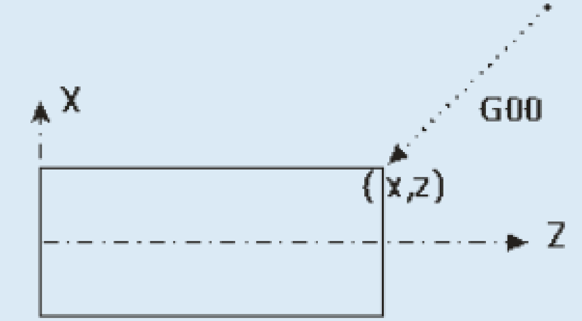


Command group	G-code	Function and Command Statement	Illustration
Plane Selection	G17	XY - Plane selection	
	G18	ZX - Plane selection	
	G19	YZ - plane selection	

Command group	G-code	Function and Command Statement	Illustration
Unit Selection	G20 or G70	Inch unit selection	
	G21 or G71	Metric unit selection	

Command group	G-code	Function and Command Statement	Illustration
Offset and compensation	G40	Cutter diameter compensation cancel	
	G41	Cutter diameter cancellation left	
	G42	Cutter diameter compensation righ	

<table>
<tr><th>Command group</th><th>G-code</th><th>Function and Command Statement</th><th>Illustration</th></tr>
<tr><td rowspan="4">Tool motion</td><td>G00</td><td>Rapid traverse
G00 Xx Zz</td><td>
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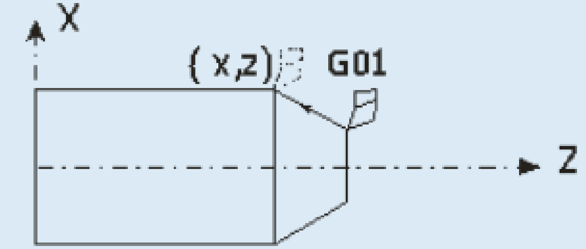
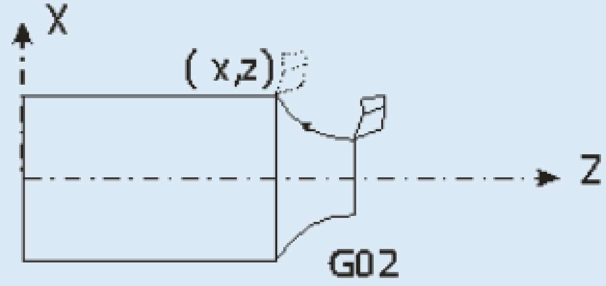
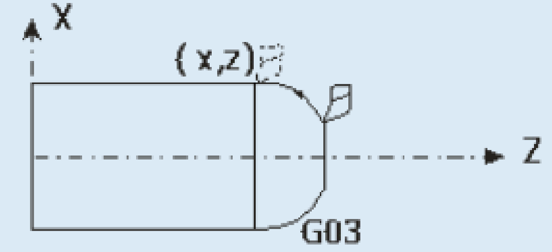
<tr><td>G01</td><td>Linear interpolation
G01 Xx Zz</td><td>
</td></tr>
<tr><td>G02</td><td>Circular Interpolation in clock-wise direction
G02 Xx Zz Ii Kk
(or)
G02 Xx Zz Rr</td><td>
</td></tr>
<tr><td>G03</td><td>Circular interpolation in counter-clockwise direction
G03 Xx Zz Ii Kk
(or)
G03 Yy Zz Rr</td><td>
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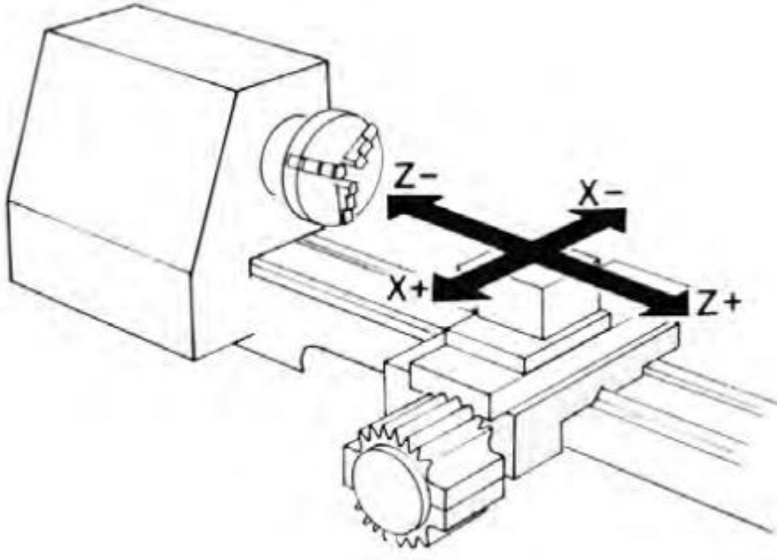
CNC Lathe and Milling

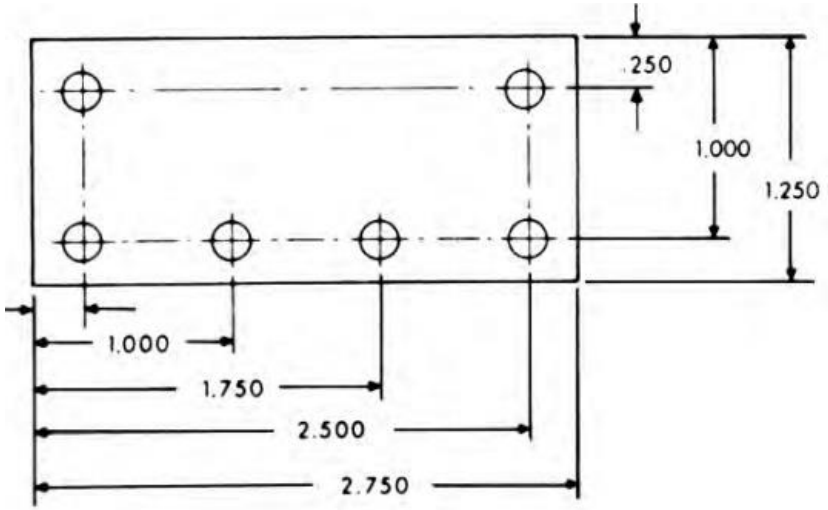
Programming Systems



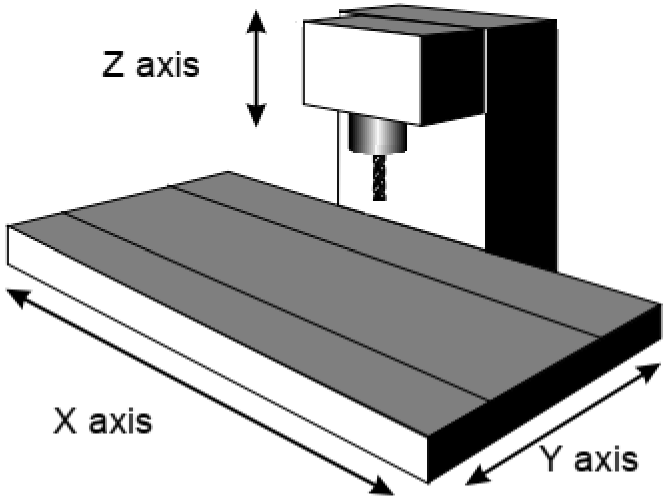
main axes of a lathe or turning center

Positioning Reference Point Systems

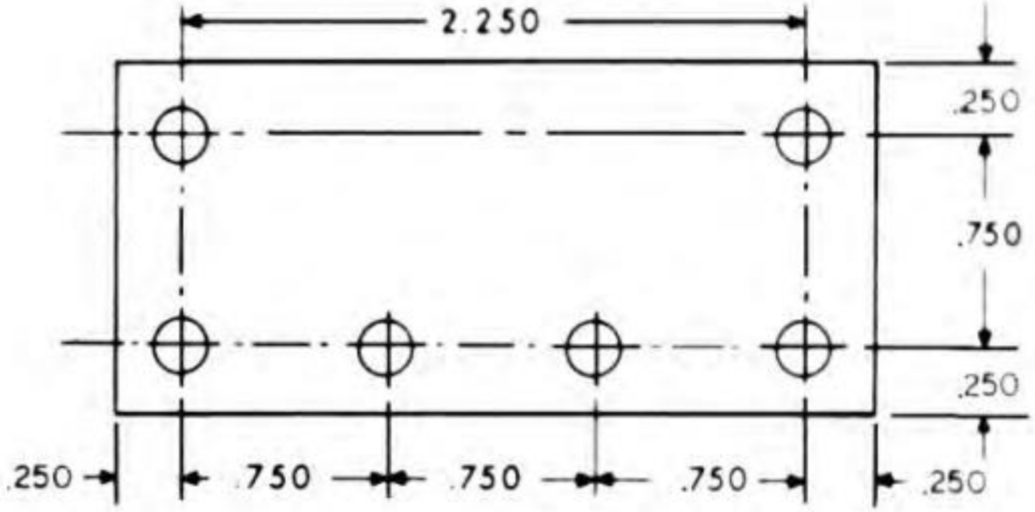
- Incremental
- Absolute



absolute system mode



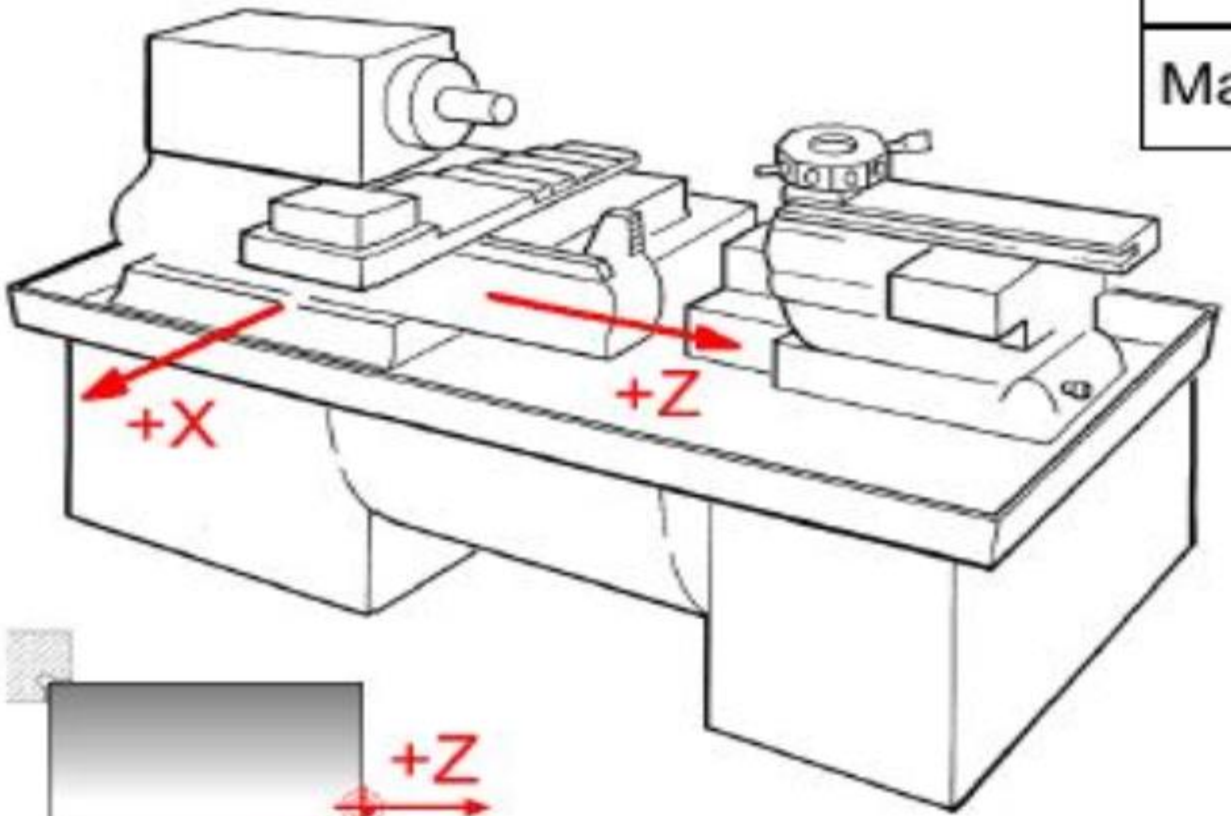
main axes of a vertical machining center



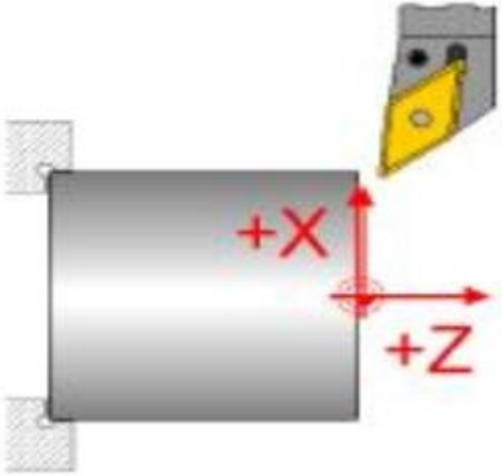
incremental system mode

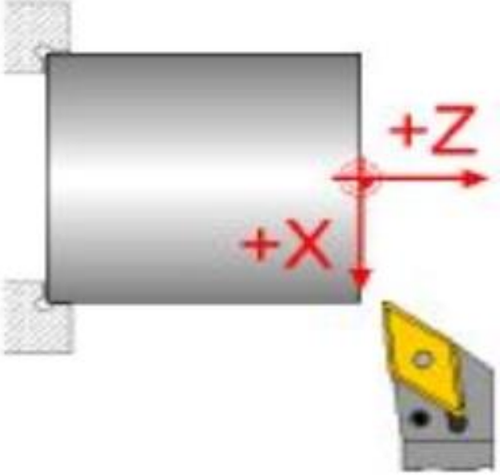
Axes in CNC lathe

Max. turning diameter	Axis X
Max. turning length	Axis Z



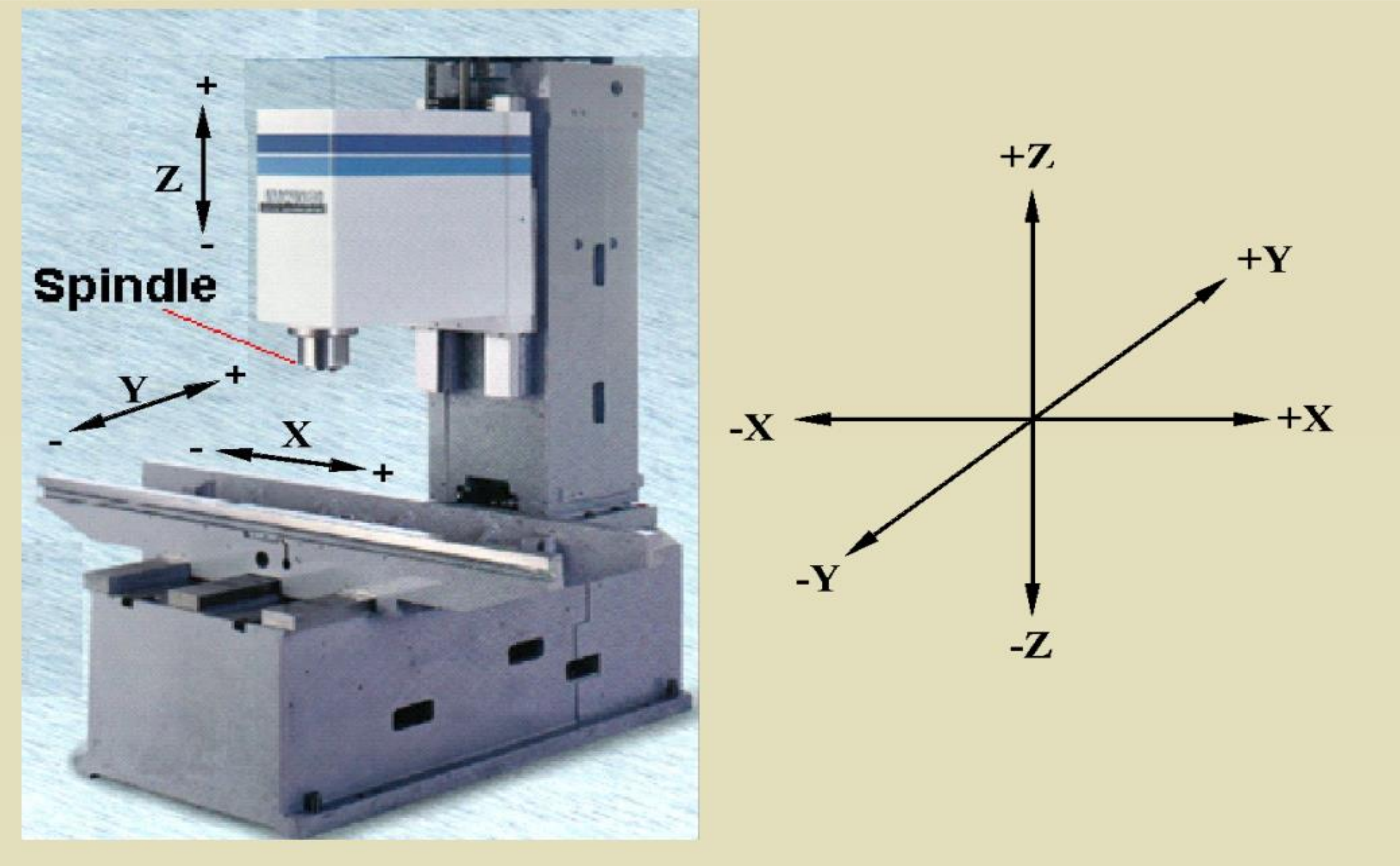
Incliend Bed



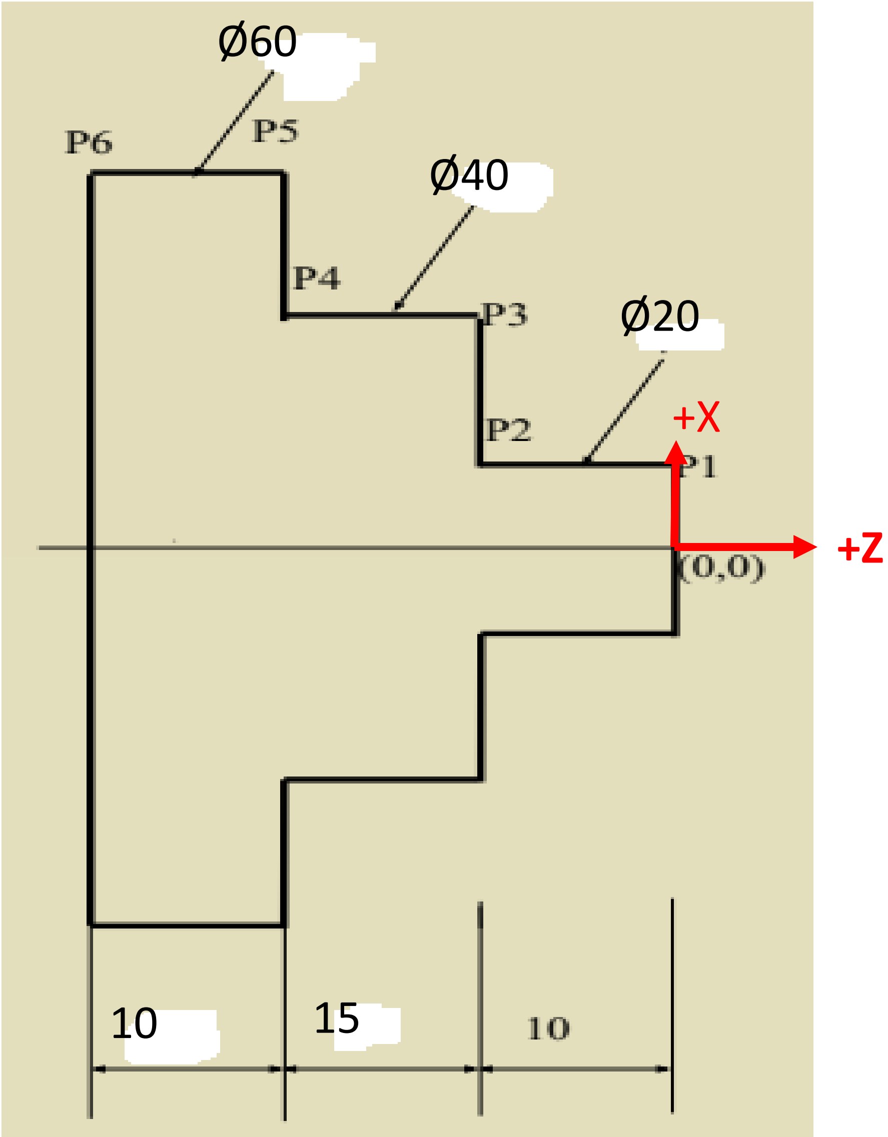


Flat Bed

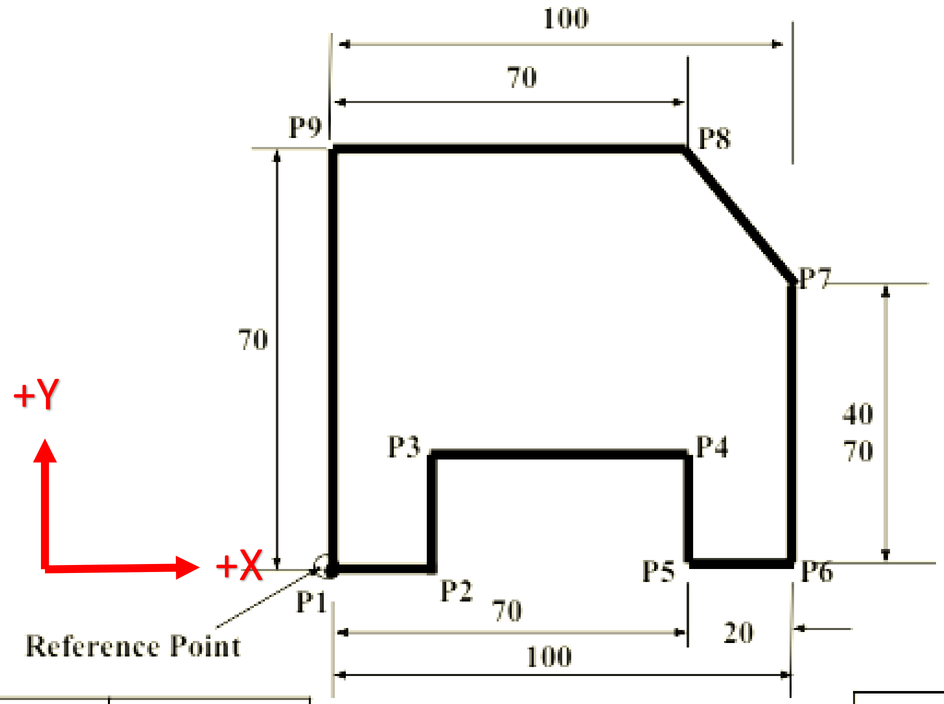
Axis in CNC Milling



DIMENSION SYSTEM



ABSOLUTE DIMENSIONING			INCREMENIAL DIMENSIONING		
POINTS	X	Z	POINTS	U	W
P1	10	0	P1	10	0
P2	10	-10	P2	0	-10
P3	20	-10	P3	10	0
P4	20	-25	P4	0	-15
P5	30	-25	P5	10	0
P6	30	-35	P6	0	-10



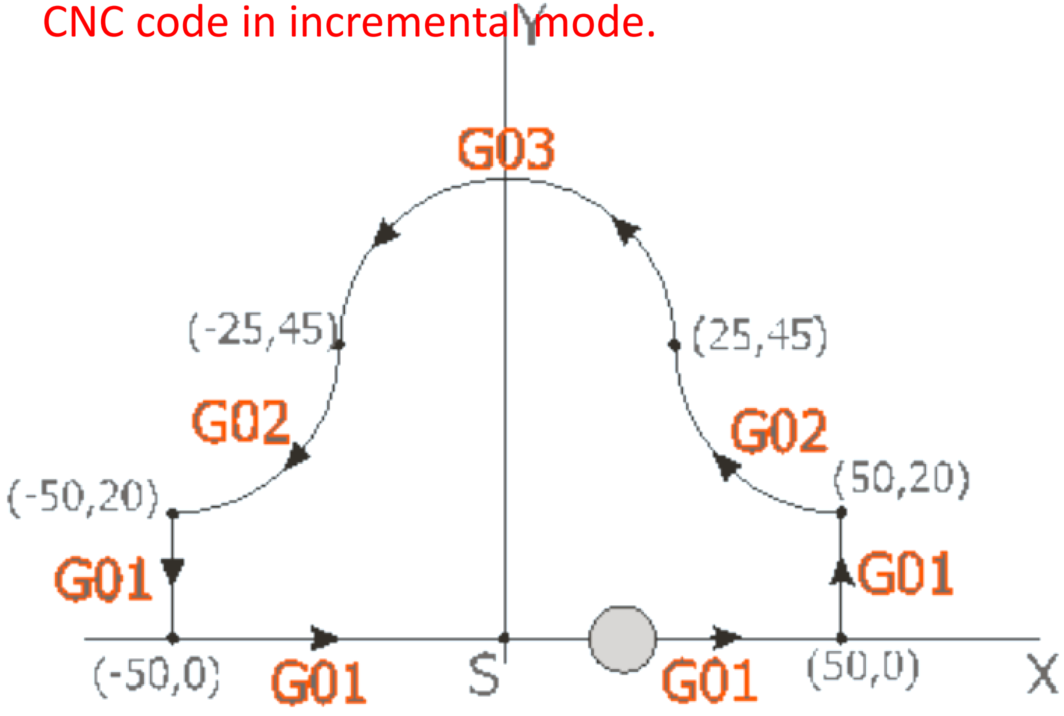
POINTS	X VALUE	Y VALUE
P1	0	0
P2	20	0
P3	20	20
P4	70	20
P5	70	0
P6	100	0
P7	100	40
P8	70	70
P9	0	70

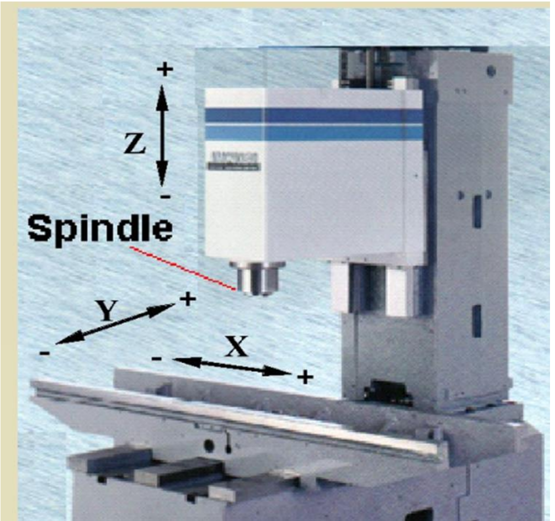
ABSOLUTE SYSTEM (G90)

POINTS	XVALUE	Y VALUE
P1	0	0
P2	20	0
P3	0	20
P4	50	0
P5	0	-20
P6	30	0
P7	0	40
P8	-30	30
P9	-70	0

INCREMENTAL SYSTEM (G91)

The profile shown in the figure below is to be cut using a CNC milling. The thickness of the plate is 10 mm. Assuming all curvature of radius 25mm, write the CNC code in incremental mode.





O5678	Program number
N02 G21	Metric programming
N03 M03 S1000	Spindle start clockwise with 1000rpm
N04 G00 X0 Y0	Rapid motion towards (0,0)
N05 G00 Z-10.0	Rapid motion towards Z=-10 plane
N06 G01 X50.0	Linear interpolation
N07 G01 Y20.0	Linear interpolation
N08 G02 X25.0 Y45.0 R25.0	Circular interpolation clockwise(cw)
N09 G03 X-25.0 Y45.0 R25.0	Circular interpolation counter clockwise(ccw)
N10 G02 X-50.0 Y20.0 R25.0	Circular interpolation clockwise(cw)
N11 G01 Y0.0	Linear interpolation
N12 G01 X0.0	Linear interpolation
N13 G00 Z10.0	Rapid motion towards Z=10 plane
N14 M05 M09	Spindle stop and program end

PREPARATORY FUNCTION (G - FUNCTION)

G codes are instructions describing machine tool movement

G00	Rapid Traverse
G01	Linear Interpolation (cutting feed)
G02	Circular Interpolation (clockwise)
G03	Circular Interpolation (counter clockwise)
G20	Imperial (input in inches)
G21	Metric (input in metric)
G28	Goto Reference Point (Home Position)
G70	Finishing Cycle
G71	Stock Removal in Turning (Multiple Turning Cycle)
G74	Peck Drilling Cycle
G76	Multiple Threading Cycle
G90	Box Turning Cycle
G98	Feed Per Minute
G99	Feed Per Rev.

MISCELLANEOUS FUNCTIONS (M - CODES)

M Codes are instructions describing miscellaneous functions like calling the tool, spindle rotation, coolant on/off etc.,

M00	Program Stop
M01	Optional Stop
M02	Program End
M03	Spindle Forward
M04	Spindle Reverse
M05	Spindle Stop
M06	Automatic Tool change
M08	Coolant On
M09	Coolant Off
M10	Vice / Chuck Open
M11	Vice / Chuck Close
M30	Program Stop & Rewind
M38	Door Open
M39	Door Close
M98	Sub program Call
M99	Subprogram Exit

END of CNC machines

Rapid Prototyping

Other names: additive fabrication, three dimensional printing, solid freeform fabrication (SFF), layered manufacturing

(1) Introduction

(2) Methodology of Rapid Prototyping (RP)

(2.1) Development of a CAD model

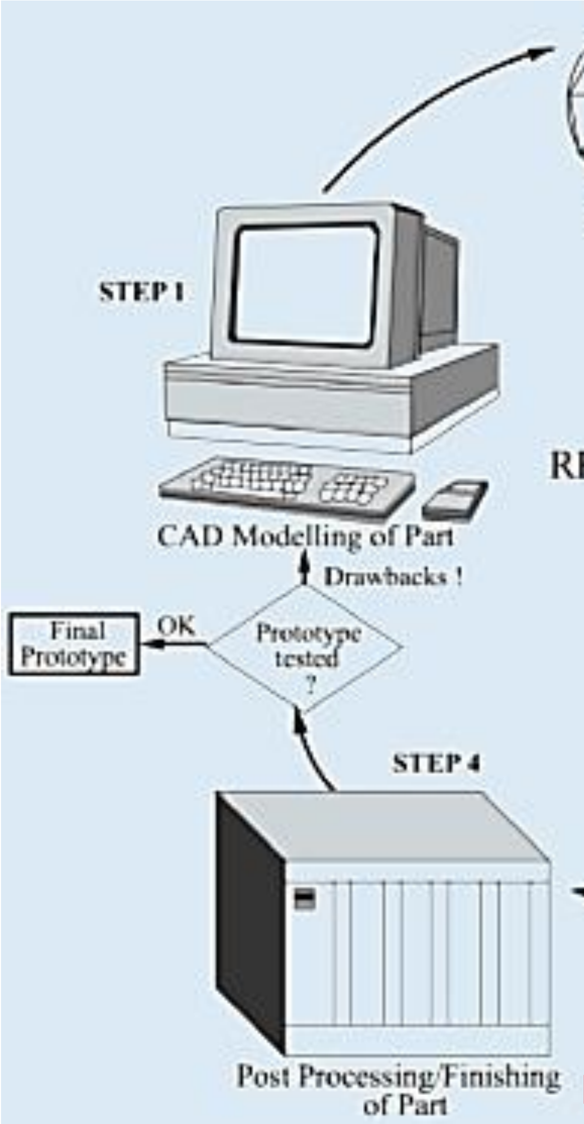
(2.2) Generation of Standard triangulation language (STL) file

(2.3) Slicing the STL file

(2.4) Support Structures

(2.5) Manufacturing

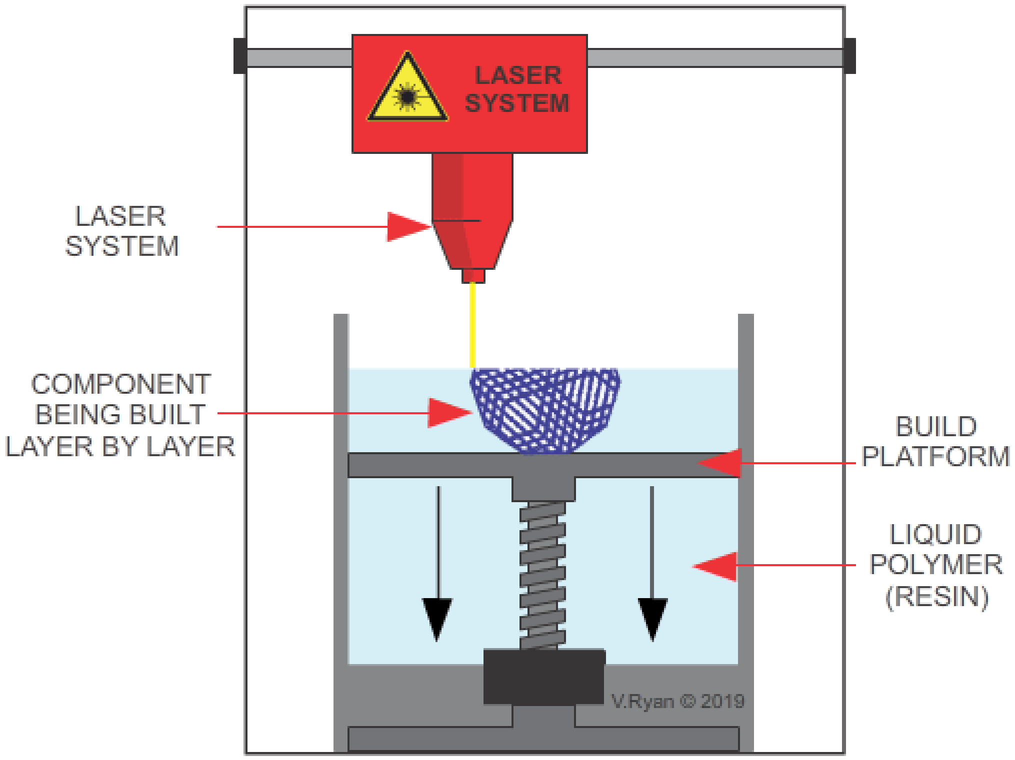
(2.6) Post processing



Methodology of Rapid Prototyping (RP)

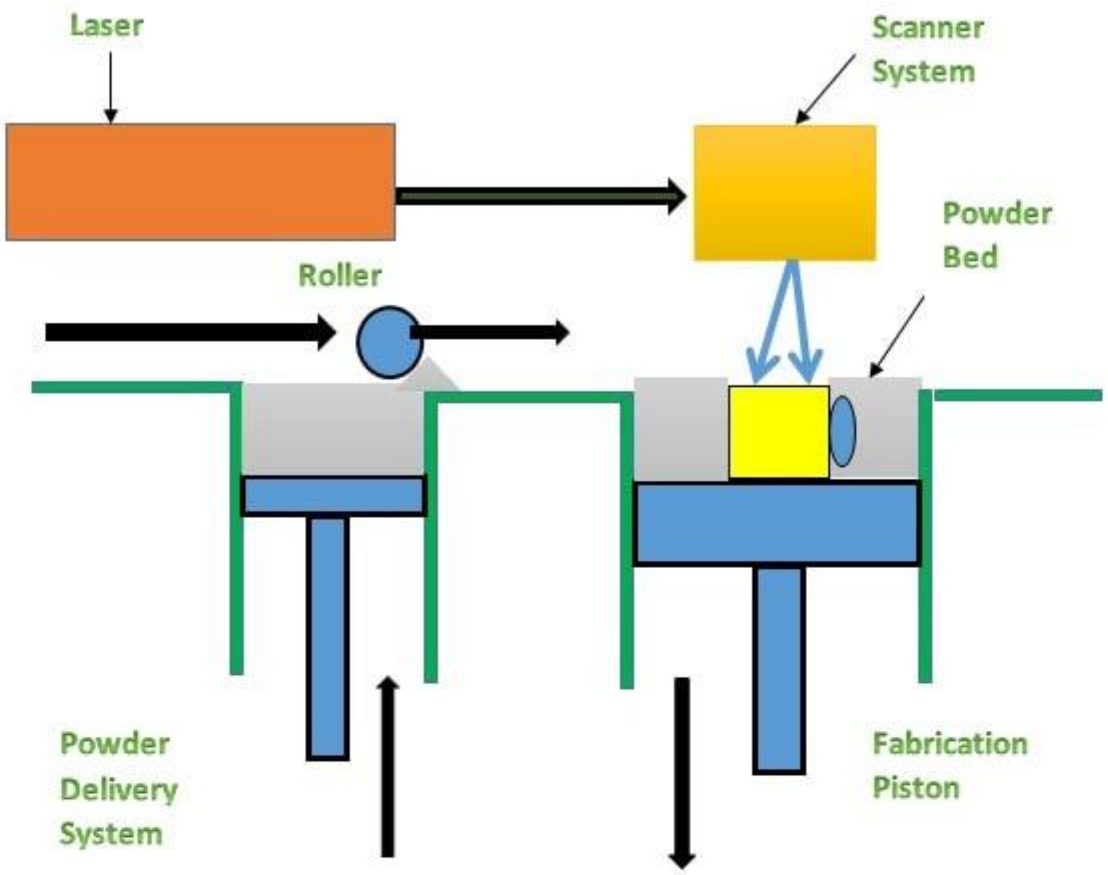
Some of the commercially popular RP processes are :

Stereolithograpy

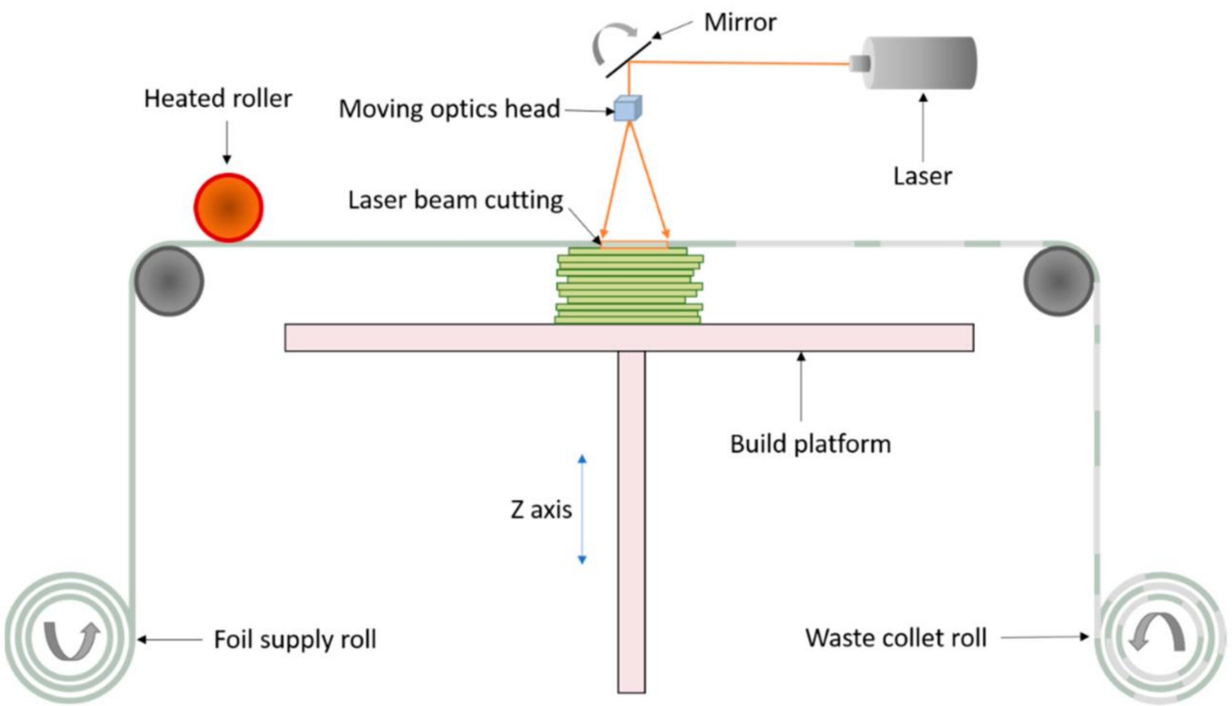


BUILD TANK

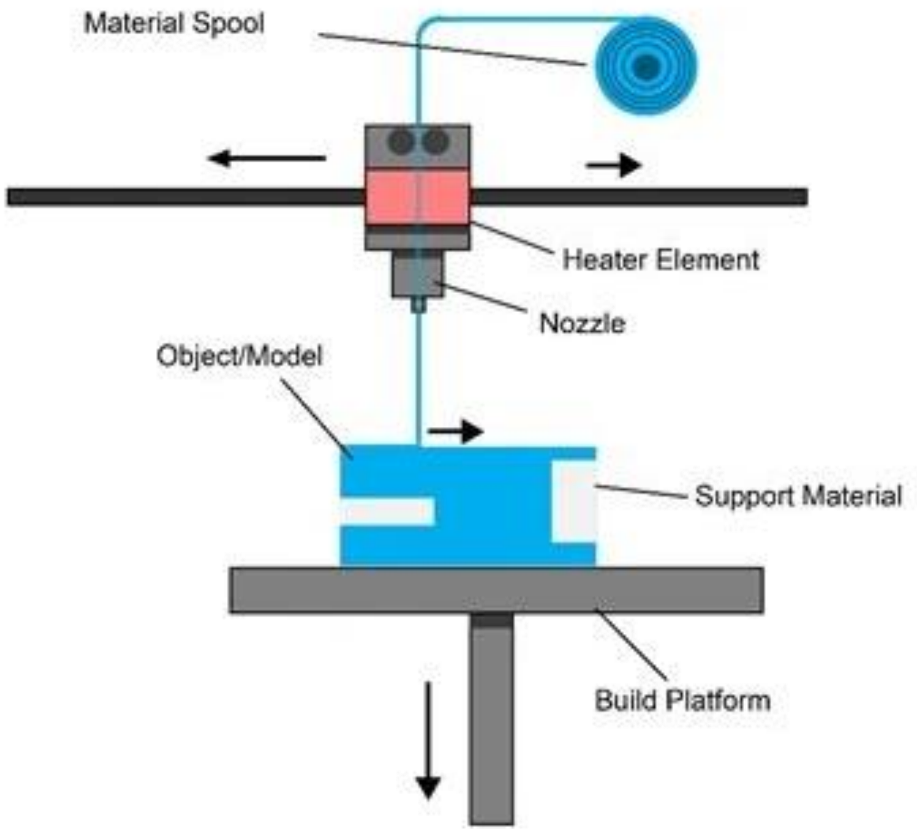
Selective Laser Sintering



Laminated Object manufacturing (LOM)



Fusion Deposition Modeling (FDM)



END OF 3D Printing

Application of robots in Manufacturing

Introduction to robot and robotics

- What is a robot?
- What is robotics?
- Why do we study robotics?
- How can we teach a robot to perform a particular task?
- What are possible applications of robots?
- Can a human being be replaced by a robot?,

and so on.

Definitions

- The term: robot has come from the Czech word: robota, which means forced or slave laborer
- In 1921, Karel Capek, a Czech playwright, used the term: robot first in his drama named Rossum's Universal Robots (R.U.R)
- According to Karel Capek, a robot is a machine look-wise similar to a human being

1) According to Oxford English Dictionary
A machine capable of carrying out a complex series of actions automatically, especially one programmable by a computer

2) According to International Organization for Standardization (ISO): An automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications

3) According to Robot Institute of America (RIA)
It is a reprogrammable multi-functional manipulator designed to move materials, parts, tools or specialized devices through variable programmed motions for the performance of a variety of tasks

Note: A CNC machine is not a robot : Level of reprogram ability is more in robot

Robotics:

- It is a science, which deals with the issues related to design, manufacturing, usages of robots
- In 1942, the term: robotics was introduced by Isaac Asimov in his story named Runaround

3 Hs of human beings are copied into Robotics, such as

- Hand
- Head
- Heart

Motivation

To cope with increasing demands of a dynamic and competitive market, modern manufacturing methods should satisfy the following requirements:

- Reduced production cost
- Increased productivity
- Improved product quality

Notes:

(1) Automation can help to fulfil the above requirements

(2) Automation: Either Hard or flexible automation

(3) Robotics is an example of flexible automation

A brief history of Robotics

Year	Events and Development
1954	First patent on manipulator by George Devol, the father of robot
1956	Joseph Engelberger started the first robotics company: Unimation
1962	General Motors used the manipulator: Unimate in die-casting application

Year	Events and Development
1967	General Electric Corporation made a 4-legged vehicle
1969	❖ SAM was built by the NASA, USA ❖ Shakey, an intelligent mobile robot, was built by Stanford Research Institute (SRI)
1970	❖ Victor Scheinman demonstrated a manipulator known as Stanford Arm ❖ Lunokhod I was built and sent to the moon by USSR ❖ ODEX 1 was built by Odetics

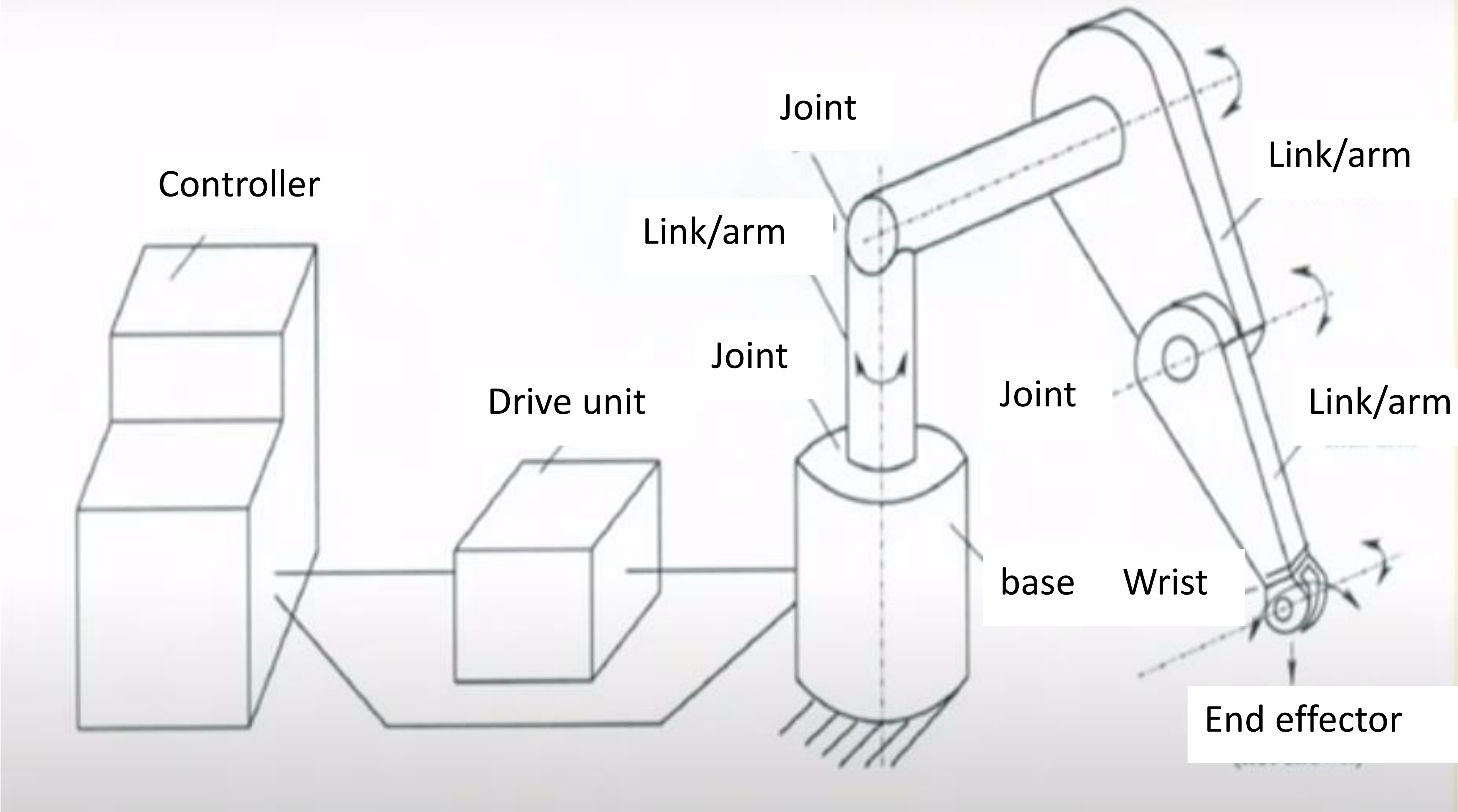
Year	Events and Development
1973	Richard Hohn of Cincinnati Milacron Corporation manufactured T^3 (The Tomorrow Tool) robot
1975	Raibart at CMU, USA, built a one-legged hopping machine, the first dynamically stable machine
1978	Unimation developed PUMA (Programmable Universal Machine for Assembly)

Year	Events and Development
1983	Odetics introduced a unique experimental six-legged device
1986	ASV (Adaptive Suspension Vehicle) was developed at Ohio State University, USA
1997	Pathfinder and Sojourner was sent to the Mars by the NASA, USA

A brief history of Robotics contd….

Year	Events and Development
2000	Asimo humanoid robot was developed by Honda
2004	The surface of the Mars was explored by Spirit and Opportunity
2012	Curiosity was sent to the Mars by the NASA, USA
2015	Sophia (humanoid) was built by Hanson Robotics, Hong Kong

A robotic system



Various Components

1. Base
2. Links and Joints
3. End-effector / gripper
4. Wrist
5. Drive / Actuator
6. Controller
7. Sensors

Serial manipulator: Robot with fixed base

Interdisciplinary Areas in Robotics

Mechanical Engineering

- Kinematics: Motion of robot arm without considering the forces and /or moments
- Dynamics: Study of the forces and/or moments
- Sensing: Collecting information of the environment

Computer Science

- Motion Planning: Planning the course of action
- Artificial Intelligence: To design and develop suitable brain for the robots

Electrical and Electronics Engg.

- Control schemes and hardware implementations

General Sciences

- Physics
- Mathematics

Classification of Robots

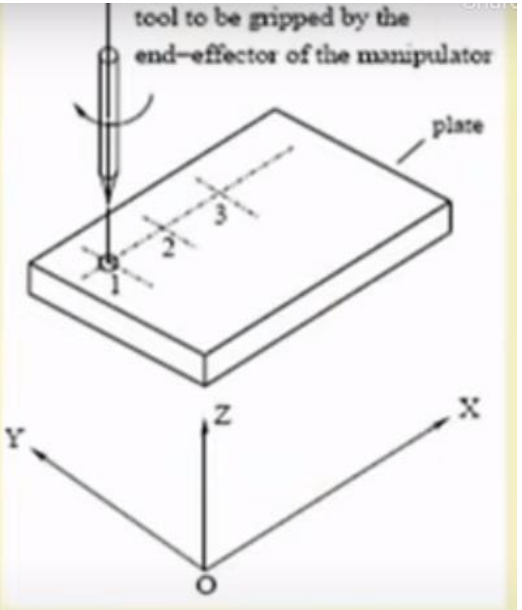
❖ Based on the Type of Tasks Performed

1. Point-to-Point Robots

Examples:

Unimate 2000

T^3

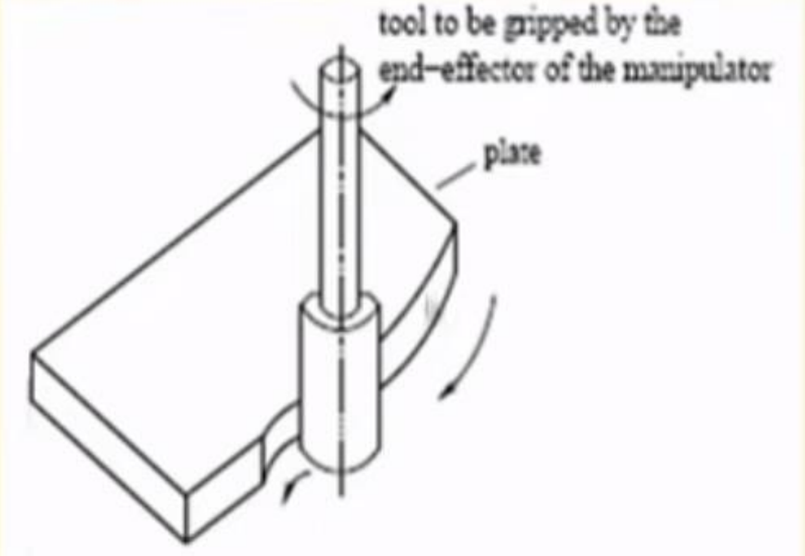


2. Continuous Path Robots

Examples:

PUMA

CRS



PUMA: Programmable Universal Machine for Assembly.

Classification based on the types of controller

1. **Non-Servo-Controlled Robots**

- Open-loop control system

Examples: Seiko PN-100

- Less accurate and less expensive

2. **Servo-Controlled Robots**

- Closed-loop control system

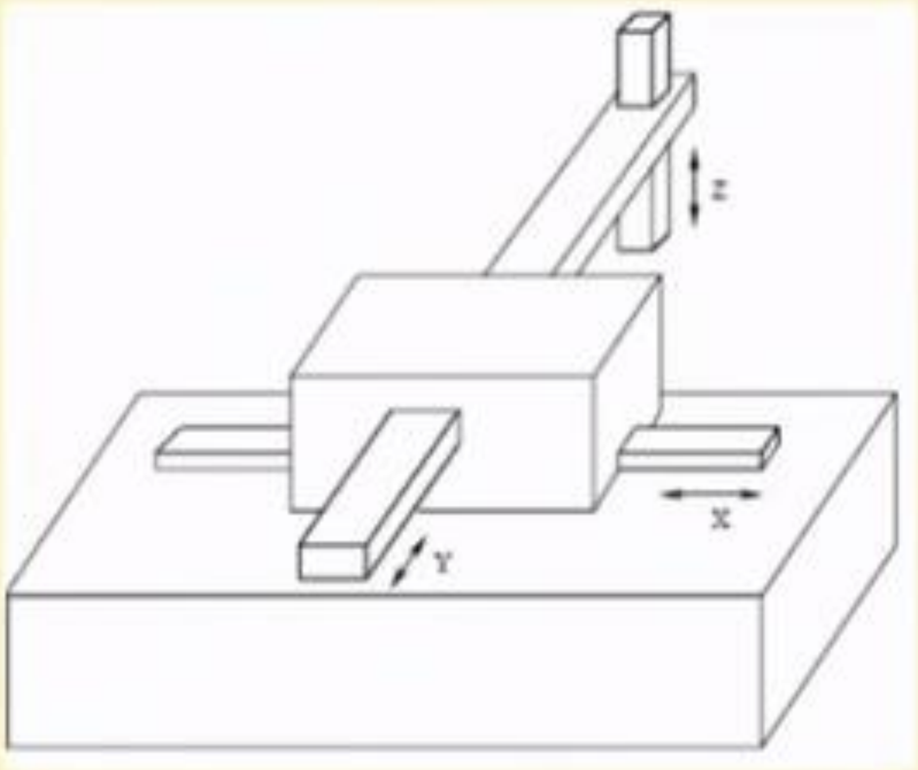
Examples: Unimate 2000, PUMA, T^3

- More accurate and more expensive

- Based on Configuration (coordinate system) of the Robot

1. Cartesian Coordinate Robots

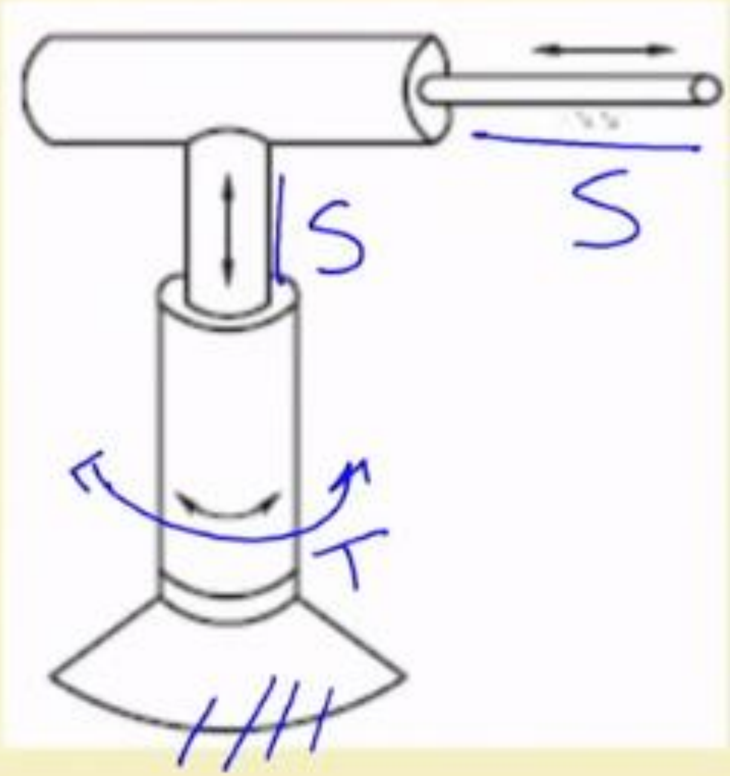
- Linear movement along three different axes
- Have either sliding or prismatic joints, that is, SSS or PPP
- Rigid and accurate
- Suitable for pick and place type of operations
- Examples: IBM's RS-1, Sigma robot



P- prismatic joint, S- Sliding joint

2. Cylindrical Coordinate Robots

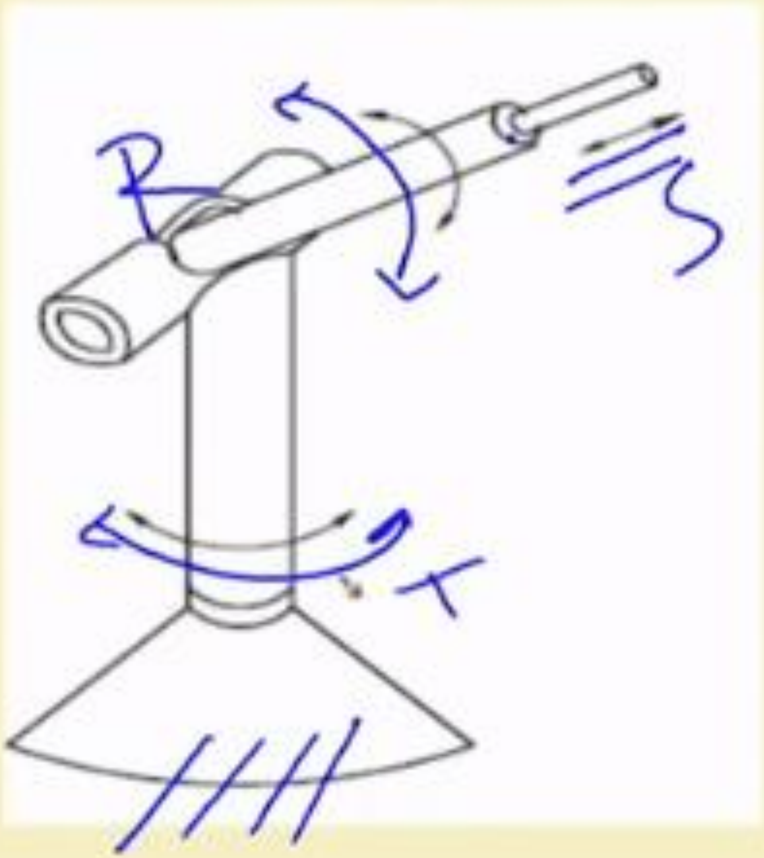
- Two linear and one rotary movements
- Represented as TPP, TSS
- Used to handle parts/ objects in manufacturing
- Cannot reach the objects lying on the floor
- Poor dynamic performance
- Examples: Versatran 600



P- prismatic joint, S- Sliding joint, T: Twisting joint, R: Revolute joint

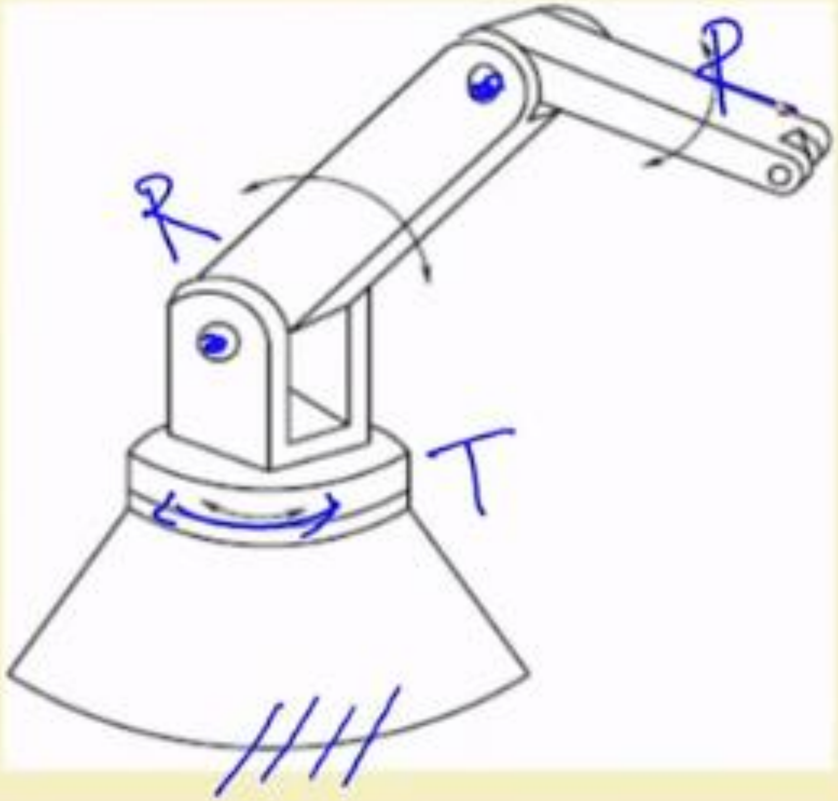
3. Spherical Coordinate or Polar Coordinate Robots

- One linear and two rotary movement
- Represented as TRP, TRS
- Suitable for handling parts/objects in manufacturing
- Can pick up objects lying on the floor
- Poor dynamic performance
- Examples: Unimate 2000B



4. Revolute Coordinate or Articulated Coordinate Robots

- Rotary movement about three independent axes
- Represented as TRR
- Suitable for handling parts/components in manufacturing system
- Rigidity and accuracy may not be good enough
- Examples: T3, PUMA



PUMA: Programmable Universal Machine for Assembly.

- **Based on Mobility Levels**

1. Robots with fixed base (also known as manipulators)

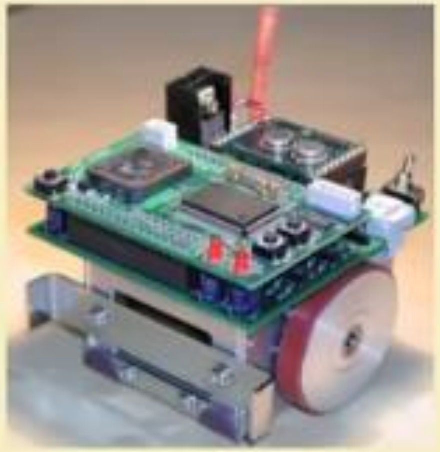
Manipulators
- Serial: PUMA, CRS
- Parallel: Stewart platform

2. Mobile robots

Mobile robots
- Wheeled robots
- Tracked robots
- Multi-legged robots

- **Based on Mobility Levels (contd.)**

2. Mobile robots



Wheeled Robot

Six-legged Robot

Workspace of Manipulators

It is the volume of space that the end-effector of a manipulator can reach

END