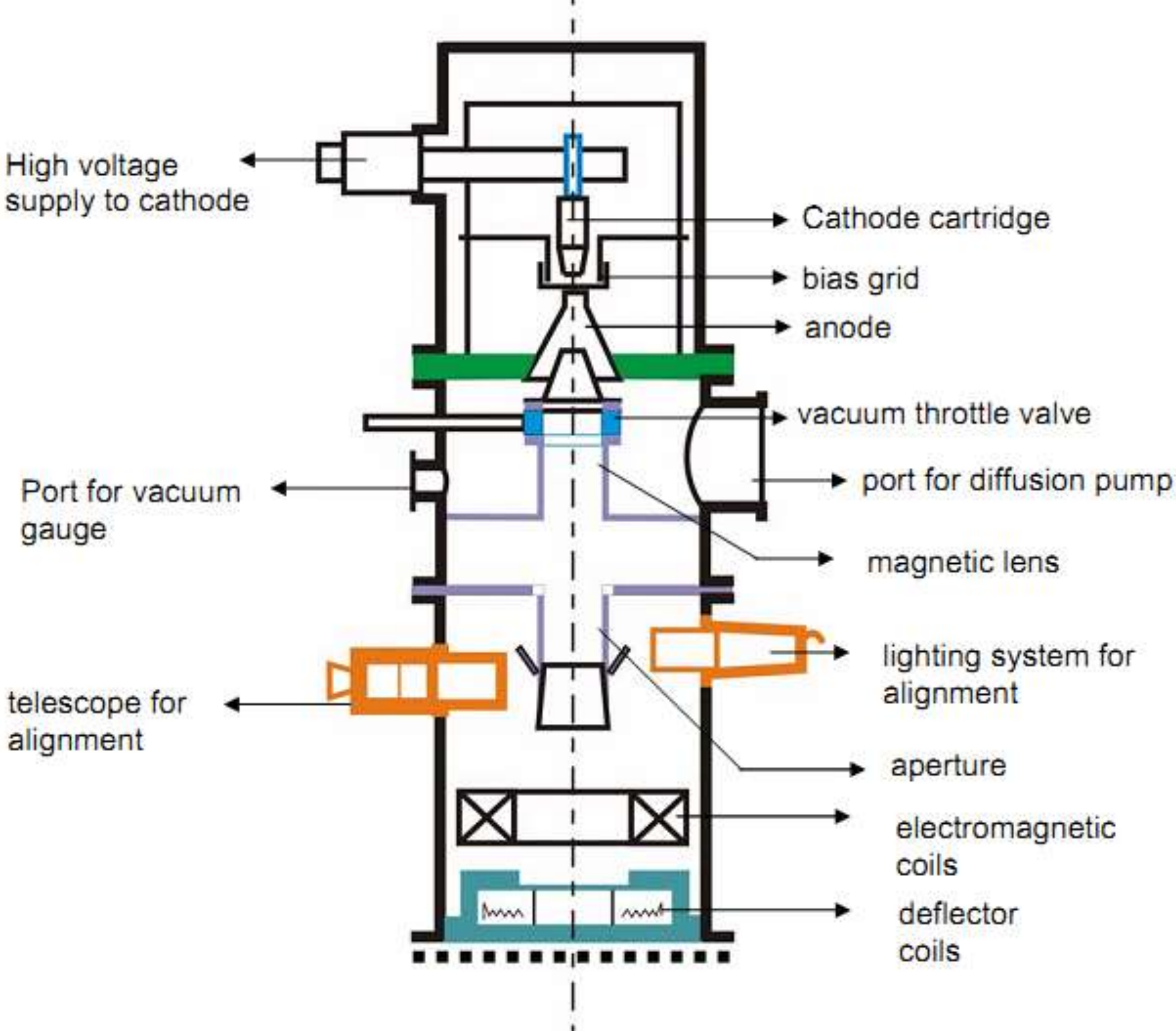
Electron Beam
and
Laser Beam Machining



Electron Beam Gun

Fig. shows the schematic representation of an electron beam gun, which is the **heart of any electron beam machining** facility. The basic functions of any electron beam gun are to **generate free electrons at the cathode, accelerate them to a sufficiently high velocity and to focus them over a small spot size**. Further, the beam needs to be maneuvered if required by the gun.

The cathode is generally made of **tungsten or tantalum**. Such cathode filaments are heated, often inductively, to a temperature of around **2500^0C**. Such heating leads to **thermo-ionic emission** of electrons, which is further enhanced by maintaining very low vacuum within the chamber of the electron beam gun. Moreover, this **cathode** cartridge **is** highly **negatively biased** so that the thermo-ionic electrons are strongly repelled away form the cathode. This cathode is often in the form of a cartridge so that it can be changed very quickly to reduce down time in case of failure.

Just after the cathode, there is an **annular bias grid**. A high **negative bias** is applied to this grid so that the electrons generated by this cathode do not diverge and approach the next element, the annular anode, in the form of a beam. The annular anode now attracts the electron beam and gradually gets accelerated. As they leave the anode section, the electrons may achieve a velocity as high as **half the velocity of light**.

The nature of biasing just after the cathode controls the flow of electrons and the biased grid is used as a switch to operate the electron beam gun in pulsed mode.

After the anode, the electron beam passes through a series of **magnetic lenses and apertures**. The magnetic lenses shape the beam and try to reduce the divergence. Apertures on the other hand allow only the convergent electrons to pass and **capture the divergent low energy electrons** from the fringes. This way, the aperture and the magnetic lenses **improve the quality of the electron beam.**

Then the electron beam passes through the final section of the electromagnetic lens and deflection coil. The **electromagnetic lens** focuses the electron beam to a desired spot. The deflection coil can manoeuvre the electron beam, though by small amount, to improve shape of the machined holes.

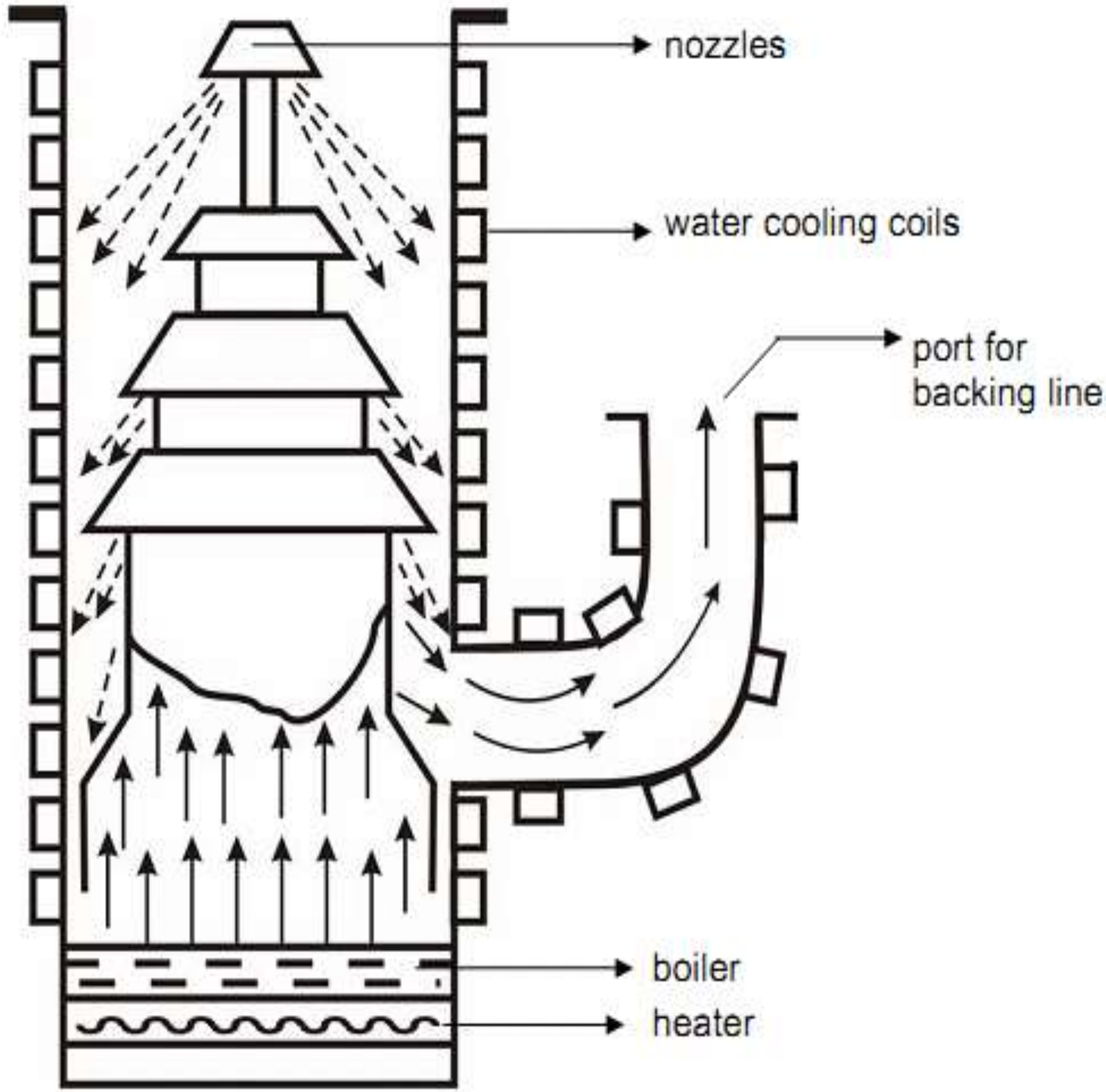
Generally in between the electron beam gun and the work piece, which is also under vacuum, there would be a series of **slotted rotating discs**. Such discs allow the electron beam to pass and machine materials but helpfully **prevent metal fumes and vapour generated during machining to reach the gun**. Thus it is essential to synchronize the motion of the rotating disc and pulsing of the electron beam gun.

Electron beam guns are also provided with **illumination facility and a telescope** for **alignment of the beam** with the work piece.

Workpiece is mounted on a CNC table so that holes of any shape can be machined using the CNC control

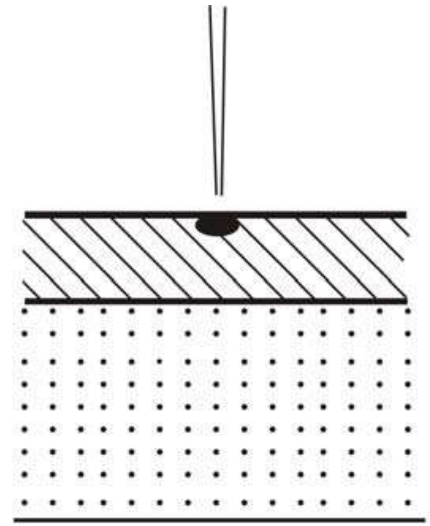
One of the major requirements of EBM operation of electron beam gun is maintenance of desired vacuum. Level of vacuum within the gun is in the order of **10^{-4} to 10^{-6} Torr**. ***Maintenance of suitable vacuum is essential so that electrons do not loose their energy and a significant life of the cathode cartridge is obtained. Such vacuum is achieved and maintained using a combination of rotary pump and diffusion pump.***

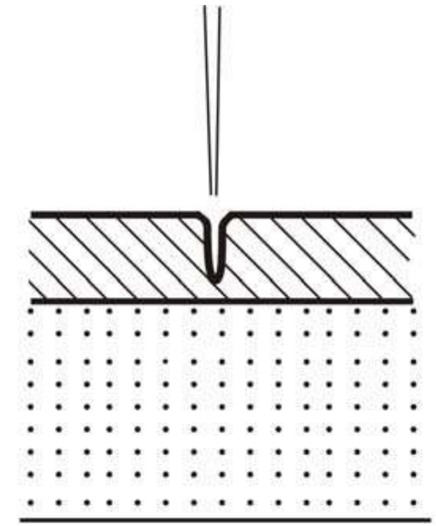
Diffusion pump is essentially an oil heater. As the oil is heated the oil vapour rushes upward where gradually converging structure as shown in Fig. is present. The nozzles change the direction of motion of the oil vapour and the oil vapour starts moving downward at a high velocity as jet. Such high velocity jets of oil vapour entrain any air molecules present within the gun. This oil is evacuated by a rotary pump via the backing line. The oil vapour condenses due to presence of cooling water jacket around the diffusion pump.

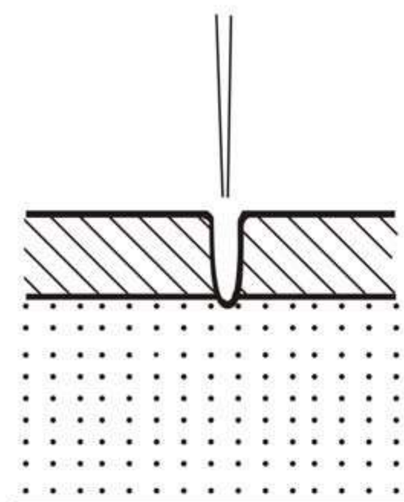


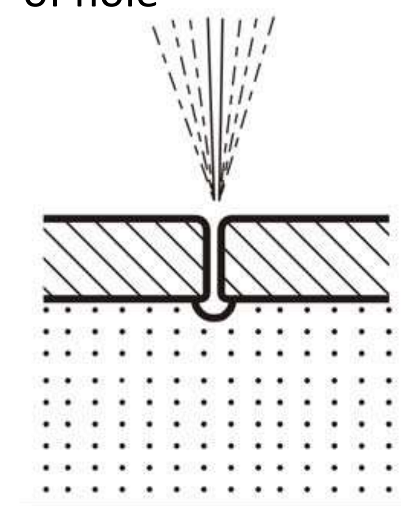
Working of a Diffusion Pump

Electron beam gun provides high velocity electrons over a very small spot size.
Electron Beam Machining is required to be carried out in vacuum. Otherwise the electrons would interact with the air molecules, thus they would loose their energy and cutting ability. Thus the workpiece to be machined is located under the electron beam and is kept under vacuum. The high-energy focused electron beam is made to impinge on the workpiece with a spot size of 10 – 100 μm. The kinetic energy of the high velocity electrons is converted to heat energy as the electrons strike the work material. Due to high power density instant melting and vaporisation starts and "melt – vaporisation" front gradually progresses, as shown in Fig. Finally the molten material, if any at the top of the front, is expelled from the cutting zone by the high vapour pressure at the lower part. Unlike in Electron Beam Welding, the gun in EBM is used in pulsed mode


Localized heating by focused electron beam


Gradual formation of hole


Penetration till the auxiliary support


Removal due to high vapour pressure

Electron Beam Process – Parameters

- The accelerating voltage (100 KV)
- The beam current (250 μA – 1A
- Pulse duration (50 μS– 50 mS)
- Energy per pulse (100 J/pulse)
- Power per pulse
- Lens current
- Spot size (10 μm – 500 μm)
- Power density

Advantages and Limitations

EBM provides **very high drilling rates when small holes with large aspect ratio are to be drilled**. Moreover it can **machine almost any material** irrespective of their mechanical properties. As it applies no mechanical cutting force**, work holding and fixturing cost is very less**. Further for the same reason fragile and brittle materials can also be processed. **The heat affected zone in EBM is rather less due to shorter pulses**. EBM can provide **holes of any shape by combining beam deflection using electromagnetic coils and the CNC table with high accuracy.**

However, EBM has its own share of limitations. The primary limitations are the **high capital cost** of the equipment and **necessary regular maintenance** applicable for any equipment using vacuum system. Moreover in EBM there is significant amount of **non-productive pump down period** for attaining desired vacuum. However this can be reduced to some extent using vacuum load locks. Though heat affected zone is rather less in EBM but **recast layer formation cannot be avoided.**

Electron Beam Machine

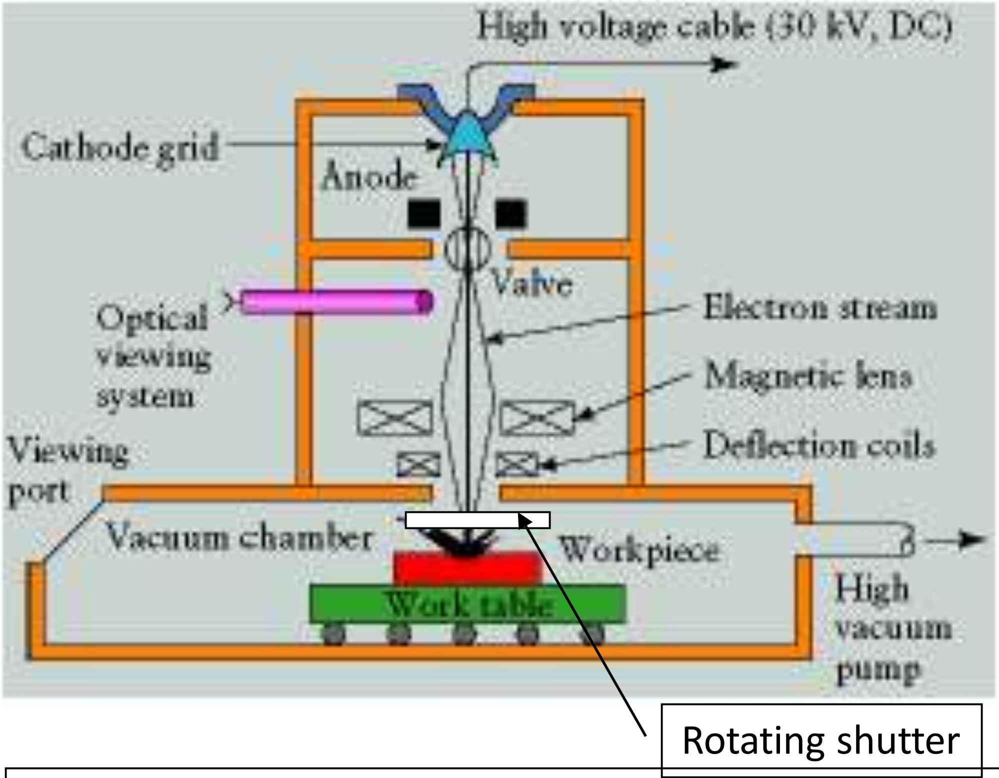
Four sub-systems

Electron beam gun: Electrons are generated by thermionic emission from hot tungsten cathode. In E-beam gun for cutting & drilling applications, there is a grid between anode & cathode on which negative voltage is applied to pulse / modulate the e-beam.

Power supply: Up to 150kV, Current : 1.5A.

Vacuum-chamber: 10^{-4}-10^{-6} Torr achieved by rotary pump backed diffusion pump.

Vacuum compatible **CNC workstation**



Mode of E-beam Operation:

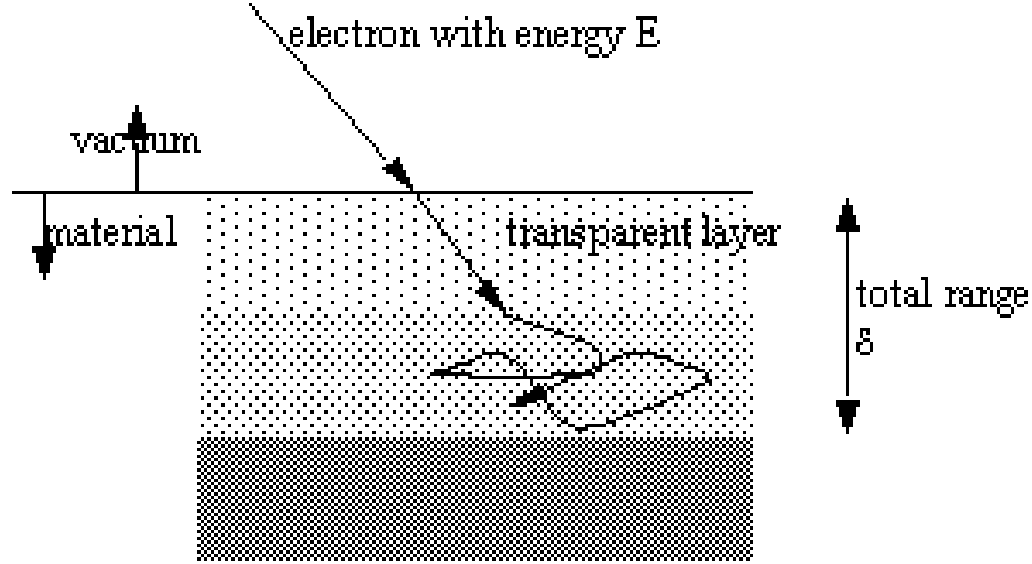
For drilling and cutting-Pulsed electron beam
Single pulse : A single hole in thin sheet;
Multiple pulses: To drill in a thicker material.

For welding : DC electron beam
Parameters so chosen that loss of material due to vaporization is minimum.

* Energy of Electrons ⇒ Electrons and lattice of material through collisions.

* Energy transfer⇒ Function of electron energy. e-energy⇑, Transfer rate ⇓

* Maximum rise in temperature- At a certain depth, not at the surface, unlike laser heating. * Due to scattering of electrons, its energy not localized within the area determined by the diameter of beam – Poor material removal efficiency



Typical range: V=50kV, ρ = 8g/cm^3

$\delta \approx 8\mu m$

Electron Velocity=10-50% of Light velocity

Depth of penetration:

$\delta = 2.6 \times 10^{-17} (V^2/\rho)$ mm

V=Accelerating Voltage (Volts)

ρ= Material density (kg/mm^3)

Kinetic Energy of Electron $= \frac{1}{2} m_e.v^2 = e.V$

$\Rightarrow$ v (km/s) = $600V^{1/2}$

$m_e = 9.1 \times 10^{-31}$kg, $e = 1.6 \times 10^{-19}$Coulomb.

KE is dissipated in the impinging material.

Process Capabilities :

EBM:

* A wide range of materials, such as stainless steel, nickel and cobalt alloys, copper, aluminum, titanium, ceramic, leather and plastic.
* Cutting up to a thickness of 10mm : *material removal by vaporization*
* Hole-diameter ranging from 0.1- 1.4mm in thickness up to 10mm.
* High aspect (depth to diameter) 15:1
* Holes at very shallow angle from 20^0-90^0
* No much force to the work-piece, thereby allowing brittle and fragile materials to be processed without danger of fracturing.
* Hole diameter accuracy $\pm$ 0.02mm in thin sheets

EBW (welding):

* Deep penetration welding up 300mm in high vacuum
* Various weld geometry: Butt, Lap, T- joints
* Owing to very high power density a wide range of metals can be welded: steel, copper, nickel based alloys, aluminum alloys and refractory such as zirconium, tantalum, titanium and niobium.

Current Control:

Hot cathode emits electrons and the thermionic emission is given by the Richardson- Dushman equation:

$$j = A\,T^2 \exp(-eW/kT)$$

Where

j = Current density (amp/cm^2) from the cathode surface

W = Work function of the cathode material (Volts)

T = Absolute Temperature of cathode (K)

e = Electron charge (Coulomb)

k = Boltzmann constant (1.3×10^{-23} J/K)

A = Constant (~120Amp/cm^2.K^2)

Temperature $T \Uparrow$ - $j \Uparrow$

Electrons emitted from cathode are in thermal equilibrium at temperature T and their velocity is govern by Maxwellian distribution. This is reflected in focusing the electrons on the work-piece.

Cathode Material: Tungsten or thoriated tungsten

Application Examples:

EB Drilling: Suitable where large no. of holes is to be drilled
where drilling holes with conventional process is difficult due to material hardness or hole-geometry.

Used in aerospace, instrumentation, food , chemical & textile industries.

Thousands of tiny holes (0.1- 0.9$\pm$0.05mm) in

Turbine (steel) engine combustor.

Cobalt alloy fiber spinning heads.

Filters & Screens used in food processing.

Perforation in artificial leather to make shoes for air-breathing:
0.12mm hole made at 5000/s.

EBW: Welding with minimum distortion- Finished components

Parts of target pistols,

Bimetal strips,

Dissimilar metals,

Aircraft gas turbine components,

Automobile catalytic converter, etc.

Advantages of EBM:

Drilling & Cutting

- ✓ Any material can be machined
- ✓ No cutting forces are involved so no stresses imposed on part
- ✓ Exceptional drilling speeds possible with high position accuracy and form
- ✓ Extremely small kerf width, little wastage of material
- ✓ Little mechanical or thermal distortion
- ✓ Computer-controlled parameters
- ✓ High aspect ratio
- ✓ High accuracy

EBW (welding)

- ✓ Minimum thermal input
- ✓ Minimum HAZ & Shrinkage
- ✓ High aspect ratio & Deep penetration
- ✓ High purity, no contamination
- ✓ Welds high-conductivity materials

Disadvantages of EBM :

- High capital cost
- Nonproductive pump down time
- Recast at the edges
- High level of operator skill required
- Maximum thickness that can be cut about 10mm (3/8”)
- A suitable backing material must be used
- Ferrous material to be demagnetized as otherwise could affect the e-beam
- Work area must be under a vacuum

- High joint preparation & tooling costs for welding
- X-ray shielding required
- Seam tracking sometimes difficult.

Summary of EBM Characteristics:

Mechanics of material removal	:	Melting, Vaporization
Medium	:	Vacuum (10^{-4}-10^{-6} Torr), Air with high power, high Voltage beam (not yet commercially popular)
Tool	:	High velocity electron beam
Maximum material removal rate	:	~50mm^3/min
Specific cutting energy	:	~1500J/mm^3
Critical Parameters	:	Accelerating voltage, beam current, beam diameter, work speed, melting temperature
Material applications	:	All materials
Shape applications	:	Drilling fine holes, contour cutting, cutting narrow slots
Limitations	:	High specific energy, Necessity of vacuum, Very high machine cost.

Quiz Questions

1. Mechanism of material removal in Electron Beam Machining is due to

a) Mechanical erosion due to impact of high of energy electrons
b) Chemical etching by the high energy electron
c) Sputtering due to high energy electrons
d) Melting and vaporization due to thermal effect of impingement of high energy electron
Answer – (d)

2. Generally Electron Beam Gun is operated at

a) Atmospheric pressure
b) At 1.2 bar pressure above atmosphere
c) c) At 10 – 100 mTorr pressure
d) At 0.01 – 0.001 mTorr pressure
Answer – (d)

Numerical Problems:

1. Estimate the penetration depth of electron beam accelerated at 100kV impinging in steel having density of 7.6g/cc.

$\delta = 2.6 \times 10^{-17} (V^2 / \rho)$ mm, V in Volts & ρ in kg/mm^3

$\delta = 0.034 \mu m$

2. Electron Beam power required is proportional to material removal rate: P =C.Q Where C is constant of proportionality & Q is MRR in mm^3 /min.

Typical energy requirements for cutting are,

Material	C (W/mm^3/min)
Tungsten	12
Fe	7
Ti	6
Al	4

Determine the cutting speed to cut a 250 micron wide slot in a 0.5mm thick tungsten sheet using a 1kW electron beam

C = P/Q $\Rightarrow$ 12 W/mm^3/min = 1000W / ($250 \times 10^{-3} \times 0.5 \times$ V in mm/min)

V in mm/min = 1000/(12 x 0.25x0.5) = 667mm/min =11mm/s

LASER BEAM MACHINING

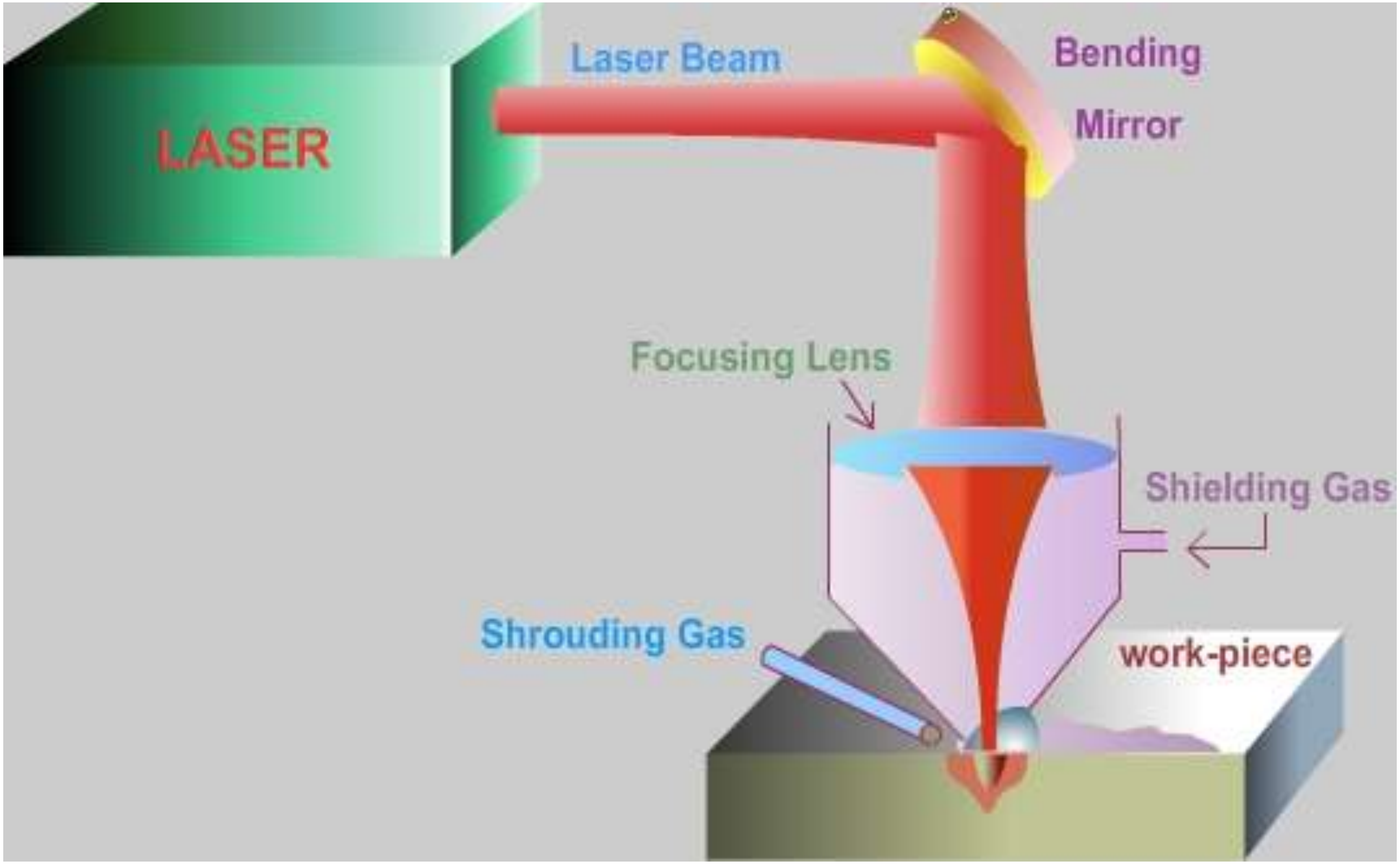
Laser Beam Machining

Laser Beam Machining or more broadly laser material processing deals with machining and material processing like heat treatment, alloying, sheet metal bending etc. Such processing is carried out utilizing the energy of coherent photons or laser beam, which is mostly converted into thermal energy upon interaction with most of the materials. Nowadays, laser is also finding application in regenerative machining or rapid prototyping as in processes like stereo–lithography, selective laser sintering etc.

Laser : Light Amplification by Stimulated Emission of Radiation

Laser beam can very easily be focused using optical lenses as their wavelength ranges from half micron to around 70 microns. Focused laser beam as indicated earlier can have power density in excess of 1 MW/mm^2. As laser interacts with the material, the energy of the photon is absorbed by the work material leading to rapid substantial rise in local temperature. This in turn results in melting and vaporization of the work material and finally material removal.

Laser Beam Machining: An Introduction



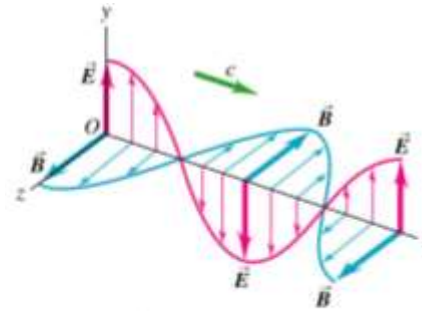
*** What is LASER ?**

LASER: **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation

* What is Light?

Electromagnetic Radiation :

Carries Energy in the direction of propagation



Wave nature:

Transverse Wave i.e. Oscillation of electric & magnetic fields are transverse to the direction of propagation.

Velocity in vacuum or air, **c** = 3×10^8 m/s,

Frequency = ν ,

Wavelength = λ = **c/** ν

In a medium of refractive index n,

Light velocity, **v = c/n**

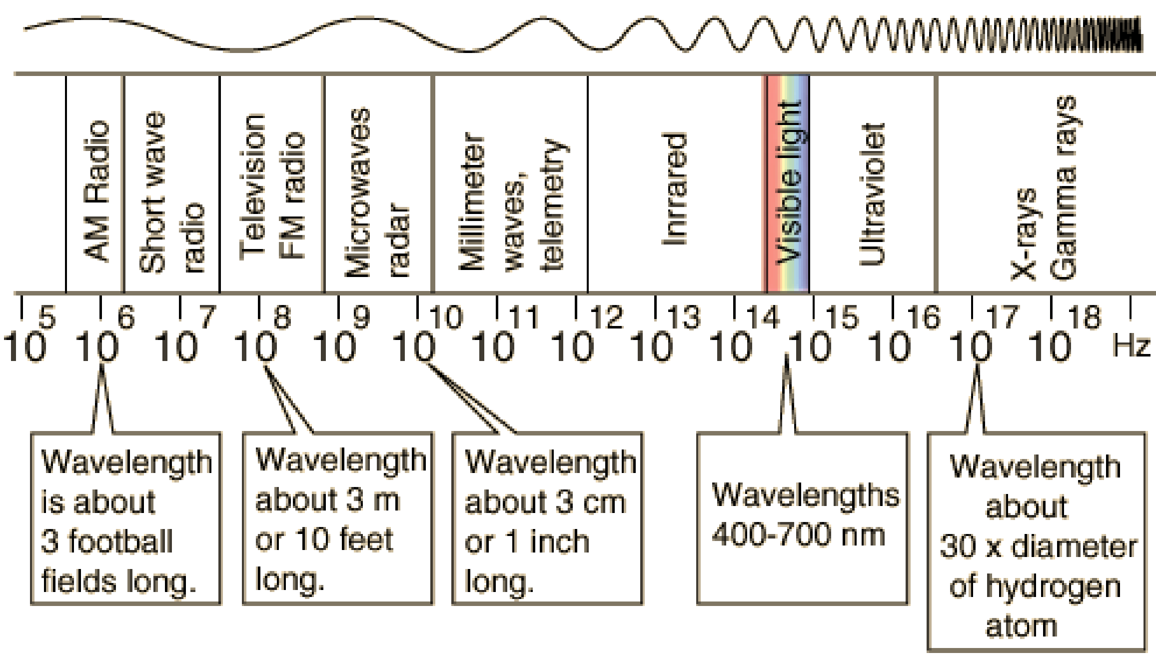
Wavelength = **c/ n**ν

Particle nature:

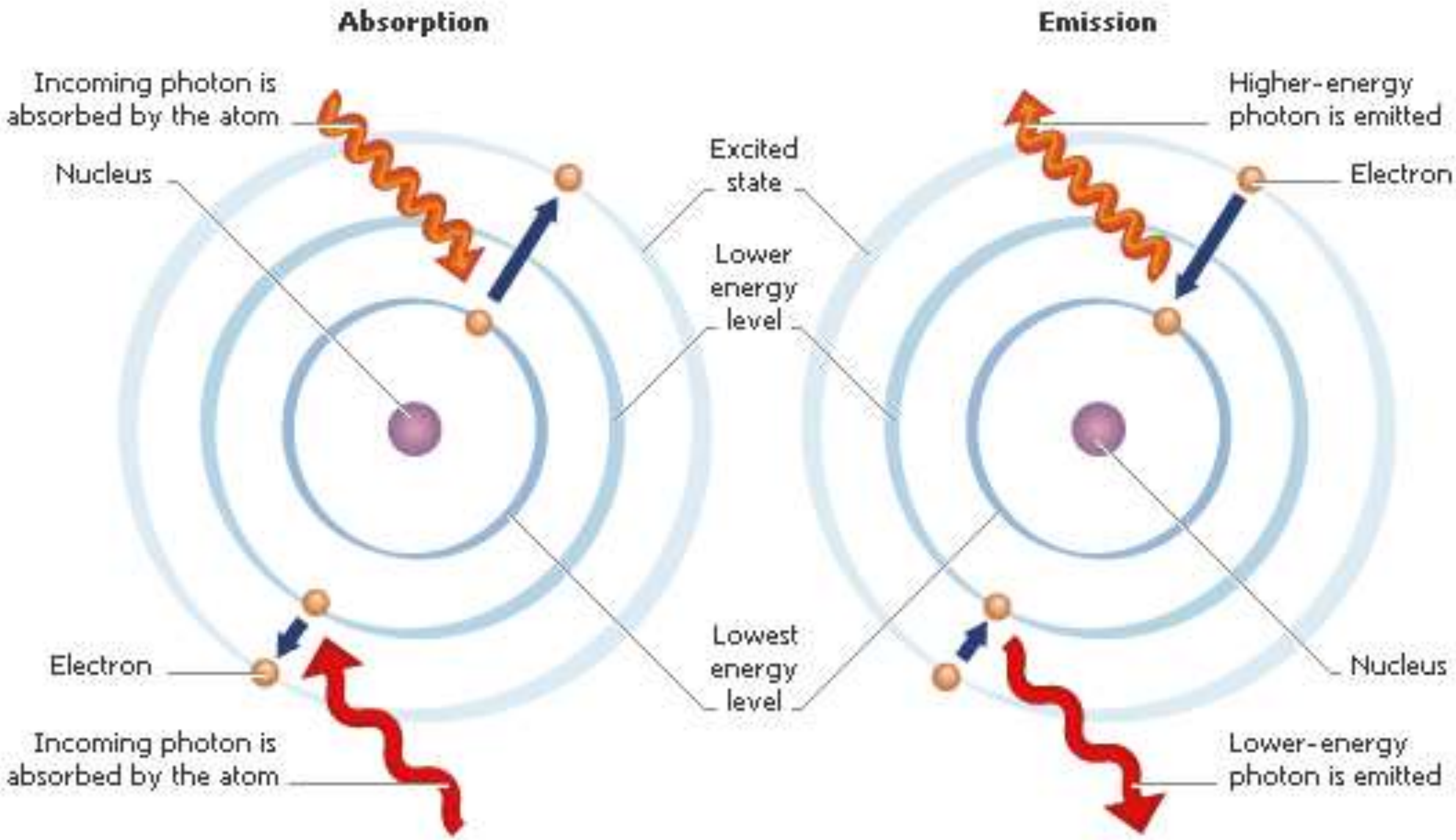
Photon Energy = $h\nu$,

Photon momentum p = $h\nu/c$

h= Planck's constant = 6.626×10^{-34} J-sec.

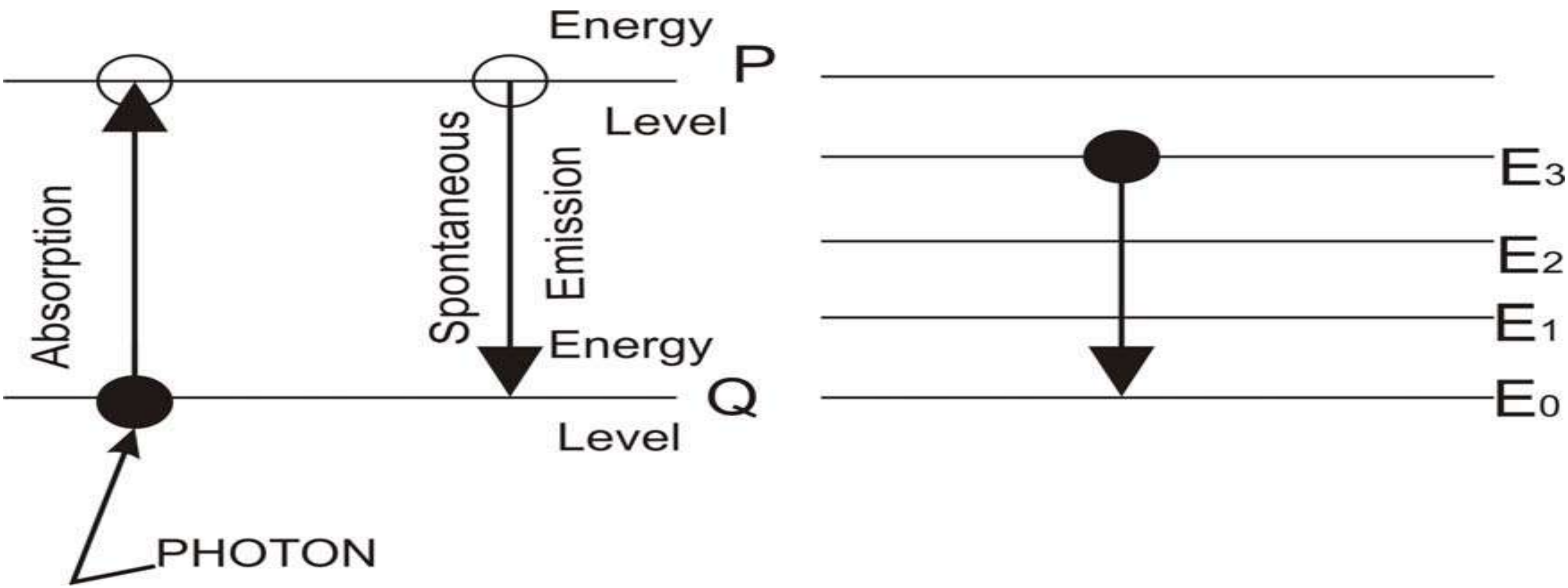


Absorption & Spontaneous Emission of Photons



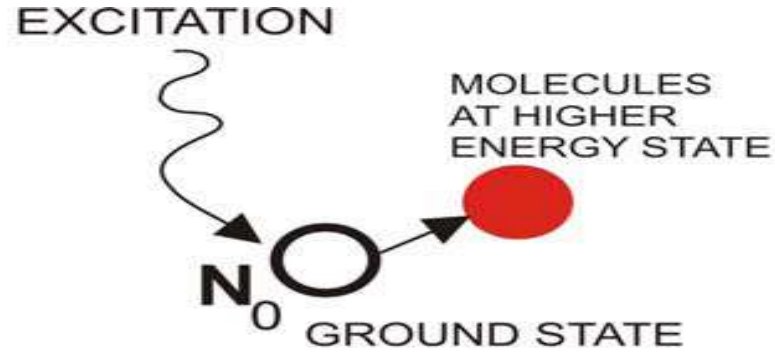
Ordinary Source of Light Emits Light by Spontaneous Emission Process

Laser Beam Machining – the lasing process

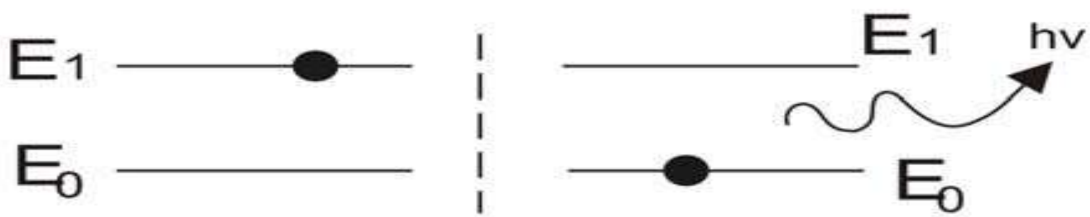


In a material, if more number of electrons can be somehow pumped to the higher meta-stable energy state as compared to number of atoms at ground state, then it is called "population inversion".

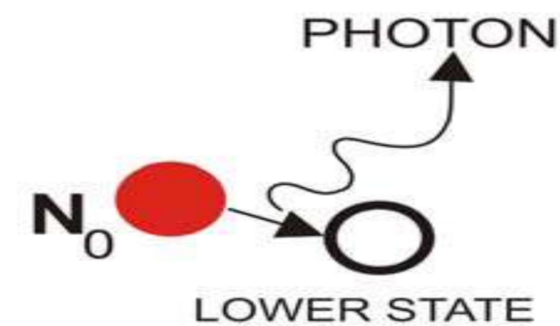
STIMULATED ABSORPTION



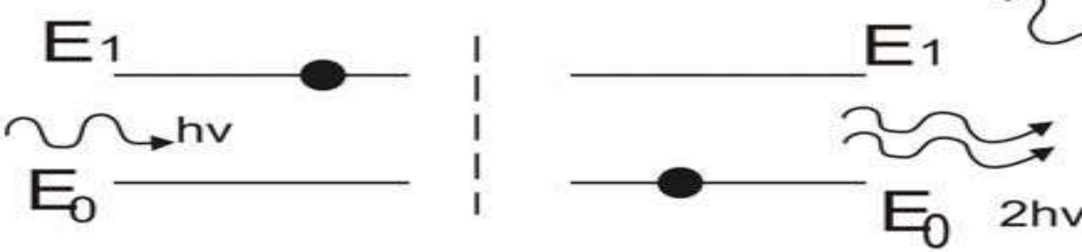
STIMULATED EMISSION

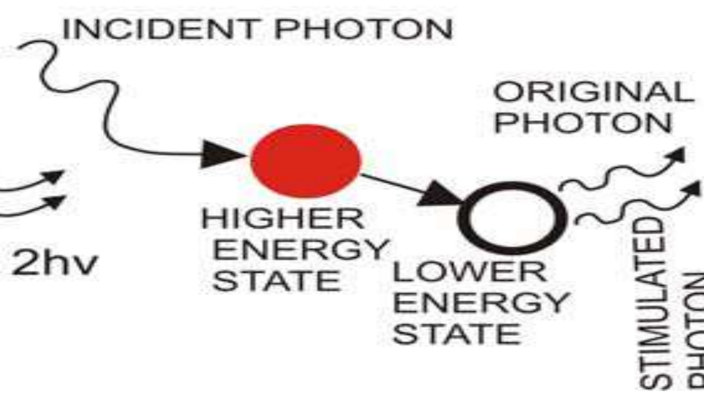


Spontaneous emission

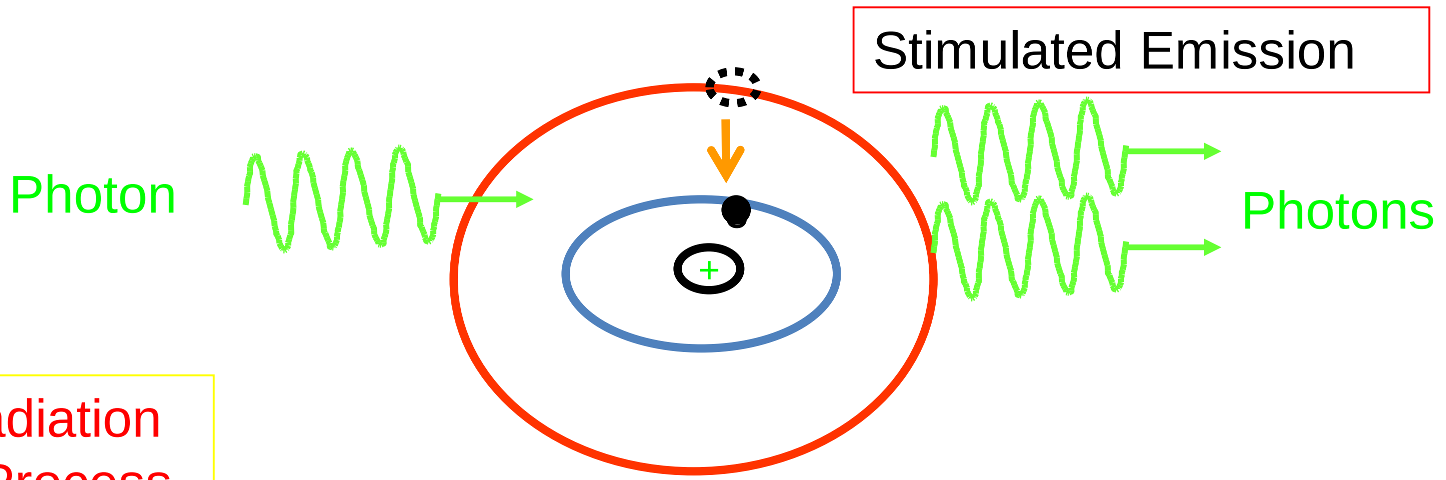


POPULATION INVERSION





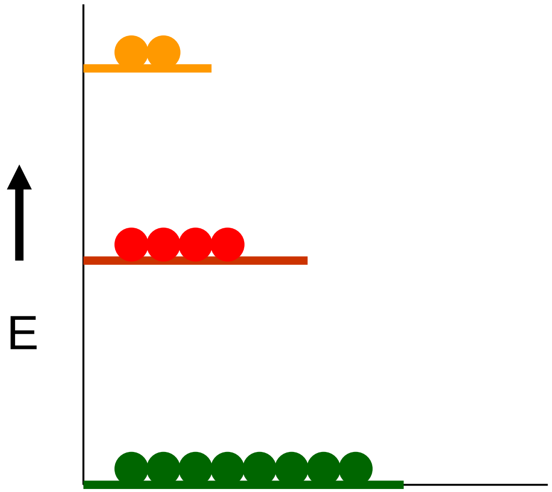
Stimulated Emission of Radiation



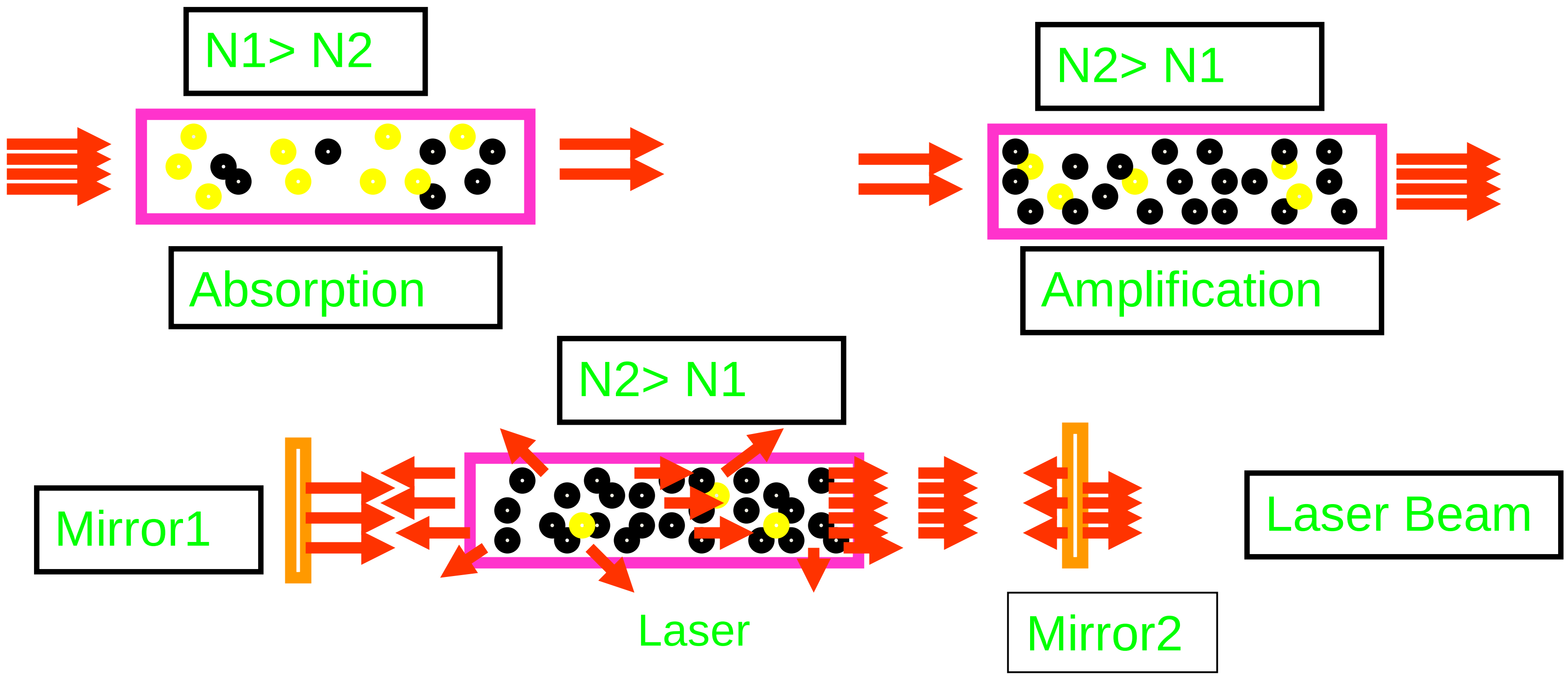
Laser Emits Radiation by Stimulated Process

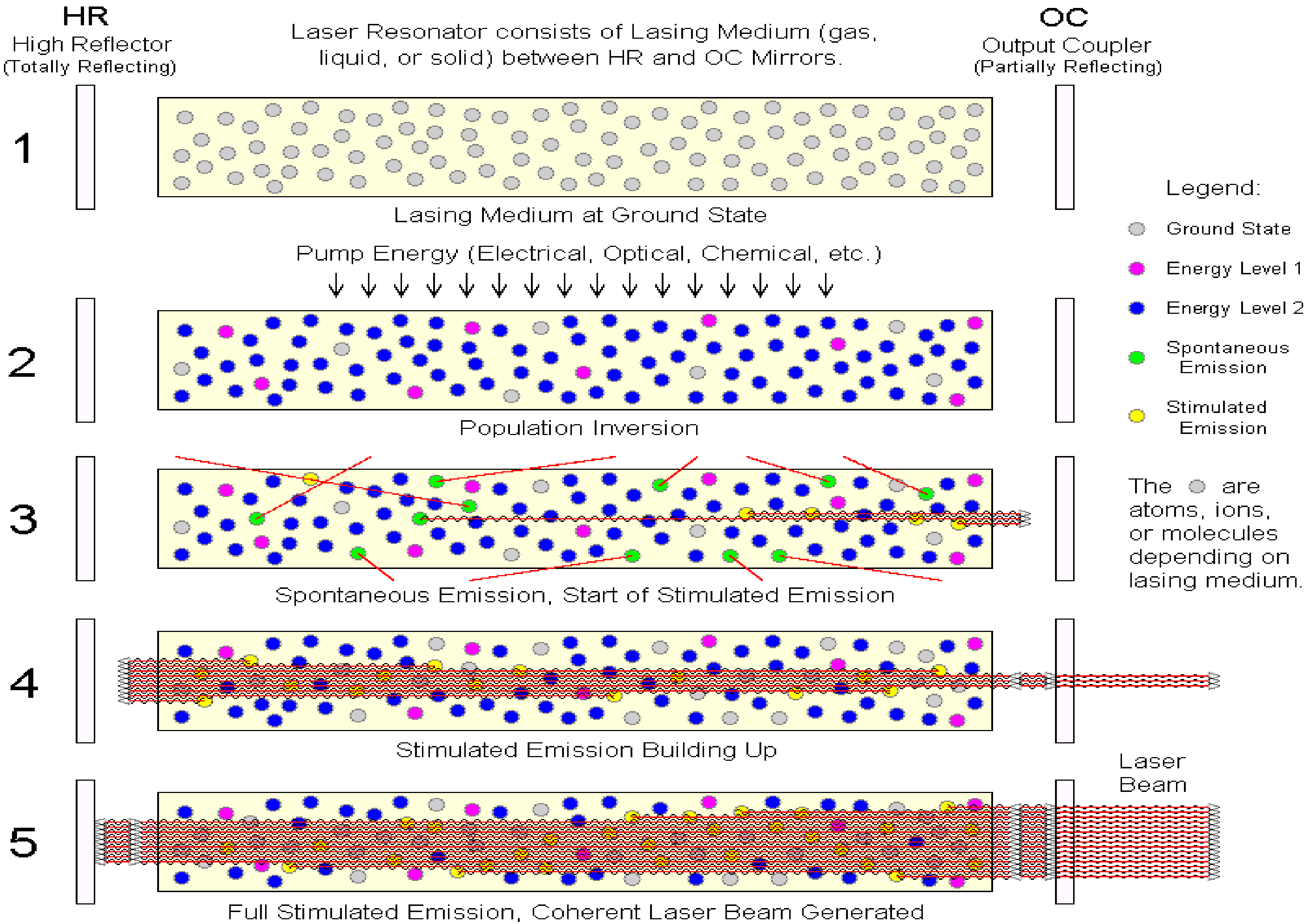
Probability of Absorption = Probability of Stimulated emission

In normal condition (Thermal Equilibrium) more population in lower energy levels than higher energy levels,
Absorption dominates over Stimulated Emission



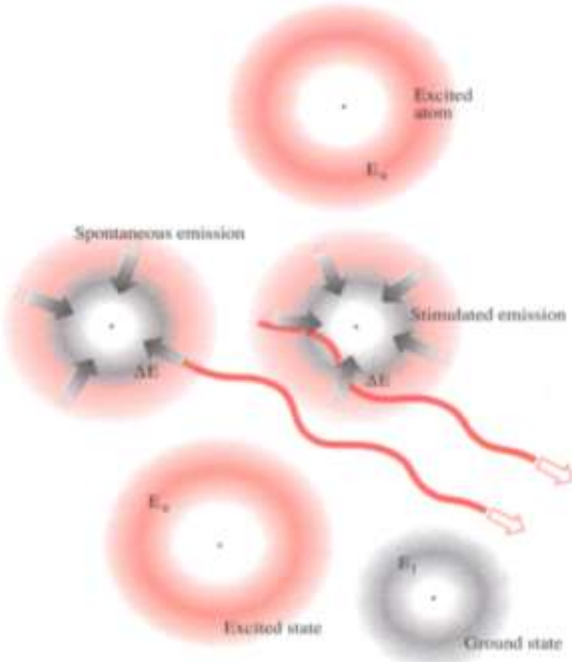
Stimulated Process to dominate over Absorption Process: More Population in Excited State

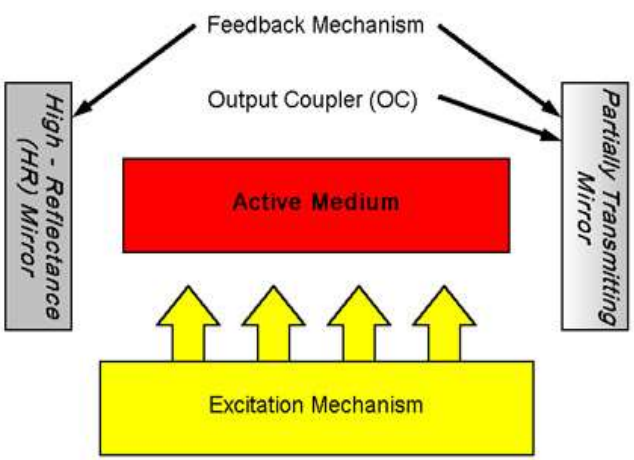


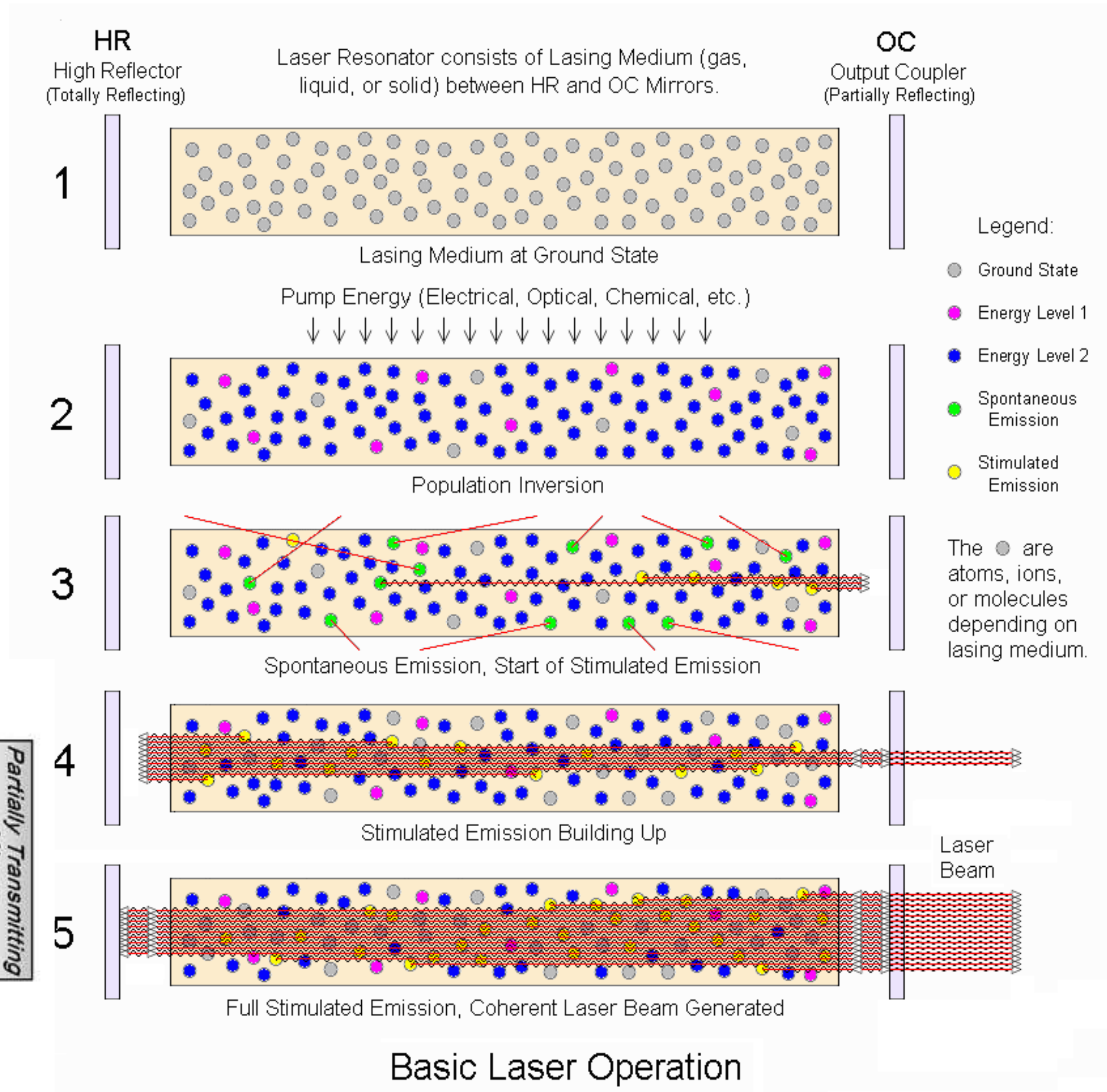


Basic Laser Operation

Light Amplification by Stimulated Emission of Radiation

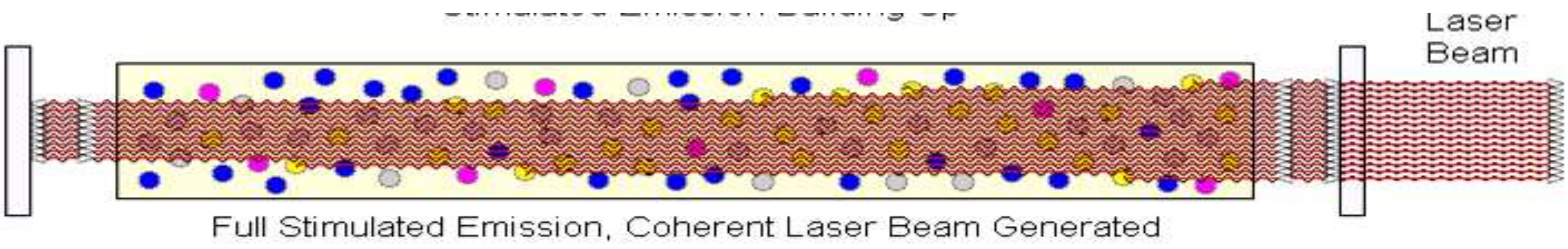






* Stimulating & stimulated Photons have same wavelength, phase, direction, and polarization

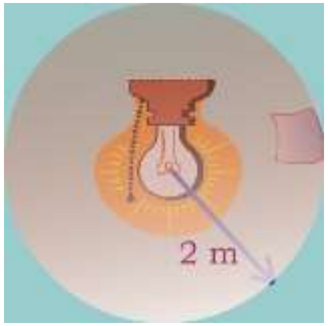
* Optical resonator support waves parallel to its axis



- Coherent
- Monochromatic
- Low Beam Divergence / Directional : Focusibility
- High Brightness
- High Power and High Power Density
- Tunability
- Ultra-short duration pulse

Laser Material Processing

Ordinary Source of light

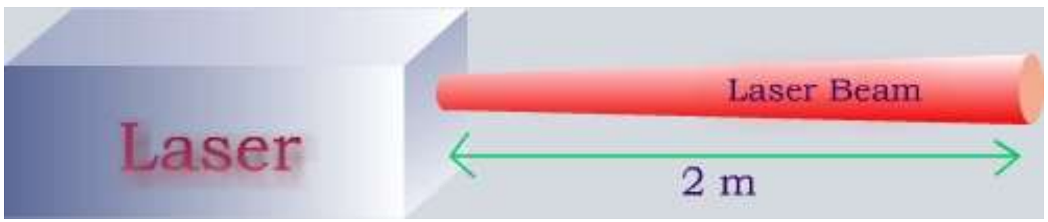


Ordinary Source of Light :

Incoherent: No Phase relation between waves emitted by different atoms

Wide frequency spectrum, $\Delta\nu \approx 10^{14}$Hz

Emits light in all ($\approx 4\pi$ radian) direction



Laser beam : Coherent- Constant phase relation between waves in time and space

Laser emits rays of narrow frequency spectrum, $\Delta\nu \approx 10^{6-9}$Hz

Emits light in a small angle (Divergence angle $\approx$ a few milli-radian)

Laser Power : mW – Several kW's

Laser can operate in continuous wave (CW) and pulse mode; Pulse duration ranging from ms (10^{-3}s) to 10's of fs (10^{-15}s)

High Power & Low Divergence Exploited in Laser Material Processing

Important components of a laser:

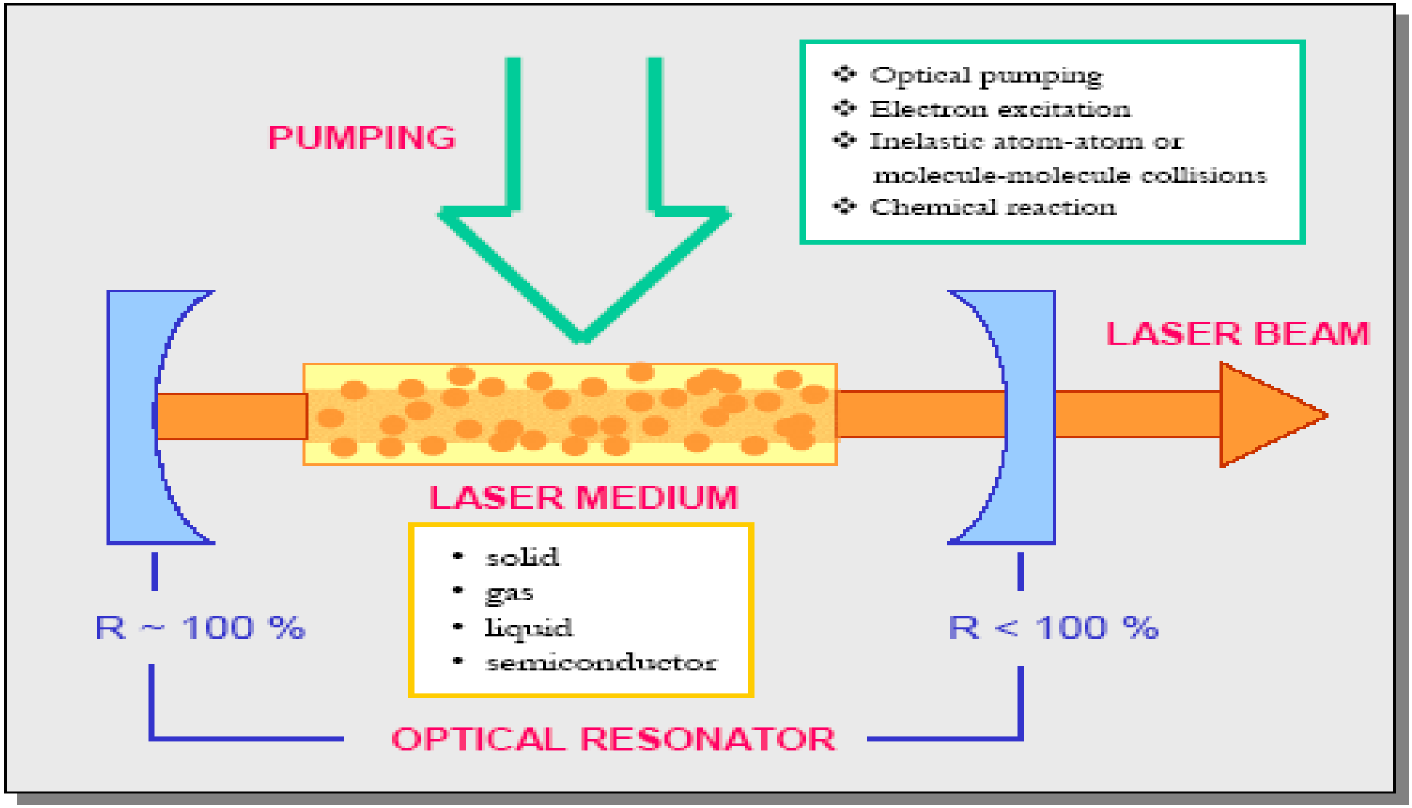
1.Active medium

* Solid: Nd:YAG, Optical Fiber

* Liquid: Dye Laser

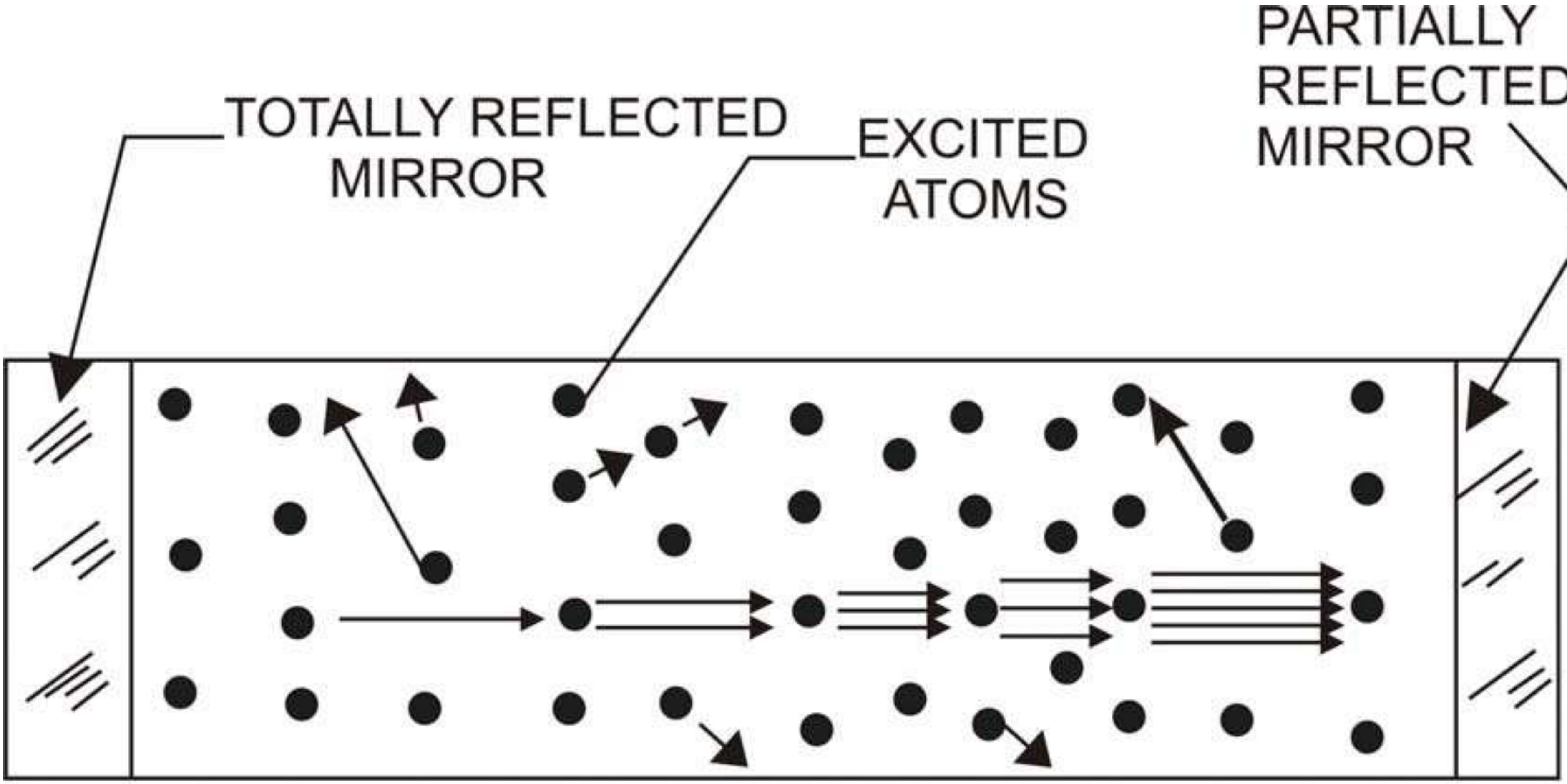
* Gas: He-Ne, CO_2, Excimer Ar+ ion

* Semiconductor Diodes



2. Excitation or Pump Source to produce population inversion in lasing medium.
   * Optical Pump (Flash Lamp, Other Laser) : Solid State & Fiber Lasers
   * Electrical discharge (DC, AC, RF, Pulsed) : Gas Lasers
   * Current injection : Diode Lasers

3. Optical Resonator formed by a pair of parallel mirrors, one ~100% reflecting and other partial reflecting. They provide feedback into the active medium and facilitates laser beam to build up. Laser beam comes out through the partial reflecting mirror.


TOTALLY REFLECTED MIRROR
EXCITED ATOMS
PARTIALLY REFLECTED MIRROR

Lasing Medium

Many materials can be used as the heart of the laser. Depending on the lasing medium lasers are classified as **solid state and gas laser.**

Solid-state lasers are commonly of the following type

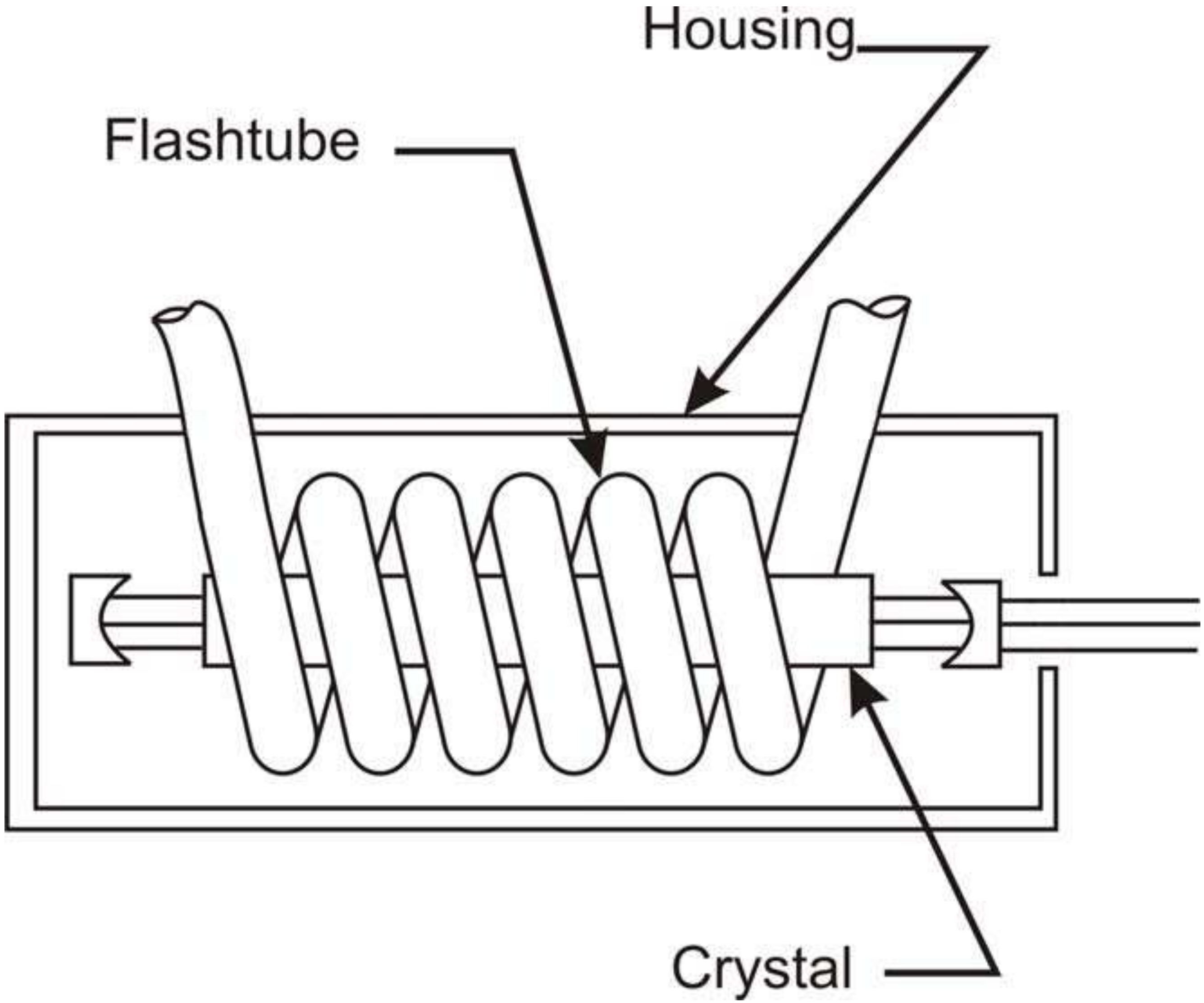
- Ruby which is a chromium – alumina alloy having a wavelength of 0.7 µm
- Nd-glass lasers having a wavelength of 1.64 µm
- **Nd:YAG (neodymium-doped yttrium aluminium garnet**; **Nd:$Y_3Al_5O_{12}$**) laser having a wavelength of 1.06 µm

These solid-state lasers are generally used in material processing.

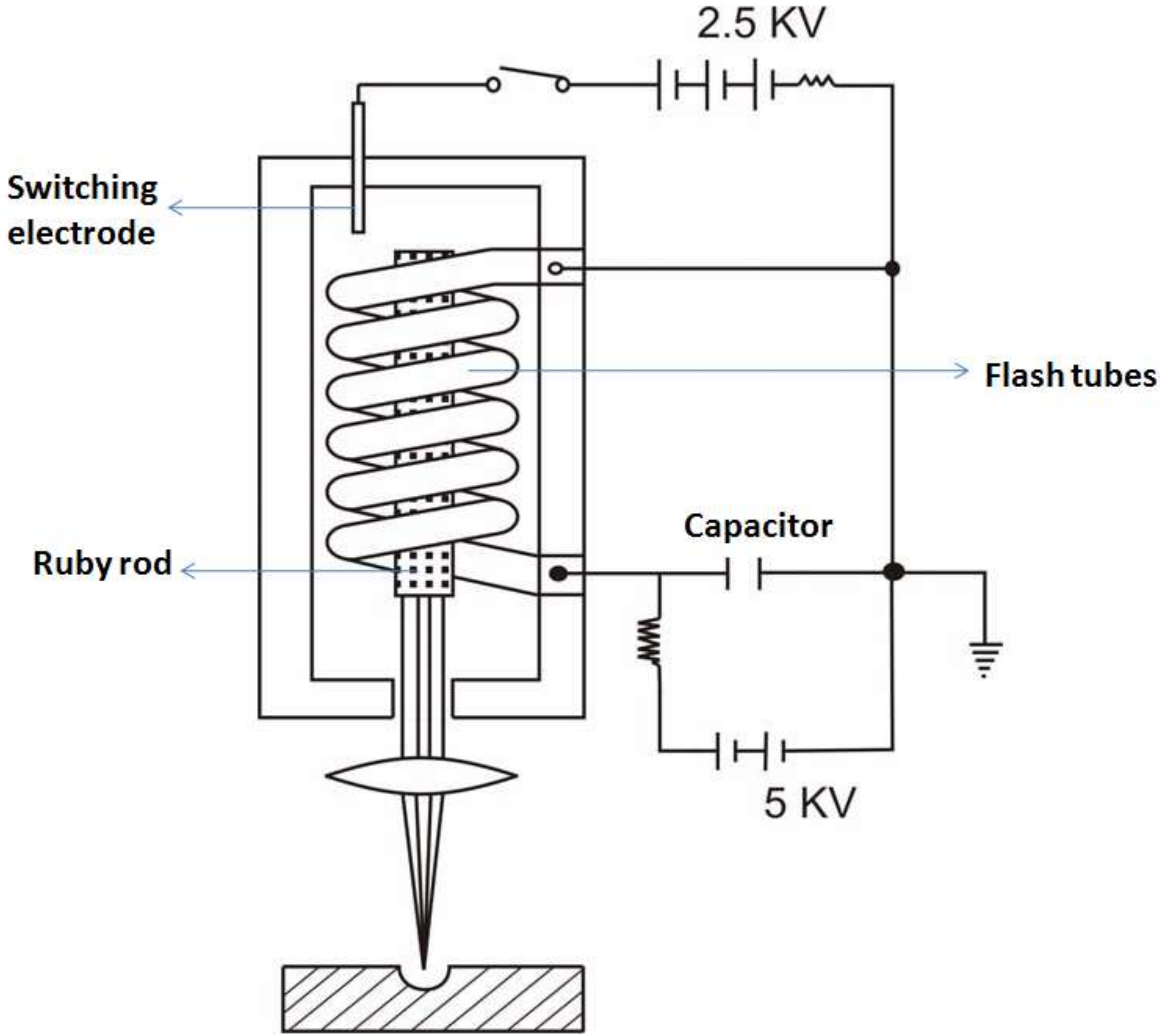
The generally used gas lasers are

- Helium – Neon
- Argon
- CO_2 etc. – Wave length 10.6 µm

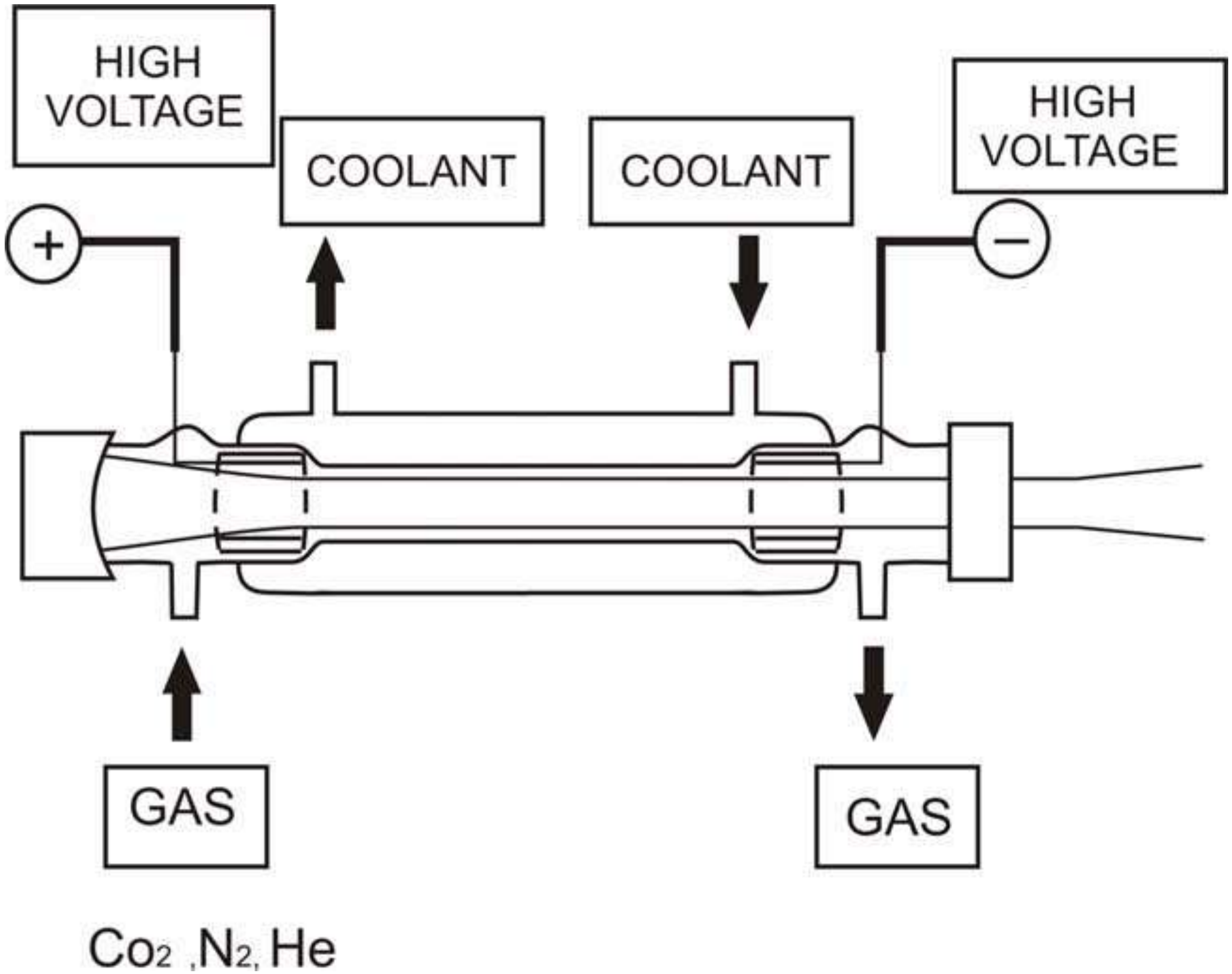
Lasers can be operated in continuous mode or pulsed mode. Typically CO_2 gas laser is operated in continuous mode and Nd – YAG laser is operated in pulsed mode.



Solid-state laser with its optical pumping unit



Working of a solid-state laser



Construction of a CO_2 laser

Application

Laser can be used in wide range of manufacturing applications

- Material removal – drilling, cutting and tre-panning
- Cladding
- Alloying
- Welding

Drilling micro-sized holes using laser in difficult – to – machine materials is the most dominant application in industry. In laser drilling the laser beam is focused over the desired spot size. For thin sheets pulse laser can be used. For thicker ones continuous laser may be used.

Advantages

- In laser machining there is no physical tool. Thus no machining force or wear of the tool takes place.
- Large aspect ratio in laser drilling can be achieved along with acceptable accuracy or dimension, form or location
- Micro-holes can be drilled in difficult – to – machine materials
- Though laser processing is a thermal processing but heat affected zone specially in pulse laser processing is not very significant due to shorter pulse duration.

Limitations

- High initial capital cost
- High maintenance cost
- Not very efficient process
- Presence of Heat Affected Zone – specially in gas assist CO_2 laser cutting
- Thermal process – not suitable for heat sensitive materials like aluminium glass fibre laminate

Application	Type of laser
Large holes upto 1.5 mm dia.	Ruby, Nd-glass, Nd-YAG
Large holes (trepanned)	Nd-YAG, CO_2
Small holes > 0.25 mm dia.	Ruby, Nd-glass, Nd-YAG
Drilling (punching or percussion)	Nd-YAG, Ruby
Thick cutting	CO_2 with gas assist
Thin slitting of metals	Nd-YAG
Thin slitting of plastics	CO_2
Plastics	CO_2
Metals	Nd-YAG, ruby, Nd-glass
Organics, Non-metal	Pulsed CO_2
Ceramics	Pulsed CO_2, Nd-YAG

Lasing materials	Ruby	**Nd-YAG**	Nd-glass	**CO_2**
Type	Solid state	**Solid state**	Solid state	**Gas**
Composition	0.03 – 0.7% Nd in Al_3O_2	**1% Nd doped Yttrium – Aluminium-Garnet**	2-6% Nd in glass	**CO_2+He+N_2 (3:8:4)**
Wavelength (radiation)	0.69 μm	**1.064 μm**	1.064 μm	**10.6 μm**
Efficiency	1% max.	**2%**	2%	**10-15%**
Beam mode	Pulsed or CW	**Pulsed or CW**	Pulsed	**Pulsed or CW**
Spot size	0.015 mm	**0.015 mm**	0.025 mm	**0.075 mm**
Pulse repetition rate (normal operation).	1-10 pps	**1-300 pps or CW**	1-3 pps	**CW**
Beam output	10-100 W	**10-1000 W**	10 – 100 W	**0.1 – 10 kW**
Peak power	200 kW	**400 kW**	200 kW	**100 kW**

QUIZ

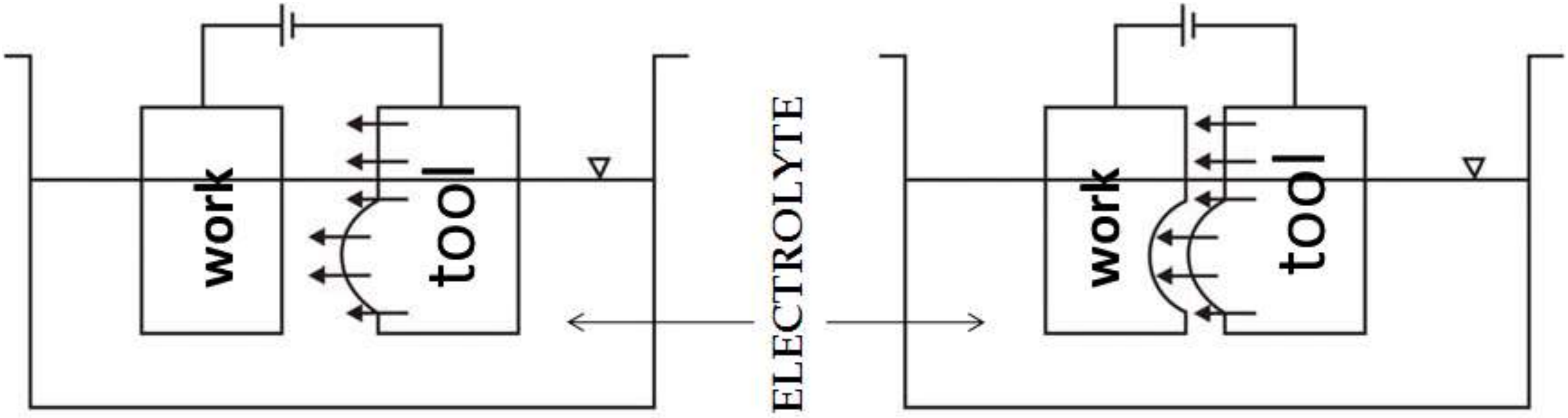
1. Mechanism of material removal in Electron Beam Machining is due to
a) Mechanical erosion due to impact of high of energy electrons
b) Chemical etching by the high energy electron
c) Sputtering due to high energy electrons
d) Melting and vaporisation due to thermal effect of impingement of high energy electron

2. Mechanism of material removal in Laser Beam Machining is due to
a) Mechanical erosion due to impact of high of energy photons
b) Electro-chemical etching
c) Melting and vaporisation due to thermal effect of impingement of high energy laser beam
d) Fatigue failure

3. Generally Electron Beam Gun is operated at
a) Atmospheric pressure
b) At 1.2 bar pressure above atmosphere
c) At 10 – 100 mTorr pressure
d) At 0.01 – 0.001 mTorr pressure

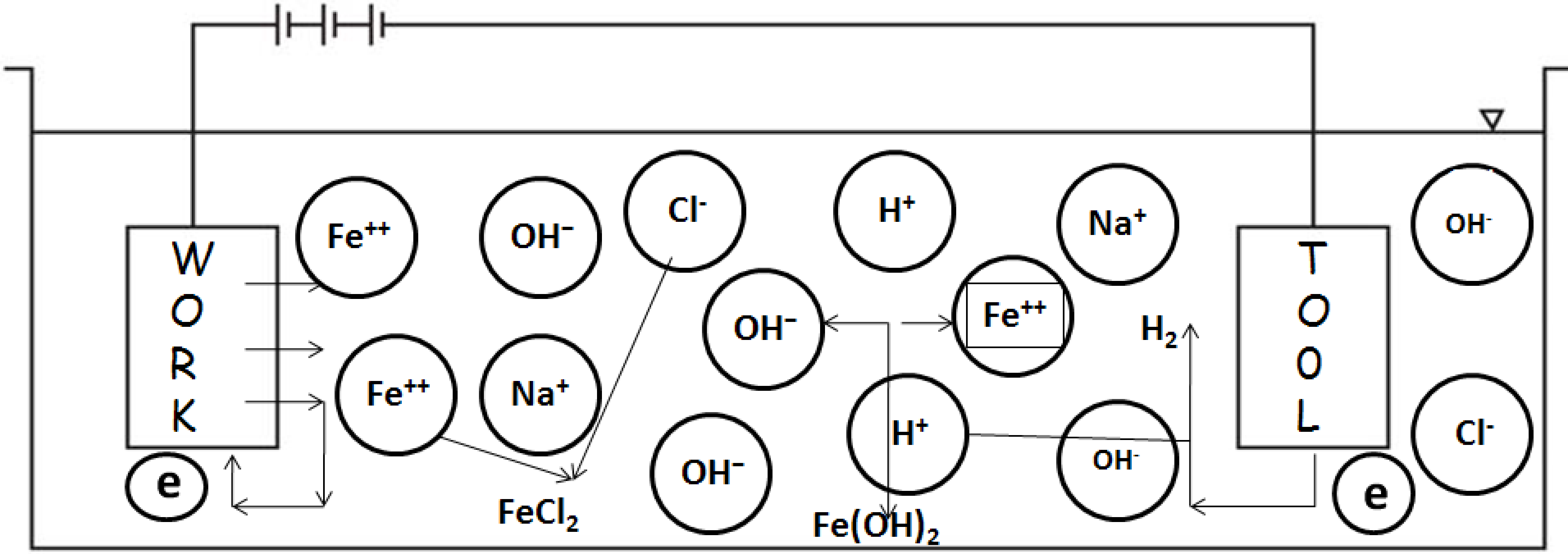
4. Laser Beam is produced due to
a) Spontaneous emission
b) Stimulated emission followed by spontaneous emission
c) Spontaneous emission followed by Spontaneous absorption
d) Spontaneous absorption leading to "population inversion" and followed by stimulated emission

Electro Chemical Machining



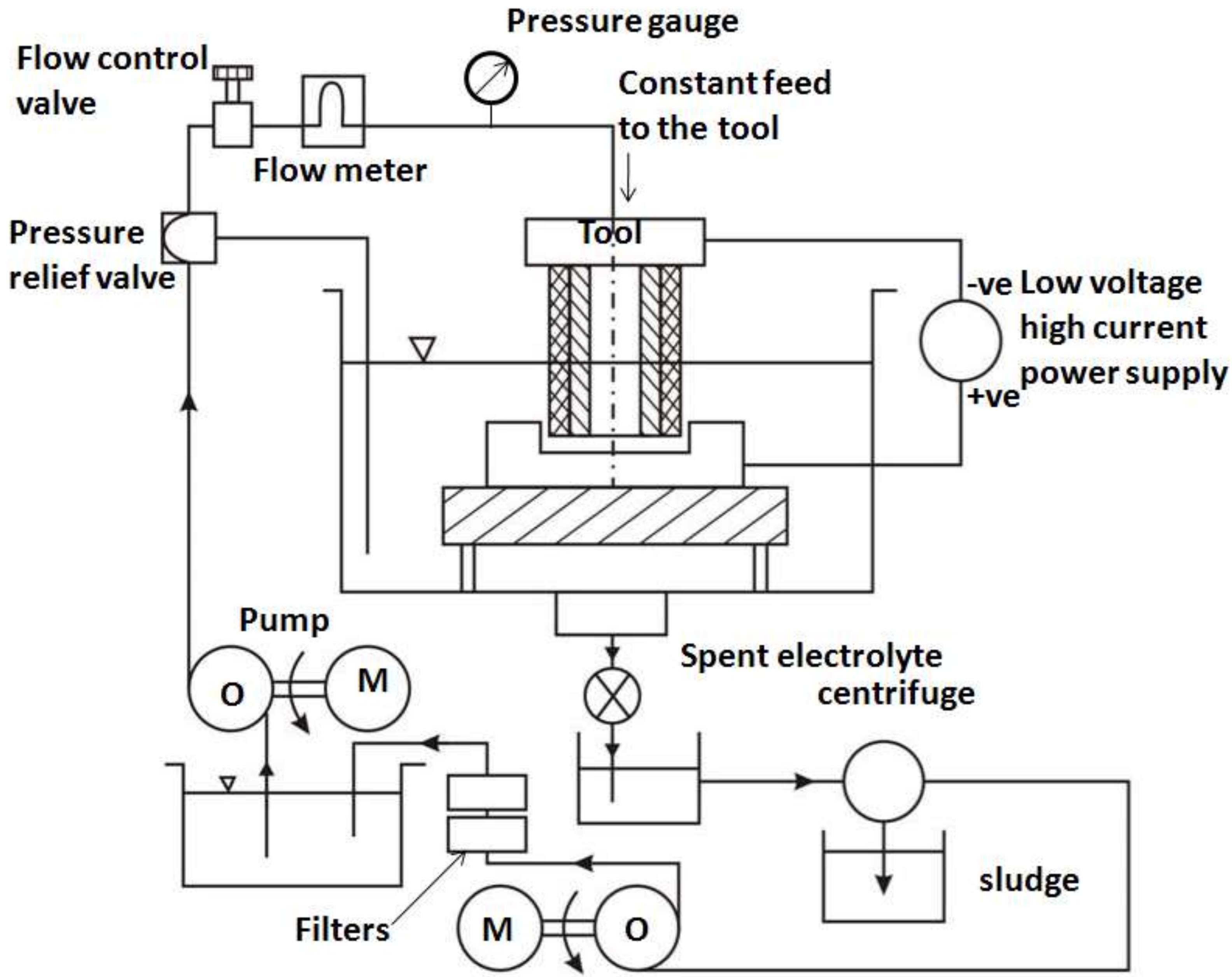
ECM is **opposite** of electrochemical or galvanic coating or deposition process **(Electroplating).**

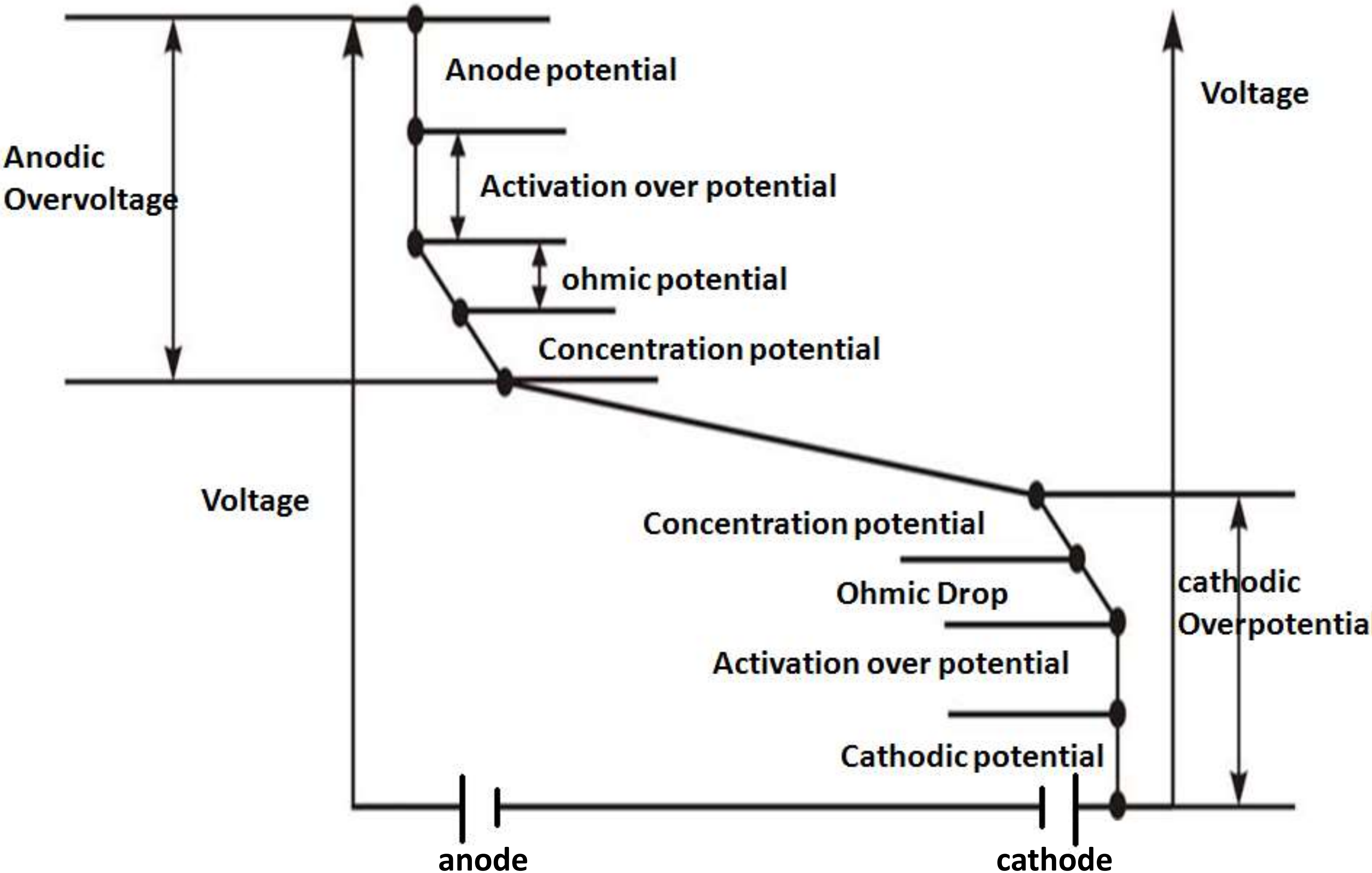
Thus ECM can be thought of a controlled **anodic dissolution** at atomic level of the work piece that is **electrically conductive** by a shaped tool **(Maintaining constant gap)** due to flow of **high current** at relatively **low potential** difference through an **electrolyte** which is quite often water based neutral salt solution.



Schematic representation of electro-chemical reactions

For electrochemical machining of steel, generally a neutral salt solution of sodium chloride (NaCl) is taken as the electrolyte.


Pressure gauge
Flow control valve
Constant feed to the tool
Flow meter
Pressure relief valve
Tool
-ve
Low voltage high current power supply
+ve
Pump
O
M
Spent electrolyte
centrifuge
sludge
Filters
M
O



Total potential drop in ECM cell

Process Parameters

- Power Supply
  - Type direct current
  - Voltage 2 to 35 V
  - Current 50 to 40,000 A
  - Current density 0.1 A/mm^2 to 5 A/mm^2
- Electrolyte
  - Material NaCl and $NaNO_3$
  - Temperature 20^{o}C – 50^{o}C
  - Flow rate 20 lpm per 100 A current
  - Pressure 0.5 to 20 bar
  - Dilution 100 g/l to 500 g/l
- Working gap 0.1 mm to 2 mm
- Overcut 0.2 mm to 3 mm
- Feed rate 0.5 mm/min to 15 mm/min
- Electrode material Copper, brass, bronze
- Surface roughness, R_a 0.2 to 1.5 μm

MODELLING OF MATERIAL REMOVAL RATE

In ECM, material removal takes place due to atomic dissolution of work material.

Electrochemical dissolution is governed by Faraday's laws.

The first law states that the amount of electrochemical dissolution or deposition is proportional to amount of charge passed through the electrochemical cell, which may be expressed as: $m \propto Q$,

where m = Mass of material dissolved or deposited

Q = Amount of charge passed

The second law states that the amount of material deposited or dissolved further depends on Electrochemical Equivalence (ECE) of the material that is again the ratio atomic weigh and valency.

Thus $m \propto ECE \propto A/v$

Thus $m \propto QA/v$

where F = Faraday's constant = 96500 coulombs

➡ $m = QA/Fv = ItA/Fv$

$\therefore MRR = m/t\rho = IA/F\rho v$

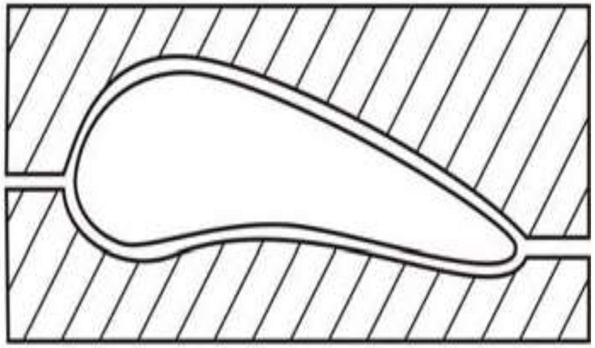
where I = current

ρ = density of the material

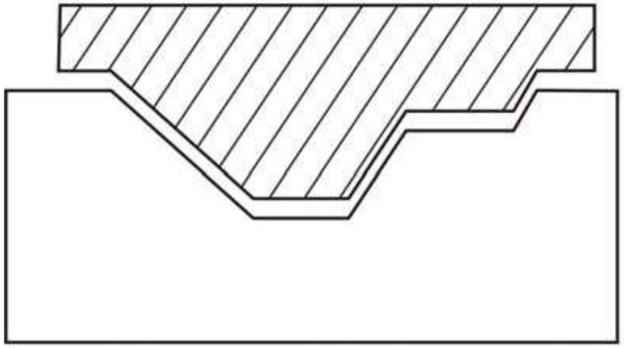
Applications

ECM technique removes material by atomic level dissolution of the same by electrochemical action. Thus the material removal rate or machining is not dependent on the mechanical or physical properties of the work material. It only depends on the atomic weight and valency of the work material and the condition that it should be electrically conductive. Thus ECM can machine any electrically conductive work material irrespective of their hardness, strength or even thermal properties. Moreover as ECM leads to atomic level dissolution, the surface finish is excellent with almost stress free machined surface and without any thermal damage.

ECM is used for



- Die sinking
- Profiling and contouring
- Trepanning
- Grinding
- Drilling
- Micro-machining



QUIZ

1. For ECM of steel which is used as the electrolyte
(a) Kerosene (b) NaCl ⟵
(c) Deionised water (d) HNO_3

2. MRR in ECM depends on
(a) Hardness of work material
(b) atomic weight of work material ⟵
(c) thermal conductivity of work material
(d) ductility of work material

3. ECM cannot be undertaken for
(a) steel (b) Nickel based super alloy
(c) Al_2O_3 ⟵
(d) Titanium alloy

4. Commercial ECM is carried out at a combination of
(a) low voltage high current ⟵
(b) low current low voltage
(c) high current high voltage
(d) low current low voltage

1. In electrochemical machining of pure iron a material removal rate of 600 mm^3/min is required. Estimate current requirement. $\rho = 7.8$ gm/cc

2. Composition of a Nickel super alloy is as follows: Ni = 70.0%, Cr = 20.0%, Fe = 5.0% and rest Titanium

Calculate rate of dissolution if the area of the tool is 1500 mm^2 and a current of 2000 A is being passed through the cell. Assume dissolution to take place at lowest valency of the elements.

$A_{Ni} = 58.71$ $\rho_{Ni} = 8.9$ $v_{Ni} = 2$

$A_{Cr} = 51.99$ $\rho_{Cr} = 7.19$ $v_{Cr} = 2$

$A_{Fe} = 55.85$ $\rho_{Fe} = 7.86$ $v_{Fe} = 2$

$A_{Ti} = 47.9$ $\rho_{Ti} = 4.51$ $v_{Ti} = 3$

3. An alloy consist of the following composition.

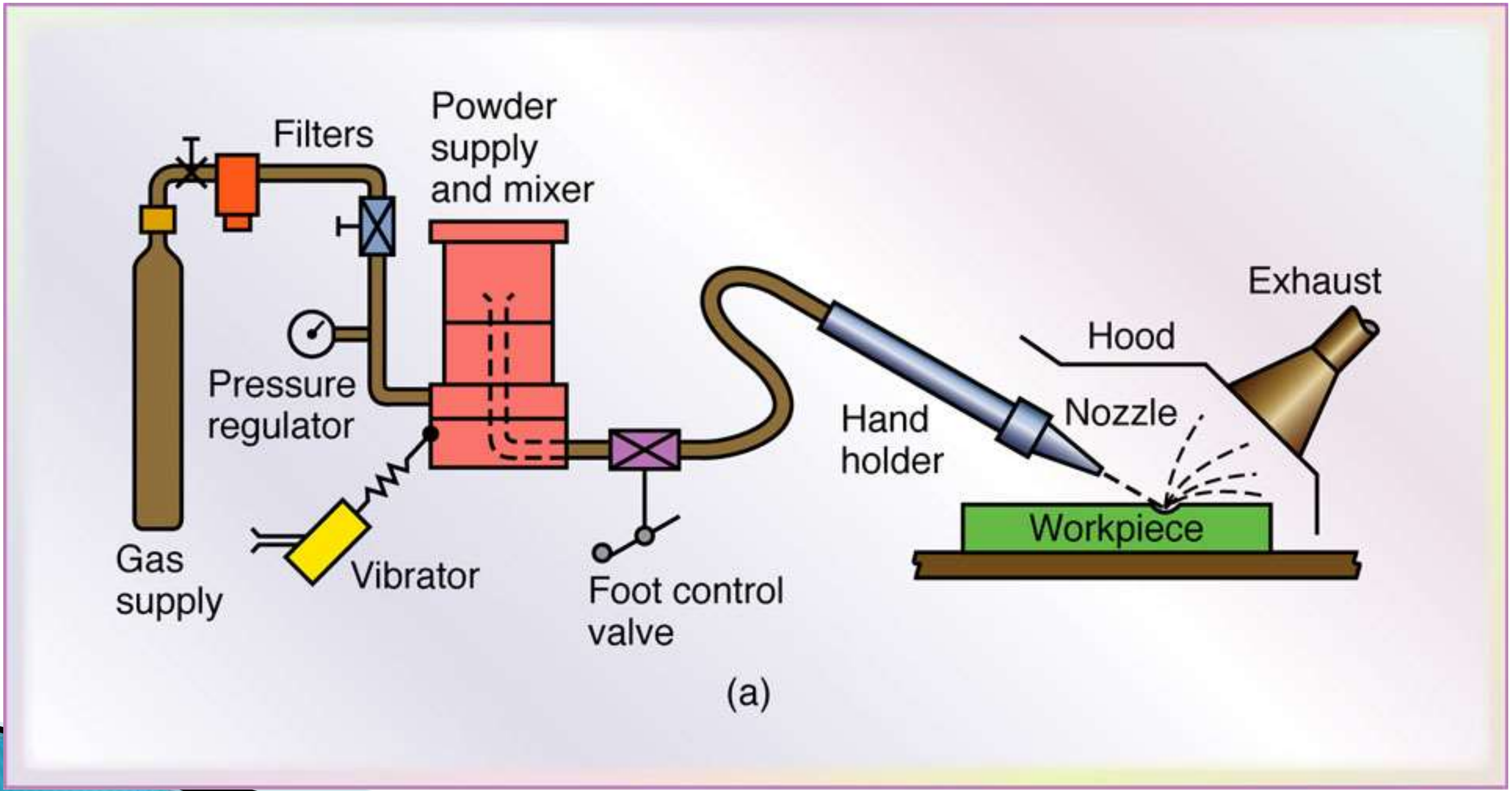
	Ni	Cr	Fe	Ti	Si	Mn	Cu
Wt. %	72.5	19.5	5	0.4	1.0	1.0	0.6
A	58.71	51.99	55.85	47.9	28.09	54.94	63.57
v	2	2	2	2	2	2	2
ρ	8.9	7.17	7.86	4.51	2.33	7.43	8.96

Calculate the material removal rate When a current of 1000 Ampere passes through it.

Abrasive Jet Machining Process

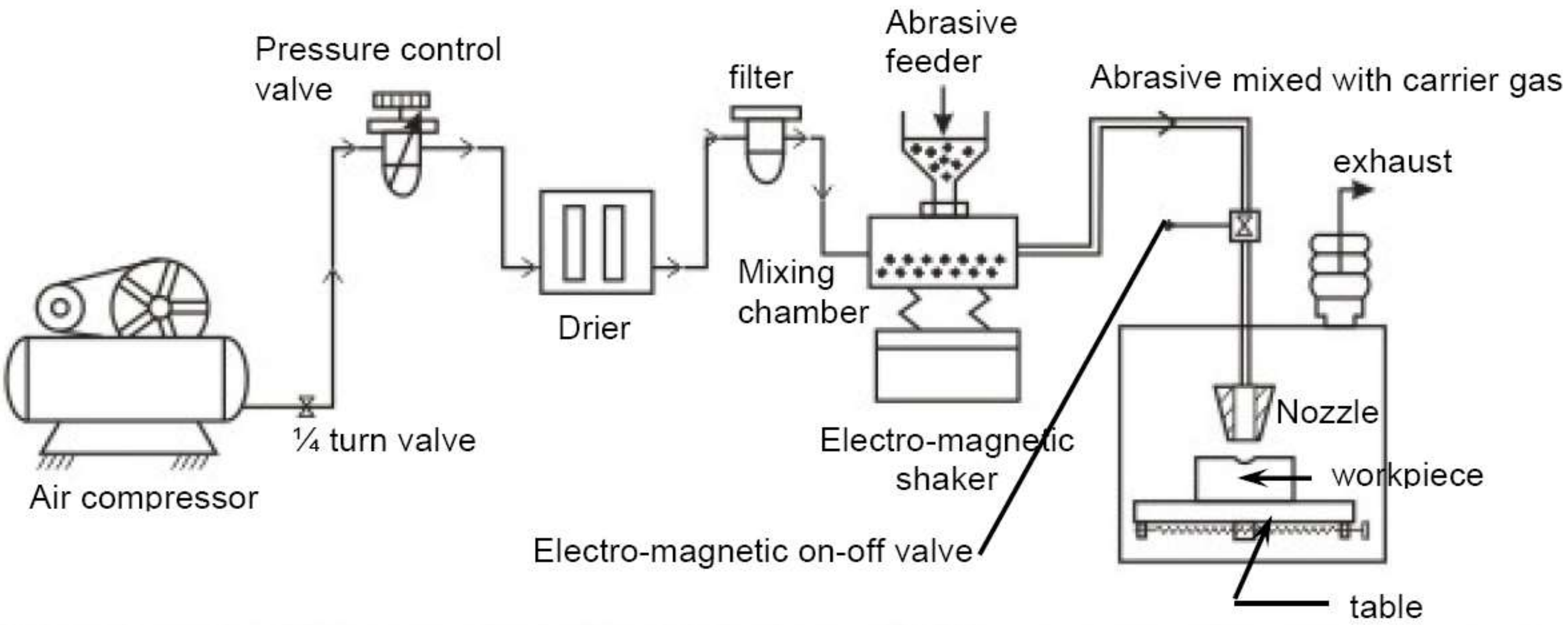
Working Principle

AJM works on the principle of impact erosion through the action of a concentrated high velocity stream of grit abrasives entered in a high velocity gas (air) stream.



EQUIPMENT

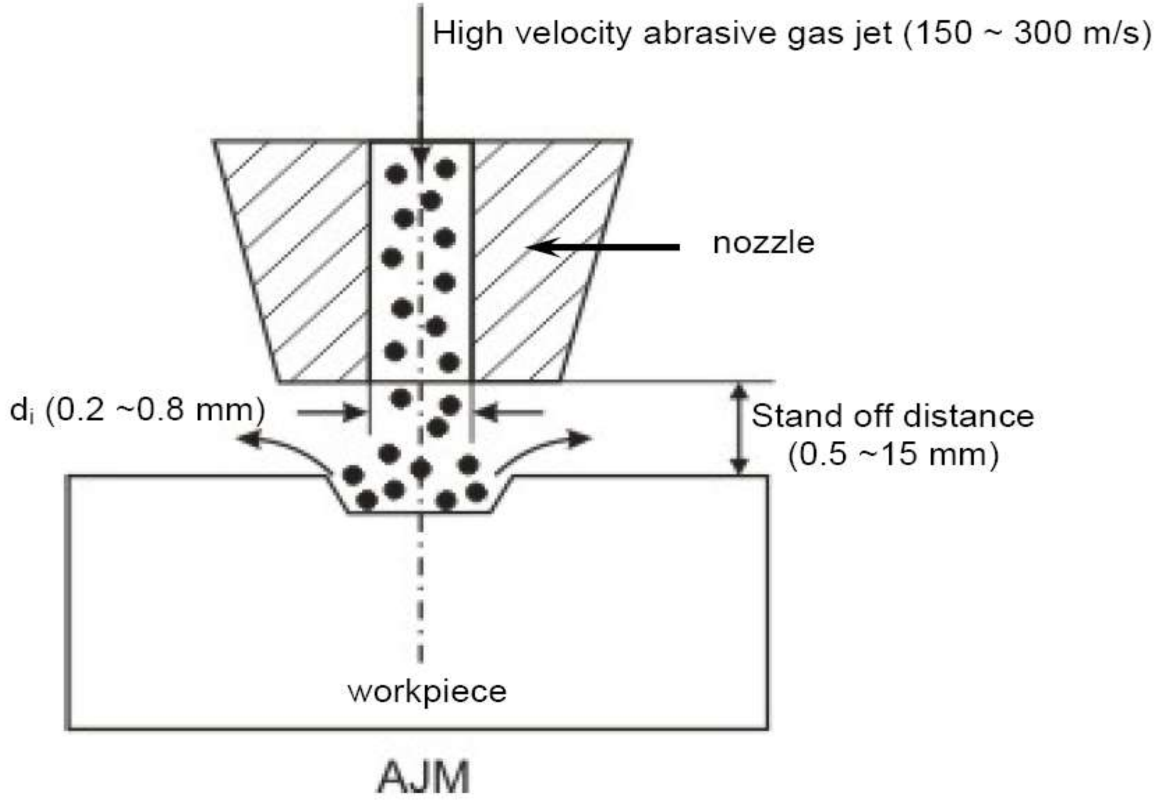
AJM is different from standard shot or sand blasting, as in AJM, finer abrasive grits are used and the parameters can be controlled more effectively providing better control over product quality.



Schematic diagram of AJM Process

Mechanism of material removal

The high velocity stream of abrasive is generated by converting the pressure energy of the carrier gas or air to its kinetic energy and hence high velocity jet. The nozzle directs the abrasive jet in a controlled manner onto the work material, so that the distance between the nozzle and the work piece and the impingement angle can be set desirably. The high velocity abrasive particles remove the material by micro-cutting action as well as brittle fracture of the work material.

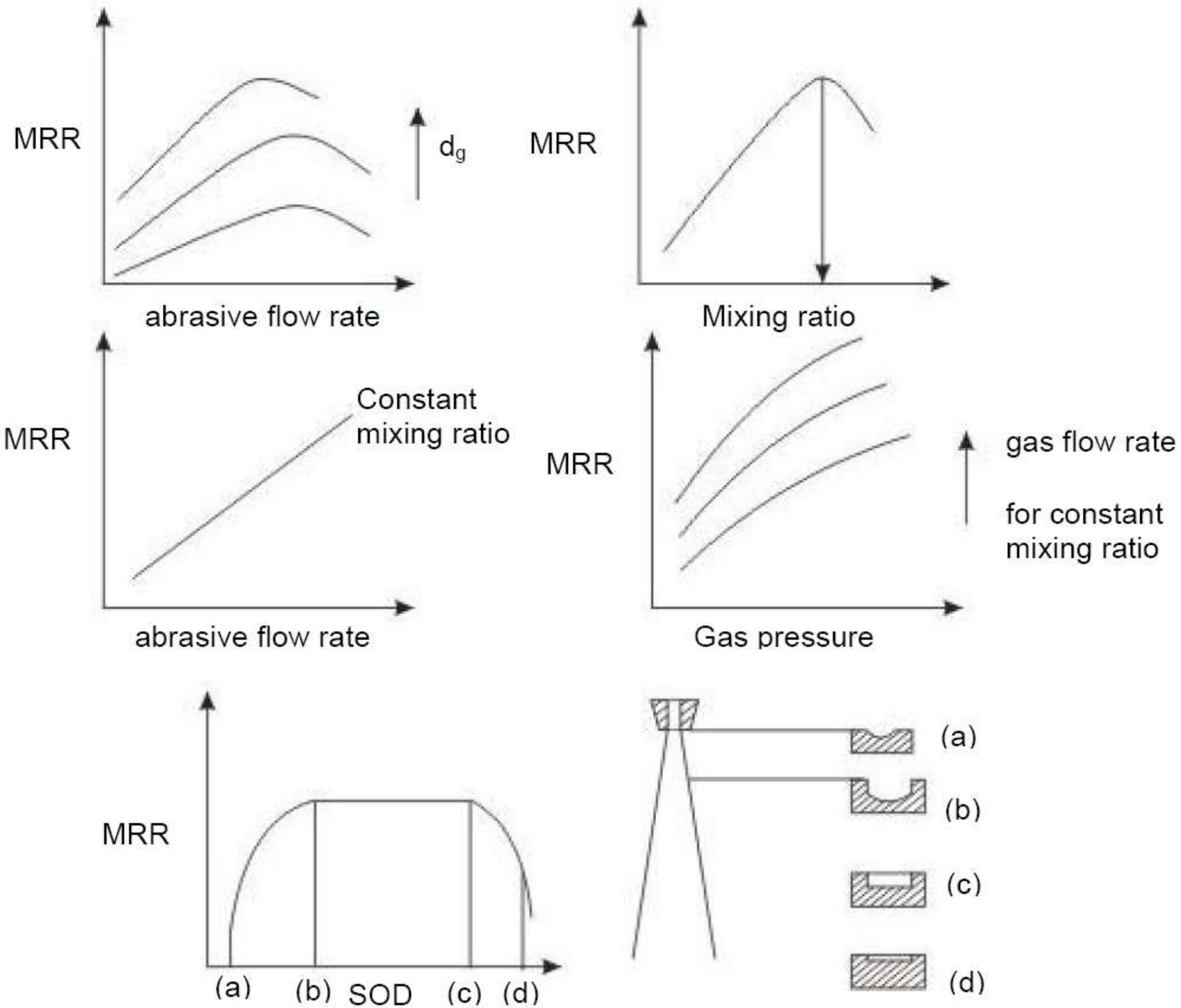


Schematic representation of AJM

Process parameters

- Carrier gas
  - Composition – Air, CO_2, N_2
  - Density – Air ~ 1.3 kg/m^3
  - Pressure – 2 ~ 10 bar
  - Flow rate – 5 ~ 30 gm/min
- Abrasive
  - Material – Al_2O_3 / SiC / glass beads
  - Shape – irregular / spherical
  - Size – 10 ~ 50 μm
  - Mass flow rate – 2 ~ 20 gm/min
- Abrasive Jet
  - Velocity – 100 ~ 300 m/s
  - Mixing ratio – mass flow ratio of abrasive to gas
  - Stand-off distance – 0.5 ~ 5 mm
  - Impingement Angle – 60^0 ~ 90^0
- Nozzle
  - Material – WC / sapphire
  - Diameter – (Internal) 0.2 ~ 0.8 mm
  - Life – 10 ~ 300 hours

Effect of Process parameters on MRR



Modelling of material removal

Material removal in AJM takes place due to brittle fracture of the work material due to impact of high velocity abrasive particles

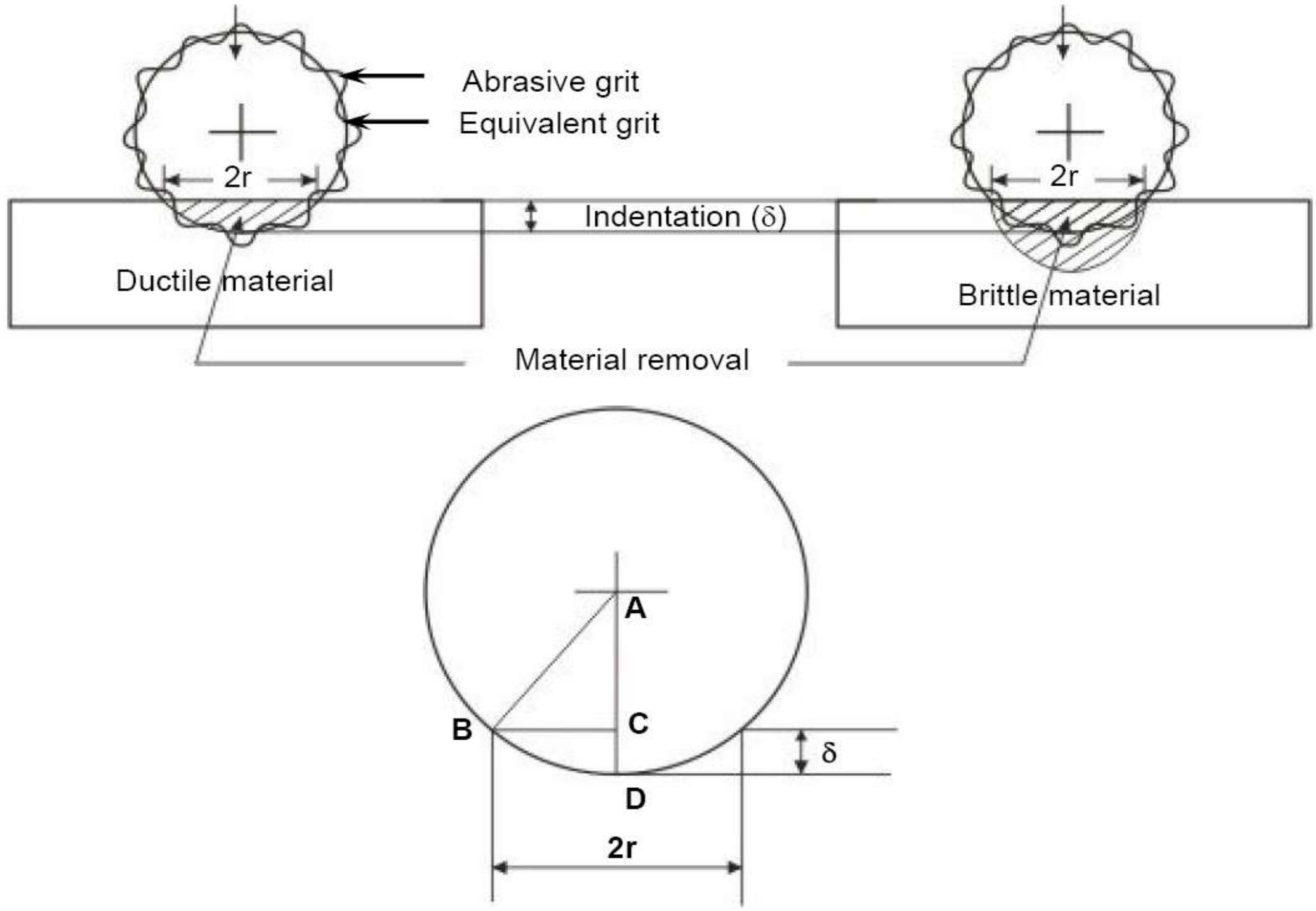
Assumptions:

(i) Abrasives are spherical in shape and rigid. The particles are characterised by the mean grit diameter

(ii) The kinetic energy of the abrasives are fully utilised in removing material

(iii) Brittle materials are considered to fail due to brittle fracture and the fracture volume is considered to be hemispherical with diameter equal to chordal length of the indentation

(iv) For ductile material, removal volume is assumed to be equal to the indentation volume due to particulate impact.



Interaction of the abrasive particle and the work material in AJM.

From the geometry of the indentation

$$AB^2 = AC^2 + BC^2$$

$$BC^2 = r^2 = AB^2 - AC^2$$

$$r^2 = \left(\frac{d_g}{2}\right)^2 - \left\{\frac{d_g}{2} - \delta\right\}^2$$

$$r^2 = -\delta^2 + d_g\delta \cong d_g\delta$$

$$r = \sqrt{d_g\delta}$$

∴ Volume of material removal in brittle material is the volume of the hemispherical impact crater and is given by:

$$V_B = \frac{2}{3}\pi r^3 = \frac{2\pi}{3}(d_g\delta)^{3/2}$$

For ductile material, volume of material removal in single impact is equal to the volume of the indentation and is expressed as:

$$V_D = \pi\delta^2\left[\frac{d_g}{2} - \frac{\delta}{3}\right] = \frac{\pi\delta^2 d_g}{2}$$

Kinetic energy of a single abrasive particle is given by

$$K.E._g = \frac{1}{2} m_g v^2 = \frac{1}{2}\left\{\frac{\pi}{6} d_g{}^3 \rho_g\right\} v^2 = \frac{\pi}{12} d_g{}^3 \rho_g v^2$$

where, v = velocity of the abrasive particle

m_g = mass of a single abrasive grit

d_g = diameter of the grit

ρ_g = density of the grit

On impact, the work material would be subjected to a maximum force **F** which would lead to an indentation of 'δ'. Thus the work done during such indentation is given by

$$W = \frac{1}{2} F\delta$$

Now considering H as the hardness or the flow strength of the work material, the impact force (F) can be expressed as:

$$F = \text{indentation area x hardness}$$

$$F = \pi r^2 H$$

where, r = the indentation radius

$$\therefore W = \frac{1}{2} F\delta = \frac{1}{2} \pi r^2 H \delta$$

On impact, the work material would be subjected to a maximum force **F** which would lead to an indentation of ‘δ’. Thus the work done during such indentation is given by

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where, r = the indentation radius

$$\therefore W = \frac{1}{2} F\delta = \frac{1}{2} \pi r^2 H \delta$$

Now, as it is assumed that the K.E. of the abrasive is fully used for material removal, then the work done is equated to the energy

$$W = \text{K.E.}$$

$$\frac{1}{2} \pi r^2 \delta H = \frac{\pi}{12} d_g^{\,3} \rho_g v^2$$

$$\delta = \frac{d_g^{\,3} \rho_g v^2}{6 r^2 H} \qquad \textit{now } r = \sqrt{d_g \delta} \quad \Rightarrow r^2 = d_g \delta$$

$$\delta^2 = \frac{d_g^{\,2} \rho_g v^2}{6H}$$

$$\delta = d_g v \left(\frac{\rho_g}{6H} \right)^{1/2}$$

Now MRR in AJM of brittle materials can be expressed as:

$$MRR_B = V_B \times \text{Number of impacts by abrasive grits per second} = V_B N$$

$$MRR_B = V_B \frac{\dot{m}_a}{\text{mass of a grit}} = V_B \frac{\dot{m}_a}{\frac{\pi}{6} d_g^{\,3} \rho_g} = V_B \frac{\dot{m}_a}{\pi d_g^{\,3} \rho_g} \qquad as \; V_B = \frac{2\pi}{3}(d_g \delta)^{3/2}$$

$$= \frac{6x \frac{2\pi}{3}(d_g \delta)^{3/2} \dot{m}_a}{\pi d_g^{\,3} \rho_g} = \frac{4 \dot{m}_a}{\rho_g}\left(\frac{\delta}{d_g}\right)^{3/2}$$

$$MRR_B = \left(\frac{4 \dot{m}_a}{\rho_g}\right)\left(\frac{\delta}{d_g}\right)^{3/2}$$

$$as \quad \delta = d_g v \left(\frac{\rho_g}{6H}\right)^{1/2}$$

$$MRR_B = \frac{4 \dot{m}_a}{\rho_g} \cdot \left(\frac{d_g v}{d_g}\right)^{3/2} \left(\frac{\rho_g}{6H}\right)^{3/4}$$

$$MRR_B = \frac{4 \dot{m}_a v^{3/2}}{6^{3/4} \rho_g^{\,1/4} H^{3/4}} \approx \frac{\dot{m}_a v^{3/2}}{\rho_g^{\,1/4} H^{3/4}}$$

as $V_D = \dfrac{\pi \delta^2 d_g}{2}$ MRR for ductile material can be simplified as:

$$MRR_D = V_D N = V_D \frac{6\dot{m}_a}{\pi d_g^{\,3} \rho_g} = \frac{\pi \delta^2 d_g 6 \dot{m}_a}{2\pi d_g^{\,3} \rho_g}$$

$$MRR_D = \frac{6\pi\delta^2 \dot{m}_a}{2\pi d_g^{\,2} \rho_g}$$

$$as \quad \delta = d_g v \left(\frac{\rho_g}{6H}\right)^{1/2}$$

$$MRR_D = \frac{6\dot{m}_a d_g^{\,2} v^2}{2 d_g^{\,2} \rho_g}\left(\frac{\rho_g}{6H}\right)$$

$$MRR_D = \frac{1}{2}\frac{\dot{m}_a v^2}{H}$$

Applications

- For drilling holes of intricate shapes in hard and brittle materials
- For machining fragile, brittle and heat sensitive materials
- AJM can be used for drilling, cutting, deburring, cleaning and etching.
- Micro-machining of brittle materials
- Reproducing design on glass surface with the help of mask

Advantages

- Capability of cutting hole of intricate shape in hard materials
- Mechanical contact between tool and w/p is avoided
- High surface finish can be achieved
- Depth of surface damage is low
- Simple ,economical, low capital investment, low power consumption

Limitations

- MRR is rather low (around ~ 15 mm^3/min for machining glass)
- Abrasive particles tend to get embedded particularly if the work material is ductile
- Tapering occurs due to flaring of the jet
- Environmental pollution is rather high
- Abrasive particles can not reused
- High rate of nozzle wear

Numerical Problems

1. Estimate the material removal rate in AJM of a brittle material with flow strength of 4 Gpa . The abrasive flow rate is 2 gm/min, velocity is 200 m/s and density of the abrasive is 3 gm/cc.

Solution

$$MRR_B \approx \frac{\dot{m}_a v^{3/2}}{\rho_g^{\;1/4} H^{3/4}} = \frac{\dfrac{2x10^{-3}}{60} x(200)^{3/2}}{(3000)^{1/4} x(4x10^9)^{3/4}}$$

$$MRR_B = 8x10^{-10} m^3 / s = 8x10^{-1} x60 \quad mm^3 / s \cong 48 \quad mm^3 / \min$$

2. Material removal rate in AJM is 0.5 mm³/sec. Calculate material removal per impact if mass flow rate of abrasive is 3 gm/min, density is 3 gm/cc and grit size is 60 μm as well as indentation radius.

Solution

$$Mass\ of\ grit = \frac{\pi}{6} d_g{}^3 . \rho_g$$

$$\therefore No.\ of\ impact\ /\ time = \frac{\dot{m}_a}{\frac{\pi}{6} d_g{}^3 \rho_g} = \frac{6x\frac{3x10^{-3}}{60}}{\pi x\left(50x10^{-6}\right)^3 x3000}$$

N = 254648

$$\Gamma_B = \frac{MRR}{N} = \frac{0.5mm^3/s}{2546648/s} = 1.96x10^{-6} mm^3 = 1960 \mu m^3$$

$$\text{Indentation volume} = \frac{2}{3}\pi r^3 = 1960 \quad \mu m^3$$

$$\text{Indentation radius, } r \approx 9.78 \approx 10 \mu m$$

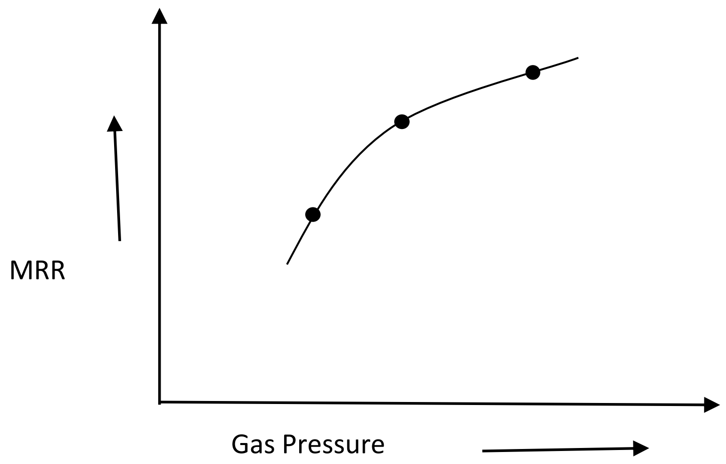
Quiz Question

1. AJM nozzles are made of
   (a) low carbon steel
   (b) HSS
   (c) WC
   (d) Stainless steel

2. Material removal in AJM of glass is around
   (a) 0.1 mm^3/min
   (b) 15 mm^3/min
   (c) 15 mm^3/s
   (d) 1500 mm^3/min

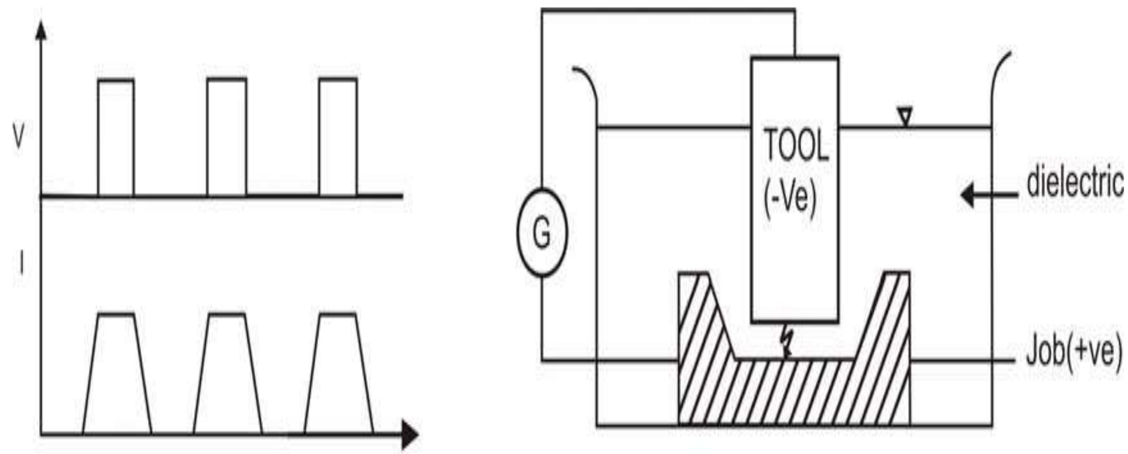
3. Material removal takes place in AJM due to
   (a) electrochemical action
   (b) mechanical impact
   (c) fatigue failure of the material
   (d) sparking on impact

4. As the stand off distance increases, the depth of penetration in AJM
   (a) increases
   (b) decreases
   (c) does not change
   (d) initially increases and then remains steady

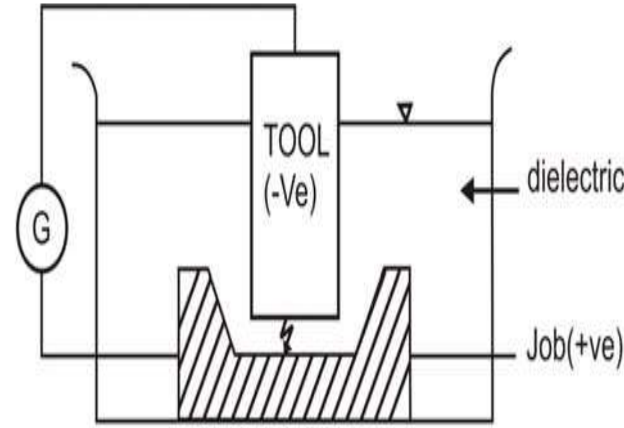

MRR
Gas Pressure

Electro Discharge Machining

- Electro Discharge Machining (EDM) is an electro-thermal non-traditional machining process, where electrical energy is used to generate electrical spark and material removal mainly occurs due to thermal energy of the spark.
- EDM is mainly used to machine difficult-to-machine materials and high strength temperature resistant alloys. EDM can be used to machine difficult geometries in small batches or even on job-shop basis.
- **Work material to be machined by EDM has to be electrically conductive.**

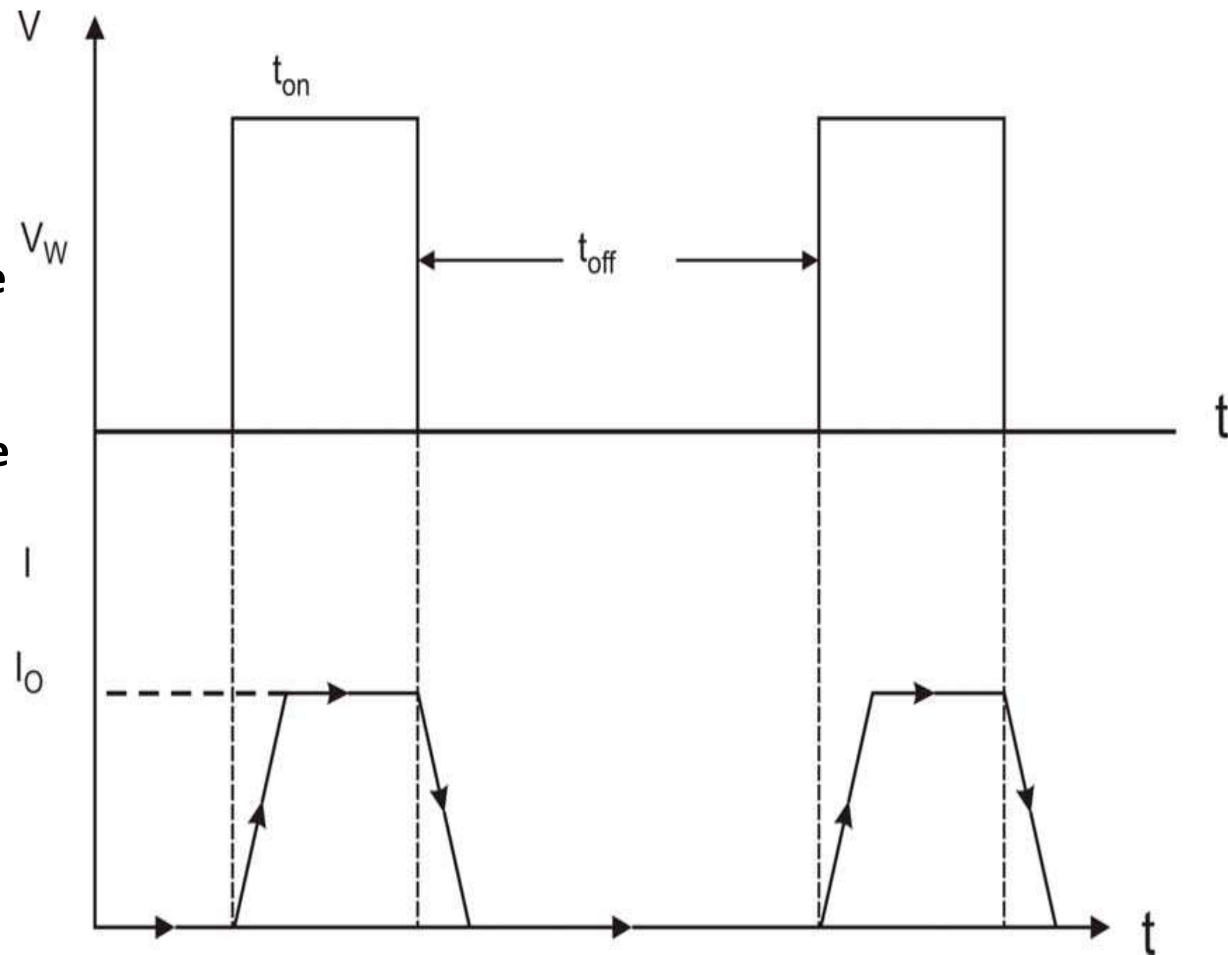


- A potential difference is applied between the tool and workpiece. Both the tool and the work material are to be conductors of electricity.
- Depending upon the applied potential difference and the gap between the tool and work piece, an electric field would be established.
- Generally the tool is connected to the negative terminal of the generator and the workpiece is connected to positive terminal.
- If the work function or the bonding energy of the electrons is less, electrons would be emitted from the tool. Such emission of electrons are called or termed as cold emission. they gain velocity and energy, and start moving towards the job, there would be collisions between the electrons and dielectric molecules. Such collision may result in ionisation of the dielectric molecule depending upon the work function or ionisation energy of the dielectric molecule and the energy of the electron.
- **"plasma"** formation ⇒ **Avalanche motion of electrons** ⇒ **Spark.**
- Intense localized heat flux leads to extreme instantaneous confined rise in temperature which would be in excess of 10,000^{o}C.
- Material removal occurs due to instant Vapourization of the material as well as due to melting.
- As the plasma channel collapse, it generates pressure or shock waves, which evacuates the molten material forming a crater of removed material around the site of the spark.
- The material removal in EDM mainly occurs due to formation of shock waves as the plasma channel collapse owing to discontinuation of applied potential difference.



The waveform is characterised by the

- The open circuit voltage - V_o
- The working voltage - V_w
- The maximum current - I_o
- The pulse on time – the duration for which the voltage pulse is applied - t_{on}
- The pulse off time - t_{off}
- The gap between the work piece and the tool – spark gap - δ
- The polarity – straight polarity – tool (-ve)
- The dielectric medium
- External flushing through the spark gap.



Characteristics of EDM

(a) The process can be used to machine any work material if it is electrically conductive
(b) Material removal depends on mainly thermal properties of the work material rather than its strength, hardness etc
(c) In EDM there is a physical tool and geometry of the tool is the positive impression of the hole or geometric feature machined
(d) The tool has to be electrically conductive as well. The tool wear once again depends on the thermal properties of the tool material
(e) Though the local temperature rise is rather high, still due to very small pulse on time, there is not enough time for the heat to diffuse and thus almost no increase in bulk temperature takes place. Thus the heat affected zone is limited to 2 – 4 μm of the spark crater
(f) However rapid heating and cooling and local high temperature leads to surface hardening which may be desirable in some applications
(g) Though there is a possibility of taper cut and overcut in EDM, they can be controlled and compensated.

Dielectric

- In EDM, material removal mainly occurs due to thermal evaporation and melting. As thermal processing is required to be carried out in absence of oxygen so that the process can be controlled and oxidation avoided.

- Oxidation often leads to poor surface conductivity (electrical) of the work piece hindering further machining. Hence, dielectric fluid should provide an oxygen free machining environment.

- Further it should have enough strong dielectric resistance so that it does not breakdown electrically too easily but at the same time ionise when electrons collide with its molecule. Moreover, during sparking it should be thermally resistant as well.
- Generally kerosene and deionised water is used as dielectric fluid in EDM.

- Dielectric medium is generally flushed around the spark zone. It is also applied through the tool to achieve efficient removal of molten material.

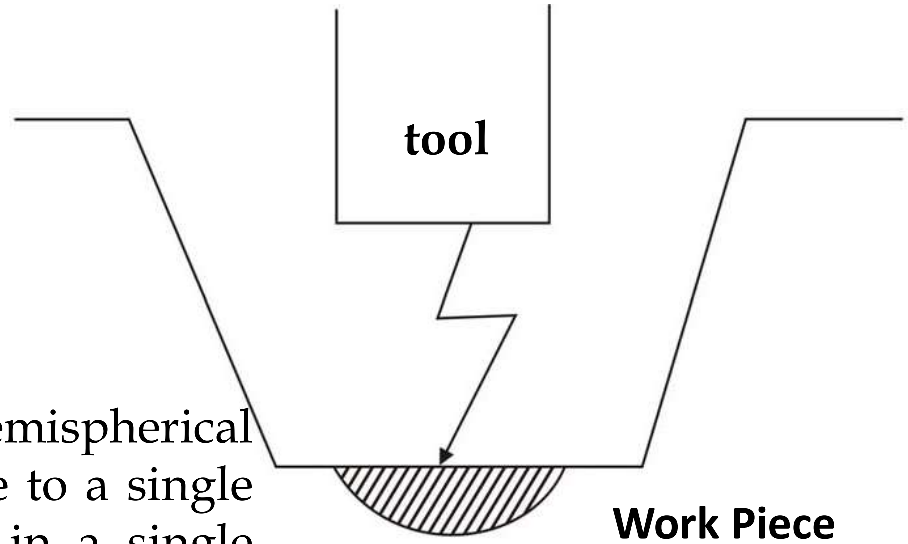
Electrode Material

Electrode material should be such that it would not undergo much tool wear when it is impinged by positive ions. Thus the localized temperature rise has to be less by tailoring or properly choosing its properties or even when temperature increases, there would be less melting. Further, the tool should be easily workable as intricate shaped geometric features are machined in EDM. Thus the basic characteristics of electrode materials are:

- High electrical conductivity – electrons are cold emitted more easily and there is less bulk electrical heating
- High thermal conductivity
- Higher density
- High melting point – high melting point leads to less tool wear due to less tool material melting for the same heat load
- Easy manufacturability
- Cost – cheap

Graphite
Electrolytic oxygen free copper
Tellurium copper – 99% Cu + 0.5% tellurium
Brass

Modeling of Material Removal



In EDM Material removal mainly occurs due to intense localized heating almost by point heat source for a rather small time frame. Such heating leads to melting and crater formation

The molten crater can be assumed to be hemispherical in nature with a radius r which forms due to a single pulse or spark. Hence material removal in a single spark can be expressed as

$$V = 2/3\pi r^3$$

Now, the energy content of a single spark is given as

$$E_s = VIt_{on}$$

A part of this spark energy gets lost in heating the dielectric, and rest is distributed between the impinging electrons and ions. Thus the energy available as heat at the workpiece is given by $E_w \alpha\ Es \Rightarrow E_w = KEs$

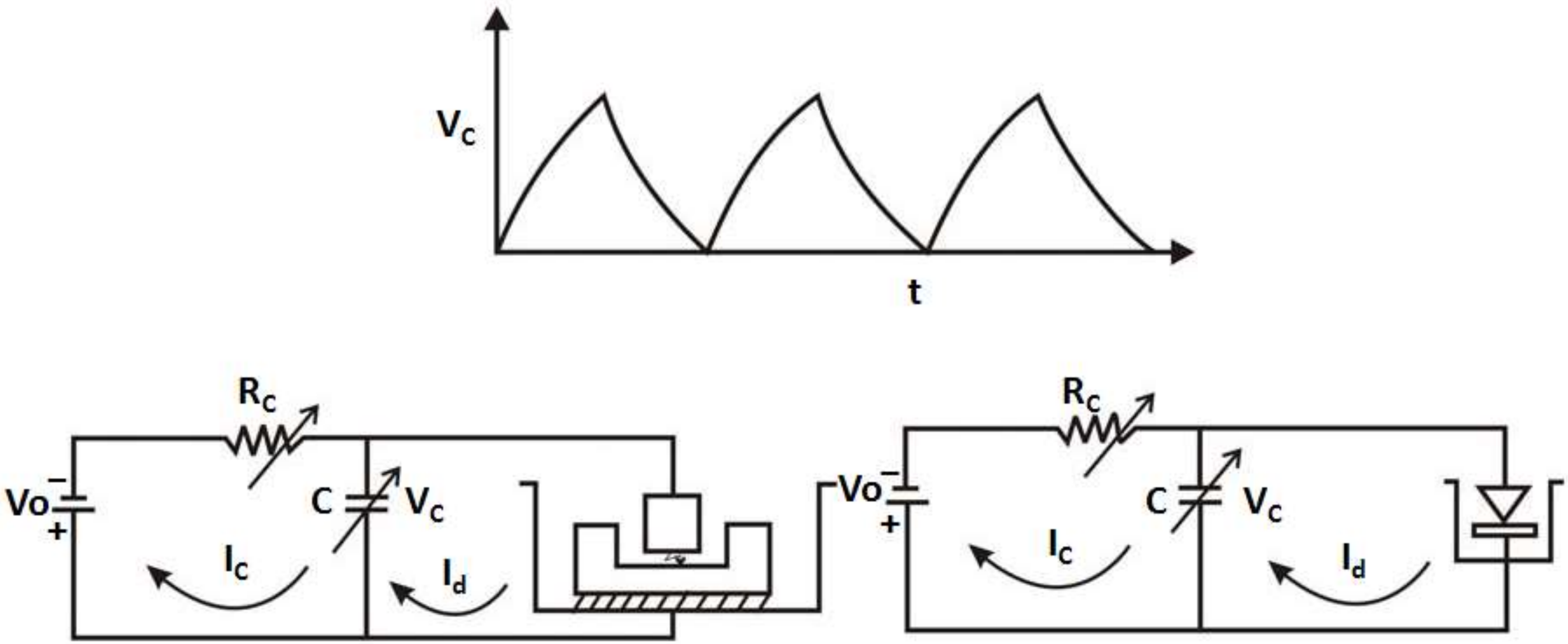
It can be logically assumed that material removal in a single spark would be proportional to the spark energy. Thus **$Vm\ \alpha\ E_w\ \alpha\ Es \Rightarrow Vm = gEs \Rightarrow Vm = g\ VIt_{on}$**

Now material removal rate is the ratio of material removed in a single spark to cycle time.

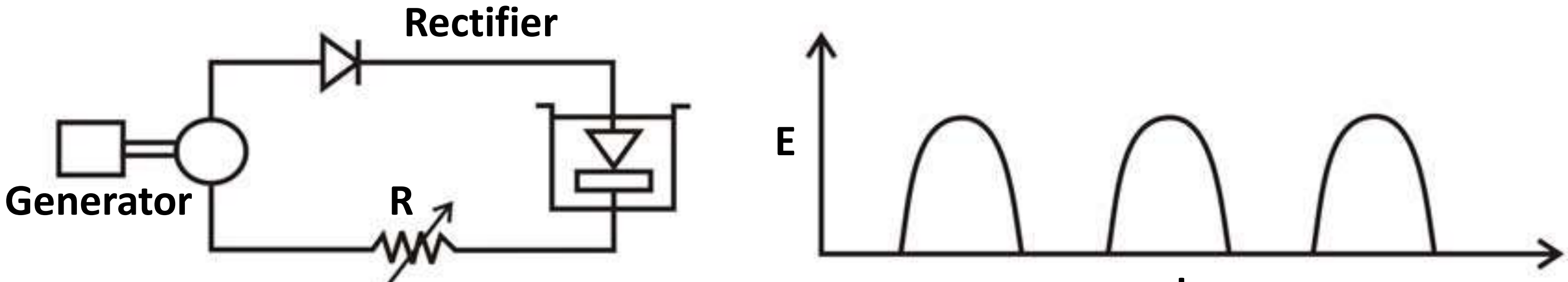
Thus MRR = $Vm/(t_{on} + t_{off})$ = **$g\ VIt_{on}/(t_{on} + t_{off})$**

Power generator

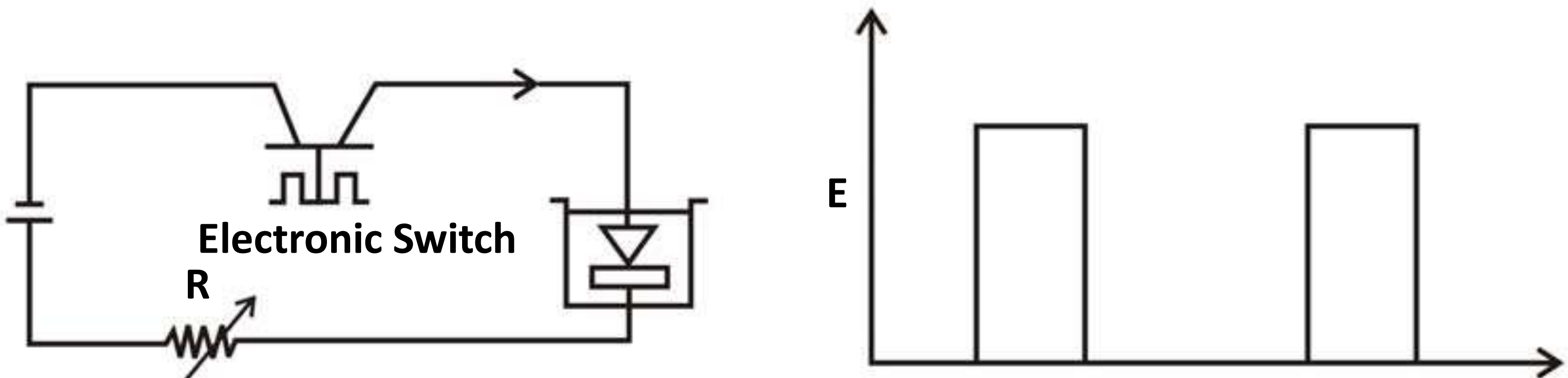
- Resistance-Capacitance type (RC type) Relaxation generator
- Rotary impulse type generator
- Electronic pulse generator
- Hybrid EDM generator



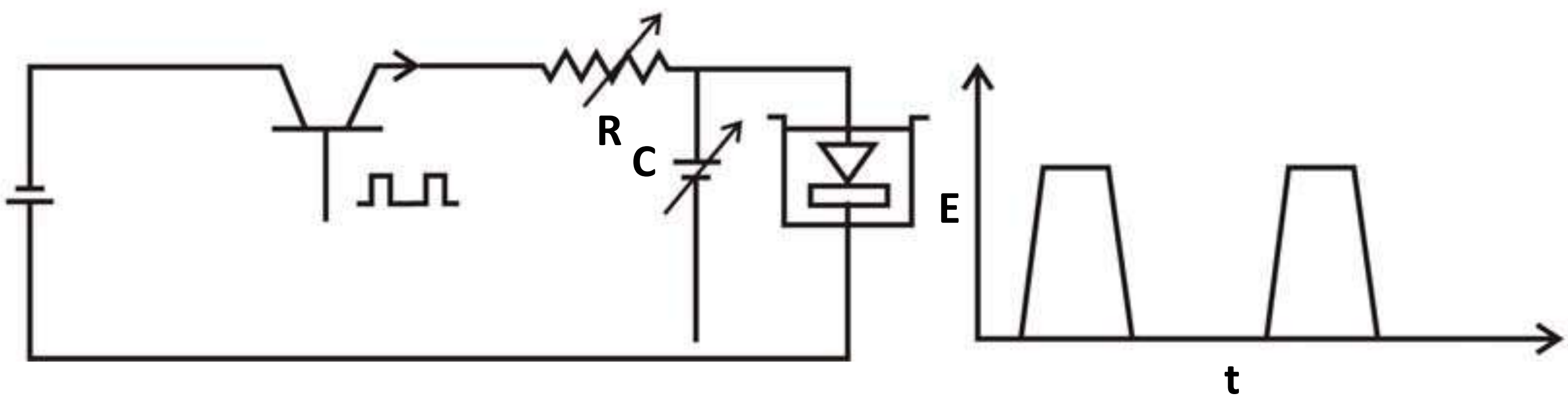
RC type Relaxation generator



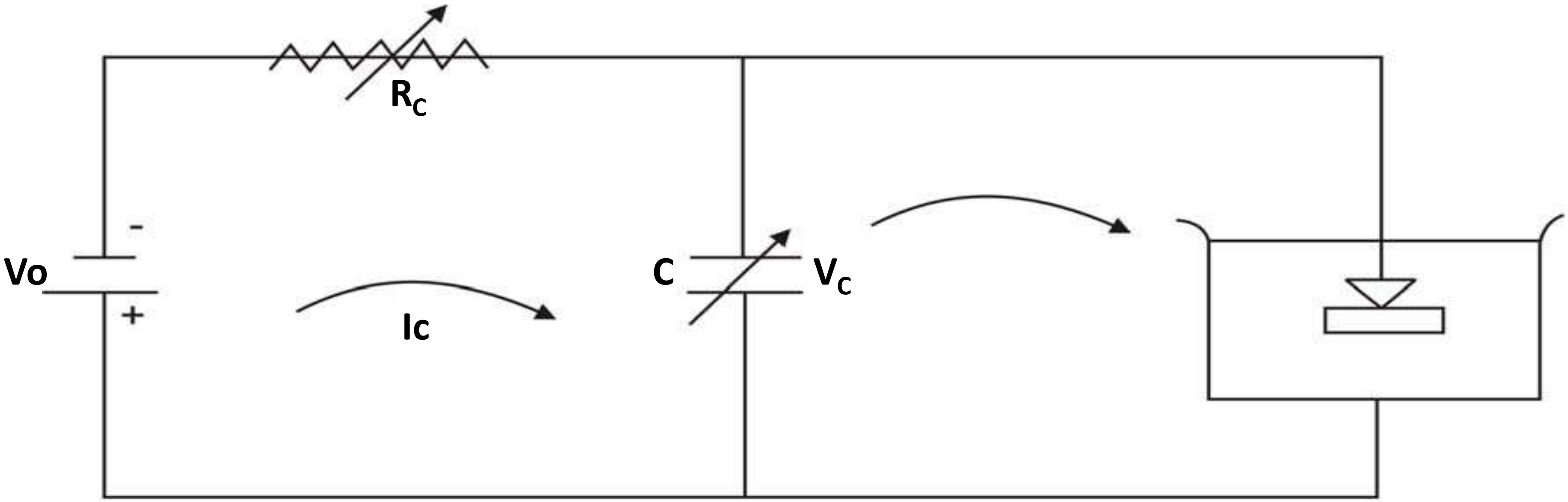
Rotary impulse generator with rectifier



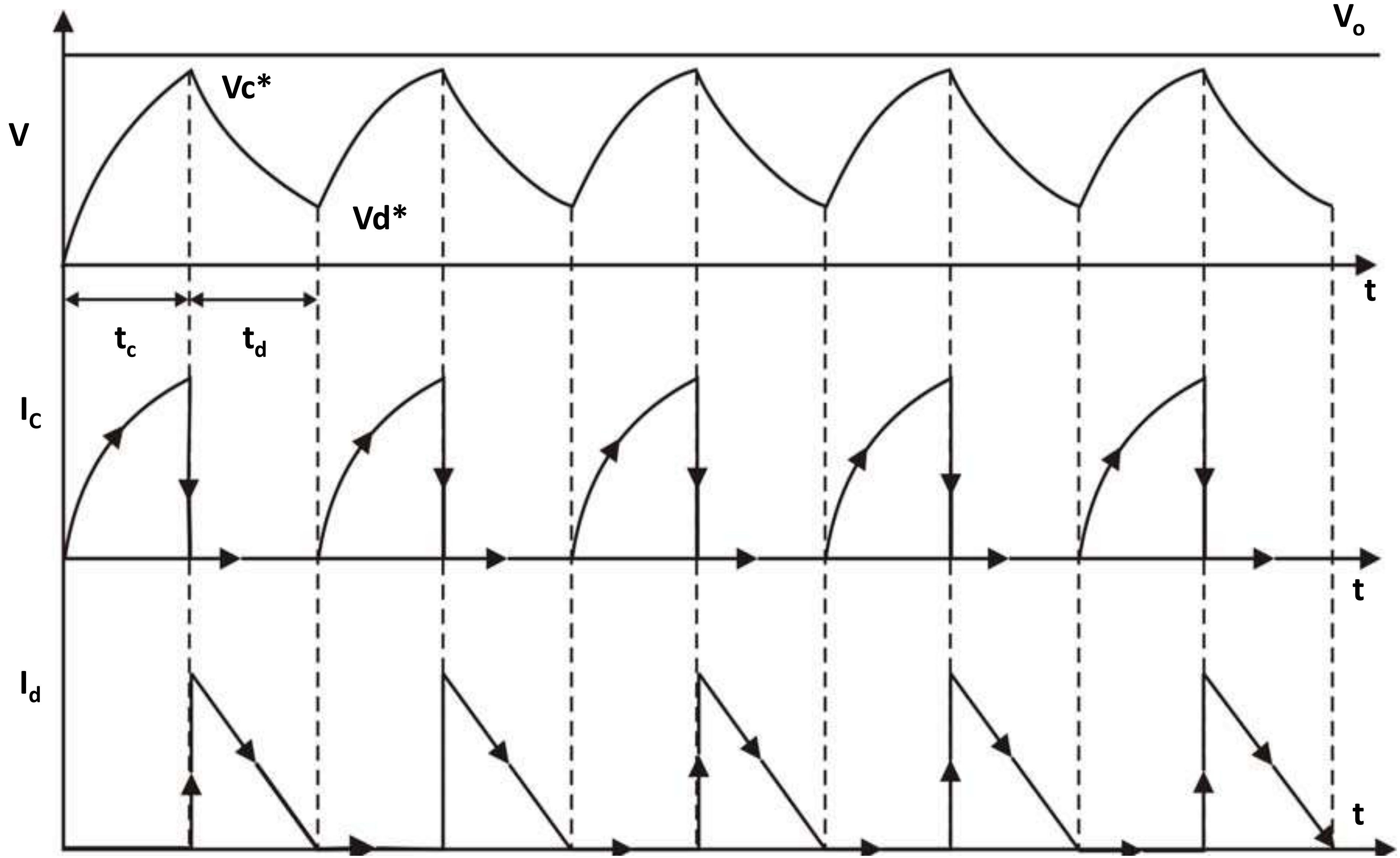
Electronic pulse generator



Analysis of RC type Relaxation EDM Generator



In RC type generator, the capacitor is charged from a DC source. As long as the voltage in the capacitor is not reaching the breakdown voltage of the dielectric medium under the prevailing machining condition, capacitor would continue to charge. Once the breakdown voltage is reached the capacitor would start discharging and a spark would be established between the tool and work piece leading to machining. Such discharging would continue as long as the spark can be sustained. Once the voltage becomes too low to sustain the spark, the charging of the capacitor would continue.



V
Vₒ
Vc*
Vd*
t
t_c
t_d
I_C
t
I_d
t

QUIZ

1. Which of the following material cannot be machined by EDM
   (a) steel
   (b) WC
   (c) Titanium
   (d) Glass ←

2. Which of the following is used as dielectric medium in EDM
   (a) tap water
   (b) kerosene ←
   (c) NaCL solution
   (d) KOH solution

3. Tool should not have
   (a) low thermal conductivity ←
   (b) high machinability
   (c) high melting point
   (d) high specific heat

1. **In a RC type generator, the maximum charging voltage is 80 V and the charging capacitor is 100 μF. Determine spark energy.**

2. **If in a RC type generator, to get an idle time of 500 μs for open circuit voltage of 100 V and maximum charging voltage of 70 V, determine charging resistance.**
Assume C = 100 μF.

3. **For a RC type generator to get maximum power dissipation during charging $V_c^* = V_o \times 0.716$. Determine idle time for $R_c = 10$ Ω and C = 200 μF**

4. **Determine on time or discharge time if $V_o = 100$ V and $V^{d*} = 15$ V. Spark energy = 0.5 J. Generator is expected for maximum power during charging.**
Machine resistance = 0.5 Ω.

DEFINE AUTOMATION

Automation is a technology concerned with the application of mechanical, electronic, and computer- based systems to operate and control production. This technology includes automatic machine tools to process parts, automatic assembly machines, industrial robots, automatic material handling and storage systems, automatic inspection systems for quality control, feedback control and computer process control, computer systems for planning, data collection and decision-making to support manufacturing activities.

Complicated systems, such as modern factories, airplanes and ships typically use all these combined techniques. The benefit of automation includes labor savings, savings in electricity costs, savings in material costs, and improvements to quality, accuracy, and precision.

TYPES OF AUTOMATION

Automated production systems can be classified into three basic types:

1. Fixed automation,
2. Programmable automation, and
3. Flexible automation.

Fixed Automation examples

FIXED AUTOMATION

It is a system in which the sequence of processing (or assembly) operations is fixed by the equipment configuration. The operations in the sequence are usually simple. It is the integration and coordination of many such operations into one piece of equipment that makes the system complex. The typical features of fixed automation are:

a. High initial investment for custom–Engineered equipment;
b. High production rates; and
c. Relatively inflexible in accommodating product changes.

The economic justification for fixed automation is found in products with very high demand rates and volumes. The high initial cost of the equipment can be spread over a very large number of units, thus making the unit cost attractive compared to alternative methods of production. Examples of fixed automation include mechanized assembly and machining transfer lines.

PROGRAMMABLE AUTOMATION

In this the production equipment is designed with the capability to change the sequence of operations to accommodate different product configurations. The operation sequence is controlled by a program, which is a set of instructions coded so that the system can read and interpret them. New programs can be prepared and entered into the equipment to produce new products. Some of the features that characterize programmable automation are:

a. High investment in general-purpose equipment;
b. Low production rates relative to fixed automation;
c. Flexibility to deal with changes in product configuration; and
d. Most suitable for batch production.

Automated production systems that are programmable are used in low and medium volume production. The parts or products are typically made in batches. To produce each new batch of a different product, the system must be reprogrammed with the set of machine instructions that correspond to the new product. The physical setup of the machine must also be changed over: Tools must be loaded, fixtures must be attached to the machine table also be changed machine settings must be entered. This changeover procedure takes time. Consequently, the typical cycle for given product includes a period during which the setup and reprogramming takes place, followed by a period in which the batch is produced. Examples of programmed automation include numerically controlled machine tools and industrial robots.

FLEXIBLE AUTOMATION

It is an extension of programmable automation. A flexible automated system is one that is capable of producing a variety of products (or parts) with virtually no time lost for changeovers from one product to the next. There is no production time lost while reprogramming the system and altering the physical setup (tooling, fixtures, and machine setting). Consequently, the system can produce various combinations and schedules of products instead of requiring that they be made in separate batches. The features of flexible automation can be summarized as follows:

1. High investment for a custom-engineered system.
2. Continuous production of variable mixtures of products.
3. Medium production rates.
4. Flexibility to deal with product design variations.

The essential features that distinguish flexible automation from programmable automation are:

1. the capacity to change part programs with no lost production time; and
2. the capability to changeover the physical setup, again with no lost production time.

These features allow the automated production system to continue production without the downtime between batches that is characteristic of programmable automation. Changing the part programs is generally accomplished by preparing the programs off-line on a computer system and electronically transmitting the programs to the automated production system. Therefore, the time required to do the programming for the next job does not interrupt production on the current job. Advances in computer systems technology are largely responsible for this programming capability in flexible automation. Changing the physical setup between parts is accomplished by making the changeover off-line and then moving it into place simultaneously as the next part comes into position for processing. The use of pallet fixtures that hold the parts and transfer into position at the workplace is one way of implementing this approach. For these approaches to be successful; the variety of parts that can be made on a flexible automated production system is usually more limited than a system controlled by programmable automation.

NEEDS / REASONS FOR AUTOMATION

Reasons for Automation in Manufacturing

1. ***Increased productivity:*** Automation of manufacturing operations holds the promise of increasing the productivity of labor. This means greater output per hour of labor input. Higher production rates (output per hour) are achieved with automation than with the corresponding manual operations.

2. ***High cost of labor:*** The trend in the industrialized societies of the world has been toward ever-increasing labor costs. As a result, higher investment in automated equipment has become economically justifiable to replace manual operations. The high cost of labor is forcing business leaders to substitute machines for human labor. Because machines can produce at higher rates of output, the use of automation results in a lower cost per unit of product.

3. ***Labor shortages:*** In many advanced nations there has been a general shortage of labor. Labor shortages stimulate the development of automation as a substitute for labor.

4. ***Trend of labor toward the service sector:*** This trend has been especially prevalent in India. There are also social and institutional forces that are responsible for the trend. There has been a tendency for people to view factory work as tedious, demeaning, and dirty. This view has caused them to seek employment in the service sector of the economy government, insurance, personal services, legal, sales, etc. Hence, the proportion of the work force employed in manufacturing is reducing.

5. ***Safety:*** By automating the operation and transferring the operator from an active participation to a supervisory role, work is made safer.

6. ***High cost of raw materials:*** The high cost of raw materials in manufacturing results in the need for greater efficiency in using these materials. The reduction of scrap is one of the benefits of automation.

7. ***Improved product quality:*** Automated operations not only produce parts at faster rates but they produce parts with greater consistency and conformity to quality specifications.

8. ***Reduced manufacturing lead time:*** With reduced manufacturing lead time automation allows the manufacturer a competitive advantage in promoting good customer service.

9. ***Reduction of in-process inventory:*** Holding large inventories of work-in-process represents a significant cost to the manufacturer because it ties up capital. In-process inventory is of no value. It serves none of the purposes of raw materials stock or finished product inventory. Automation tends to accomplish this goal by reducing the time a workpart spends in the factory.

10. ***High cost of not automating:*** A significant competitive advantage is gained by automating a manufacturing plant. The benefits of automation show up in intangible and unexpected ways, such as, improved quality, higher sales, better labor relations, and better company image. All of these factors act together to make production automation a feasible and attractive alternative to manual methods of manufacture.

Advance manufacturing & CAD/CAM

CH-1 - Non conventional M/C process

CH-2 - Automation.

CH-3 - Numerical control.

CH-4 - Robotic Technology.

CH-5 - FMS

CH-6 - CAD/CAM & CIM

~~TEXT~~ P

CH-3

Numerical Control

Instructional objective:-

After learning the lesson, Student will be able to

(a) Describe the main feature of CNC M/C.

(b) Describe its advantages (why we spent so much money on it)

(c) Explain the main features of parts programming.

(d) Draw the architecture of CNC drives there requirement.

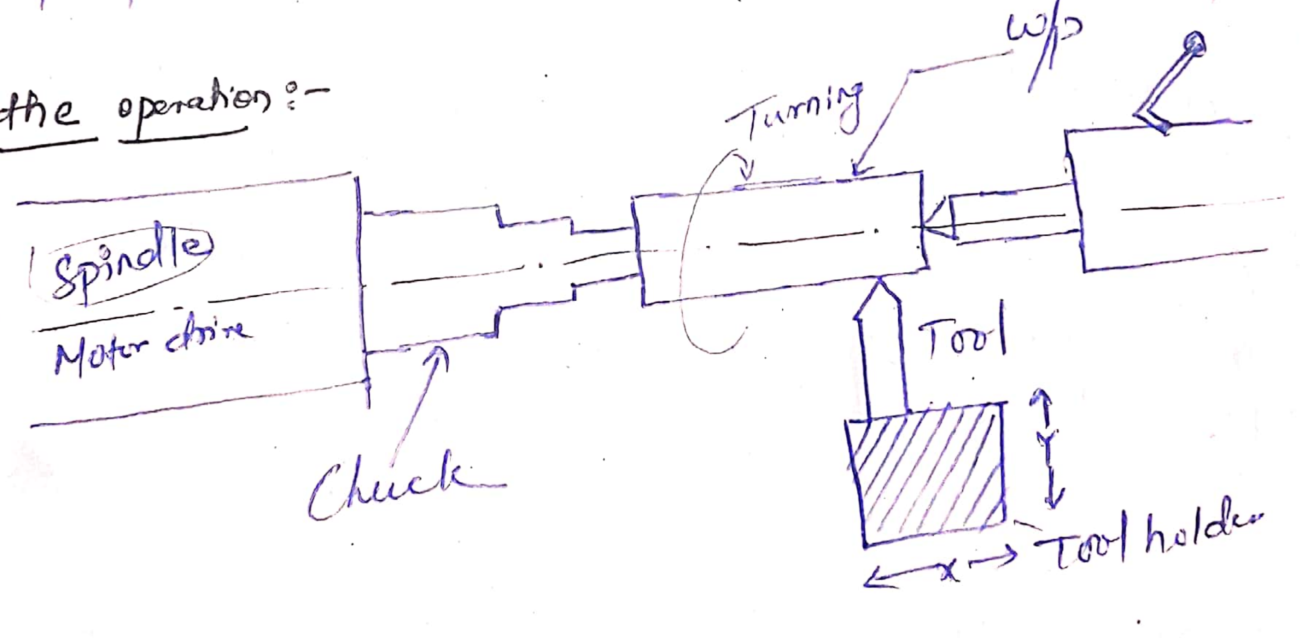
* As the machines are computer control, so it can be programmed. Like all machines CNC machines create motion. Actually they use drives.

The technology which generates the power and control for creating precise motion against heavy load.

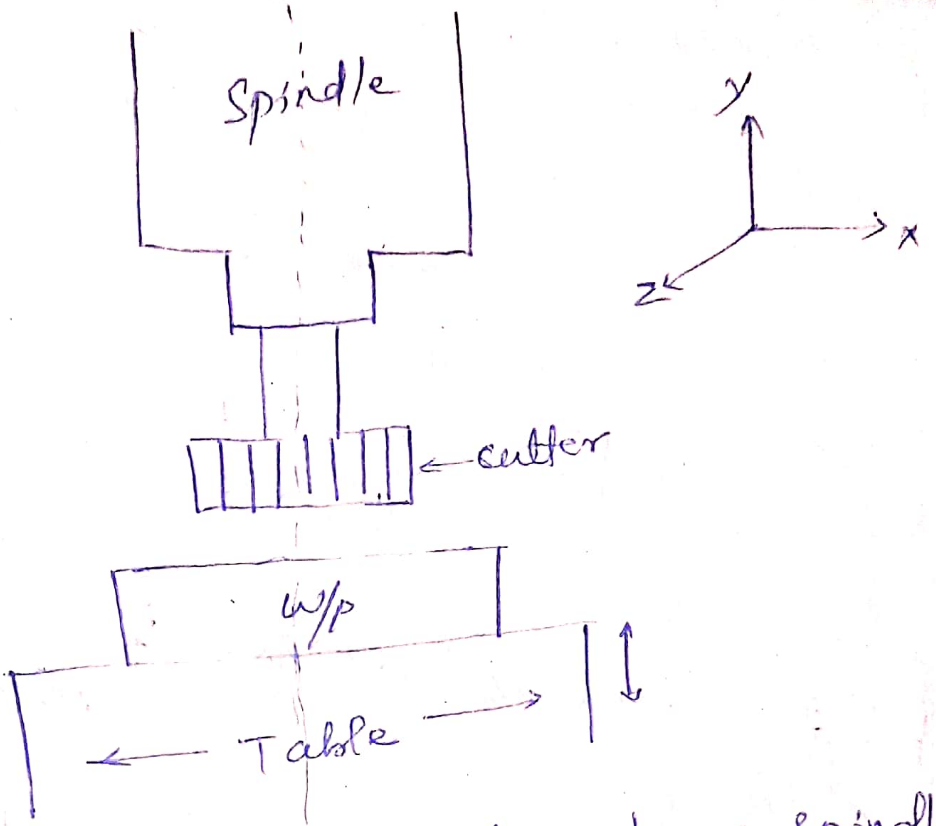
Machining process :-

The process of removing excess materials from a blank precisely, so that a part will process of specific geometry. Essentially it is a metal removal process; which means that it uses a specific tool; which made up of a certain material like carbide, diamond, CBN (cubic boron nitride). Essentially we have to produce releative motion between job & tool. There are various kinds of machining process. The most common one is turning (to using lathe machine). In this process job rotate (hold by a suitable chuck) power supplied by spindle. Tool moves in a linear direction (rectilinear motion)

Lathe operation :-



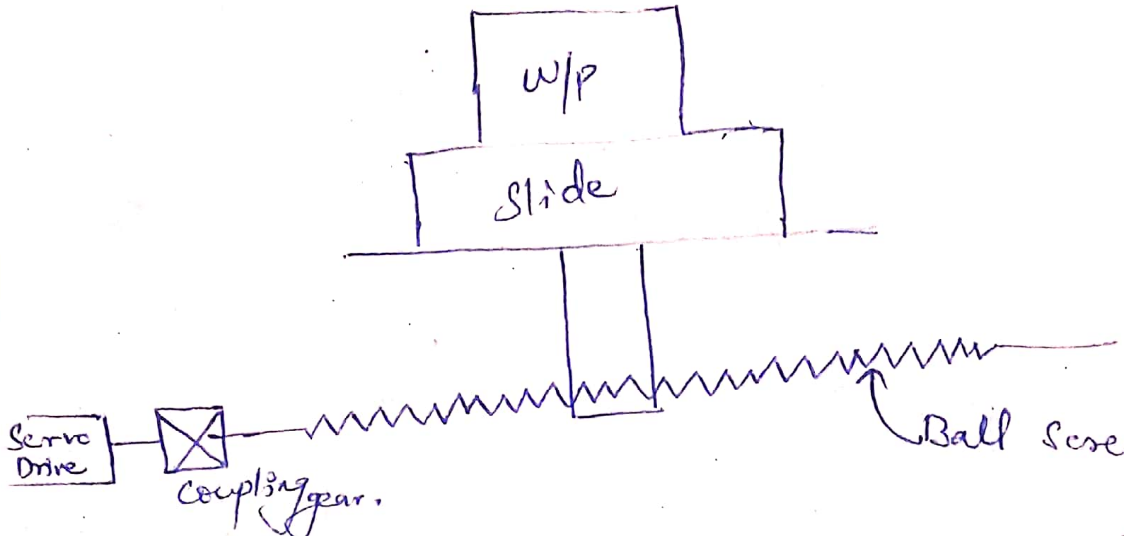
Milling



Cutter of milling m/c driven by a spindle, which get power from motor drived. The w/p here having rectilinear motion (x-y-z). So you can creat 3-D motion and cutter is revolving and steady at one place. So if ~~to~~ we compare turning and milling, In turning job rotate at high speed and in milling cutter (tool revolve at high speed).

Drilling:-

In drilling w/p move in a 2D plane tool rotate at a high speed about its own axis and in the same time it move in a straight line to make a hole. It shows any metal cutting m/c requires motion for tool and w/p. and this motions have to be very precise. Speed, feed & Depth of cut are cutting parameters which must be maintain during machining. The idea is to put precise motion against heavy load.



Here the w/p is resting upon the slide and moved in 2D plane here we see how the movement is created. The rotating or rotation is actually very very simple obviously it just connected to the shaft of the drive motor. So as the motor rotates the tool in the case of milling or the w/p of the chuck in the case of turning will rotate. thats very simple for creating 2D motion of the table this kind of mechanism is created; where there is a provision of slide. Here we are only showing the motion of slide in one direction. In this direction slide can move along this. Because it is connected to a ball screw so the drive is still a motor, which is coupled to a ball screw may be through a gear. So as the ball screw rotate, this slide can move in either direction, just like a screw motion the ball screws are very well designed such that there the precise motion is created and things like back lash which affect the accuracy of manufacturing are minimized. That can be minimized by engineering designed.

29-01-2020

Features of machines:-

① Rotational motion:- created by spindle drive

② Linear motion - created by Table drive.

In a table drive, Basically the drive is rotational and that motion is converted to linear motion by ball screw, Generally ball screw gives better accuracy.

③ Guide ways:-
so that there are no transverse motion. a Motion are strickly in the linear direction, in which the drive is provided.

④
Drives that are generally provide are servo motor drive, because we need to have precise motion controlled. and we need to have good transient respond. So therefore they have to Start & Stop at the right moment. Sometimes Speed ratio have to maintain along the two axis. ~~Sometimes~~ for cutting the things like surfaces, Cylinder surfaces, cutting corners. So we employed Servomotor drives, DC drive, Ac drive, stepper motor drive, for very large m/c we need hydraullic drive also.

Generally we employed DC & AC drive. For very small things Stepper drive are used. But they are generally not of that high rating. Mostly Bh DC (Brush less) drive used.

⑤ Feedback:-

Naturally you need feedback. Digital feedback like shaft encoders, resolvers, sometime you can have possition sensors, like LVDTS (linear variable differential transformers), potensometer etc. So you need basically creat rotational or liner motion, precise motion. So you need precise drive created by motors. Speed and possitioned feedback provided by the sensors. and similarly you have mechanical arrangement which creat precise motion ball screw etc. So these are the major part in the M/c. Also there are several auxilliary part like, for example there is very high heat generation at the tool, w/p interface. So there is cooling media or Coolend has to be applied (liquid coolant) directly at the tool job interface So that the interface donot heated up. That will affect the quality of machining. So theres is a coolant and all kind of other things like for automation there are whole automation setup, somebody can enter programme, so there is an operator display, all kinds of protection mechinism so they are auxilliary components.

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CNC Machines :-

N.C. machine :-

NC machine was developed in 1950's, it was understood that there is a lot of things to be gain if we can control the m/c precisely using digital techniques and finally by computer. like components specially microprocessor, can interfaced to it. So this kind of controllers will lead to very precise control of the m/c; which is not possible by a manual operator.

⇒ CNC systems developed in 1970's. So it was soon realize that this system can led to very quality engineering & also reduce unproductive time.

Numerical Control :-

"A system in which actions are controlled by direct insertion of numerical data at some point. The system must automatically interpret atleast some portion of this data. So even if you don't have a computer, you can have a papper punch cardreader, there were early, the version of CNC version."

⇒ Even if you have a paper tape, which is punched and there should be a paper tape reader and that reader is to creat the motion. So even if there is no expleet electronic computer, here also in the paper tape you are there is some numeric data which is punched & accordingly to that numeric data the m/c was controlled. that is It is called NC.

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But in mordern m/c this thing don't exist at all. Modern m/c are all computer controlled. So basically computer numerically controlled mean that computer control. So basically computer numerically control means that computer control. So it generally be a microprocessor, it may be a industrial PC, some time there will PLC (Progrmibble logical control) So various kinds industrial computers are used.

⇒ NC replaces the manual action of operators.

⇒ part programme describe the activities which are interpreted and executed by the m/c. So the instruction to the m/c which are required for its operation are written in the form of kind of Programme; called part programme.

Fundamental concept classification and Structure of NC:

A machine tool is said to be numerically controlled if it operated in a semi-automatic or automatic cycle as per instruction transmitted to it in a coded form. It is obvious that numbers by themselfs can cannot do any work, leave aside operating a m/c. A comprehensive electrical, electronics and metallical processing and transmission system is required to affect the movement of a slide or cutting tool from information coded on a programme medium, Such as a punch card, punch tape, magnetic tape etc.

⇒ The elements of numerical control systems and their operating principle will be described, starting with the example of turning.

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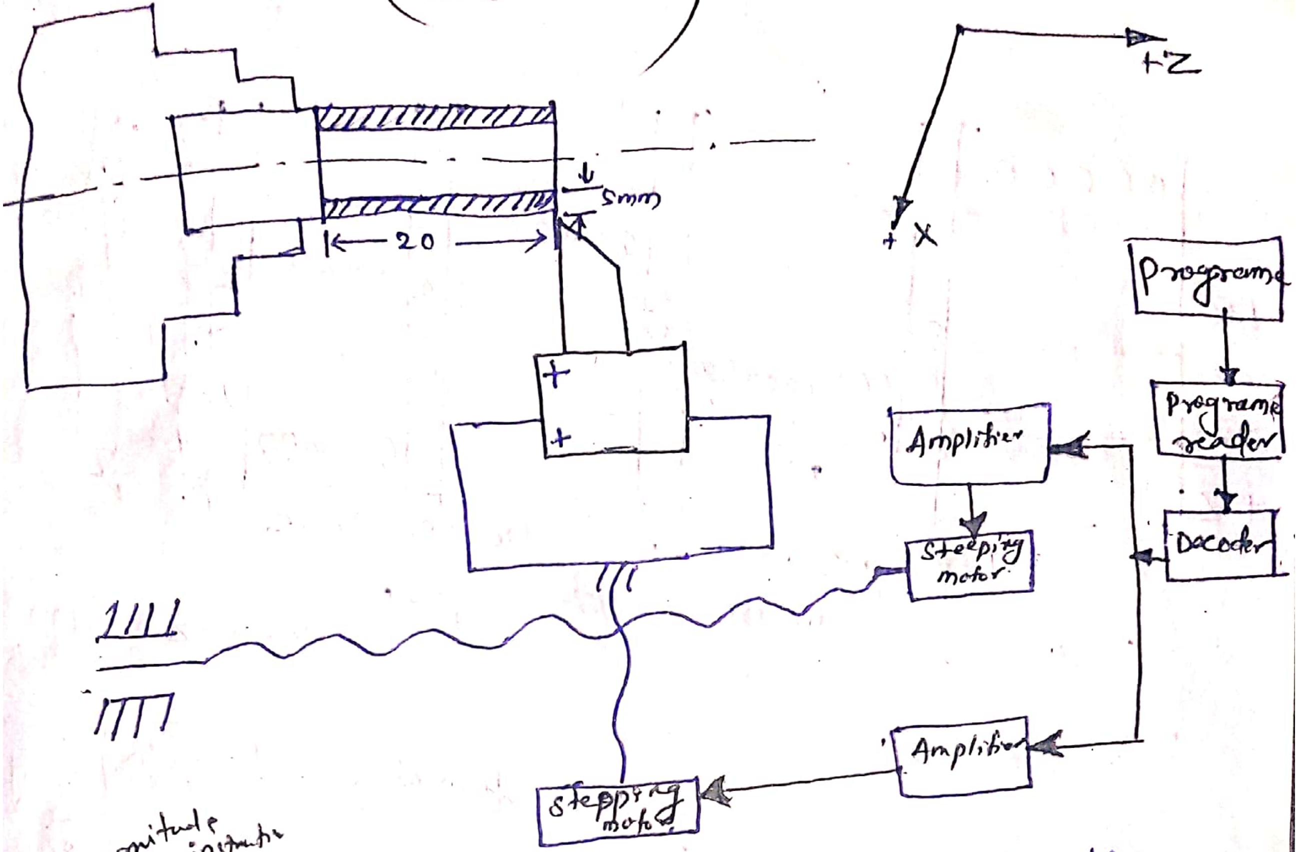
(figure - 1)



path magnitude instruction

For complete machining cycle it would envolve the following motion.

1. Travel of the tool post -X dirⁿ through 5mm.
2. Travel of the tool post -z dirⁿ through 25mm.
3. Travel of the tool post +X dirⁿ through 5mm.
4. Travel of the tool post +Z dirⁿ through 25mm.

switch instruction sp.

It may be seen that the instruction for executing the motion are of two types.

(i) path magnitude instruction.
(ii) Switching instruction. (Spindle speed, coolant on/off, tool change etc)

(punch Tape)

1.1 programme in unit pulse code for the component of fig. 1.

STOP -Z 25STOP

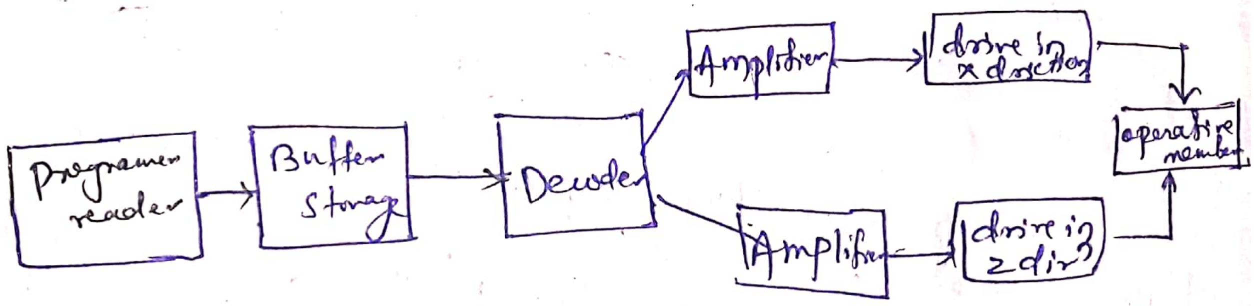


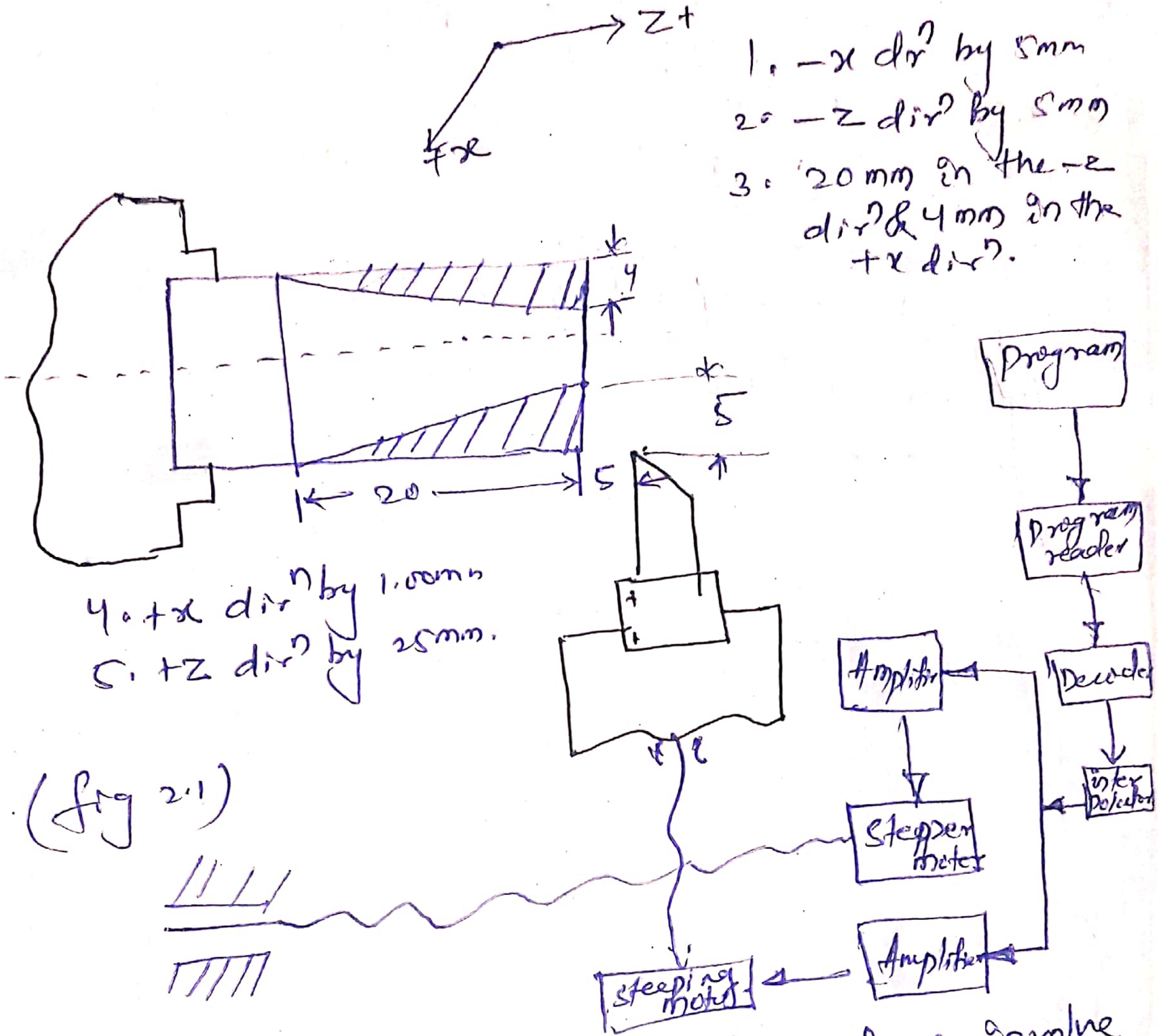
fig 1.2. Block diagram of an NC an NC lathe for simple operation.

The set of instruction between two stop command contains the neccessary information for executing a particular motion. This is known as a sentance i.e. stop-z25 stop constitute a sentance. The sentance consists of words (stop), symbols (- sign), letters (z) and numericals (25). while machining with instructions are being carried in accordance the information contain a particular sentance, the information contain in the next sentance is read and storeded temporily in a memory device, known as buffer

Storage. when the operation has been completed the information from buffer storage is instantaneously transfer to the active storage, thus ensuring continuous running of the programe.

e.g. Let now consider the example of a taper turning operation which is shown in the machining fig 2.1. The motion involve in the cycle are.

1. −x dirⁿ by 5mm
2. −z dirⁿ by 5mm
3. 20mm in the −z dirⁿ & 4mm in the +x dirⁿ.
4. +x dirⁿ by 1.00mm
5. +z dirⁿ by 25mm.



(fig 2.1)

The generation of the tapered surface involve simultaneous movement of the tool in −z & +x direction such that

(i) The movements in both direction start simultaneously.
(ii) The displacement through 4mm in the positive +x direction takes exactly the same time as the displacement through 20mm in the −z direction
(iii) The second requirement presages that the two direction stepping motor pulse rates in the (and they control the corresponding feeds) would be different & would depend upon profile or countour being machined. The task of calculating the feed rate of simultaneous

movement and there co-ordination is done by a control element known as the interpolator.

→ The interpolator is basically a microprocessor and is an essential part of NC systems for machining profile and countours involving two or more simultaneous motion.

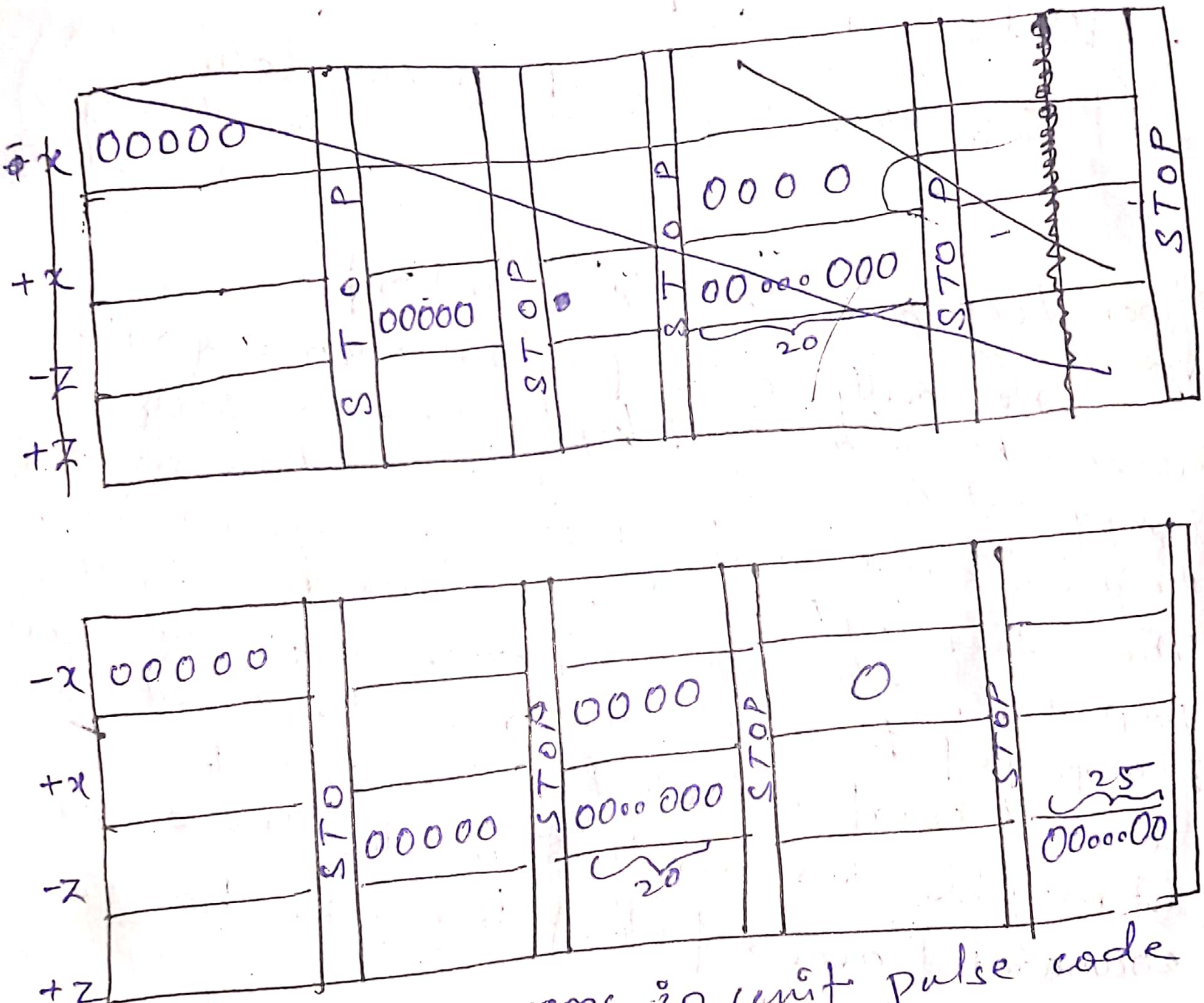
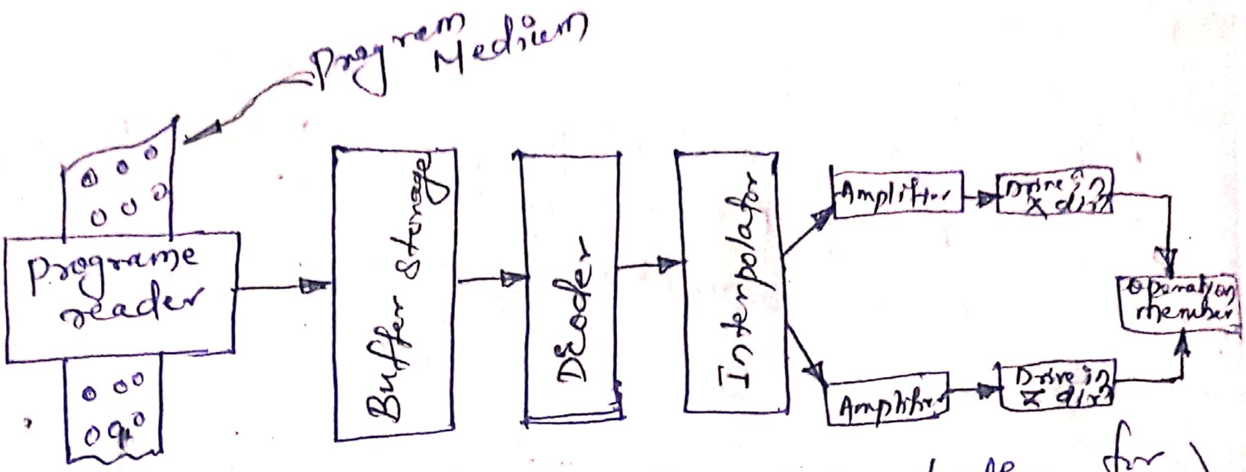


fig.(2·2) Programs in unit pulse code for component fig 2·1 (Punch tape for taper turning operⁿ as shown in fig 2·1)

⇒



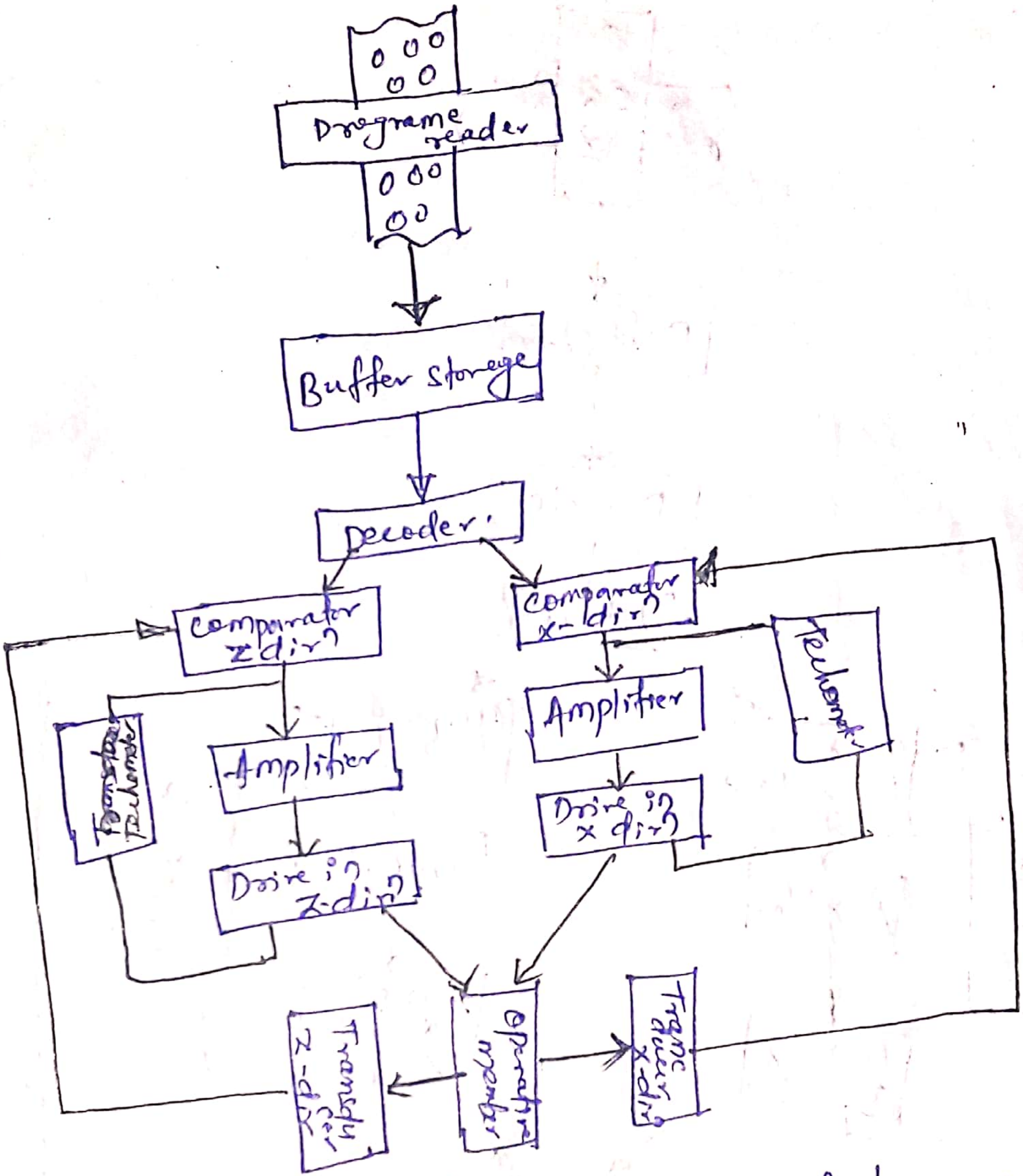
(fig 2.3 Block diagram of an NC lathe for taper turning)

Open Loop and closed loop system :-

Numerically controlled system with a feedback device are known as closed loop system. The feedback arrangement consist of a transducer which monitors the actual displacement of the operative member. The actual displacement is compared with the programmed displacement and the difference signal is employed to actuate the drive motor untill the command signal and actual position coincide.

It may be thus seen that besides the six element enumerated above. A closed loop system has two additional element.

1. Program Reader
2. Buffer storage
3. Decoder
4. Interpolator.
5. Amplifier
6. Drive
7. Transducer (A displacement measuring / monitoring device)
8. A comparator



(figure 3.1. Block diagram of closed loop NC system for an simple turning.)

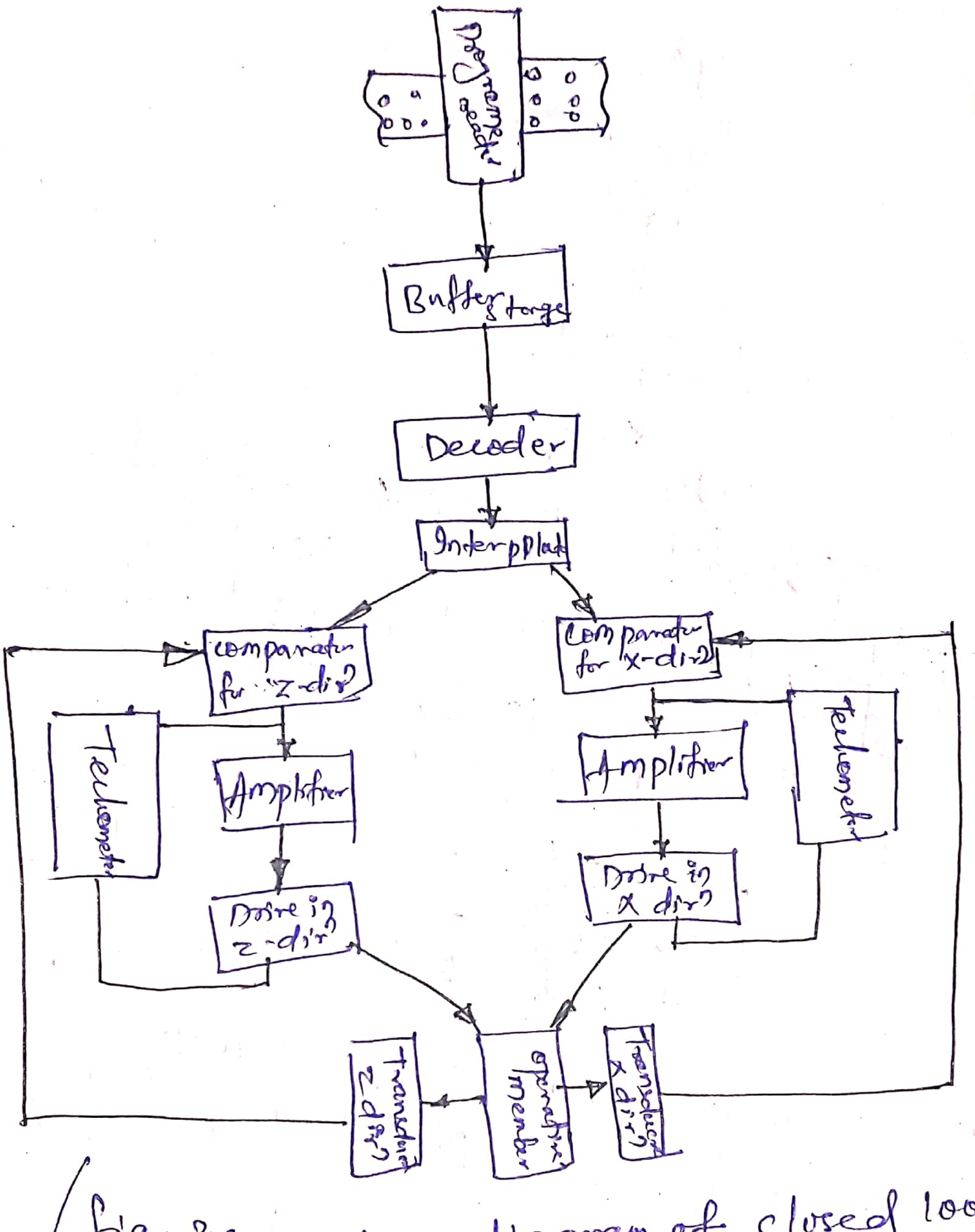


fig. 3.2. Block diagram of closed loop NC system for an taper turning oper

~~1. According to~~

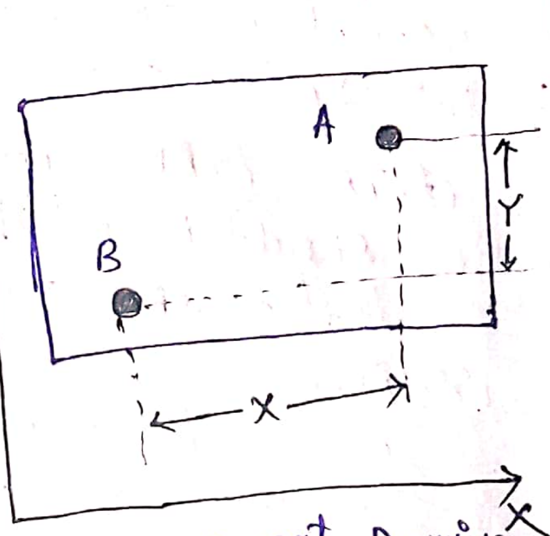
point to point (positioning) & ~~countour~~ continuous path (contouring) system

Depending upon the type of function assigned to the machined tool, control system are classified as

1. P-T-P or positioning c.system.
2. positioning-cum-straight cut system
3. Continuous-path or contouring system.

① P-T-P :-

In P-T-P systems, the table (or spindle) is moved by numerical control from one defined location to another. Suppose a hole is being drilled at position A (as shown in fig) after this hole has been drilled and the drill are track out of contact with the W/P, It is necessary to move the table so that point B occupies the working position under the spindle presently occupied by point A. It may be thus seen that in PTP C.S, there needn't be any co-ordination between the movements in the two dirn. The only requirement is that the table should move to the desired location, irrespective of the path. An important feature of these systems is that the cutting tool is not in contact with the W/P when the positioning movement is being executed.



component Drawing

→ P-T-P c.s is generally applied in drilling & boring m/c.

→ Hole punching m/c, spot welding m/c & assembly m/c also use of PTP NC system.

② positioning-cum-straight cut system :-

The systems are basically positioning system with the additional capability of cutting along straight lines parallel to the co-ordinate axis, such as milling of slots or grooves. The important features of this systems are

(i) The table speed during machining operation should be equal to the feed rate and not that of the accelerated travel.

(ii) During the machining operation the simultaneous movement along the co-ordinate axis cannot be co-ordinated. However, in some machine, it is possible to use both feeds simultaneously, thereby making it possible to take cuts at 45° to the co-ordinate axis.

(iii) The feed motor should have a higher capacity than the feed motor of a positioning system.

→ This type of C.S is generally applied in milling m/c & simple lathe. It permits the machining of rectangular block & straight grooves and machining of (turning) of cylindrical workpiece with perpendicular shoulder.

③ Continuous path or contouring system :-

In contouring C.S the simultaneous movement of the tool & w/p are co-ordinate to generate the desired profile.

→ Contouring N.C m/c tools can machine not only straight line at any angle, but also complicated profile. The profile is approximated by elementary straight line, arc of circle or segments of parabolas. to described the locus of the tool cutting edge. This task is done by an appropriate interpolator, which may correspondingly the linear, circular or parabolic.

To ensure reliability in maintaining the functional releationship between the movements, almost all contouring NC m/c tool are equipped with a feed back arrangement, i.e. they function as closed-loop system.

→ Many contouring NC m/c such as lathes, vertical milling m/c, one of two type ars.

Manual part programming

The programme for machining a particular workpiece depends not only upon the w/p shape & dimension but also upon NC machine tool on which it is machined. The programme for machining a w/p on one N.C. machine tool can differ significantlly from the programme for machining the same w/p on another NC machine tool.

The cause of variation lies in the difference between formats of the m/c tools. Machine tool format differ not only from one type of machine tool to another (say the lathe and milling m/c), but also between m/c tool of a particular time marketed by different manufacturer

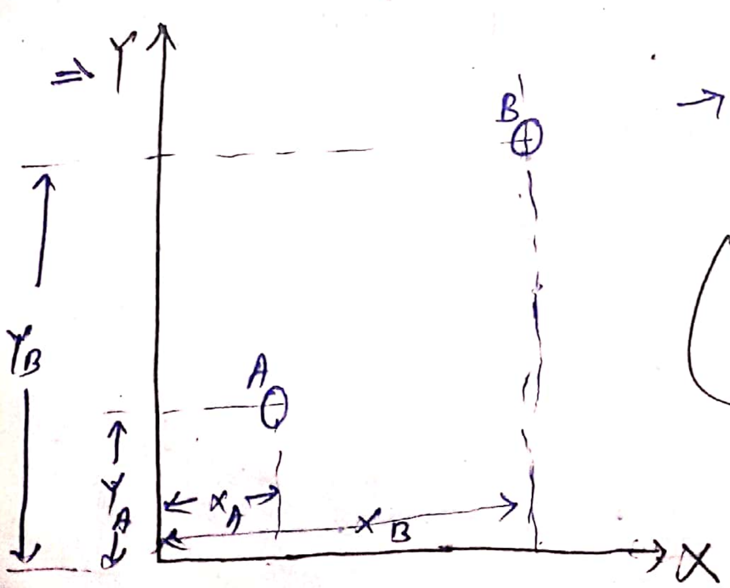
Machine tool formats :-

The information which the programmer must have about the concerned m/c tool is as follows:-

1. Does the m/c tool have a P-T-P c.s, positioning, cum straight line cut system or continuing c.s?
2. Does the m/c tool have a absolute or incremental mode of listing the co-ordinate position?
3. Does the m/c tool have a fixed, zero, full zero shift or a full-floating zero?
4. Does it employ a tab sequential, fixed block, word address or variable block programing format?
5. How many digits are used for specifying dimension where is the decimel point located?
6. Does the machine tool control have the provision for supressing leading zeros, or trailing zero or none?

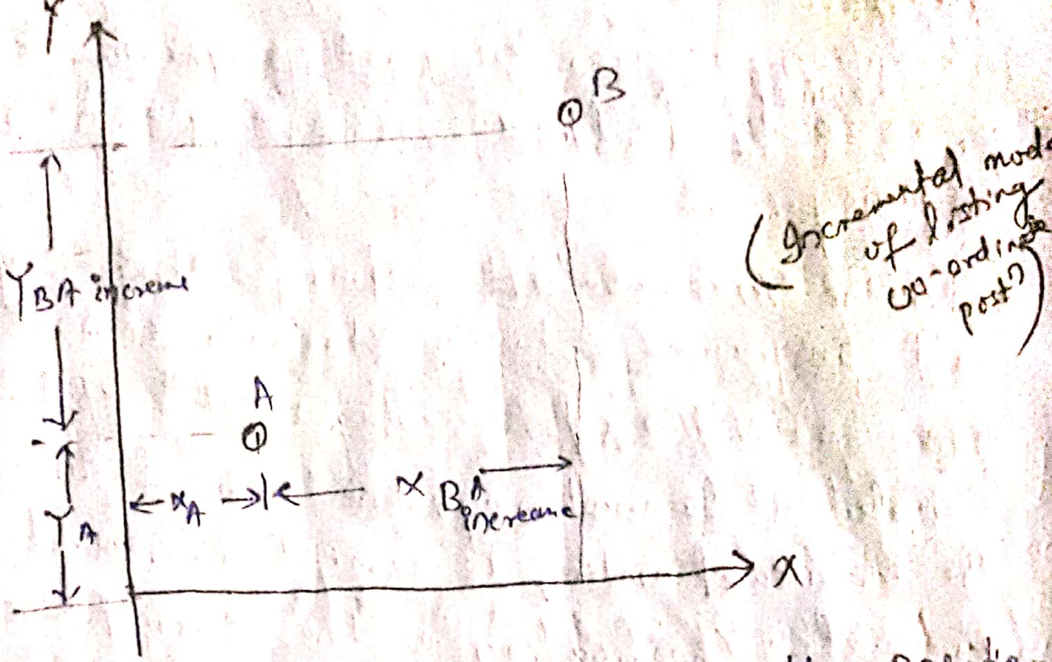
Mode of listing Co-ordinates :-

The two modes of listing co-ordinate positions are (a) Absolute (b) Incremental.



→ In the Absolute method, the co-ordinate points are specified from the origin

(Absolute mode of listing co-ordinate po



⇒ In the absolute measuring system, the position of a point is defined by its displacement from a fixed datum or centre of co-ordinate, while in the incremental system the pos^n of a point is determinate by its departure from the preceding point.

Dt-10-11-2020

Incremental measuring system :-

It is a variable viable for small and medium displacement positioning NC machines and continious path m/c with digital interpolators.

On apparent drawback of the incremental system is that it being an additive system an error during any stage of measurement will be carried over to all substiquent measurement, thus giving wrong positional readings. On the other hand the incremental measuring devices are relatively simple and lower cost.

In an incremental system it is impossible to return the tool to the starting position of the segment in which the interruption occured.

Therefore in an incremental system, every time an interaption occurs, the part programme has to be rewined fully and restarting from the very begining.

→ In the incremental system, for the segment of part programme between starting of tool from home posit? and returning to it after the completion of machining, the sum of increments of the individual motion is zero. This provides an automatic verification of the correct inputing of positional data.

Absolute mod

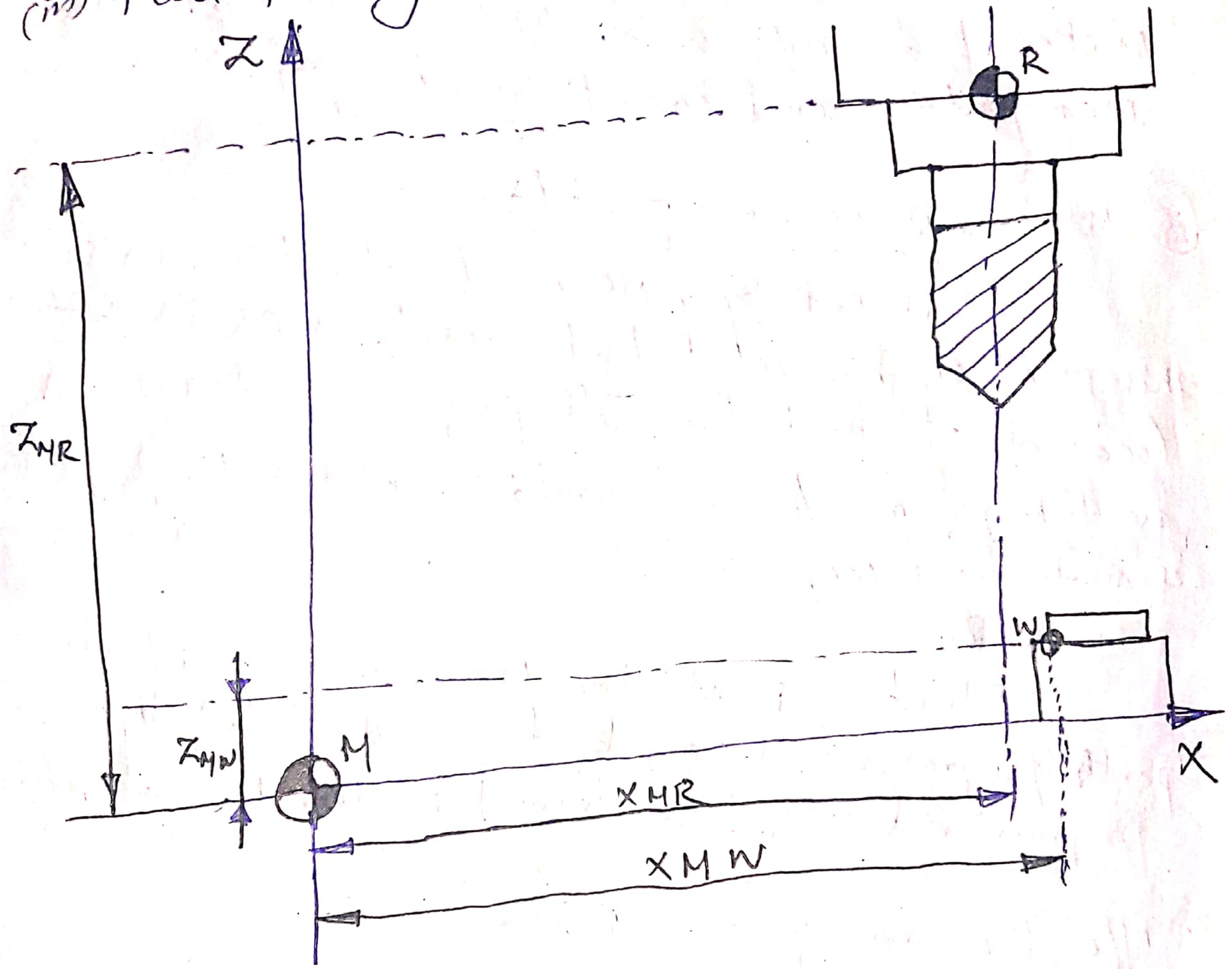
In the earliest stage of development of NC machine tool there existed a popular measuring system called absolute dimensioning system.

Absolute measuring systems are preferable for positioning, straight line, and continious path control on large m/c tool. The most significant advantage of the absolute system is observed in case of interaptions that force stopage of the m/c that is after tool breakage, incase of a m/c with absolute system, the operator changes the tool and rewined the programmes to the begining of the block in which the interaption occured and takes the tool to the starting posit? by impossing the absolute co-ordinates.

Another advantages of the absolute system lies in the ease with which dimensional data in the programme can be changed, because a modification in the co-ordinates of one position doesn't affect the rest of the programme.

Zero System :-
There are three types of zero system.

(i) Fixed zero system
(ii) Full shifted zero system / Full zero shift
(iii) Full floating zero system.



M = Machine Zero
W = Work/part zero
R = M/c reference point.
XMW, YMW, ZMW = Co-ordinates of part Zero.

XMR, YMR, ZMR = Co-ordinates of machine reference point. (REF value).

① Machine zero point :- (M).

The m/c zero point (M) is the m/c reference position or the origin of m/c co-ordinate system. Machine zero is also the position in which all tool changes takes place. Therefore, for tool changing operation machine must be positioned at m/c zero. It is fixed by m/c manufacturer and can not be changed.

Coordinate syst.
MCS – Machine
WCS – work

② Work piece zero point (W) :-

"It is set by CNC machinist, he can set this point on his whil, but mostly WCS is ~~isoto~~ located at front face. all programming dimensions are taken from w/p zero point; when a CNC programme is made for a component."

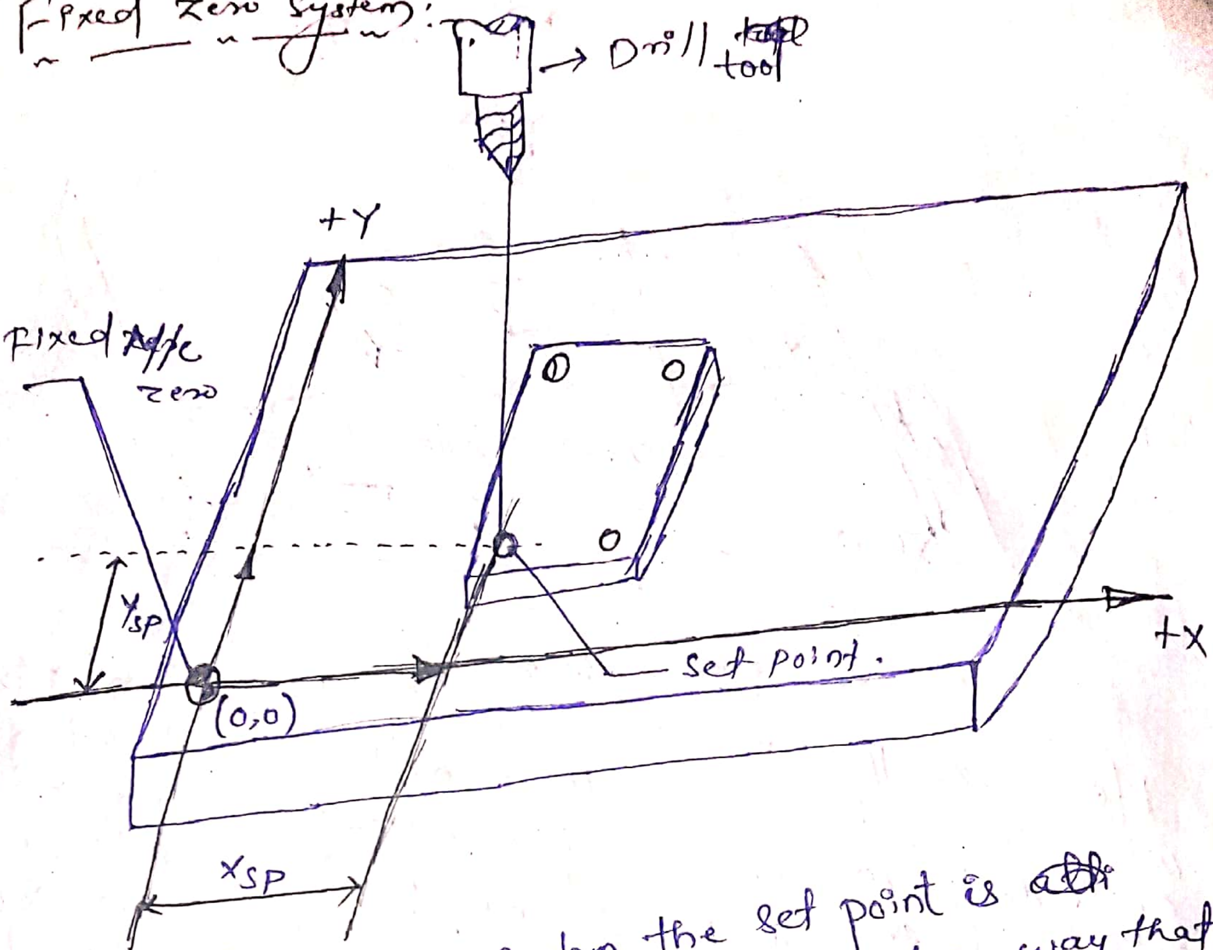
OR

"Starting point for the dimension in the part programme. It can be free established by the programmer & moved as desired within the part program."

③ M/C Reference point (R) :-

The m/c reference point (R) of the m/c is determinate by measuring system. It is essential to know the distance between R&M in order to releate the position of the axis to that of the reference point.

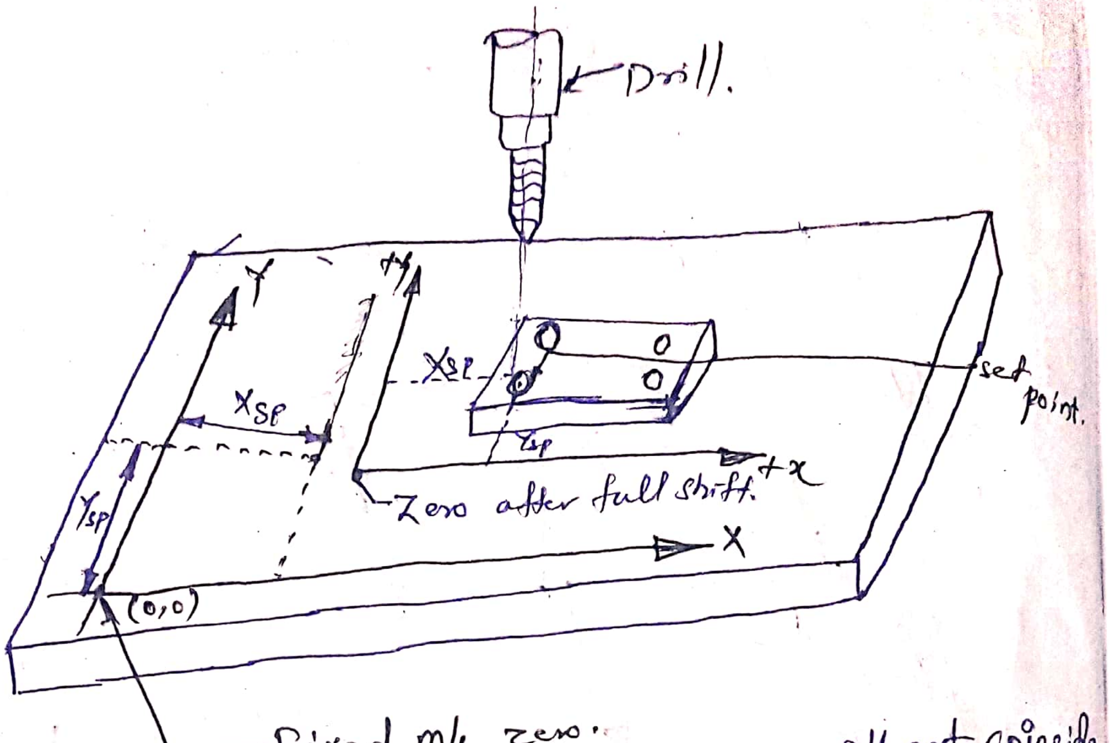
Fixed zero system:



In the fixed zero system the set point is in such a way that aligned on the machine table its co-ordinates with respect to m/c zero are (Xsp, Ysp) as aside by the part programmer. This calls for considerable skill of the operator setting. In this zero system, the co-ordinate of the part are taken from the m/c zero and the part is placed in the first Quadrant while writting the part programme.

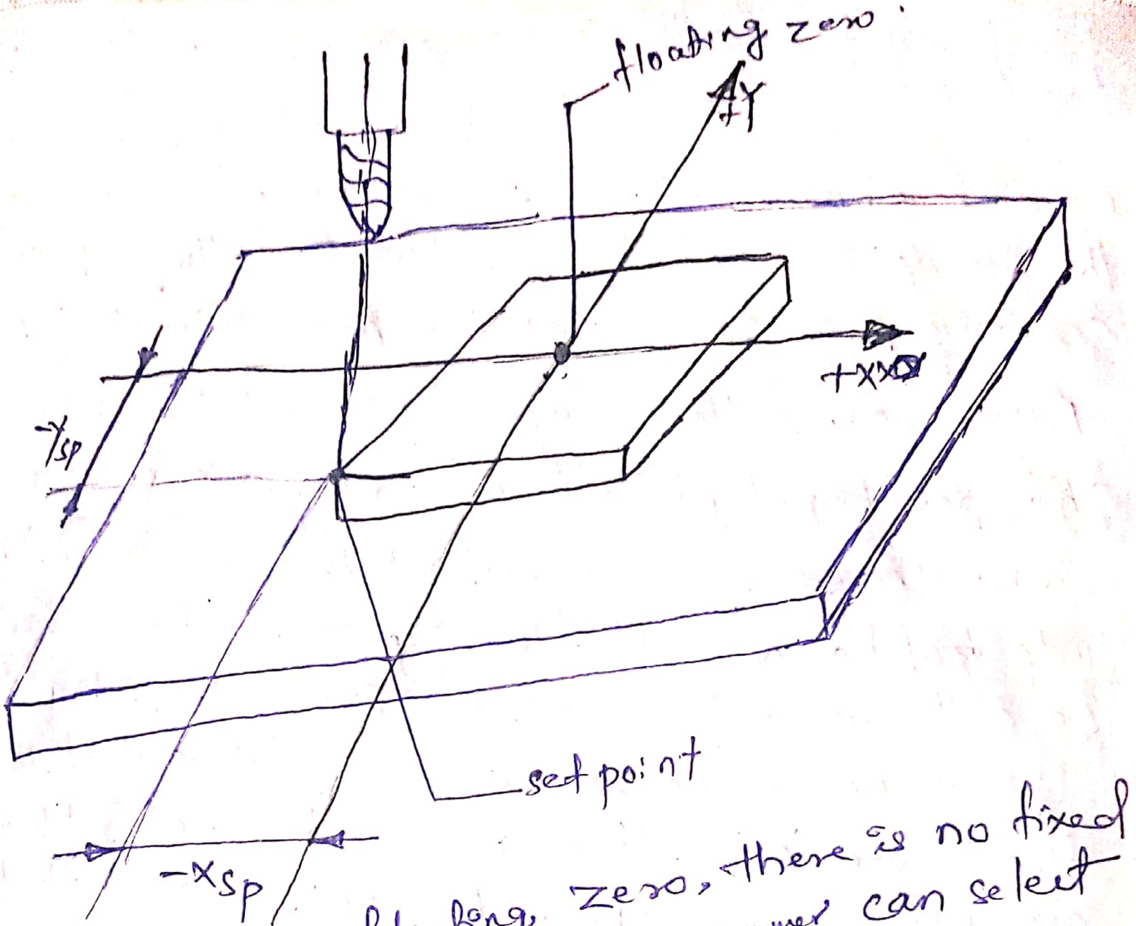
Full zero-shift :-

In the system with full zero shift. the operator clamped the w/p in a convinient posn on the m/c table. He than enters the set point Co-ordinates in the MCU (m/c control unit) consule and presses the start botton. As a result the centre of the spindle will moved to the position (Xsp, Ysp), with respect to the m/c zero.



However, this location of the spindle will not coincide with the set point of the w/p. To make the two coincident the operator manipulate the zero shift dails of the ~~set up point~~ m/c point to shift the m/c zero to the position from where the setup point of the part will have the co-ordinate Xsp, Ysp. In principle the m/c zero can be shifted to any location by the procedure describe above. This system is more convinient than the fixed zero system & the zero setting doesn't required high skill.

Full floating zero system :-



In machines with floating zero, there is no fixed zero point of the m/c and programmer can select any point as the m/c zero. ~~pot~~ without any dimension constraint. On the sign of the programmed dimension
The setup point is the lower left hand corner of the job having co-ordinates (-Xsp, -Ysp) with respect to the planned m/c zero. To carry out zero setting of the m/c, the operator takes the spindle to the setup point & enter the co-ordinate (-Xsp, -Ysp) This will set the m/c zero at the centre of the job.

Programming formats :- (Fixed block format)

~~Program~~ In the fixed block format the number characters in every block is the same and the words in each block must followed a fixed sequency e.g. sequency number, followed by X-dimension, Y dimension, followed by end of block statement. The position of direction, words, X & Y are fixed and therefore, they needn't be punched. If the m/c tool has a full floating zero, then every co-ordinate value must be preceeded by its sign. This is not necessary in case of m/c tool with fixed zero or full zero shift as all the dimension are positive. It should be kept in mind that even if X or Y location doesn't change it must be repeated in the next block.

Tab sequential format :-

→ In a m/c tool that has a tap sequential format, the tap character is utilised to seperate the words in a block. This format is similar to the fixed block format in the sense that the words follows a fixed sequence. However, this format simplifies programming to a certain extend due to the feature which ~~produ~~ provides that a repeated word (dimension) needn't be punched and may be passed over by pressing the tab character. Because, except the tool change function all other numbers are retained in the MCU memory.

Word address format:-

In the word address format, the words in a block needn't follow a fixed sequency, as each displacement information is preceeded by an identifying word (X, Y) which act as the address. Thus the major distinguishing features of the word address format is that X & Y characters must be punched. This makes the programme longer but at the same time offers greater flexibility to the programmer. Since the words are address, a word not required, that is a repeated word, needn't be punched. It may be noted that X, Y, Z, G and M 50-59 commands remain in effect till they are replaced by new one.

Variable block format:-

The variable block format, combines, word address and tab sequential format for both flexibility & simplicity. In this format each displacement information (word) is qualified by its address & the word address pair is separated by a tab character. The repeated words needn't be punched.

Function Codes:-

There are a number of function which are essential to the process of material removal for making a part. examples of this functⁿ are tool changing, switching the spindle on, turning the coolant on setting the proper feed rate & RPM. This function may be executed manually by the operator or may be numerically controlled. On most NC machine tool a few function such as loading & unloading are done manually. while a majority of the function are programmed. The important functions and there codes are described as follows:-

(1) Sequence-number-function:-
The function identifies a block & constitutes its first word it is represented by N plus three digit.

(2) Tool selection function:-
The function is coded ~~this function~~ on m/c tool that have programmable turrets and automatic tool changers. It is represented by T plus as many as 5 digit.

(3) Speed function:-
This function is coded on m/c tools which have provision for automatic speed selection. The speed function is represented by 'S' plus three digits. The manner in which the RPM should be coded is specified in the m/c tool format, the conversion of the RPM value into a magic 3 code equivalent is done as follows.

RPM value → Magic-Three code

132 → 613

10 → 510

100 → 610

730 → 673

3250 → 732

00150 → 800

④ Feed rate function:-

The feed rate is expressed through F+3digit the digits may represent the feedrate in mm/min or mm/rev. The manner in which the machine control unit excepts the feedrate function command is specified in the m/c tool format. The conversion of mm/rev or mm/min values in to the magic ~~cod~~ three code equivalent is done in the same way as explained above.

Feed rate mm/rev or mm/min	→ Magic three code equivalent. (3 - 0/3)
0.195	→ 319
0.026	→ 226
0.0079	→ 179
0.0226	→ 222

⑤ Dimensional data function:-

The dimensional data is represented by a symbol plus ~~a~~ five to eight digits. The symbols used for some important dimensions (motions) are

X → primary X dimension
Y → primary Y dimension
Z → primary Z dimension
A → Angular dimension about the X axis.
B → Angular dimension about the Y axis.
C → Angular dimension about the Z axis.
U → secondary dimension parallel to the X axis.
V → secondary dimension parallel to the Y axis.
W → secondary dimension parallel to the Z axis.

I → Interpolation parameter parallel to the 'x' axis.

J → " " " to the 'y' axis

K → " " " to the 'z' axis.

NC machine tools are identified by the number of independently controlled motion axis that can be controlled by them. For, instance a NC milling m/c with control of X, Y, & Z axis would be refered as a three axis m/c, while one with additional control of angular dimension 'A' would be turned four axis m/c.

⑥ Preparatory function :- (G-code)

The preparatory function instructs the m/c tool to get prepared for the operation to follow. In a block of the programmed menu script, the preparatory function comes immediately after the sequency number. Preparatory functions are represented by G plus two digit. Thus there is provision for coding a total of 100 preparatory functions from G00 to G99. Some of the important preparatory func

codes are given in the table :-

→ Generally it is a code telling the m/c tool what type of action to perform. Such Rapid move, controlled feed move in a straight line or arc, etc.

Code : function

G00 : positioning (rapid traverse)

G01 : linear interpolation

G02 : circular interpolation (clockwise)

G03 : circular interpolation (ccw)

G04 : Dwell

G08 : Ram down inhibit

G09 : Cancel G08

G17 : X, Y plane selection for interpolation.

G18 : X, Z plane seelection for interpolation.

G19 : Y, Z plane selection for interpolation.

G28 : Return to reference point.

G30 : Cancel mirror image.

G31 : Mirron image with axis command.

G39 : Tool radius, vectors setting prior to change of direction

G40 :- Cancel cutter dia/tool nose radius compensation.

G41 : cutter dia/tool nose radius compensation, left

G42 : cutter dia/ tool nose radius compensentation, right

G45 : tool offset increase

G46 : tool offset decrease

G49 : Cancel tool length compensation.

G50 : programming of absolute Zero point in turning / cancellation of do loop

G51 : Do loop

G-55 : Full zero shift in CNC milling/drilling M/c

G70 : Data input in inch system.

G71 : " " " metric system.

G78 : Milling cycle stop

G79 : Milling cycle '

G80 : Cancel cycle.

G81 : Drilling cycle.

G82 : Facing cycle.

G84 : Tapping cycle.

G85 : Boring cycle.

G90 : Absolute dimension input.

G91 : incremental dimension input.

G92 : programming of absolute zero point in milling.

G94 : Feed in mm/min (inch/min)

G95 : Feed in mm/rev (inch/rev)

G96 : Constant surface speed.

G97 : Spindle speed in rev/min.

G98 : Return to initial level in canned cycle

G99 : Return to R level in canned cycle.

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Misillanous functions (M-Code) :-

Miscellaneous function are used to described instructions other than dimension. These are not a part of the cutting process but are nondelays important from the point of view of greater productivity. This function is denoted by M plus two digit. The codes of some M function are given in the table.

Codes	function
M00	program stop. Stopall slide movements spindle rotation and coolant.
M01	optional Stop. ignored unless activated manually from consoul.
M02	End of program, m/c stops. programme is rewound.
M03	Spindle start c.w.
M04	Spindle start c.c.w.
M05	Spindle stop.
M06	tool change
M08	Coolant on.
M09	coolant off.
M10	Clamp (spindle, cuill, fixture, slide etc)
M11	Declamp. (spindle, cuill, fixture, slide etc)
M13	Spindle start c.w & coolant on.
M14	spindle start c.c.w & coolant on.
M19	Oriented spindle stop; the spindle stops in a prespecified angular positn.
M21	Mirror image 'X'.

M22 : " Y.

M25 : Mirror image off.

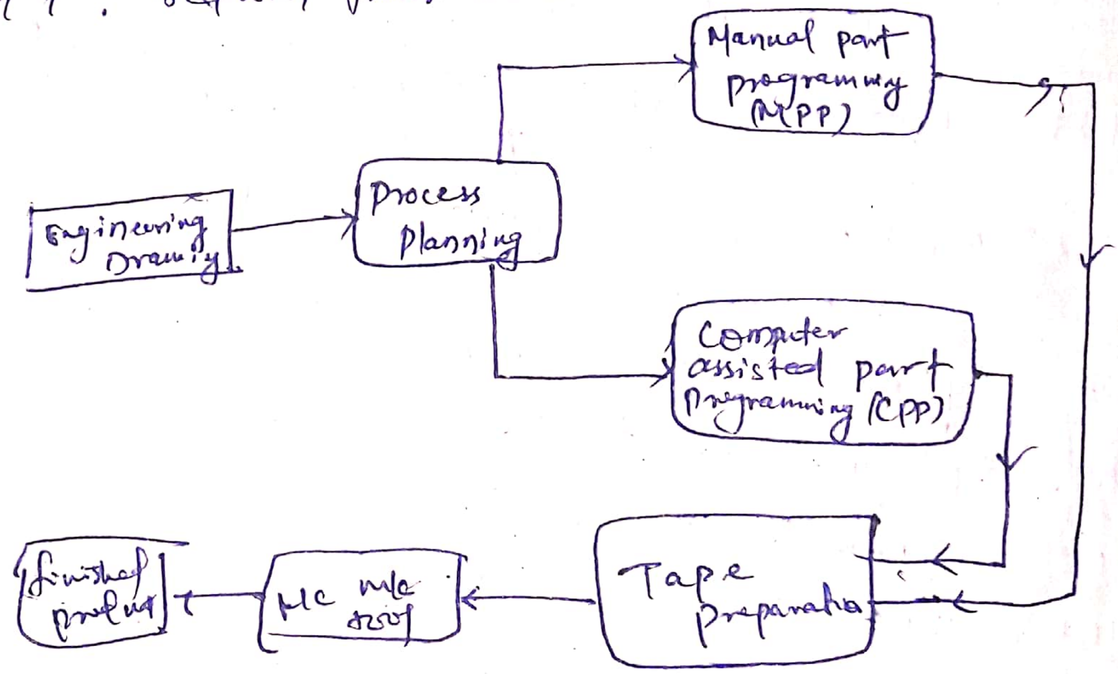
M30 : End of program. m/c stop memory rewound.

M41-45 : Gear change.

M51-59 : Z' axis setting with the help of cam & switches. on two to halve axis CNC m/c.

M98 : Go to sub routine.

M99 : return from sub routine.



Classification of NC system:-

1) According to tool positioning or programming mode

(i) Absolute system (ii) Incremental system.

2) According to motion control system.

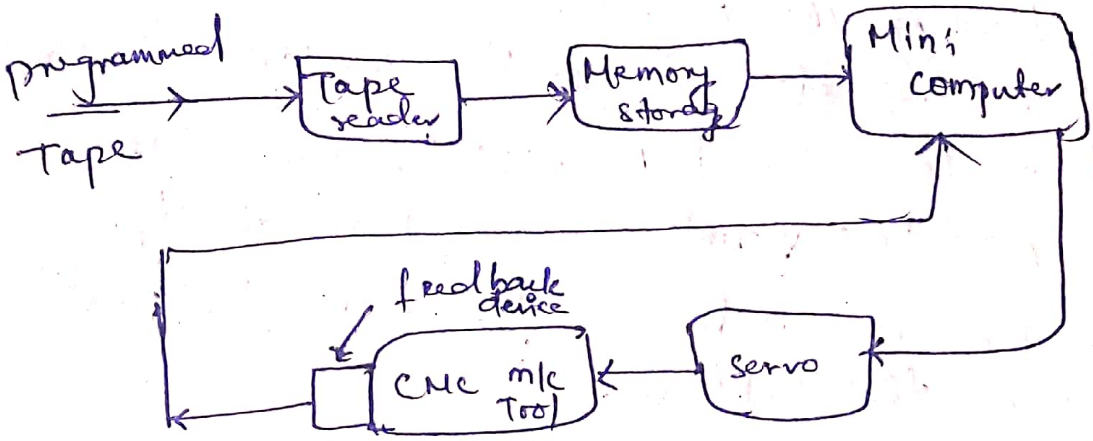
(i) Point to point system.

(ii) Straight line or straight cut system.

(iii) Contouring or continuous path system.

3) According to the types of feed back devices.
(a) Analog (b) Digital.
4) According to Servo control system
(a) Open loop system (b) Closed loop system.

Computer Numerical Control (CNC) :-



It is a software based system, in which the computer replaces the control units of the conventional NC. It does not carry the hard-wired logic systems and all their functions for controlling the m/c tool are performed by the software programme of the computer. That is why it is known as "software based system". Also, since a separate computer is used for each m/c tool, with a stored programmable logic, it is known as self contained NC system for that particular m/c tool. The computer used is known as mini computer.

→ The main objective of using this system is to simplify the hardware of conventional NC and replace it with the software to the maximum possible extent. The programme is entered in to the computer through a tape or keyboard and store in its memory, which can be called whenever a part is to be machined.

Also, it is easy to edit & modify a programme if required.

Thus, the programmed tape is required only once for feeding the programme into computer memory and the repeated use of tape reader is eliminated, unlike conventional NC. This results in considerable saving of time & cost & increased reliability.

The problem can be easily detected & rectified through this software.

Direct Numerical Control (DNC):-

It is also a computerised NC, but it differs from a CNC system in that it employs a separetly located central computer & directly control. Several m/c tool simultaneously, whereas in the latter case each machine tool is separately controlled by its own mini-computer. The central computer, also known as main frame computer, carries a large memory storage facility in which the part programme or machine programmes of all the m/c tools, connected to the central computer, are stored in a device like magnetic disk or drum. This computer also performs the function of processing and post processing of the part programme's, enable an easy and quick correction of these programmes. Alternatively, the processing work can be separately performed in another computer and the two linked to each other.

→ Whenever an operation is to be performed, the central computer collects the relevant programme instructions from the memory storage and sends these instructions to the concerned m/c tool. There is also a feedback of data from the m/c tools to the central computer to enable it to instantaneously provide further necessary programmed instruction to the m/c tool concerned according to the latter's needs.

→ The most significant and distinct feature of a DNC system is that a single main-frame computer control a large number of different m/c tools simultaneously, providing necessary programme instruction from its memory storage instantly to each individual m/c tool linked to it. It supplies controlled centrally, which facilates adoption of this system in computer integrated Manufacturing (CIM) and FMS.

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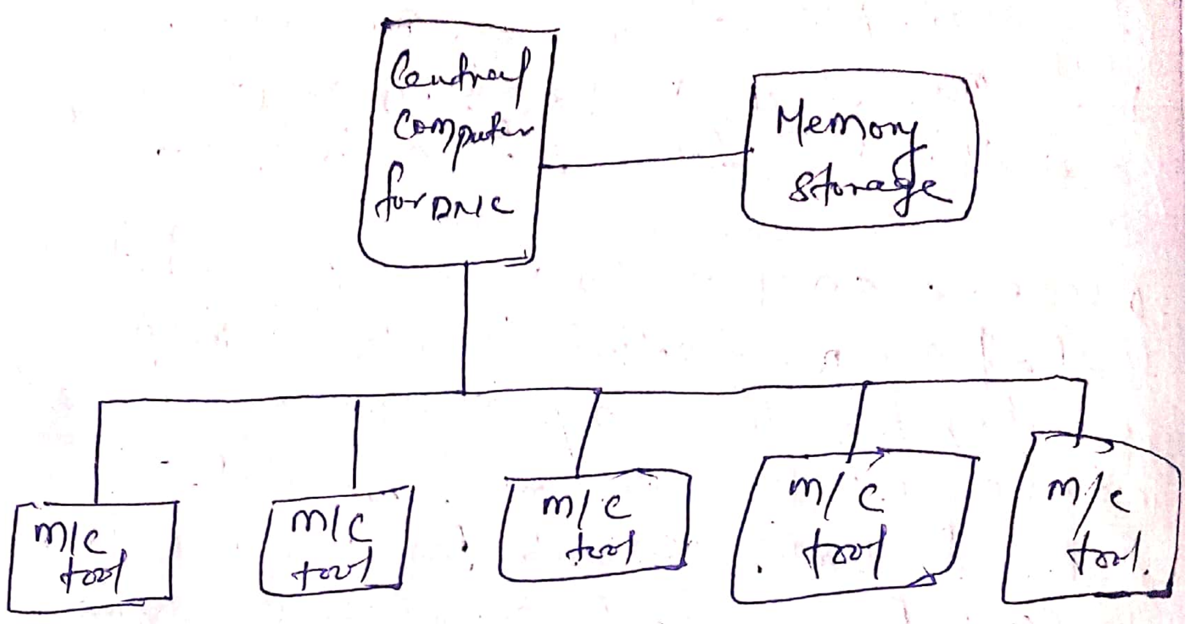


Adaptive Control (AC) :-

Adaptive control system is an improvement over NC & CNC system. In NC machining the part programmer has to select & prescribe the cutting speed, feed and other process variables, based on his experience and available data, in order that the w/p can be machined accurately and in the minimum period of time.

↳ The AC system automatically determines the process variables, such as cutting speed, and feed, during the process and makes them change (vary) within the prescribed (programmed) limits) to suit the changed requirement of the process in progress. It thus makes the speed & feed vary automatically according to the needs of actual cutting condⁿ present while the machining process is in progress.

The method of operation of this system is as follows:-

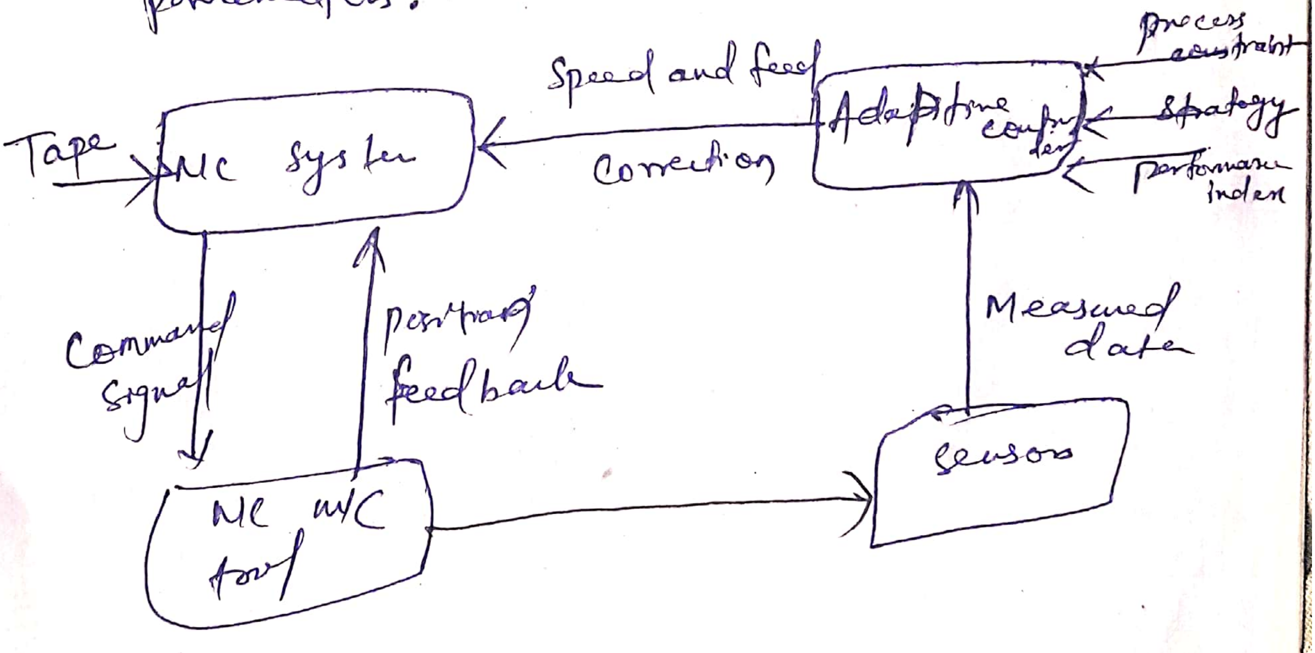
(i) Measure the output variable of the process.

(ii) Determine machining constraint or performance level from the data obtained through these measurement.

(iii) Decide a proper strategy for improving the performance level.

(iv) Vary the cutting speed & feed.

(v) Thus, orient the system to achieving optimum machining condⁿ, enabling an increase in toollife, reduction in machining time, better utilisation of various machining parameters.



Shree S'ad Vidya Mandal Institute of Technology

Branch : Mechanical Engineering
Semester : 7th Sem
Year : 2016-2017
Subject : Computer Aided Manufacturing (2171903)
Presentation Topic : Introduction to NC, CNC & DNC machine tools.
Enrollment No : 130454119006, 140453119007, 140453119006, 140453119005
Guided by : PROF. Khushbu Panchal

Outline of presentation :-

1. Introduction to NC Machine tools.
2. Introduction to CNC Machine tools.
3. Introduction to DNC Machine tools.
4. Difference Between NC, CNC and DNC machine tools.

Content references :-

1. Content taken from : Computer Aided Manufacturing by R .B . Patil
2. Images : Google images & flow diagram’s self prepared using power point tools.
3. Videos : Taken from Youtube

Numerical Control (NC) Defined

- **NC (numerical control) machine tools** are the machine tool, of which the various functions are controlled by : letters , numbers and symbols.

- The NC machine tool runs on a program fed to it; without human operator. The NC program consist of a set of instruction or statement for controlling the motion of the drives of the machine tools as well as the motion of the cutting tool.

- **NC machine tools , one or more of the following function may be automatic :**

i. Starting and stopping of the machine tool spindle;
ii. Controlling the spindle speed;
iii. Positioning the tool at the desired location and guiding it along the desired path by automatic control of the motion of slides;
iv. Controlling the feed rate; and
v. Changing the tools.


LMX VII
TANAKA
CNC Laser Cutting Machine, Capacity upto 28 mm Thickness.

Components of NC machine tool system

1. **Part program:-**

- Using the part drawing and the cutting parameters, the part program is written.
- The part program is a set of step by instruction to the machine tool for carrying out the operation.
- **Method use for part programming**

1. Manual part programming
2. Computer-aided part programming

2. **Program Tape:-**

- The part program is entered on the program tape.
- The program is entered on the tape in the form of punched holes. The holes are punched with the help of punching machine.

3. **Machine Control Unit(MCU):-**

- The program tape is read by the tape reader.
- The controller takes input from the tape reader.

4. **Machine Tool:-**

- The machine tool is operated by the controller of the machine control unit.

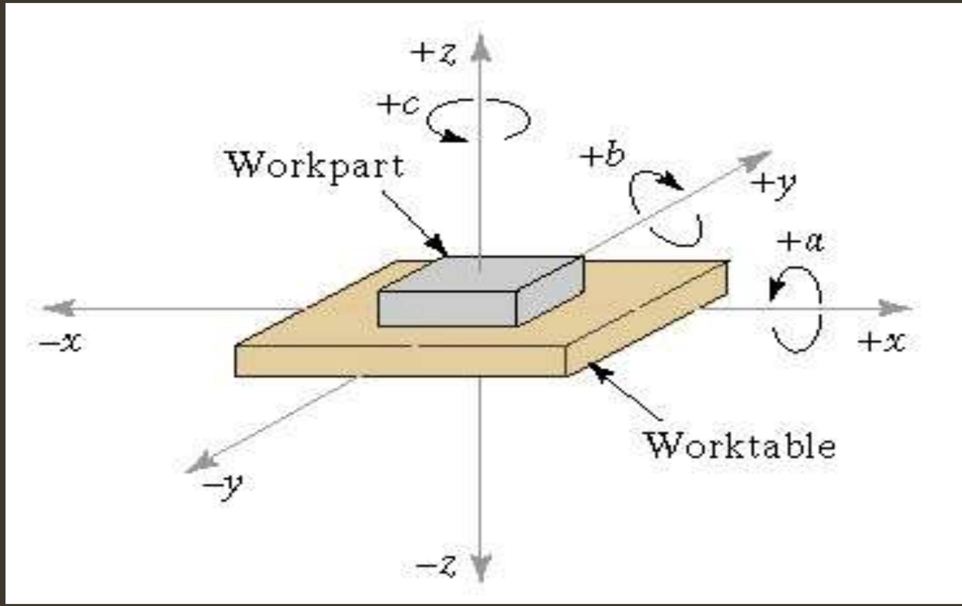
NC Coordinate Systems

- **For flat and prismatic (block-like) parts:**

➢ Milling and drilling operations

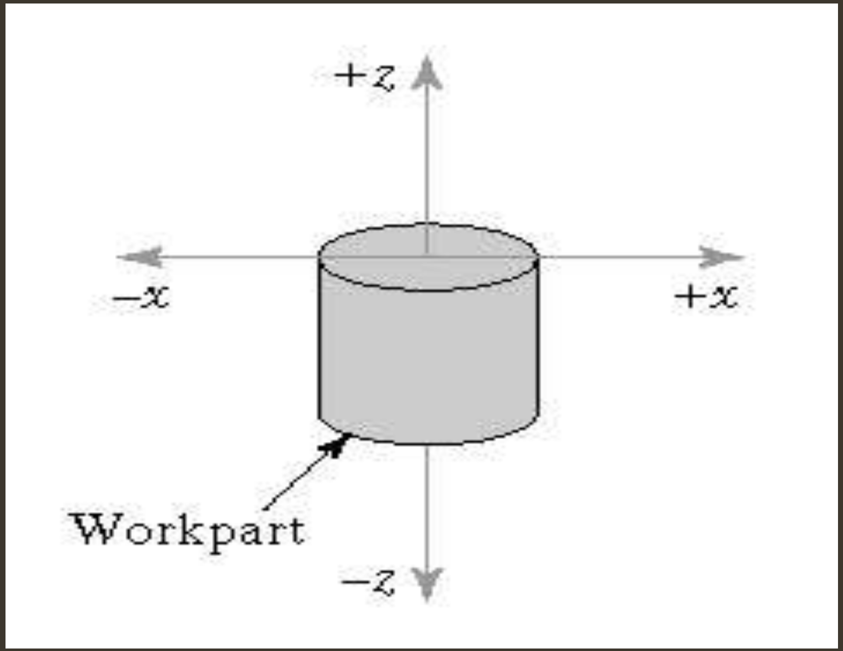
➢ Conventional Cartesian coordinate system

➢ Rotational axes about each linear axis



NC Coordinate Systems

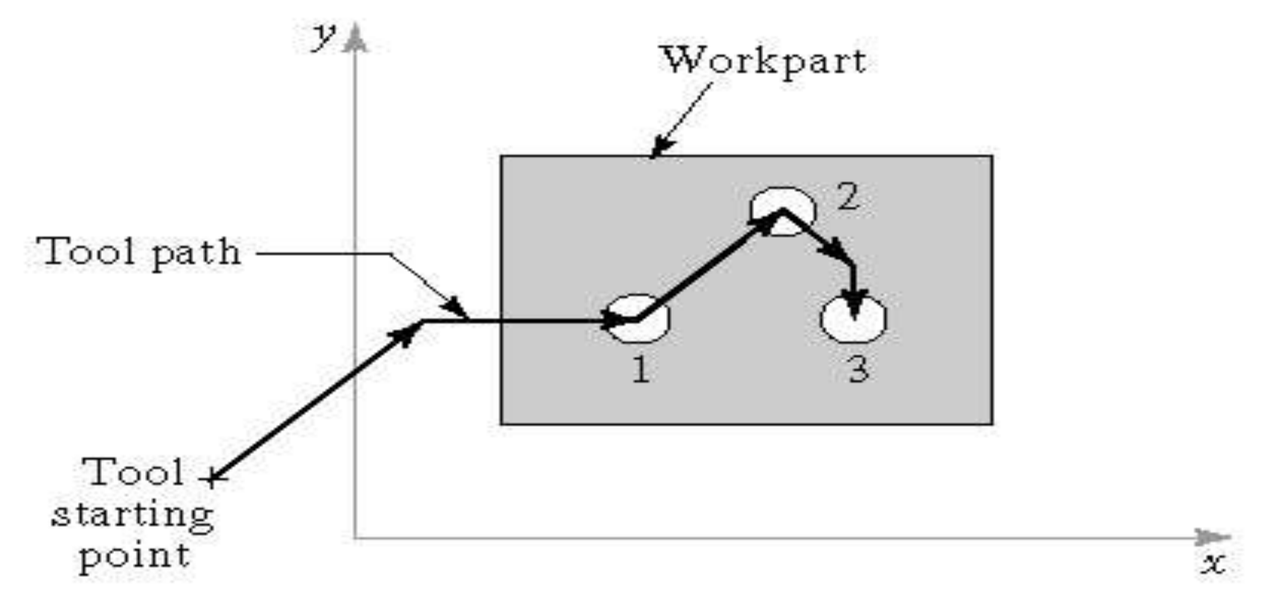
- **For rotational parts:**
  - Turning operations
  - Only *x*- and *z*-axes



Motion Control Systems

1. **Point-to-Point systems**

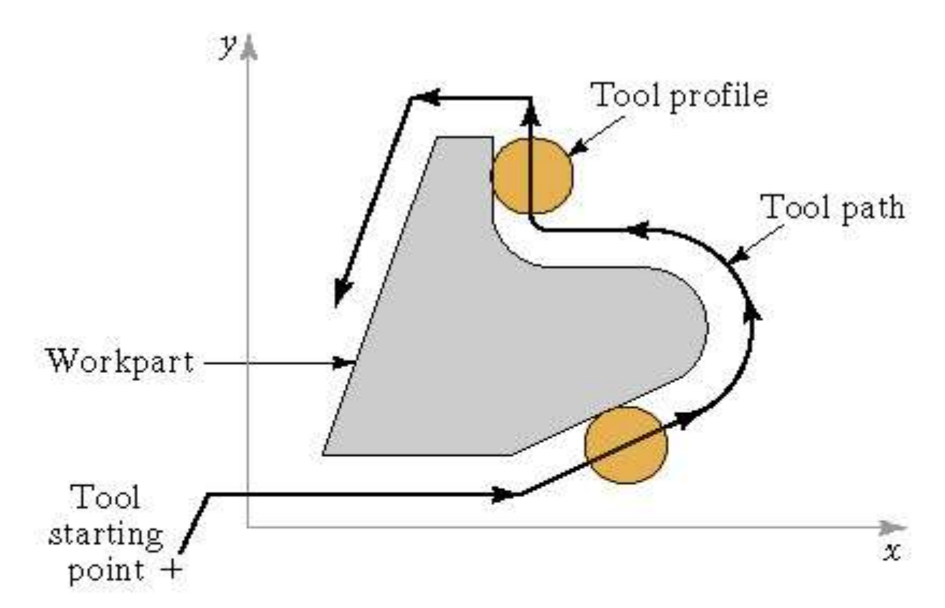
- Also called position systems
- System moves to a location and performs an operation at that location (e.g., drilling)
- Also applicable in robotics



Motion Control Systems

2. Continuous path systems

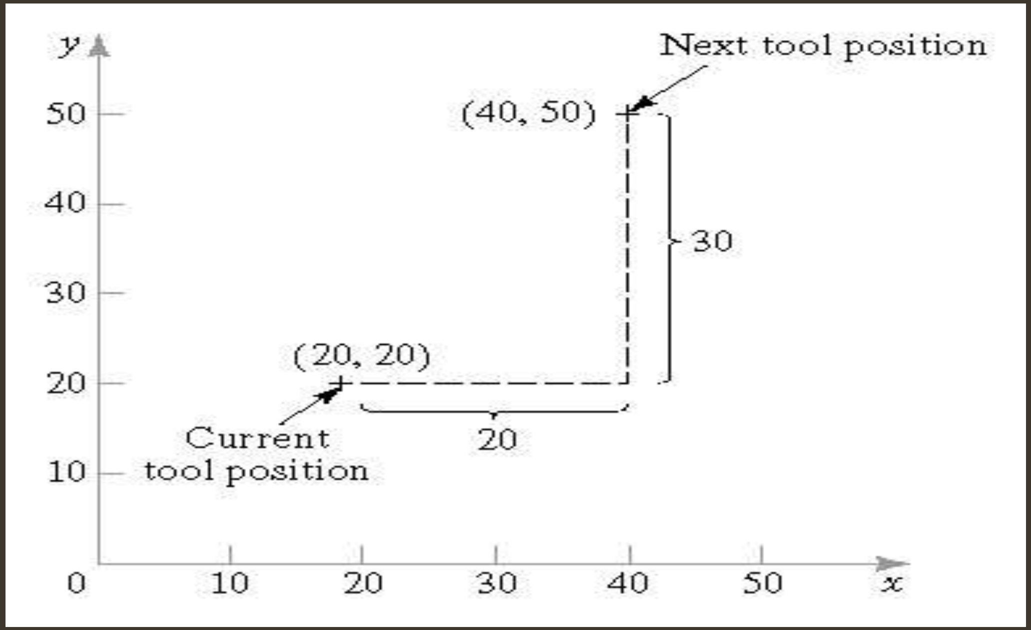
- Also called contouring systems in machining
- System performs an operation during movement (e.g., milling and turning)



Absolute vs. Incremental Positioning

- Absolute positioning
  - *Move is: x* = 40, *y* = 50

- Incremental positioning
  - *Move is: x* = 20, *y* = 30.



Advantages of NC machine tool

- Cycle time reduction
- Complex machining operation
- High degree of accuracy
- Less inspection required
- Reduction of scrap and wastage
- Increasing productivity
- Lower tooling cost
- Reduction of human error
- Greater operation safety
- Greater operation efficiency
- Reduction space required
- Operator skill-level reduced

Limitation of NC machine tool

- High investment cost
- High maintenance effort
- Need for skilled programmers
- High utilization required

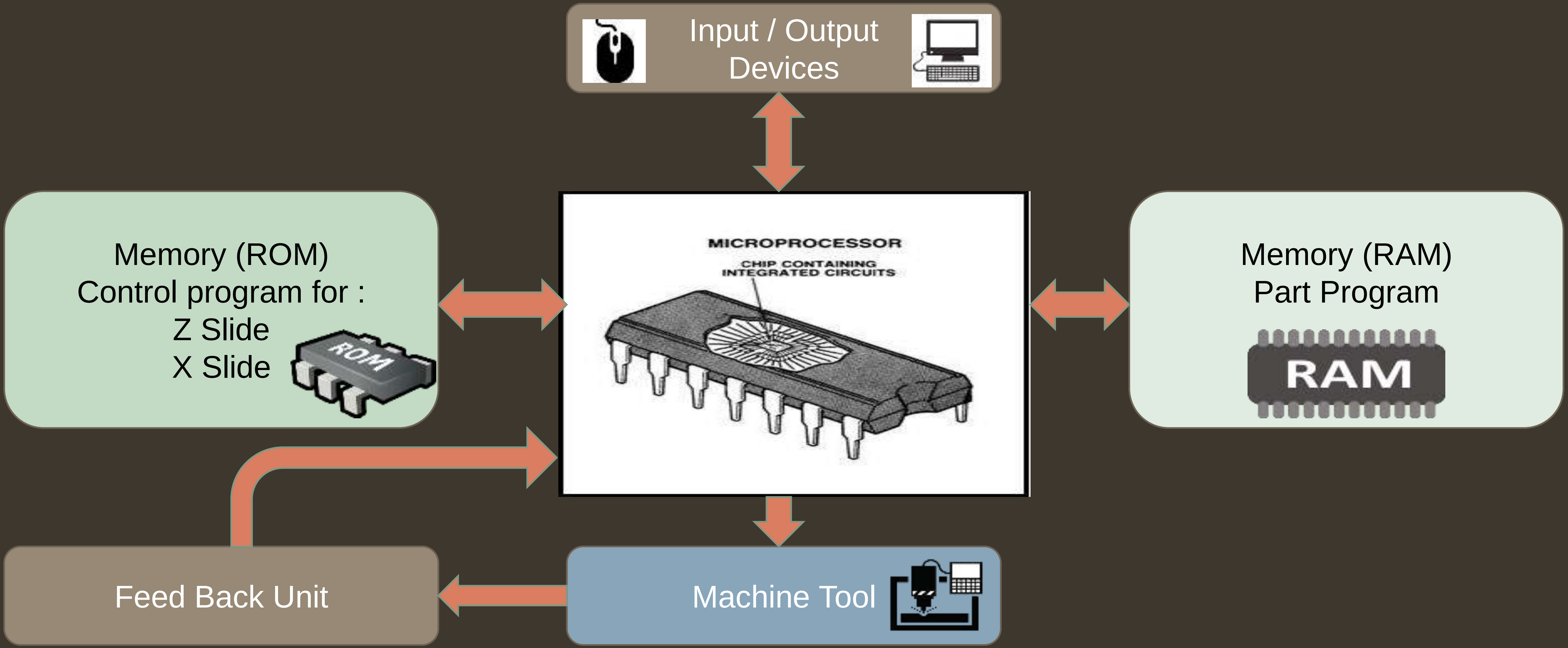
Introduction to CNC Machine Tools

- In **CNC (Computer Numerical Control) machines**, a dedicated computer is used to perform the most of basic NC machine functions.
- **CNC (Computer Numerical Control) machine** is a NC machine which uses a dedicated computer as the machine control unit.
- The entire program is entered and stored in computer memory. The machining cycle for each component is controlled by the program contained in the computer memory.
- The stored part program listing can be used for future production also.

Components of CNC machine tool system

- The main components of CNC machine tools are as follows :

1. Input / Output Console.
2. Microprocessor Based control unit.
3. Memory.
4. Feedback unit.
5. Machine Tool.
6. Interfaces.


Input / Output Devices
Memory (ROM)
Control program for :
Z Slide
X Slide
ROM
MICROPROCESSOR
CHIP CONTAINING INTEGRATED CIRCUITS
Memory (RAM)
Part Program
RAM
Feed Back Unit
Machine Tool

- Input / Output Console : It is the unit through which part program is fed to the CNC machine tool system and required output is taken out. It basically consists of monitor and Keyboard.
- Microprocessor : This controller takes input from Input / Output device, Feedback from feedback unit and actuates the drives as well as the tool of the machine tool.
- Memory : It consists of RAM & ROM. The RAM stores part program, while ROM stores the programs for machine control.
- Feedback unit : The feedback unit takes input from machine tool and transfers it to control unit for necessary corrections.
- Machine tool : Machine tool is operated by the control unit.
- Interfaces : They are the connections between the different components of the CNC machine tool system.

Classification of CNC Machine tool systems

(a) According to type of Feedback systems

1. Open loop type CNC machine.
2. Closed loop type CNC machine.

(b) According to type of tool motion control

1. Finite positioning control CNC machines.
2. Continuous path control CNC machines.

(c) According to program methods

1. Absolute Programming CNC machine systems.
2. Incremental Programming CNC machine systems.

(d) According to type of controller

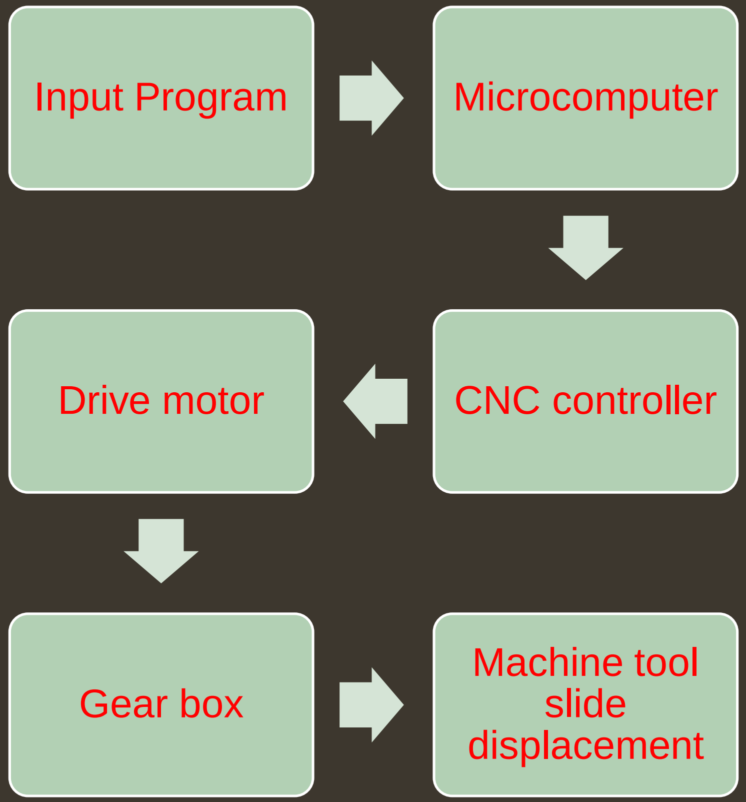
1. Hybrid controller CNC systems.
2. Straight controller CNC systems.

(e) According to axis & type of operations

1. CNC horizontal machining centre.
2. CNC vertical machining centre.
3. CNC turning centre.
4. CNC milling centre.

Classification based on type of feedback systems

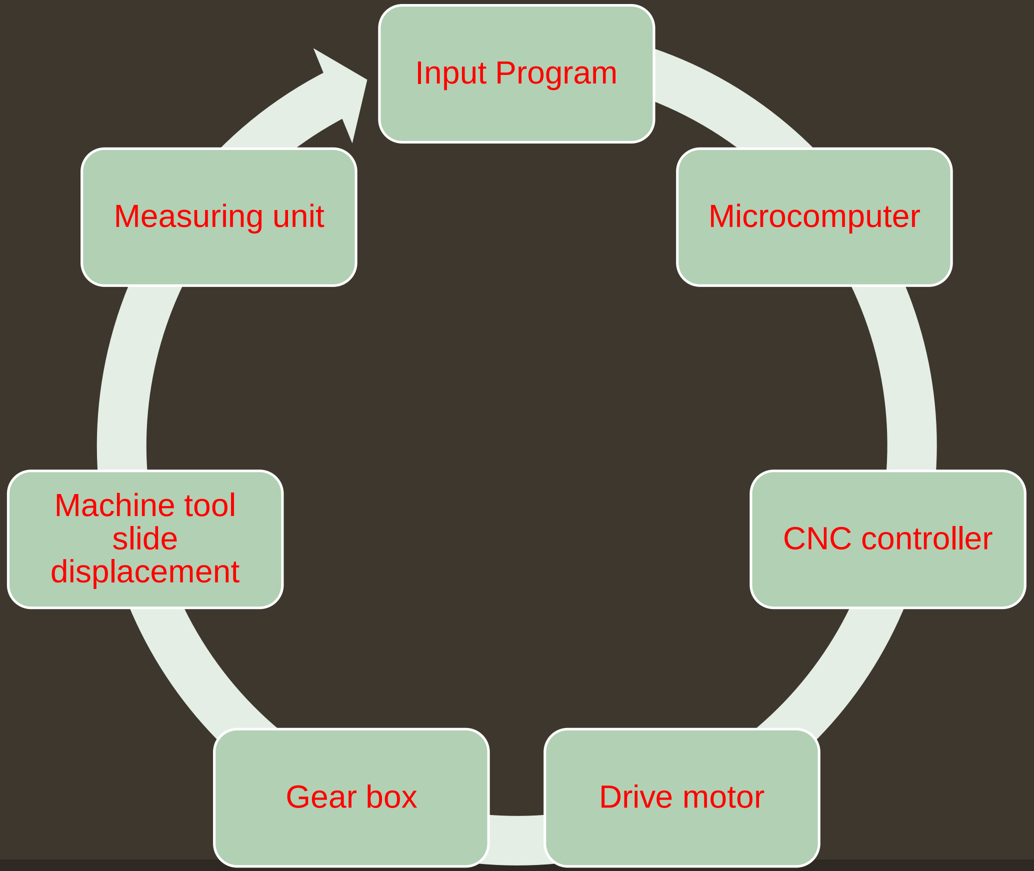
1. Open-Loop type CNC Machine



- It does not have any feedback mechanism.
- It only has motion control but do not have any provision for feedback, which is needed to be compared with input for better control & correction of drive system.

Classification based on type of feedback systems

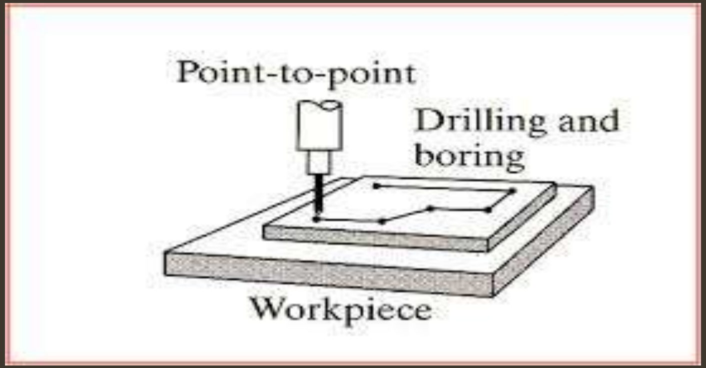
2. Closed-Loop type CNC Machine

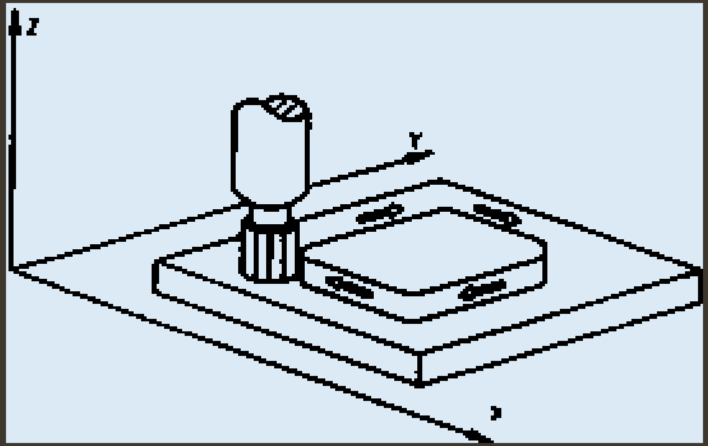


- It has a feedback mechanism.
- It has the motion control with a provision of feedback of feedback.
- Which can be used for accurately controlling the drive system by comparing it with the input information until the required or desired position is achived.

According to type of tool motion control:

1. Finite position control CNC machine

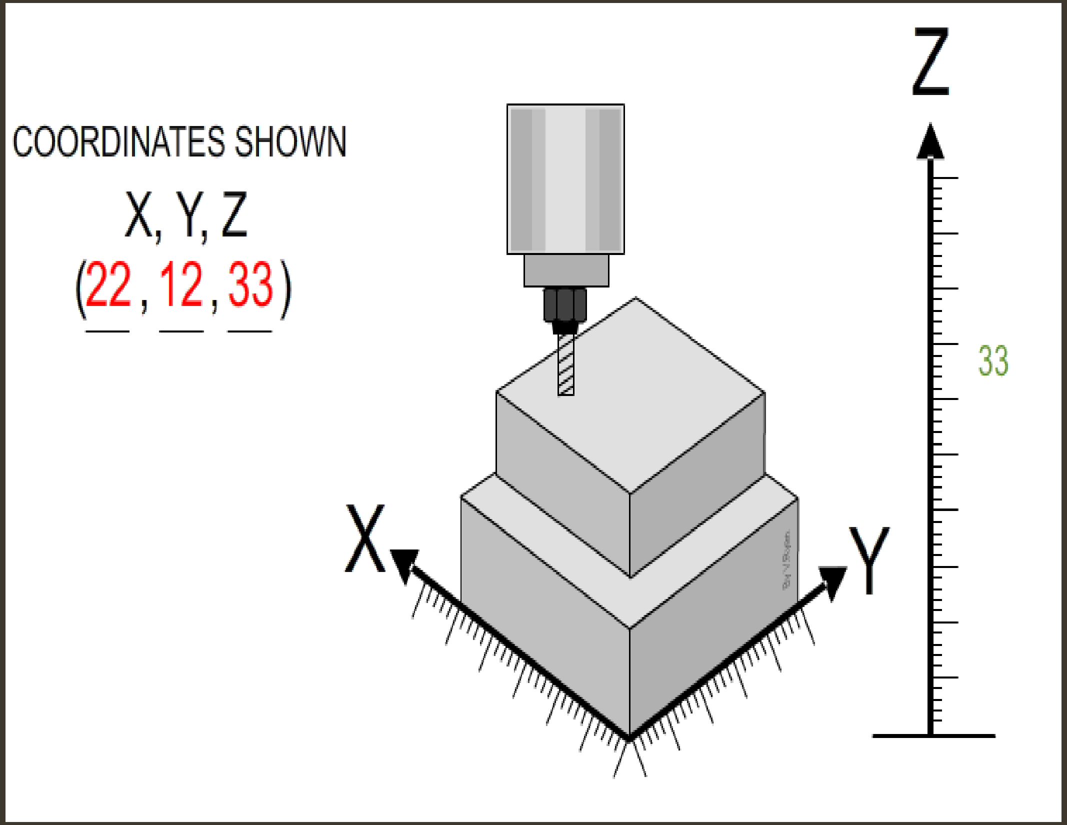




- In point to point CNC machines, the movement of cutting tool from one predefined position to another predefined position is important, while the path along which this tool moves is irrelevant. Commonly used in drilling & punching operations.
- Straight cut line control mode is the extension version of point to point method, straight cut is obtained controlling the movement of tool with controlled feed rate in one of the axis direction at a time. Commonly used in Face milling, pocket milling and step turning operations.

According to type of tool motion control:

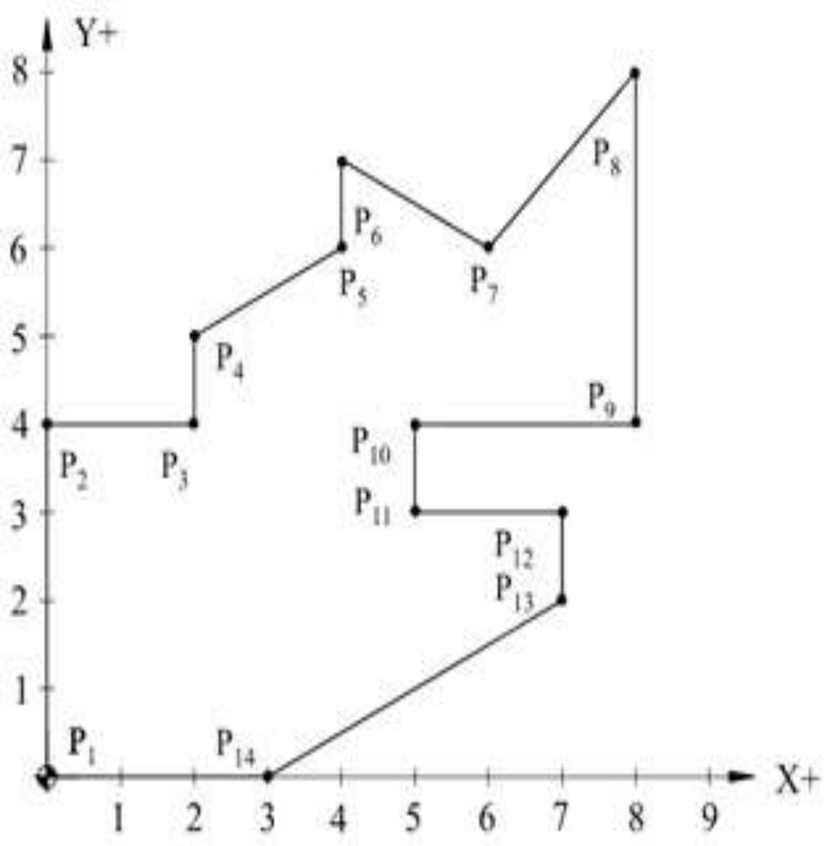
2. Continuous path control CNC machine



- The continuous path control system is used for continuous, simultaneous & coordinated motions of cutting tool & work piece along different axes.
- Such motion enables machining of different contoured profiles & curved surfaces.
- Types : 2 axis, 2 ½ axis, 3 axis, Multi axis countering.

According to programming Methods

1. Absolute programming CNC machine systems

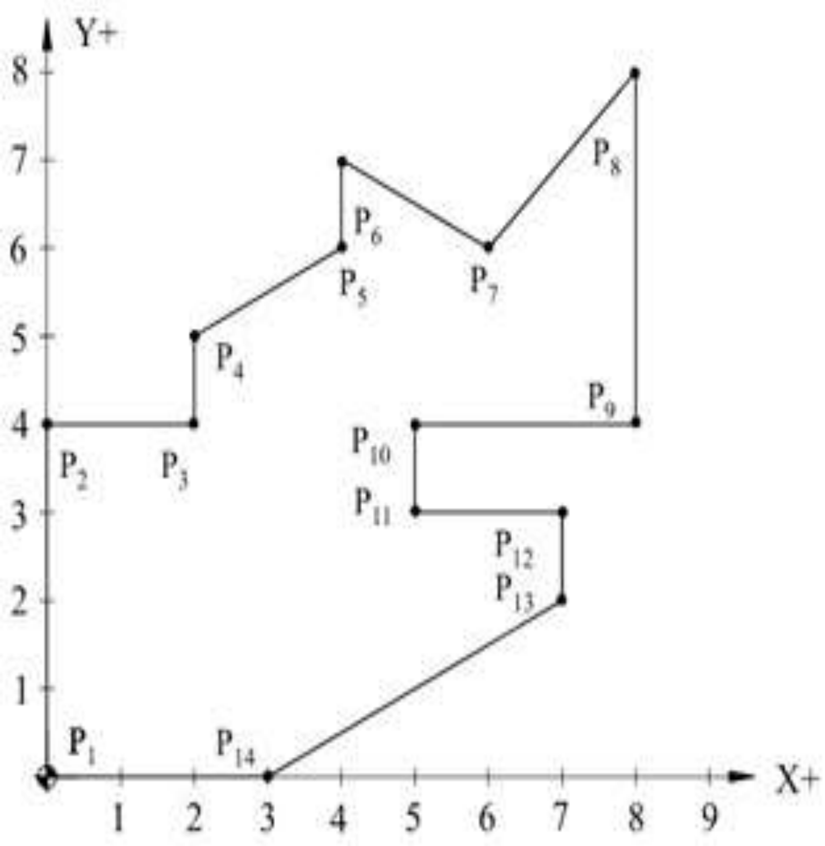


X	Y
0	0
0	4
2	4
2	5
4	6
4	7
6	6
8	8
8	4
5	4

- In Cartesian coordinate geometry system using absolute measurement, each point is always specified using same zero established for a given coordinate system.

According to programming Methods

2. Incremental programming CNC machine systems

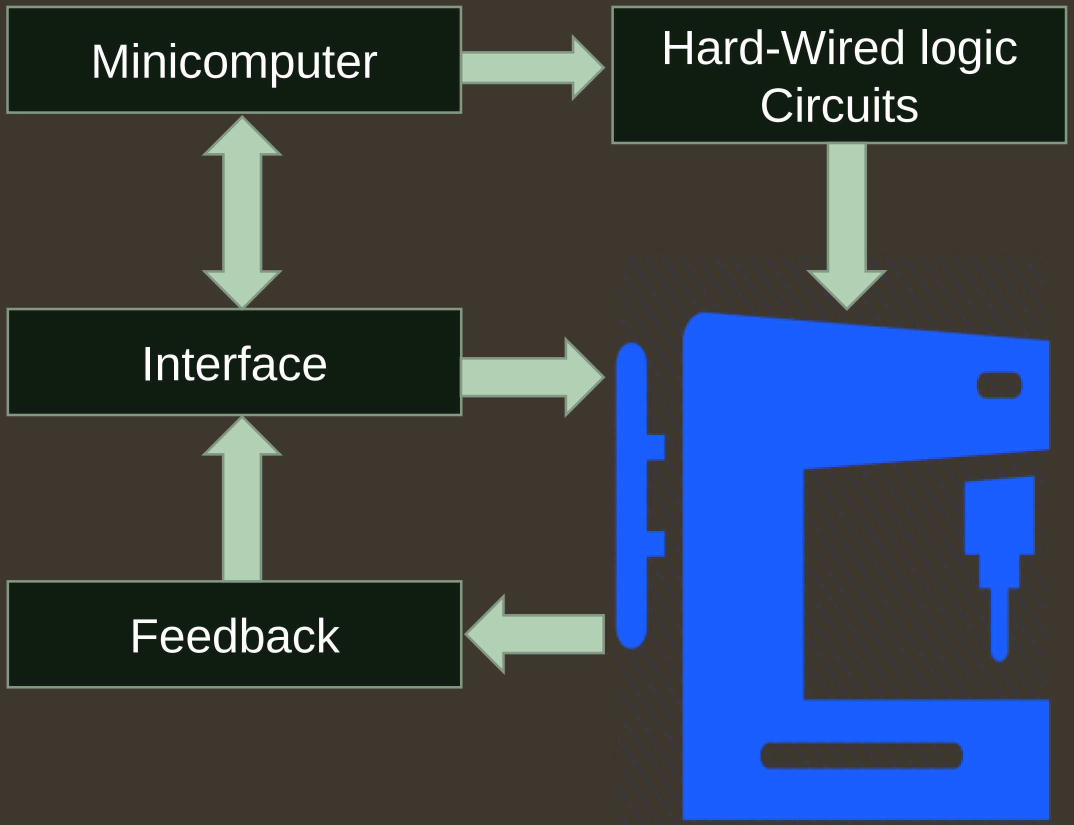


X	Y
0	0
0	4
2	0
0	1
2	1
0	1
2	-1
2	2
0	-4
-	-

- In Cartesian coordinate geometry system using incremental measurement , each point is specified using the path differential from the preceding point position. So in such programming , controller must store and process additional path measurement.

According to type of controllers

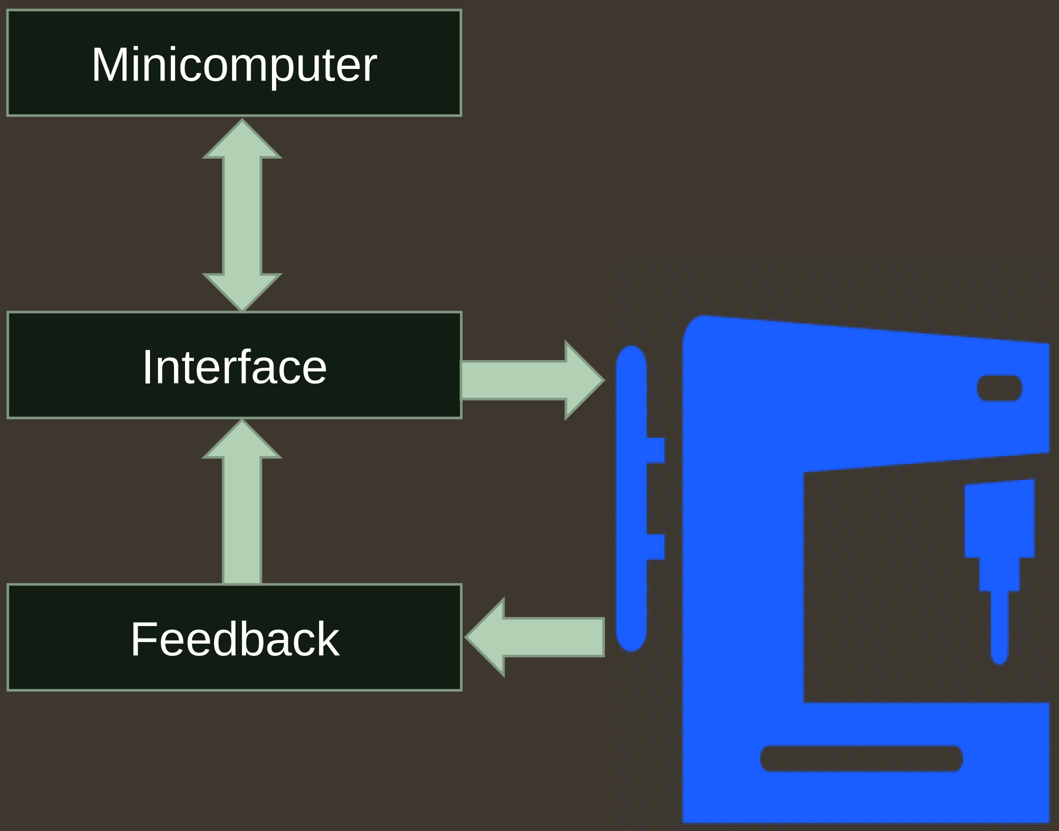
1. Hybrid controller CNC systems



1. Hard wired logic circuits : It performs those functions for which they are best suited, such as feed rate generation and interpolation.
2. Soft wired computer : The computer performs the remaining control functions plus other duties not normally associated with a conventional hard-wired controller.

According to type of controllers

2. Stage controller CNC systems



- It uses a computer to perform all the functions.
- The interpolation, feed rate generation and all other functions are performed by the computer with the help of software.
- The only hard-wired elements are those required to interface the computer with machine tool and operator’s console.

Advantages & Limitations of CNC machine tools

Advantages

- Ease of program input.
- Multiple program storage.
- Online part programming and editing.
- Use of advanced interpolation.
- Automatic tool compensation.
- Auto generation of part program for existing components.
- Change in system of units.

Limitations

- Higher investment cost.
- Higher maintenance cost.
- Requires specialised operators.

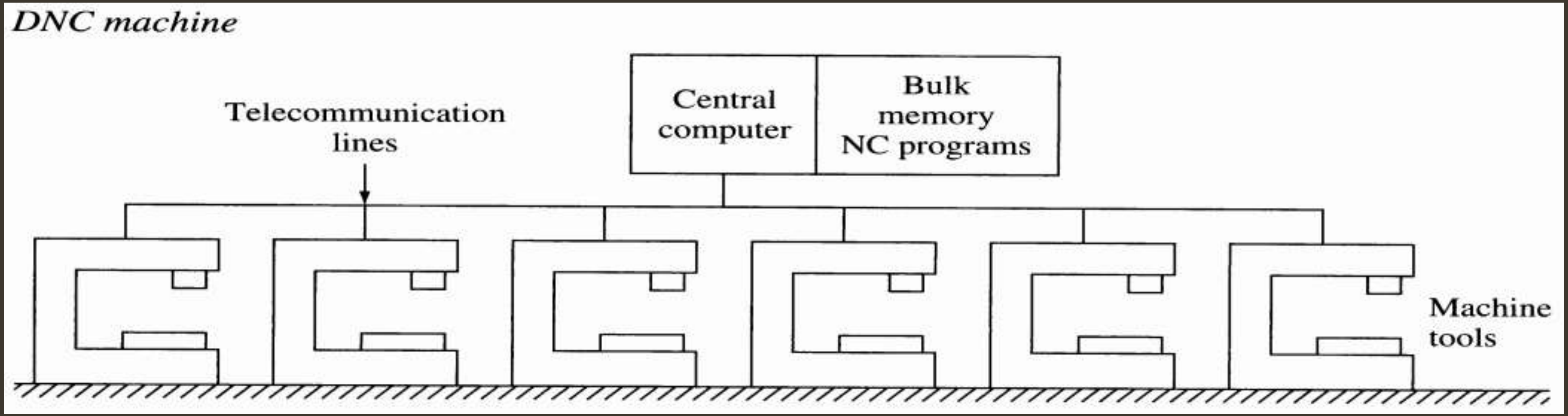
Introduction DNC

- DNC is a manufacturing system in which a number of machines are controlled by a computer through direct- connection and in real time.
- Also, defined by EIA as: DNC is a system connecting a set of NC machines to a common memory for part program or machine program storage with provision for on- demand distribution of data to machines.
- The tape reader is omitted.
- Involves data connection and processing from the machine tool back to the computer.

Components

1. Central computer
2. Bulk memory which stores the NC part programs.
3. Telecommunication lines
4. Machine Tools.

Principle



DNC machine
Telecommunication lines
Central computer
Bulk memory NC programs
Machine tools

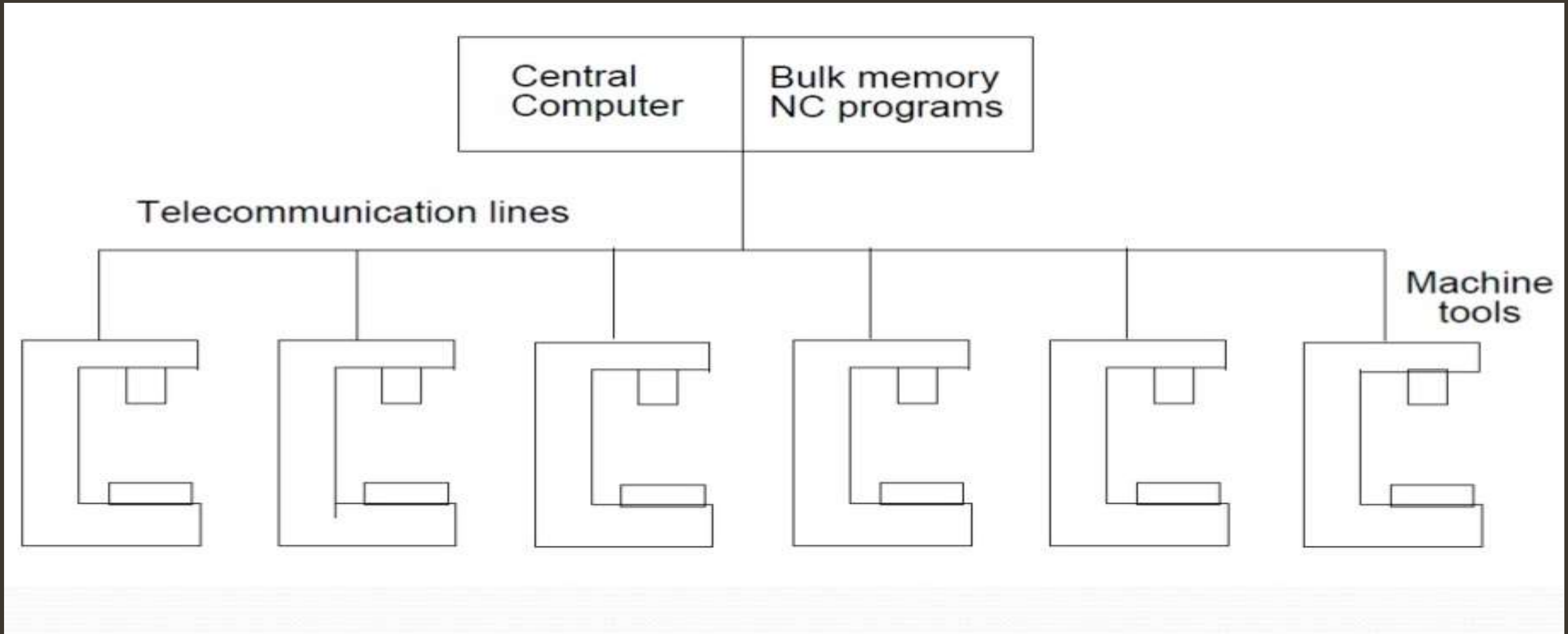
- A central computer connected to a number of machine tools and control them
- Part program of all machine tools are stored in the memory of the central computer and transmitted on direct transmission lines on demand
- Two way information flow take place in real time
- Various machine tools can communicate with the computer in real time
- Programs in full or segment can be transferred to NC machines
- Computer can be used for program editing
- No tape readers are used
- No limitation for the number or size of programs stored

The configuration of the DNC system can be divided into:

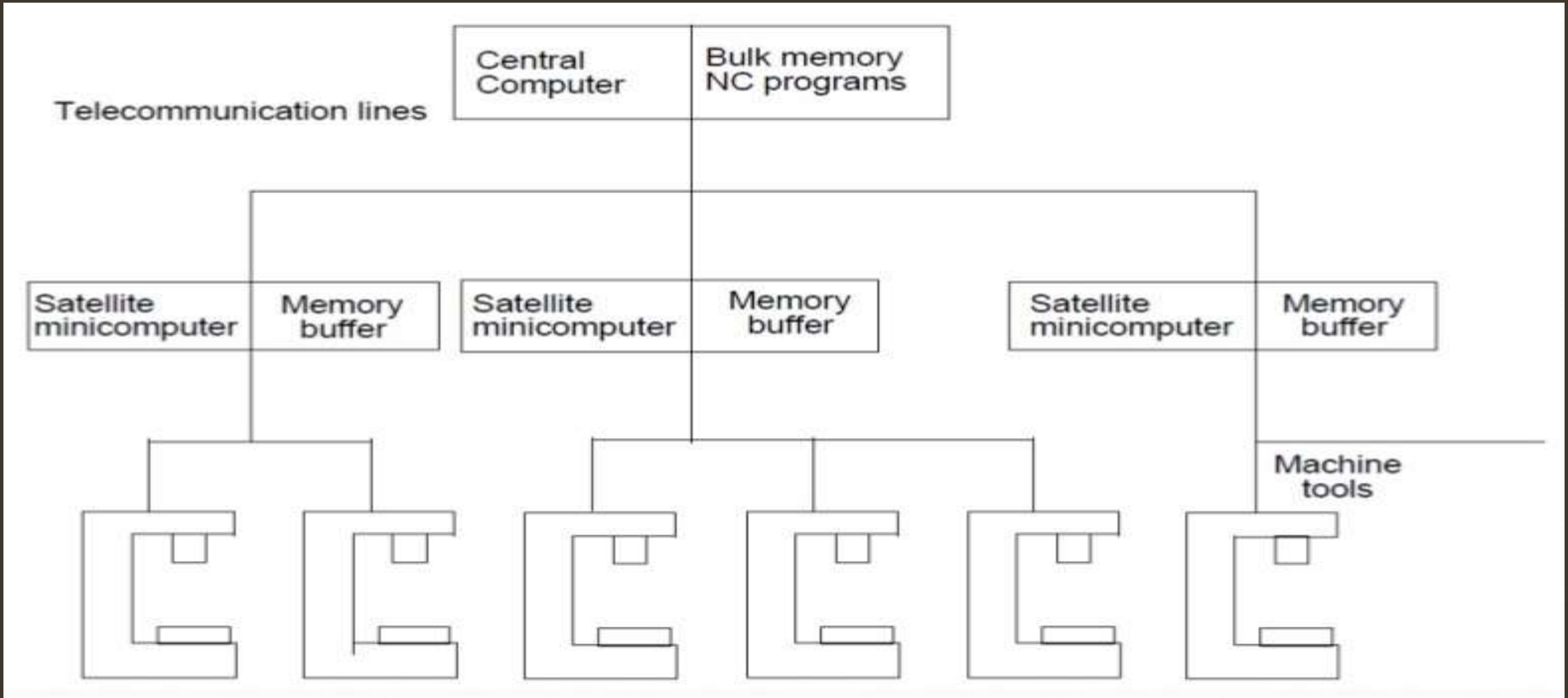
1. DNC system without satellite computer.
2. DNC system with satellite computer.

Satellite computers are minicomputers and they serve to take some of the burden off central computer. Each satellites controls several machine tools.

DNC system without satellite computer



DNC system with satellite computer



Functions of DNC

The functions which a DNC system is designed to perform:

1. NC without punched tape.
2. NC part program storage.
3. Data collection, processing, and reporting.
4. Communication

Advantages of DNC System

- Elimination of punched tapes and tape readers
- Convenient storage of NC part programs in computer files
- Greater computational capability and flexibility
- Reporting of shop performance.
- Convenient editing and diagnostic features.

Comparison between NC, CNC and DNC machine tools

NC Machine Tool System

1. The part program is fed to the machine through the tapes or other such media.
2. In order to modify the program, the tapes have to be changed.
3. In NC machine tool system, tape reader is a part of machine control unit.
4. System has no memory storage and each time it is run using the tape.
5. It can not import CAD files.
6. It can not use feedback system.
7. They are not software driven.

CNC Machine Tool System

1. In CNC machine tool system, the program is fed to the machine through the computer.
2. The programs can be easily modified with the help of computer.
3. The microprocessor or minicomputer forms the machine control unit. The CNC machine does not need tape reader.
4. It has memory storage ability, in which part program can be stored.
5. System can import CAD files and convert it to part program.
6. The system can use feedback system.
7. The system is software driven.

DNC Machine Tool System

1. The part program is fed to the machine through the Main computer
2. In order to modify the program, single computer is used
3. Large memory of DNC allows it to store a large amount of part program.
4. Same part program can be run on different machines at the same time.
5. The data can be processed using the MIS software so as to effectively carry out the Production planning and scheduling.

The End of Presentation
Thank you

ADAPTIVE CONTROL SYSTEMS

- SUBMITTED TO :-
- Dr. B.S. PABLA
- PROFESSOR
- MECHANICAL ENGG.
- NITTTR CHANDIGARH

- SUBMITTED BY:-
- SUMIT ATTRI
- ROLL NO. 152225
- 3rd SEM M.E.
- MECHANICAL ENGG.
- NITTTR CHANDIGARH

Introduction

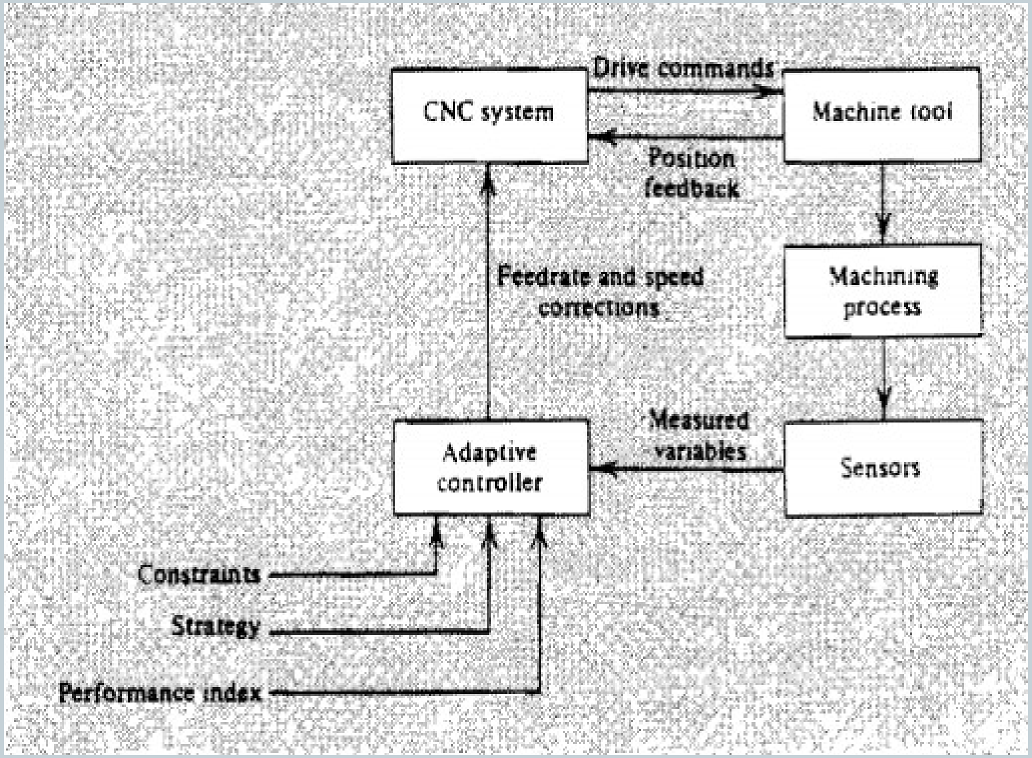
- Adaptive control system is a **logical extension** of the CNC-mechanism.
- In CNC mechanism the cutting speed and feed rates are prescribed by the **part programmer**.
- The determination of these operating parameters **depends on the Knowledge and experience** of programmer regarding the work piece, tool materials, coolant conditions and other factors.
- By contrast in adaptive control machining, there is **improvement** in the production rate and reduction in the machining cost as a result of calculating and setting of optimal parameters **during machining**.

Origin

- Adaptive control (AC) machining originated out of research in early **1970's** sponsored by **U.S Air Force**.
- The **initial** adaptive control systems were **based on analog devices**, representing the technology at that time.
- Today adaptive control uses **microprocessor** based controls and is typically **integrated** with an existing **CNC system**.

DEFINITION OF AC MACHINING

- For a machining operation the term AC denotes **control systems** that **measures** certain **output variables** and uses to control speed or feed.



- Some of the process variables that have been used in AC machining systems include spindle deflection or force, torque, cutting temperature and horse power.

- The adaptive control is basically a **feedback system** that treats the CNC as an internal unit and in which the machining variables **automatically** adapt themselves to the actual conditions of the machining process.
- Note:- IP (**Performance Index**) is usually an economic function such as max production rate or minimum machining cost.

Functions of AC

The three **functions** of adaptive control are:

- Identification function.
- Decision function.
- Modification function.
- The main idea of AC is the **improvement of the cutting process** by **automatic** on line determination of speed and/or cutting.
- The AC is basically **a feedback system** in which cutting **speed and feed automatically adapt themselves** to the actual condition of the process and are varied accordingly to the changes in the work conditions as work progresses.

IDENTIFICATION FUNCTIONS

- This involves determining the **current performance** of the process or system .
- The identification function is concerned with **determining the current value** of this performance measure by **making use of the feedback data** from the process.

DECISION FUNCTION

- Once the system performance is determined, the next function is to decide how the control mechanism should be **adjusted** to **improve** process performance.
- The decision procedure is carried out by means of a pre-programmed logic provided by the designer.

MODIFICATION FUNCTION

- The third AC function is to implement the decision.
- While the decision function is a logic function, modification **is concerned with a physical or mechanical change** in the system.
- The modification **involves changing the system parameters or variables** so as to drive the process towards a more **optimal state**.

WHERE TO USE ADAPTIVE CONTROL

- Adaptive control is not suitable for every machining situation.
- In general, the following characteristics can be used to identify situations where adaptive control can be beneficially applied.
- The **in-process time** consumes a significant portion of the machining cycle time.
- There are significant **sources of variability** in the job for which AC can compensate.
- The **cost of operating** the machine tool is high.
- The typical jobs involve steels, titanium and **high strength alloys.**

Classification of AC systems

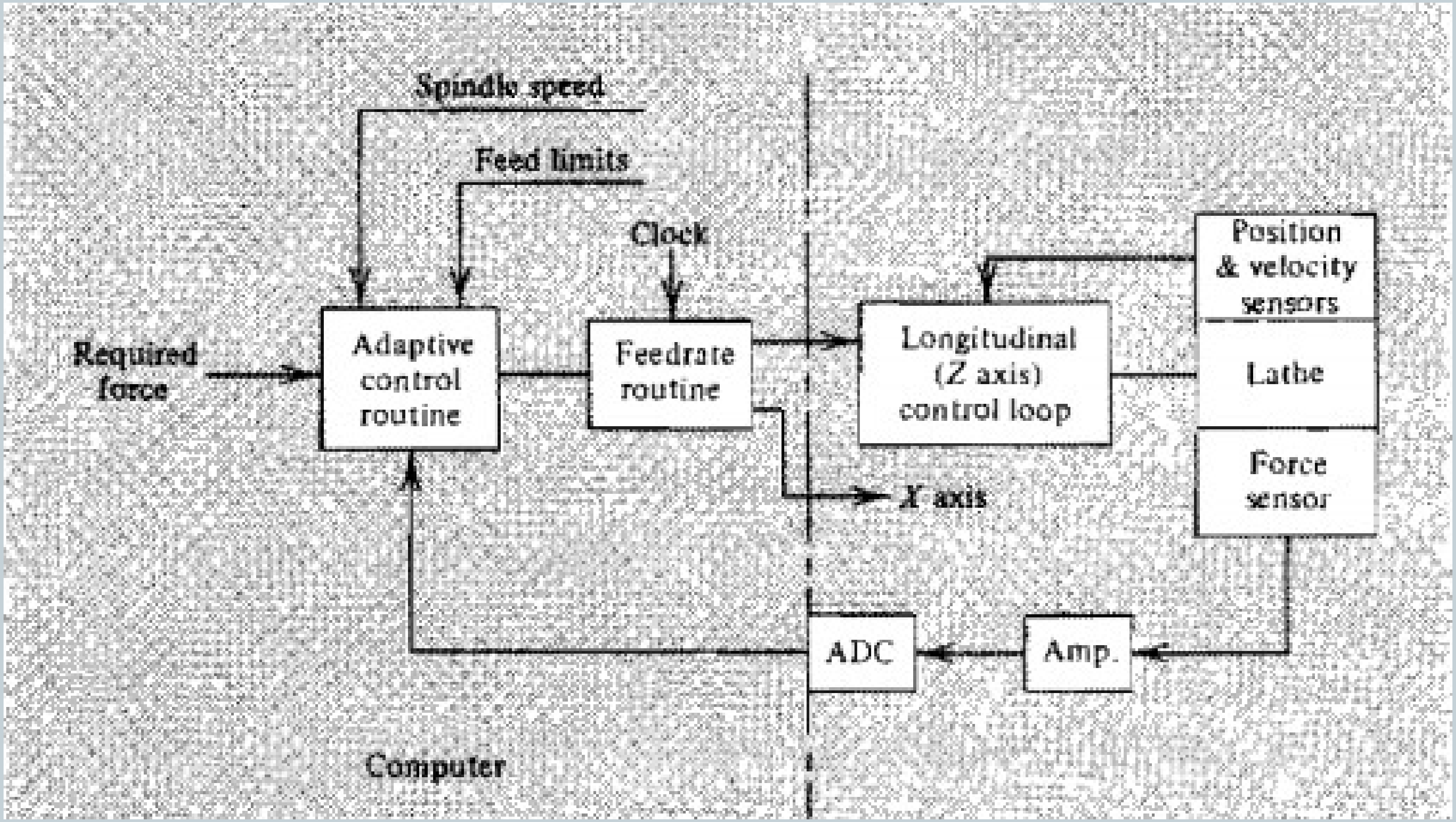
In practice the AC system of machine tools can be classified into two types:

- AC with optimization (**ACO**)
- AC with constrains (**ACC**)
- Geometric Adaptive Control (**GAC**)

ACC

- ACC are systems in which **machining conditions** such as spindle speed or feed rate **are maximized** within the **prescribed limits** of machines and tool **constrains** such as maximum torque, force or horse power.
- In AC system the correct feed and speed are **automatically found** and it is not necessary to spend efforts on calculations of optimum feeds and speeds.
- ACC systems do not utilize a performance index and are based on **maximizing a machining variable** (e.g., feed rate) subject to process and machine constraints (e.g., allowable cutting force on the tool, or maximum power of the machine).
- The **objective** of most ACC types of systems is to increase the MRR during rough cutting operations.

Basic Structure of ACC



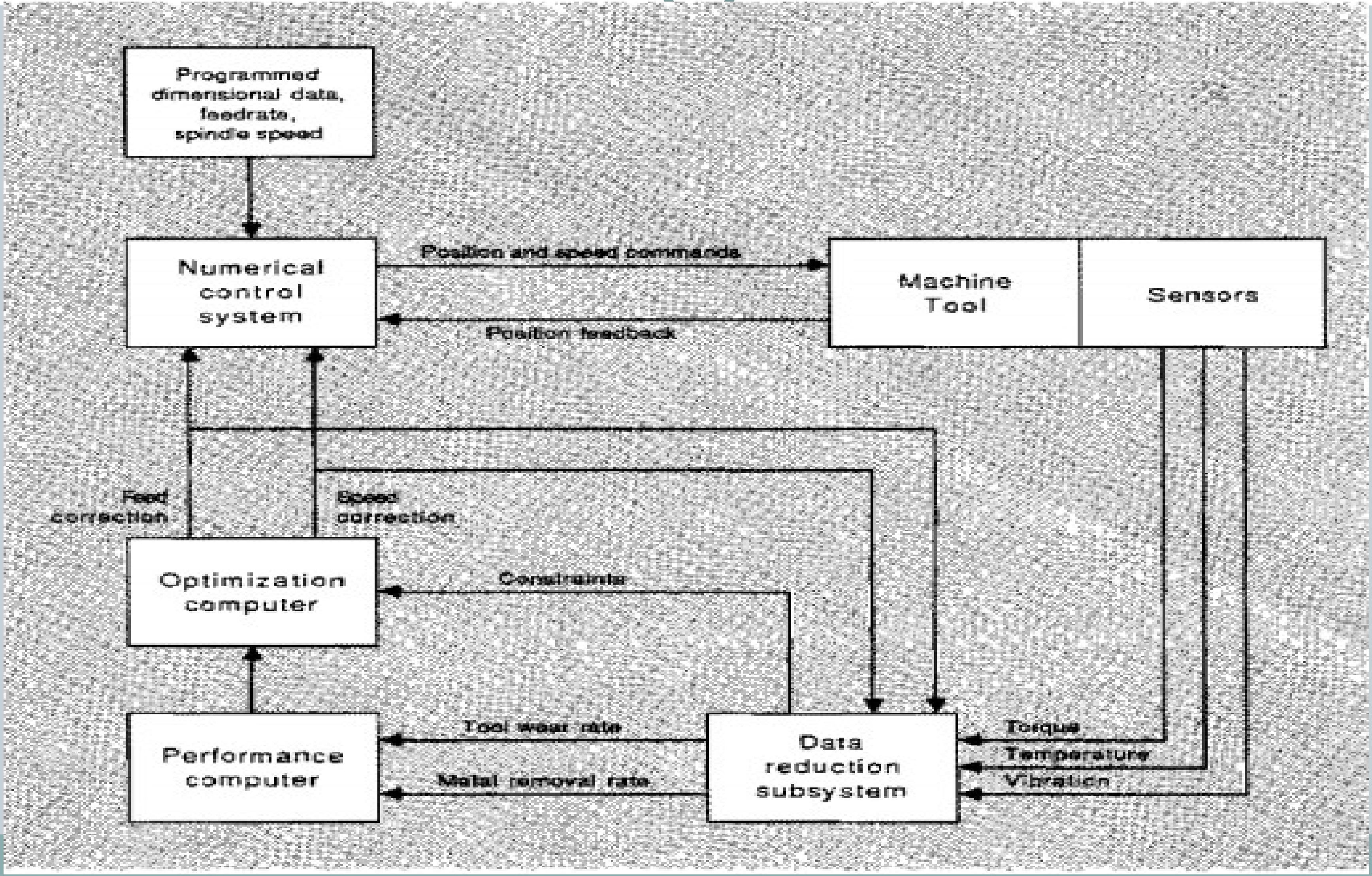
ACC Example

- For example, to **maximize** the machining feedrate while maintaining a **constant load** on the cutter, despite variations in width and depth of cut.
- In a **normal CNC** system, the feedrate is programmed to accommodate the largest width and depth in a particular cut, and this small feedrate is maintained along the entire cut. As a result the machining rate is reduced.
- By contrast, with the **ACC system**, the maximum allowable load (e.g., cutting force) on the cutter is programmed.
- As a result, when the width or depth of cut are small the feedrate is high; when either the width or depth of cut (or both) are increased, the feedrate is automatically reduced, and consequently the allowable load on the cutter is not exceeded.
- The **result** is, the average feed with ACC is much larger than its programmed counterpart.

ACO System

- The ACO Systems for N/C machine tools is a control system that **optimizes performance index** subjects to various constraints.
- It is basically a sophisticated closed loop control system, which **automatically works in optimum conditions**, even in the presences of work piece and tools materials variations.

Basic Structure of ACO System



Drawback of ACO

- The **main problem** is that this require on-line measurement of tool wear.
- So far there have been no industrially acceptable methods developed for the direct measurement of tool wear.
- Indirect measurement assumes that tool wear is proportional to other measurable variables such as cutting forces and temperatures.
- The drawback of using these indirect measurements is that variations in their values can be caused by process variations other than tool wear, such as workpiece hardness or cutting conditions.
- Thus making it difficult to identify the tool wear effect from the effect of the other parameter variations on the measurements.

GEOMETRIC ADAPTIVE CONTROL

- GAC are typically **used in finish machining** operations.
- In GACs the part quality is maintained in real time by compensating for the deflection and wear of cutting tools.
- The objective of GAC is to achieve:-
- (1) the required dimensional accuracy and
- (2) a consistency of surface finish of machined parts

despite tool wear or tool deflection

Drawback of GAC

- Both the dimensional accuracy and the surface finish are affected by the flank wear and the crater wear of the tools which deteriorate during cutting.
- These variables cannot be measured in real time; neither can they be accurately predicted from off-line tool testing.

Benefits of AC

- Increased production rates.
- Increased tool life.
- Greater part protection.
- Less operator intervention.

Limitations

- A major drawback is the unavailability of suitable sensors that have a reliable operation in a manufacturing environment . (Tool wear sensor).
- Another problem is the interface of an AC system with CNC units. As yet, manufacturers have not standardized interfaces.

Sources

- Adaptive Control Systems for Machining by YORMI KOREN
  Dept of Mechanical Engineering and Applied Mechanics,
  The University of Michigan.
- CAD/CAM Computer aided design and Manufacturing,
  M.P.Groover


Thank You

ROBOT DEFINITION ACCORIDING TO INERNATIONAL STANDARD ORGANISATION (ISO)

An industrial robot is an automatic, servo control, freely programmable, manipulator, with several areas for the handling of workpiece , tool and special devices . Variably programmed operations of a robot make a better execution of a multiplicity of tasks possible.

APPLICATIONS OF ROBOT

The following robotic applications are the most common in the automotive industry:

1. **Collaborative Robots**

These collaborative robots are built to work together with other robots, on enormous assembly lines. Robots must collaborate between handling and welding robots to make such assembly lines function properly.

2. **Robotic Painting**

Professional painters are difficult to find and the job is a highly toxic one. This makes it perfect for robots, because the paint job needs to be highly consistent over a large area of paint, and reducing the amount of wasted material can add up to quite a bit of savings over time.

3. Robotic Welding

Robotic welding has been the top robotic application in the automotive sector for a long time, as every car needs a high number of welds before it’s complete. Given the high value of the finished product, productivity from automation is enormous.

4. Robotic Assembly

In many automotive plants, robots are assembling smaller components like pumps and motors at high speeds. Often, robots are performing tasks like windshield installation and wheel mounting to increase throughput.

5. Material Removal

High consistency and repeatability make robots perfect for material removal processes like trimming and cutting. This could be in the form of cutting fabrics, trimming plastic moldings and die castings or even polishing molds.

6. Part Transfer and Machine Tending

Pouring molten metal, transferring metal stamps, and loading and unloading CNC machines are all best completed by a robot as they are dangerous. When completed consistently with little downtime they can also be a source of major productivity.

Robots have been used in the automotive industry for a long time, and while today they are used in many different ways, but the 6 applications mentioned above are some of the most common uses of robotics in this industry.

OVERVIEW

- Classification of Industrial Robots
- Work Volume
- Arm Configuration
- Advantages and Disadvantages of Robot Configurations

CLASSIFICATION OF ROBOTS

1. Based on Robot Arm Configuration
   - *Cartesian coordinate*
   - *Cylindrical coordinate*
   - *Polar coordinate*
   - *Jointed arm configuration*

2. Based on Power Source
   - *Pneumatic*
   - *Hydraulic*
   - *Electric*

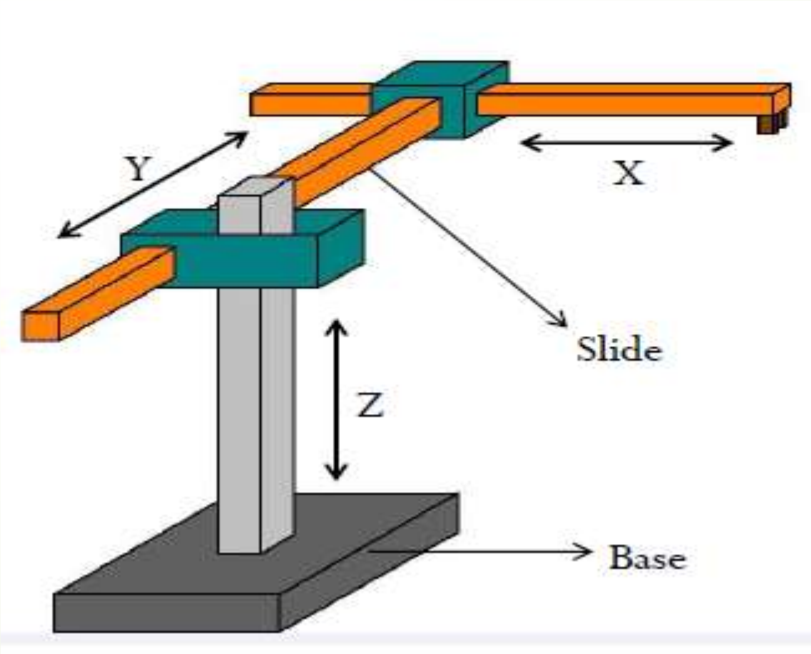
3. Based on path control
   - *Limited Sequence Robot*
   - *Point to point control*
   - *Path controlled Robot*

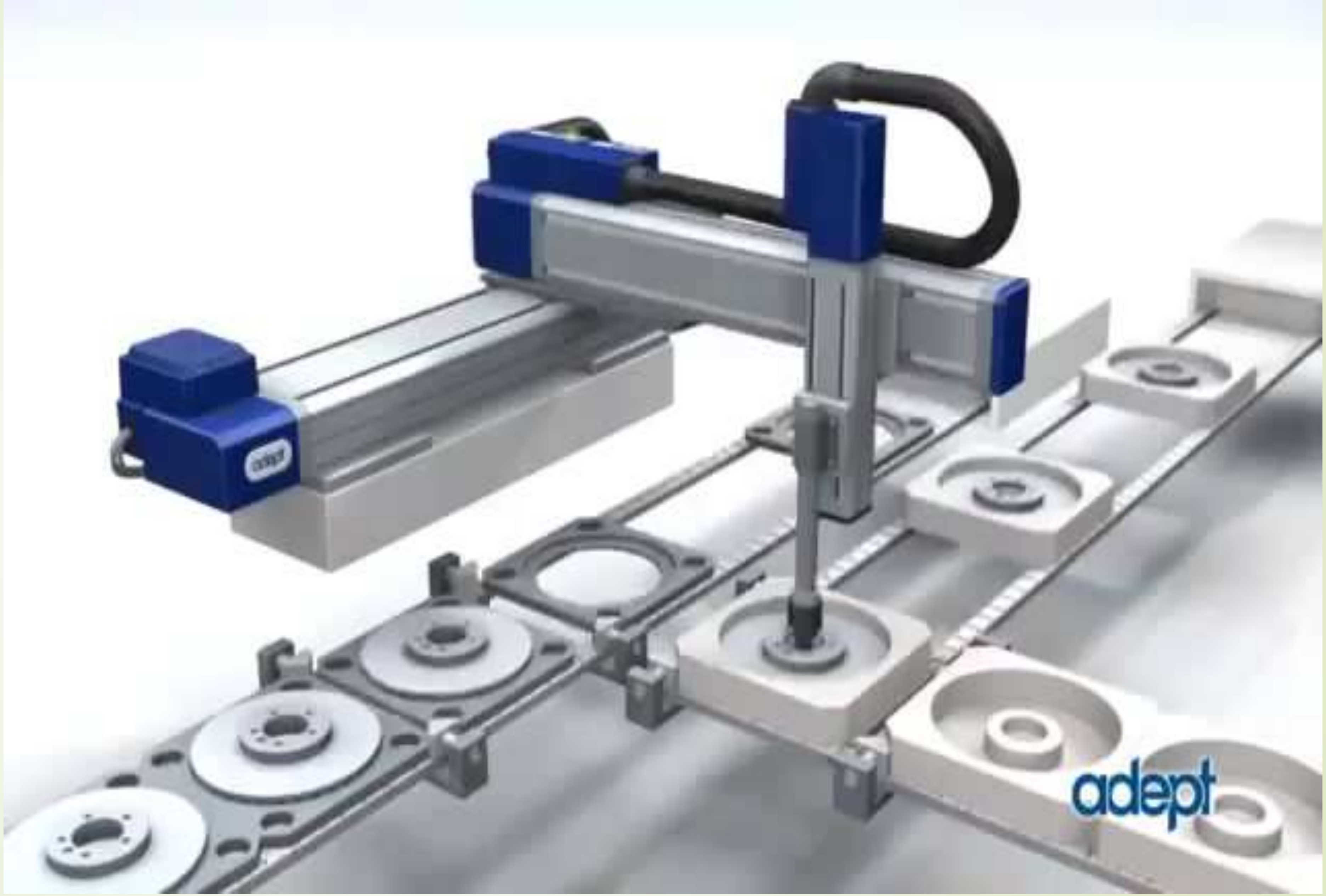
WORK VOLUME

- Work volume or work envelope refers to the space within which the robot can manipulate its wrist end.
- *For defining the work volume, the wrist end convention is adopted to avoid the complication of different sizes of end effectors that might be attached to the robot's wrist.*
- The work volume is determined by the following physical characteristics:
  1. Robot's physical configuration.
  2. Sizes of the body, arm and wrist components.
  3. Limits of robot's joint movements.

ARM CONFIGURATION

- *Cartesian Coordinate System*
  - In this there are three orthogonal directions X,Y and Z.
  - X-coordinate axis may represent left and right motion.
  - Y-coordinate axis may represent forward and backward motion.
  - Z-coordinate axis may represent up and down motions.
  - Example of Cartesian System is *Overhead Crane Movement.*

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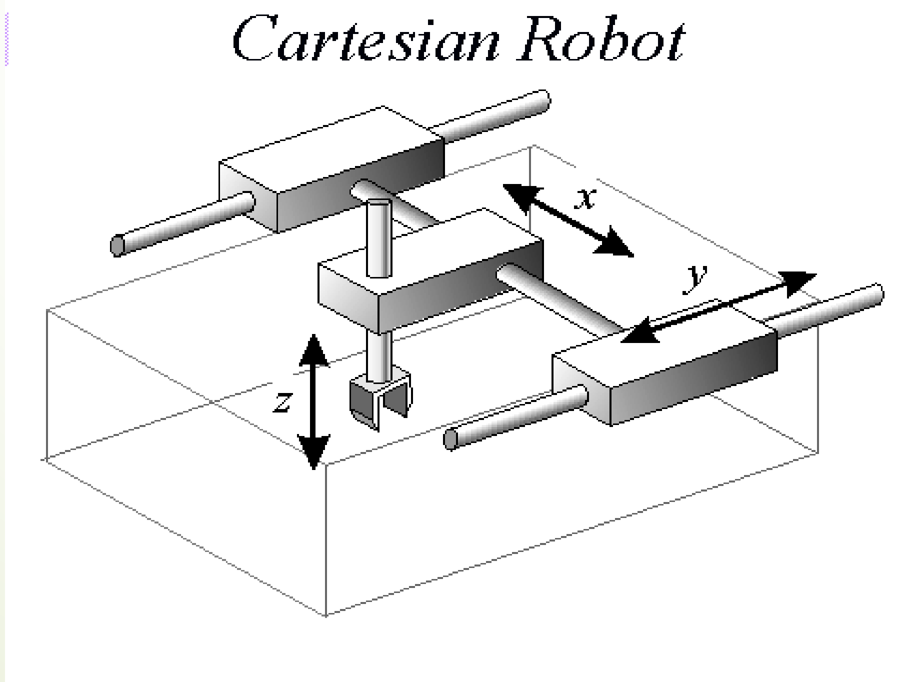
Working Envelope of Cartesian Configuration Robot

- The working envelope of the Cartesian configuration is a *rectangular prism.*
- The robot can manipulate its maximum payload throughout the working volume.



Advantages:

- Work envelope can be increased by travelling along the x axis.
- Linear movement and hence simpler control.
- High degree of accuracy and repeatability due to their structure.
- Can carry heavier loads since load carrying capacity does not differ at different position of the work envelope.

Disadvantages:

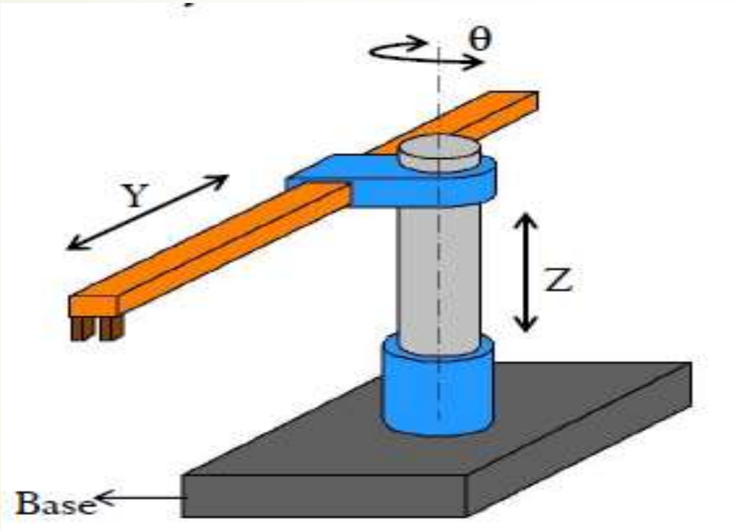
- Movement is limited to only one direction at a time.

Applications:

- Pick and place operation.
- Adhesive applications.
- Assembly and sub assembly.
- Nuclear material handling.
- Welding

Cylindrical Configuration Robot

- It uses a vertical column and a slide that can be moved up or down along the column.
- The robot arm is attached to the slide so that it can be moved radially with respect to the column.
- By rotating the column, the robot is capable of achieving a work space that approximates a cylinder.
- It contains *two linear motions and one rotational motion.*
- *Angular Motion, θ along vertical axis; Translation Motion, z along z-direction that corresponds to up and down motion; Radial, r in or out translation.*



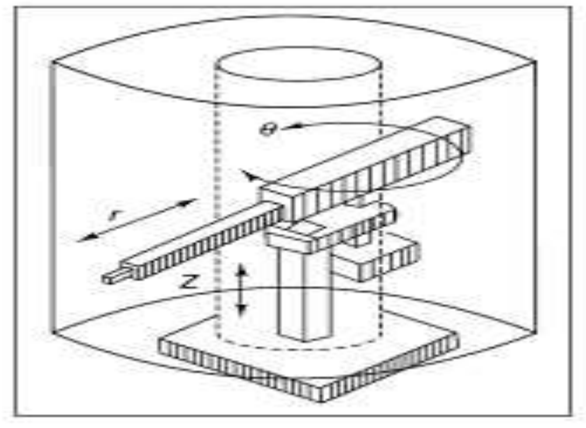
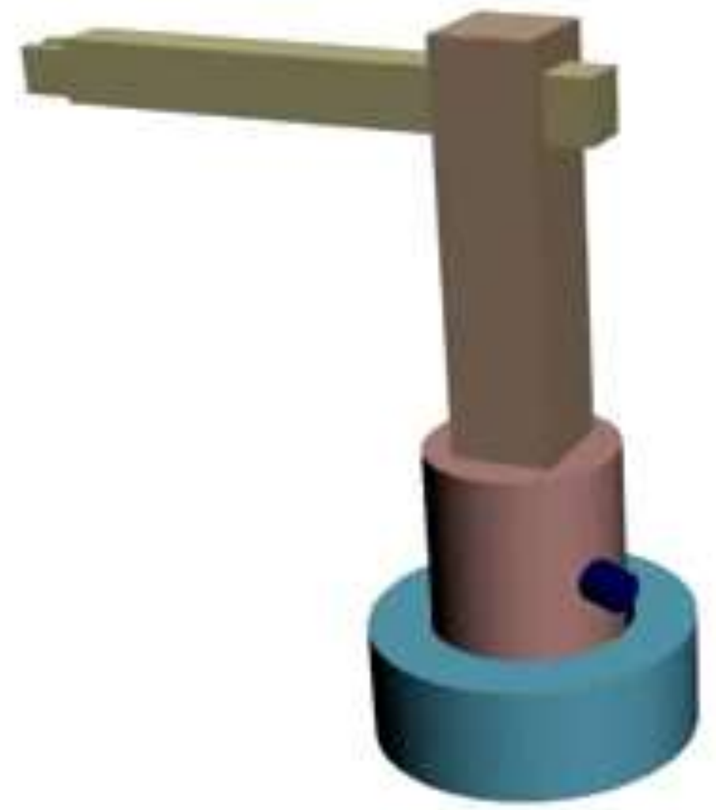
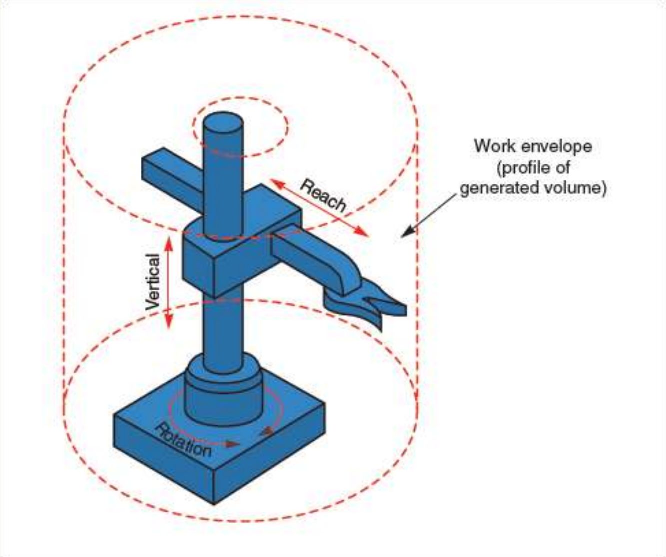


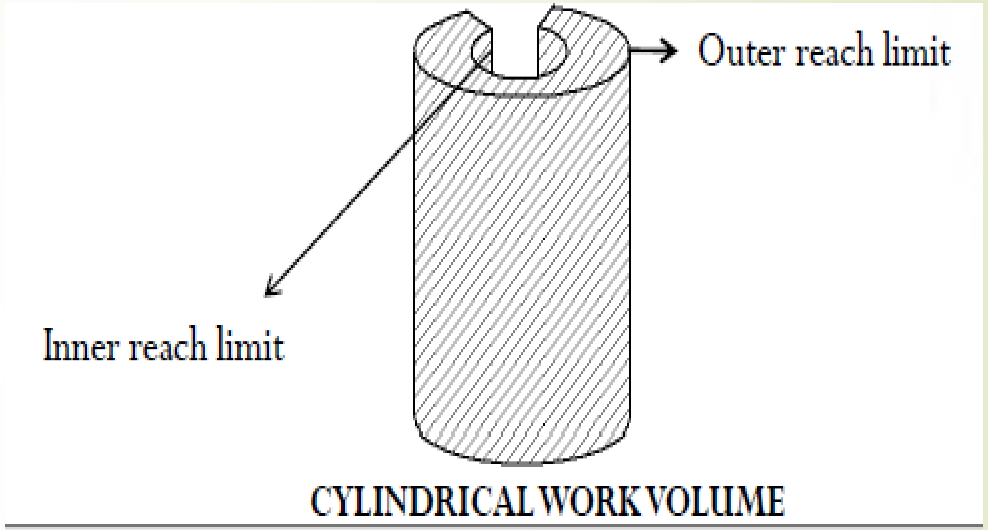
FIG. 1.13 Cylindrical coordinates



Working Envelope of Cylindrical Configuration Robot

- The working envelope of this configuration is as its name suggests a *cylinder.*





Advantages

- Results in larger work volume than a rectangular manipulator.
- Vertical structure conserves floor space.
- Capable of carrying large payloads.

Disadvantages

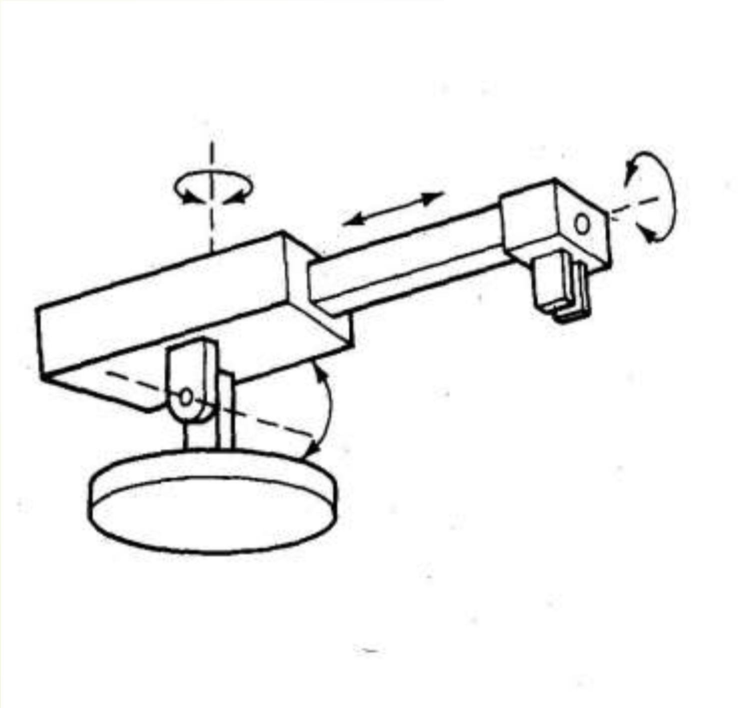
- Repeatability and accuracy are lower in the direction of rotary motion.
- Requires more sophisticated control system.

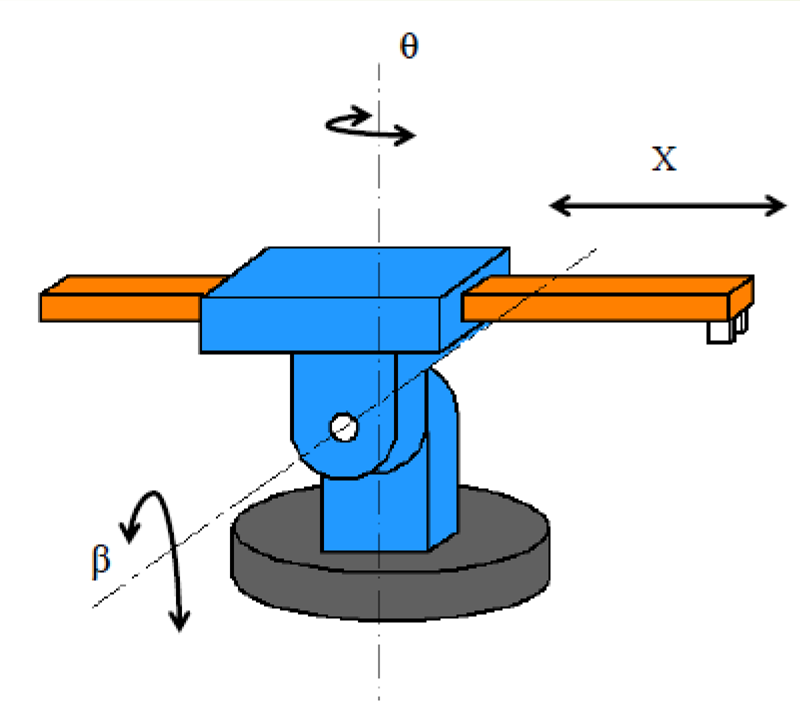
Applications

- Assembly.
- Coating application
- Die casting.
- Foundry and forging application
- Machine loading and unloading.

Polar Configuration Robot

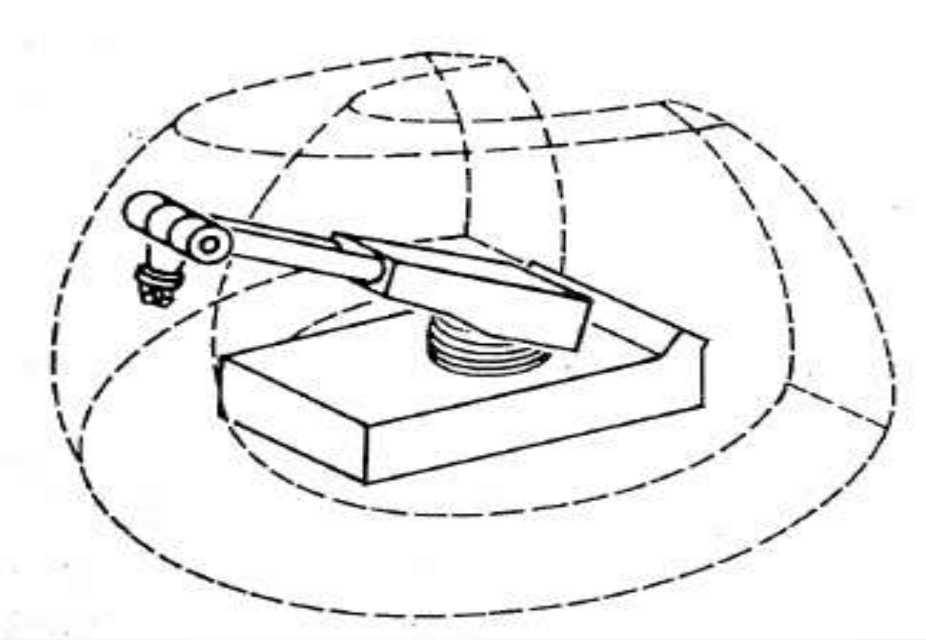
- It uses a arm that can be raised or lowered about a horizontal pivot.
- The pivot is mounted on a rotating base.
- The various joints provide the robot with capability to move its arm within a spherical space, and hence it is also called as *" Spherical Coordinate Robot."*
- It has *one linear and two rotary motions.*
- The UNIMATE 2000 series is an example of spherical robot.





Work Volume of a Polar configuration Robot

- The work volume of a polar configuration robot is in the form of a *sphere.*
- It consist of one linear and two angular motions.
- *The linear motion, r, corresponds to a radial in or out translation.*
- *The angular motion corresponds to a base rotation, θ, about a vertical axis.*
- *Another angular motion, β, about an axis which is perpendicular to the vertical through the base and sometimes is termed as elbow rotation.*



Advantages

- Larger work envelope than the rectilinear or cylindrical configuration.
- Vertical structure conserves less space.

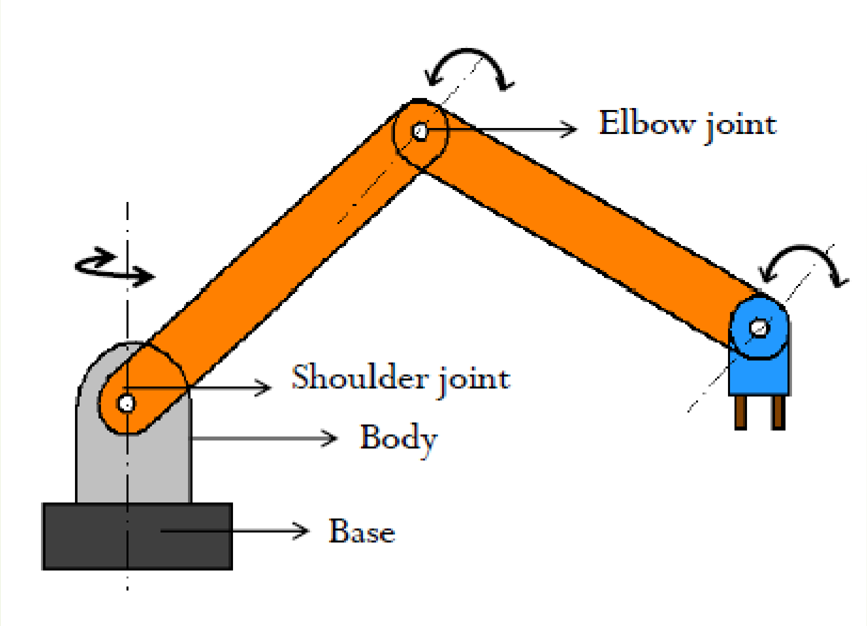
Disadvantages

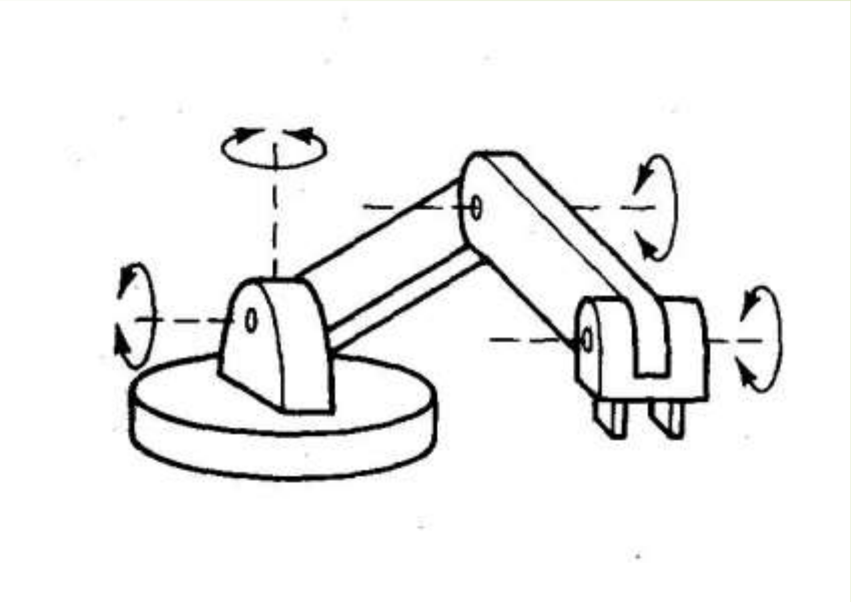
- Repeatability and accuracy are also lower in the direction of rotary motion.
- Requires more sophisticated control system.

Applications

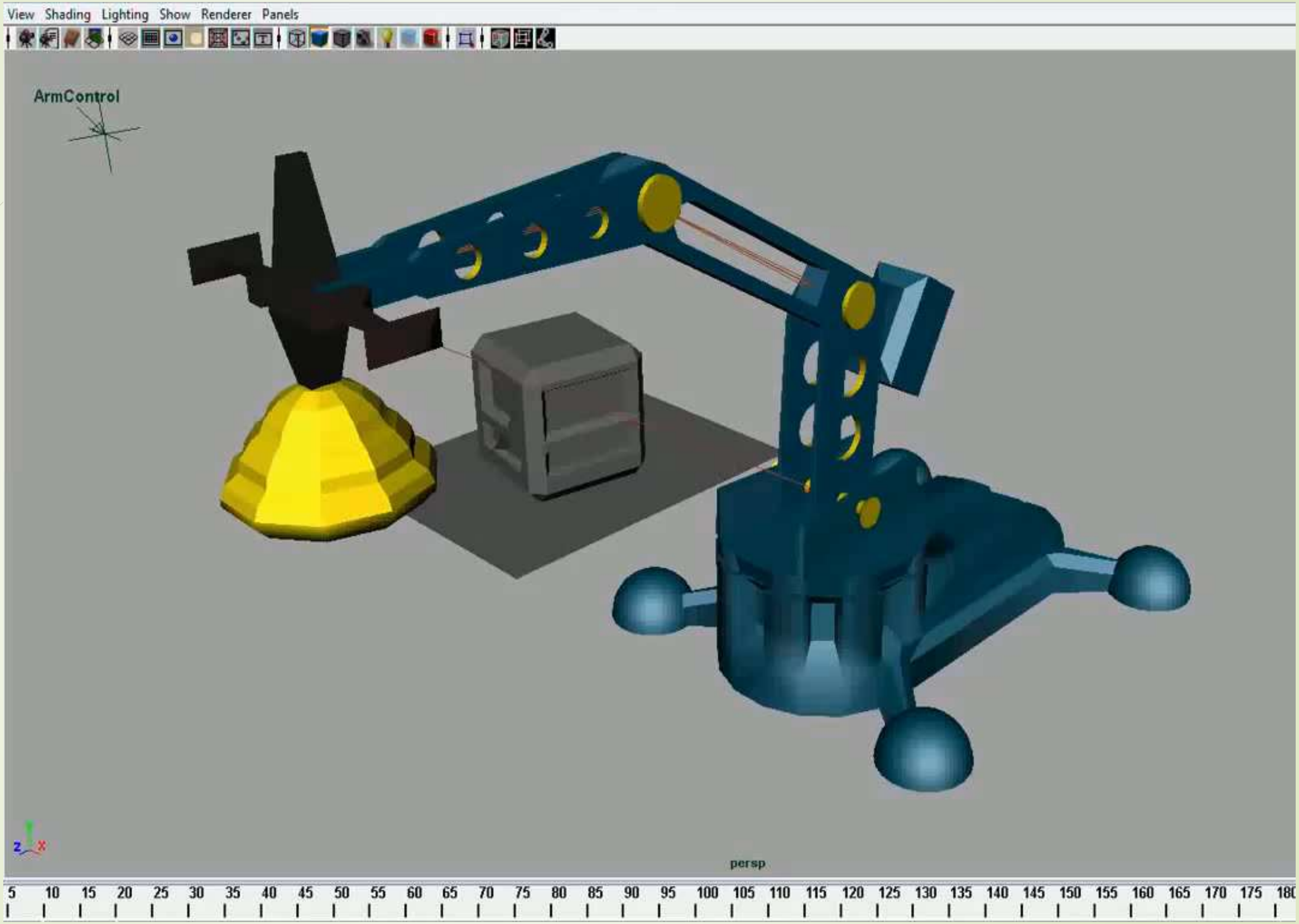
- Die casting.
- Forging.
- Glass handling.
- Injection molding.
- Stacking and unstacking.

- *Jointed Arm Configuration*
  - Its configuration is similar to that of a human arm.
  - These components are connected by two rotary joints corresponding to shoulder and elbow.
  - A wrist is attached to the end of forearm, thus providing several additional joints.
  - Cincinnati Milacron T3 (Model 776) robot is a commercially available.






Cargotech
Cargotech


View Shading Lighting Show Renderer Panels
ArmControl
persp
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155 160 165 170 175 180

Work Envelope of Jointed-Arm Configuration

- It is similar to the configuration of a human arm.
- It consists of a vertical column that swivels (rotate) about the base using a T-joint.
- Shoulder joint (R-joint) is located at the top of the column.
- The output link is an elbow joint (another R joint).

SCARA Robot

- SCARA is a special type of jointed arm configuration.
- It stands for ***Selective Compliance Automated Robot Arm (or) Selective Compliance Articulated Robot Arm.***
- It is similar to jointed-arm except that the vertical axes are used for shoulder and elbow joints to be compliant in horizontal direction vertical insertion tasks.

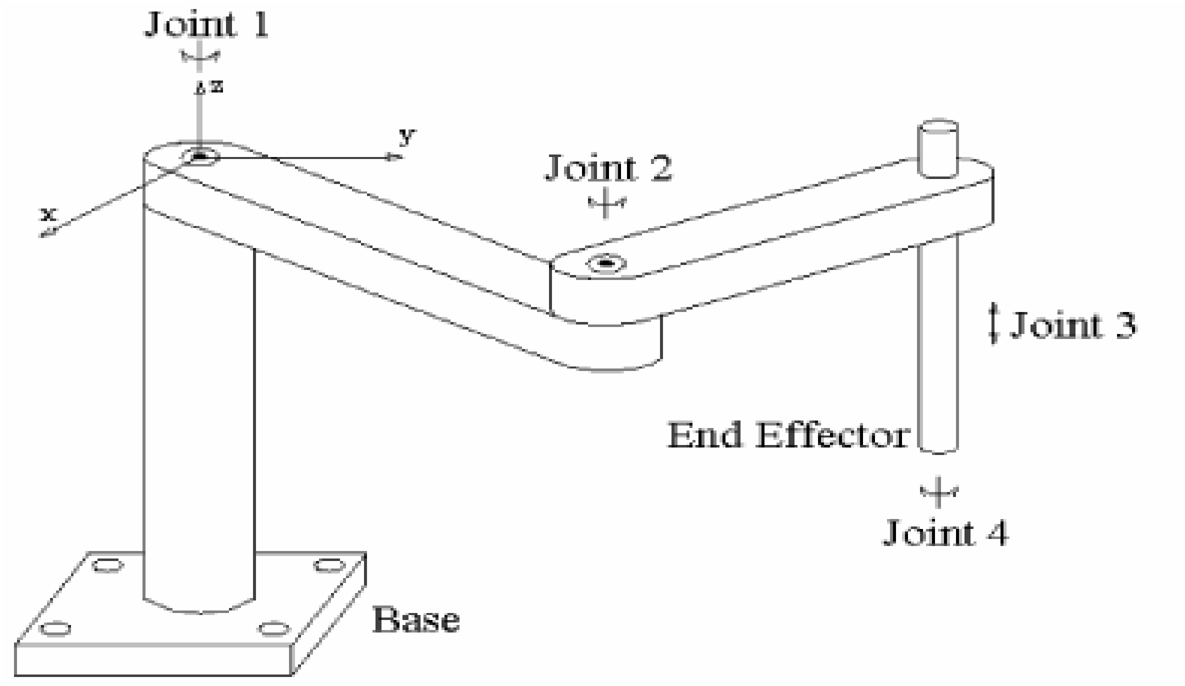
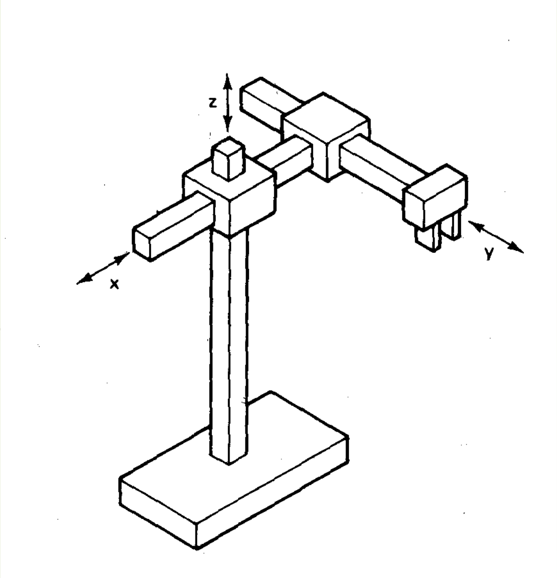


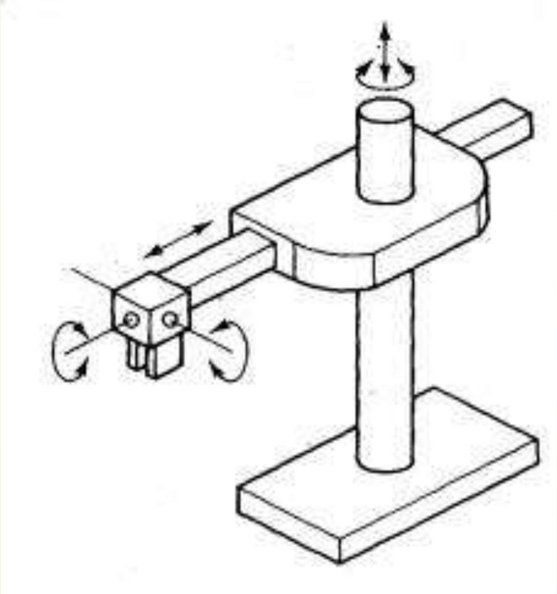
Figure 5. SCARA - Selective Compliance Assembly Robot Arm.

JOINT NOTATION SCHEME

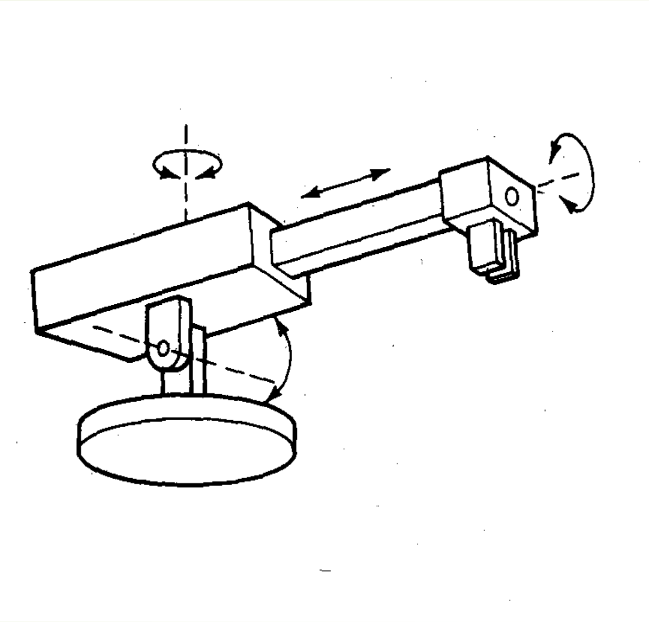
- The physical configuration can be described by means of a joint notation scheme.
  - *L-Linear Joint*
  - *T-Twisting Joint*
  - *R-Rotational Joint*
  - *V-Revolving Joint*



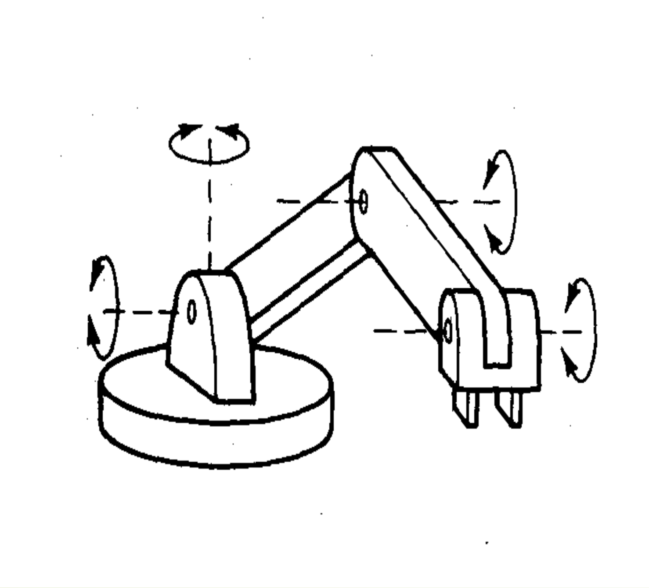
Robots with *Cartesian Configurations* consists of links connected by linear joints (L) - ***LLL***



Robots with *Cylindrical Configuration* have one rotary (R) joint at the base and linear (L) joints succeeded to connect the links - ***TLL***

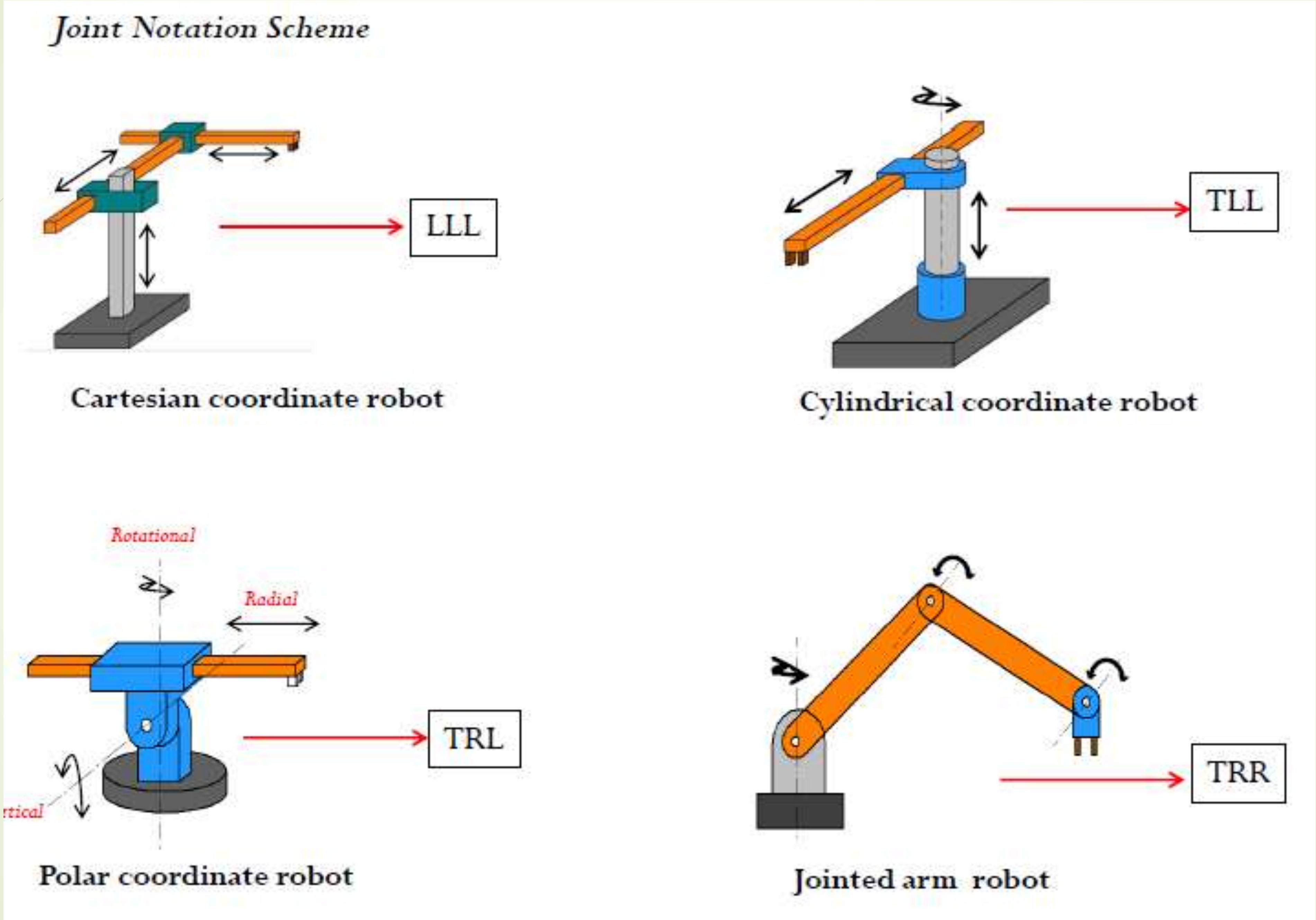


Polar Configuration Robot, the arm is connected to the base with a twisting (T) joint and rotatory (R) and linear (L) joints follow - ***TRL***



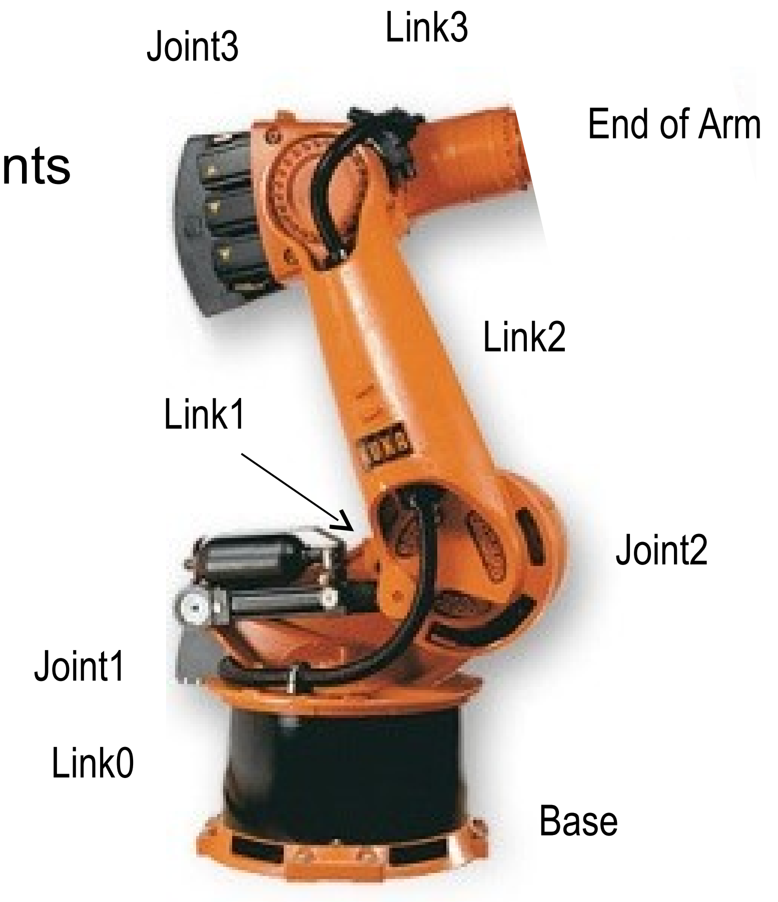
Joint Arm Configuration, the arm of the robot is connected to the base with a twisting joint. The links in the arm are connected by rotatory joints - ***TRR***

Robot Configuration (Arm and Body)	Symbol
Polar Configuration	TRL
Cylindrical Configuration	TLL,LTL,LVL
Cartesian Configuration	LLL
Jointed Arm Configuration	TRR, VVR


Joint Notation Scheme
LLL
Cartesian coordinate robot
TLL
Cylindrical coordinate robot
Rotational
Radial
TRL
Polar coordinate robot
TRR
Jointed arm robot

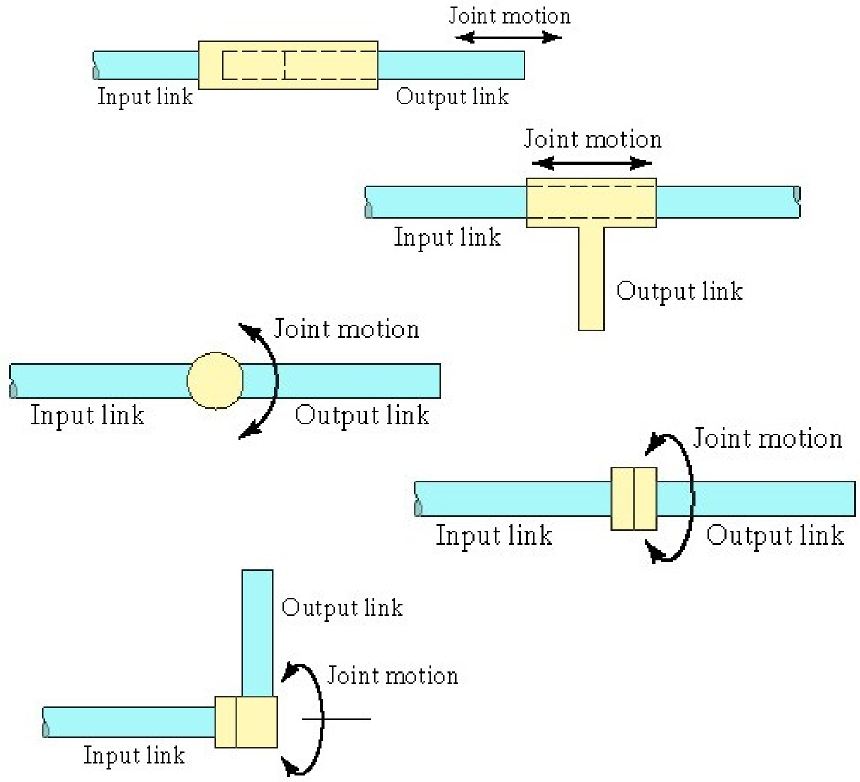
Robot Anatomy

- Manipulator consists of joints and links
  - Joints provide relative motion
  - Links are rigid members between joints
  - Various joint types: linear and rotary
  - Each joint provides a “degree-of-freedom”
  - Most robots possess five or six degrees-of-freedom
- Robot manipulator consists of two sections:
  - Body-and-arm – for positioning of objects in the robot's work volume
  - Wrist assembly – for orientation of objects



Manipulator Joints

- Translational motion
  - Linear joint (type L)
  - Orthogonal joint (type O)
- Rotary motion
  - Rotational joint (type R)
  - Twisting joint (type T)
  - Revolving joint (type V)

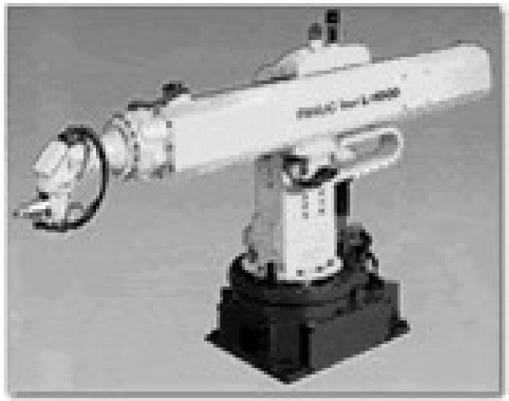


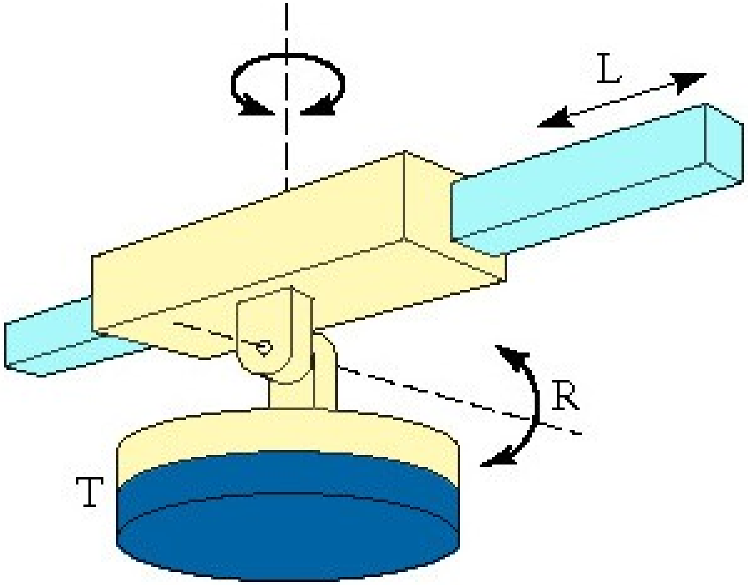
Joint Notation Scheme

- Uses the joint symbols (L, O, R, T, V) to designate joint types used to construct robot manipulator
- Separates body-and-arm assembly from wrist assembly using a colon (:)
- Example: TLR : TR
- Common body-and-arm configurations …

Polar Coordinate Body-and-Arm Assembly

- Notation TRL:

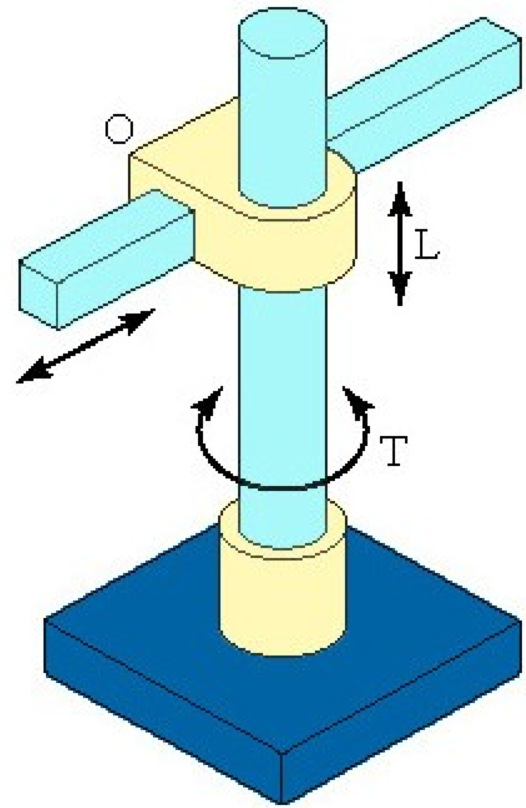




- Consists of a sliding arm (L joint) actuated relative to the body, which can rotate about both a vertical axis (T joint) and horizontal axis (R joint)

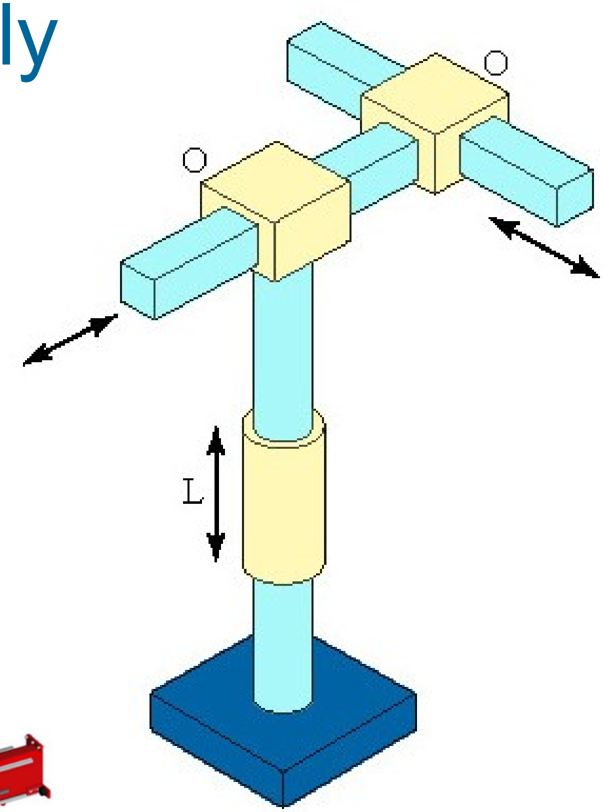
Cylindrical Body-and-Arm Assembly

- Notation TLO:

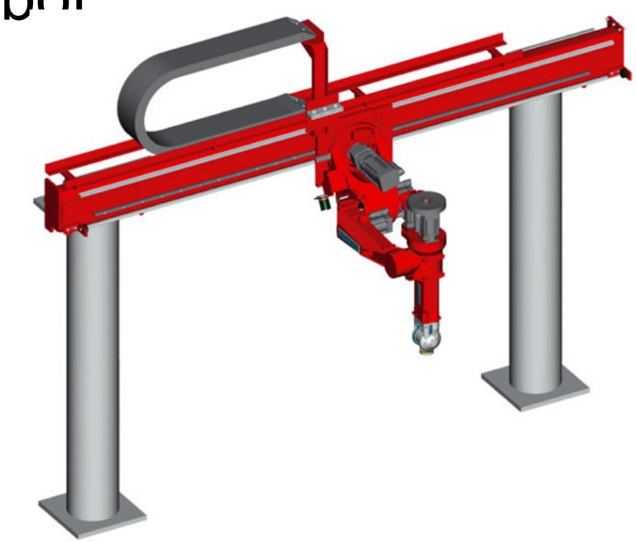


- Consists of a vertical column, relative to which an arm assembly is moved up or down
- The arm can be moved in or out relative to the column

Cartesian Coordinate Body-and-Arm Assembly

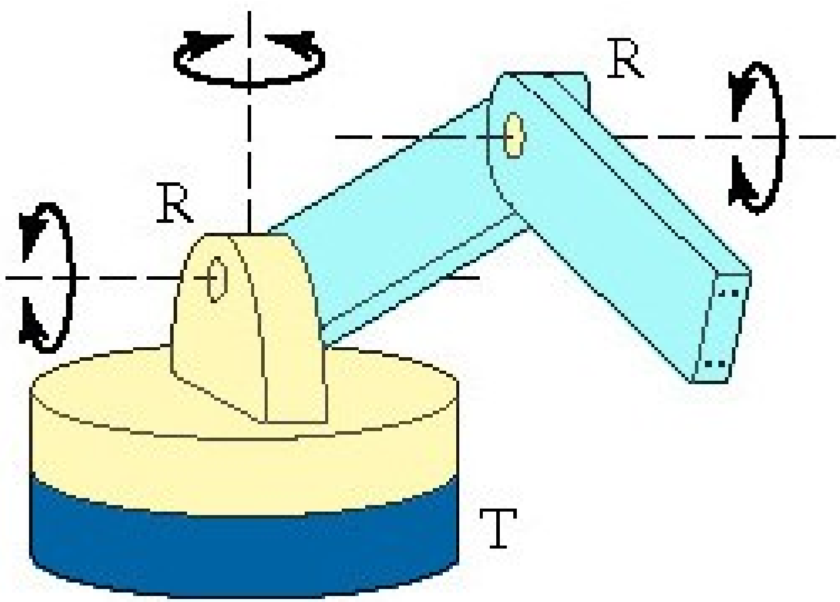


- Notation LOO:
- Consists of three sliding joints, two of which are orthogonal
- Other names include rectilinear robot and x-y-z robot

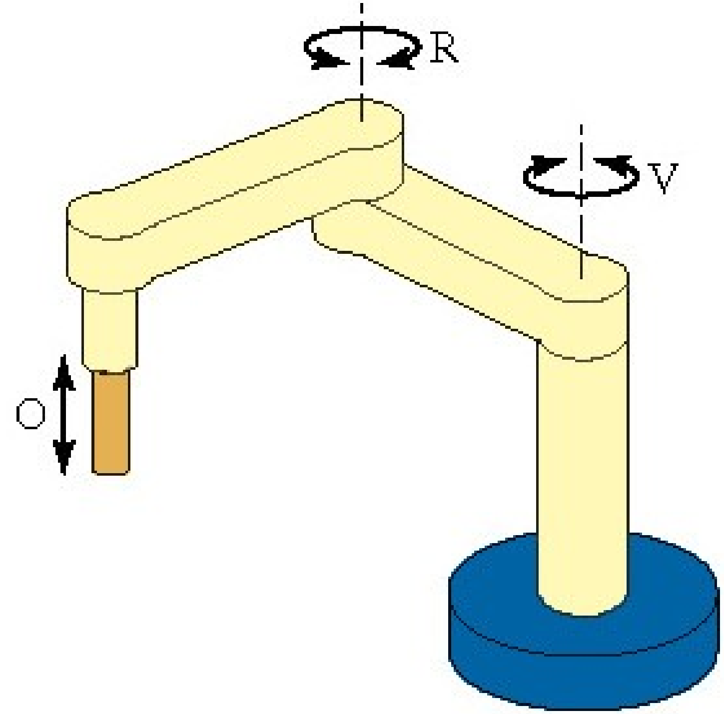


Jointed-Arm Robot

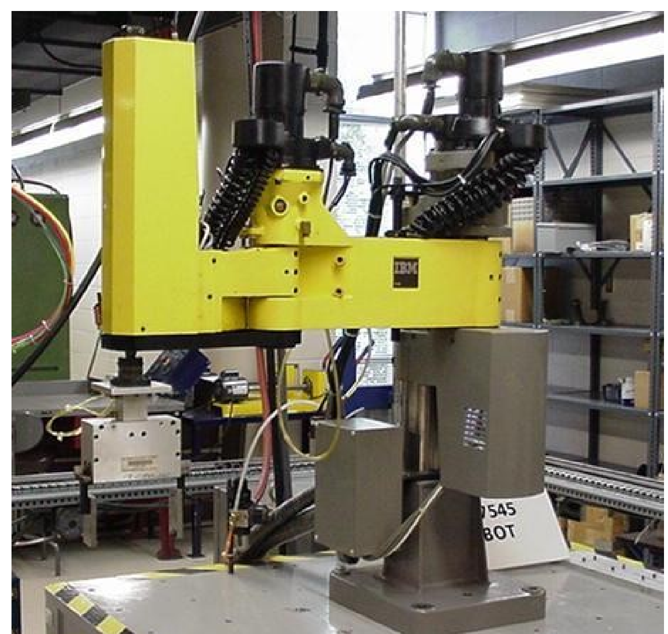
- Notation TRR:



SCARA Robot

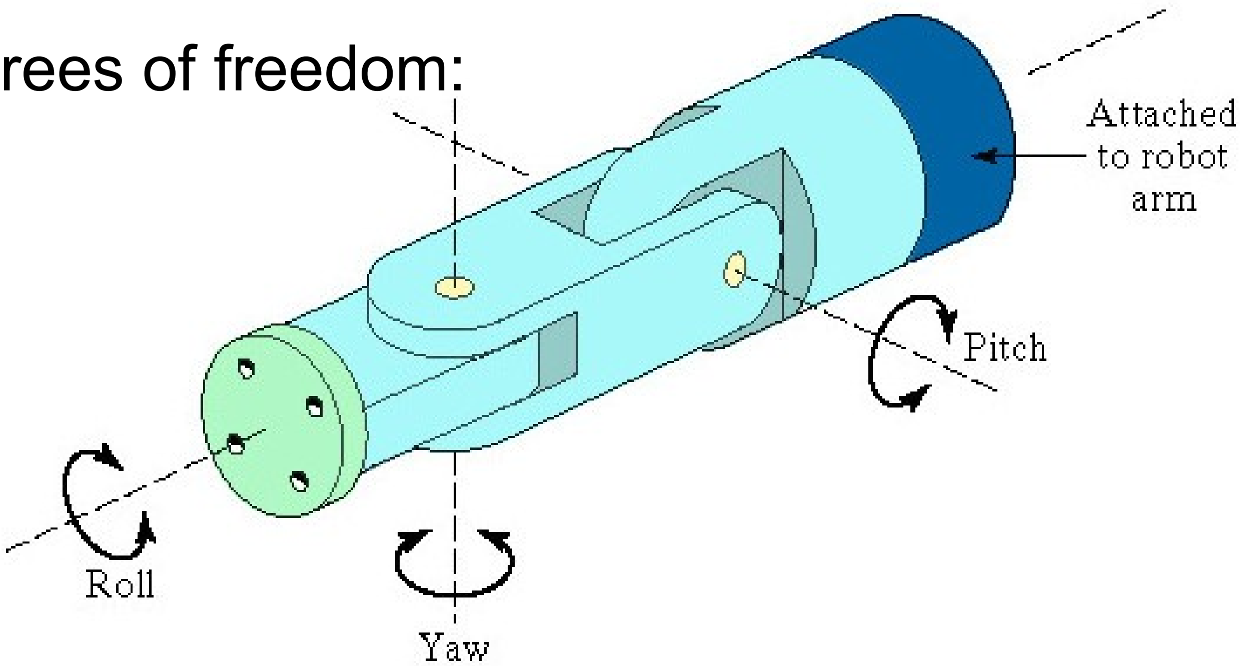


- Notation VRO
- SCARA stands for Selectively Compliant Assembly Robot Arm
- Similar to jointed-arm robot except that vertical axes are used for shoulder and elbow joints to be compliant in horizontal direction for vertical insertion tasks



Wrist Configurations

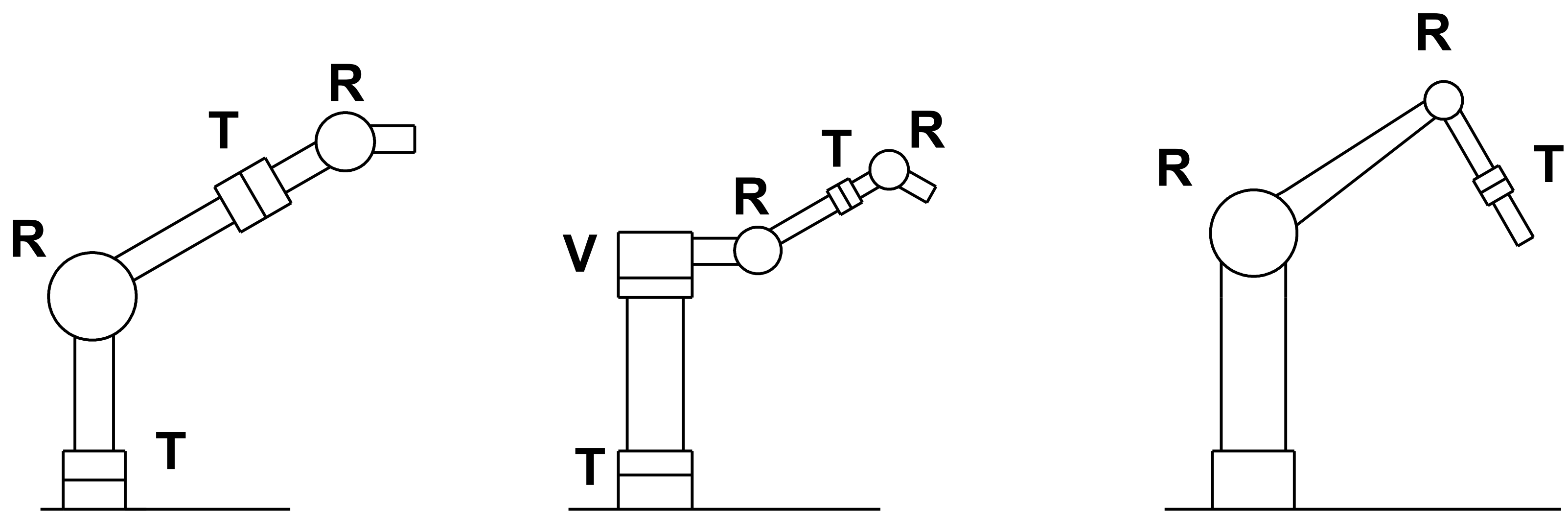
- Wrist assembly is attached to end-of-arm
- End effector is attached to wrist assembly
- Function of wrist assembly is to orient end effector
  - Body-and-arm determines global position of end effector
- Two or three degrees of freedom:
  - Roll
  - Pitch
  - Yaw
- Notation :RRT



Example

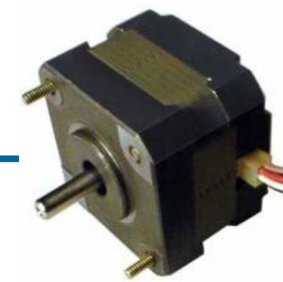
- Sketch following manipulator configurations
- (a) TRT:R, (b) TVR:TR, (c) RR:T.

Solution:

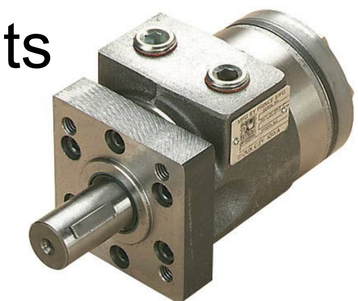


(a) TRT:R **(b) TVR:TR** **(c) RR:T**

Joint Drive Systems



- Electric
  - Uses electric motors to actuate individual joints
  - Preferred drive system in today's robots
- Hydraulic
  - Uses hydraulic pistons and rotary vane actuators
  - Noted for their high power and lift capacity
- Pneumatic
  - Typically limited to smaller robots and simple material transfer applications



Flexible Manufacturing System

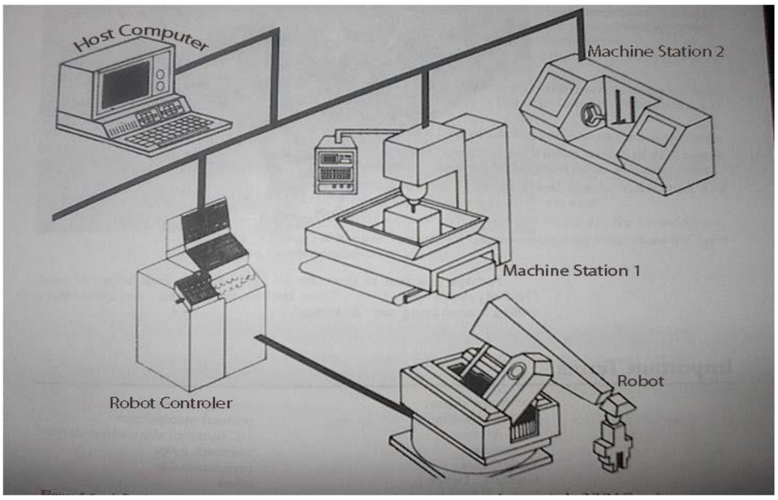
A flexible manufacturing system (FMS) is a manufacturing system in which there is some amount of flexibility to react in the case of changes, whether predicted or unpredicted. This flexibility can be divided into two categories:

١. **Machine flexibility**, covers the system's ability to be changed to produce new product types, and ability to change the order of operations executed on a part, and

٢. **Routing flexibility**, this consists of the ability to use multiple machines to perform the same operation on a part, as well as the system's ability to absorb large-scale changes, such as in volume, capacity, or capability.

Most FMS systems consist of three main systems.
١. The work machines which are often using computerized machines,
٢. Material handling system to optimize parts flow, and
٣. The central control computer which controls material movements and machine flow.

An Industrial Flexible Manufacturing System (FMS) consists of robots, Computer-controlled Machines, Numerical controlled machines (CNC), instrumentation devices, computers, sensors, and other stand-alone systems such as inspection machines as shown in Figure



Need For FMS: Some of the major needs/requirement associated with FMS include reduced **manufacturing** cost, increased labor productivity, increased machine efficiency, improved product quality, increased **system** reliability, reduced parts inventory, shorter lead times, and increased **production** rate.

Advantages and disadvantages of FMSs implementation

Advantages

• Faster, lower- cost changes from one part to another which will improve capital utilization
• Lower direct labor cost, due to the reduction in number of workers
• Reduced inventory, due to the planning and programming precision
• Consistent and better quality, due to the automated control
• Lower cost/unit of output, due to the greater productivity using the same number of workers
• Savings from the indirect labor, from reduced errors, rework, repairs and rejects

Disadvantages

• Limited ability to adapt to changes in product or product mix (ex. machines are of limited
capacity and the tooling necessary for products, even of the same family, is not always feasible in a given FMS)
• Substantial pre-planning activity
• Expensive, costing millions of dollars
• Technological problems of exact component positioning and precise timing necessary to
process a component
• Sophisticated manufacturing systems

COMPONENT OF FMS

1. WORK STATION
2. MATERIAL HANDLING AND STORAGE
3. COMPUTER CONTRROL SYSTEM

WORK STATION:

The types of workstations that may be utilized in FMSs include: load/unload stations, machining and turning stations, other industry-specific processing stations (such as sheet metal fabrication and forging), assembly stations, and supporting stations.

The workstations types to be met with in the typical FMS are detailed in Table

Workstation	Description
Load/Unload	Physical interface between the FMS and the rest of the factory, it is where raw parts enter the system, and completely-processed parts exit the system. Loading and unloading can be performed manually by personnel, or it can be automated as part of the material handling system. Should be designed to permit the safe movement of parts, and may be supported by various mechanical devices (e.g. cranes, forklifts). The station includes a data entry unit and monitor for communication between the operator and computer system, regarding parts to enter the system, and parts to exit the system. In some FMSs, various pallet fixtures to accommodate different

	pallet sizes may have to be put in place at load/unload stations.
Machining	The most common FMS application occurs at machining stations. These are usually CNC machine tools with appropriate automatic tool changing and tool storage features to facilitate quick physical changeover, as necessary. Machining centres can be ordered with automatic pallet changers that can be readily interfaced with the FMS part handling system. Machining centers used for non-rotational parts; for rotational parts turning centres are used. Milling centres may also be used where there are requirements for multi-tooth rotational cutters
Other	Other possible stations may be found in specific industries, such as—for example—sheet metal fabrication, which has stations for press-working operations, such as punching, shearing, and certain bending and forming processes. Forging is another labor intensive operation which may be broken into specific station categories, such as heating furnace, forging press, and trimming station.
Assembly	Associated with assembly FMSs, the assembly operation usually consists of a number of workstations with industrial robots that sequentially assemble components to the base part to create the overall assembly. They can be programmed to perform tasks with variations in sequence and motion pattern to accommodate the different product styles assembled in the system.
Supporting	Supporting stations may include inspection stations where various inspection tasks may be carried out. Co-ordinate measuring machines, special inspection probes, and machine vision may all be used here. Other supporting stations may include pallet and part washing stations for particularly dirty or oily FMSs, and temporary storage stations for both parts and pallets.

1. MATERIAL HANDLING AND STORAGE

Functions of the material handling and storage system in FMSs include: the allowance of random, independent movement of workparts between stations; the handling of a variety of work part configurations; the provision of temporary storage; the provision of convenient load and unload stations; and the creation of compatibility with computer control.

We address material handling and storage systems for FMS in three subsections: functions, equipment, and lay-out configurations.

The following functions of the material handling and storage system in FMSs may be noted:

Allows random, independent movement of workparts between stations so as to allow for various routing alternatives for the different parts in the system Enables handling of a variety of workpart configurations by means of pallet fixtures for prismatic parts, and industrial robots for rotational parts Provides temporary storage—small queues of parts awaiting processing may be allowed to build-up in front of each station in the system Provides convenient access for loading and unloading workparts at load and unload stations Creates compatibility with computer control.

15.4.2.2 Material Handling Equipment

FMS material handling equipment uses a variety of conventional material transport equipment (see unit 8), in-line transfer mechanisms (see unit 13), and industrial robotics (see unit 6). There is a primary and secondary material handling system used in most FMSs. The primary handling system establishes the FMS lay-out and is responsible for moving parts between stations in the system.

The secondary handling system consists of transfer devices, automatic pallet changers, and other mechanisms to transfer parts from the primary material handling system to the workhead of the processing station, or to a supporting station. The secondary handling system is responsible also for the accurate positioning of the part at the workstation, so that the machining process may be performed upon the part in the correct manner. Other purposes of the secondary handling system include: (1) re-orientation of the part if necessary to present the surface that is to be processed; and (2) to act as buffer storage as the workstation, should this be needed.

KEYPOINT
FMS material handling equipment consists of a primary handling system to establish material handling lay-out, and a secondary handling system to transfer parts from the primary material handling system to the workhead of the processing station, or to a supporting station.
END KEYPOINT

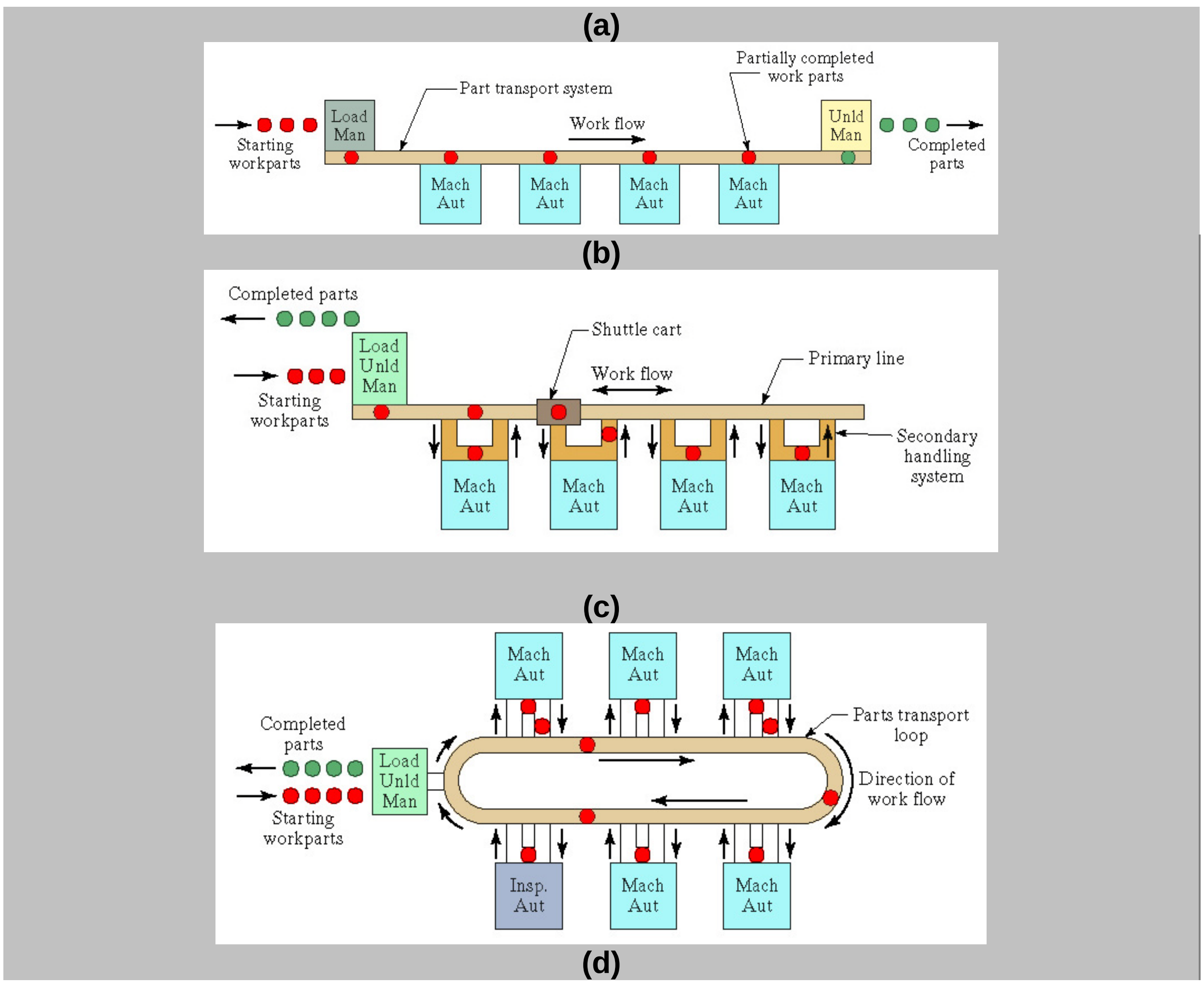
15.4.2.3 Flexible Manufacturing System Layout Configurations

There are five categories of FMS layout; these are discussed in detail in Table 15.2.

Table 15.2: Categories of FMS layout

Layout	Description
In-line	The machines and handling system are arranged in a straight line. In Figure 15.7(a) parts progress from one workstation to the next in a well-defined sequence with work always moving in one direction and with no back-flow. Similar operation to a transfer line (see unit 13), except the system holds a greater variety of parts. Routing flexibility can be increased by installing a linear transfer system with bi-directional flow, as shown in Figure 15.7(b). Here a secondary handling system is provided at each workstation to separate most of the parts from the primary line. Material handling equipment used: in-line transfer system; conveyor system; or rail-guided vehicle system.
Loop	Workstations are organized in a loop that is served by a looped parts handling system. In Figure 15.7(c) parts usually flow in one direction around the loop with the capability to stop and be transferred to any station. Each station has secondary handling equipment so that part can be brought-to and transferred-from the station workhead to the material handling loop. Load/unload stations are usually located at one end of the loop.

	An alternative form is the rectangular layout shown in Figure 15.7(d). This arrangement allows for the return of pallets to the starting position in a straight line arrangement.
Ladder	This consists of a loop with rungs upon which workstations are located. The rungs increase the number of possible ways of getting from one machine to the next, and obviates the need for a secondary material handling system. It reduces average travel distance and minimizes congestion in the handling system, thereby reducing transport time between stations. See Figure 15.7(e).
Open field	Consists of multiple loops and ladders, and may include sidings also. This layout is generally used to process a large family of parts, although the number of different machine types may be limited, and parts are usually routed to different workstations—depending on which one becomes available first. See Figure 15.7(f).
Robot-centred	This layout uses one or more robots as the material handling system (see Figure 15.7 (g)).



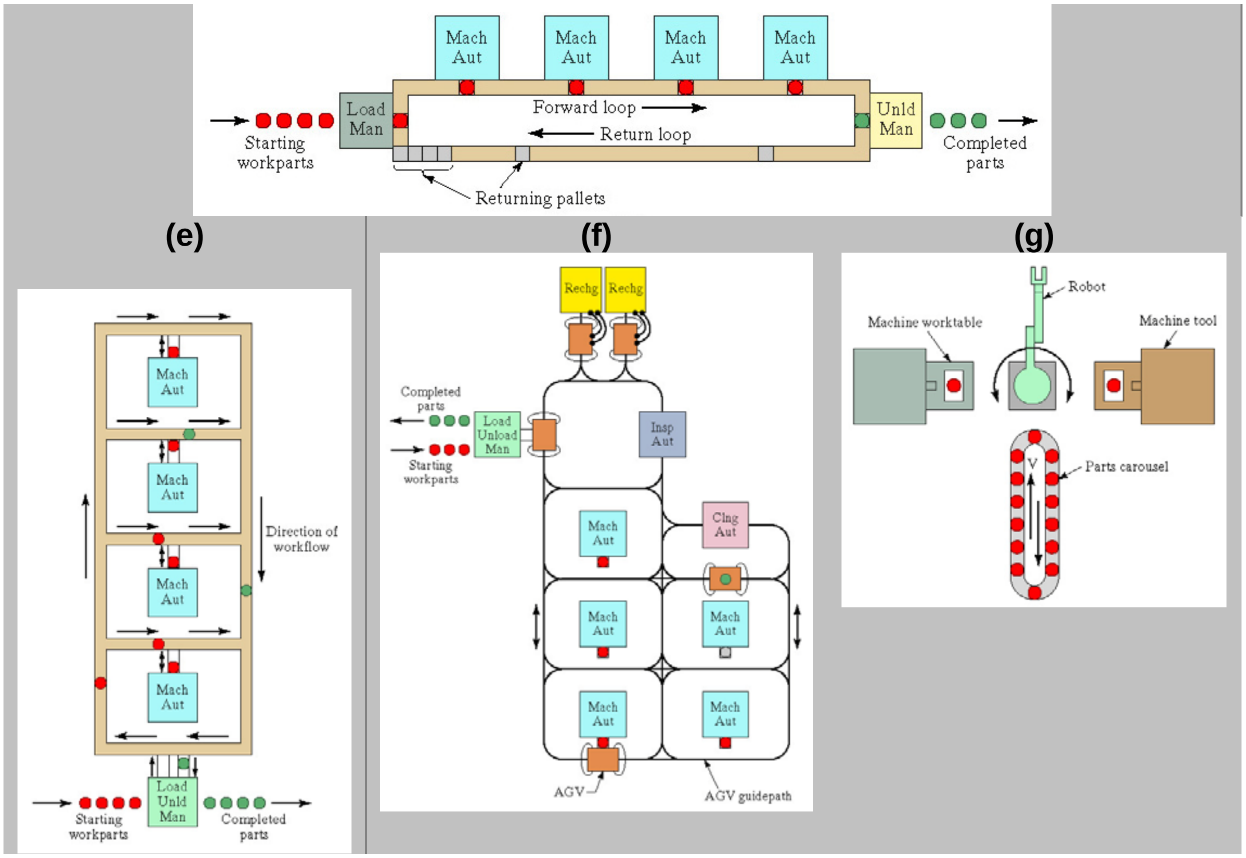


Figure 15.7: FMS lay-out configurations

KEYPOINT
There are five categories of FMS layout; these are: in-line layout; loop layout; ladder layout; open field layout; and robot-centred layout.
END KEYPOINT

15.4.3 Computer Control System

To operate, the FMS uses a distributed computer system that is interfaced with all workstations in the system, as well as with the material handling system and other hardware components. It consists of a central computer and a series of micro-computers that control individual machines in the FMS. The central computer co-ordinates the activities of the components to achieve smooth operational control of the system. The following control functions may be noted:

BULLETLIST
Workstation control—fully automated FMSs use some form of workstation control at each station, often in the form of CNC control

Distribution of control instructions to workstations—a central computer is required to handle the processing occurring at disparate workstations; this involves the dissemination of part programmes to individual workstations, based upon an overall schedule held by the central computer

Production control—management of the mix and rate at which various parts are launched into the system is important; alongside data input of a number of essential metrics, such as: daily desired production rates, number of raw workparts available, work-in-progress etc.

Traffic control—management of the primary handling system is essential so that parts arrive at the right location at the right time and in the right condition

Shuttle control—management of the secondary handling system is also important, to ensure the correct delivery of the workpart to the station's workhead

Workpiece monitoring—the computer must monitor the status of each cart or pallet in the primary and secondary handling systems, to ensure that we know the location of every element in the system

Tool control—this is concerned with managing tool location (keeping track of the different tools used at different workstations, which can be a determinant on where a part can be processed), and tool life (keeping track on how much usage the tool has gone through, so as to determine when it should be replaced)

Performance monitoring and reporting—the computer must collected data on the various operations on-going in the FMS and present performance findings based on this

Diagnostics—the computer must be able to diagnose, to a high degree of accuracy, where a problem may be occurring in the FMS
ENDLIST

KEYPOINT
The computer control system in an FMS has the following functions: workstation control; distribution of control instructions to workstations; production control; traffic control; shuttle control; workpiece monitoring; tool control; performance monitoring and reporting; and diagnostics.
END KEYPOINT

15.4.4 Human Resources

Human personnel manage the overall operations of the system. Humans are also required in the FMS to perform a variety of supporting operations in the system; these include: loading raw workparts into the system; unloading finished parts or assemblies from the system; changing and setting tools; performing equipment

Computer Aided Design

- Use of computer systems to assist in creation, modification, analysis and optimization of a design.

- Computer assistance, while a designer converts his or her ideas and knowledge, into a mathematical and graphical model represented in a computer.

Computer Aided Manufacturing

- Use of computers systems to plan, manage and control the operations of a manufacturing plant through either direct or indirect computer interface with plant's production resources.
- Manufacturing support applications –Use of computers in process planning, scheduling, shop floor control, work study, tool design, quality control etc.

Computer Integrated Manufacturing

- A process of integration of CAD, CAM and business aspects of a factory. It attempts complete automation with all processes functioning under computer control.

CIM

Need for CAD/CAM/CIM

- To increase productivity of the designer
- To improve quality of the design
- To improve communications
- To create a manufacturing database
- To create and test tool paths and optimize them
- To help in production scheduling and MRP models
- To have effective shop floor control

CAD/CAM Hardware

The hardware part of a CAD/CAM system consists of the following components

⑴ one or mare design workstations,

⑵ digital computer,

⑶ plotters and other output devices, and

⑷ storage devices.

In addition, the CAD/CAM system would have a communication interface to permit transmission of data to and from other computer systems, thus enabling some of the benefits of computer integration. The workstation is the interface between computer and user in the CAD system.

The design of the CAD workstation and its available features have an important influence on the convenience, productivity, and quality of the user´s output. The workstation must include a digital computer with a high-speed control processing unit(CPU). It contains require a logic/arithmetic section for the system. The most widely used secondary storage medium in CAD/CAM is the hard disk, floppy diskette, or a combination of both. Input devices are generally used to transfer information from a human or storage medium to a computer where ¨CAD functions¨ are carried out.

There are two basic approaches to input an existing drawing:model the object on a drawing or digitize the drawing. The standard output device for CAD/CAM is a CRT display. There are two major of CRT displays: random-scan-line-drawing displays and raster-scan displays. In addition to CRT, there are also plasma panel displays and liquid-crystal displays. CAD/CAM Software Software allows the human user to turn a hardware configuration into a powerful design and manufacturing system.

CAD/CAM Software Software

It allows the human user to turn a hardware configuration into a powerful design and manufacturing system. CAD/CAM software falls into two broad categories,2-D and 3-D, based on the number of dimensions are called 2-D representations of 3-D objects is inherently confusing. Equally problem has been the inability of manufacturing personnel to properly read and interpret complicated 2-D representations of objects. 3-D software permits the parts to be viewed with the 3-D planes-height, width, and depth-visible. The trend in CAD/CAM is toward 3-D representation of graphic images. Such representation approximates the actual shape and appearance of the object to be produced; therefore, they are easier to read and understand.

Difference between cad and cam

CAD	CAM
• CAD is the implementation of digital computers in engineering design and production.	• CAM is the implementation of computers in transforming engineering designs into end products.
• These are the process involved in CAD - Definition of a geometric model, definition translator, geometric model, interface algorithm, design and analysis algorithms, drafting and detailing, documentation.	• These are the process involved in CAM – Geometric model, process planning, interface algorithm, NC programs, inspection, assembly and packaging.
• It requires Design conceptualization and analysis.	• It requires Control and coordination of the necessary physical processes, equipment, materials, and labor.
• Software requires for CAD - AutoCAD, Autodesk Inventor, CATIA, Solid Works.	• Software requires for CAM - Siemens NX, Power MILL, WorkNC, SolidCAM

Definition of *CIM*

- "CIM is the integration of the total manufacturing enterprise through the use of integrated systems and data communications coupled with new managerial philosophies that improve organizational and personnel efficiency."

  Computer-integrated manufacturing (CIM) is the manufacturing approach of using computers to control the entire production process.

What is CIM?

- CIM is the integration of all enterprise operations and activities around a common corporate data repository.
- It is the use of integrated systems and data communications coupled with new managerial philosophies.
- CIM is not a product that can be purchased and installed.
- It is a way of thinking and solving problems.
- This integration allows individual processes to exchange information with each other and initiate actions.

Potential Benefits of CIM

- Improved customer service
- Improved quality
- Shorter time to market with new products
- Shorter flow time
- Shorter vendor lead time
- Reduced inventory levels
- Improved schedule performance
- Greater flexibility and responsiveness
- Improved competitiveness
- Lower total cost
- Shorter customer lead time
- Increase in manufacturing productivity
- Decrease in work-in process inventory

Role of Computer in Manufacturing

The computer has had a substantial impact on almost all activities of a factory.

The operation of a CIM system gives the user substantial benefits:

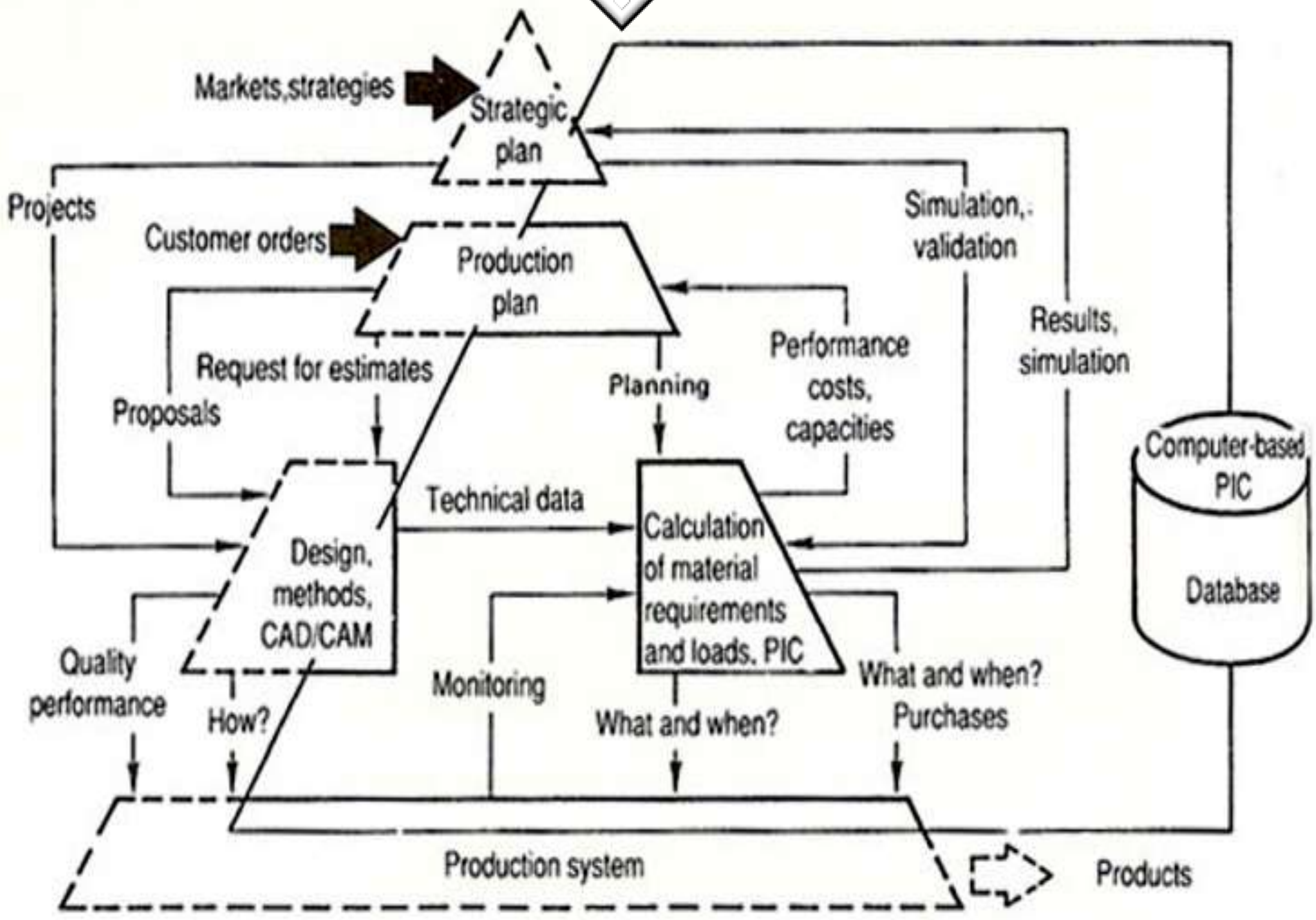
- Reduction of design costs by 15-30%;
- Reduction of the in-shop time of a part by 30-60%;
- Increase of productivity by 40-70%;
- Better product quality, reduction of scrap 20-50%.

Manufacturing Method

As a method of manufacturing, three components distinguish CIM from other manufacturing methodologies:

- Means for data storage, retrieval, manipulation and presentation;
- Mechanisms for sensing state and modifying processes;
- Algorithms for uniting the data processing component with the sensor/modification component.
- CIM is an example of the implementation of **Information and Communication Technologies**(ICTs) in manufacturing.

CIM & Production Control System



Key challenges

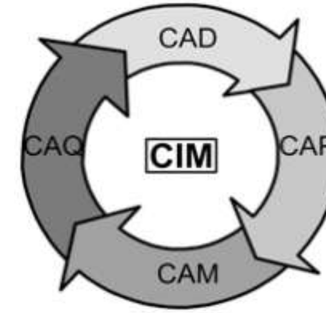
There are three major challenges for the development of a smoothly operating computer-integrated manufacturing system:

- **Integration of components from different suppliers**: When different machines, such as CNC, conveyors and robots, are using different communications protocols. In the case of AGVs (automated guided vehicles), even differing lengths of time for charging the batteries may cause problems.

- **Data integrity**: The higher the degree of automation, the more critical is the integrity of the data used to control the machines. While the CIM system saves on labor of operating the machines, it requires extra human labor in ensuring that there are proper safeguards for the data signals that are used to control the machines.

- **Process control**: Computers may be used to assist the human operators of the manufacturing facility, but there must always be a competent engineer on hand to handle circumstances which could not be foreseen by the designers of the control software.

Subsystems in computer-integrated manufacturing



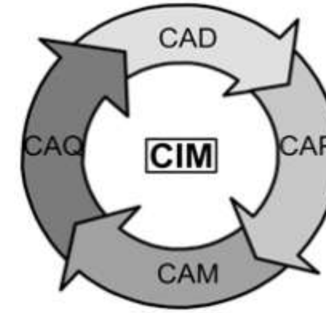
➢**CAD (<u>Computer-Aided Design</u>)** involves the use of computers to create design drawings and product models.

➢**CAE (<u>Computer-Aided Engineering</u>)** is the broad usage of computer software to aid in engineering tasks .

➢**CAM (C<u>omputer-Aided Manufacturing</u>)** is the use of computer software to control machine tools and related machinery in the manufacturing of work pieces.

➢**CAPP (<u>Computer-Aided Process Planning</u>)** is the use of computer technology to aid in the process planning of a part or product, in manufacturing.

Cont…

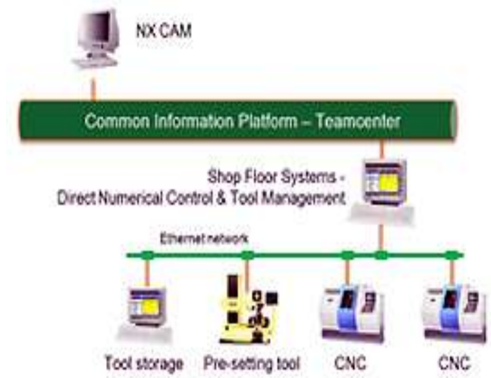


- **CAQ (Computer-Aided Quality Assurance)** is the engineering application of computers and computer controlled machines for the inspection of the quality of products.
- **PPC (Production Planning and Control)** A production (or manufacturing) planning and control (MPC) system is concerned with planning and controlling all aspects of manufacturing, including materials, scheduling machines and people, and coordinating suppliers and customers.
- **ERP (Enterprise Resource Planning)** systems integrate internal and external management information across an entire organization, embracing finance/accounting, manufacturing, and sales and services.

Devices and Equipment used in CIM

CNC

PNC



DNC

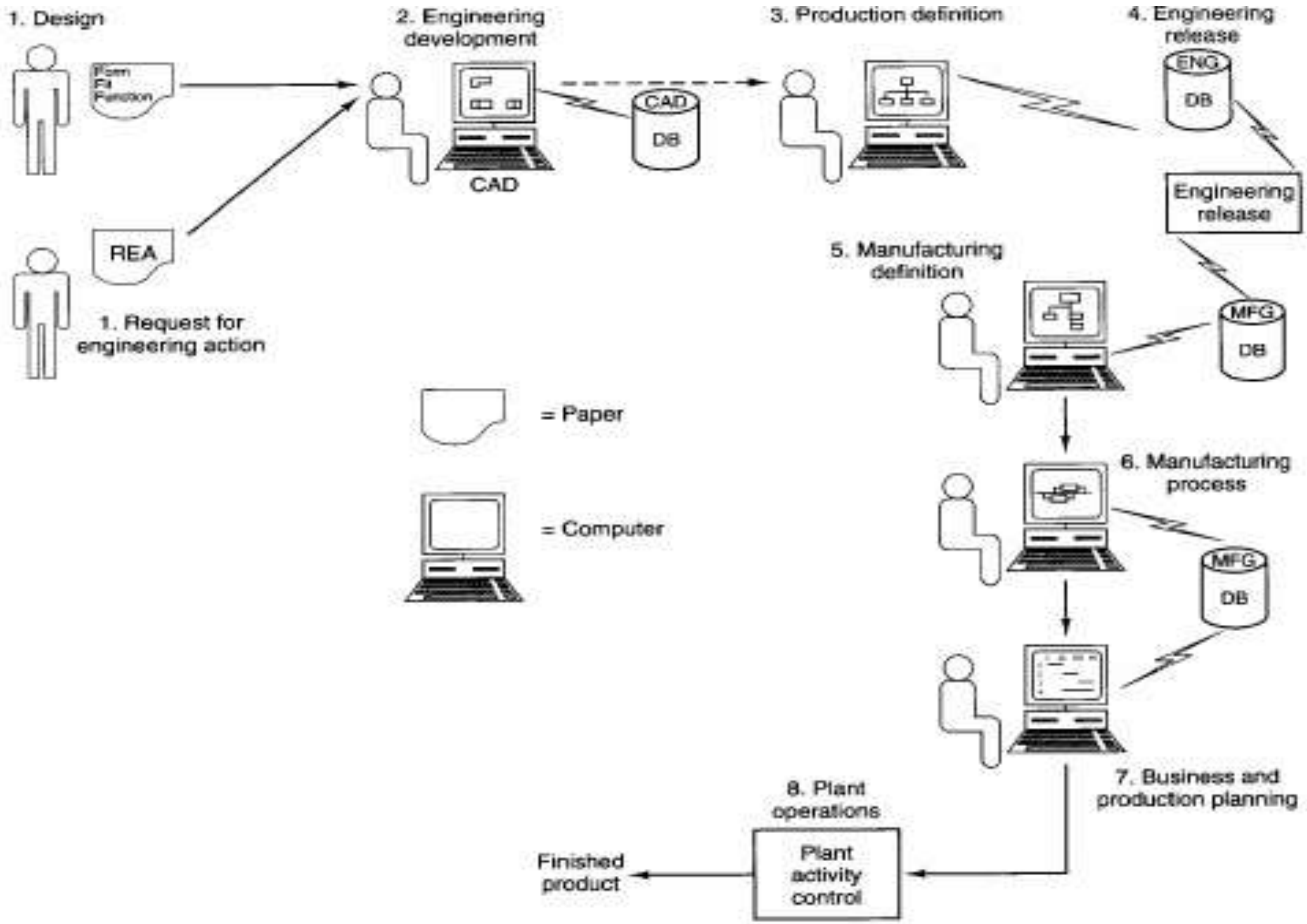
Other Devices....

1. Robotics
2. Computers
3. Software
4. Controllers
5. Networks & Interfacing

Technologies in CIM

1. FMS (Flexible Manufacturing System)
2. ASRS (Automated Storage and Retrieval System)
3. AGV (Automated Guided Vehicle)
4. Automated conveyance systems & Robotics

Schematic diagram of the CIM



‘CIMOSA’ (Computer Integrated Manufacturing Open System Architecture)

- CIMOSA provides a solution for business integration with four types of products:

- The CIMOSA Enterprise Modeling Framework, which provides a reference architecture for enterprise architecture.

- CIMOSA IIS, a standard for physical and application integration.

- CIMOSA Systems Life Cycle, is a life cycle model for CIM development and deployment.

- Inputs to standardization, basics for international standard development.

Advantages

- Responsiveness to shorter product life cycles
- Better process control emphasizes product quality and uniformity.
- Supports and co-ordinates exchange of information
- Designs components for machines.
- Decreases the cost of production and maintenance

Disadvantages

- Unfamiliar technologies used.
- Requires major change in corporate culture.
- Reduction in short term profit.
- Perceived risk is high.
- High maintenance cost and expensive implementation.

Conclusion

- **Computer-integrated manufacturing (CIM)** is the manufacturing approach of using computers to control the entire production process.

- This integration allows individual processes to exchange information with each other and initiate actions.

- Through the integration of computers, manufacturing can be faster and less error-prone, although the main advantage is the ability to create automated manufacturing processes