MADHA
Expertise | Empathy | Excellence
ENGINEERING COLLEGE

Department of Mechanical Engineering

Lecture Notes

Subject Code : ME8792

Subject Name: POWER PLANT ENGINEERING

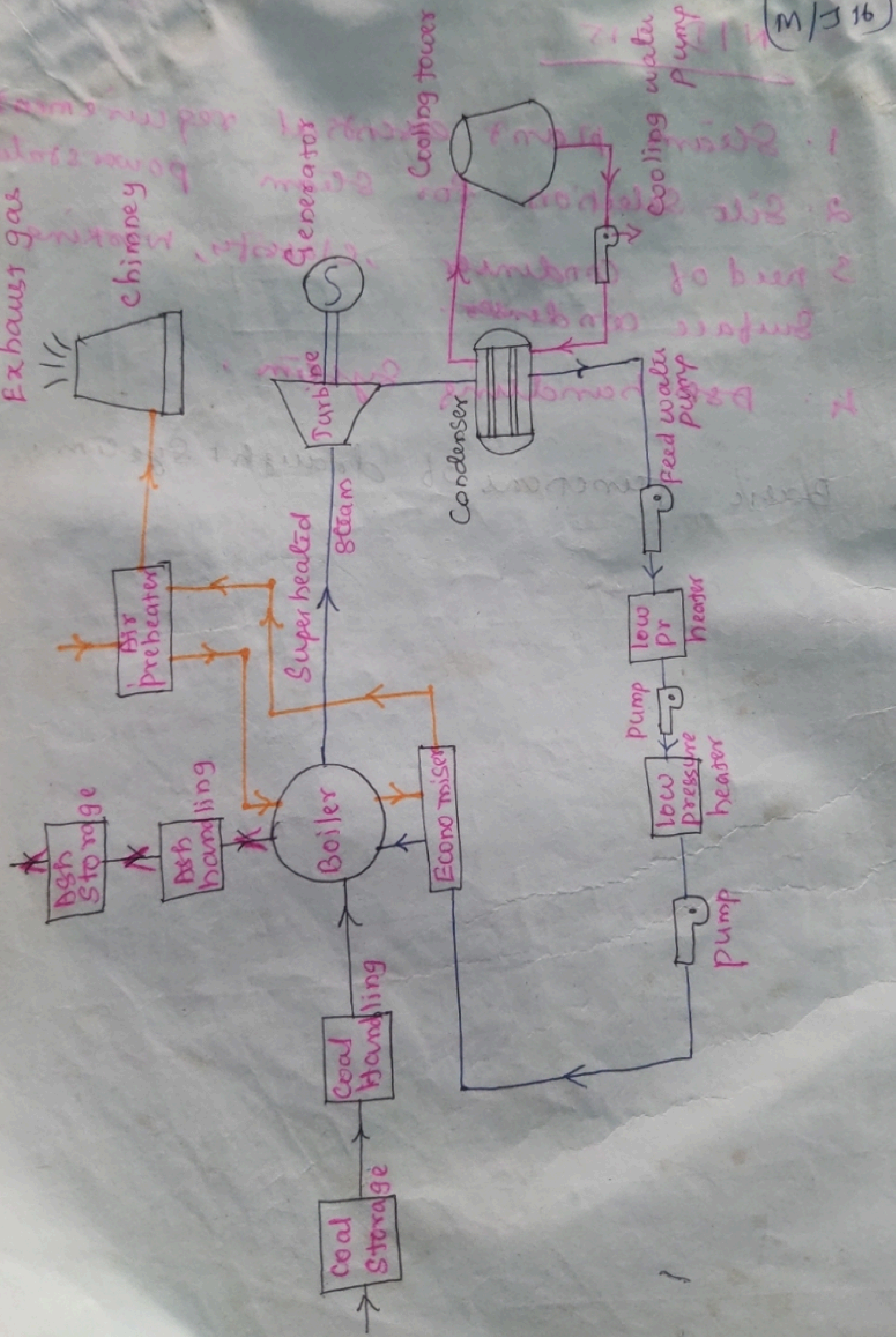
Sem/Year : 07/IV

Regulation : 2017

1.2 Layout of modern coal power plant :-

(May / June 2014) (16 M)

(M/J 16)



either through F.D or I.D fan. (or) by using both. dust removed, The exhaust gases carrying sufficient quantity of heat and ash are passed through the air heater. where exhaust heat of the gases is given to the air and then it is passed through the dust collectors where most of the dust is removed before exhausting the gases to the atm through chimney.

Feed water and steam circuit:-

Steam generated in the boiler is fed to the steam prime movers to develop power. The steam coming out of the condenser is condensed in the condensers and then fed to the boiler with the help of pump. The condensate is heated in the feed heaters using the steam tapped from diff points of the turbine. The feed heaters may be of mixed type or Indirect heating type.

Feed water is added to compensate the losses from different components. It has to purify to avoid

Scaling of the boiler tubes.

Cooling water circuit:-

The quantity of cooling water required to condense the steam is considerably and it is taken either from lake, river or sea. The cooling water is taken from the upper side of the river it is passed through the condenser and heated water is discharged to the lower side of the river. This is called open system. When adequate water is not available the water coming out from the condenser is cooled either in cooling pond or cooling tower. This called closed system.

- 400 MW require 5000 to 6000 tons of coal per day.
- 20 to 40% ash. 1500 to 2000 tons per day, 400MW require nearly 10 hectare area per year dumped to height of 65m.

1.3 Super Critical Boilers :-

Steam generating plants working ranges between 180 atm & 510°C to 300 atm and 660°C.

Super Critical Boiler requires only economizer and Superheater for capacity above 300 MW capacity.

Advantages:- 1. High Thermal η.
2. Heat transfer rate is high
3. erosion & corrosion minimized.
4. Stable pressure level maintained.
5. For peak load.

1.4 Fluidized Bed Boilers (FBC) :-

Types → Bubbling
→ Circulating

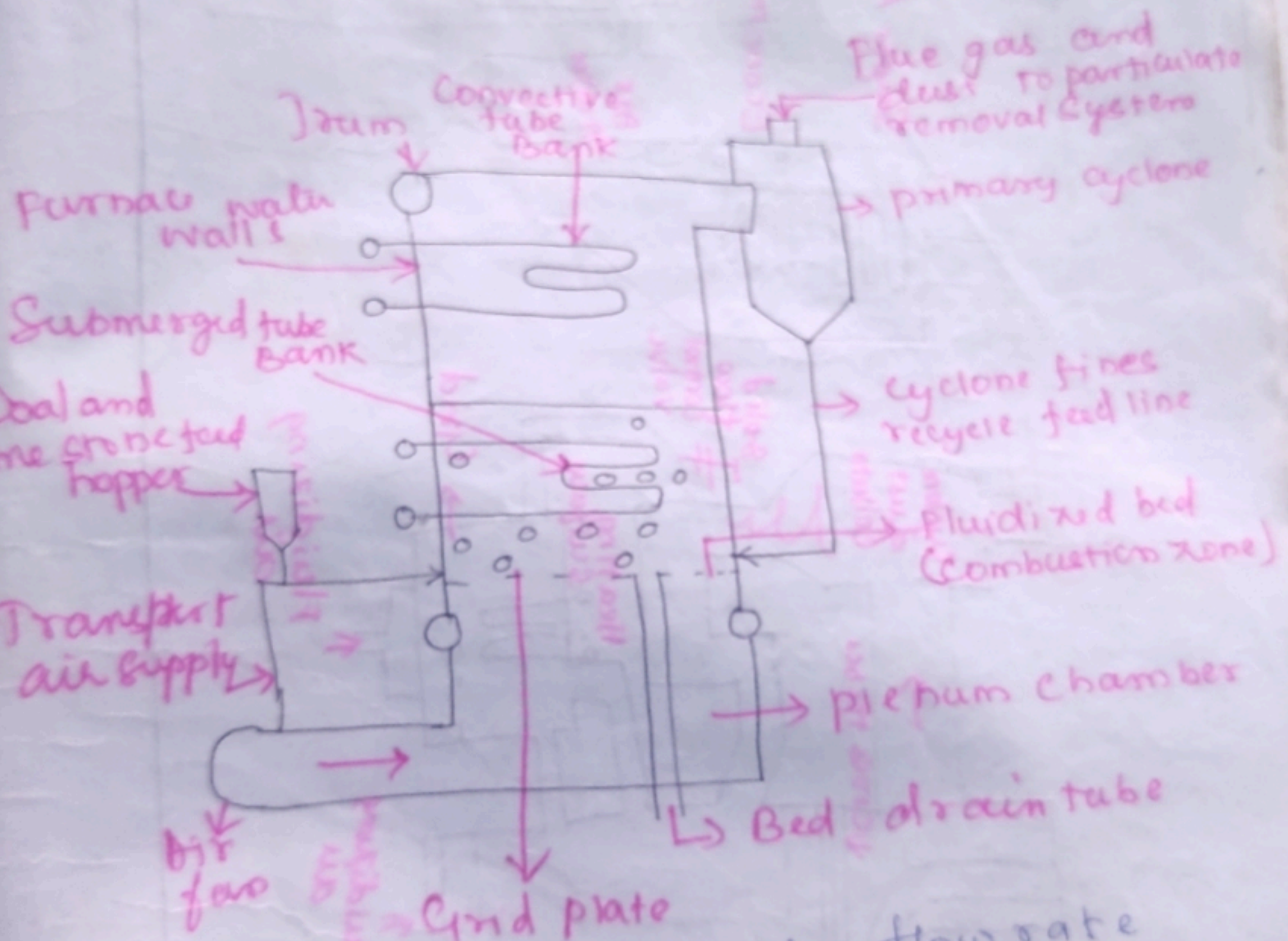
(May/June 2014) (10 M)
(May/June 16)

Bubbling :-

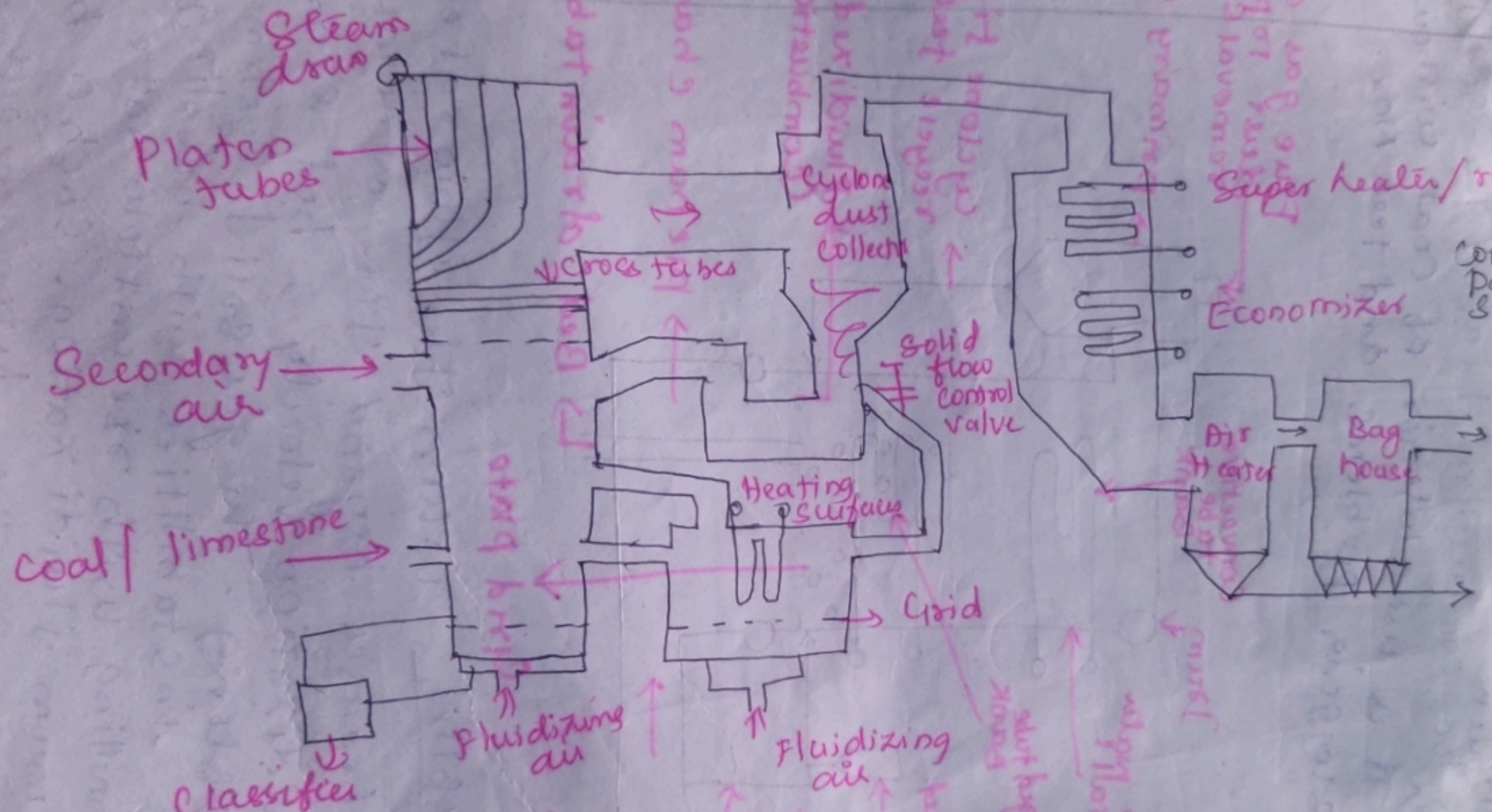
Crushed coal (6-20mm) injected into the fluidized bed of limestone just above air distribution grid which located at the bottom of the bed.

→ Combustion product collected in Cyclone Separator to remove carbon particle.

→ gases can be cooled to lower temperature before leaving the stack
→ H_2SO_4 acid formation less due to sulphur in coal is retained in the bed by limestone.
Due to
→ low combustion temp (800-900°C) lower
^
It is use inferior of coal without slagging problems and less NO_x.



Bubbling when the flow rate increases beyond the minimum fluidization velocity, bed starts bubbling. The gas solid system shows large instabilities with bubbling and gas channelling with rise of flow rate beyond minimum fluidization. Such a bed is called aggregative, heterogeneous or bubbling fluidized.


Steam drum
Platen tubes
Secondary air
Coal / limestone
Classifier
Cyclone dust collector
Cross tubes
Solid flow control valve
Heating surface
Grid
Fluidizing air
Fluidizing air
Super heater / reheater
Economizer
Convective Passheating Surfaces
Air heater
Bag house
To ID fans and stack

a) Furnace or fast fluidized bed
b) gas - Solid Separator (cyclone)
c) Solid recycle device (L-valve)
d) external heat exchanger (optional)

Bed temperature 800-900°C.

Sorbent (limestone)

- Second Section Remaining heat from the flue gas absorbed by Reheater, Superheater, Economiser, Air preheater.

⇒ Unburned char and particles of limestone recycle back to furnace.

⇒ Finer solid residues (ash and solid sorbents) by ESP.

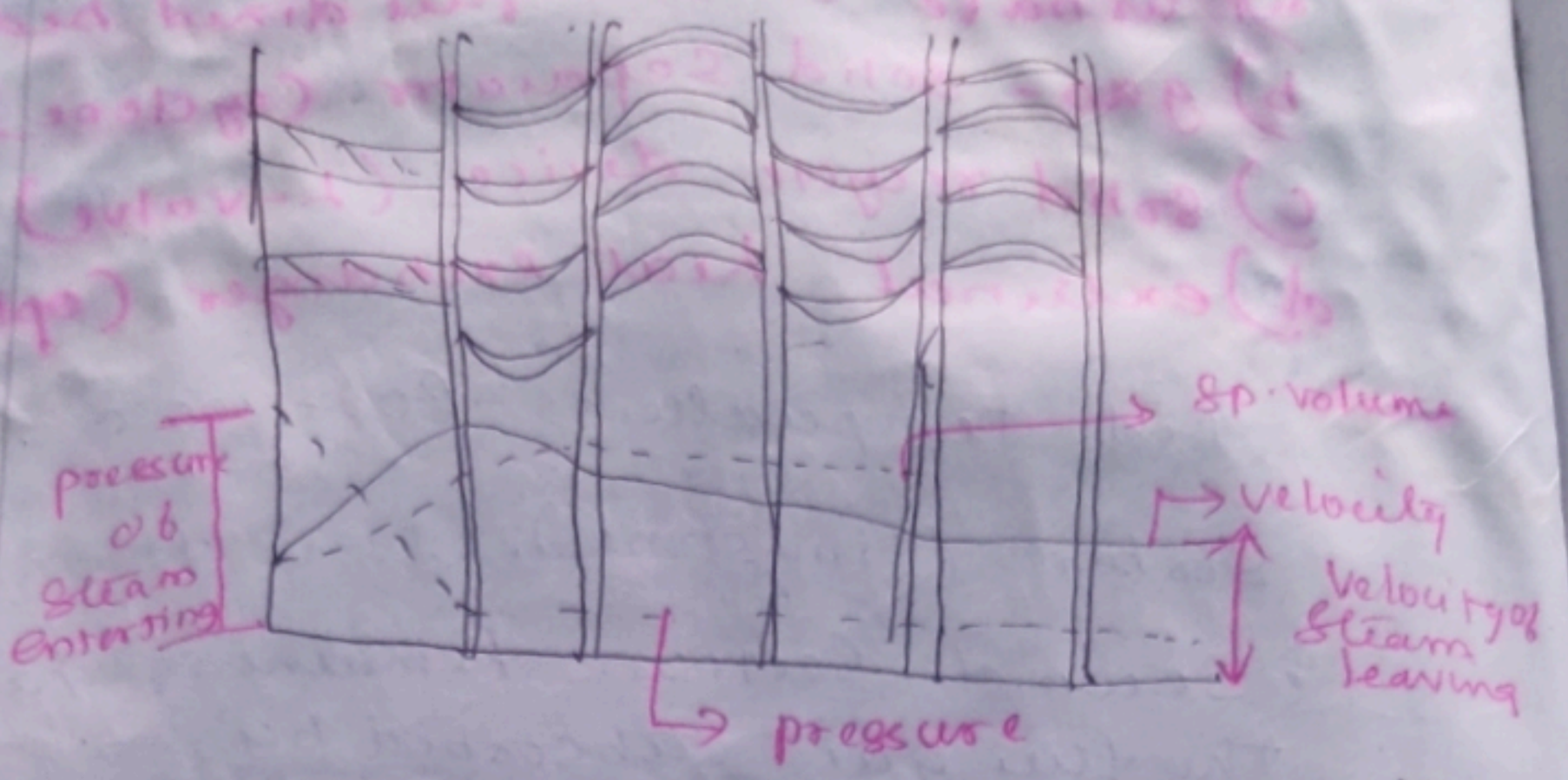
1.5 Turbines:-

1. Impulse → High velocity from nozzle through the fixed nozzles impinges on the blades fixed on the periphery of a rotor. The resulting motive force gives the rotation to the turbine shaft.

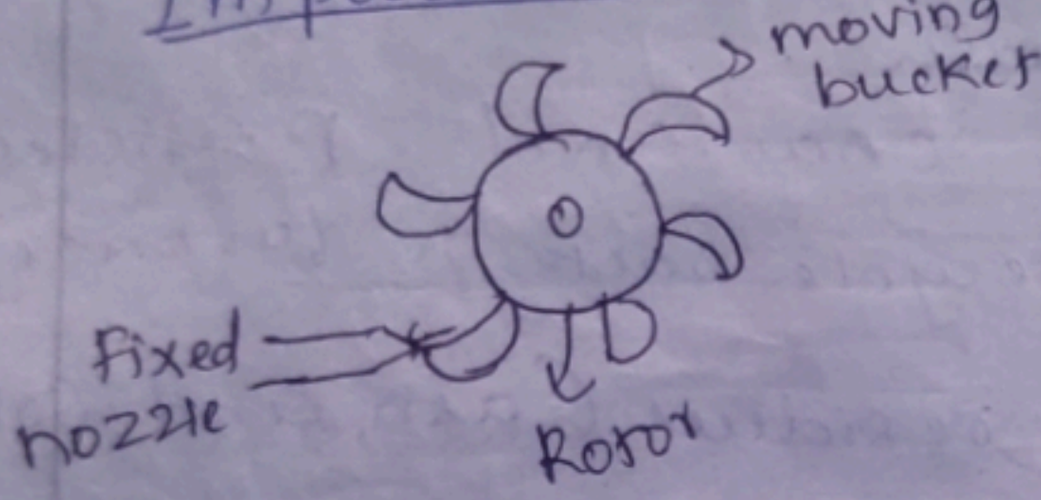
ex. Delavel, Curties & Reteau.

2. Reaction - Steam expands both in fixed and moving blades continuosly as the steam passes over them.

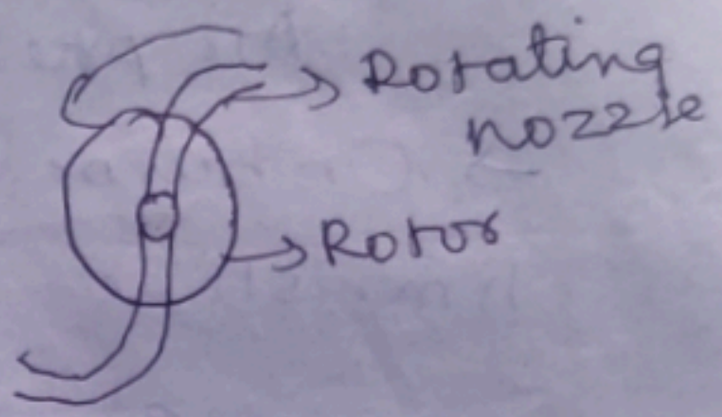
ex parson's turbine.

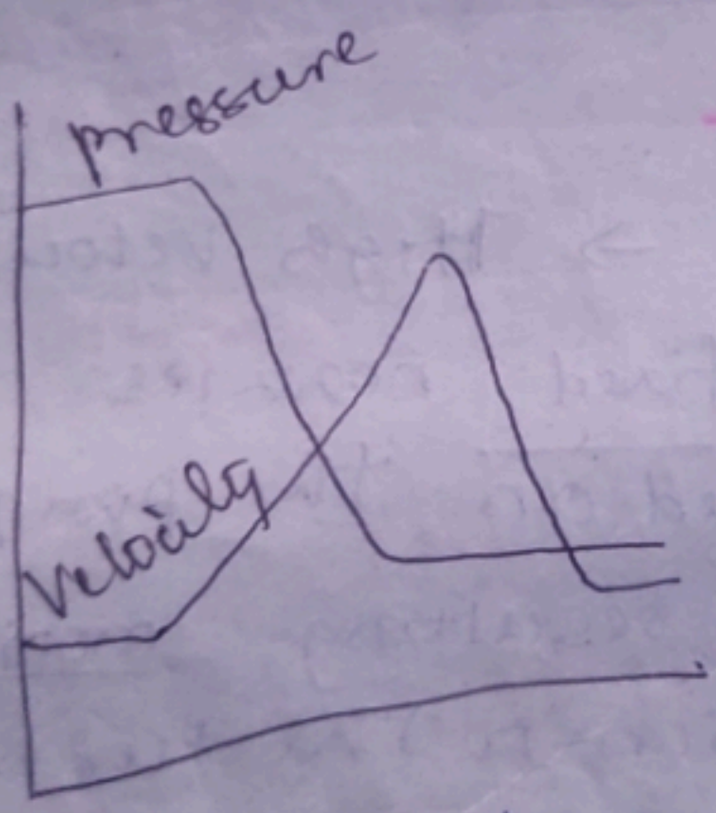


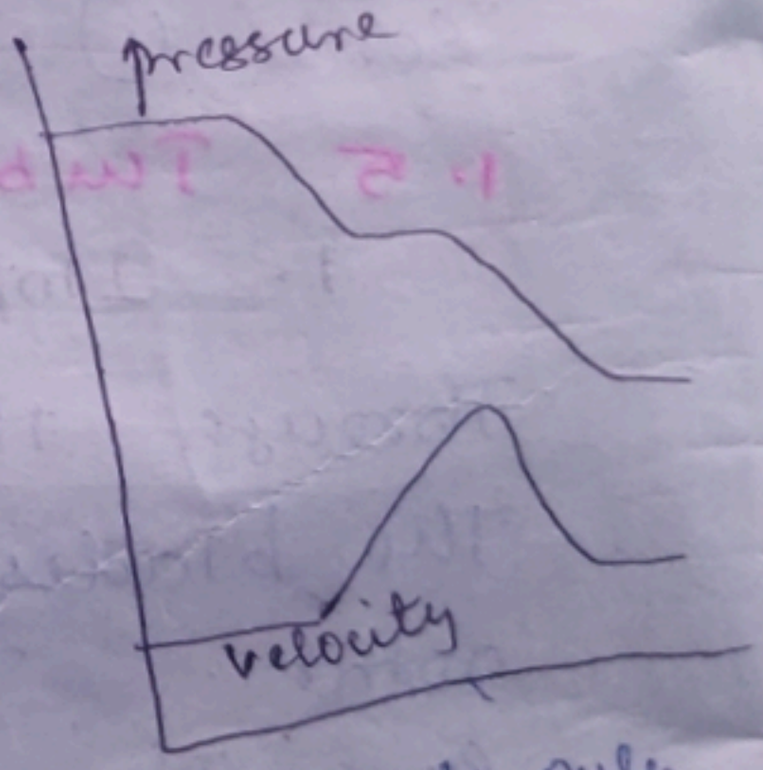
Impulse Turbine :-



Reaction turbine







Pr comp ▷ no. of simple Impuls
Turbine Sets arranged in Series

Governor :- Maintain The Speed
Const Irrespective of load on the turbin

Direct Contact type Condensers:-

where the condensate and Cooling water directly mix and come out as a singel stream.

Surface condensers:-

which are shell and tube heat exchangers where the two fluids donot come in direct contact and the heat released by the condensation of steam is transferred through the walls of the tubes into the cooling water circulating inside them.

Direct contact:-

Spray Condenser, Barometric, Jet.

Surface condenser:-

Downflow type, Central flow, Evaporati

Downflow type:-

It consists of an cylindrical shell closed at each end. The exhaust steam from the prime mover enters at the top of the condenser and surrounds the condenser tubes through which cooling water is circulated underforce.

The steam gets condensed as it comes in contact with cold surface of the tubes. The cooling water flows in one direction through the first set of tubes located in the lower half of condenser and returns in the opposite direction through the second set of tubes.

Central flow Condenser:-

In this cooling section is provided at the centre of the tube nest and air is extracted from this section. Condensate collected from bottom.

Evaporation Condenser:-

Steam to be condensed is passed through a series of tubes and cooling water falls over these tube in the form of spray.

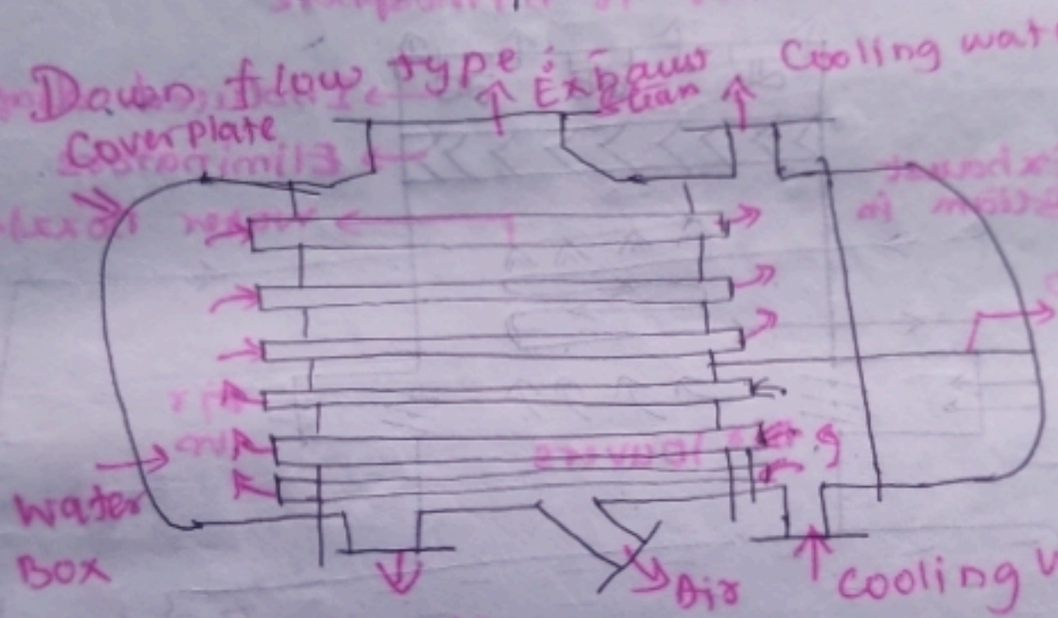
1.6 Condensers

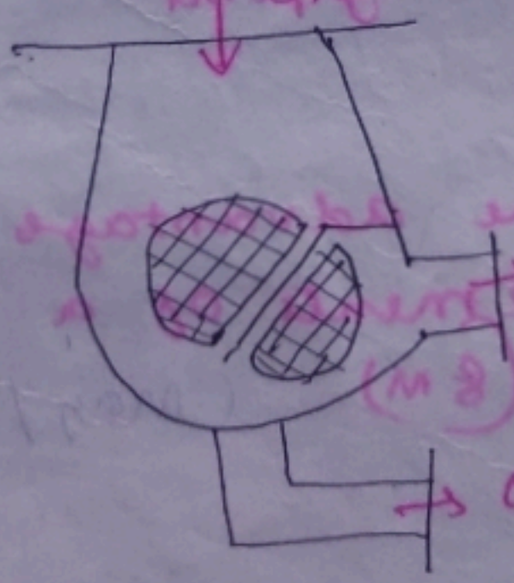
Types → Mixing Type (or) Jet condensers
→ Non Mixing Type (or) Surface condensers

Surface condenser:- Cooling water in tubes.
Steam surrounds the tube.

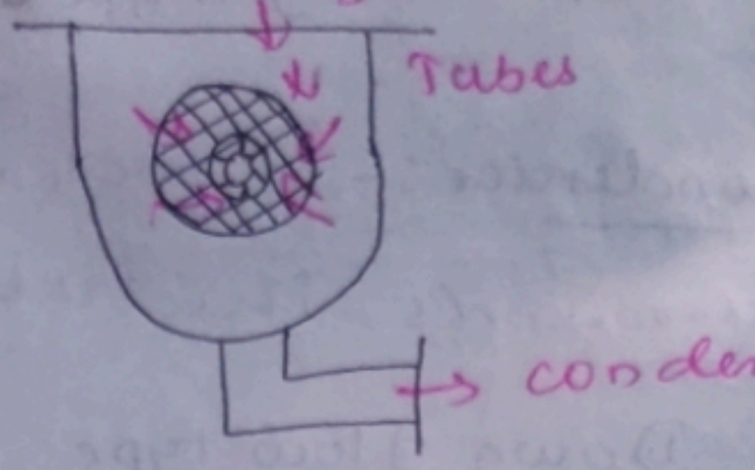
Types:- 1 Down flow type
2. Central flow Condenser
3. Evaporation Condenser

Down flow type:-

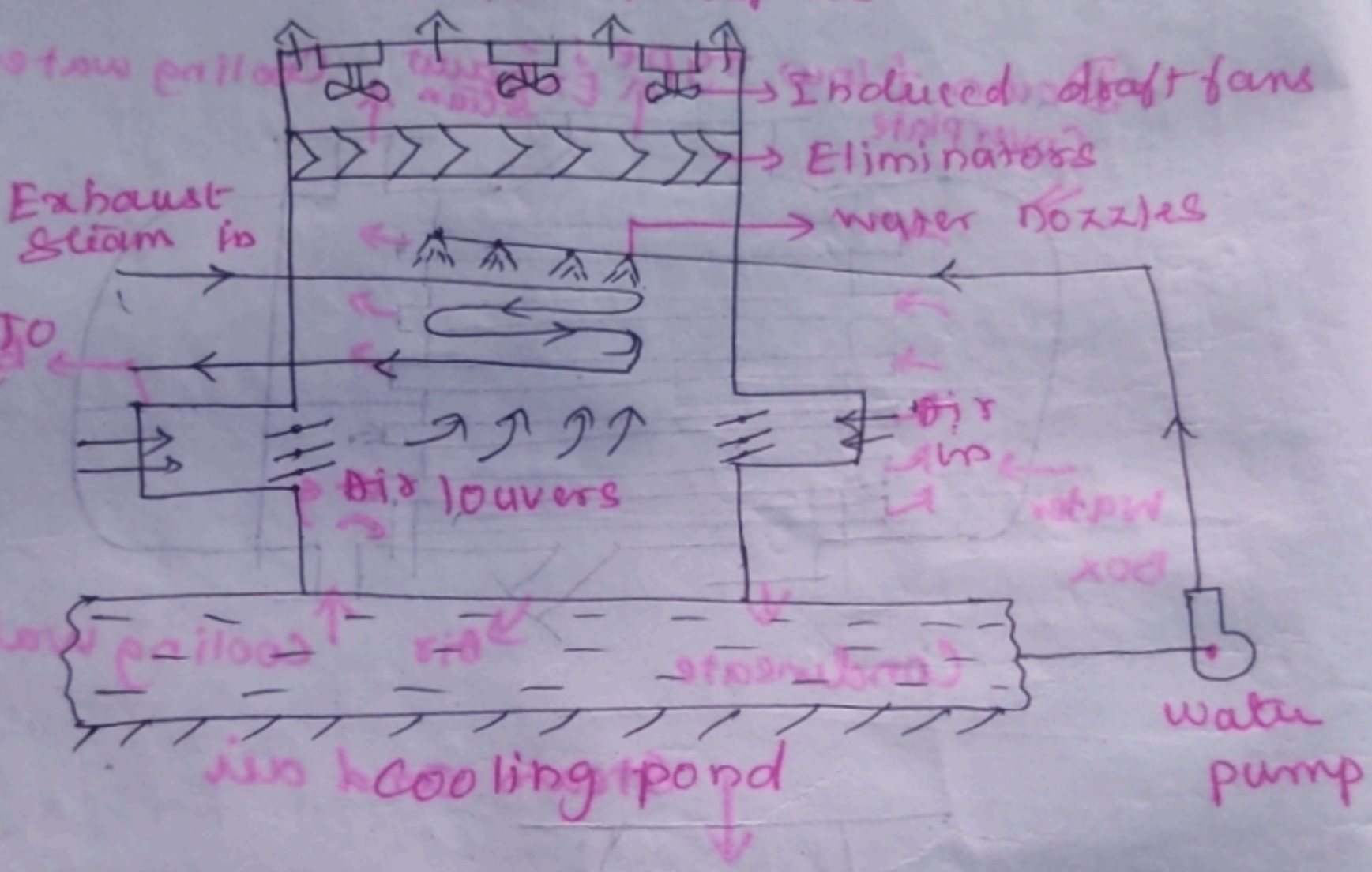




Central flow Condenser:-



Evaporative Condenser:-



Discuss the advantages, disadvantages and requirements of a surface condenser (8M) (May/June 13)

Requirements :-

→ Steam should be evenly distributed whole cooling surface.

→ Should not be Undercooling of condensate

→ deposition of dirt on outer surface prevented. This is achieved by cooling water in tube, steam in shell.

→ no air leakage. If it is pump should be used.

Advantages :-

1. High vacuum (about 73.5 cm of Hg) It ↑ the Thermal

2. condensate can be feed water for Boiler.

3. Cooling water can be used. (tube)

Disadvantages :-

→ Bulk, Require Space

→ capital cost high

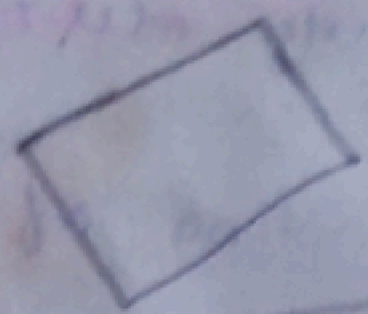
→ maintenance, running cost high.

1.7 Fuel and Ash handling :-

Coal preparation :-

Sizing, removal of rock originating mine roof, from

→ Crusher, Sizer, Dryers, Magnetic Separator.



Crusher
Sizers
Dryer
Magnetic
Separators.

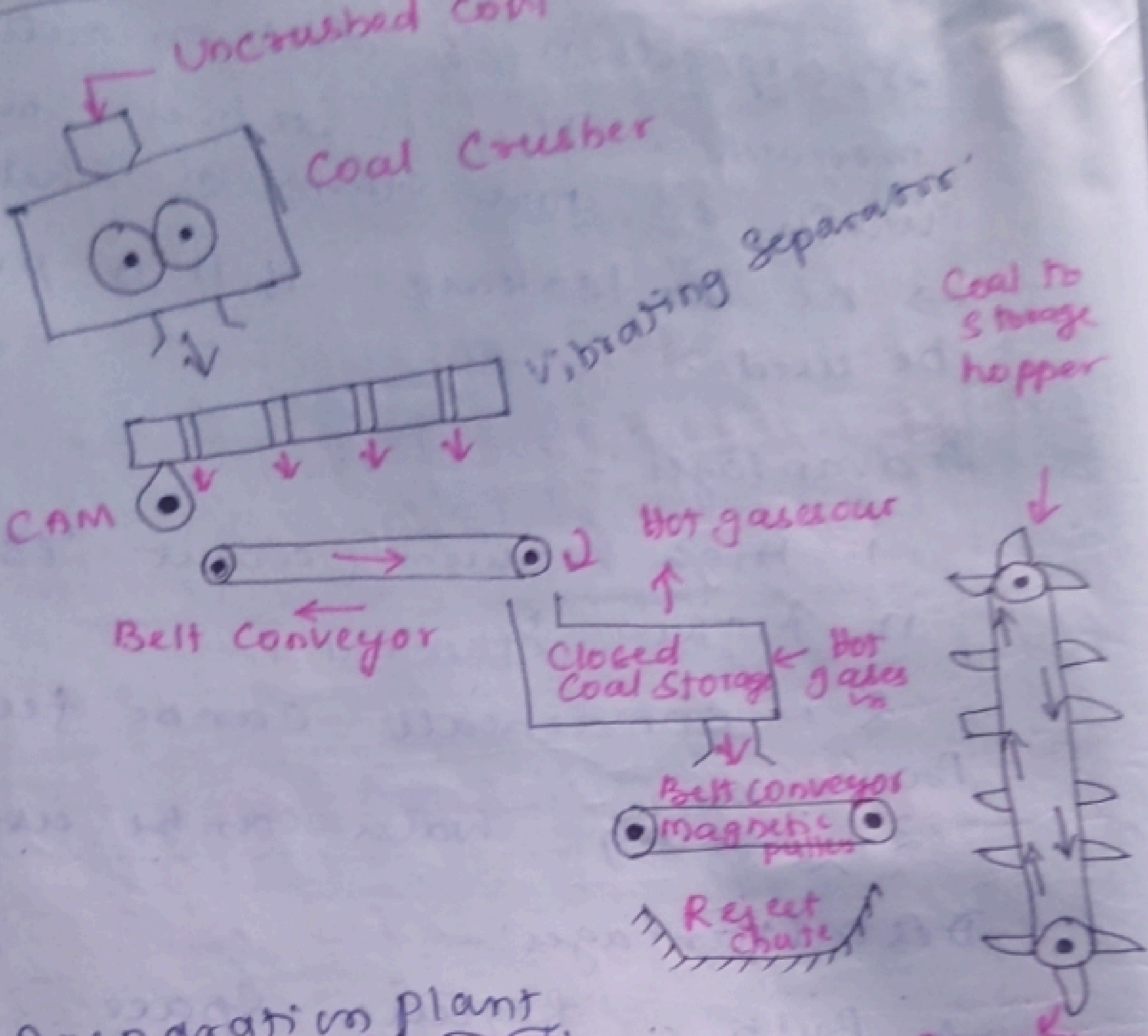


Fig: Coal preparation plant

600ton/hr

→ Coal Crusher are used to size before feeding to combustion chamber.

→ Sizers – Separation of coal to the required size.

→ Drier – remove moisture by using hot flue gas.

→ Before coal goes to storage hopper the Iron scrap are removed.

- Iron – may choke the burners and may increase the wear of the handling equipment.

→ India was the Third top coal producer in 2010.

→ Coal - 185,172 MW, Oil - 24,508 MW, Gas - 10 1076 MW 5,331 MW 993 MW 411 MW

→ Renewable - 84000 MW.

→ N - 986.50 H - 2182.20 OH 8423.15

→ Conventional - non Conventional

Wind, Solar, Biomass, Hydel. waste to power.

↳ Solar - 6 acre Land needed / MW.

→ India 5th wind power capacity in the world. Tamilnadu (1st in India) 30%.

→ One kg of Uranium → 3100 ton of coal, 1700 to oil

→ Renewable energy is generally defined as energy that is collected from resources which are naturally replenished on a human timescale sunlight, wind, rain tides. wave, geothermal heat.

→ generator - rotating machine that converts mechanical power into electrical power. The relative motion b/w magnetic field and a conductor creates an (Movements of matter) (metal wire) electric current.

Mechanical moving energy into electrical energy

Coal cleaning equipments:-

1. coal cleaning
2. coal sizing
3. Size classification
4. coal dryeng equipments.
5. concentraling equipments
6. Dewalering equipments.

1. Removal of dirt - less Than 8cm size.
cleaned by washeng. greater Than 8cm
cleaned by hand.
2. Coal dryeng - ① Steam dryeng ② oil dehydration
③ fuel gas dryeng moisture removed 10%.
by flue gas healing.

3. Coal sizing - Uniform size is required
for better Utilization of coal.
4. Shilphur removal - upto 2.5% accepted
fouling, corrosion, i) physitic - 50 to 80%.
ii) Organic 40%.

5. Washing:- Washings, Concentrating tables
Hydro cyclone, Heavy medium

• The feed slurry flow tangentially under pressure into cylinder moves to conical section
• High dense move downward

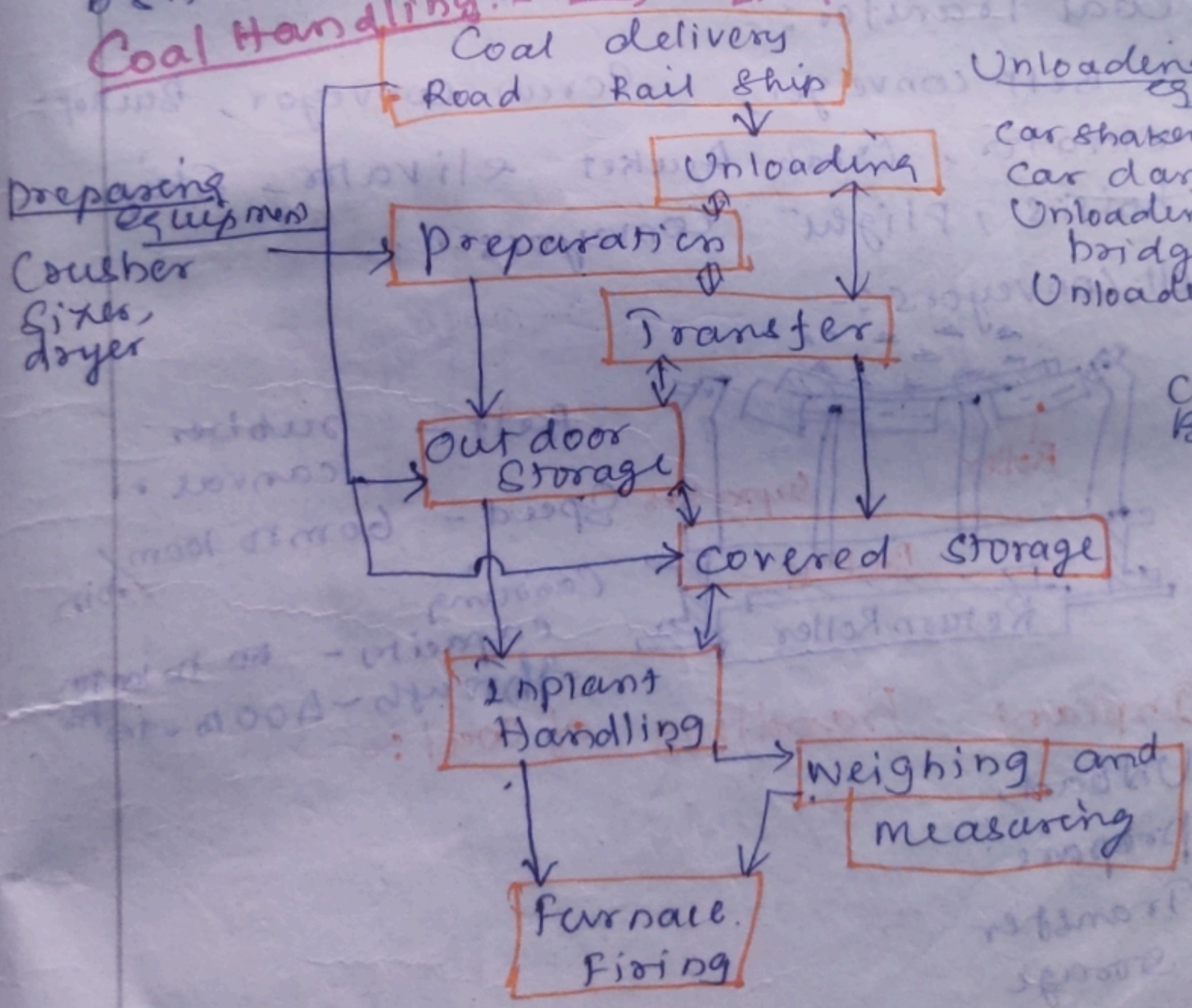
Hydro cyclone

Heavy
• used to clean coarse coal (6mm).
• low sp gravity particles float on the surface and discharged.

Advantages of coal preparation :-
1. Improves coal quality 2. Reduced Transportation of waste is eliminated 3. maintenance cost is less. Boiler performance is improved. 5. Sulphur removal is easier.

Ash handling ⇒ easy

Coal Handling :- ⇒ out plant handling, In plant handling



Transfer equipments:-
Belt conveyor, Screw Conveyor, Bucket elevator, Skip hoist, Fliger conveyor

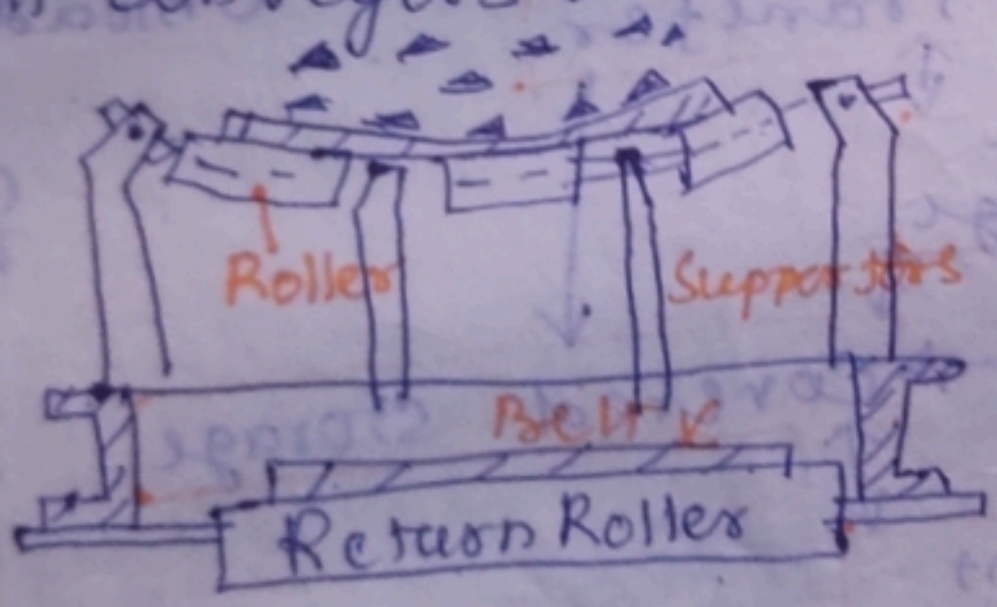
Storage equipment:-
Bulldozer, Scraper, Tramways, Cranes, Conveyor System.

Covered Storage equipment:-
Bin, Bunker, Indicators Valves

weighing devices:-
Scales, Coal metres, Samplers.

Coal Transfer:-
Belt conveyor, Screw Conveyor, Bucket elevator, Grab Bucket elivator, Skip hoists, Fliger Conveyors.

Belt Conveyors:-



Belt → rubber canvas
Speed - 60m to 100m/min
Carrying capacity - 60 to 100 ton/hr
Through - 400 tons/hr

Inplant handling of coal:-
Unload,
prepare
Transfer
Storage
Covered Storage
weighing devices.

advantages

1. Most economical method.
2. Coal transfer easy.
4. repair and maintenance cost minimum
5. power consumption minimum.

Disadvantages:- ① not suitable for short distance, greater heights.

② It cannot be used to carry the coal greater heights and inclination 20°.

Screw conveyer:-

Capacity - 125 tons/hr

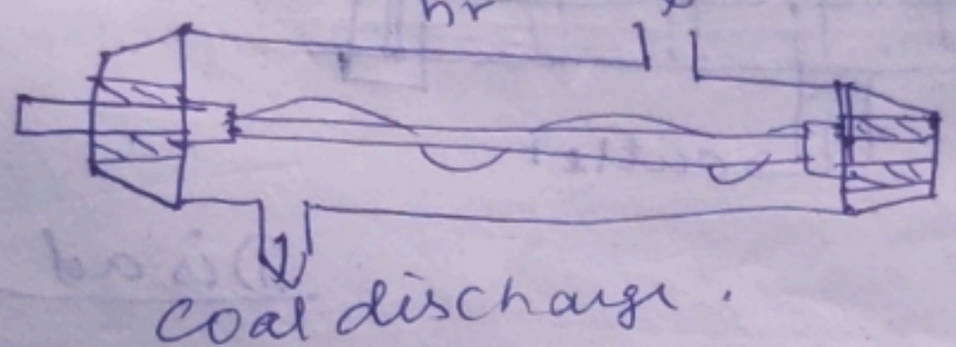
helicoid screw

Screw dia - 15cm to 50cm

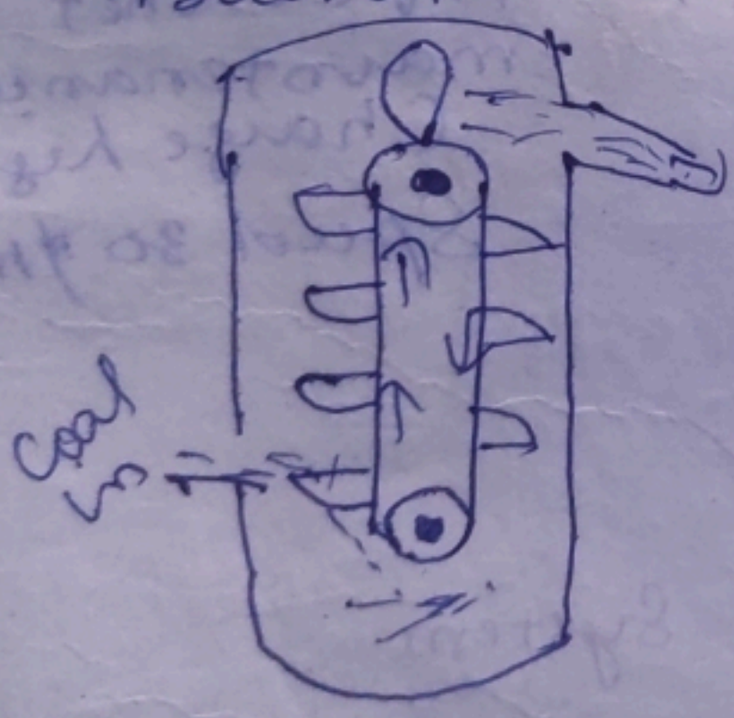
Speed - 70 to 120 rpm

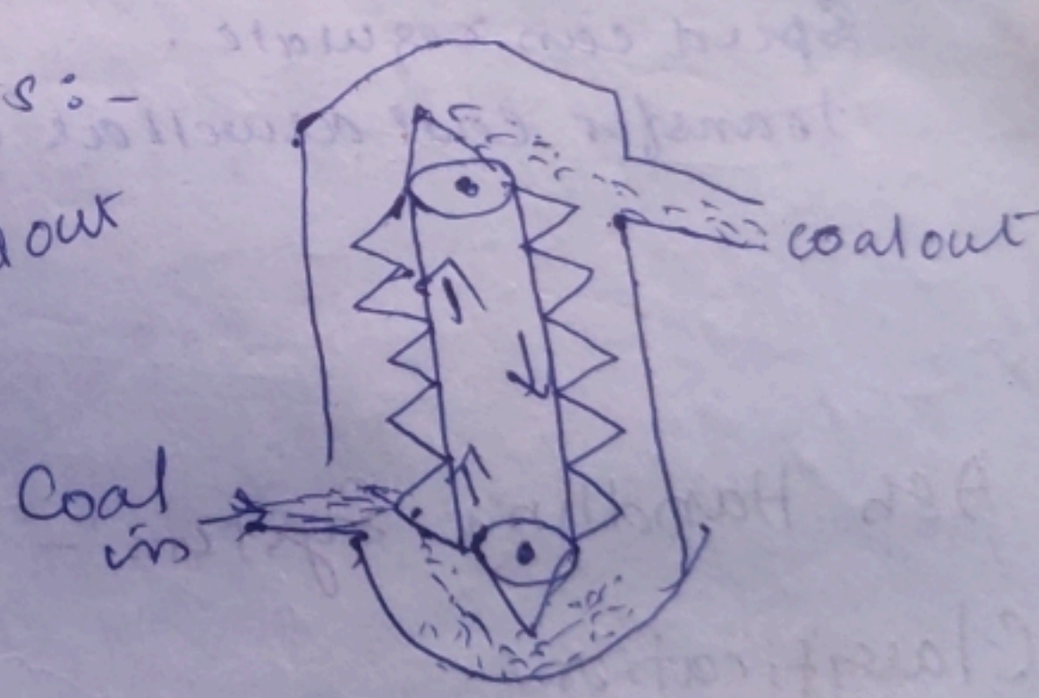
driving mechanism.

Ball Bearings.



Bucket elevators:-





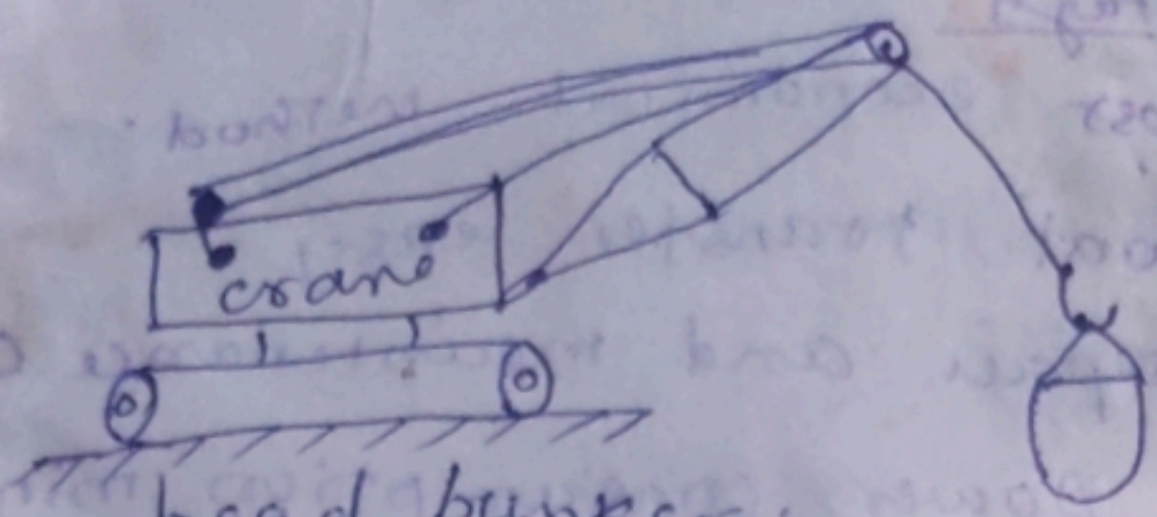
height - 30.5m.

Speed - 75 m/min (Centrifugal discharge)

35 m/min (continuous discharge)

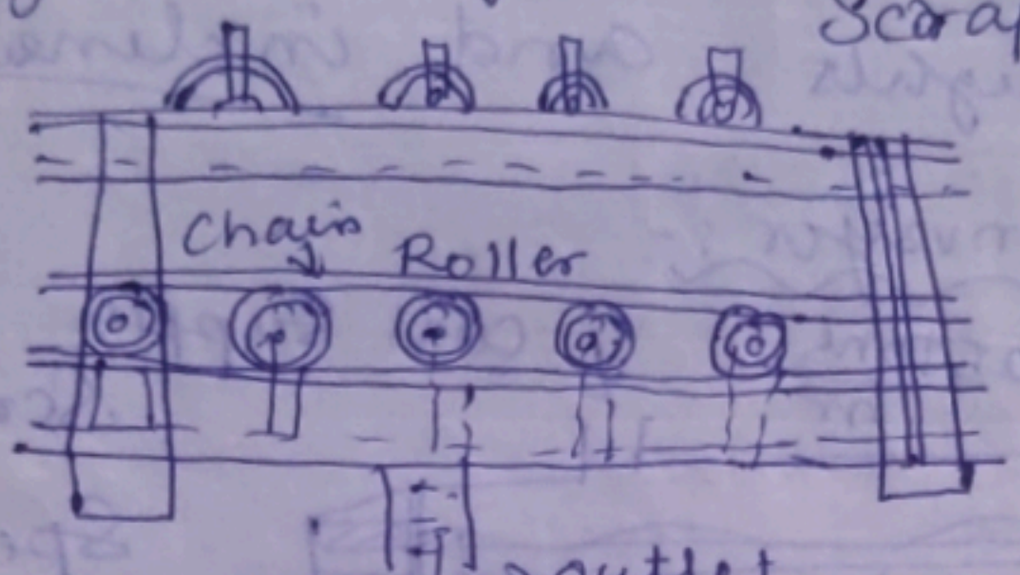
for 60 ton capacity/hour.

inclination - 60°.



: Overhead bunker.
: 23 cu.m Bucket, distance bore transfers 100 ton of Coal/hour.

Fligat Conveyor :-



transfer of coal under the conveyor.

Advantage

Small head room
Speed can regulate.
Transfer coal as well as ash.

Disad

Excessive wear and tear.
life is shot.
maintenance Charge high.
Speed 30 ft/min

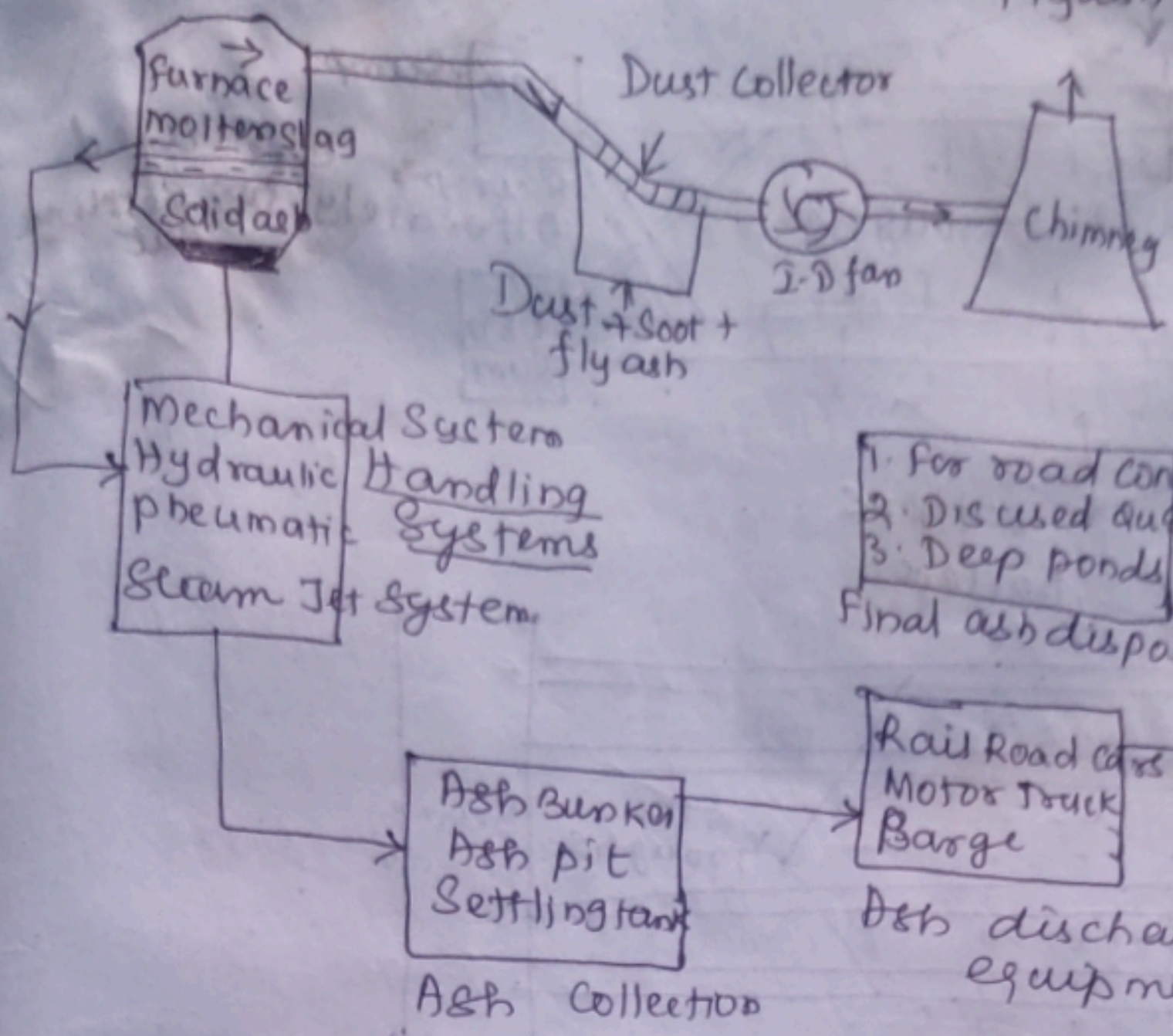
Ash Handling System:-

Classification:-

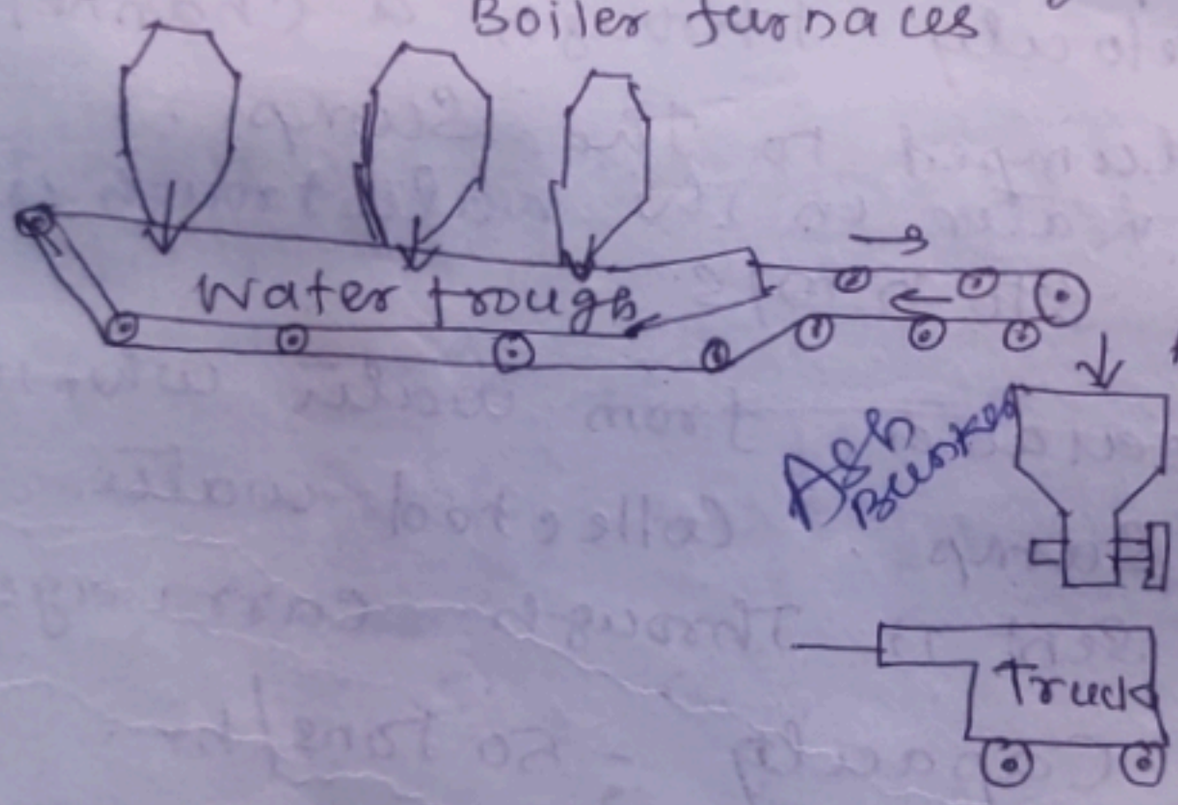
1. Mechanical handling System
2. Hydraulic System
3. Pneumatic System
4. Steam jet System

General Layout of ash handling and dust Collection System :-

(M) J-12 (Dm)



Mechanical Handling System :-



(11) low capacity
5 tons/hr

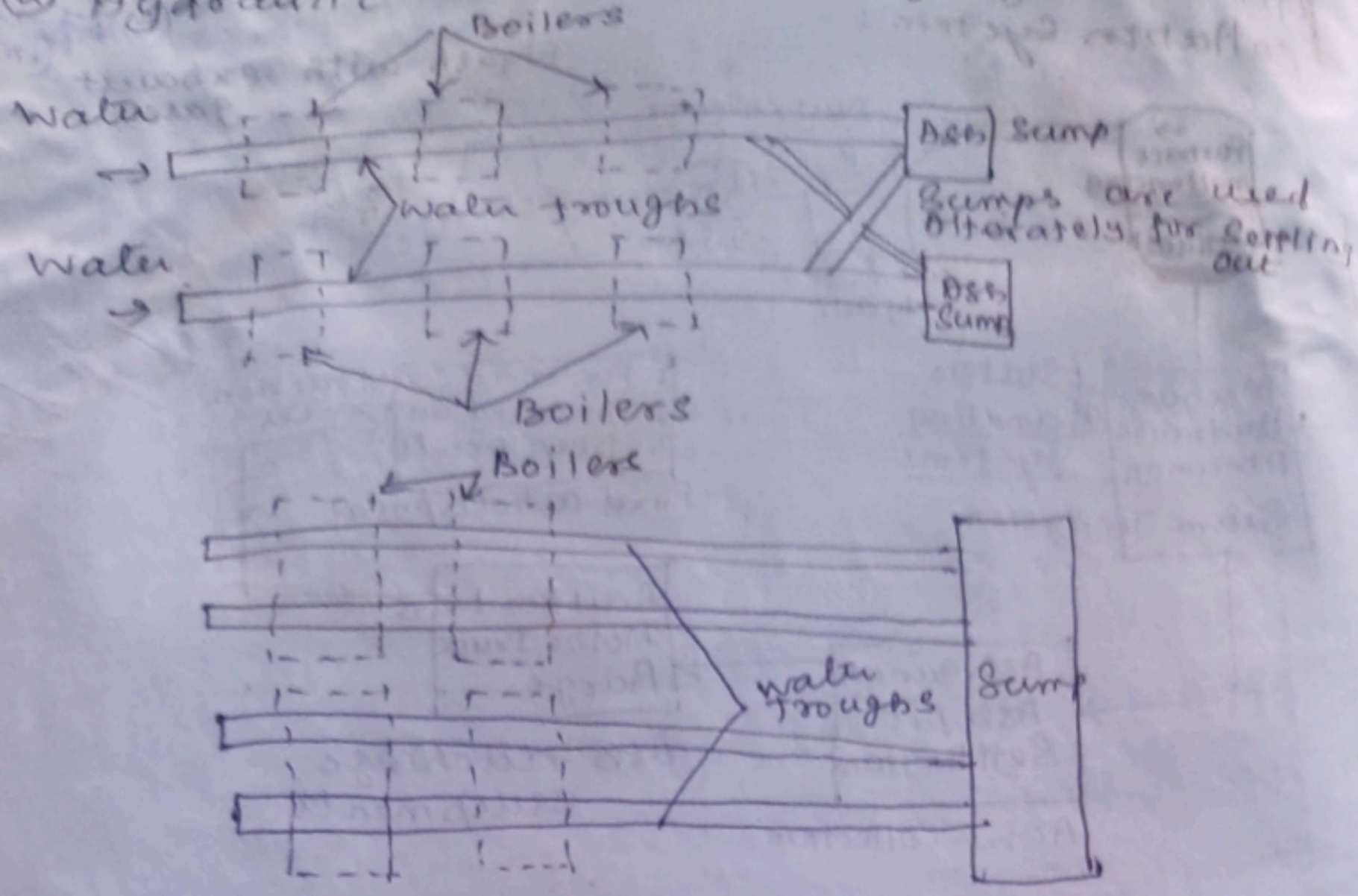
advantages :-
low power consumption

Hot ash → Belt Conveyor → dumping Site → Truck
(Water Seal) (CB Overhead Bunker)

- life - 5 to 10 years.

- Hot ash is made to fall over the belt conveyor through a water seal.
- control valve is opened and closed manually to load the trucks.

② Hydraulic ASH Handling System:



- Carries ash with the flow of water with high velocity through a channel and finally dumped to the sump.
- The velocity of water in the water trough is
  → low velocity — 3 to 5 m/s.
- The ash is separated from water when it reached to the sump. Collected water reused again sent it through carriages.
- ash carrying capacity - 50 tons/hr.
- Distance covered 2500 metres.

High velocity:-

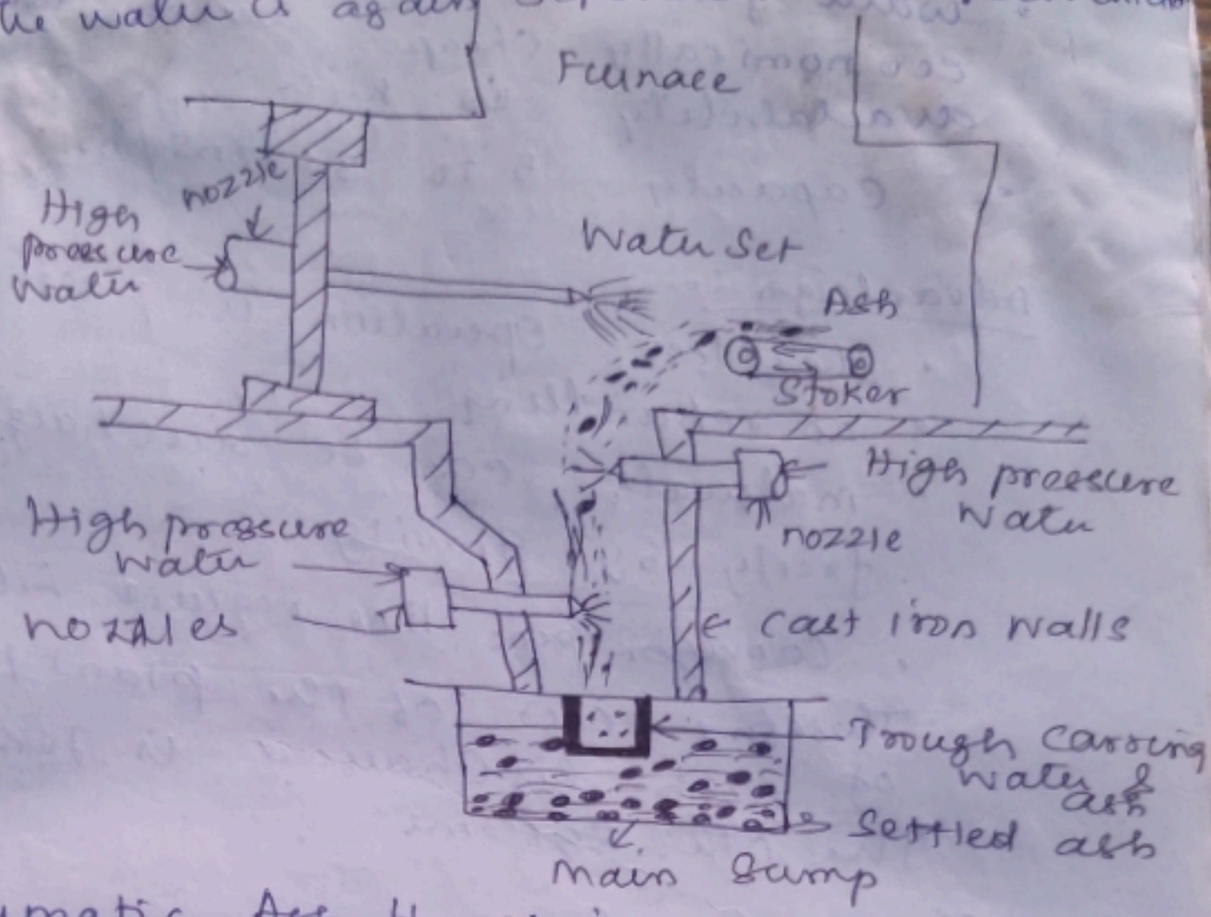
capacity - 120 tons/hr.

Distance - 1000 m.

- The molten slag produced in the pulverised coal our high pr hydraulic system high pr water jets disintegrate into small particles slag. It has to flow sluice.

The hoppers below the boiler are fitted with water nozzles at the top and on the sides.

- Top nozzle cool the ash and side nozzle provide the driving force to carry ash through trough.
- The water is again separated and recirculated.



Pneumatic Ash Handling System :-

This system has been developed for

- Abrasive as well as fine dusty material such as fly-ash and soot.
- The ash carried by the air is separated into the primary and secondary separators working on cyclone principle.
- Exhauster - I.D fan.
- Mechanical exhauster is used for large tonnage of material.
- power required for mechanical exhauster 5 H.P./ton of material.
- Steam - jet exhauster for small and medium size plant

high velocity air stream

- Steam consumption 120 kg / ton
- water jet exhauster easily available economically cheap. where water availability is high.
- capacity 5 to 30 tons / hr.

Advantages :-

- dustless operation is possible.
- no rehandling
- materials can be discharged freely by gravity.
- conveyor pipe line require little space

Therefore cost of the plant per ton of ash discharged is less than the other systems.

Steam Jet System :-

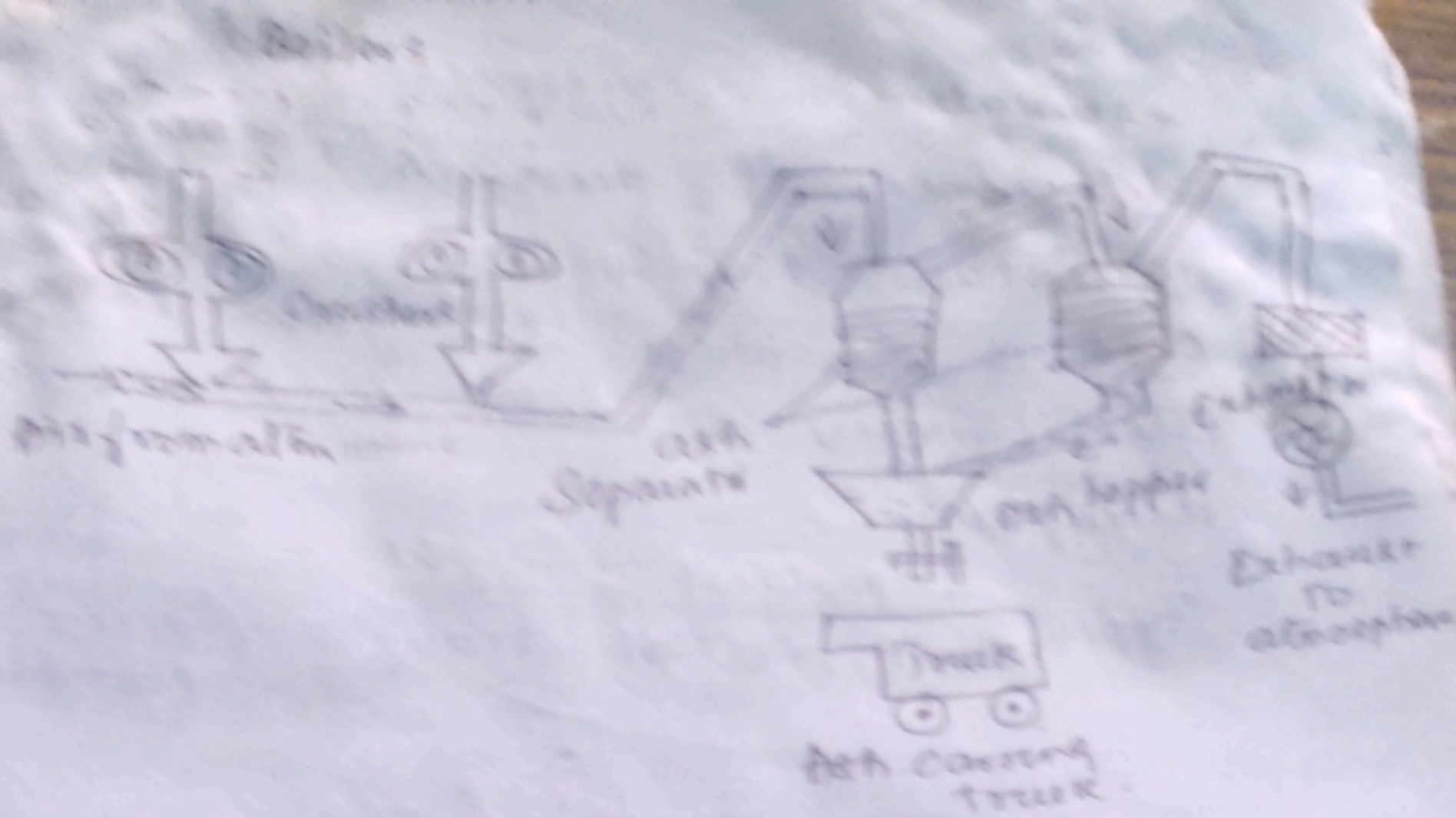
high velocity. which is capable of carrying dry solid materials

Advantages, disadvantages

- capital cost of this system / ton of ash
- It require less space.

Disadvantage :- • pipe has to be lined with nickel alloy.

- operation is noisy.
- capacity 15 tons per hour.



Draught System :-

The purpose of draught is to supply required quantity of air for combustion and remove the burnt products from the system.

To move the air through the fuel bed and to produce a flow of hot gases through the boiler, economizer, preheater and chimney requires a difference of pressure equal to that necessary to accelerate the burnt gases to their final velocity and to overcome the pressure losses.

equivalent to pressure head. The difference of pressure required to maintain the constant flow of air and to discharge the gases through the chimney to atm is known as draught.

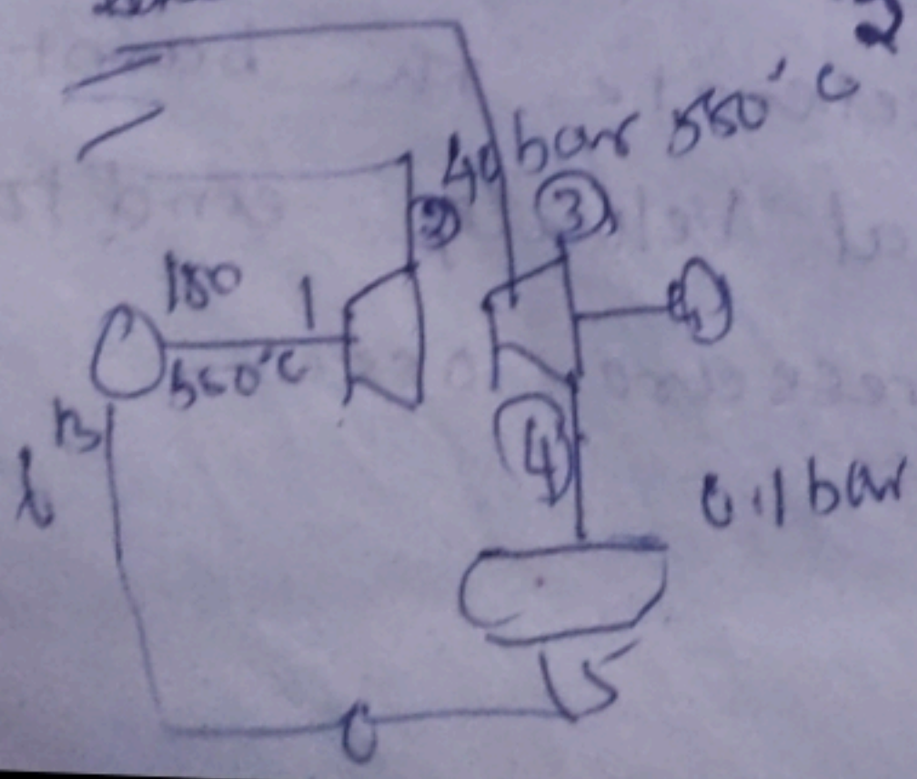
Types → Natural draught - (help of chimney)
→ Artificial draught (except chimney)

A steam power plant uses steam at boiler pressure of 150 bar and temp 550°c with reheat at 40 bar and 550°c at condenser pressure of 0.1 bar. Find the quality of steam at turbine exhaust cycle efficiency and steam rate.

Given $P_1 = 150$ bar

$T_1 = 550°C$

$P_2 = 40$ bar, $T_3 = 550°C$, $P_4 = 0.1$ bar.



Solution:-

properties of steam from steam table

at 150 bar & 550°C.

$h_1 = 3445.2$ KJ/kg, $s_1 = 6.5125$ KJ/kgk.

At 40 bar & 550°C.

$h_3 = 3558.9$ KJ/kg, $s_3 = 7.2295$ KJ/kgK

At ~~40~~ 40 bar → 6.069 = Sg

$T_{sat} = 250.3°C = 523.3K$

$h_f = 1087.4$ KJ/kg $h_{fg} = 1712.9$ KJ/kg.

$s_f = 2.797$ KJ/kgk $s_{fg} = 3.272$ KJ/kgK

At 0.1 bar

$h_f = 191.8$ KJ/kg $h_{fg} = 2392.9$ KJ/kg.

$s_f = 0.649$ KJ/kgK, $s_{fg} = 7.502$ KJ/kgk.

1-2 ⇒ Isentropic.

$s_1 = s = 6.5125$ KJ/kg.K — 8.151 (0.1 bar)

$s_2 > s_g$ at 40 bar.

Exit of HP turbine is superheat

$T_{sup} = 332°C$. $h_2 = 3047.18$ KJ/kg.

$s_4 < s_g$ at 0.1 bar.

Steam is at wet condition.

$s_4 = s_3 = 7.2295$ KJ/kgK.

$s_4 = s_{f4} + x_4 \times s_{fg4}$

$$x_4 = \frac{s_4 - s_{f4}}{s_{fg4}} = \frac{7.2295 - 0.649}{7.502} \quad 20.87$$

$h_4 = h_{f4} + x_4 \times h_{fg4}$ $\Rightarrow 191.8 + 0.87 \times 2392.9$

$$\boxed{h_4 = 2290.37 \text{ KJ/kgk}}$$

$$\eta = \frac{(h_1 - h_2) + (h_3 - h_4)}{(h_1 - h_{f4}) + (h_3 - h_2)}$$

$$= \frac{(3445.2 - 3047.15) + (3558.9 - 2290.37)}{(3445.2 - 191.8) + (3558.9 - 3047.18)}$$

$$= 0.4426 \times 100 = 44.26\%$$

$$\text{Steam rate} = \frac{3600}{(h_1 - h_2) + (h_3 - h_4)}$$

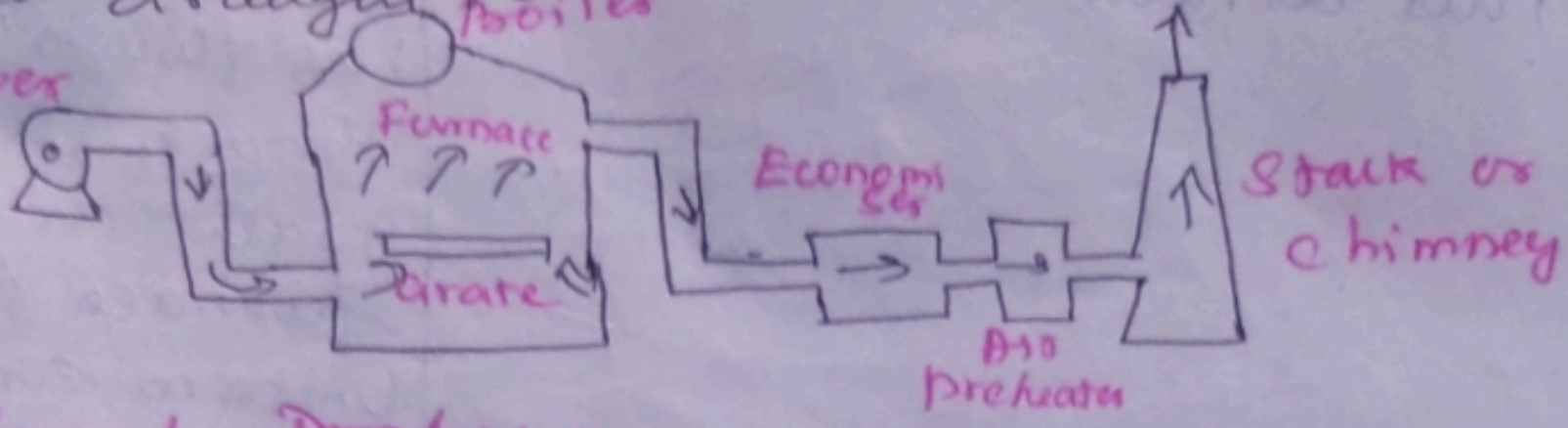
$$= \frac{3600}{(3445.2 - 3047.18) + (3558.9 - 2290.31)}$$

$$= 2.16 \text{ kg/kw-hr}.$$

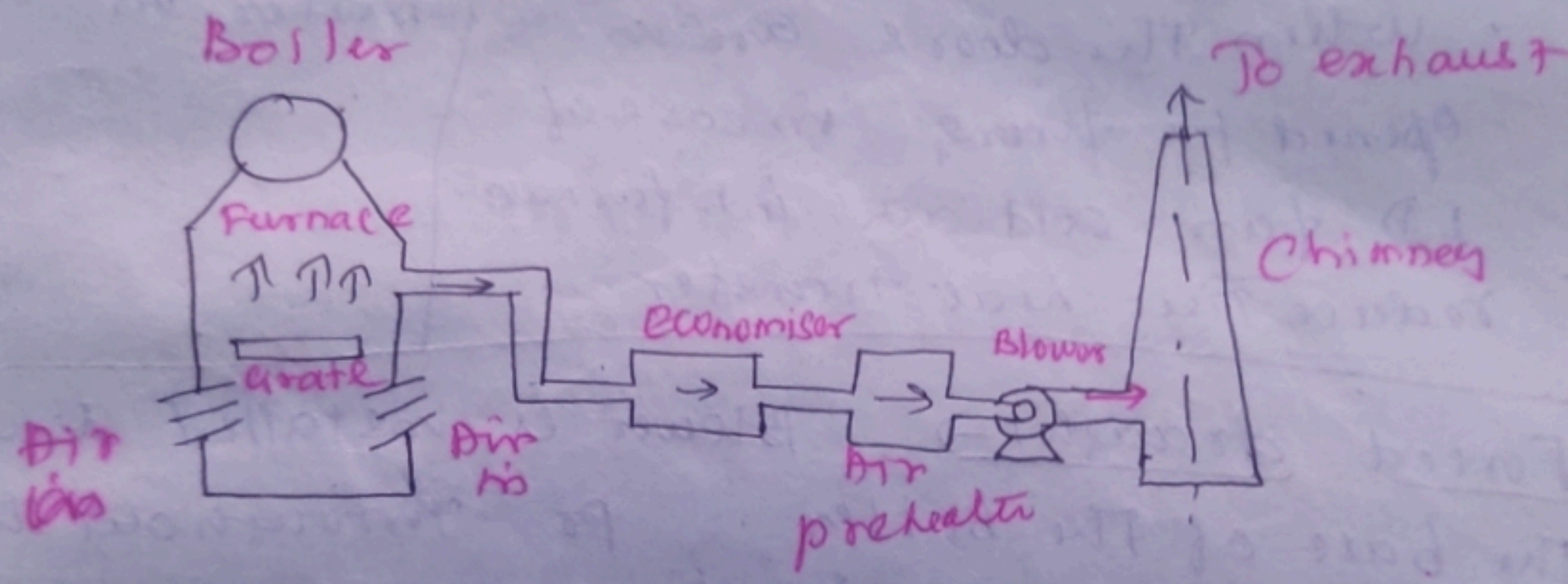
Artificial draught (Forced and Induced Draught):-

- 200000 ton steam / hr.
- Advantages of fan → reduce the height of the chimney.

Forced draught



Induced Draught:-



Induced draught	Forced draught
• Size and power required is higher because it handles more gases (air and fuel)	There is no leakage of air.
• 1.3 times the size of forced draught fan.	
• Water cooled bearings are required.	

- There is continuous leakage of air in the furnace with induced draught as the pressure inside the furnace is less than the atm pro. This dilutes the combustion.

- When the doors are opened for firing in case of ID fan cold air into furnace reduce the heat transfer

The flow of air through the grate and furnace is more uniform and it penetrates better in.

Forced draught → Blower is installed near the base of the boiler. So throughout the system is above atm pressure.

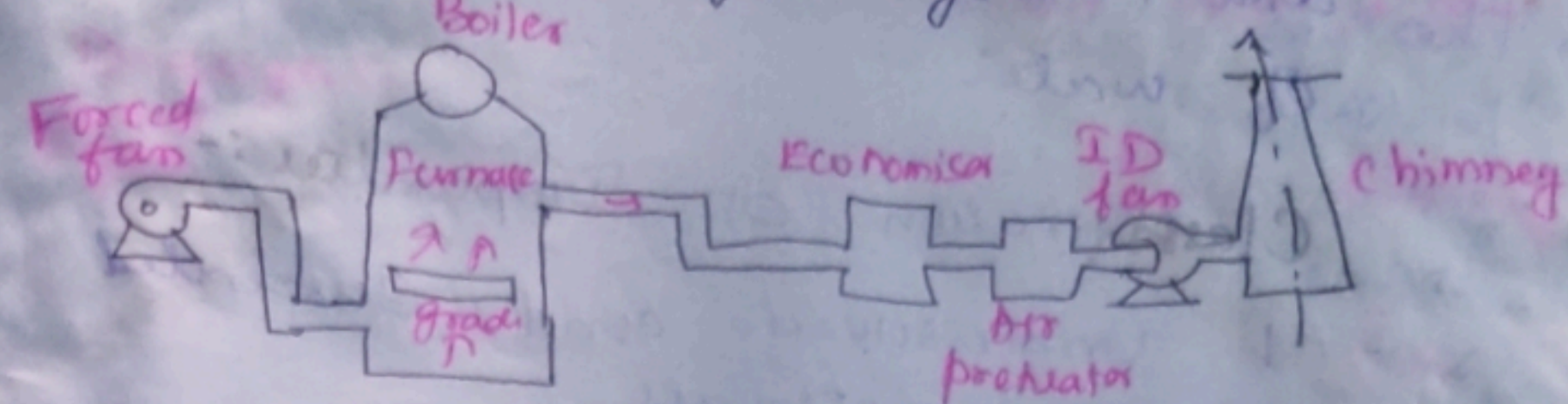
Induced fan :- Fan is located near the base of the chimney, instead of near the grate. Suction pressure in this system is below atm.

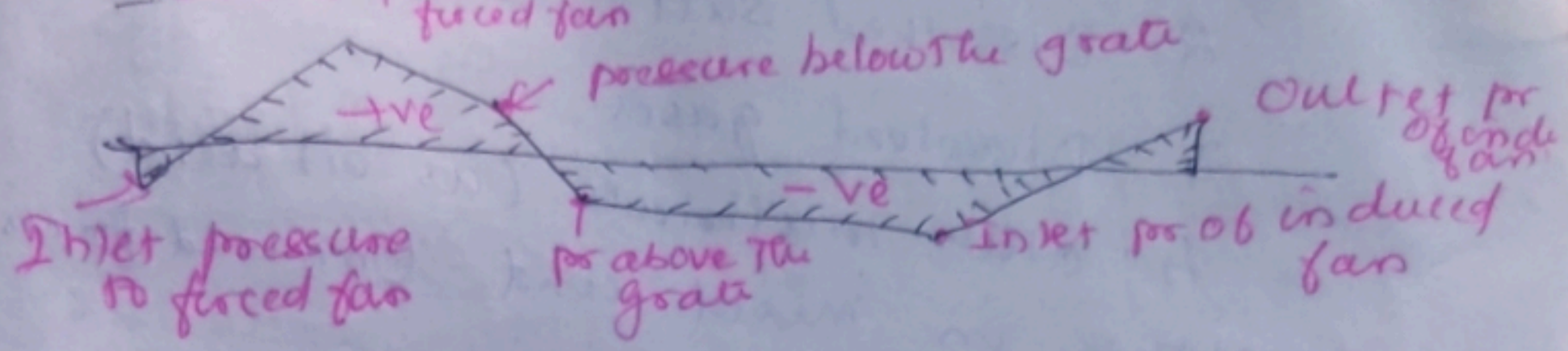
$$\text{power input} = \frac{Wf\,(1+A/F)\times Vg\,\Delta P_{ID}}{\eta_{ID}}$$

Wf - fuel Burning rate
A/F - Air fuel ratio
Vg - Specific Volume of flue gases

ΔP_{ID} - pressure head developed
η_{ID} - η of Induced draught

Balanced Draught Systems:-





- It is the combination of induced and forced draught system.
- The forced draught is used to force the air through the bed and induced draught is used to suck the gases from the boiler and discharges them to the chimney.

Feed water treatment:- Boiler make up water 1.5-2%. Fittings, Bearings

Maintain the operation at the best possible levels of availability economy and efficiency and control the chemical in the water. Prevent the To prevent Scale and Steam deposit formations on heating surfaces to prevent the Scale and deposit formation.

1) Elimination of corrosion.
2) Prevention of Silica deposition and corrosion damage to turbine blad
   control of carry over to eliminate deposition on superheate

and to maintain high level purity of water.

Classification of Impurities :-

1. Undissolved and Suspended Solid materials
2. Dissolved Salts and minerals
3. Dissolved gases
4. other materials (as oil acid) either in mixed and Unmixed forms.

1. Undissolved and Suspended materials :-

a) Turbidity and Sediment -

Coarse particles (mud, Sediment, sand) should not exceed 5ppm, removed by Settling coagulation.

- Hardness is taken as calcium Carbonate ($CaCO_3$) in PPm

b) Sodium potassium Salts

c) Chlorides - cause corrosion.

d) Iron - ferrous bicarbonate, even 0.3 ppm can create trouble in the feed water System by Soft Scale formation accelerating the corrosion.

e) Manganese -

f) Silica - most water contains from 1 to 100 ppm. It forms very hard scale in boilers and forms insoluble deposits.

g) Microbiological growth - Can form clog flow passages reduce heat transfer rate.

b) Colour - cause in foaming in boilers. removed by chlorination or absorption by activated carbon.

2) Dissolved Salts and Minerals:-

a) Calcium and Magnesium Salts:-

Calcium magnisium is the form of Bicarbonates, Sulphates, Chlorides.

Temporary Hardness - Bi carbonates of calcium and magnesium, can be removed by Boiling. permanent Hardness caused by presence of chlorides, Sulphates nitrates of calcium and magnesium removed by blowdown method.

3) Dissolved gases:-

a) oxygen:- As it corrosive to iron, Zinc, brass and other metals. It causes pitting of water lines Boilers and heat exchangers.

- Boiler makeup water to the extent of 1.5 - 2 % of the total flow rate is required to replenish the losses from fittings, bearings blow down, turbine glands, other causes

b) Carbon dioxide:- river water 50ppm and well water contains 2 to 50 ppm of CO_2. Corrosion

$$CO_2 + H_2O \rightarrow H_2CO_3$$

(carbonic acid)

A) other materials:-

a) Free Mineral acid - Usually present as Sulphuric & hydro chloric acid. causes corrosion.

b) Oil - form Scale, foam, removal by strainers, baffle separators.

Different methods of water Treatment:-

Dissolved solids in the water removed in the boiler itself by a chemical treatment - then the method is known as "Internal treatment". If they are removed from the water before supplying to the boiler is External treatment.

Internal Treatment :-

Treating water in the boiler during evaporation.

compounds in raw water	Treating Chemicals	Sludge formed
Calcium Bicarbonate		

External Treatment :-

- Chlorinate - prevent biofouling
- Suspended solids removed by aluminium sulphate ($Al_2(SO_4)_3$).
- gravity filter, pressure type filters are used
- Activated Carbon can absorb organics and remove residual chlorine from the chlorination process.
- The dissolved Salts of calcium and magnesium give to water a quality called hardness.

① Lime Soda process :-

lime - calcium hydroxide.
Soda ash - Sodium Carbonate.
normal temp - cold process. near boiling point - hot process.

$$MgCl_2 + Ca(OH)_2 = Mg(OH)_2 + CaCl_2$$

$$CaCl_2 + Na_2CO_3 = CaCO_3 + 2NaCl.$$

② Hot phosphate Softening :-

- Calcium and magnesium hardness is removed by phosphate and caustic Soda. Tricalcium phosphate ($Ca_3(PO_4)_2$) and magnesium hydroxide are precipitated

- process is carried out above 100°C
- This is costlier than lime soda process for water hardness 60ppm or less.

$$CaCO_3 + 2Na_3PO_4 \rightarrow Ca_3(PO_4)_2 + 2Na_2CO_3.$$

(3) Sodium Zeolite Softening:-

water passed through sodium Zeolite bed.

$$CaCO_2 + Na_2Z = CaZ + Na_2CO_3$$

- The bed can be regenerated by flushing it with brine (NaCl).

$$CaZ + 2NaCl = Na_2Z + CaCl_2.$$

Reasons:-

- (1) water of high or low ph have a deleterious effect on Zeolites.
- (2) High temperatures also have a bad effect.
- (3) Turbid waters coat the Zeolite material. reducing its efficiency.
- (4) There is no reduction in alkalinity or total solids.

(4) Hydrogen Zeolite Softening:-

$$Mg(HCO_3)_2 + H_2Z = MgZ + 2H_2CO_3.$$

$$MgZ + H_2SO_4 = H_2Z + MgSO_4.$$

- Calcium, magnesium and Sodium ions is passed Through hydrogen Zeolite These ions are exchanged for bicarbonate, Sulphate, chloride and nitrate.

(b) Anion Exchangers:-

It can remove anions like Chlorides, Sulphates and nitrates present in hydro Zeolite effluent by resinous materials which absorb Them.

$$HCl + RCO_3 = RCl_2 + H_2CO_3$$

- Carbonic acid Sprayed in a Shower to expose area CO_2 is released.

(b) Demineralizing plant:-

- Removing dissolved Solids in water by ion exchange is called demineralization
- ~~Anion~~ The cation resin hydrogen Zeolite where hydrogen ion exchanged for Calcium, magnesium, Sodium. anions chlorides, nitrates and Sulphates.
- electro dialysis (or reverse osmosis

(1) Condensate polishing

- Condensate passing Through mixed bed Units which contain both cation and anion resins.
- Resins act as filters.

⑧ Deaeration :-

- Degasification
- depends on solubility of dissolved gases.

⑨ evaporation :-

B Internal treatment :-

$$HOH \rightleftharpoons H^+ + (OH)^-$$

- pH is > 7 water is alkaline, if pH < 7 it is acidic.
- Trisodium phosphate, Na_3PO_4 is increase alkalinity, Monosodium phosphate NaH_2PO_4 is used to decrease alkalinity.
- Scale formation and corrosion decreases The pH value.
- pH 10.5 is usually maintained for Boiler.

Scale prevention - ① periodic (or) blowdown ② External or continuous blowdown

internal treatment

Boiler Blowdown :-

% Blowdown = $\frac{\text{quantity of water blown down}}{\text{quantity of feed water}} \times 100$

Steam purity :-

Electrical conductivity is a solids in the water.

Foaming - formation of bubbles
priming - Violent, Uneven water Circulation, and rapid changes in steaming rate. For the desired steam purity both foaming & priming controlled

Binary Vapour Cycle :-

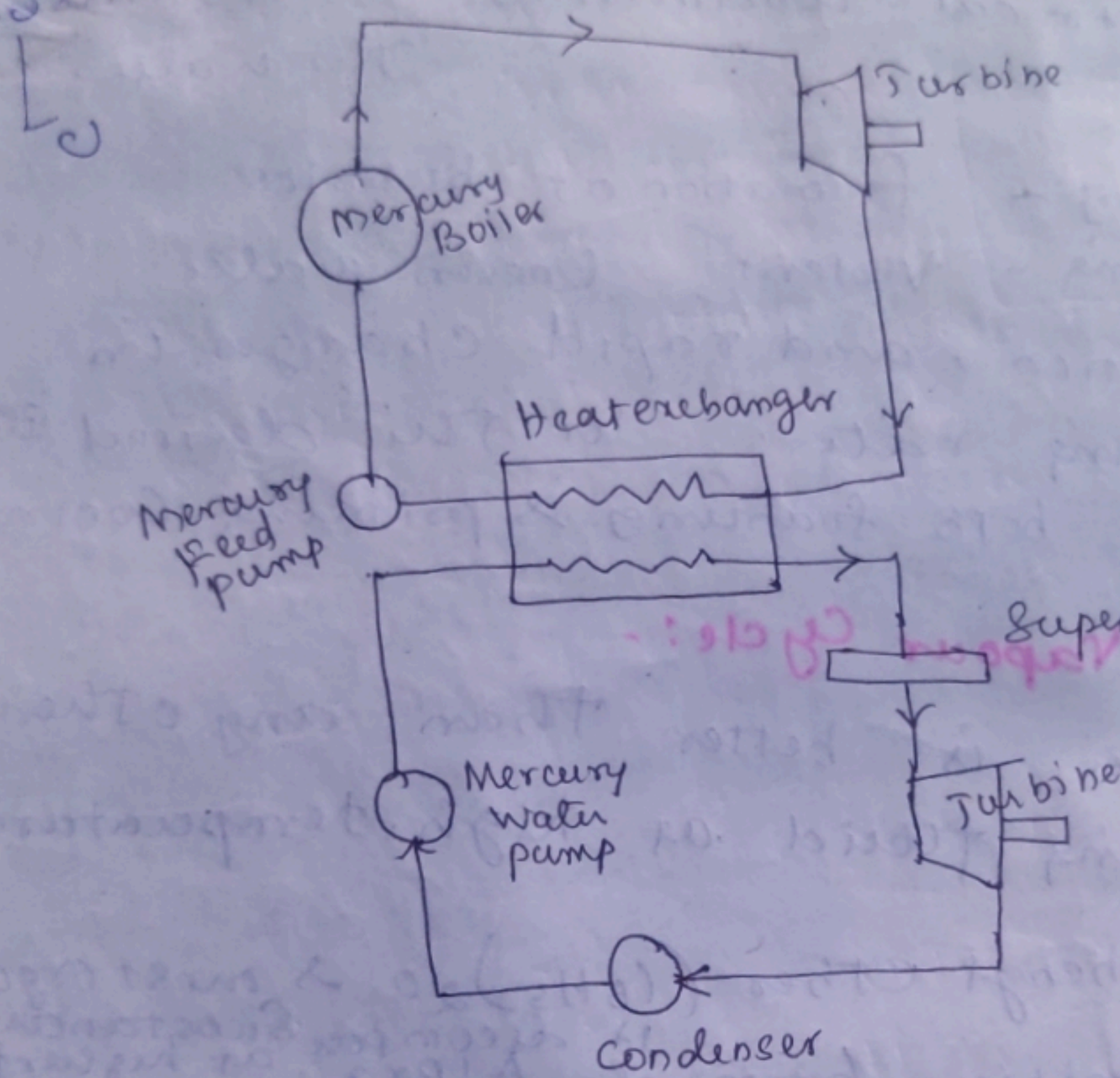
- water is better than any other working fluid at high temperature.

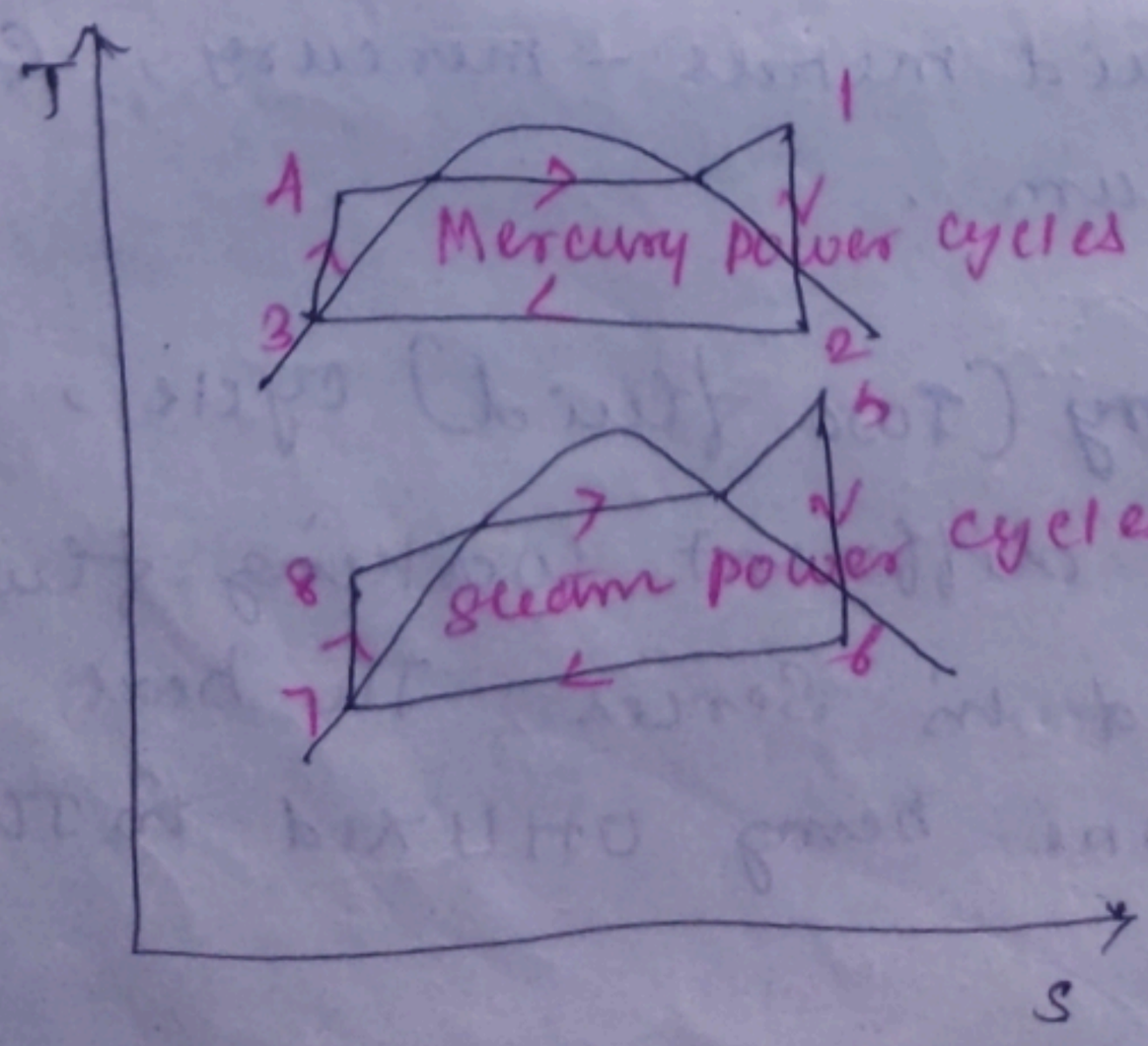
(a) diphenyl ether $(C_6H_5)_2O$ → most organic substances. It decompose at higher temp
b) Aluminium bromide $AlBr_3$.
c) liquid metals - mercury, Sodium, potassium.

- Binary (Two fluid) cycle, two cycles with different working fluids are coupled in series, The heat rejected by one being utilized in the other.

at 12 bar.

- Mercury — Saturation temp – 560°C
- Critical pressure & temp
  ⇒ 1060 bar and 1460°C respectively.

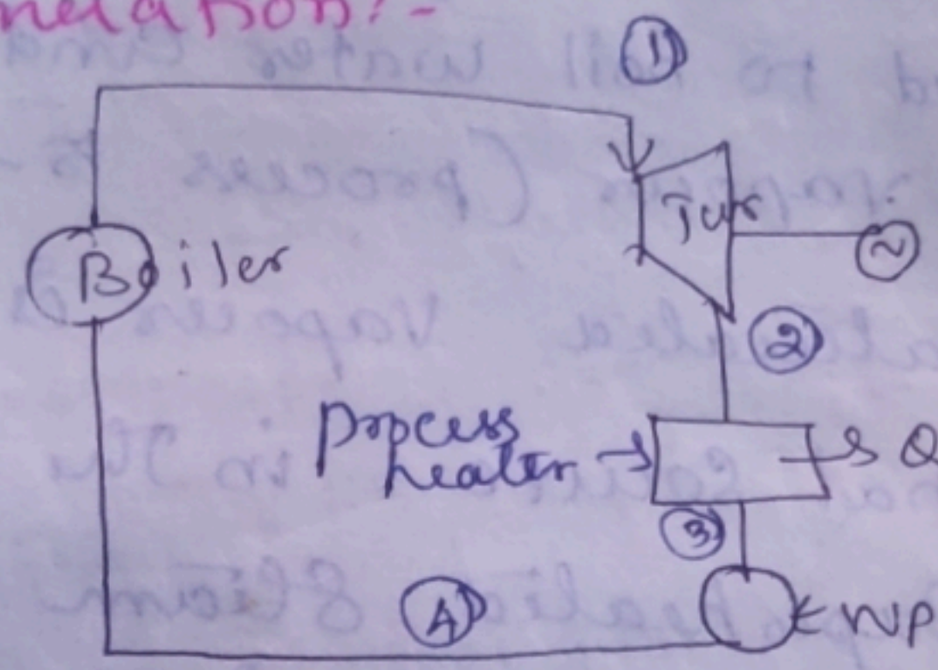




The cycle has one high temperature region and one low temperature region. This is called a Binary Vapour cycle. In this cycle, the condenses of the high temperature cycle called topping cycle, and low temperature cycle termed as bottoming cycle.

Cogeneration:-

process heater is replaced condenser.

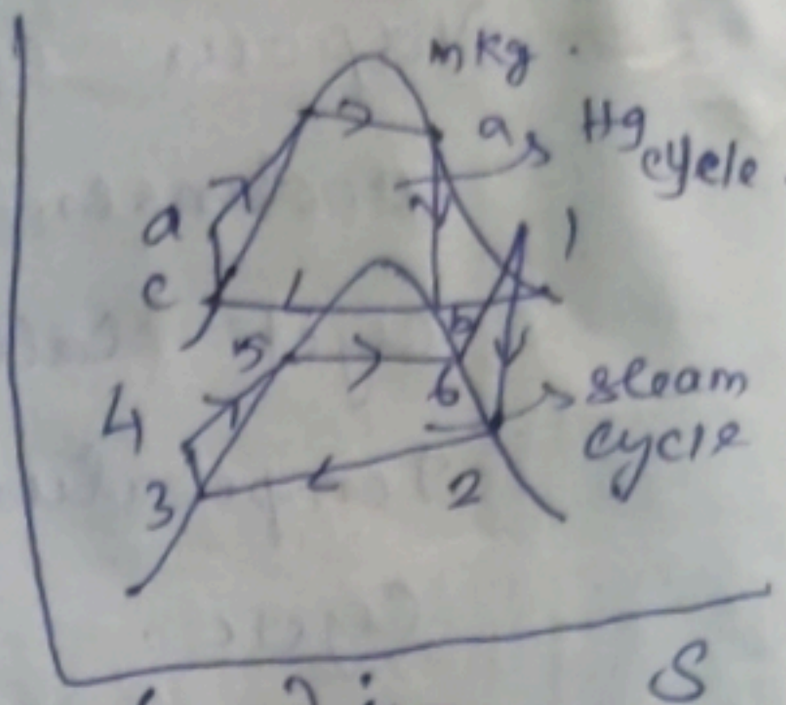


- A plant producing both electrical power and process heat simultaneously is called cogeneration plant.
- Exhaust steam from the turbine is utilized for process heating, the process heater replacing the condenser of the ordinary Rankine cycle.

$$\eta_{co} = \frac{W_T + Q_H}{Q_1}$$

Binary cycle :-

- As is at pr 12 bar, water, aluminium Bromide
mercury - 184°c 482.5°c, 560°C



- The mercury cycle I a-b-c-d is a Simple Rankine cycle using Saturated vapour. The heat rejected by mercury during Condensation (process b-c) is transferred to boil water and form Saturated vapour (process 5-6).
- The Saturated vapour is heated from the external source in the Superheater (6-1). Superheated Steam expands in the turbine and is then condensed.
- The condensate is then pumped to the economiser where it is heated till it becomes Saturated liquid by the outgoing flue gases (4-5)

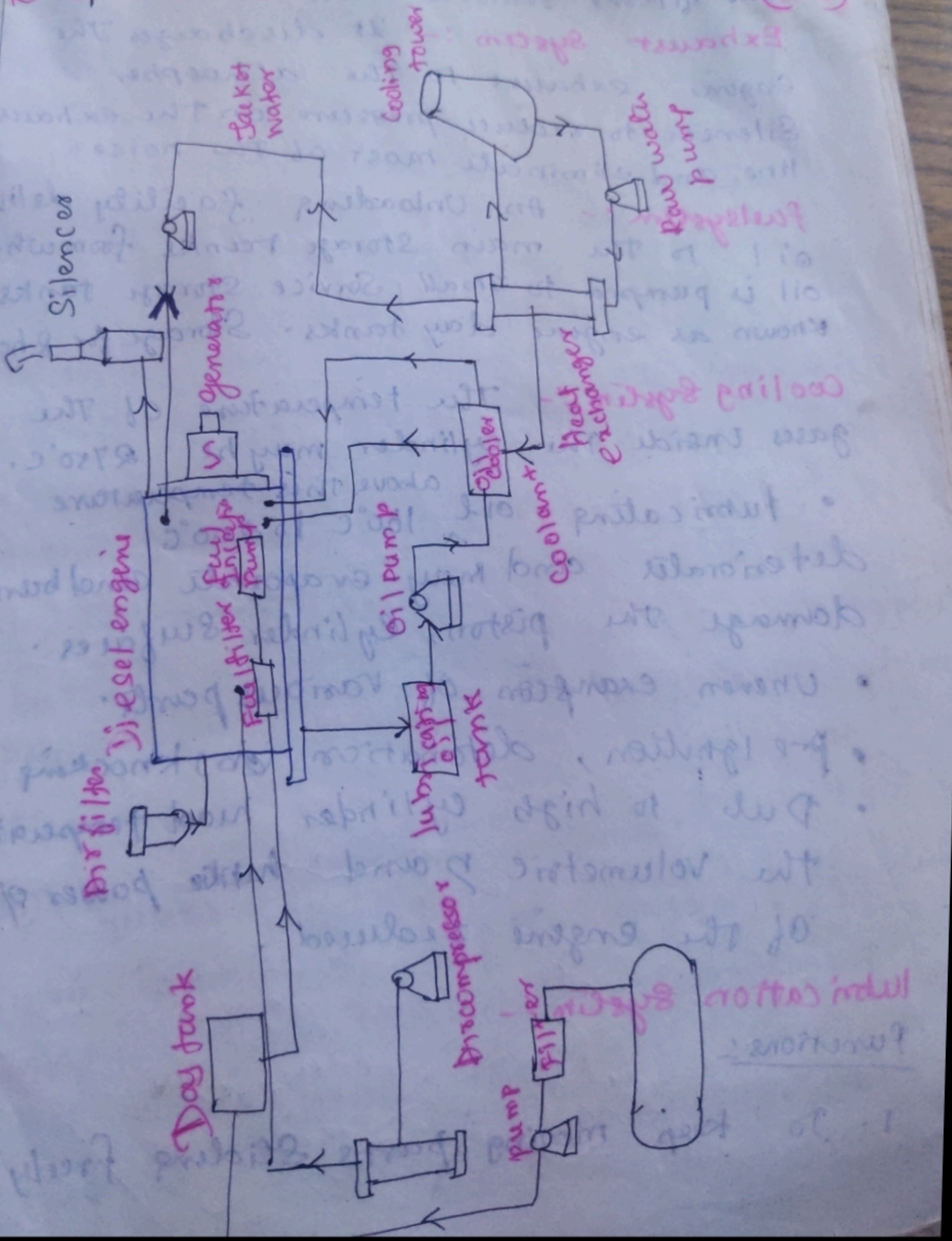
Back pressure turbine :-

The pressure at exhaust from the turbine is the Saturation pressure corresponding to the temperature desired in the process heater. Such a turbine is called a back pressure turbine.

UNIT - II

Diesel, Gas turbine and Combined cycle power plants.

Components of diesel power plants:- (16M)



Engine:- It is the main component and is directly coupled to the plant generator.

Air intake System:- It conveys fresh air to engine. Air filters removes dirt.

Exhaust System:- It discharges the engine exhaust to the atmospher. Silencer to reduce pressure on the exhaust line and eliminate most of the noise.

Fuelsystem:- On Unloading facility delivers oil to the main storage tanks from where oil is pumped to small Service storage tanks known as engine day tanks. Storage for 8 hours.

Cooling System:- The temperature of the gases inside the cylinder may be 2750°C. above this temperature
- lubricating oil 160°C to 200°C

deteriorates and may evaporate and burn damage the piston, cylinder surfaces.
- Uneven expansion of various parts.
- pre ignition, detonation or knocking.
- Due to high cylinder head temperature the volumetric η and hence power o/p of the engine reduced.

lubrication System:-

Functions:-

1. To keep moving parts sliding freely

Thus reduce the engine friction and wear.

- Cooling - ~~Taking~~ away a part of heat caused by friction.
- Cleaning To keep bearings and piston rings clean products of Combustion by washing them away.
- Sealing - good seal b/w piston rings and cylinder walls.
- Reducing noise - To reduce the noise of the engine by absorbing vibration

Starting of engine -

i) By an Auxilary engine - which is mounted close to the main engine and drives the latter through a cluth and gears.

ii) By using electric motor - storage battery of 12 to 36 volts is used to supply power to an electric motor that drives the engine

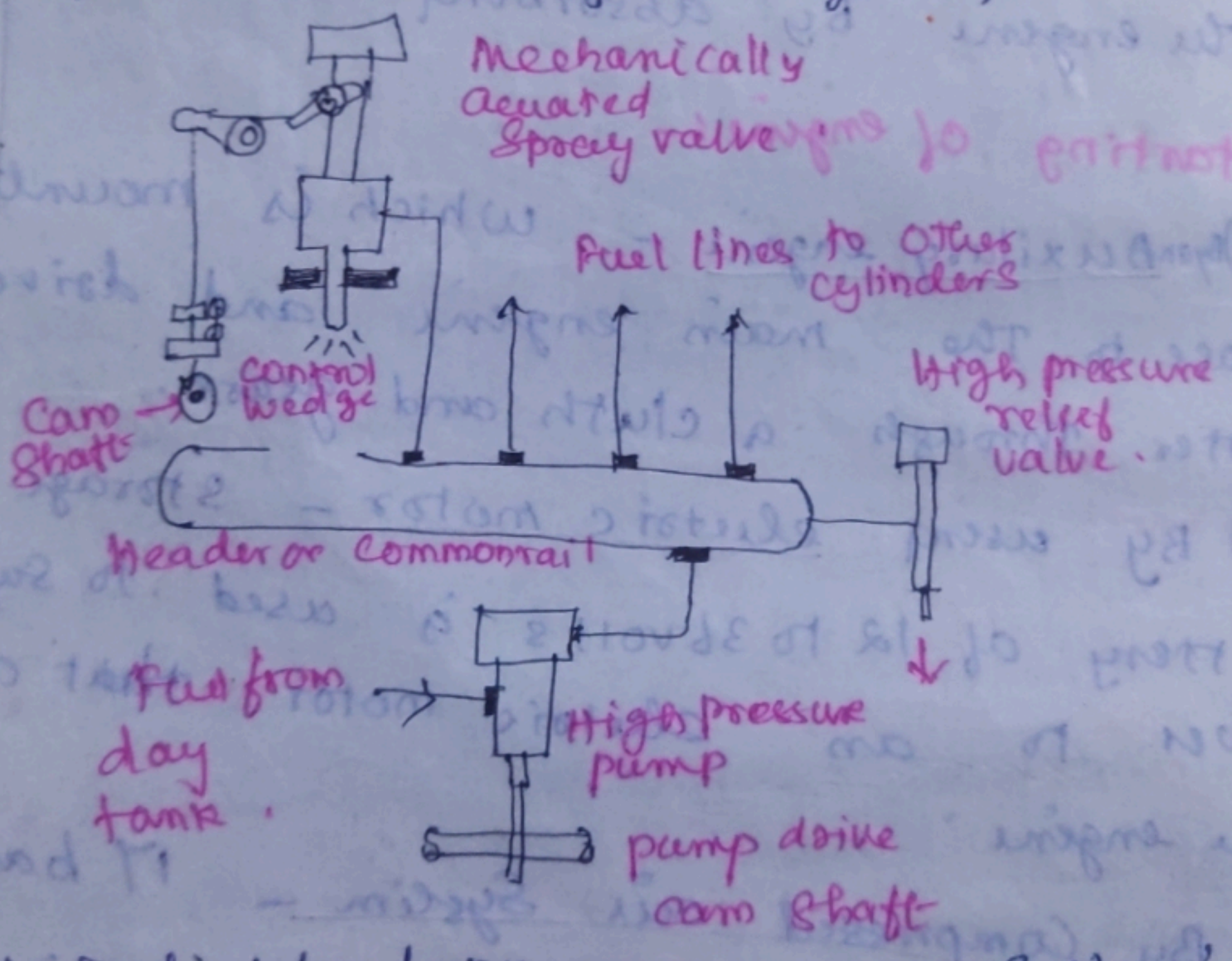
iii) By Compressed air System - 17 bar air admitted to a few engine cylinders making them work like reciprocating air motors to turn the engine shaft. It is used for starting large plant.

a) Filter the fuel
b) meter the correct quantity of the fuel to be injected
c) Time the injection process.
d) Regulate the fuel supply
e) Secure fine atomization of fuel oil
f) Distribute the atomized fuel properly in the combustion chamber.

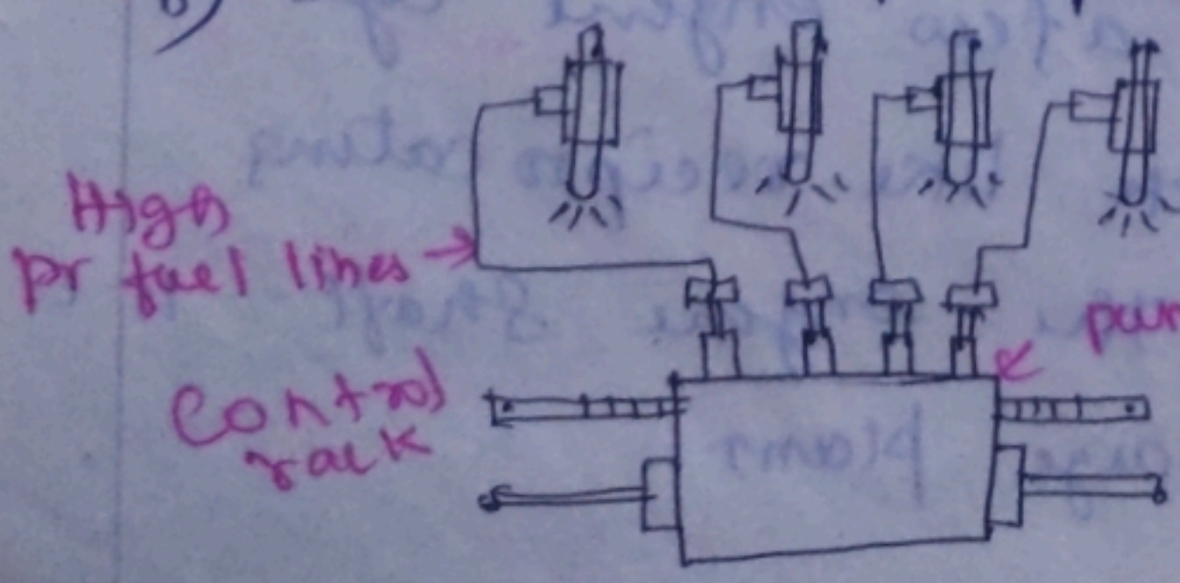
Fuel System of diesel power plant :- (M-13)

Injection System :-

a) common rail injection System :-



b) Individual pump Injection System :-

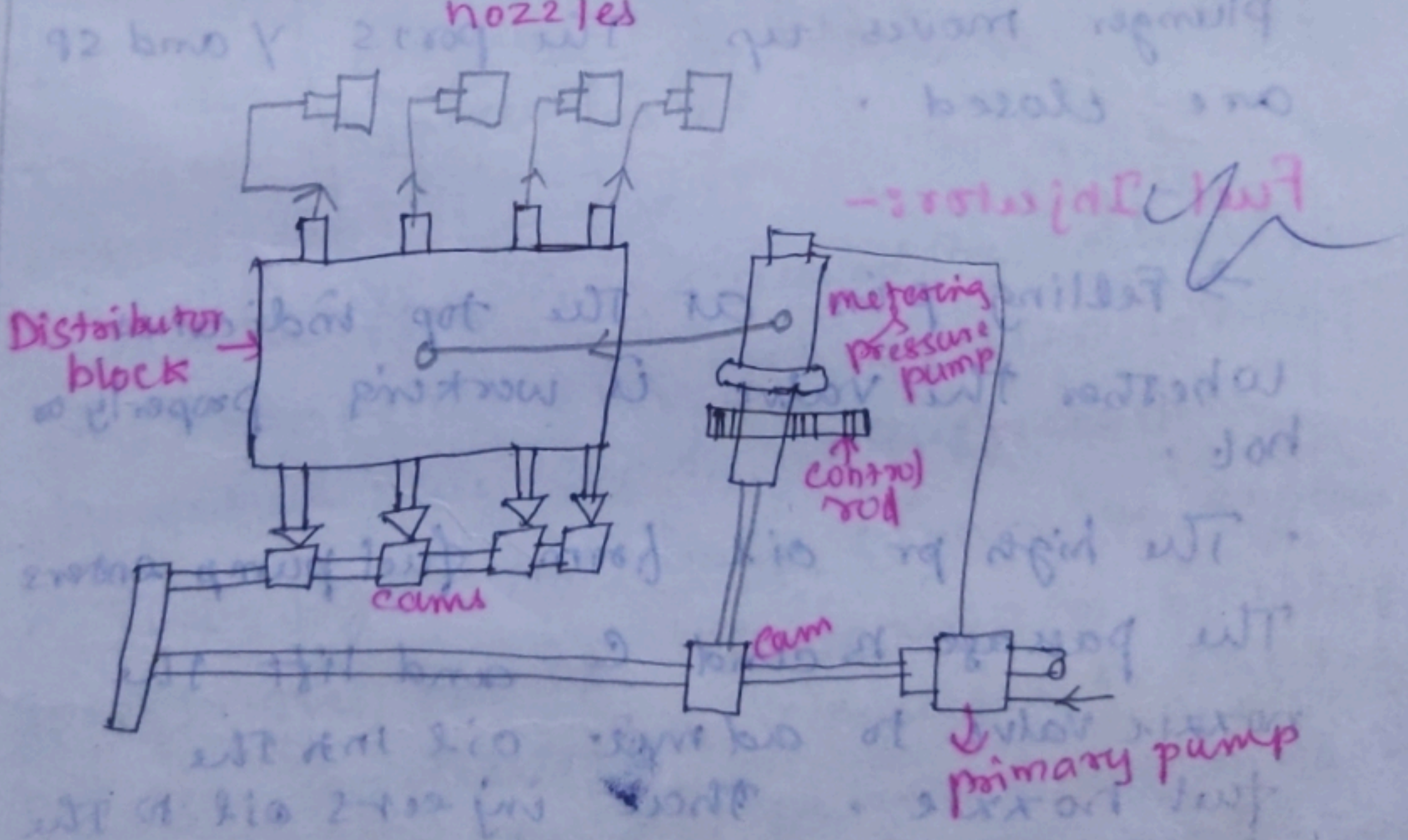


Common rail injection System -

1. The high pressure in the header forces the fuel to each of the nozzles located in the cylinders at the proper time a mechanically operated valve

b) Individual pump injection System :-
each cylinder is provided with one pump and one injector.

c) Distributor System :-



fuel metered at central pump.
fuel distributed to cylinders in correct firing order by cam operated poppet valves

Tappet mechanism

Fuel pump :-

It is a plunger (L) driven by a cam, reciprocates inside a barrel (B).

2. The delivery valve (V) lifts off its seat under oil pressure against the spring force.

- When the plunger is at the bottom the supply port Y and spill port (SP) are uncovered and low pressure filtered oil is forced into the barrel. As the plunger moves up the ports Y and SP are closed.

Fuel Injector :-

⇒ Felling pin at the top indicates whether the valve is working properly or not.

- The high pr oil from fuel pump enters the passage B and C and lift the nozzle valve to admit oil into the fuel nozzle, that injects oil to the cylinder in fine atomized spray.

- As the oil pr falls, the nozzle valve comes back to its seat under spring force and the fuel supply is cut off.

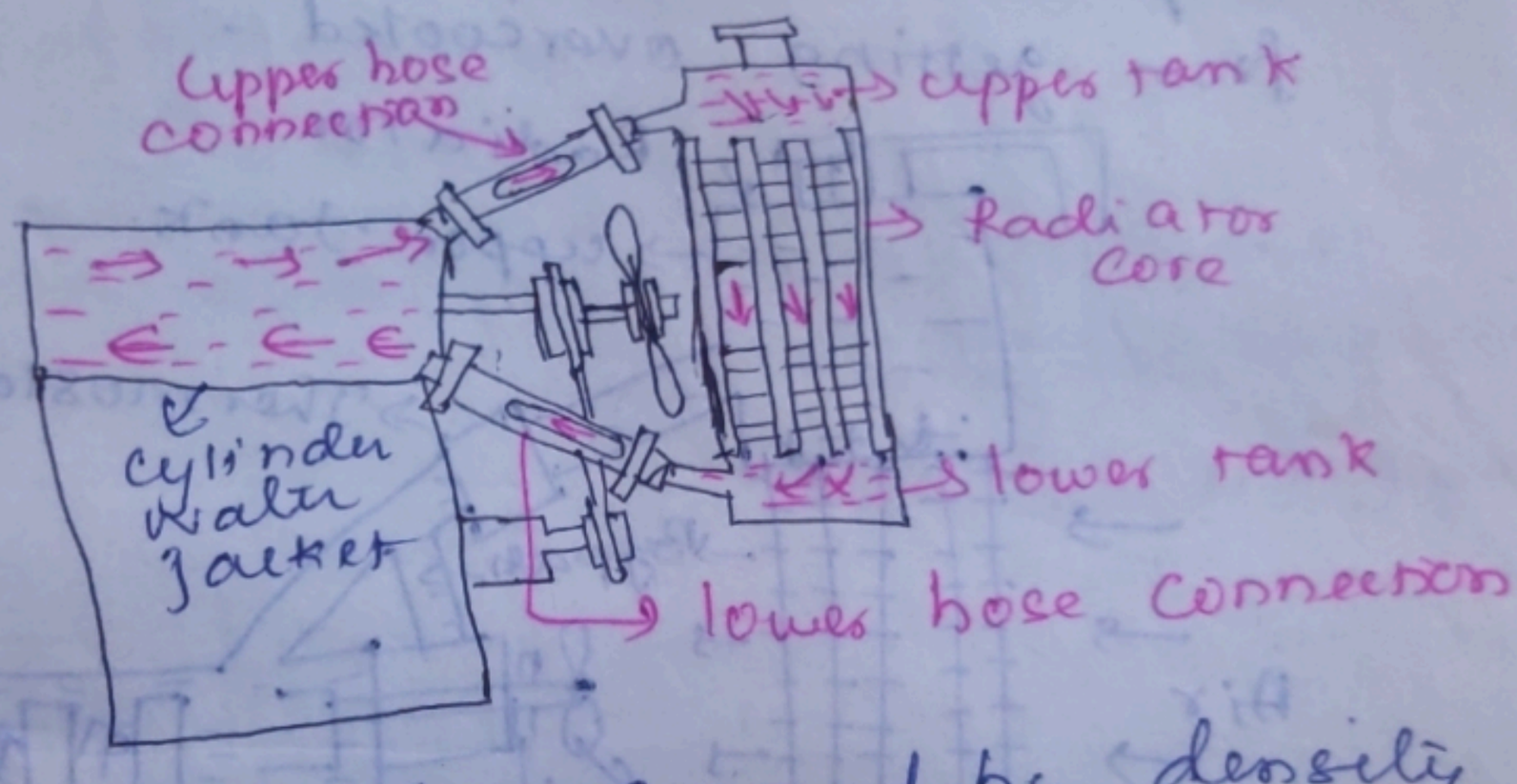
• orifice Single orifice, Multi orifice pintle orifice (clogged by less by carbon particles and less expensive).

i) Air cooling:-

It is used in small engines.
fins.

ii) water cooling:

Thermosyphon Cooling:-



• water flow is caused by density difference. The rate of circulation however slow and insufficient.

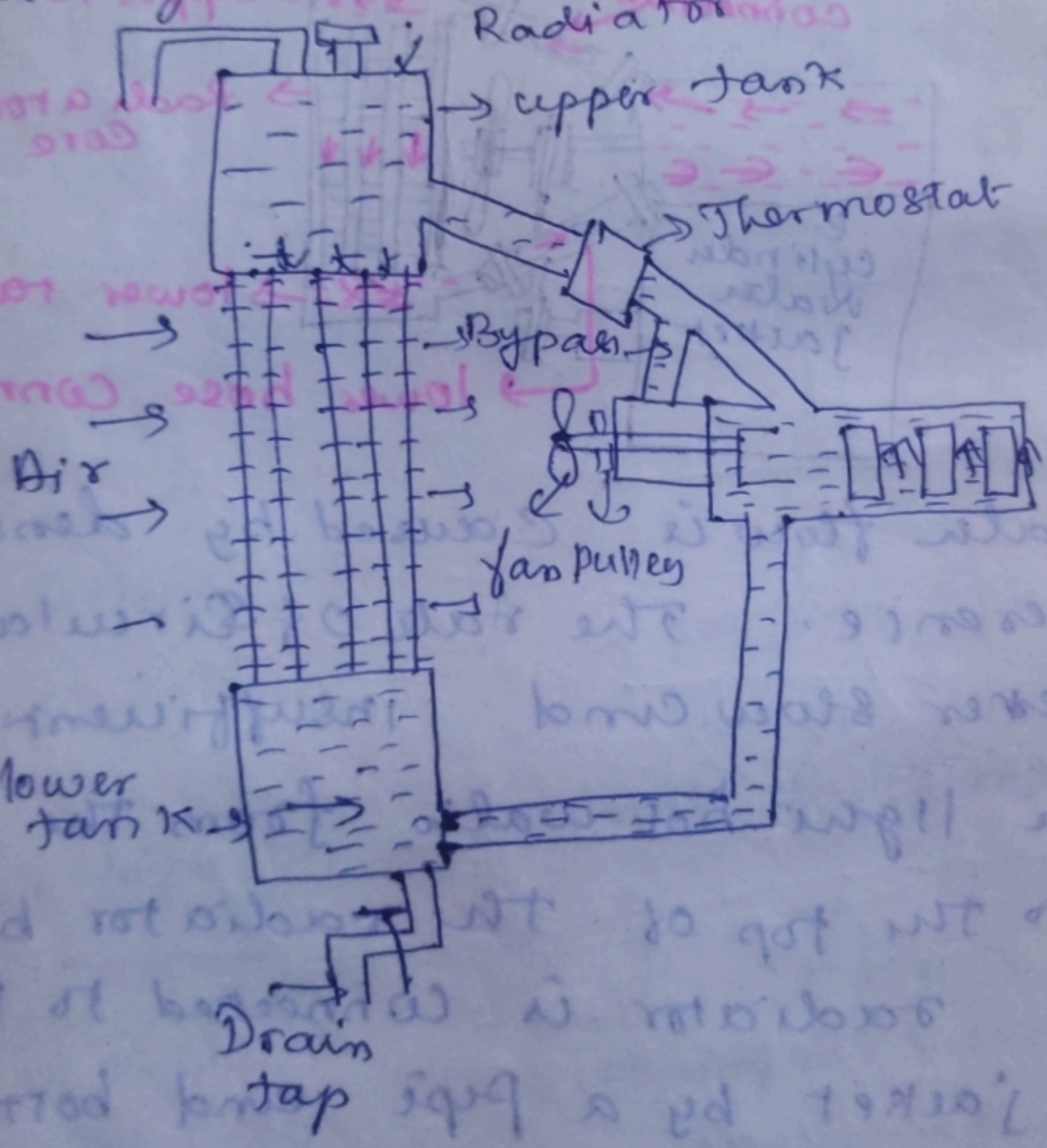
• The liquid for water from the engine goes to the top of the radiator by itself. Top of radiator is connected to the top of water jacket by a pipe and bottom of the radiator to the bottom of the water Jac

Forced cooling by pump:-

Forces water to circulate, ensuring engine cooling Under all operating conditions There may be over cooling which may cause corrosion.

Thermostat cooling:-

- This is a method in which a thermostat maintains the desired temperature and protects the engine from getting overcooled.



- The volatile liquid changes into vapour at the correct working temperature and creates enough pressure to expand the bellows. The movement of bellows opens the main valve in the ratio of temperature rise.

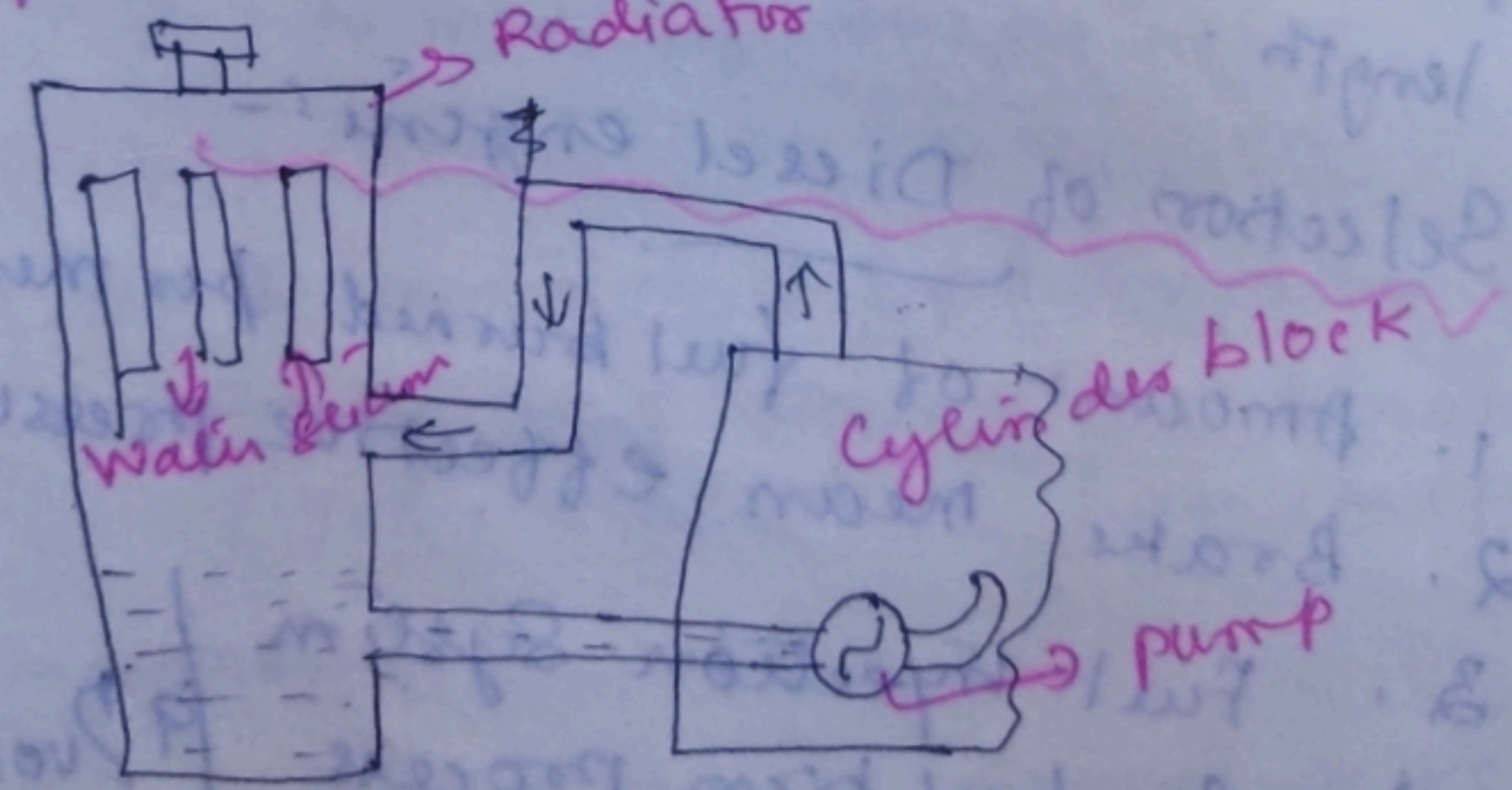
- Temp of water rises it causes Thermo Stat valve to open. The pr. of water pumped falls.

pressurized water cooling:-

→ 1.5 to 2 bar is maintained to increase heat transfer in the radiator.

→ A pr relief valve is provided against any pressure drop.

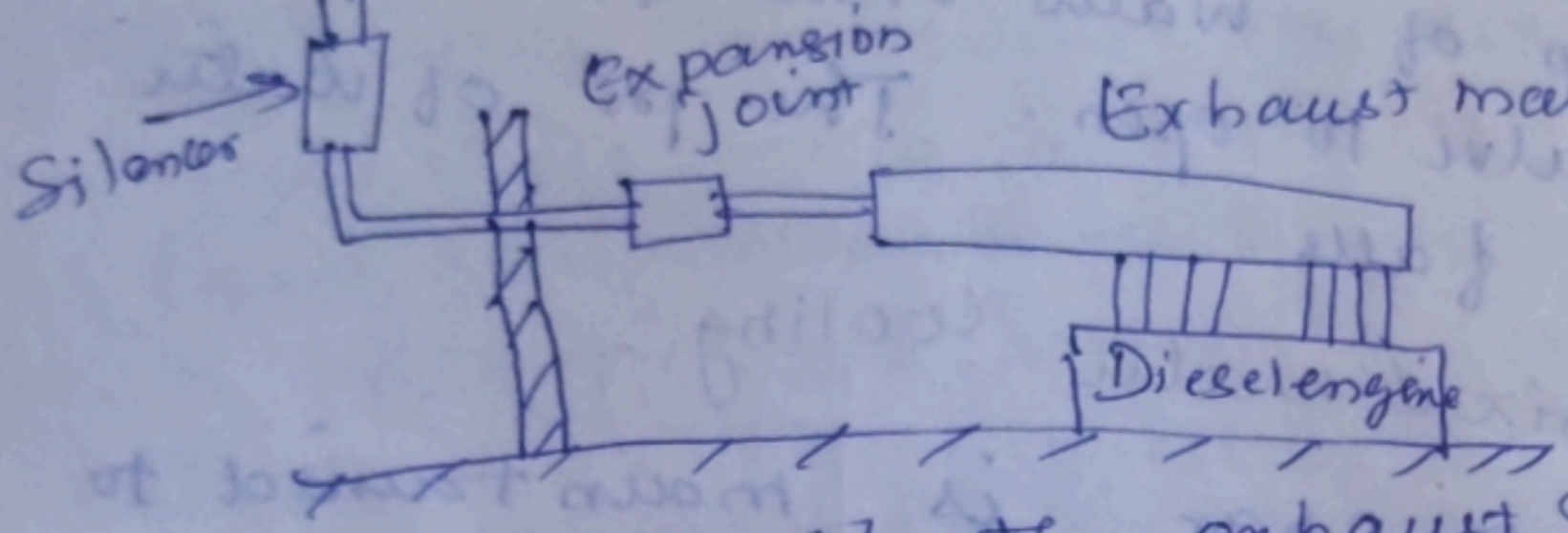
Evaporative cooling:-



Water is allowed to evaporate by absorbing the latent heat of evaporation from the cylinder walls.

Coolant is always liquid but steam formed is flashed off in the separate vessel. The make up water formed is sent back for cooling.

Exhaust System:-



The purpose of the exhaust system is to discharge the engine exhaust to the atm outside. The exhaust gas is used to preheat the oil and air. The exhaust pipe should be short in length.

Selection of Diesel engine:-

1. Amount of fuel burned per minute
2. Brake mean effective pressure
3. Fuel injection System
4. Combustion process
5. fuel air ratio
6. Type of engine
7. Cooling method
8. size of cylinder
9. Vol
10. Sp. weight

1. Foundation Sub soil condition
2. Distance from the load centre
3. Access to the site
4. Availability of water
5. Fuel transportation.

Hot gas is used to run the turbine used in Aircraft engine, electric power generation, marine propulsion.

1. According to the Cycle of Operation
2. According to the process
3. According to the use.
4. According to the type of load.
5. Application
6. Type of fuel
7. number of shafts.

- Application :-

1. peak load power plant.
emergency stand by Unit,
hydro station, base load plant.

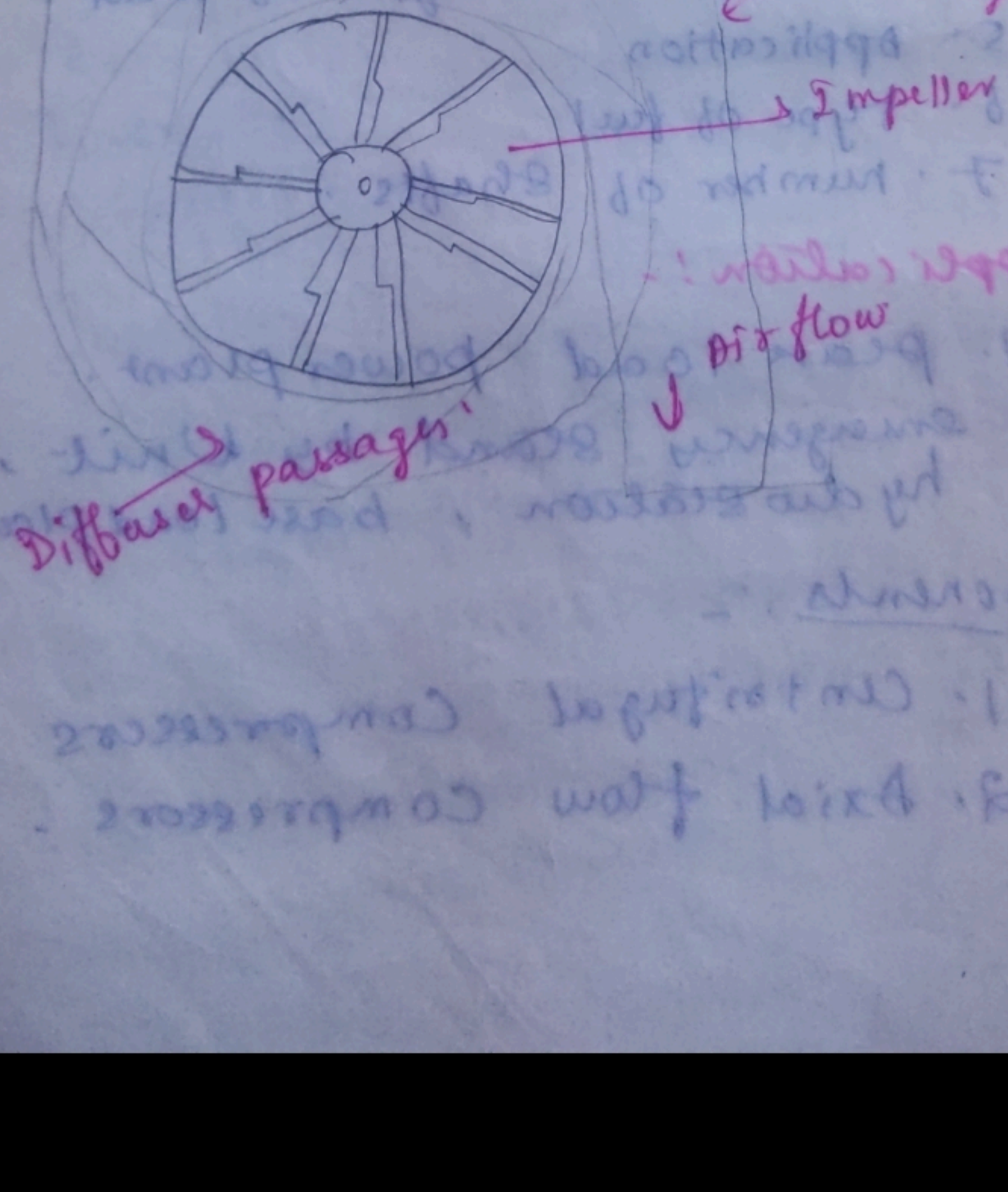
Components :-

1. Centrifugal Compressors
2. Axial flow compressors.

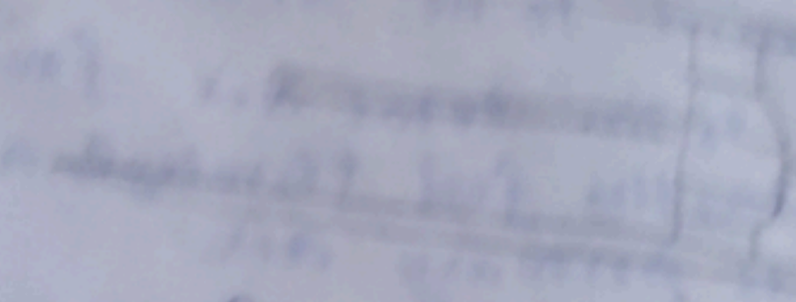
Centrifugal compressor :-

It consists of an impeller with a series of curved radial vanes. Air is sucked near the hub called impeller eye and is whirled round at high speed by the vanes on the impeller rotating at high rpm. The static pr of air increases from the eye to the tip of the impeller. Air leaving the impeller tip flows through diffuser passages. Which convert the kinetic energy to pr energy.

If double inlet impeller having an eye on either side air is drawn on both sides.



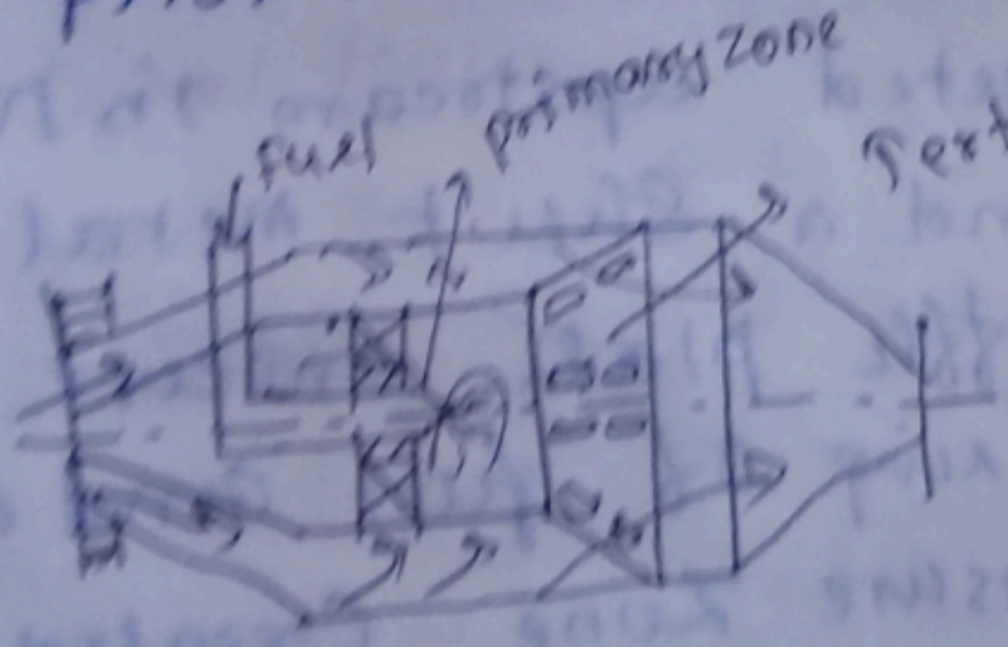
Axial flow compressor



- Succession of rotating blades
The rotor assembly and fixed blades arranged around the stator (casing)
- Air flows axially through the moving and fixed blades with diffuser passage throughout which continuously increase the pressure and decrease the velocity.

Combustion chamber:-

- It require steady and stable flame inside the combustion chamber.
- Pilot and control for flame stabilization. It is creating different methods to create the pilot zone for flame stabilization.



- Combustion is initiated by an electric spark. once the fuel starts burning, the flame is required to be stabilized.

→ About 20 %. of the total air from the compressor is directly fed through a swirler to the burner as primary air

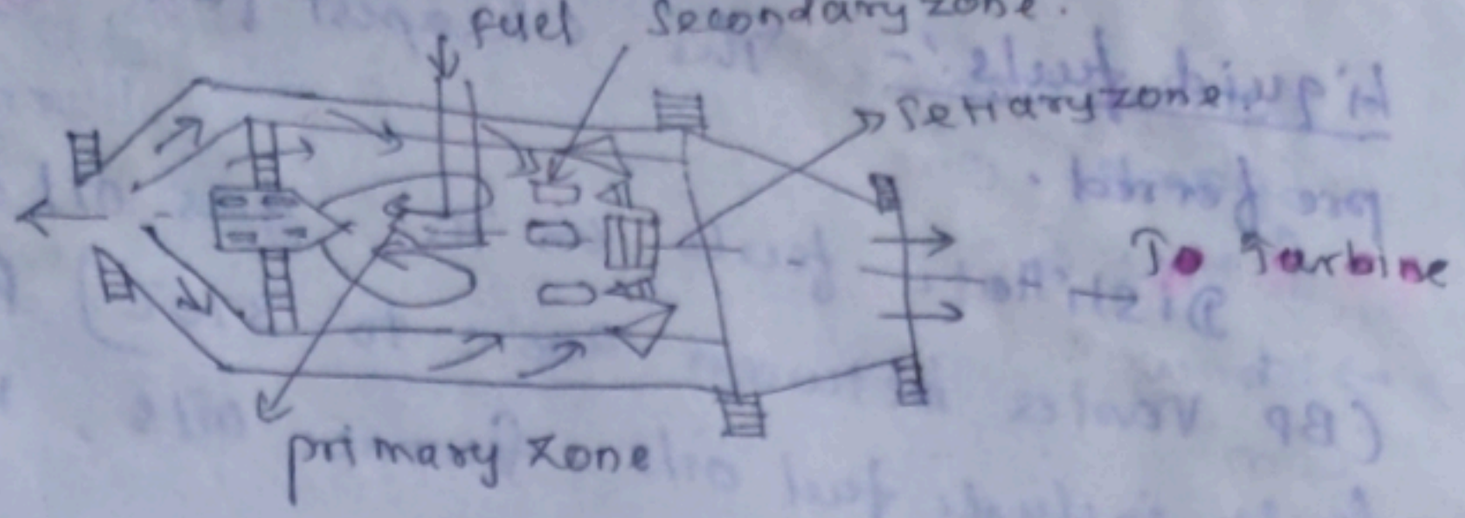
→ 30 % fuel of total air is supplied through dilution holes in the secondary zone through the annulus round the flame tube to complete the combustion.

→ The secondary air not only helps to complete the combustion process but also helps to cool the flame tube.

→ The remaining 50 % of air is mixed with burnt gases in the tertiary zone to cool the gases down to the temperature suited to the turbine blades turbines.

Bluff Body:-

Fuel is injected upstream in to the air flow and a sheet metal cone and perforated baffle plate ensure the necessary mixing of fuel and air. The low pressure zone created down stream side causes the reversal of flow along the axis of cc.



→ The air fuel ratio varies from 60/1 to 120/1 and air velocity at entry 15m/s.

Combustion η = Theoritical fuel - air ratio for actual Temperature rise / Actual fuel air ratio for actual Temperature rise.

Gas Turbines :-

More Stages are always preferred in gas turbine power plants it helps to reduce the Stresses in the blades. increases the overall life of the turbine

Axial flow turbines are used.

Turbines are light weight, high efficiency reliability in operation, long working life.

(N/D -13) (16M)

Gas Turbine fuels :-

Natural gas :- It contains major percentage of methane and Small percentage of ethane, propane butane. Sulphur Compound (H_2S) is kept below 0.1 percent by volume.

Liquid fuels:- The cheapest fuel is always preferred.

Distillate fuels in the gas oil range (BP varies between 200°C to 370°C) Residual fuels include fuel oils, furnace oils, boiler fuel oils

Solid fuels:- Coal → i) Integrated Gasification, where coal is completely or partially gasified and the fuel gas produced is consumed in the gas turbine combustor. ii) pressurized bubbling circulating fluidized bed, where the fuel gas, after its adequality filtered. expands in the gas turbine. Ceramic or others is the key to its use.

Gas Turbine materials:-

i) materials must withstand high temp & high Stress.

ii) It must have low creep rate.

iii) It must have high resistance to oxidation, Corrosion, erosion

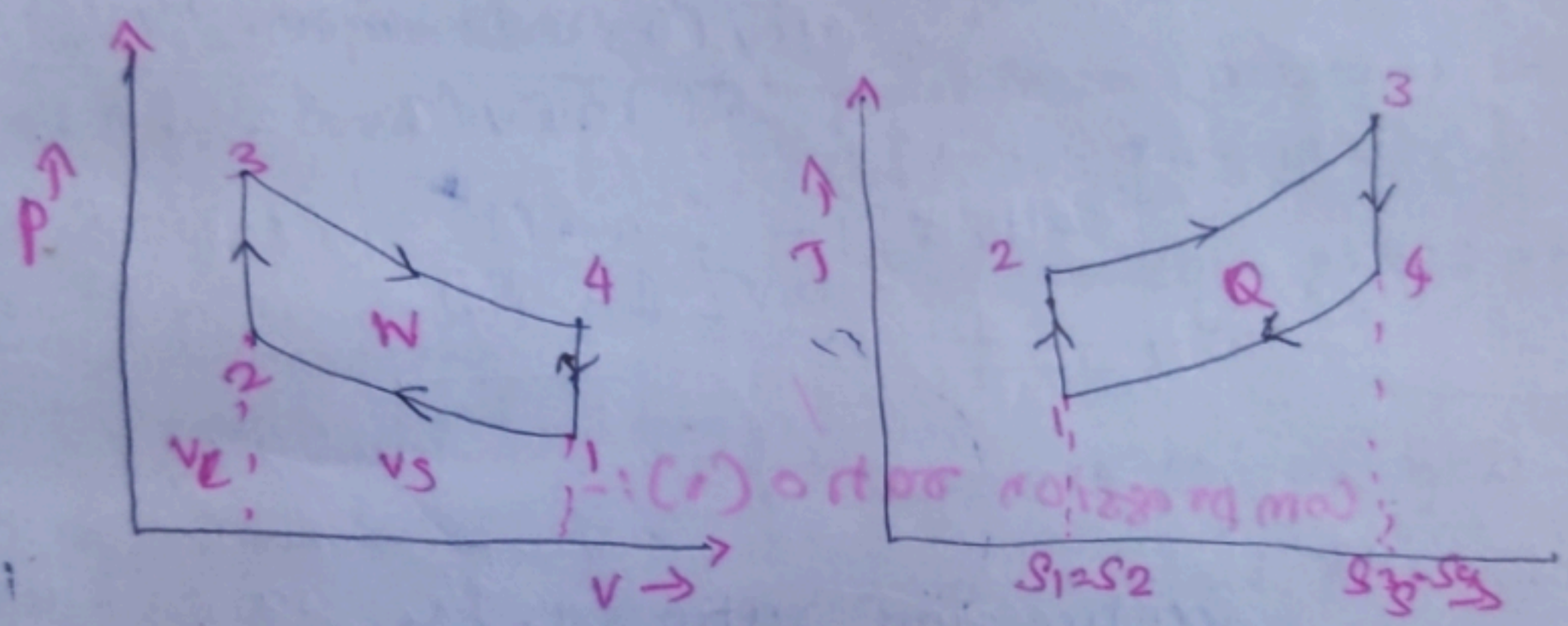
iv) It must maintain Structural Stability.

Metals for turbine rotor discs:-

Steel - 12 to 18 % chromium
8 to 12 % nickel.
Small percentage of Tungsten.

Material for turbine rotor blade:-
Stainless steel alloy & 8-20 nickel Chromium alloys → Nimonic alloys.
Material for combustion chamber - Nimonic 75 alloy. capacity to with stand heavy thermal shock.
Material for Compressor:-
Dluminium alloys.
Axial flow - titanium alloys and are strongly resistance to corrosion.

Otto cycle:-



process 1-2 :-
Isentropic Compression process pr increases from P_1 to P_2 and temperature vs creases from T_1 to T_2. Volume decreases from V_1 to V_2 and entropy remains constant

process 2-3:-
process 2-3 is constant volume heat addition process. pr. increases P_2 to P_3 Temperature increase T_2 to T_3 entropy increases from S_2 to S_3. Volume Constant $V_2=V_3$.

process 3-4 :- Isentropic expansion process.
Temperature decreases T_3 to T_4. The
Temperature decreases T_3 to T_4. Volume
increases from V_3 to V_4.
process 4-1 :- Constant volume heat
rejection process. Pr decreases P_4 to P_1.
Temperature decreases from T_4 to T_1.
entropy decreases S_4 to S_1.

$$Q_R = m C_v (T_4 - T_1)$$

$$\eta = \frac{Q_S - Q_R}{Q_S}$$

$$= \frac{m C_v (T_3 - T_2) - m C_v (T_4 - T_1)}{m C_v (T_3 - T_2)}$$

$$\boxed{\eta_{otto} = 1 - \frac{(T_4 - T_1)}{(T_3 - T_2)}}$$

Compression ratio (r) :-

Compression ratio is the ratio between the total cylinder volume and clearance volume.

$$r = \frac{V_1}{V_2} =$$

$$\eta_{otto} = 1 - \frac{1}{(r)^{\gamma - 1}}$$

Mean effective pressure (P_m) :-

$$k = \frac{P_4}{P_1} = \frac{P_3}{P_2}$$

$$P_m = \frac{\text{Work done}}{\text{Stroke volume}}$$

$$\text{Work done} = \frac{P_1 r}{\gamma - 1}\left(r^{\gamma-1} - 1\right)(k-1)$$

Stroke Volume $= V_1 - V_2$.

$$P_m = P_1 r \left(\frac{k-1}{\gamma-1}\right)\left(\frac{r^{\gamma-1}-1}{r-1}\right)$$

$$P_m = \frac{W}{v_1 - v_2}$$

- A Spark ignition engine working on ideal otto cycle has the compression ratio 6. The initial pressure and temperature of air are 1 bar and 37°C. The maximum pressure in the cycle is 30 bar. For Unit mass flow Calculate
  i) P_1 V and T at various salient points of the cycle and
  ii) the ratio of heat supplied to the heat rejected. Assume $\gamma = 1.4$ and $R = 8.314$ KJ/Kmolk.

Given data:-

$r = 6$, $P_1 = 1$ bar $= 100\ KN/m^2$

$T_1 = 37°C = 37 + 273 = 310K$

$P_3 = 30$ bar $= 3000\ KN/m^2$.

Solution:-

Consider process 1-2 (adiabatic process):-

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{\gamma}.$$

$$P_2 = \left(\frac{V_1}{V_2}\right)^{\gamma} \times P_1$$

$$= (6)^{1.4} \times 100 = 1228.6\ KN/m^2.$$

$$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{\gamma-1}$$

$$T_2 = \left(\frac{V_1}{V_2}\right)^{\gamma-1} \times T_1$$

$$= (6)^{1.4-1} \times 310 = \underline{634.78K.}$$

Consider process 2-3 Constant Volume process:-

$$\frac{P_3}{P_2} = \frac{T_3}{T_2}$$

$$T_2 = \frac{P_3}{P_2} \times T_2 \Rightarrow \frac{3000}{100} \times 634.78$$

$$\boxed{T_3 = 19043.4K}$$

Consider process 3-4 (adiabatic process):-

$$\frac{P_4}{P_3} = \left(\frac{V_3}{V_4}\right)^{\gamma}$$

$$= \left(\frac{V_3}{V_4}\right)^{\gamma} \times P_3 \Rightarrow \left(\frac{1}{6}\right)^{1.4} \times 3000$$

$$\boxed{P_4 = 244.18\ KN/m^2}$$

$$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{\gamma-1}$$

$$= \left(\frac{V_3}{V_4}\right)^{\gamma-1} \times T_3 = \left(\frac{1}{6}\right)^{0.4} \times 19043.4$$

$T_4 = 9300K$

Heat Supplied $Q_S = mcv\,(T_3 - T_2)$

$= 1 \times 0.718\,(1904.3.4 - 634.78)$

$Q_S = 13217.39\ kJ/kg$

Heat Rejected $Q_R = mcv\,(T_4 - T_1)$

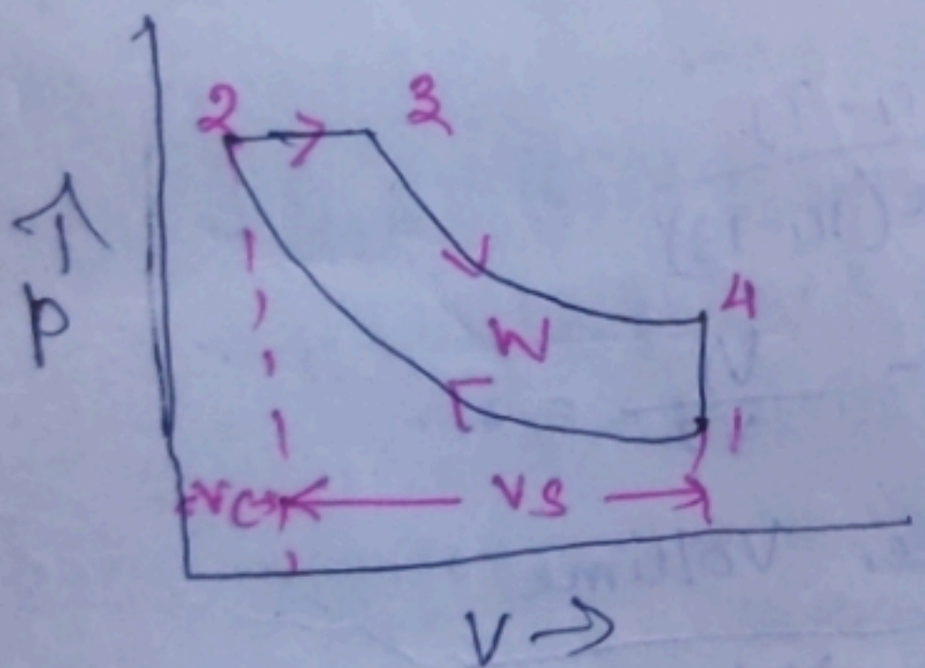
$= 1 \times 0.718\,(9300 - 310)$

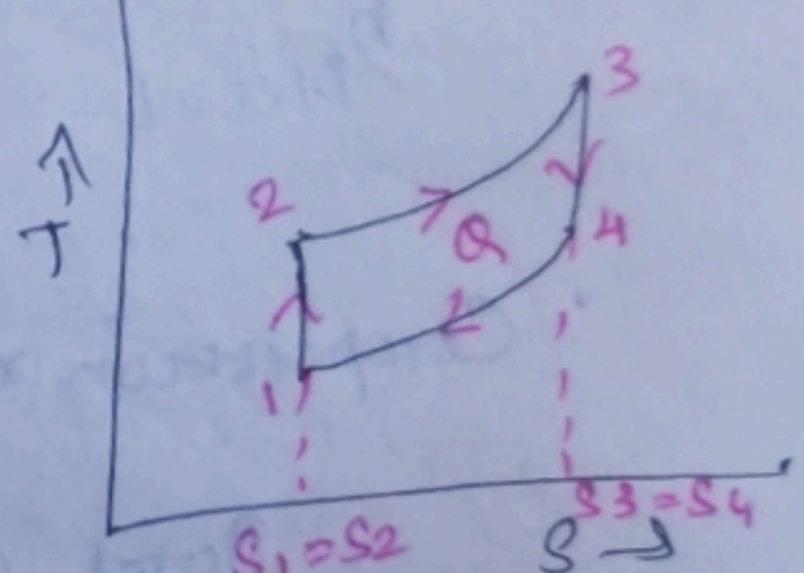
$Q_R = 6454.82\ kJ/kg.$

$\frac{Q_S}{Q_R} = \frac{13217.39}{6454.82} = \frac{2.0848}{}$

Diesel cycle:-

1. Two reversible adiabatic or isentropic
2. One constant volume.
3. One constant pressure processes.





process 1-2 - Isentropic Compression process.

During the process, the air is isentropically Compressed from P_1 to P_2. entropy remains constant ($S_1 = S_2$).

process 2-3 - constant pressure heat addition process:-

During the process the air is heated from

T2 to T3 but the pressure remains constant ($P_2 = P_3$)

$$Q_s = m c_p (T_3 - T_2)$$

process 3-4 Isentropic expansion process :-
During process, the air isentropically expands from P_3 to P_4. Temperature decreases from T_3 to T_4.

process 4-1 :- Constant volume heat rejection process.

Temperature decreases from T_4 to T_1.

$$Q_R = m c_v (T_4 - T_1)$$

$$\eta_{Diesel} = \frac{Q_s - Q_R}{Q_s}$$

$$\eta_{Diesel} = 1 - \frac{T_4 - T_1}{\gamma (T_4 - T_3)}$$

Compression ratio - $\frac{V_1}{V_2} = r$.

$$= \frac{\text{Total Cylinder Volume}}{\text{Clearance Volume}}$$

Cut off ratio - Ratio between volume at the point of cut off and clearance volume.

$$\text{Cut off ratio } \rho = \frac{\text{Cut off volume}}{\text{clearance volume}} = \frac{V_3}{V_2}$$

$$\text{Expansion ratio} = \frac{V_4}{V_3} = \frac{r}{\rho}.$$

$$\eta_{Diesel} = 1 - \frac{1}{\gamma r^{\gamma-1}}\left(\frac{\rho^{\gamma}-1}{\rho-1}\right)$$

$$P_m = \frac{P_1 r^{\gamma}\left[\gamma(\rho-1) - r^{1-\gamma}(\rho^{\gamma}-1)\right]}{(\gamma-1)(r-1)}$$

In an air standard diesel cycle, the pressure and temperatures of air at the beginning of cycle are 1 bar and 40°C. The Temperatures before and after the heat supplied are 400°C and 1500°C. Find the air standard efficiency and mean effective pressure of the cycle. What is the power output if it makes 100 cycles/min?

Given data:- $P_1 = 1\text{ bar} = 100\text{KN/m}^2$

$T_1 = 40°C = 40+273 = 313K$

$T_2 = 400°C = 673K.$

$T_3 = 1500°C = 1773K.$

Solution:- Consider the process 1-2 (Isentropic Compression)

$$\frac{T_2}{T_1} = \left(\frac{v_1}{v_2}\right)^{\gamma-1}$$

Compression ratio,

$$r = \frac{v_1}{v_2} = \left(\frac{T_2}{T_1}\right)^{\frac{1}{\gamma-1}} = \left(\frac{673}{313}\right)^{\frac{1}{1.4-1}} = 6.779.$$

Consider the process 2-3 Constan Pressure heating,

$$\frac{v_2}{T_2} = \frac{v_3}{T_3}$$

cut off ratio $\rho = \frac{v_3}{v_2} = \frac{T_3}{T_2} = \frac{1773}{673} = 2.634$.

$$\eta = 1 - \frac{1}{r(r)^{\gamma-1}} \left(\frac{\rho^{\gamma}-1}{\rho-1}\right)$$

$$= 1 - \frac{1}{1.4(6.773)^{1.4-1}} \left(\frac{2.634^{1.4}-1}{2.634-1}\right)$$

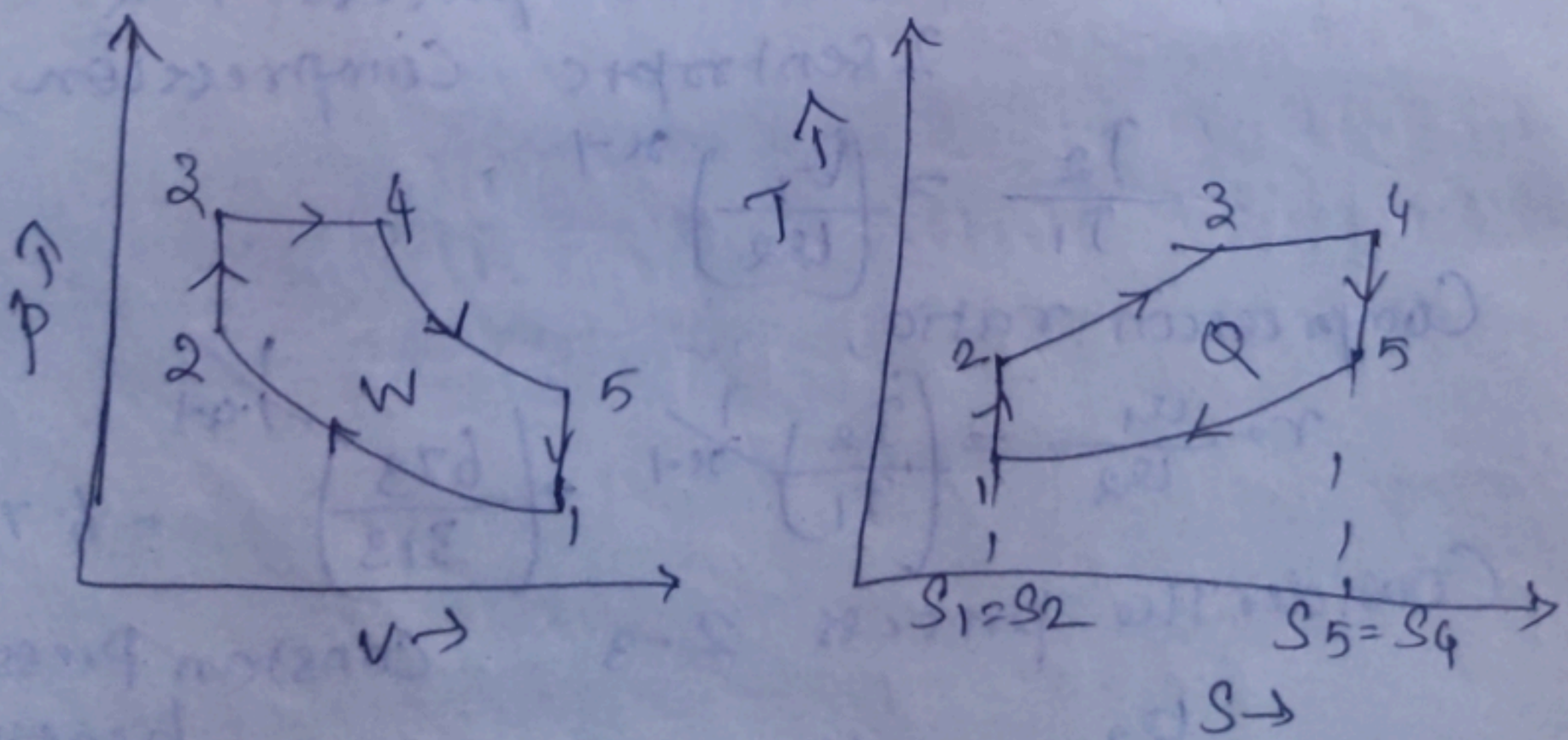
$$\eta = 41.42\%$$

Dual cycle! -

1. Two reversible adiabatic or Isentropic
2. Two constant volume
3. One constant pressure processes.

process 1-2 - Isentropic compression proces.

During the process, the air is isentropically compressed from P_1 to P_2. entropy remains constant $S_1 = S_2$.



process 2:3 Constant volume heat addition process:-

The compressed air is partially heated by constant volume process $V_2 = V_3$. Both temperature and entropy increases T_2 to T_3 S_2 to S_3.

$$Q_{S_2} = m C_v (T_3 - T_2)$$

process 3-4 - constant pressure heat addition process.

The partially heated air is then heated by constant pressure process $P_3 = P_4$. Both temperature and entropy increase from T_3 to T_4 and S_3 to S_4.

$$Q_{S_2} = mcp (T_4 - T_3).$$

process 4-5 - Isentropic expansion process:-

During the process the heated air is entropically expands from P_4 to P_5. Temperature decreases T_4 to T_5.

process 5-1 - Constant volume heat rejection process:- Temperature decreases from S_5 to S_1. The system attain its original position. $Q_R = m c_v (T_5 - T_1)$

$$Q_S = Q_{S_1} + Q_{S_2} = m C_v (T_3 - T_2) + m C_p (T_4 - T_3)$$

$$\eta = \frac{W}{Q_S}$$

$$\eta = 1 - \frac{(T_5 - T_1)}{(T_3 - T_2) + \gamma (T_4 - T_3)} \left(\frac{C_p}{C_v} = \gamma \right)$$

Compression ratio $r = \frac{V_1}{V_2}$

pressure ratio $k = \frac{P_3}{P_2}$

Cut off ratio $\rho = \frac{V_4}{V_3}$ $\left[\begin{matrix} V_5 = V_1 \\ V_3 = V_2 \end{matrix}\right]$

Expansion ratio $\Rightarrow \frac{V_5}{V_4} = \frac{V_1}{V_4} = \frac{V_1}{V_2} \times \frac{V_2}{V_4}$

$= \frac{V_1}{V_2} \times \frac{V_3}{V_4} = r/\rho$.

$\eta_{Dual} = 1 - \frac{1}{(r)^{\gamma-1}} \left[\frac{k\rho^{\gamma} - 1}{(k-1) + \gamma k (\rho - 1)} \right]$

$P_m = \frac{P_1 r^{\gamma} \left[k\gamma(\rho-1) + (k-1) - r^{1-\gamma}(k\rho^{\gamma}-1) \right]}{(\gamma-1)(r-1)}$

In engine working on a dual cycle, the temperature and pressure at the beginning of the cycle are 90°C and 1 bar. The compression ratio is 9. The maximum pressure is limited to 68 bar and total heat supplied per kg of air is 1750 kJ. Determine the air standard efficiency and mean effective pressure.

Given data:-

$P_1 = 1$ bar,

$T_1 = 90°C = 363$ K.

$P_3 = P_4 = 68$ bar

$r = 9$

$Q_s = 1750$ KJ/kg.

Solution:- Isentropic Compression process,

$$P_2 = (r)^x \times P_1 = (9)^{1.4} \times 1 = 21.67 \text{ bar}$$

$$T_2 = (r)^{x-1} \times T_1 = (9)^{0.4} \times 363 = 874 \text{ K}.$$

$$T_3 = \left(\frac{P_3}{P_2}\right) T_2 \Rightarrow \frac{68}{21.67} \times 874 = 2743 \text{ K}.$$

Constant pressure heat addition process,

$$Q_s = C_v (T_3 - T_2) + C_p (T_4 - T_3)$$

$$1750 = 0.718 (2743 - 874) + 1.005 (T_4 - 2743)$$

$$T_4 = 3149 \text{ K}.$$

$$v_1 = \frac{RT_1}{P_1} = \frac{287 \times 363}{1 \times 10^5} = 1.04181 \text{ m}^3/\text{kg}$$

$$v_2 = v_2 = \frac{v_1}{r} = \frac{1.04181}{9} = 0.11576 \text{ m}^3/\text{kg}$$

$$v_4 = \left(\frac{T_4}{T_3}\right) v_3$$

$$= \left(\frac{3149}{2743}\right) 0.11576 = 0.132894 \text{ m}^3/\text{kg}$$

$$\rho = \frac{v_4}{v_3} = \frac{0.13289}{0.11576} = 1.148$$

$$K = \frac{P_3}{P_2} = \frac{68}{21.67} = 3.138.$$

$$\eta = 1 - \frac{1}{(r)^{x-1}} \left[\frac{K\rho^x - 1}{(K-1) + Kx(\rho - 1)}\right]$$

$$= 1 - \frac{1}{(9)^{1.4-1}}\left[\frac{3.138 \times 1.148^{1.4} - 1)}{(3.138-1) + 3.138 \times 1.4\,(1.148)}\right]$$

$$= 58.19\ \%.$$

$$W_{net} = \eta \times Q_s$$

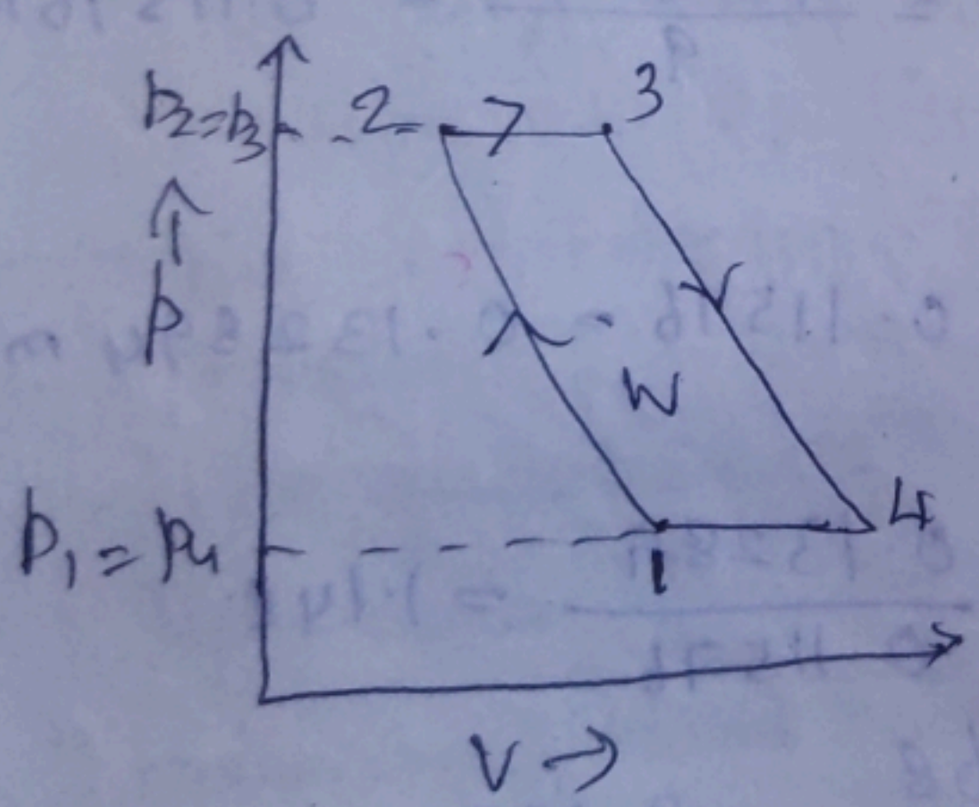
$$= 0.5819 \times 1750 = 1018.33\ kJ/kg.$$

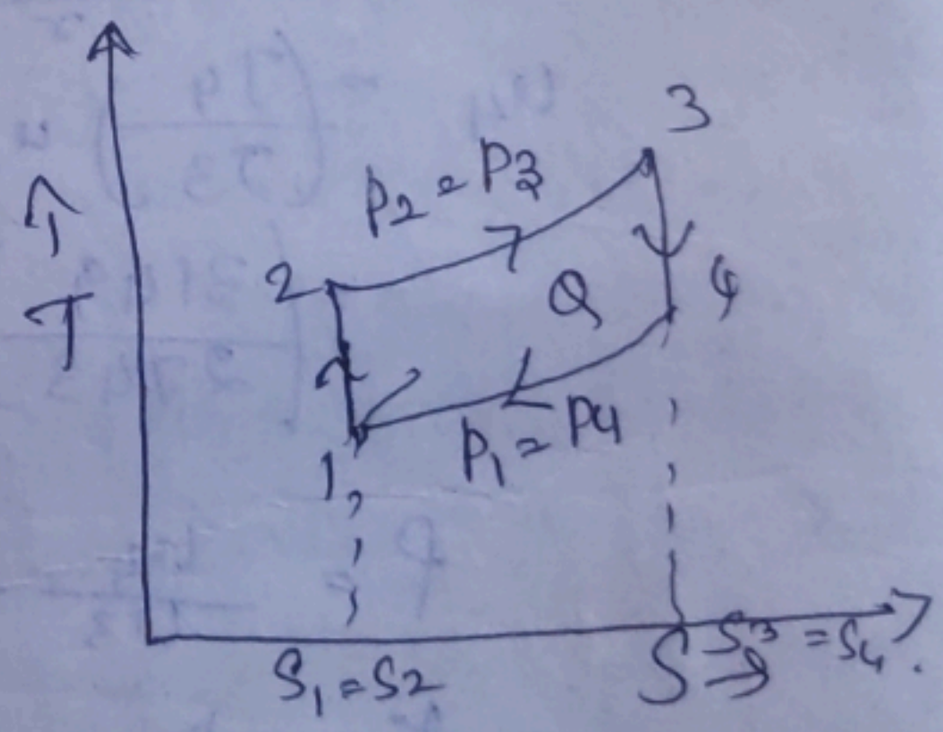
$$P_m = \frac{W_{net}}{v_1 - v_2} = \frac{1018.33}{1.04181 - 0.11576}$$

$$\boxed{P_m = 10.98\ bar}$$

Brayton Cycle or Joule Cycle :-

It consists of two rerersible adiabatic processes and two constant pressure processes. This cycle is therefore also called constant pressure cycle.





⇒ Brayton cycle is The Theoritical cycle for gas turbines.

process 1-2 Isentropic Compression process.

$W_C = mcp(T_2 - T_1)$

pressure increases P_1 to P_2 and Temperature increases T_1 to T_2, volume reduces to V_1 to V_2.

2-3 Constant pressure heat addition process:

The compressed air is passed through the combustion chamber where the fuel is injected and Burned at constant press P_2 and Temperature increases from T_2 to T_3

$$Q_S = mcp(T_3 - T_2).$$

3-4 Isentropic expansion process,

$$W_T = mcp(T_3 - T_4)$$

process 4-1 $\Rightarrow$ constant pressure heat rejection process.

$$Q_R = mcp(T_4 - T_1)$$

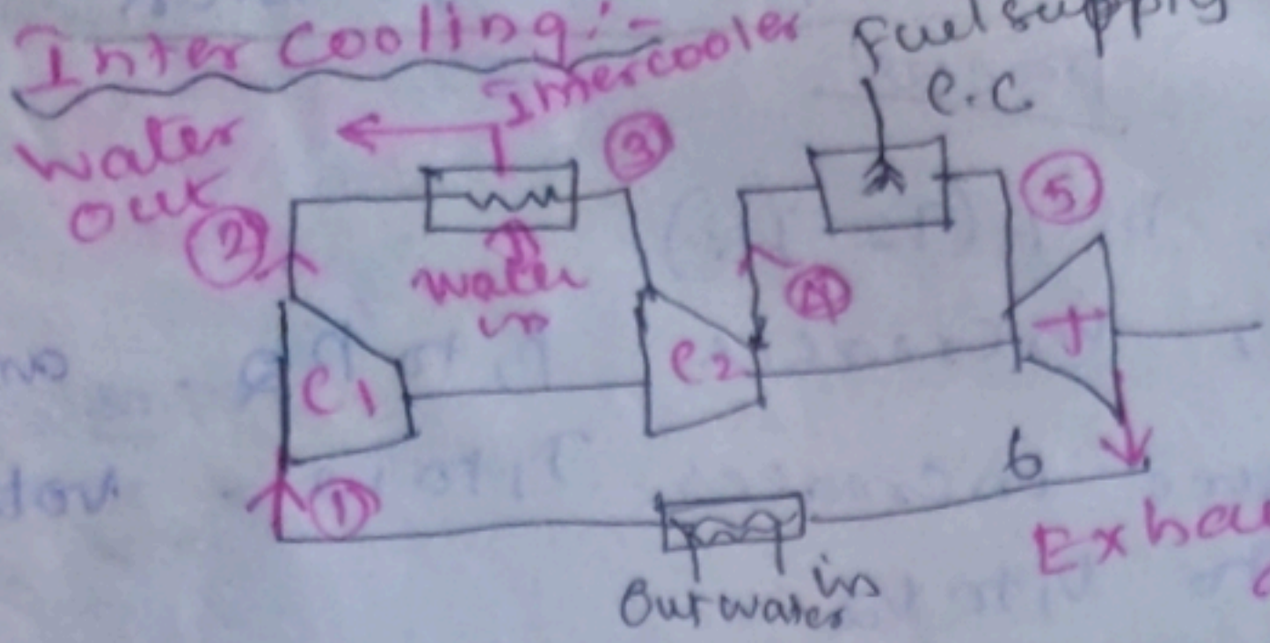
$$\eta_{Brayton} = \frac{W}{Q_S} = \frac{Q_S - Q_R}{Q_S}$$

$$\boxed{\eta = 1 - \frac{T_4 - T_1}{T_3 - T_2}}$$

$$r = \frac{V_1}{V_2} = \frac{V_4}{V_3}$$

$$R_P = \frac{P_2}{P_1} = \frac{P_3}{P_4}.$$

Inter cooling:-



Major percentage of power developed (66%) by the turbine is used to run the Compressor. The power required to run the

Isentropic compression,

$$\frac{T_2}{T_1} = \left(\frac{V_2}{V_1}\right)^{\gamma-1} = (r)^{\gamma-1}$$

$$T_2 = T_1 (r)^{\gamma-1}$$

$$\frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{\gamma-1} = (r)^{\gamma-1}$$

$$T_3 = T_4 (r)^{\gamma-1}$$

$$\frac{T_3}{T_4} = \left(\frac{P_3}{P_4}\right)^{\frac{\gamma-1}{\gamma}}, \quad T_3 = T_4 (R_P)^{\frac{\gamma-1}{\gamma}}$$

$$\eta = 1 - \frac{T_4 - T_1}{T_4 (R_P)^{\frac{\gamma-1}{\gamma}} - T_1 (R_P)^{\frac{\gamma-1}{\gamma}}}$$

$$\eta_{Brayton} = 1 - \frac{1}{(R_P)^{\frac{\gamma-1}{\gamma}}}$$

$$\eta_{Brayton} = 1 - \frac{1}{(r)^{\gamma-1}}$$

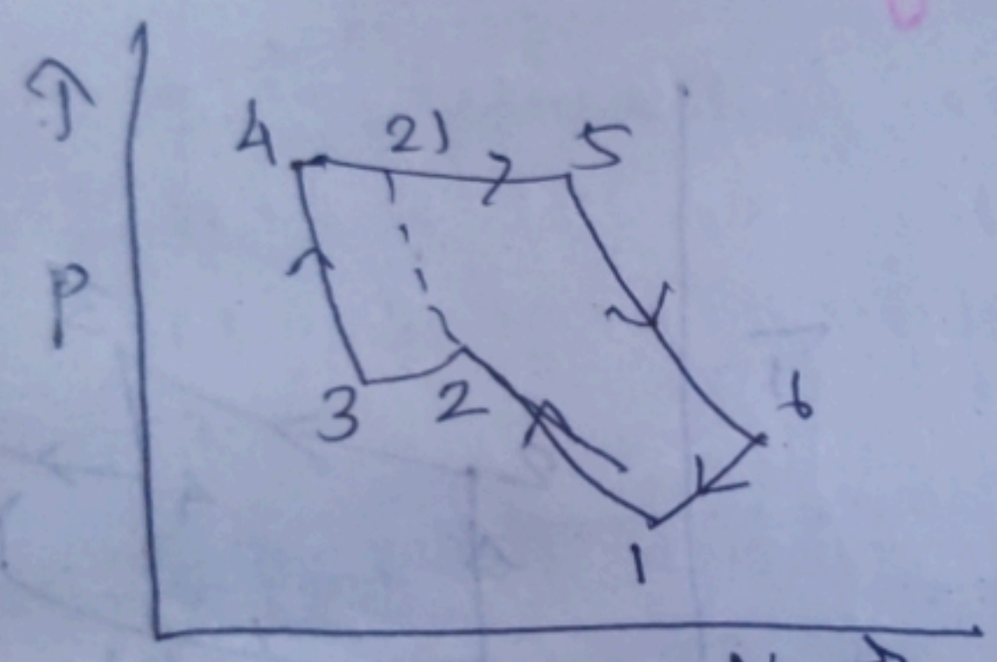
Work ratio :-

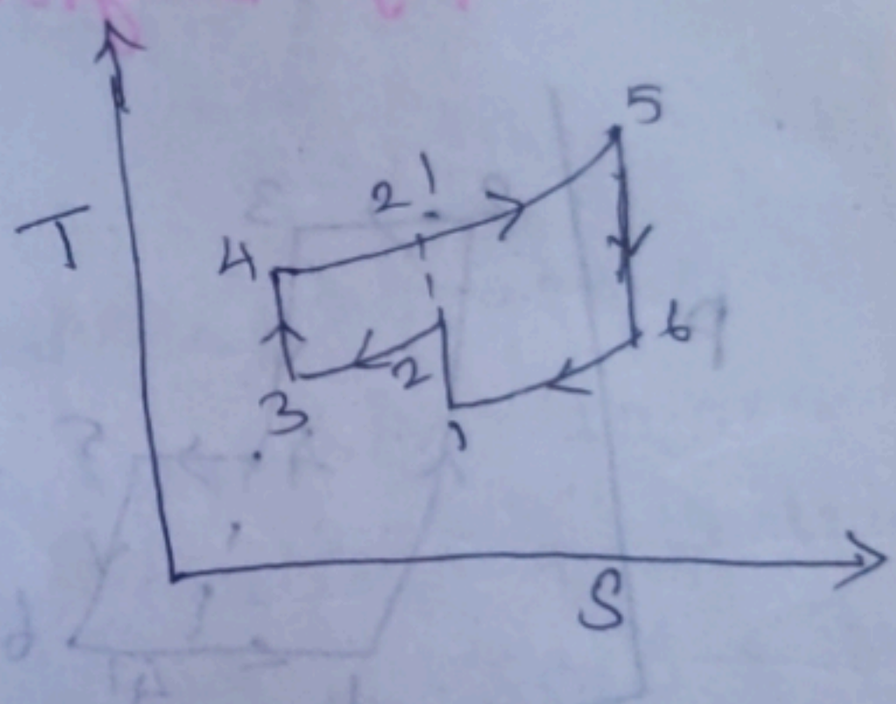
$$\text{Work ratio} = \frac{\text{Net work transfer}}{\text{positive work transfer}}$$

$$= 1 - \frac{T_1\left[(R_p)^{\frac{\gamma-1}{\gamma}} - 1\right]}{T_3\left[1 - \frac{1}{(R_p)^{\frac{\gamma-1}{\gamma}}}\right]}$$

$$\text{Work ratio} = 1 - \frac{T_1}{T_3}(R_p)^{\frac{\gamma-1}{\gamma}}$$

Intercooling :-





$$W_T = C_p(T_5 - T_6)$$

$$W_C = C_p(T_2 - T_1) + C_p(T_4 - T_3)$$

$$\text{Network} = W = W_T - W_C$$

for perfect inter cooling $T_1 = T_3$ and $T_2 = T_4$.

Intermediate pressure for perfect intercooling

$$P_3 = P_2 = \sqrt{P_1 \times P_4} = \sqrt{P_5 \times P_6}$$

Brayton cycle with Rebeater :-

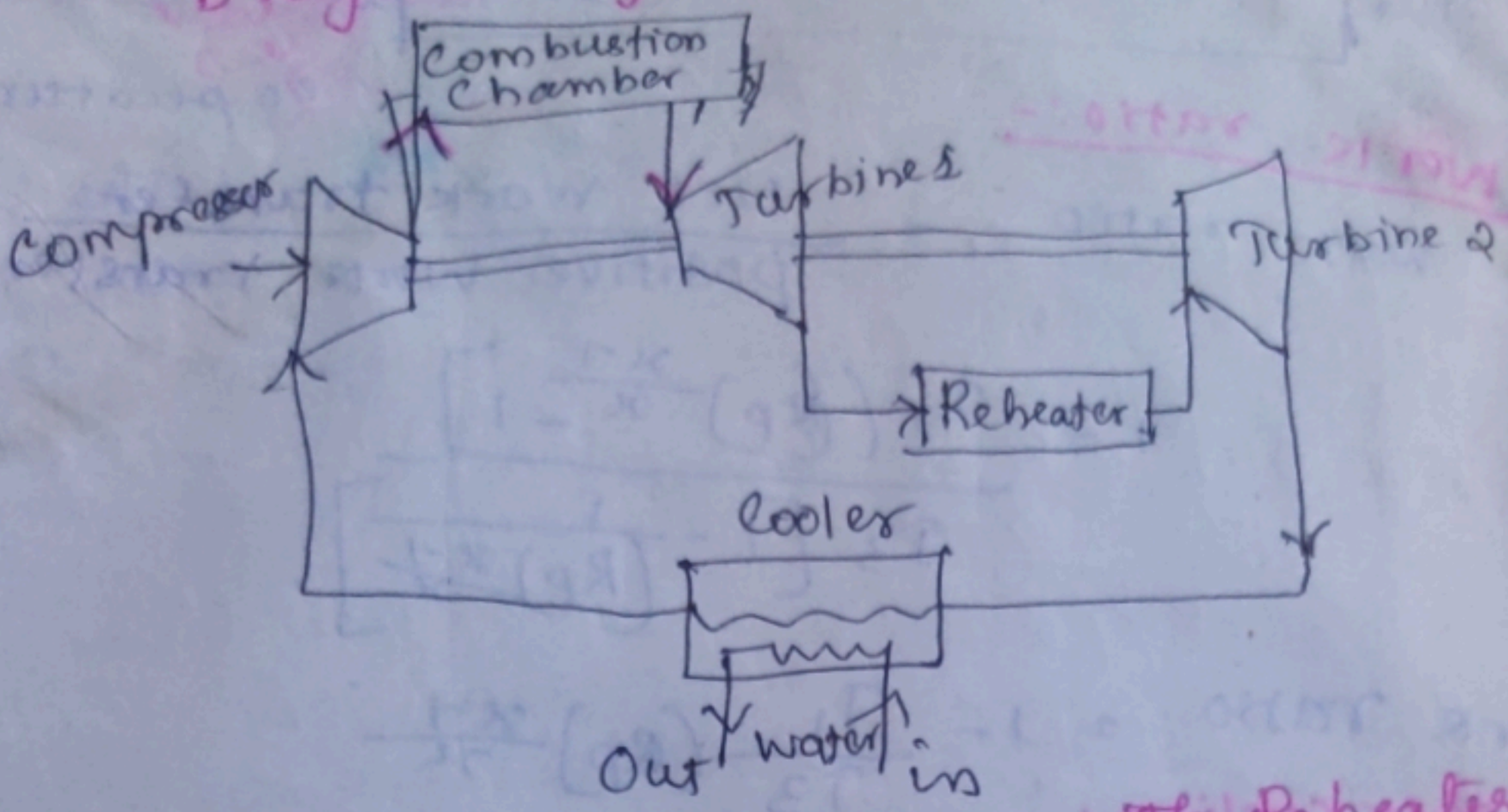
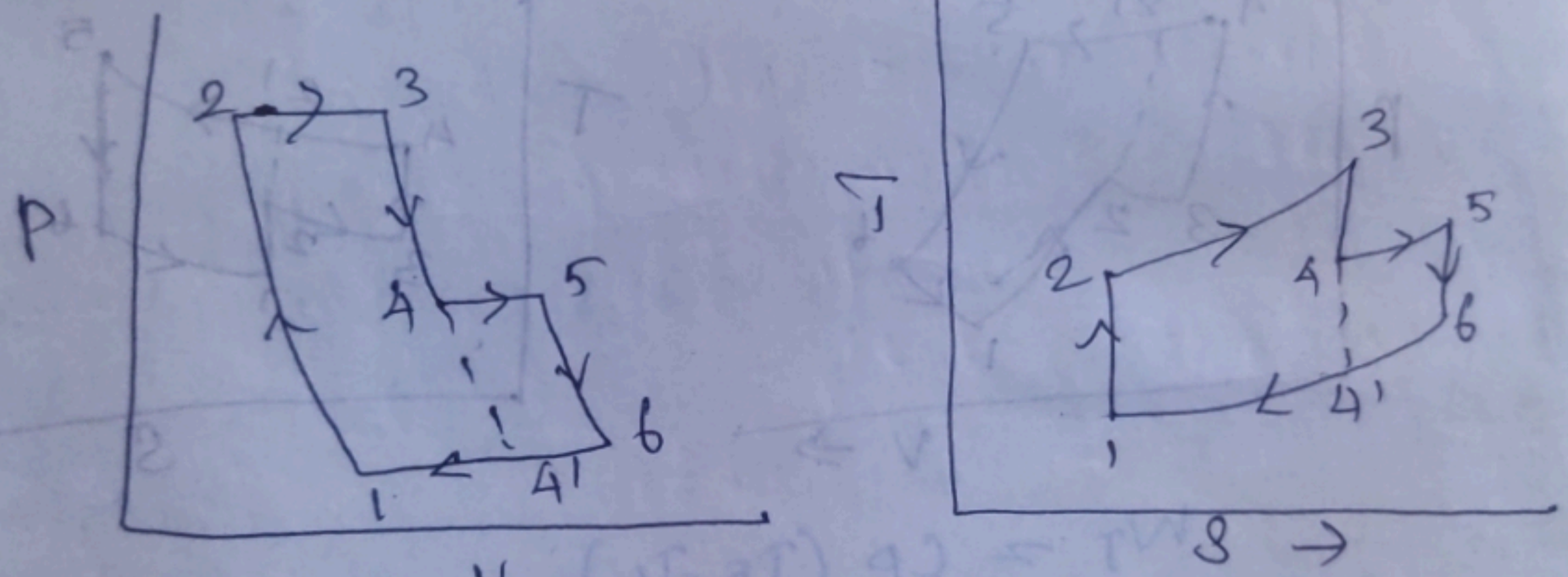


Fig: Brayton cycle with Rebeater



$$W_C = C_p(T_2 - T_1)$$

$$W_T = C_p(T_3 - T_4) + C_p(T_5 - T_6)$$

Network W_I $W_T - W_C$.

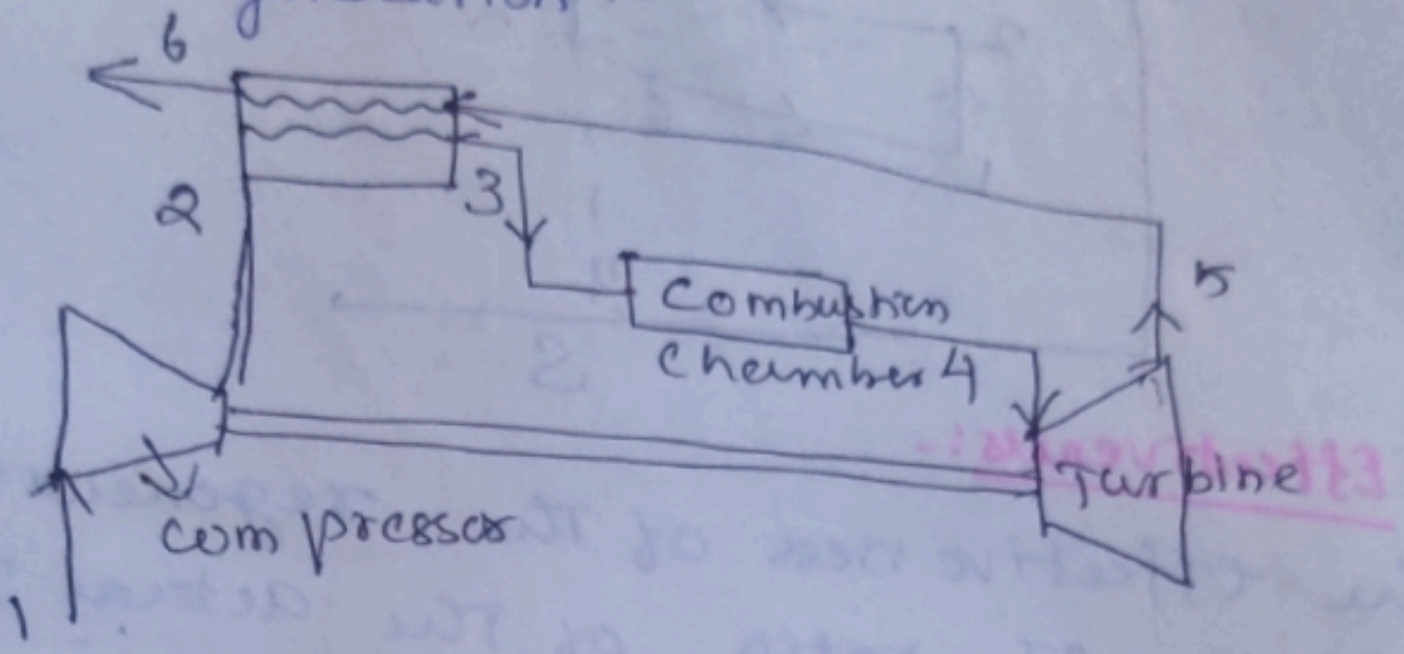
For obtaining maximum work $\frac{P_3}{P_4} = \frac{P_5}{P_6}$

$$P_4 = P_5 = \sqrt{P_2 \times P_6} = \sqrt{P_1 \times P_2}$$

$$\left[\begin{matrix} P_1 = P_6 \\ P_2 = P_3 \end{matrix}\right]$$

Brayton with Regeneration:-

The temperature of the exhaust gases of the turbine is higher than the temperature of the air after compression. If the Heat energy is used to heat air after compression in the heat exchanger. It is called regeneration.

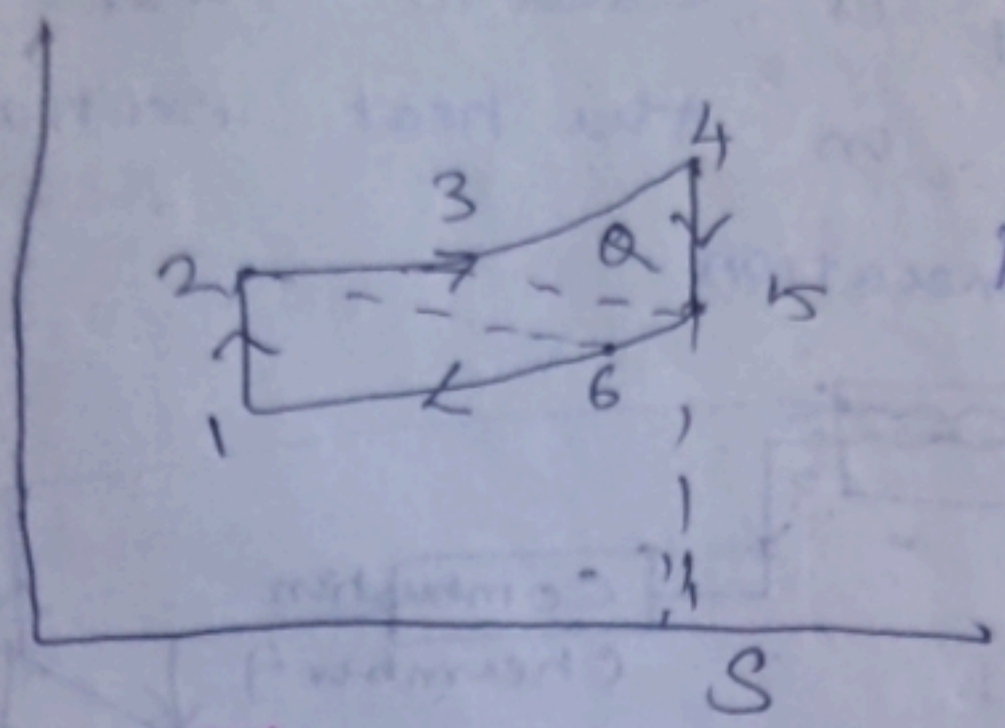


Air is drawn from the atmosphere into the compressor and isentropically compressed to State 2. It is then heated at constant pressure in the regenerator to State 3 by the exhaust gases from the turbine.

Since the temperature of the air is increased before it reaches the combustion chamber, less amount of fuel will be required to attain the designed turbine inlet temperature of the products of combustion.

After the combustion at constant pressure in the combustion chamber the gas enters the turbine at State 4. and expands to 5. It then enters the regenerator

the Stirling engine. Isothermal process of it a heat energy to the Compressed air from the Compressor and leaves the regenerator at State 6



Ideal = $T_3 = T_5$

Brayton and R

Effectiveness:-

The effectiveness of the regenerator is given by the ratio of the actual temperature rise to the maximum possible rise.

Effectiveness $\epsilon = \frac{T_3 - T_2}{T_5 - T_6} = \frac{T_3 - T_2}{T_5 - T_2}$ $(T_2 = T_6$ ideal)

$Q_S = C_p (T_4 - T_3)$

$Q_R = C_p (T_6 - T_1)$

$W_T = C_p (T_4 - T_5)$, $W_C = C_p (T_2 - T_1)$

$$\eta = 1 - \frac{Q_R}{Q_S} = 1 - \frac{T_6 - T_1}{T_4 - T_5}$$

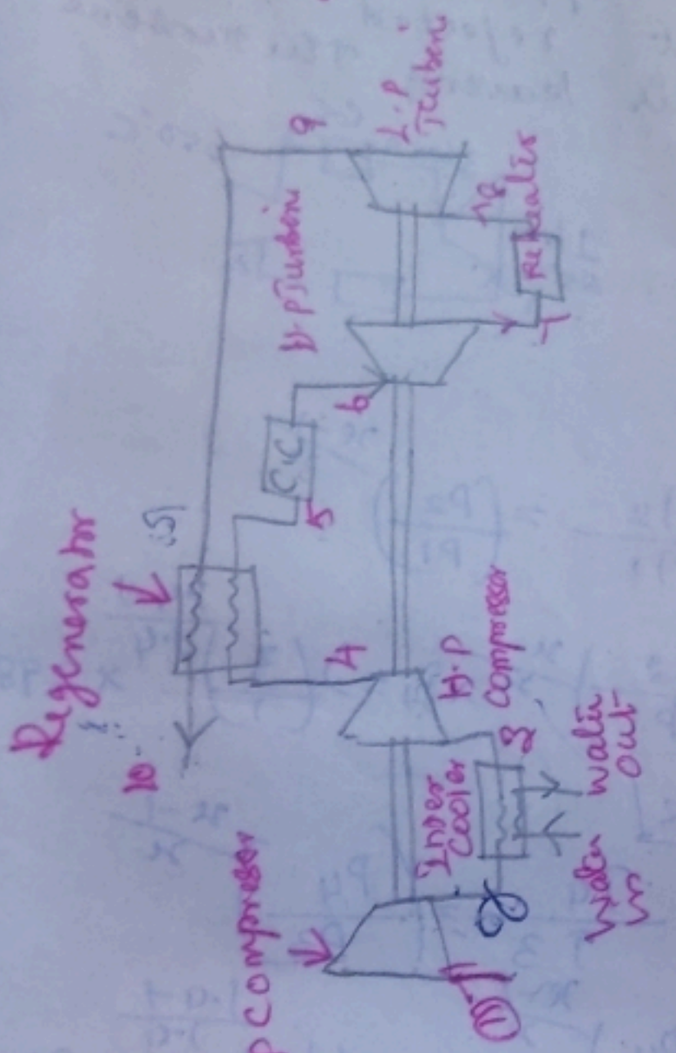
$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma - 1}{\gamma}}$$

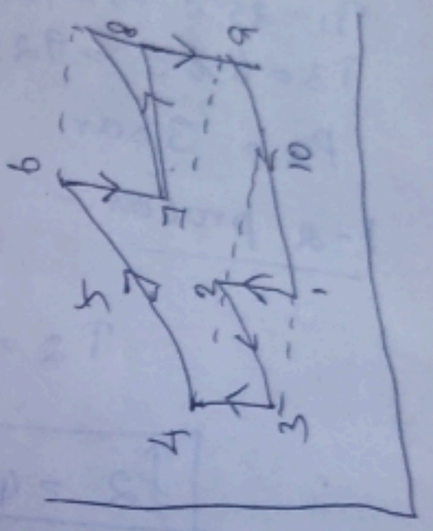
$$\frac{T_5}{T_4} = \left(\frac{P_5}{P_4}\right)^{\frac{\gamma - 1}{\gamma}} = \left(\frac{P_1}{P_2}\right)^{\frac{\gamma - 1}{\gamma}}$$

$$\eta = 1 - \frac{T_1}{T_4}\left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$$

$$\boxed{\eta = 1 - \frac{T_1}{T_4}(R_P)^{\frac{\gamma-1}{\gamma}}}$$

Brayton Cycle with inter cooling, Reheating and Regeneration:-





$$W_C = C_p(T_2 - T_1) + C_p(T_4 - T_3)$$

$$W_T = C_p(T_6 - T_7) + C_p(T_8 - T_9)$$

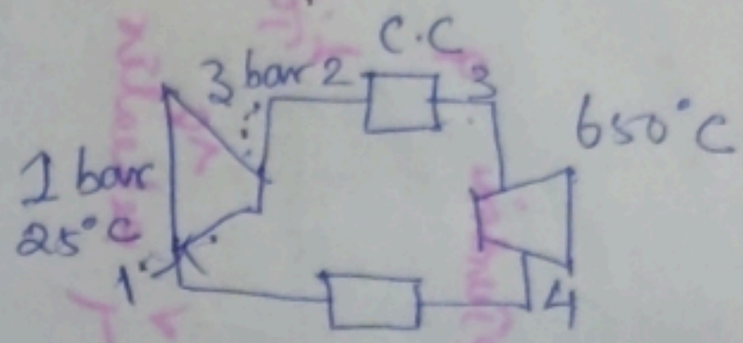
$$W = W_T - W_C$$

$$Q_S = C_p(T_6 - T_5) + C_p(T_8 - T_7)$$

$$Q_R = C_p(T_{10} - T_1) + C_p(T_2 - T_3)$$

$$\eta = 1 - \frac{Q_R}{Q_S} = 1 - \frac{(T_6 - T_5) + (T_8 - T_7)}{(T_{10} - T_1) + (T_2 - T_3)}$$

In a Brayton cycle, the air enters the Compressor at 1 bar and 25°C. The pressure of air leaving the Compressor is 3 bar and temperature at turbine inlet is 650°C. Determine per kg of air i) cycle efficiency. heat supplied to air, work input heat rejected to the cooler. Temperature of air leaving the turbine.



Solution:-

$P_1 = 1$ bar

$T_1 = 25°C = 298K$

$T_3 = 650°C = 923K$.

$P_2 = 3$ bar.

1-2 process:- $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}}$

$T_2 = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} \times T_1 \Rightarrow \left(\frac{3}{1}\right)^{\frac{1.4-1}{1.4}} \times 298$

$\boxed{T_2 = 408K}$

3-4 process:- $\frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{\gamma-1}{\gamma}}$

$T_4 = \left(\frac{P_4}{P_3}\right)^{\frac{\gamma-1}{\gamma}} \times T_2 = \left(\frac{1}{3}\right)^{\frac{1.4-1}{1.4}} \times 923$

$\boxed{T_4 = 674.3K}$

$\eta = 1 - \frac{1}{(r_p)^{\frac{\gamma-1}{\gamma}}}$

$= 1 - \frac{1}{(3)^{\frac{1.4-1}{1.4}}}$

$\boxed{\eta = 26.94\%}$

$Q_S = C_p(T_3 - T_2) \Rightarrow 1.005\ (923 - 408)$

$\boxed{Q_S = 517.575\ kJ/kg}$

$Q_R = C_p(T_4 - T_1) \Rightarrow 1.005\ (673.4 - 298)$

$\boxed{Q_R = 377.277\ kJ/kg}$

$W_C = C_p(T_2 - T_1) = 1.005\ (408 - 298)$

$= 110.55\ kJ$.

$W_e = C_p(T_3 - T_4) = 1.005\ (923 - 673.4)$

$= 250.848\ kJ$.

Work output $W = W_e - W_C$

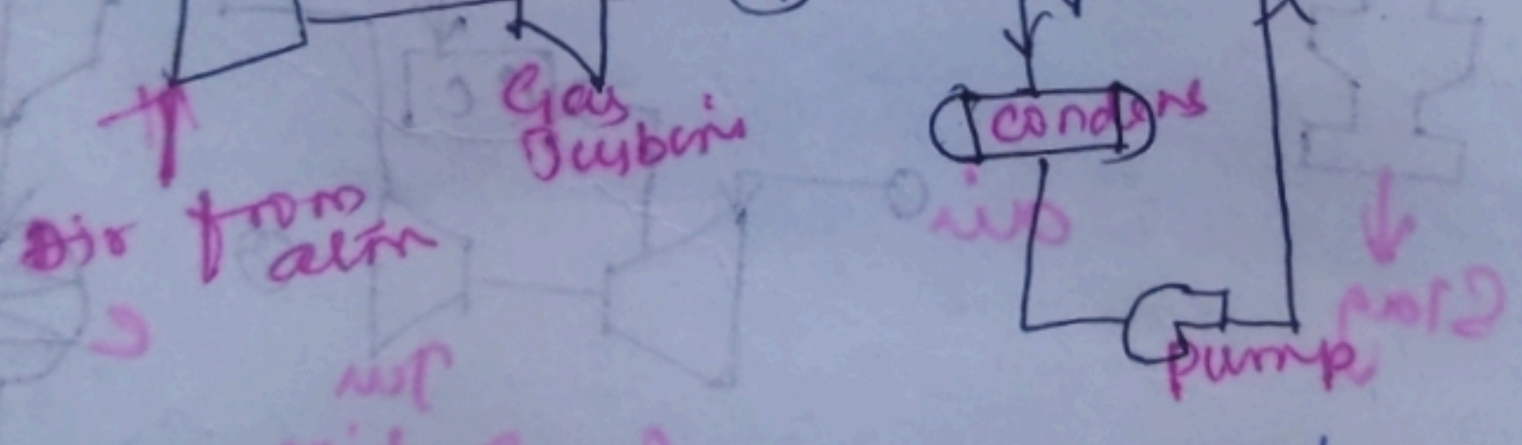
$= 250.848 - 110.55$

$= 140.288\ kJ/kg$.

Temperature of air leaving the turbine,

$\boxed{T_4 = 673.4K}$

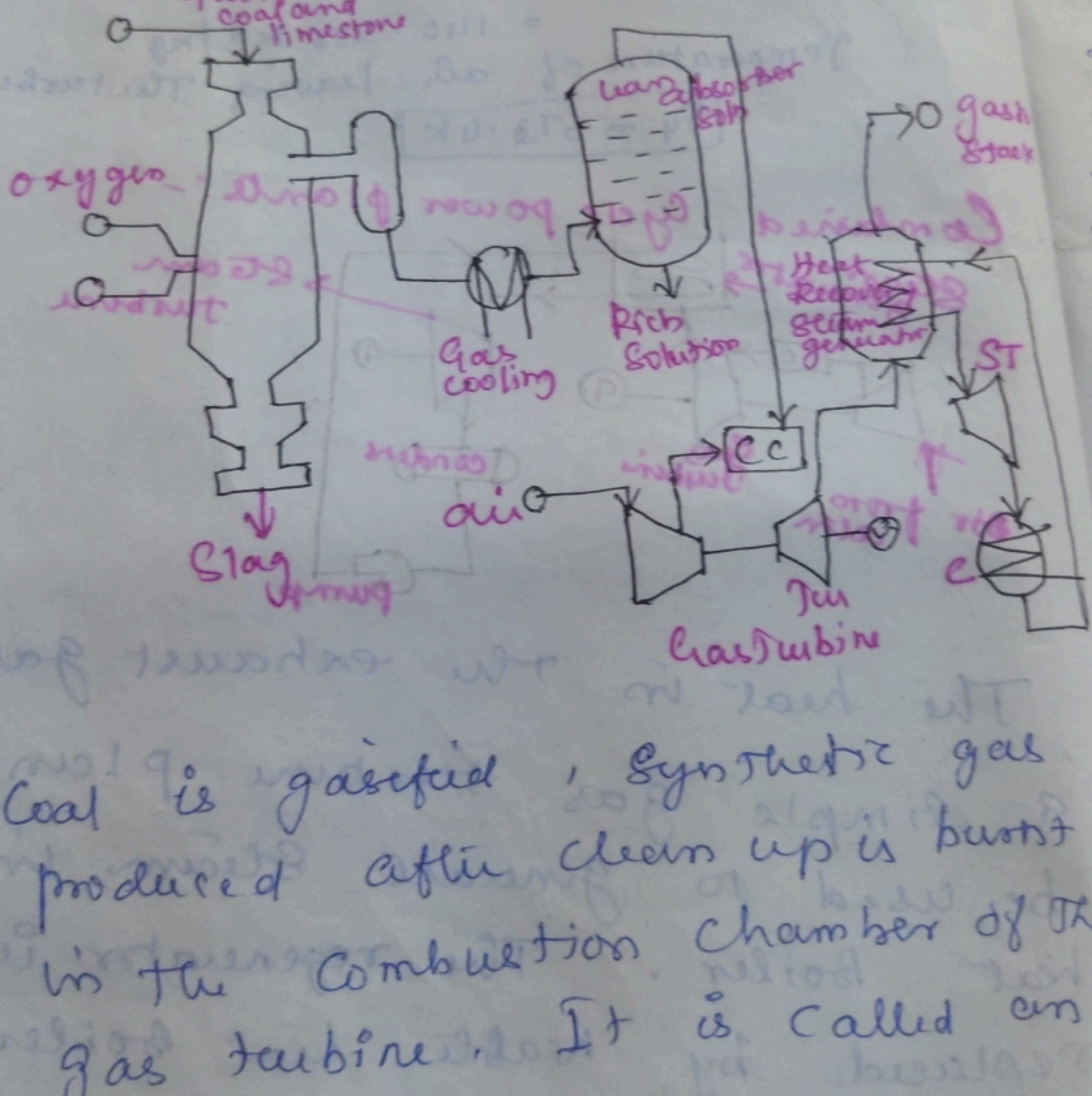
Combined cycle power plants :-



The heat in the exhaust gases of gas turbine plant can be used to generate steam in waste heat Boiler. The regenerator is replaced by waste heat Boiler.

- The heat in the exhaust and O_2 carried with the exhaust gases both are used in the waste heat Boiler by supplying the fuel in the Secondary combustion chamber. The steam generated is used with steam power plant.

Integrated Gasifier based Combined Cycle Systems :-



Coal is gasified, Synthetic gas produced after clean up is burnt in the combustion chamber of the gas turbine. It is called an

Integrated gasification combined cycle (IGCC). Coal and lime stone are fed to a pressure vessel. The coal being gasified by oxygen and steam. The use of air instead of oxygen produces a gas of lower calorific value. The exhaust gases from the GT raise steam in the Heat Recovery Steam generator (HRSG).

A gas turbine power plant takes air in 15°C and 1.01 bar and the pressure ratio is 6. The Isentropic efficiencies of the compressor and turbine

In a gas turbine power plant working on Brayton cycle. The inlet air temp is 30°C and pr 1.0 bar. pressure ratio 6.25 maximum temp 827°C. Find compressor work, turbine work, cycle η, work ratio.

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{\gamma-1}{\gamma}} = 6.25^{\frac{1.4-1}{1.4}} = 511.5K.$$

3-4, $\frac{T_4}{T_3} = \left(\frac{P_4}{P_3}\right)^{\frac{\gamma-1}{\gamma}}$.

$T_4 = \left(1/6.25\right)^{\frac{\gamma-1}{\gamma}} \times 1100 = 651.63K$

$W_C = C_p (T_2 - T_1)$ $= 1.005 (511.5 - 303)$

$= 209.54 kJ/kg$

$W_T = C_p (T_3 - T_4)$ $= 1.005 (1100 - 651.63)$

$= 450.61 kJ/kg.$

$\eta = 1 - \frac{1}{(R_p)^{\frac{\gamma-1}{\gamma}}} = 1 - \frac{1}{(6.25)^{\frac{1.4-1}{1.4}}} =$

$0.4076 = 40.76$

$WR = \frac{\text{Net work}}{\text{Coors work}} = \frac{450.61 - 209.54}{450.61} =$

0.535

$1 - \frac{T_1}{T_2} = 1 - \frac{303}{1100} = 0.7245 = 72.4\%$

Increase in $\eta = 72.46 - 40.76 = 31.7\%$

$= \frac{72.46 - 40.76}{72.46} = 43.75\%$

UNIT - III

Basics of Nuclear Engineering, layout and Subsystems of Nuclear power plants, Working of Nuclear Reactors - BWR, PWR, CANDU, Breeder, Gas cooled and Liquid metal Cooled Reactors. Safety measures for Nuclear power plants.

3.1 Basics of Nuclear Engineering :-

→ large amount of energy that can be released from a small mass of active material.

→ Complete fission of 1 kg of Uranium Contains the energy equivalent to 3100 tons of Coal (or) 1700 tons of oil.

→ Nuclear power NOT only available abundance, It is cheaper.

→ Large deposits of Thorium in Beach Sand compare to low grade Uranium.

→ Tarapur - 1400MW, Rawatbhata - 1,180
(Maharastra) - PHWR (Rajastan) - PHWR
Kundankulam - 1000MW.
(TN)

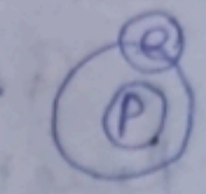
→ Total - 5,480 MW from Nuclear power in India.

→ VVER - (water - water energy - reactor
Russian.

→ 5th Source. 17 plants, TN - 2000MW
production - 7480. MW - 440 MW

- Horizontal Steam generators, Hexagonal fuel assemblies, No Bottom penetrations in the pressure vessel.

- Atomic Nuclei:-
  positively Charged nucleus surrounded by no of (-)ve charged electrons.



- Nucleus - protons and neutrons both are nucleons. proton - (+)ve charge, Neutron - Uncharged.
- The no. of electron on the orbit = No. of protons in the nucleus.
- Any addition of electron to the neutral atom makes the atom negative charged. Substraction of electron will make it positively charged. Such atomic ion. process of Charging atom is known as Ionization.

- Atomic Number - The no. of protons in a given atom (number of positive charges) Symbol Z.
- Mass Number - The total no. of protons and neutrons in an atomic nucleus is called mass number. A.

Isotopes - Same atomic number, different mass number.

- Uranium - 0.006 %. Of $_{92}U^{233}$
  0.714 % $_{92}U^{235}$
  99.28 %. $_{92}U^{238}$

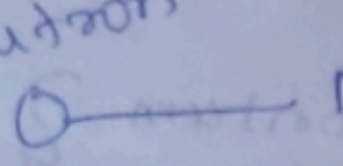
Atomic mass Unit:-

$$1 \text{ amu} = \frac{1}{6.0225 \times 10^{23}} \text{ grams} = 1.6604 \times 10^{-24} \text{ gram}$$

mass of electron - 0.00055 amu
" proton - 1.00758 amu
neutron - 1.00897 amu

Half life time:- The half life time of particular isotope is defined as the time required for the number of active nuclei to decay to half of its initial number.

Inelastic Scattering:-



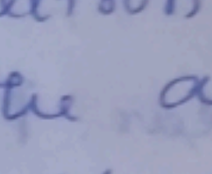
When a neutron Undergoes inelastic Scattering, It is first captured by the target to form a compound nucleus. Then a neutron of lower kinetic energy is expelled from the target nucleus leaving the nucleus in excited state.

Elastic Scattering:- kinetic energy of The neutron is conserved. when the neutron strikes the target nucleus, it impart the part of kinetic energy to the target nucleus and its original kinetic energy is reduced.

Neutron capture:- The colliding neutron is absorbed by the target nucleus and increases its mass number by Unity.

- Horizontal Steam generators, Hexagonal fuel assemblies, No Bottom penetrations in the pressure Vessel.

- Atomic Nuclei:
  positively Charged nucleus surrounded by no of (-)ve charged electrons.



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- Uranium - 0.006% of $_{92}U^{233}$
  0.714% $_{92}U^{235}$
  99.28% $_{92}U^{238}$

Fission products:-

The fission products $_{92}U^{235}$ are given below.

$$_{92}U^{235} + {}_0n^1 \rightarrow {}_{56}Ba^{141} + {}_{36}Kr^{92} + 3\,{}_0n^1 + Q$$

$$_{92}U^{235} + {}_0n^1 \rightarrow {}_{57}La^{147} + {}_{35}Br^{87} + 2\,{}_0n^1 + Q$$

$$_{92}U^{235} + {}_0n^1 \rightarrow {}_{38}Sr^{94} + {}_{54}Xe^{139} + 3\,{}_0n^1 + Q$$

The fission chain reaction:- (M)J-13)

The no. of neutrons produced must be sufficient to maintain the chain reaction and to supply the losses (escape, absorption, non-fission reactions). There fore the essential condition to maintain the chain reaction is that the fission neutron nucleus must produce at least one secondary neutron to cause fission of other nucleus.

multiplication factor (or) Reproduction factor:-

K = Number of neutrons of any one generation

Number of neutrons of immediately preceeding generation.

When $K < 1$ ⇒ Subcritical (Stopping the reactor)

$K > 1$ – Super Critical (atom bomb)

$K = 1$ ⇒ Critical ⇒ desirable requirement for power reactors.

Fertile materials:-

There are materials like $_{92}U^{238}$ and $_{90}Th^{232}$ which are not fissible but can be converted into fissile materials by the bombardment of neutrons. Such materials are known as fertile materials.

Fissile products — $_{94}Pu^{239}$, $_{92}U^{233}$

Breeding:-

The process of converting more fertile material into fissile material in a reactor is known as Breeding.

Controlling of Chain reaction:- (M/J-12)

If neutron is <1, reaction will not produced. >1 - explosion

(Th) The Controlled chain reaction of a nuclear reactor fuel assemblies are connected and the control rods are slowly lifted to initiate the chain reaction. The fissionable atoms of fuel rod allow the reaction to proceed spontaneously in a controlled manner.

Difference between Fission and Fusion (N/D-12)

Nuclear Fission	Nuclear fusion
① It is the process of spliting a heavy nucleus with some projectiles into two or more light fragments with liberation of a large amount of energy.	It is the process of fusing two light nuclei into single nucleus with the liberation of a large amounts of heat.
② Emission of radioactive rays.	does not emit radio active rays.
③ new elements are considered less than Reactive materials	mass & atomic no higher than starting elements.
④ neutrons are emitted	Protons are emitted.

Critical mass; m/J -12

The minimum amount of fissile material needed to maintain a nuclear chain reaction.

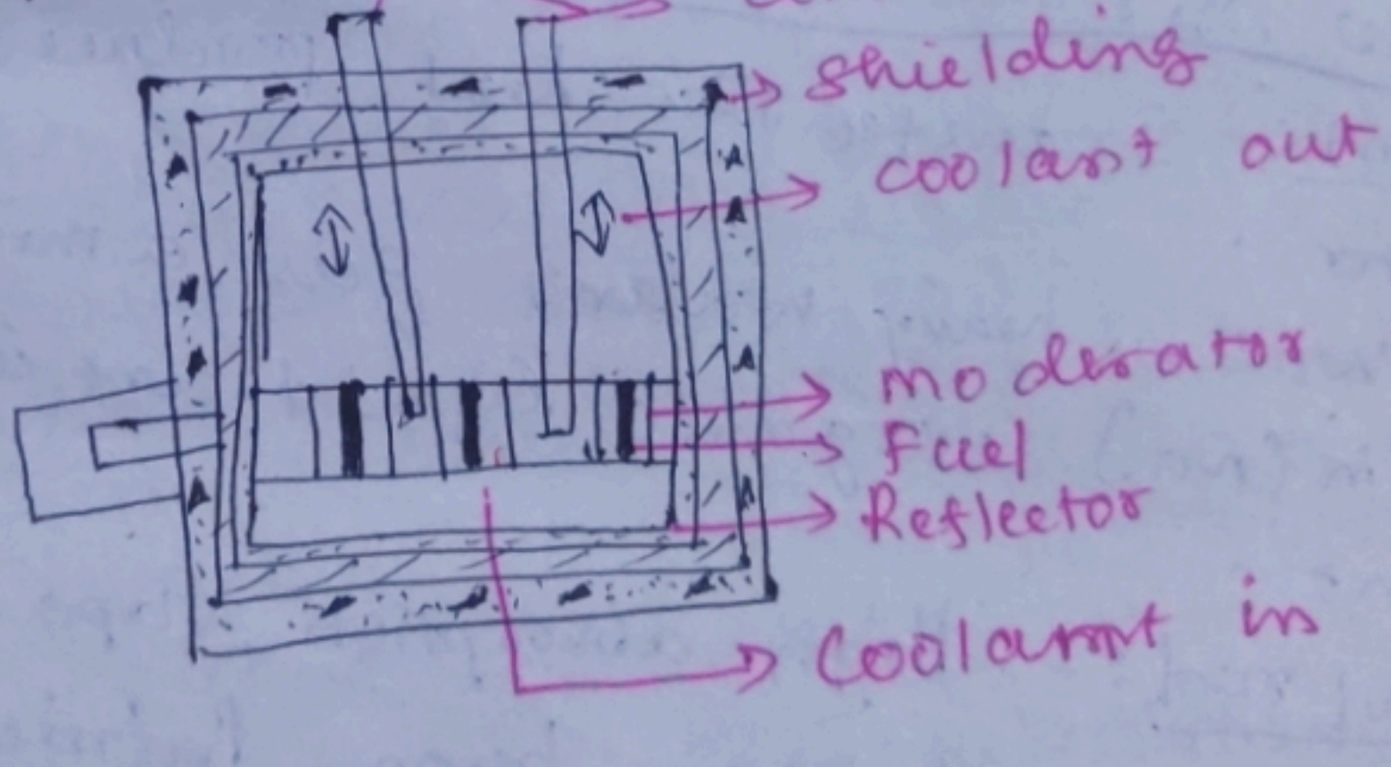
Critical Size:-

The actual size of material which allows the escape of neutrons to such an extent that at least one neutron is positively left behind per fission reaction.

Components of Nuclear reactor:-

Fuel, moderator, Reflector, Coolant, control rods. Shielding.

Function of moderator:- which reduce the kinetic energy of fast neutron (1 MeV to 0.25 eV) 13200 Km/s 2200 m/s.



Fuel:- $_{94}Pu^{239}$ / $_{92}U^{233}$ → are formed in the nuclear reactor during fission process from $_{92}U^{238+1}$, & $_{90}Th^{232+1}$

$_{92}U^{235}$, $_{92}U^{238}$

Moderator materials:- → Light elements
H_2, D_2, N_2, O_2,
↓
Graphite, Heavy water,
Beryllium.

Desirable properties:- must be light, able to Slow down the neutrons earliest possible but it must not absorb them. High coolant Corrosion. High melting point. must be cheap.

Reflector:- It is always necessary to conserve the neutrons as much as possible in order to reduce the consumptions of fissile material. To keep the size of the reactor small.

Required properties:- low absorption and high reflection for neutron. high resistance to Oxidation.

- H_2O, D_2O and Carbon are used as reflectors.

① Coolant:- Transfer the heat produced in reactor.
The water, heavy water, gas a metal in liquid
for m (Na), organic liquid are used as
coolant.

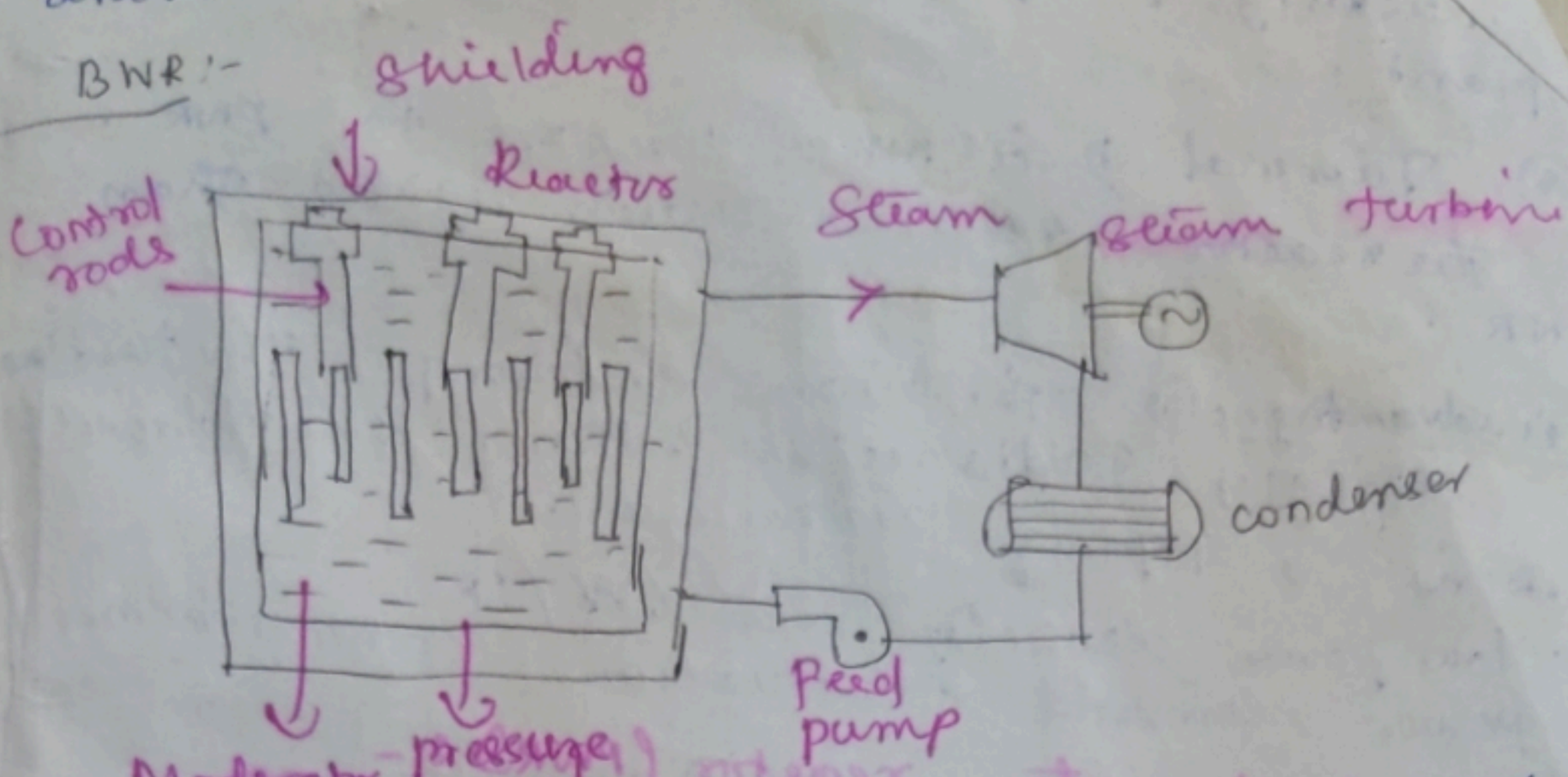
Control rod:- High absorption capacity for neutrons. Cadmium, boron, Hafnium.

Shielding Radiations are very harmful.
Shielding - absorbed by the concrete and
steel. 50 to 60cm Thick steel plate.
Thermal shield is cooled by the circulation
of water.

Reactor
above.
BWR:-
Control rods

Reactor Vessel. It has to with stand rod? above.

BWR:-



- Enriched Uranium is used as a fuel and Water is used as moderator. Coolant and reflector is.
- BWR is That in a The Steam is generated in The reactor itself instead of a Separate Steam generator.
- water enters The reactor at The bottom. This water is heated by The heat released due to This fission of fuel and gets converted into Steam. The Steam which leaves from The top of The reactor is passed Through The turbine and expanded.
- Exhaust Steam from The turbine passes Through The condenser and Condensed and is again recirculated again by using feed pump.

Advantage ① There is no B.E, pressurizer circulating pump. This reduces cost of the plant.

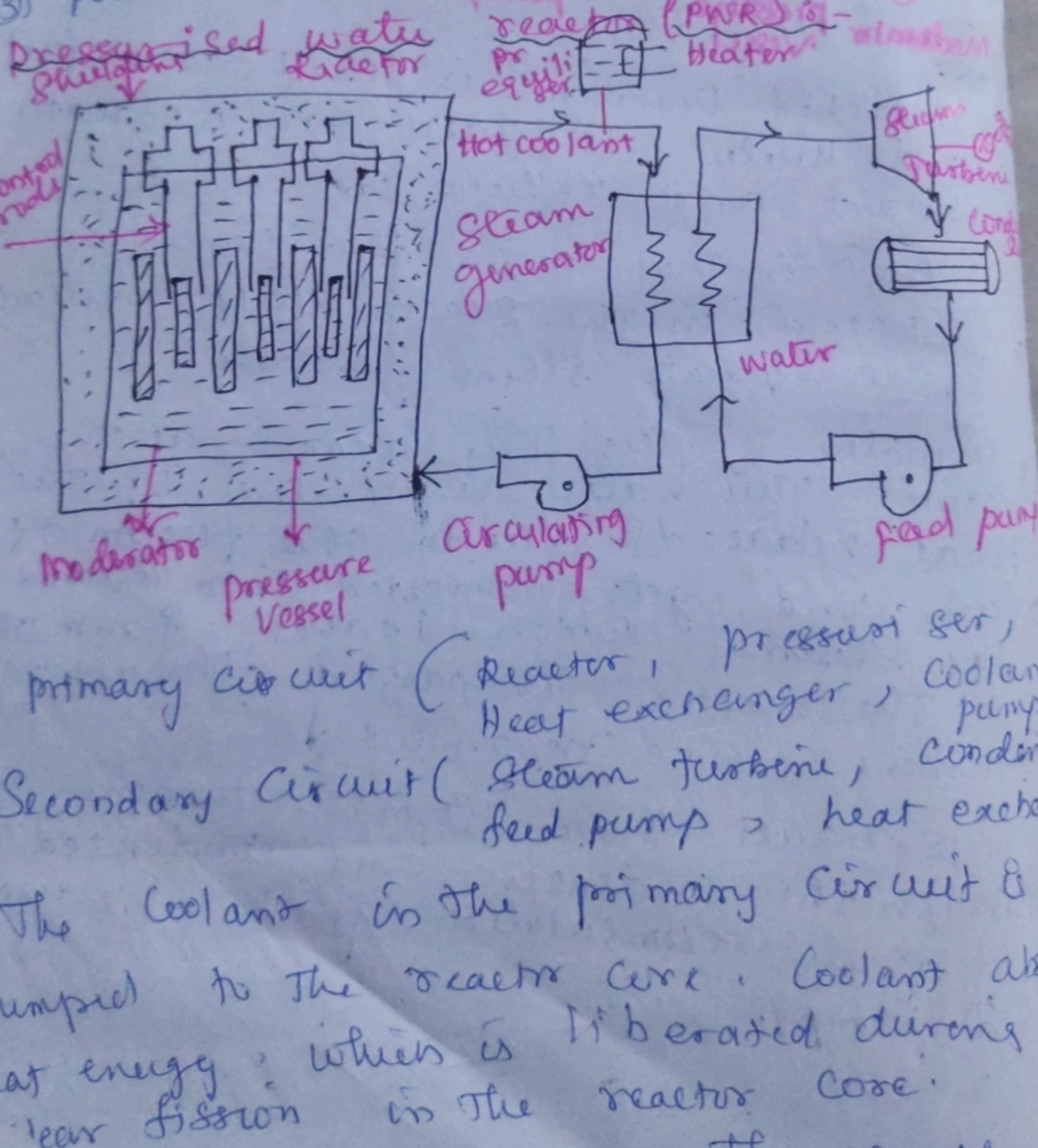
② Thermal η is more compare to PWR.

③ The reactor vessel is much lighter than PWR.

Disadvantage: ① The steam entering the turbine is slightly radioactive. Hence shielding, piping are needed.

② Low power density 33.6 kW/lt.

③ power demand fluctuations cannot be met.



primary circuit (Reactor, pressuriser, Heat exchanger, Coolant pumps)

Secondary Circuit (Steam turbine, Condenser, feed pumps, heat exchanger)

The coolant in the primary circuit is pumped to the reactor core. Coolant absorbs heat energy which is liberated during nuclear fission in the reactor core.

Hot coolant passes Through the

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Department of Mechanical Engineering

Lecture Notes

Subject Code : ME8793

Subject Name: PROCESS PLANNING AND COST ESTIMATION

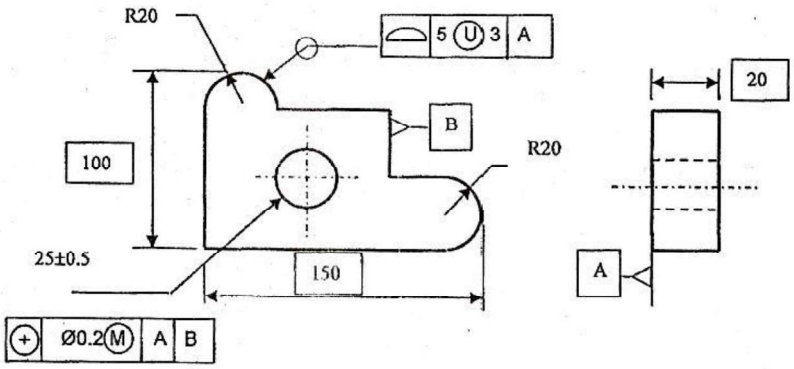
Sem/Year : 07/IV

Regulation : 2017

Unit -1 Introduction to Process Planning

Part A

1. **What are the details required for process planning? (AU A/M '18)**
   - Detailed engineering drawings
   - Knowledge of materials for manufacture
   - Knowledge of manufacturing processes
   - Knowledge of jigs and fixtures
   - Knowledge of the relative costs of materials, processes and tooling
   - Manufacturing parameters (speed, feed etc) and costs
   - Knowledge of inspection/QA procedures and specifications
2. **Study the drawing shown in fig and interpret any one geometric tolerance symbol (AU A/M '18)**

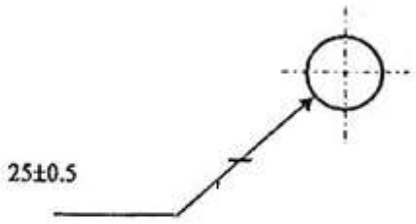


Symbols used for Geometric tolerance

20	Boxed dimension (theoretically exact)
B	Datum indication
∅	Circular or cylindrical tolerance
⌖	Location (position)

3. **List the objectives of process planning (AU N/D '17)**
   - To manufacture a product that meets its design specification
   - The manufacture of the product must be cost-effective, that is, maximize the added value, and meet the agreed deadlines, that is, be completed on time.
4. **What is bilateral tolerance? Give examples (AU N/D '17)**

Bilateral Tolerances are those when variation in actual dimension of the part can be tolerated to both sides of the given Nominal value .e.g. ϕ 25 (+/- 0.5).



Upper deviation : + 0.5; lower deviation: - 0.5

5. **Define process planning. (AU A/M'17) (AU N/D '16) (AU N/D '15)**

Process planning is defined as the determination of the processes and the sequence of operations required making the product. It consists of devising, selecting and specifying processes, machine tools and other equipment to transform the raw material into finished product as per the specifications called for by the drawings.

6. **Write any four cutting tool materials (AU A/M'17)**

Carbon steels, High speed steels, cobalt alloys and carbides.

7. **Write the approaches to process planning (AU N/D '13) (AU M/J '13) (AU M/J '12)**
   - Manual process planning
   - Computer Aided process planning
     - Varient approach
     - Generative approach

8. **List out factors considered on the selection of machinery (AU N/D '13)**
   - Volume of production (Quantity to be produced) *i.e.*, no. of components to be produced.
   - Quality of finished product, and
   - Advantages and disadvantages of the various types of equipment capable of doing the work.

9. **Write the Advantages of computer aided process planning (AU N/D '12)**
   - Efficient processing
   - Standardized procedures
   - Shorter development time
   - Lower hardware costs

10. **Define: Contingency allowance(AU N/D '14)**

In a shop, there may be small delays due to
1. Waiting for the inspector.
2. Consulting the supervisor.
3. Obtaining special tools etc.

These delays are of very short duration. The allowance given to compensate these delays is called contingency allowance. Generally 5% of basic time is given as contingency allowance.

Part – B

1. **Why is process planning required to estimate cost? State its advantages. Discuss in detail the methods how computer can be used in cost estimations (13 marks) (AU N/D '18)**

Estimating is the calculation of the costs which are expected to be incurred in manufacturing a component in advance before the component is actually manufactured.

In this rapid developing and competitive age, it is necessary for a factory that the advance information about the cost of a job or a manufacturing order to be put through should be available before taking up the actual production. Estimating which is predetermination of cost is mainly concerned with the factory owner. It helps him to decide about the manufacturing, and selling prices.

Reasons for doing Estimates

Cost estimates are developed for a variety of different reasons. The most important reasons are shown below.

Should the product be produced? When a company designs a new product, a detailed estimate of cost is developed to assist management in making an intelligent decision about producing the product. This detailed estimate of cost includes an estimate of material cost, labour cost, purchased components and assembly cost.

In addition to product cost, many other elements must be estimated. These include all tooling costs. A cost estimate must be developed for jigs, fixtures, tools, dies and gauges. Also, the cost of any capital equipment must be entered into the estimate. These figures are usually supplied through quotation by vendors. An estimate of this nature will include a vast amount of details, because if management approves the project, the estimate now becomes the budget.

Computer Estimating

Use of group technology

GT can be used very efficiently in estimating cost. Assume a company manufactures shaft-type parts. Also arsum there is a computer data base named SHAFT that contains 10-digit code followed by a part number, that is, code part number, and so on. When an estimator must estimate the cost of a new shaft, the process starts by developing a code that describes the characteristics of the part. The first digit in the code might be assigned the part length, while the second digit is assigned the largest diameter and so on. Next, the code is keyed in and the computer finds all the parts that meet the numeric descriptions and points out the part numbers. The best fit is selected to be modified into a new part. All the details of each description are retrieved. These include diameter, length of cut, number of surfaces, and the like. The estimator can alter these features and make the old part into a new one.

Advantages and disadvantages

Shown below are some of the major advantages of computer cost estimating.

Accuracy versus consistency - Computer estimates are very consistent, provided they calculate the detail of an estimate. Because these estimates are consistent, they can be made to be accurate. Through the use of consistent efficiency factors or leaving curves, estimates can be adjusted up or down. This is one of the chief advantages of computer cost estimating.

Levels of details

Some computer estimating systems provide different levels of estimating cost. The level of detail selected by the user depends on the dollar risk. Many estimators produce an estimate in more detail because the computer can calculate speeds and feeds, for example, much faster than an estimator can a hand-held calculators.

Refinements

Some computer estimating systems provide many refinements that would be impossible for the estimator to do in any timely manner. One example is to adjust speeds and feeds for material hardness. Typically, the harder the material the more slowly a part will be turned or bored. Another refinement is the ability to calculate a feed state and adjust it based on the width of a form tool.

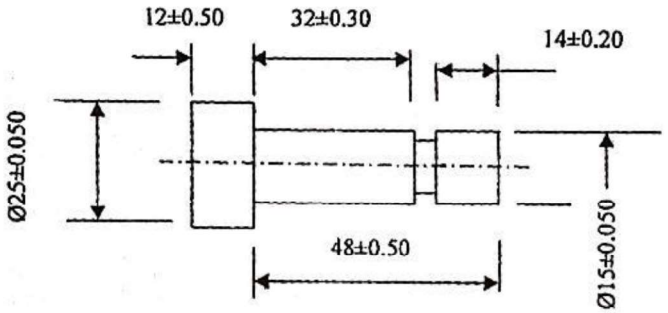
Source code

Some companies offer the source code uncompiled to their users. This is important because it affords the user the opportunity to customize the software. In addition, many companies have written their own software to do something that is not available on the market. If the source code is not compiled, the users can build upon a computer estimating system.

Disadvantages

The chief disadvantage of computer estimating is that no one estimating system can suit everyone's need. This is especially true if the source code is compiled and not customizable. Another problem with computer estimating is that the estimator will, in all probability, have to change some estimating methods. Computer software for estimating cost is seldom written around one method of estimating.

2. Discuss the production equipment and tool selection for the component shown in fig undercut diameter is 12mm. (13 marks) (AU N/D '18)



Solution

a. *Evaluation of process and machine selection*. As stated in the problem, the process identified is turning and the machine tool is a small bench lathe. This limits the tools to select from to those we have in machine shop

b. *Analysis of machining operations*. The operations identified are facing, roughing, finishing and parting off. From this, two specific tools can be identified:

Turning/facing tool- facing, roughing and finishing;

Parting off tool- parting off

c. *Analysis of workpiece characteristics.* The fact that the workpiece material is brass means that HSS tooling is more than sufficient to carry out all operations. This is due to brass being highly machinable material.

However, in terms of workpiece and tool geometry, there are two issues to be considered. In terms of the facing and roughing out, a left-handed tool will not be able to completely finish the arc in the middle of the part. There are two options that can be considered. The first is to produce half the arc with the left-handed tool and change to a right-handed tool for the other half. However, it would be much simpler to use a contouring tool for the complete arc. Furthermore, a contouring tool will be required for the 'chamfered groove' to the left-hand end of the part.

Therefore, it makes sense to use the contouring tool for both features, rake angles permitting, as this uses the least number of tools.

d. *Tooling analysis*. From the above stages, the following tooling list and operation description can be generated:

Facing: left-hand turning tool
Roughing: left-hand turning tool
Finishing: contouring tool
Parting off: parting-off tool

Face the end and rough out the excess material with the left-hand tuming tool. The majority of the finish turning can be carried out with the left-hand turning tool. However, the radius and the chamfered groove will be machined with the contour tool and finally the part will be cut from the billet by the parting off tool.

As the problem is simply to identify the tooting, the problem is basically solved. Therefore, there is no need to go to the stage of selecting a suitable tool holder. It can also be seen from the above example that even fairly simple geometries will require more than one cutting tool.

3. **Explain with neat sketch various methods of process planning (AU N/D '18) (AU N/D '16) (or) Describe various approaches to process planning (AU N/D '15) (or) Explain the use of computers in process planning and cost estimation and list out the advantages of CAPP. (AU N/D '14) (AU N/D '12) (or)**
How will you distinguish retrieval and generative computer aided planning systems? Which is more effective? State reasons. (AU M/J '16) (16 Marks)

Approaches of process planning

- Manual Process Planning
- Computer Aided Process Planning

Manual process planning

This type of planning is known as non-variant process planning. It is the commonest type of planning used for production today.

Planning the operations to be used to produce a part requires knowledge of two groups of variables.

(a) The part requirements, and

(b) The available machines and processes and the capabilities of each process.

The manual approach to process planning begins when a detailed engineering drawing and data on batch size are issued to a production engineer. This information is used to determine the following:

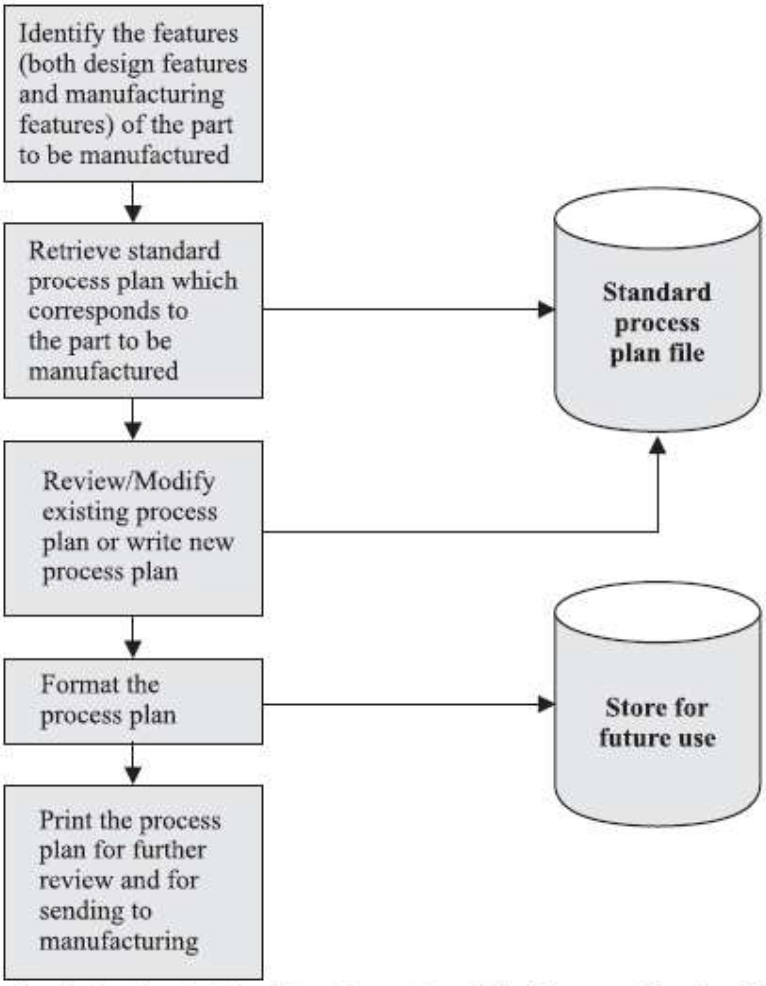
- The manufacturing processes involved.
- The machine tools required to execute these processes.
- The tools required at each stage of processing.
- The fixtures required at each stage of processing.
- The number and depth of passes in a machining operation.
- The feeds and speeds appropriate to each operation.
- The type of finishing process necessary to achieve the specified tolerances and surface quality.

As a first step, the production engineer examines the part drawing to identify similarities with previously produced parts. If similarities are recognized, a process plan is manually retrieved for the similar item. The process plan is either used without modifications for identical parts or modified to meet the manufacturing requirements of the new part. Although old process plans are used as references for similar parts,

there is still significant duplication of effort due to the lack of efficient information retrieval, comparison, and editing techniques. The manual method may also lead to inconsistency in the final plans because it is unlikely that two process planners will generate identical process plans.

It is difficult or impossible to achieve consistent, optimized process plans with the conventional manual method. As a consequence planning and manufacturing costs are increased because of the duplication of effort in the process planning function as well as specification of excessive tooling and material requirements. Production lead times also increase due to redundancies in the planning function.

Computer Aided process planning



Procedure for developing the Retrieval type Computer—Aided Process Planning (CAPP) system

Computer Aided Process Planning represents the link between design and manufacturing in a CAD/CAM system. Process planning is concerned with determining the sequence of processing and assembly steps that must be accomplished to make the product. The processing sequence is documented on a sheet called a route sheet. The route sheet typically lists the production operations, machine tools, work centres or work stations where each operation is performed, jigs, fixtures and tooling required and standard time for each task.

Computer Aided Process Planning (CAPP) Systems are designed with two approaches in mind. These approaches are called:
(a) Retrieval CAPP Systems, and (*b*) Generative CAPP Systems

Variant or Retrieval Method of Process Planning (Retrieval CAPP System)

In this method, the computer makes a search of its storage or a data base or a no. of standard or completed process plans that have been previously developed by the company's process planners.

The development of the data base of these process plans requires substantial knowledge of machining, time and efforts. Using the current design data supplied by the CAD system, (after a component has been designed and dimensioned), it searches for a process plan that was based on a part of similar design. (This search can make effective use of GT, Group Technology, design coding to simplify the search for similar part design).

The process plan **retrieved** is then modified or suitably **varied** (*i.e.*, altered) by the process planner, to suit the exact requirements of the current part design. The use of Computer and Group Technology (GT) to search for the most appropriate or similar part design, and to retrieve the process plan for that design, significantly reduces the work required of the process planners. This also saves considerable amount of time required to develop a process plan for a new part.

The task of process planner becomes one of modifying the existing plan to suit the particular dimensions of the current part. (*i.e.,* the selected process plan is provided to the user for modification and variation). Process planners are required to perform the entire process planning method only in the case of a completely new part design. This approach of process planning is also known as Retrieval CAPP system. This is based on the principles of Group Technology and parts classification and coding. One of the pre-requisites for implementation of this method is that the industries must develop and maintain a large computer data base of standard completed process plans. In addition, the part designs are to be developed using CAD systems.

Generative Method of Process Planning (Generative CAPP System)

The second method of computerized process planning is the generative method. In this method the computer uses the stored manufacturing and design data to generate a complete list of all possible process plans that could be used to manufacture the current part. It then exhaustively searches this list for the one which optimizes the cost function. This method always yields the optimum process plan for manufacturing a particular part.

However, it has a very high cost in terms of time and computer processing expenses. The computations required to provide even a single process plan for an arbitrary part design can be enormously complex. To repeat this for every feasible process plan or a part can become very costly. This approach of process planning is also known as **Generative CAPP System.**

Both the approaches viz. Variant (or retrieval) method of process planning and Generative method of process planning involves a systematic development of Code Numbers using Group Technology concepts and principles for the design and manufacture of the part.

Both of these methods of computerized process planning can be enhanced through the application of AI (Artificial Intelligence) in the form of expert systems.

Benefits of CAPP

The benefits derived from computer aided process planning are the following

1. Process rationalization and standardization: Automated process planning leads to more logical and consistent process plans than when process planning is done completely manually.

2. CAPP helps in arriving at standard and consistent process plans : Standard plans tend to result in lower manufacturing costs and higher product quality.

3. Increased productivity of process planners : The systematic approach and the availability of standard process plans in the data files permit more work to be accomplished by the process planners.

4. Reduced lead time for process planning : Process planners working with the CAPP system can provide route sheets in a shorter lead time compared to manual preparation.

5. Improved legibility and readability : Computer prepared route sheets are legible and easier to read than manually prepared route sheets.

6. Incorporation of other application programmes : The CAPP programme can be integrated with other application programmes, such as estimation of standard time, cost estimating and formulation of work standards.

4. **Write down the procedure to be followed during material selection. Discuss the factors that are taken into account in process selection and equipment selection. (AU N/D '16) (10 Marks) (or)**
   What are the factors influencing process selection and write down the process selection parameters (AU N/D '14) (16 marks)

Factors Influencing Process Selection

After a product design is made process selection is to be carried out. There are several factors which influence the process selection, These are :

- Shape requirements
- Size or dimensional requirements
- Tolerance requirements
- Surface finish requirements
- Annual volume requirements (*i.e.*, production quantity required per annum)
- Material characteristics.

Process selection requires a broad and extensive knowledge of various materials and the associated manufacturing processes. A good understanding of the capabilities and limitations of the various processes available is an asset to any process planner. Evaluation of alternative processes can also be carried out simultaneously and a logical decision taken with respect to proper selection of the process. It must be emphasized that the selection of a

process is done and evaluated in the context of p**roduct design - material - manufacturing process** in an integrated manner.

Process Selection Parameters

There are several factors which govern the selection of a manufacturing process:

1. Shape requirements of the final product *i.e.*, Geometric Form :

Geometric parameters such as solid shape, hollow shape, flat shape, flanged shape, concave shape, convex shape, cylindrical shape, presence of any part feartures such as groove, threaded shape, hole, chamfer, etc. are considered in the selection of a manufacturing process. Each process has its own capabilities and limitations with respect to the production of the above shapes and part features.

2. Size or Dimensional requirements :

Some processes are capable of handling parts of small sizes and some processes can handle large sized parts economically and effectively.

3. Tolerance requirements :

Each manufacturing process has got its own capability with regard to tolerance or accuracy of parts that can be produced using that process *e.g.* grinding process always gives close tolerances when compared with turning process. Depending upon the tolerance specified on the part drawing, suitable machining process is to be selected.

4. Surface finish requirements:

Each manufacturing process has got its own capability with regard to the surface finish which it can provide on the part machined, *e.g.* reaming process can provide a better surface finish in a hole when compared with drilling process. Similarly cylindrical grinding give a better surface finish, than a plain turning process. Depending on the finish requirements specified on the component drawing, appropriate machining process need to be selected.

5. Production volume requirements:

The economics of any machining process depends on the production volume, *i.e.*, no. of components required on a weekly, monthly or annual basis as the case may be. Existing order quantity as well as any anticipated future orders and their quantity need to be considered in the process selection. Some of the processes and additional cost incurred in the specialized toolings, jigs and fixtures can be justified only when there is a large volume of production.

6. Material requirements:

The hardness and strength characteristics of the material influence the tooling required. To machine hard and tough materials, carbide and ceramic tools are required. If slender or thin materials are machined, proper work holding devices and specially designed jigs and fixtures are required is order to avoid distortion and bending of work pieces during machining. Thus material requirements of the part also influence the appropriate selection of machining process.

Material Selection

Material selection is done by the product designer considering the requirements of the parts designed and the hardness, strength properties and other mechanical characteristics of the material. Cost and availability of the material are also considered. Material should be strong enough and at the same time manufacturing or producibility of the part using the given material and the process are also equally important.

In the initial stages of design, the broad material groups such as ferrous or non-ferrous or other non-metallic materials can be considered. At a later stage specific material in the group can be identified.

In certain products or components specific properties of materials such as fatigue strength, thermal conductivity, electrical properties like conductivity, magnetic permeability and insulation resistance may have to be considered.

Material Selection parameters

(*i*) Functional requirements:

The primary function of the part for which the material is selected is the foremost consideration. A good knowledge of the product application is important. The properties of materials which have a direct bearing on the functional requirement of the part are : fatigue characteristics, strength, hardness, electrical and thermal properties.

(*ii*) Reliability:

Reliability of the materials refers to the consistency with which the material will meet all the products requirement throughout its service life. This is important for trouble-free maintenance of the product during its life time.

(*iii*) Service life durability :

The length of service (years or hours of operation of the product) over which material is able to perform its function satisfactorily.

(*iv*) Aesthetics and appearance :

Factors like colour, texture, lusture, smoothness and finish play an important role in the aesthetics or appearance of the final product.

(*v*) Environmental Factors :

Environmental factors such as temperature, humidity, corrosive atmosphere affects the product and its performance. Hence proper materials which can with stand such environmental effects should be selected and they should be given suitable protective coatings.

(*vi*) Compatibility with other materials during service :

When one type of material is used in combination with another type of material in a product or in an assembly the properties of both types of materials should be compatible and should suit each other. Otherwise deterioration in the performance of the product or assembly such as excessive wear & tear, and corrosion of parts in fitment are likely to take place.

(*vii*) Producibility or manufacturability: The extent to which the material can be processed effectively and easily using a particular machine tool or process should also be considered in

the selection of the material. Machinability of materials for machined components is an important factor.

(*viii*) Cost: The cost of material is a significant factor in many situations. The availability of the material is equally important. Appropriate material for the product or component is to be selected taking into consideration all the above factors.

5. **Explain how to develop manufacturing logic and knowledge (8 marks) (AU N/D '15) (or) Write short notes on developing manufacturing logic and knowledge (AU M/J '16) (8 marks)**

   Developing manufacturing logic and knowledge :

   (i) Product : design, (*i.e.*, parts requirements) manufacturing process and materials characteristics all must be considered together in an integrated manner while developing a process plan.
   (ii) Identify the datum surface on the component drawings which will form the basis for measurement and inspection of dimensions.
   (iii) Adequate attention must be paid so that the component is properly located and clamped. The accuracy of the machined part and the time taken depend on these factors. This will also avoid any distortion that might occur on the machined component. Three point support (locating pins) are suitable for positioning large flat surfaces.
   (iv) The no. of settings required to machine a part may be reduced to a minimum. Less no. of settings more is the accuracy of the part machined.
   (v) Frequent tool changing can be reduced to a minimum.
   (vi) Rough machining operations must be carried out first before finish machining operations.
   (vii) Identify critical operations and provide for inspection immediately after critical operations.
   (viii) Use appropriate cutting fluid depending on the severity of the operation, the work material and the tool material used.
   (ix) Use of jigs and fixtures are justified when the production quantity is large.

6. **What are the factors to be considered in machine selection (8 marks) (AU M/J '13)**

   Machine Selection

   Product manufacturing requires tools and machines that can produce economically as well as accurately. Economy depends to a large extent on the proper selection of the machine or process for the job that will give a satisfactory finished product. The selection of the machine is influenced, in turn by the quantity of items to be produced. Usually there is one machine best suited for a certain output.

   In small lot or jobbing type manufacture, general purpose machines such as the lathe, drill press, and milling machine may prove to be the best type since they are adoptable, have lower initial cost, require less maintenance, and possess the flexibility to meet changing conditions in the shop. However, a special purpose machine should be considered when large quantities of a standard product are to be produced. A

machine built for one type of work or operation, such as the grinding of a piston or the machining of a cylinder head, will do the job well, quickly and at a low cost requiring only the service of a semi-skilled operator.

Many of the special-purpose machines or tools differ from the usual standard type in that they have built into them some of the skill of the operator. A simple bolt may be produced on either a lathe or an automatic screw machine. The lathe operator must not only know how to make the bolt but must also be sufficiently skilled to operate the lathe. On the automatic machine the sequence of operations and movements of tools are controlled by cams and stops, and each item produced is identical with the previous one. This "transfer of skill" into the machine makes possible the use of less skillfull operators, but it does requires greater skill in supervision and maintenance. Often it is not economical to make a machine completely automatic, as the cost may become prohibitive.

The selection of the best machine or process for a given product requires knowledge of all possible production methods. Factors that must be considered are:

- Volume of production (Quantity to be produced) *i.e.*, no. of components to be produced.
- Quality of finished product, and
- Advantages and disadvantages of the various types of equipment capable of doing the work.

Too much emphasis cannot be given to the fact that production can be by several methods, but usually there is one way that is most economical.

7. Explain the technological frame work of process planning by using a block diagram. (16 marks) (AU M/J '13)

Process planning

Process planning has been defined as the sub-system responsible for the conversion of design data to work instruction. Process planning can also be defined as the systematic determination of the methods by which a product is to be manufactured economically and competitively. It consists of devising, selecting and specifying processes, machine tools and other equipment to convert raw material into finished and assembled products.

Purpose of Process Planning

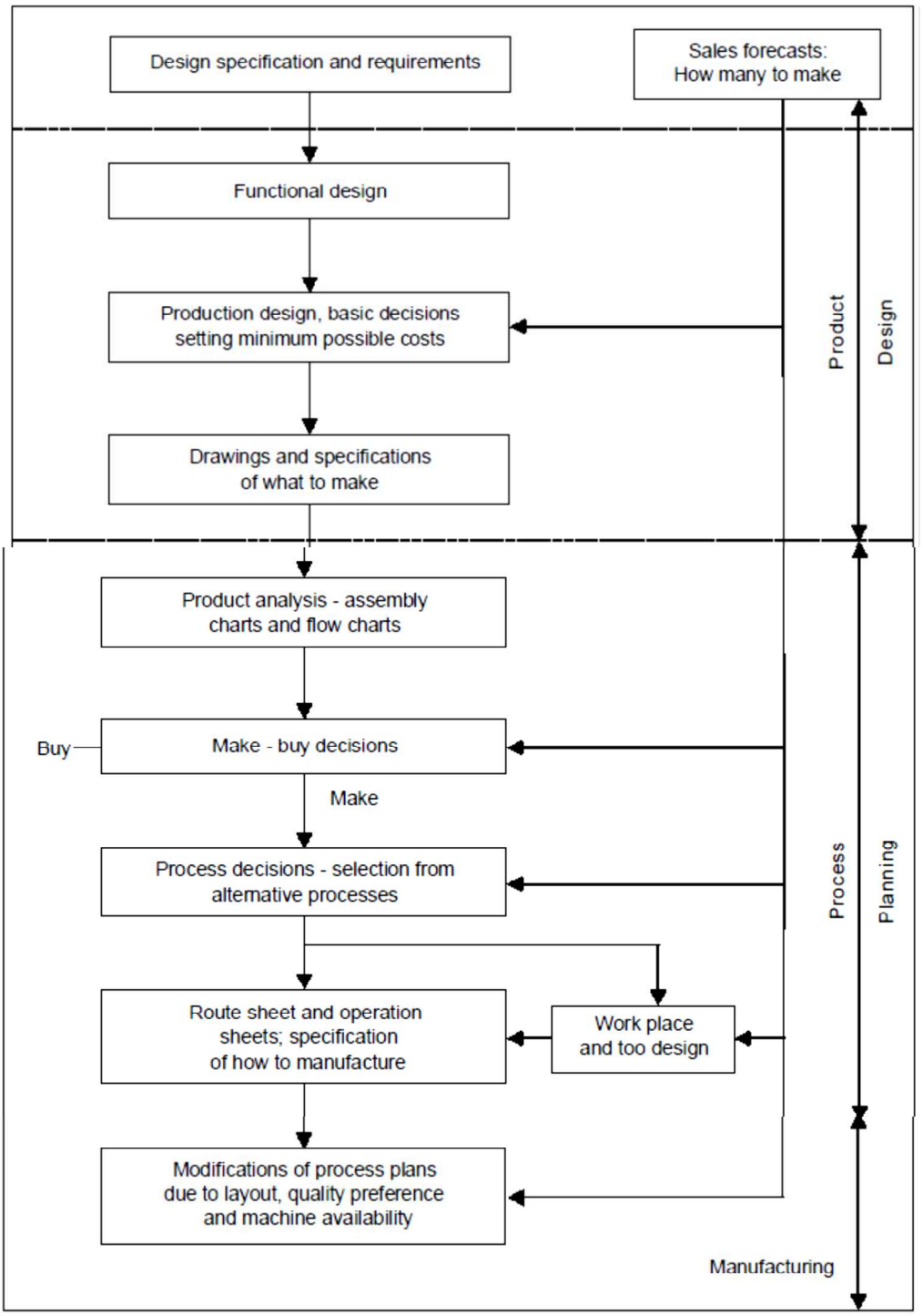
The purpose of process planning is to determine and describe the best process for each job so that,

1. Specific requirements are established for which machines, tools and others equipment can be designed or selected.

2. The efforts of all engaged in manufacturing the product are coordinated.

3. A guide is furnished to show the best way to use the existing or the providing facilities.

Process planning is an intermediate stage between designing the product and manufacturing it (fig).



Where the product design ends, the process planning begins. However, the basic process planning must begin during the product design stages where the selection of materials and initial forms, such as casting, forging and die casting take place. The accepted end point for production design is manifested by the drawing release, which summarizes the exact specifications of what is to be made.

Process planning takes over from this point and develops the broad plan of manufacture for the part of product. Process planning takes as its inputs the drawings

or other specifications which indicate what is to be made and how many are to be made.

The drawings are then analysed to determine the overall scope of the project. If it is a complex assembled product, considerable effort may go into exploding the product into its components and subassemblies.

Preliminary decisions about subassembly groupings to determine which parts to make and which to buy, as well as to determine the general level of tooling expenditure, may be made at this point.

Then, for each part, a detailed routing is developed. Here technical knowledge of processes, machines, and their capabilities is required, but of almost equal importance is knowledge of production economics.

In brief, the engineering drawing of the component is interpreted in terms of the manufacturing process to be used. This step is referred to as process planning and it is concerned with the preparation of a route sheet.

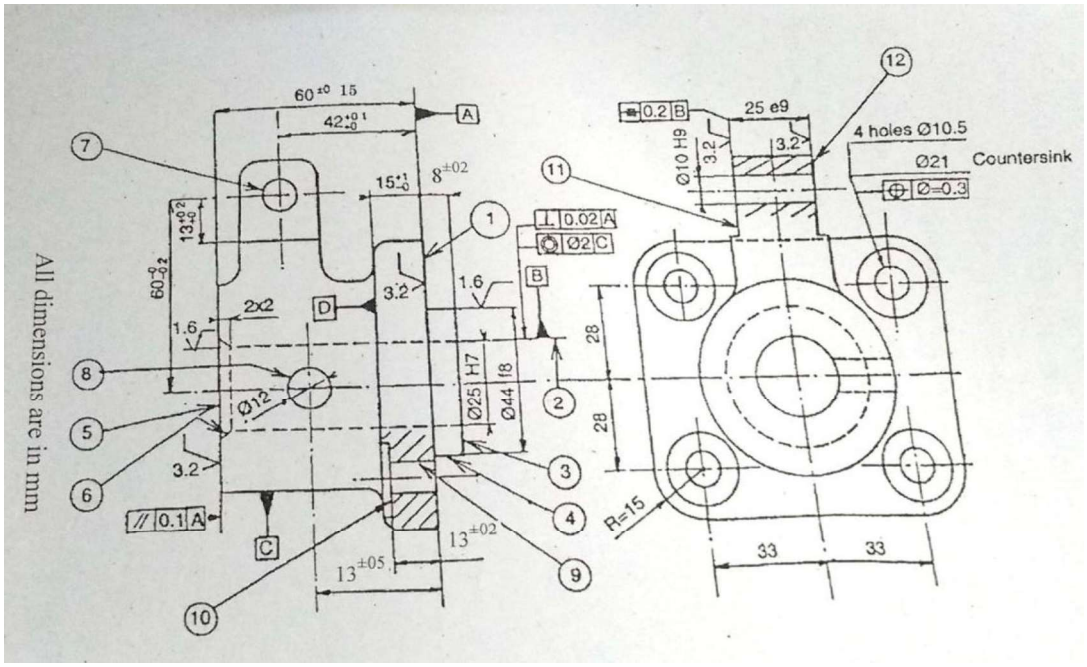
The route sheet is a listing of the sequence of operations which must be performed on the component. It is called a route sheet because it also lists the machines through which the part must be routed in order to accomplish the sequence of operations.

8. In the figure, interpret the meaning of any two

a. Dimensional tolerance symbols (4 marks)

b. Form tolerance feature control frames (8 marks)

c. Surface finish symbols (4 marks) (AU A/M'17)



a. Dimensional tolerance symbols

Parallelism

//	**0.1**	**A**

Position

⊕	Ø = 0.3

Perpendicularity

⊥	0.02	A

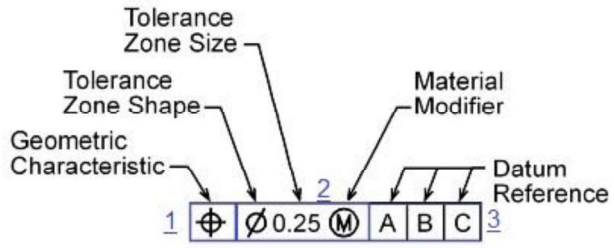
Symmetry

⌯	0.2	B

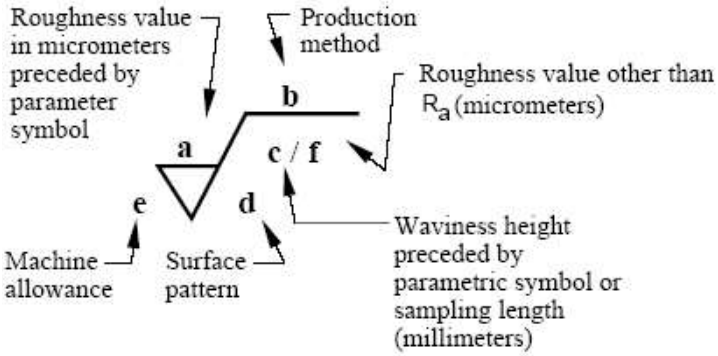
Concentricity

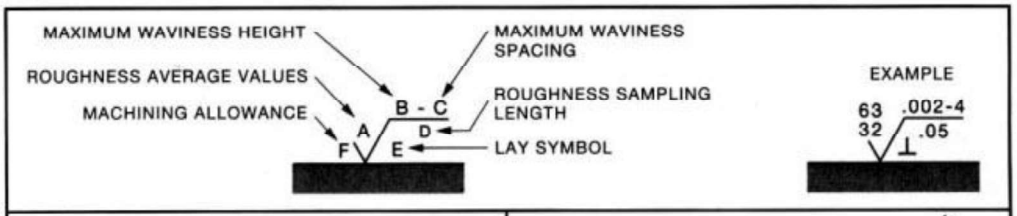
◎	Ø 2	C

b. Form tolerance feature control frame



b. Surface finish symbols





BASIC SURFACE TEXTURE SYMBOL	MAXIMUM WAVINESS SPACING RATING (C). SPECIFY IN INCHES OR MILLIMETERS. HORIZONTAL BAR ADDED TO BASIC SYMBOL. .002-4
ROUGHNESS AVERAGE VALUES (A). SPECIFY IN MICROINCHES, MICROMETERS, OR ROUGHNESS GRADE NUMBERS. 63 N7	LAY SYMBOL (E)
MAXIMUM AND MINIMUM ROUGHNESS AVERAGE VALUES (A), SPECIFY IN MICROINCHES, MICROMETERS, OR ROUGHNESS GRADE NUMBERS. 63 N7 / 32 N6	ROUGHNESS SAMPLING LENGTH OR CUTOFF RATING (D). WHEN NO VALUE IS SHOWN USE .03 INCH (0.8 MILLIMETERS. .05
MAXIMUM WAVINESS HEIGHT RATING (B) SPECIFY IN INCHES OR MILLIMETERS. HORIZONTAL BAR ADDED TO BASIC SYMBOL. .002	MACHINING ALLOWANCE (F). SPECIFY IN INCHES OR MILLIMETERS. .06

NOTE: WAVINESS IS NOT USED IN ISO STANDARDS.

Unit -2 Process Planning Activities

Part A

11. What is activity based costing? (AU A/M '18)

Activity-based costing (ABC) is a costing methodology that identifies activities in an organization and assigns the cost of each activity with resources to all products and services according to the actual consumption by each. This model assigns more indirect costs (overhead) into direct costs compared to conventional costing.

12. What are the main reasons for using jigs and fixtures? (AU N/D '17)

The main purpose of any work holding device is to position and hold a work piece in a precise location while manufacturing operation is being performed

13. What are the most influential factors in terms of tool performance? (AU N/D '17)

Factors affecting tool performance

- Cutting tool materials
- Cutting tool geometry
- Cutting fluids

14. What are the factors to be considered during the selection of a process? (AU N/D '16)

- Quality of work to be completed
- Availability of equipments, tools and personnels
- Sequence in which operations will be performed on the raw material
- Standard time for each operation

15. Enumerate the documents required for process planning (AU N/D '15) (AU N/D '12) (AU M/J '13)

- Product design and the engineering drawings pertaining to all the components of the product.
- Machining/Machinability Data Handbook
- Catalogues of various cutting tools and tool inserts.
- Specifications of various machine tools available in the shop/catalogues of machine tools in the shop
- Sizes of standard materials commercially available in the market.
- Machine Hr. cost of all equipment available in the shop.
- Design Data Handbook.
- Charts of Limits, Fits & Tolerances.
- Tables showing tolerances and surface finish obtainable for different machining processes.
- Tables of standard cost.
- Table of allowances (such as Personal Allowance, Fatigue Allowance etc. in % of standard time followed by the company).

16. State the parameters involved in material selection (AU N/D '14) (AU M/J '16)

(*i*) Functional requirements

(*ii*) Reliability

(*iii*) Service life durability
(*iv*) Aesthetics and appearance
(*v*) Environmental Factors
(*vi*) Compatibility with other materials during service
(*vii*) Producibility or manufacturability
(*viii*) Cost

17. What are the activities associated with process planning? (AU M/J '12)

- Analyse the part requirements
- Determine operation sequence
- Select the equipment
- Calculate processing times
- Select inspection methods
- Estimate manufacturing cost
- Document process plan
- Communicate to manufacturing engineer

18. State the procedure to select cost optimal process (AU N/D'11)

- Break even point
- Break even chart
- Break even analysis

19. What is the difference between routing sheet and operations list? (AU A/M'17)

A route sheet determines the sequence or order of arrangement of various departments in a facility. Thus, a route sheet is a document which has information and data inputs and a step wise listing of all the processes or transactions performed. It also contains details such as date and time, remarks, log in/out, point of contact etc.

It is a list of operations has to be performed in a process without sequence.

20. What is the relation between tolerance and surface finish? (AU A/M'17)

Components must fit together and function properly in a predicted dimension is defined as tolerance, whereas surface finish is the depth of irregularities and vertical deviations of a surface resulting from the manufacturing process used to produce it.

21. What is the purpose of a work holding device?

The main purpose of any work holding device is to position and hold a work piece in a precise location while the manufacturing operation is being performed.

22. List the types of work holding devices.

- General work holding devices
  - Vices
  - Clamps
  - Mandrels
  - Chucks
- Specialist work holding devices
  - Jigs
  - Fixtures

23. What is meant by Statistical Quality Control (SQC)?

SQC is about employing inspection methodologies derived from statistical sampling theory to ensure conformance to requirements

24. List seven statistical tools of quality that are used in quality control

(i) Flowchart
(ii) Cause and effect diagram
(iii) Check sheet
(iv) Scatter diagram
(v) Histogram
(vi) Control chart
(vii) Pareto diagram

25. What is meant by break even analysis (BEA)?

BEA also known as cost volume profit analysis is the study of inter-relationships among a firms sales, costs and operating profit at various levels of output.

Part – B

1. Describe the basic method employed for the selection of cutting tools. (AU N/D '17)

(i) ***Evaluation of process and machine selections-*** Provided the selection of processes and machines is satisfactory, the range of tools that can be used should be limited to those suitable for the processes and machines selected. Therefore, this limits the initial list of possible suitable tooling.

(ii) ***Analysis of machining operations-*** A specific machine will carry out every operation required. Each machine tool to be used will have specific tool types to carry out certain operations. Therefore, this analysis should enable the identification of specific tool types for specific operations.

(iii) ***Analysis of workpiece characteristics -*** The focus of the workpiece analysis is on the workpiece material and geometry and the capability in terms of dimensional and geometric accuracy and surface finish. The analysis of the first two characteristics enables suitable tool materials and geometry (in terms of size and shape) to be identified. The third characteristic allows the tool type and geometry to be refined further to suit the operations.

(iv) ***Tooling analysis***- Using the tooling data available, the general tooling specifications generated at the third stage can be translated into a statement of tooling requirements for the job, that is, a tooling list. This will obviously reflect whatever tooling is actually available for the operations required.

(v) ***Selection of tooling*** - There are two routes that the tool selection can take at this point. If single-piece tooling is being used, then a suitable toolholder should be selected before fully defining the tool geometry and material. However, if insert-type tooling is being used then the following steps should be followed:

i. select clamping system;
ii. select toolholder type and size;
iii. select insert shape;
iv. select insert size;
v. determine tool edge radius;
vi. select insert type;

vii. select tool material.

Once all of the above is completed, the machining parameters can be calculated. These will be the speeds, feeds and machining times for each operation. All of the above factors will have a significant influence on the determination of these parameters.

2. **Explain the process planning procedure and List out the information required for process planning. (16 marks) (AU N/D '16) (AU M/J '13) (or)**

What are the Set of documents required for process planning? (16 marks) (AU N/D '17) (10 marks) (AU N/D '13) (or)

Explain the steps involved in process planning. (16 marks) (AU N/D '17) (8 marks) (AU N/D '13)(AU M/J '12)

Set of documents required for process planning

(i) Product design and the engineering drawings pertaining to all the components of the product. (*i.e.,* components drawings, specifications and a bill of materials that defines how many of each component go into the product).
(ii) Machining/Machinability Data Handbook (Tables of cutting speeds, depth of cut, feeds for different processes and for different work materials).
(iii) Catalogues of various cutting tools and tool inserts.
(iv) Specifications of various machine tools available in the shop/catalogues of machine tools in the shop (speeds, feeds, capacity/power rating of motors, spindle size, table sizes etc.).
(v) Sizes of standard materials commercially available in the market.
(vi) Machine Hr. cost of all equipment available in the shop.
(vii) Design Data Handbook.
(viii) Charts of Limits, Fits & Tolerances.
(ix) Tables showing tolerances and surface finish obtainable for different machining processes.
(x) Tables of standard cost.
(xi) Table of allowances (such as Personal Allowance, Fatigue Allowance etc. in % of standard time followed by the company).
(xii) Process plans of certain standard components such as shafts, bushings, flanges etc.
(xiii) Handbooks (such as Tool Engineers Handbook, Design Data Handbook).

Steps in process planning

(i) Required operations must be determined by examining the design data and employing basic machining data such as :
(a) Holes can be made conveniently on drilling machines.
(b) Flat surfaces can be machined easily on milling machines.
(c) Cylindrical parts can be made using lathe. Design data can be obtained from the part-drawing or from the finished part design file from the CAD system.

(ii) The machines required for each operation must be determined. This selection depends on knowledge of machine factors, such as availability of the machine, specifications of machine tools available in the shop, accuracy grade of the m/c, table size, spindle size, speed and feed ranges available, torque, power, machining rate and other size limitations.

(iii) The required tools for each identified machine or process must be determined. For selection of specialized tools knowledge and prior experience of process planner will be useful.

(iv) The optimum cutting parameters for each selected tool must be determined. These parameters include cutting speed, feed rate, depth of cut, and type of coolant/lubricant to be used. This determination depends on design data, such as work material, tool material, surface finish specifications and behaviour of cutting tool. Again expertise knowledge and prior experience of process planner and methods engineer will be useful in this regard. Machining data handbooks can also be referred.

(v) Finally an optimum combination of these machining processes must be determined. The best process plan is the one which minimizes manufacturing time and cost. This provides a detailed plan for the economical manufacturing of the part.

(vi) The results of each of these five basic steps can be seen in the final form of the process plan

3. What are the factors that influence process planning? Discuss (8 marks) (AU N/D '12) (AU M/J '12) (or)
Explain the steps in process selection with suitable example (16 marks) (AU N/D '17)

Practices of Process Planning

The practices of process planning vary widely in modern industry, depending on such factors as :

- Type of product
- The equipment available, and
- The volume of production (*i.e.,* production quantity)

The individual responsible for carrying out process planning / process analysis is the Process Engineer also known as process planner, process analyst or methods engineer. To be effective on his or her job, the process analyst must be familiar with material characteristics and manufacturing processes. Knowledge of the nature, types, and properties of standard materials and new materials will assist the process analyst in selecting the most appropriate process, equipment and methods for manufacturing a particular product. The process analyst must also be familiar with engineering drawings and product design. Drawings provide the part configuration and the dimensional tolerances and specifications that need to be met by the manufacturing process selected

In addition, the process planner must be familiar with the operating characteristics and costs of the production and tooling equipment, either available in the plant or to be purchased.

Process Planning starts with a careful examination of the drawing or design of the part. The process planner must be able to analyze the engineering drawing and visualize the three dimensional part configuration. The part configuration must then be analyzed to determine its basic geometric components. Identifying these basic geometric elements assists the process planner in selecting the most appropriate process to manufacture the product.

Process Selection

Consideration should be given to the following factors in selecting a particular process

(a) Nature of part, including materials, tolerances, desired surface finish and operation required.
(b) Method of fabrication including machining or assembling of similar parts or components.
(c) Limitation of facilities including the plant and equipment available.
(d) Possibility of likely product design changes to facilitate manufacturability or cost reduction.
(e) In-plant and outside materials handling systems.
(f) Inherent process to produce specified shape, surface, finish to give desired mechanical properties.
(g) Available skill level of operators for the production. Sometimes the following additional factors affect the selection of a particular process.
(a) Proposed or anticipated production requirements, including volume requirements, production rates and short- term or long- term production runs.
(b) Total end-product costs.
(c) Time available for tooling-up.
(d) Materials receipt, storage, handling and transportation. Careful consideration of these factors will result in the selection of the most appropriate process for the manufacture of a particular product. Selection of an appropriate manufacturing process depends on many factors and requires considerable knowledge, skill and competence of the process planner or process analyst.

Machine Selection

Product manufacturing requires tools and machines that can produce economically as well as accurately. Economy depends to a large extent on the proper selection of the machine or process for the job that will give a satisfactory finished product. The selection of the machine is influenced, in turn by the quantity of items to be produced. Usually there is one machine best suited for a certain output.

In small lot or jobbing type manufacture, general purpose machines such as the lathe, drill press, and milling machine may prove to be the best type since they are

adoptable, have lower initial cost, require less maintenance, and possess the flexibility to meet changing conditions in the shop. However, a special purpose machine should be considered when large quantities of a standard product are to be produced. A machine built for one type of work or operation, such as the grinding of a piston or the machining of a cylinder head, will do the job well, quickly and at a low cost requiring only the service of a semi-skilled operator.

Many of the special-purpose machines or tools differ from the usual standard type in that they have built into them some of the skill of the operator. A simple bolt may be produced on either a lathe or an automatic screw machine. The lathe operator must not only know how to make the bolt but must also be sufficiently skilled to operate the lathe. On the automatic machine the sequence of operations and movements of tools are controlled by cams and stops, and each item produced is identical with the previous one. This "transfer of skill" into the machine makes possible the use of less skillfull operators, but it does requires greater skill in supervision and maintenance. Often it is not economical to make a machine completely automatic, as the cost may become prohibitive.

The selection of the best machine or process for a given product requires knowledge of all possible production methods. Factors that must be considered are:

- Volume of production (Quantity to be produced) *i.e.*, no. of components to be produced.
- Quality of finished product, and
- Advantages and disadvantages of the various types of equipment capable of doing the work.

Too much emphasis cannot be given to the fact that production can be by several methods, but usually there is one way that is most economical.

Material selection

Material selection is done by the product designer considering the requirements of the parts designed and the hardness, strength properties and other mechanical characteristics of the material. Cost and availability of the material are also considered. Material should be strong enough and at the same time manufacturing or producibility of the part using the given material and the process are also equally important.

In the initial stages of design, the broad material groups such as ferrous or non-ferrous or other non-metallic materials can be considered. At a later stage specific material in the group can be identified.

In certain products or components specific properties of materials such as fatigue strength, thermal conductivity, electrical properties like conductivity, magnetic permeability and insulation resistance may have to be considered.

Material Selection parameters

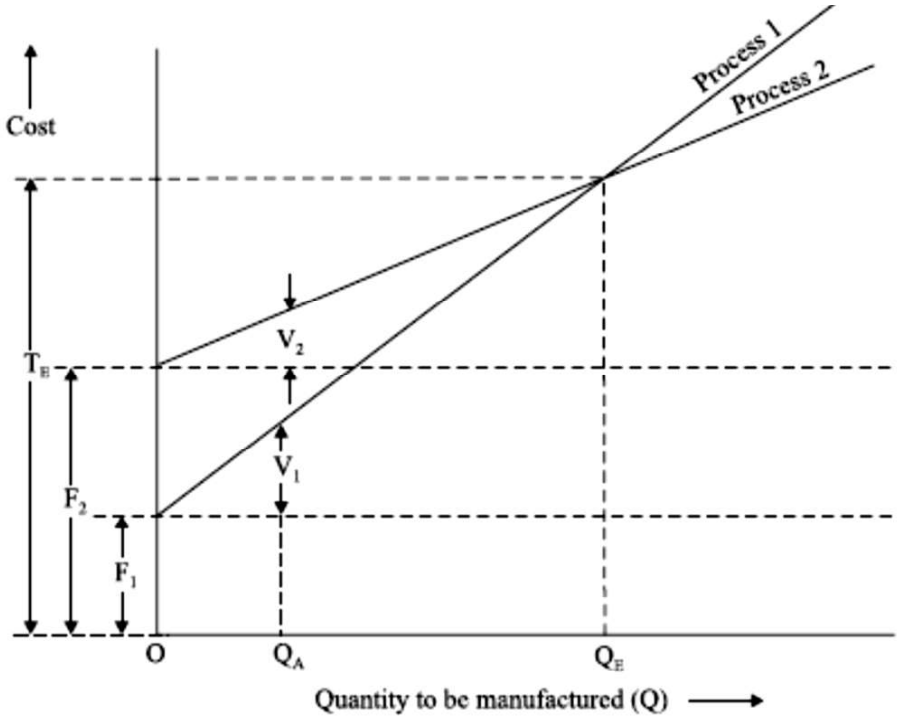
- Functional requirements
- Reliability

- Service life durability
- Aesthetics and appearance
- Environmental Factors
- Compatibility with other materials during service
- Producibility or manufacturability
- Cost

4. **Write notes on selection of cost for optimal processes. (or) write notes on economics of process planning (8 marks) (AU M/J '16) (AU A/M '18)**

Two different types of processes can be used for the same job. The processes can be compared and optimum process selected with the help of break-even charts.

Break-even charts: Break-even charts give the production engineer a powerful tool by which feasible alternative processes can be compared and the process which gives minimum cost can be selected. The fixed and variable costs for two alternative processes are plotted on a graph to a suitable scale as shown in Fig.



F_1 = Fixed costs for process (1)
F_2 = Fixed costs for process (2)
V_1 = Variable costs for process (1)
V_2 = Variable costs for process (2)
Q_E = Break-even quantity at quantity Q_A
T_E = Total costs of manufacture at quantity Q_E

For each process generally the variable cost is a linear function of the quantity manufactured. Therefore, once the fixed costs have been plotted, only one value for the variable costs is required at some value Q_A and the total cost lines can be drawn. Where these lines intersect is known as the break-even point, *i.e.*, the point where the total cost of manufacture of quantity Q_E is same for both process (1) and process (2). The break-even chart tells us to :

Use process (1) if the quantity to be manufactured $\leq Q_E$

Use process (2) if the quantity to be manufactured $\geq Q_E$

The value of QE can be scaled directly from the chart with sufficient accuracy, although it can also easily be calculated.

5. A component can be produced with equal ease on either a capstan lathe or on a single spindle cam operated automatic lathe. Find the break-even quantity Q_E if the following information is known. (8 marks) (AU N/D '15)

		Capstan Lathe	*Automatic Lathe*
(*a*)	Tooling cost	Rs. 30.00	Rs. 30.00
(*b*)	Cost of cams	—	Rs. 150.00
(*c*)	Material cost/Component	Rs. 0.25	Rs. 0.25
(*d*)	Operating labour cost	Rs. 2.50/hour	Rs. 1.00/hour
(*e*)	Cycle time/Component	5 minutes	1 minute
(*f*)	Setting up labour cost	Rs. 4.00/hour	Rs. 4.00/hour
(*g*)	Setting up time	1 hour	8 hours
(*h*)	Machine overheads (setting and operating)	300 % of (d)	1000 % of (d)

Capstan lathe :

$$\text{Overheads} = \frac{300}{100} \times 2.50 = \text{Rs. } 7.50/\text{hour}$$

$$\text{Fixed Costs} = \text{tooling cost} + \text{setting-up cost}$$
$$= 30.00 + 1(4.00 + 7.50)$$
$$= 30.00 + 11.50 = \text{Rs. } 41.50$$
$$= \text{Rs. } 42$$

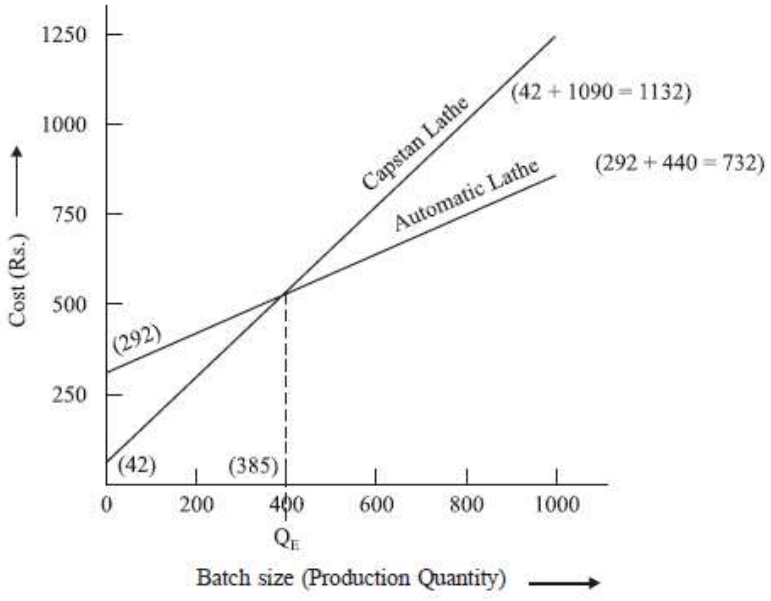
$$\text{Variable costs/Component} = \left(2.50 \times \frac{5}{60}\right) + 0.25 + \left(7.50 \times \frac{5}{60}\right)$$
$$= 0.21 + 0.25 + 0.63 = \text{Rs. } 1.09$$

$$\text{Variable costs/1000 components} = \text{Rs. } 1090.00$$

Automatic lathe :

$$\text{Overheads} = \frac{1000}{100} \times 1.00 = \text{Rs. } 10.00/\text{h}$$

$$\text{Fixed costs} = \text{tooling cost} + \text{cam cost} + \text{setting-up cost}$$



$= 30.00 + 150.00 + 8\ (4.00 + 10.00\ )$
$= 180.00 + 112.00$
$=$ Rs. 292.00

$$\text{Variable costs/Component} = \left(1.00 \times \frac{1}{60}\right) + 0.25 + \left(10.00 \times \frac{1}{60}\right)$$

$= 0.02 + 0.25 + 0.17$
$=$ Rs. 0.44

Variable costs/1000 components = Rs. 440.00.

These costs can now be plotted on a break-even chat (Fig.) to find the value of Q_E. Q_E is scaled from the break-even chart (Fig.) and found to be 385. If the batch size to be manufactured is equal to or less than 385 use the capstan lathe.

If the batch size to be manufactured is equal to or greater than 385 use the automatic lathe. The above is the graphical method of determining Break-even Quantity.

6. What is Inspection? Write briefly about the different methods of inspections followed in industries. (AU A/M'17)

Inspection is the function by which the product quality is maintained

The objectives of the Inspection are
(i) To sort out confirm and non-conforming product
(ii) To initiate means to determine variations during manufacture
(iii)To provide means to discover inefficiency during manufacture

Stages of Inspection

Inspection of incoming materials

It consists of inspecting and checking all the purchased raw materials and parts that are supplied before they are taken on to stock or used in actual manufacturing.

This inspection performed either at supplier's place or at manufacturer dispatch or gate.

Inspection of production process

The inspection is done in parallel while the production is in processing. Inspection can be done at different work centers and at the critical production points.

This has the advantages of minimize the wastage of time and money on defective units and preventing delays in assembly.

Inspection of finished goods

This is the last stage when finished goods are inspected and carried out before marketing to see that quality may be either rejected or sold at reduced price.

Methods of inspection

There are two methods of inspection. They are:
i) 100% inspection, and

ii) Sampling inspection,

A. **100% inspection**

100% or cent percent inspection is quite common when the number of parts to be inspection is relatively small.

Here every part is examined as per the specification or standard established and acceptance or rejection of the part depend on the examination.

B. **Sampling inspection**

The use of sampling inspection is made when it is not practical or too costly to inspect each piece. A random sample from a batch is inspected and the batch is accepted if the sample is satisfactory. If the sample is not to the desired specification then either entire batch may be inspected piece by piece or rejected as a whole.

Statistical methods are employed to determine the portion of total quality of batch which will serve as reliable sample.

Types of inspection

Inspection can be classified according to the type of data involved as:

1. Inspection of variable, and
2. Inspection of attributes.

All qualitative characteristics are know as attributes. All characteristics that can be quantified and measurable are known as variables.

Attributes	Variables
• Number of defective pieces found in a sample. • Percentage of accurate invoices. • Weekly number of accidents in a factory. • Number of complaints. • Mistakes per week. • Monthly number of tools rejected. • Errors per thousand lines of code • Percentage of absenteeism.	• Dimension of a measured. • Temperature during heat treatment. • Tensile strength of steel bar. • Hours per week correcting documents. • Time to process travel expense accounts. • Days from order receipt to shipment. • Cost of engineering changes per month. • Time between system crashes. • Cost of rush shipment.

Measurement instruments

The selection of appropriate measurement instrument to be employed is basically depends on the type of quality characteristic of the component considered.

Measurement: The different types of quality characteristics that are to be measured are:

(i) Dimensions/size,

(ii) Physical properties,

(iii)Functionality, and

(iv)Appearance.

7. Discuss about factors to be considered in the selection of jigs and fixtures for cost reduction (8 Marks) (AU A/M '18)

Function of work holders

The main purpose of any Work holding device is to position and hold a workpiece in a precise location while the manufacturing operation is being performed. In order to perform this function adequately, all work holders consist of four basic elements:

Locating elements - that allow the work piece to be positioned correctly

Structural elements- that can withstand the forces applied during the manufacturing operation.

Clamping elements - that can withstand the forces applied during the manufacturing operation and maintain the position of the work piece.

Fixing elements - that attach the work holder to the machine; There are many devices that adhere to the above definition that can be classified as general work holding devices as opposed to specialist work holding devices, that is, jigs and fixtures. General work holding devices can be classified as:

- Vices
- Clamps and abutments
- Chucks
- Collets
- Centers
- Mandrels
- Face plates

The entire above are sometimes referred to as low-cost jigs and fixtures.

Use of jigs and fixtures

For many machining and assembly operations, general-purpose work holding devices may not be sufficient. In these instances, these special work holding requirements are generally satisfied by designing and building special-purpose work holding devices known as jigs and fixtures. The design of special jigs, fixtures and tools is considered as one of three essential activities for facilitating interchangeable manufacture, along with process planning and the design of suitable limit gauges and gauging equipment. Consequently, the main reasons for the use of jigs and fixtures are:

- Components can be produced quicker;
- Greater interchangeability is obtained due to repeatability of manufacture which subsequently reduces assembly time;
- Accuracy can be easily obtained and maintained;
- Unskilled or semi-skilled labour may be used on a machine, resulting in reduced manufacturing costs.

Jigs:

A jig is a work holding device. However, jigs have a further important function and that is determining the location dimensions of specific features. In order to fully understand this function, the distinction between location and size dimensions must be defined. Strictly speaking, not all jigs provide guidance for tools. This is because in many

assembly processes, such as welding, the jig merely holds the parts together in the correct orientation with respect to each other while the tool carries out the joining process.

However, in the case of jigs being used with machining processes, they generally always provide guidance for the cutting tool. In summary, a jig is a specially designed and built work holding device, usually made of metal, and performs three basic functions

- holding the component;
- providing guidance for the cutting tools to determine the location dimension for the machining of a feature;
- Positively locating the component so that subsequent components are machined in the same manner.

Jigs can usually be generally classified as either drilling jigs or boring jigs and are used for operations such as drilling, reaming, tapping, chamfering, counterboring, countersinking and boring operations.

Fixture:

A fixture is similar to a jig and can be defined as a special-purpose workholding device used during machining or assembly. However, fixtures are generally of heavier construction than jigs and also usually fixed to the machine table. The main function of a fixture is to positively locate the workpiece. However, unlike a jig, no guidance is provided for cutting tools. Fixtures are used in a variety of processes including milling, broaching, planing, grinding and turning.

8. Explain the importance of selection of the right quality assurance method during manufacturing. (13 marks) (AU A/M '18)

All manufacturing organizations have the common goal of making a profit. The basic model of added value previously presented focuses on the main input of materials undergoing some transformation process and value being added to that material. A profit is made if the value added is greater than the cost to process the material. However, a profit will only be made if the customer is satisfied with the product. In the globally competitive market, this is where the factor of product quality is seen to be important.

The transformation processes mentioned above in this instance are obviously manufacturing processes. However, all manufacturing processes have some degree of inherent variability, even highly automated processes such as CNC milling. Therefore, steps must be taken to ensure that the product specification is adhered to in spite of this variability. The starting point for this is the establishment of the capability of the processes being used.

However, except in the case of the introduction of new processes, the capability of available processes should be known. These data should be documented and available to the process planner if required.

Based on the capability of the process being employed, the process planner will determine which are the most appropriate quality assurance (QA) tools and techniques to employ. These will range from basic measurement tools such as callipers, micrometers and gauges to the use of coordinate measuring machines (CMMs). Also covered will be the application of statistical process control (SPC) methods. Although SPC and process capability studies will most probably be designed and carried out by quality engineering, it is essential that the process planner has an understanding of these in order to enter into meaningful dialogue with regards to process capability. In fact, the process planner will

have to liaise closely with the quality function on a number of issues with regards to the process plan. These include:

- identifying inspection locations;
- identifying appropriate inspection and testing methods;
- the frequency of inspection and testing;
- evaluation of inspection and test data;
- Identifying corrective action where appropriate.

All of the above will influence the processes, equipment, tools and manufacturing parameters to be used for a given job, particularly in the case where corrective action involves changing any of these. Therefore, the process planner requires a knowledge and understanding of all of these aspects of product quality.

9. Explain the factors to be considered in selection of process parameters (13 marks) (AU A/M '18)

The three Process parameters to be calculated for each operation during process planning are

- Cutting Speed
- Feed Rate
- Depth of Cut

Cutting Speed:

Cutting speed is known as surface cutting speed or surface speed, can be defined as Relative speed between the tool and the work piece

Unit: meteres per minute

Factors affecting the selection of cutting speed

- Nature of the cut
  - Continuous cut like turning, boring are done at higher cutting speed
  - Shock initiated cuts in shaping, planning, slotting machine are done at lower cutting speed.
  - Intermittent cuts as in milling, hobbing are done at quite lower speed for dynamic loading
- Work material
  - Harder and stronger materials are machined at lower cutting speed
  - Soft, non-sticky materials can be machined at higher cutting speed
- Cutting tool material
- Cutting fluid application
- Purpose of machining
  - Rough machining (lower cutting speed)
  - Finish machining (higher cutting speed)
- Kind of machining operation
- Capacity of machine tool
- Condition of machine tool

Feed and feed rate

Feed is the distance through which the tool advances into the work piece during one revolution of the workpiece or the cutter

Feed rate is the speed at which the cutting tool penetrates the work piece

Unit: millimeters per minute

Factors affecting feed rate:

- Nature of the cut
- Work material
- Cutting tool material
- Cutting fluid application
- Purpose of machining
- Kind of machining operation
- Capacity of machine tool

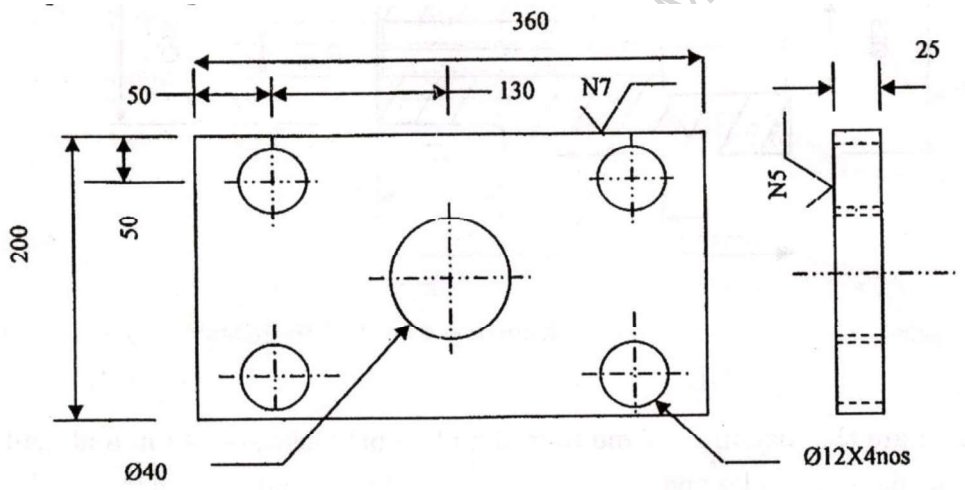
Depth of cut:

Depth of cut is the thickness of the layer of metal removed in one cut or pass, measured in a direction perpendicular to the machined surface

Unit : millimeter

The feed and depth of cut for a particular operation depend on the material to be machined, surface finish required and tool used.

10. Prepare the operation and route sheet for the component shown in fig (15 marks) (AU A/M '18)



Solution

Operation Sheet:

Comp Procedure	**A.R.C**	**Inc: Part Name Drill Plate**			**Prepared by**		
		Drilling Part No :18			**Date**		
Operation No.	*Operation Description*	*Machine Type*	*Tool*	*Dept*	*Set up Time (m)*	*Operation Time (min)*	*Material /Part*
01	Cutting	Cutter	Cutting Wheel	Machine Shop	30	20	Steel Plate
02	Surface Grinding	Grinder	Grinding Wheel	Machine Shop	15	30	Steel Plate
03	Drilling 4 Nos	Drilling Machine	Drill tool -12mm	Machine Shop	15	20	Steel Plate
04	Drilling	Drilling Machine	Drill tool -40 mm	Machine Shop	15	20	Steel Plate

Rout Sheet

Routing sheet		
Part name	Part no	Drg no
Quantity	Material	Planner
Date	Page 1 of 1	Order no
Operation no	Description	Machine tool
01	Cut off 200x360 mm bar to 25 mm thick	Hor. Bandsaw
02	Drill 40 mm dia.	Drill press no 1
03	Drill 12 mm dia x 4 nos	Drill press no 2
04	Surface Grind 5 micro meter	Grinding machine no 1

Unit – 3 Introduction to Cost Estimation

Part – A

1. **Classify the allowances considered in cost estimation (AU N/D '17)**
   - Relaxation Allowance
     - Fatigue allowance
     - Personal need allowance
   - Process allowance
   - Interference allowance
   - Contingency allowance
   - Special allowance
2. **What do you meant by cost accounting? (AU N/D '16) (AU N/D '15) (AU N/D '13) (AU N/D '12) (AU M/J '13)**

   Costing may be defined as a system of accounts which systematically and accurately records every expenditure in order to determine the cost of a product after knowing the different expenses incurred in various department.
3. **Define overhead cost. (AU N/D '16) (AU N/D '14) (AU M/J '12)**

   Overhead is the sum of indirect labour cost, indirect material cost and other expenses including service which cannot be conveniently charged to specific cost unit. These can be further classified as
   - Production expenses/Factory expenses.
   - Administrative expenses.
   - Selling expenses.
   - Distribution expenses.
4. **Distinguish between cost estimation and cost accounting (AU N/D '15) (AU A/M '17) (AU N/D '17)**

S.No	Point of comparison	Cost estimating	Cost accounting
1.	Type of cost	It gives an expected cost of the product based on the calculations by means of standard formulae or certain established rules.	It gives actual cost of the product cost based on the data collected from the different expenditures actually done

5. **List the types of estimates (AU N/D '15)**
   - Guesstimates
   - Budgetary
   - Using Past History
   - Estimating in Some Detail
   - Estimating in Complete Detail
   - Parametric Estimating
   - Project Estimating
6. **What are the sources of for cost estimation? (AU N/D '15)**
   - Cost of design.
   - Cost of drafting.

- Cost of research and development.
- Cost of raw materials.
- Cost of labour.
- Cost of inspection.
- Cost of tools, jigs and fixtures.
- Overhead cost.

7. Brief about the procedure to calculate material cost (AU N/D '15)

- Study the drawing carefully and break up the component into simple geometrical shapes. (Cubes, prisms, cylinders, etc.)
- Add the necessary machining allowances on all sides which are to be machined.
- Determine the volume of each part by applying the formulae of mensuration.
- Add the volumes of all the simple components to get total volume of the product.
- Multiply the total volume of the product by the density of the material to get the weight of the material.
- Find out the cost of the material by multiplying the cost per unit weight to the total weight of the material.

8. Define: Under estimate (AU N/D '14)

The estimated cost is below the actual cost of product, then the firm will face huge financial loss which may cause utter failure or closure of the firm. This estimation is called under estimate.

9. Define: Contingency Allowance (AU N/D '14)

Contingency Allowance: This is a small allowance of time which may be included in the standard time to meet unforeseen items of work, or delays (*e.g.* waiting for raw materials, tools). Contingency allowance is 5% (maximum) or Normal Time.

10. What is meant by conceptual cost estimating? (AU N/D '14)

In the conceptual design stage, the geometry of parts and materials has not been specified, unless they dictate essential product functions. In the conceptual design stage, the costs associated with a change in the design are low. In the conceptual design stage, the incurred costs are only 5 to 7% of the total cost whereas the committed costs are 75 to 85% of the total cost.

The accuracy of the conceptual cost estimate depends on the accuracy of the data base. The accuracy of conceptual cost estimating is approximately – 30% to + 50%. Accuracy in conceptual cost estimating is important since at the conceptual design stage only significant cost savings can occur.

11. List the elements of prime cost (AU N/D '13)

Prime cost = Direct material cost + Direct labour cost + Direct expenses

12. What is the need to include allowances in cost estimation? (AU N/D '13)

A worker cannot work for 8 hours continuously without rest. Also efficiency decreases as the time passes due to fatigue etc. He also requires for tool sharpening, checking measurements and personal calls. All these allowances come under this category. These allowances generally consumes 15 to 20% of total time.

13. Give the methods of costing. (AU N/D '13)

- Process costing.
- Job costing.

- Batch costing.
- Hybrid costing systems.

14. List the various elements of cost. (AU M/J '16) (AU A/M '18)

- Material cost,
- Labour cost and
- Other expenses

15. What shall be the effect of overestimate (AU M/J '16)

If a job is over estimated, i.e the estimated cost is much more than the actual cost of the product, then the firm will not be able to compete with its competitors who estimated the price correctly and losses the order to its competitors.

16. Mention any two functions of estimating. (AU M/J '16) (AU M/J '13) (AU M/J '12)

- To calculate the cost of new material needed to manufacture a product.
- To find the cost of parts to be purchased from outside vendors.
- To find the cost of equipment, machinery, tools, jigs and fixtures etc. required to be purchased to make the product.
- To calculate the direct and indirect labour cost associated with the manufacture of the product, based upon work study.
- To calculate various overhead charges associated with the product.
- To decide about the profit to be charged, taking into consideration other manufacturers of same product in the market.
- To calculate the selling price of the product.
- To maintain records of previous estimating activities of the company for future references.
- To decide the most economical method of making the product.
- To submit cost estimates with the competent authority for further action.

17. Differentiate direct and indirect overheads. (AU M/J '16)

Direct expenses: Direct expenses include all that expenditure which can be directly allocated and charged to a particular job. The direct expenses include cost of special jigs or fixtures, patterns, tooling made for job, or cost of research and development work done for that specific job.

Indirect expenses: Except direct expenses, all other indirect expenditure incurred by the manufacturer is called indirect expenses. The indirect expenses are also called overhead expenses or on-cost.

The indirect expenses are further classified as:

(i) Factory expenses.
(ii) Administrative expenses.
(iii) Selling and distribution expenses.

18. What is meant by direct material? Give example. (AU M/J '13) (AU M/J '12)

It is the cost of those materials which are directly used for the manufacture of the product and become a part of the finished product. This expenditure can be directly allocated and charged to the manufacture of a specific product or job and includes the scrap and waste that has been cut away from original bar or casting.

19. What is meant by direct labour cost? (AU M/J '13) (AU M/J '12)

Direct labourer is one who actually works and processes the materials to convert it into the final shape. The cost associated with direct labour is called direct labour cost. The direct labour cost can be identified and allocated to the manufacture of a specific product. Examples of the direct labour are the workers operating lathes, milling machines or welders, or assemblers in assembly shop. The direct labour cost may be allocated to a product or job on the basis of time spent by a worker on a job.

20. What is fatigue allowance? (AU M/J '13)

The efficiency of the worker decreases due to fatigue (or) working at a stretch and also due to working conditions such as poor lighting, heating (or) ventilation. The efficiency is also affected by the psychology of the worker. It may be due to domestic worries, job securities etc. For normal work, the allowance for fatigue is about 5% of the total time. This allowance can be increased depending upon the type and nature of work and working conditions.

21. What do you meant by realistic estimate? (AU M/J '12) (AU N/D '12) (AU M/J '13)

Both over-estimate and under-estimate may prove to be dangerous and harmful for a concern. Assume that on the basis of an estimate, the concern has to fill up a tender enquiry. The overestimate means the concern will quote a higher rate and thus will not get the job or contract. In case of an under-estimate, the concern will get the contract but it will not be able to complete the work within that small quoted amount and hence will suffer heavy losses. This emphasizes the importance of making realistic estimates. Realistic estimates are very essential for the survival and growth of a concern.

Part – B

1. Discuss various methods of costing in detail. (8 marks) (AU N/D '16) (AU M/J '12) (AU M/J '16) (AU M/J '13)

Methods of Costing

(a) Process costing.
(b) Job costing.
(c) Batch costing.
(d) Hybrid costing systems.

(a) Process costing

This method is employed when a standard product is being made which involves a number of distinct processes performed in a definite sequence.

- In oil refining, chemical manufacture, paper making, flour milling, and cement manufacturing etc., this method is used.
- The object i.e., record and trace cots for each distinct stage.
- While costing, the by-products of each process should be considered.
- This method indicates the cost of a product at different stages as it passes through various processes.

- The total time spent and materials used on each process, as well as services such as power, light and heating are all charged. For this purpose cost sheet may be employed.

The process cost sheet is a summary of all operations for the month. The current operating charges are entered on the sheet showing

1. The transfer cost from the previous operation.
2. The costs incurred by each operation showing materials, labour and overhead in separate columns.

This separation of transfer cost and conversion cost is extremely important for the charges incurred by a department are its measures of efficiency.

The sheet can be used as a basis for:

1. Closing entries at the end of each month.
2. Operating statements, without need to look up the ledger accounts.

Within the cost ledger an account is kept for each process. The direct material, direct labour and factory overhead costs are transferred from the process cost sheet. There are debited to the process account, and then any completed units are credited to cover the transfer to the next process. The balance on the account represents the work-in-progress at the end of the period, which, of course, becomes the opening balance for the next period.

(b) Job costing or order costing

- Job costing is concerned with finding the cost of each individual job or contract. Examples are to be found in general (job order) engineering industries, ship building, building contracts, etc.
- The main features of the system is that each job has to be planned and costed separately.
- Overhead costs may be absorbed on jobs on the basis of actual costs incurred or on predetermined costs.
- The process of determining in advance what a job or order will cost is known as estimating.

It involves consideration of the following factors for each job/order:

1. Materials requirements and prices to arrive at the direct material cost.
2. Labour hours and rates to determine labour costs.
3. Overhead costs.
4. Percentage added to total cost to cover profit.

A record of above costs per unit time is kept in separate cost sheets.

(c) Batch costing

Batch costing is a form of job costing. Instead of costing each component separately, each batch of components are taken together and treated as a job.

Thus, for example, if 100 units of a component, say a reflector are to be manufactured, then the costing would be as far a single job. The unit price would be ascertained by dividing the cost by 100.

Besides maintaining job cost sheets it may also be necessary to keep summary sheets on which the cost of each component can be transferred and the cost of the finished product can be calculated. This applies in general engineering where many hundreds of components may go towards making the finished machine or other product.

(d) Hybrid costing systems

- Many costing systems do not fall nearly into the category of either job costing or process costing. Often systems use some features of both main costing systems.
- Many engineering companies use batch costing, which treats each batch of components as a job and then finds the average cost of a single unit.
- Another variation is multiple costing, used when many different finished products are made. Many components are made which are subsequently assembled into the completed article, which may be bicycles, cars, etc. Costs have to be ascertained for operations, processes, units and jobs, building together until the total cost is found.
- Different names may be used to describe either process costing or job costing. Thus, for example, unit costing is the name given to one system where there is a natural unit, such as sack of flour, a barrel of beer etc.
- In unit costing method, the expenses on various items are charged per unit quantity or production.
- Operation costing is a variation of unit costing, and is used when production is carried out on a large scale, popularly known as mass production.
- Operation costing is the term applied to describe the system used to find the cost of performing a utility service such as transport, gas, water or electricity.
- In this method, the cost per unit is found on the basis of operating expenses incurred on various items of expenditure.
- Unit costing, operation costing and operating costing are variations of process costing.
- Contract or terminal costing is the name given to job costing employed by builders and constructional engineers.
- All these methods ascertain the actual cost.

2. Explain the procedure followed for estimating the cost of an individual product. (8 marks) (AU N/D '16) (AU N/D '14) (AU N/D '13) (AU M/J '12)

The basic steps in the cost estimation of any product are given below:

- Make thorough study of cost estimation request to understand it fully.
- Make an analysis of the product and prepare a bill of materials.
- Make separate lists of parts to be purchased from the market and parts to be manufactured in plant.

- Determine the cost of parts to be purchased from outside.
- Estimate the material cost for the parts/components to be manufactured in plant.
- Make manufacturing process plan for the parts to be manufactured in plant.
- Estimate the machining time for each operation listed in the manufacturing process plan.
- Multiply each operation time by the labour wage rate and add them up to find direct labour cost.
- Add the estimate of step 4, 5, and 8 to get prime cost of component.
- Apply overhead costs to get the total cost of the component.

3. Discuss the objectives of the cost estimation (10 marks) (AU N/D '15)

The main purpose or objectives of estimating are

- To establish the selling price of a product.
- To ascertain whether a proposed product can be manufactured and marketed profitably.
- To determine how much must be invested in equipment.
- To find whether parts or assemblies can be more cheaply fabricated or purchased from outside (make or buy decision).
- To determine the most economical process, tooling or material for making a product.
- To establish a standard of performance at the start of project.
- For feasibility studies on possible new products.
- To assist in long term financial planning.
- To prepare production budget.
- To help in responding to tender enquiries.
- To evaluate alternate designs of a product.
- To set a standard estimate of costs.
- To initiate programs of cost reduction that result in economics due to the use of new materials, which produce lower scrap losses and which create savings due to revisions in methods of tooling and processing, and
- To control actual operating costs by incorporating these estimates into the general plan of cost accounting.

4. Describe the classification and elements of cost. (16 marks) (AU N/D '15) (AU M/J '13)

Elements of cost

For the purpose of calculations, the total cost of the product is divided into the following:

(A) Material cost, (B) Labour cost, (C) Other expenses.

(A) Material Cost

Material cost consists of the cost of materials which are used in the manufacture of product. It is divided into the following

(*a*) Direct material cost: It is the cost of those materials which are directly used for the manufacture of the product and become a part of the finished product. This expenditure

can be directly allocated and charged to the manufacture of a specific product or job and includes the scrap and waste that has been cut away from original bar or casting. The procedure for calculating the direct material cost is as follows:

(i) From the product drawing, make a list of all the components required to make the final product.

(ii) Calculate the volume of each component from the drawing dimensions after adding machining allowances, where ever necessary.

(iii) The volume of component multiplied by the density of material used gives the weight of the material per component.

(iv) Add process rejection and other allowances like cutting allowance to get the gross weight per component.

(v) Multiply the gross weight by the cost of material per unit weight to get the cost of raw material per component.

(vi) The cost of raw material for all the components is, similarly, calculated and added up which gives the cost of direct material for the product.

(*b*) Indirect material cost: In addition to direct materials a number of other materials are necessary to help in the conversion of direct materials into final shape. Though these materials are consumed in the production, they don't become a part of the finished product and their cost cannot be directly booked to the manufacture of a specific product. Such materials are called indirect materials. The indirect materials include oils, general tools, grease, sand papers, coolants, cotton waste etc. The cost associated with indirect materials is called indirect material cost.

In some cases certain direct materials like nails, screws, glue, putty etc., are used in such small quantity that it is not considered worthwhile to identify and charge them as direct materials. In such cases these materials are also charged as indirect materials.

Depending upon the product manufactured, the same may be direct materials for one concern and indirect materials for others.

(B) Labour Cost

It is the expenditure made on the salaries, wages, overtime, bonuses, etc. of the employees of the enterprise. It can be classified as :

(*a*) Direct labour cost: Direct labourer is one who actually works and processes the materials to convert it into the final shape. The cost associated with direct labour is called direct labour cost. The direct labour cost can be identified and allocated to the manufacture of a specific product. Examples of the direct labour are the workers operating lathes, milling machines or welders, or assemblers in assembly shop. The direct labour cost may be allocated to a product or job on the basis of time spent by a worker on a job.

(*b*) Indirect labour cost: Indirect labourer is one who is not directly employed in the manufacturing of the product but his services are used in some indirect manner. The

indirect labour includes supervisors, inspectors, foreman, storekeeper, gatekeeper, maintenance staff, crane driver etc. The cost associated with indirect labour is called indirect labour cost. The indirect labour costs cannot be identified with a particular job or product but are charged on the total number of products made during a particular period in a plant.

To make the concept of direct and indirect labour cost clear, consider an operator working on a drilling machine. The operator in this case is direct labour whereas the man supervising the job, inspector and store man supplying the material are indirect labour.

(C) Other Expenses

In addition to the material cost and labour cost, several other expenses such as rent of building, depreciation of plant and machinery, cost of packing materials, transport and distribution expenses, wages and salaries of administrative staff and executives are also incurred by the manufacturer. All this expenditure including the indirect material cost and indirect labour cost is called other expenses. We can say that except direct material and direct labour costs all other expenditure incurred by the manufacturer is known as "Other Expenses". Expenses are further classified as:

(*a*) Direct expenses: Direct expenses include all that expenditure which can be directly allocated and charged to a particular job. The direct expenses include cost of special jigs or fixtures, patterns, tooling made for job, or cost of research and development work done for that specific job.

(*b*) Indirect expenses: Except direct expenses, all other indirect expenditure incurred by the manufacturer is called indirect expenses. The indirect expenses are also called overhead expenses or on-cost.
The indirect expenses are further classified as:

- Factory expenses.
- Administrative expenses.
- Selling and distribution expenses.

(*i*) Factory expenses: Factory expenses comprise of the indirect expenses incurred from the receipt of the order to the completion of production. In addition to indirect material and indirect labour cost it includes rent of factory building, licence fee, electricity and telephone bills of factory, insurance charges etc. Factory expenses are also called "Works expenses", or "Factory or Works overhead".

(*ii*) Administrative expenses: Administrative expenses or office expenses include the expenditure incurred on control and administration of the factory. It includes the salaries of office and administrative staff, rent of office building, postage and telephone charges, water and electricity charges for office, Director's fee, legal and audit charges etc. Administrative expenses are also known as 'Administrative overheads'.
(*c*) Selling and distribution expenses: This is the expenditure incurred on Sales Department for selling the product, *i.e.,* wages, salaries, commission and travelling

allowances of salesmen and officers in Sales Department, cost of advertisement, packing, delivery and distribution expenses, rent of warehouses etc.

5. Discuss various types of estimates (10 marks) (AU N/D '15) (AU M/J '13)

Types of Estimate

Estimates can be developed in a variety of different ways depending upon the use of the estimates and the amount of detail provided to the estimator. Every estimator should understand every estimating method and when to apply each, because no one estimating method will solve all estimating problems.

Guesstimates

Guesstimate is a slang term used to describe as estimate than lacks detail. This type of estimate relies on the estimators experience and judgment. There are many reasons why some estimates are developed using his method. One example can be found in the tool and die industry. Usually, the tool and die estimator is estimating tool cost without any tool or die drawings. The estimator typically works from a piece part drawing and must visualize what the tool or die looks like. Some estimators develop some level of detail in their estimate. Material cost, for example, is usually priced out in some detail, and this brings greater accuracy to the estimator by reducing error. If the material part of the estimate has an estimating error of plus or minus 5 per cent and the reminder of the estimate has an estimating error of plus or minus 10 per cent, the overall error is reduced.

Budgetary

The budgetary estimate can also be a guesstimate but is used for a different purpose. The budgetary estimate is used for planning the cost of a piece part, assembly, or project. This type of estimate is typically on the high side because the estimator understands that a low estimate could create real problems.

Using Past History

Using past history is a very popular way of developing estimates for new work. Some companies go to great lengths to ensure that estimates are developed in the same way actual cost is conducted. This provides a way past history in developing new estimates. New advancements in group technology now provide a way for the microcomputer to assist in this effort.

Estimating in Some Detail

Some estimators vary the amount of detail in an estimate depending on the risk and dollar amount of the estimate. This is true in most contract shops. This level of detail might be at the operation level where operation 10 might be a turning operation and the estimator would estimate the setup time at 0.5 hours and the run time at 5.00 minutes. The material part of the estimate is usually calculated out in detail to reduce estimating error.

Estimating in Complete Detail

When the risk of being wrong is high or the dollar amount of the estimate is high, the estimator will develop the estimate in as much detail as possible. Detailed estimates for machinery operations, for example, would include calculations for

speeds, feeds, cutting times, load and unload times and even machine manipulations factors. These time values are calculated as standard time and adjusted with an efficiency factor to predict actual performance.

Parametric Estimating

Parametric estimating is an estimating method developed and used by trade associations. New housing constructions can be estimated on the basis of cost per square. There would be different figures for wood construction as compared with brick and for single strong construction as compared with multilevel construction. Some heat-beating companies price work on a cost per pound basis and have different cost curves for different heat-treating methods.

Project Estimating

Project estimating is by far the most complex of all estimating tasks. This is especially true if the project is a lengthy one. A good example of project estimating is the time and cost of developing a new missile. The project might take 5 years and cost millions of dollars. The actual manufacturing cost of the missile might be a fraction of the total cost. Major projects of this nature will have a PERT network to keep track of the many complexities of the project. A team of people with a project leader is usually required to develop a project estimate.

6. Explain the data requirements for cost estimation (6 marks) (AU N/D ’15) (AU N/D ’14) (AU M/J ’12) (AU M/J ’16) (AU M/J ’13)

1. Man-hour cost (Labour rate) *i.e.,* hourly cost of skilled, semi-skilled and unskilled labours of the company.
2. Machine-hour cost for different types of equipment and machinery available in the company.
3. Material cost in respect of commercially available materials in the market :
   - Cost in Rs. per kg for different categories of materials like ferrous, non-ferrous, special steel etc., for rods of different diameters and for different thicknesses in respect of flats/sheet metals.
4. Scarp rates *i.e.,* scarp values of different materials in Rs. per kg.
5. In respect of welding operations, information such as electrode cost, gas cost, flux cost, power cost, etc.
6. Set-up time for different processes.
7. % allowances to be added for computing standard time, relaxation allowance, process allowance, special allowance as % of normal time as per the policy of the management.
8. Standard time for different types of jobs, if available.
9. Overhead charges in terms of % direct labour cost or overhead rate in Rs. per hr.
10. Life in years permitted for various types of equipment and machines available in the plant for calculation of depreciation, for cost recovery and for calculation of machine—hour rate.
11. Data base of cost calculations carried out by the company in respect of earlier products or jobs (Historical cost data).
12. Cost data of products available in the market similar to the ones manufactured by the company.

13. Budget estimates prepared by the company for new projects/products.
14. Journals or Data sheets of Professional Associations dealing with Costs and Accounting.

7. Describe different methods of estimates (10 marks) (AU N/D '15) (AU M/J '16)

Methods of Estimates

Computer Estimating

Computer estimating has become very popular in recent years primarily because of the advent of the microcomputer. Early efforts of computer estimating date back to the early 1970s but were cumbersome to use because they were on a mainframe and were card-driven. No less than 15 U.S. companies now offer estimating software for a microcomputer. Because the computer estimating industry is new, there are no real standards for estimating programs. Some programs are nothing more than a way to organize the calculations of an estimate, while others calculate all the details of the estimate.

Advantages and disadvantages

Shown below are some of the major advantages of computer cost estimating.

Accuracy versus consistency

Computer estimates are very consistent, provided they calculate the detail of an estimate. Because these estimates are consistent, they can be made to be accurate. Through the use of consistent efficiency factors or leaving curves, estimates can be adjusted up or down. This is one of the chief advantages of computer cost estimating.

Levels of details

Some computer estimating systems provide different levels of estimating cost. The level of detail selected by the user depends on the dollar risk. Many estimators produce an estimate in more detail because the computer can calculate speeds and feeds, for example, much faster than an estimator can a hand-held calculators.

Refinements

Some computer estimating systems provide many refinements that would be impossible for the estimator to do in any timely manner. One example is to adjust speeds and feeds for material hardness. Typically, the harder the material the more slowly a part will be turned or bored. Another refinement is the ability to calculate a feed state and adjust it based on the width of a form tool.

Source code

Some companies offer the source code uncompiled to their users. This is important because it affords the user the opportunity to customize the software. In addition, many companies have written their own software to do something that is not available on the market. If the source code is not compiled, the users can build upon a computer estimating system.

Disadvantages

The chief disadvantage of computer estimating is that no one estimating system can suit everyone's need. This is especially true if the source code is compiled and not customizable.

Another problem with computer estimating is that the estimator will, in all probability, have to change some estimating methods. Computer software for estimating cost is seldom written around one method of estimating.

Group Technology

Group technology is not new. It was invented by a Russian engineer over 30 years ago. Unfortunately the subject is not taught in many of our colleges and universities. Group technology (GT) is a coding system to describe something.

Several proprietary systems are on the market. One such system, the MICAPP system, uses four code lengths, a 10-, 15-, 20-, 25- digit code. The code length selected is based on the complexity of the piece part or tool being described.

Use for group technology

Shown below are several uses for group technology along with several examples of use both internally and externally.

Cost estimating

GT can be used very efficiently in estimating cost. Assume a company manufactures shaft-type parts. Also arsum there is a computer data base named SHAFT that contains 10-digit code followed by a part number, that is, code part number, and so on. When an estimator must estimate the cost of a new shaft, the process starts by developing a code that describes the characteristics of the part. The first digit in the code might be assigned the part length, while the second digit is assigned the largest diameter and so on. Next, the code is keyed in and the computer finds all the parts that meet the numeric descriptions and points out the part numbers. The best fit is selected to be modified into a new part. All the details of each description are retrieved. These include diameter, length of cut, number of surfaces, and the like. The estimator can alter these features and make the old part into a new one.

Actual performance

As the part is being produced, the estimated information is updated with actual performance and refined. This gives the estimator the ability to improve estimating accuracy, because the next time, the computer finds that part as one to be modified into a new one, the estimator is working with actual performance.

Parametric Estimating

Parametric estimating is the act of estimating cost or time by the application of mathematical formulas. These formulas can be as simple as multiplices or as complex as regression models.

Parametric estimating, sometimes refused as statistical modeling, was first documented by the Rard Corporation in the early 1950's in an attempt to predict military hardware cost.

Use of parametric estimating

Many companies use some form of parametric estimating to develop sales forecasting. The four examples cited below will give the reader a good feel of how parametric estimating is used in a variety of different industries.

Construction industry

In developing a cost estimate for residential buildings, some cost estimators use a dollar value per square foot. The estimator constitutes curves based on different construction such as wood on brick buildings and single or multi-storey dwellings. These numbers can then be multiplied by the number of square feet in the building.

Some construction companies have refined this process to provide additional detail carpeting, for example, could have a separate multiplier.

Heat treating

Most commercial heat-treating companies price their work based on a cost per pound and heat treating method. Heat-treating costs are very difficult to define because many times more than one type of part is in the heat-treating furnace at the same time. It is difficult to think of a more effective way to estimate cost for this type of industry.

Statistical Estimating

The analysis of data through the use of statistical methods has been used for centuries. These data can be cost versus other information that leads to cost development. The practitioner must have a well-founded background in the use and application of statistical methods because an endless array of methods is available, several of which are described below.

Parametric estimating

Statistical estimating is another form of parametric estimating. The parametric methods made industry oriented whereas the methods discussed below are universal.

Regression analysis

They form most popular of regression analysis are simple regression, multiple regression, log-linear regression and curvilinear regression. Each math model is different and is designed for a specific use.

8. Explain the allowances in estimation (6 marks) (AU N/D ’15) (AU M/J ’12) (AU M/J ’16)

Allowances in estimation

Normal Time = Observed time × Rating factor

Observed time and rating factor are obtained during the time study of an operation or a job.

Various allowances are considered in estimating the standard time for a job. These allowances are always expressed as % of Normal Time and are added to Normal Time to compute the Standard Time.

Standard Time = Normal Time + Allowances

Standard Time is time required to complete one cycle of operation (usually expressed in minutes).

Standard Time for a job is the basis for determining the standard output of the operator in one day or shift.

Need for Allowances

Any operator will not be able to carry out his work throughout the day without any interruptions. The operator requires some time for his personal needs and rest, and hence such time should be included in standard time. There are different types of allowances, and they can be classified as follows :

1. Relaxation Allowance : This is also known as **Rest Allowance**. This allowance is given to enable the operator to recover from the physiological and psychological effects (Fatigue) of carrying out the specified work and to attend to personal needs.

Relaxation allowance consists of :

(*i*) Fatigue allowance, and
(*ii*) Personal needs allowance.

(*i*) Fatigue allowance is intended to cater for the physiological and psychological effects of carrying out the work.

This time allowance is provided to enable to operator to overcome the effect of fatigue which occurs due to continuous doing of the work (monotony etc.).

Relaxation allowance (Fatigue allowance and Personal needs allowance put together) is commonly 5% to 10% (of normal time).

(*ii*) Personal needs allowance: This allowance is provided to enable the operator to attend to his personal needs (*e.g.* going to toilet, rest room, etc.).

2. Process Allowance: It is an allowance to compensate for enforced idleness of the worker.

During the process, it may be likely that the operator is forced to be idle due to certain reasons, such as:

- When the process is carried out on automatic machines, (the operator is idle after loading the job on the machine).
- When the operator is running more than one machine (as in the case of cellular manufacturing)

Process allowance varies from one manufacturing situation to another depending on factors such as hazardous working conditions, handling of heavy loads, strain involved, mental alertness required etc. Generally 5% of the normal time is provided towards process allowance.

Interference Allowance : This allowance is provided where in a cycle of operation, there are certain elements which are machine controlled. The operator cannot speed up those elemental operations.

This allowance is also provided when one worker is working on several machines.

4. Contingency Allowance : This is a small allowance of time which may be included in the standard time to meet unforeseen items of work, or delays (*e.g.* waiting for raw materials, tools). Contingency allowance is 5% (maximum) or Normal Time.

5. Special Allowances : These allowances are a policy matter of the management, *e.g.* when the job is newly introduced or when a new machine or new method is introduced, because worker takes some time to learn the new method or job; Special allowance is also provided depending on the working conditions such as noise, dust, etc.

Once the normal time is obtained, the standard time can be estimated or obtained by adding all the allowances to normal time.

Standard time = Normal time + Allowances

9. Write the difference between cost accounting and cost estimation (8 marks) (AU N/D '14) (AU N/D '13) (AU M/J '12) (AU M/J '13)

Points of comparison	Cost estimating	Cost accounting
1.Types of	It gives an expected cost of the	It gives actual cost of the product

cost	product based on the calculations by means of standard formula.	based on the data collected from the different expenditures actually done for a product.
2.Duration of process	It is generally carried out before actual production of a product Due to certain unexpected expenses coming to light at a later stage, estimates may be modified or revised.	It usually starts with the issue of order for production of a product and ends after the product is dispatched for sale. For sale commitments like free repair or replacement, the process continuous up to the expiry period of guarantee because the overhead expenses incurred in the above case will be included in the production cost.
3.Nature of quality	A qualified technical person or engineer having a thorough knowledge of the drawings and manufacturing process is required.	It can be done by a person qualified for accounts instead of a technical person. Thus, this work instead of being of technical nature is more of a clerical work

10. What are the methods used in conceptual cost estimation? Explain (8 marks) (AU N/D '14) (AU A/M '17)

There are different methods of estimates of cost. These are in addition to conventional method of estimating of cost such as calculating material cost, labour cost, factory expenses and overhead expenses and adding all these cost elements.

The methods of estimates are :

1. Conceptual Cost Estimating

It is estimating during the conceptual design stage. In the conceptual design stage, the geometry of parts and materials have not been specified, unless they dictate essential product functions. In the conceptual design stage, the costs associated with a change in the design are low. In the conceptual design stage, the incurred costs are only 5 to 7% of the total cost whereas the committed costs are 75 to 85% of the total cost.

The accuracy of the conceptual cost estimate depends on the accuracy of the data base. The accuracy of conceptual cost estimating is approximately – 30% to + 50%. Accuracy in conceptual cost estimating is important since at the conceptual design stage only significant cost savings can occur.

Conceptual cost estimating methods include :

(*a*) Expert opinion,

(*b*) Analogy methods, and

(*c*) Formula based methods.

(a) Conceptual Method Based on Expert Opinion

If back-up and/or historical cost data are not available, getting expert opinion is the only way for estimating cost.

The disadvantages of this method are

i. The estimate is subjected to bias.
ii. The estimate can't be quantified accurately.
iii. The estimate may not reflect the complexity of the product or project.
iv. Reliable data base for future estimates are not possible.

In spite of these disadvantages, the expert opinion is useful when historical data base is not available. It is also useful to verify cost estimate arrived at using other methods of conceptual estimating (like analogy methods and formula based methods).

(b) Conceptual Method Based on Analogy

Analogy estimating derives the cost of a new product based on past cost data of similar products. Cost adjustments are made depending on the differences between the new and previous product/system. Analogy estimating requires that the products be analogous or similar and products manufactured using similar facilities or technology. If the technology changes, the analogy estimating relationship has to changed to reflect the changes in technology. Another limitation of this method is that analogy estimates often omit important details that makes cost considerably higher than the original cost estimates.

(c) Conceptual Method Based on Formula

There are formula based methods that are primarily used in the conceptual cost estimating. These are :

(*i*) Factor method,
(*ii*) Material cost method,
(*iii*) Function method, and
(*iv*) Cost-size relationship.

These methods are known as **Global cost estimation methods** and they generally use one of the above methods only.

(i) Factor method

This is the simplest method, but it can give reliable estimates if the data are kept up-to-date, taking into consideration factors such as inflation, and environmental issues which tend to increase the cost.

(ii) Material cost method

Material cost method is justified since the material cost is the largest cost item in the prime cost of many manufacturing companies.

According to this method :

$$\text{Estimated cost of an item} = \frac{\text{material cost of the item being estimated}}{\text{material cost share of item being estimated (in \%)}}$$

(iii) Function method

In function method more variables are used and the expressions are non-linear. The function is basically a mathematical expression with constants and variables that provides a mathematical function for the cost estimate. One expression is given below:

Cost of turbo fan engine development, (in Rs. Lakhs)
$= 41.2 \times a^{0.74} \times b^{0.08}$
where a = Maximum engine thrust, in kg
and b = No. of engines produced

11. Discuss about determination of material and labour cost. (8 marks) (AU N/D '13)

Determination of Material Cost

To calculate the material cost of the product the first step is to study drawing of the product and split it into simple standard geometrical shapes and to find the volume of the material in the product and then to find the weight. The volume is multiplied by density of the metal used in the product.

The exact procedure to find the material cost is like this:

1. Study the drawing carefully and break up the component into simple geometrical shapes. (Cubes, prisms, cylinders, etc.)
2. Add the necessary machining allowances on all sides which are to be machined.
3. Determine the volume of each part by applying the formulae of mensuration.
4. Add the volumes of all the simple components to get total volume of the product.
5. Multiply the total volume of the product by the density of the material to get the weight of the material.
6. Find out the cost of the material by multiplying the cost per unit weight to the total weight of the material.

12. Discuss in detail about the computation of price of a product using the ladder of cost with appropriate example. (16 marks) (AU N/D '13)

The elements of cost can be combined to give following types of cost:

				Profit (or) Loss	
			Selling + Distribution expenses		
		Administrative expenses	Office cost (or) production	Total (or) selling cost	Selling price (or) Market price
	Factory expenses	Factory cost (or)	(or) Manufacturing cost	(or)	Catalogue price
Direct material	Prime cost (or)	Works cost	(or)		
Direct labour	Direct cost				
Direct expense					

1. Prime cost: It consists of direct material cost, direct labour cost and direct expenses.
Prime cost = Direct material cost + Direct labour cost + Direct expenses.
Prime cost is also called as direct cost.
2. Factory cost: It consists of prime cost and factory expenses.
Factory cost = prime cost + factory expenses.
Factory cost is also named as works cost.

3. Office cost: It consists of factory cost and administrative expenses.
Office cost = Factory cost + Administrative expenses
It is also named as manufacturing cost (or) cost of production.
4. Total cost: It includes manufacturing cost and selling and distribution expenses.
Total cost = Manufacturing cost + selling and distribution expenses.

Selling price

If the profit is added in the total cost of the product, it is called selling price. The customers get the
articles by paying the price which is named as selling price.
Selling price = Total cost + Profit
= Total cost – Loss

Making price (or) catalogue price: Some percentage of discount allowed to the distributors of product is added into the selling price. The result obtained is called the market price (or) catalogue price (figure).

13. Explain the various methods used in an industry for allocation of overheads with an example. (16 marks) (AU M/J '16) (AU N/D '12)

After estimating the total on-cost, next step is the allocation of this on-cost over the production. To run the business in economical way, it is necessary to know, the variation of on-cost with the variation of production. Several methods are available for the allocation of on-cost. The choice of a particular method depends upon the nature of work, type of organisation and types of machine used, etc.
Following are the different methods of on-cost allocation:

- Percentage on direct material cost.
- Percentage on direct labour cost.
- Percentage on prime cost.
- Manhour method.
- Machine hour method.
- Combination of man hour and machine hour method.
- Unit of production method.
- Space rate method.

These methods for estimation the overheads are discussed below:

Percentage on Direct Material Cost

This method is based on the theory that the overhead expense is incurred in proportion to the value of the direct materials consumed. This method is simple, but does not allow for the usual situation where in some of the materials is fabricated without the use of much equipment whereas other material in the same plant requires extensive machinery, requiring considerably more labour, power, maintenance and floor space.

However, for the allocation of material expenses such as purchasing, storage and handling, this method is useful. This method is also useful when major part of the cost is of material line foundries and mines.

$$\text{Overhead rate} = \frac{\text{Total overhead expenses}}{\text{Total direct material cost}}$$

Percentage on Direct Labour Cost

In this method, allocation of on-cost depends upon the wages paid to the direct labour. This method is very reasonable and simple in calculation. Therefore, this method is very popular. It is the ratio of the total overhead to the direct labour cost for a particular period.

$$\text{Overhead rate} = \frac{\text{Total overhead for a period}}{\text{Total direct labour for that period}}$$

It is also called as labour burden rate. It is the ratio of the annual total overheads to the annual direct labour cost.

Overhead cost = Overhead rate X Direct labour cost/unit.

This is very suitable where production is mainly carried out by hand. It may not be an accurate indicator where machines of greatly different capacity and sizes are operated. Also if two products take the same time but labour rate for both is different then this method will give less overhead cost where labour is cheap and high overhead cost where labour is costly. Therefore, this method increases the cost of a component which has already higher labour cost. Also, in many case it gives very approximate results because sometimes of overhead such as depreciation and taxes have very little relationship to labour costs.

Percentage on Prime Cost

This is a very simple method. So it has gained popularity. This method is suitable, where labour and material both play equal role. This method will give the same overhead cost for two products with equal prime cost, even though their labour and material costs will be different. This will be useful where only one type of product is being manufactured and when direct labour and direct materials costs are nearly equal.

$$\text{Overhead rate} = \frac{\text{Total overhead over a period}}{\text{Prime cost over a period}} \times 100$$

Then, overhead cost/unit = Overhead rate X Prime cost/unit.

Man-Hour Rate

This method is very similar to the percentage on direct labour cost method. The difference in the two methods is that in which the basis of allocation was the total direct labour cost, whereas in this basis of the total hours spent by the direct labour and not the wages paid to them. This is an important method over the direct labour cost method.

$$\text{Man-hour rate} = \frac{\text{Total overheads}}{\text{Total direct man hour spent}}$$

Unit Rate Method

This is also known as production unit basis method. In this, on-cost is allocated on the basis of unit of production. Unit of production is generally piece, kilogram, tonne, litres, metre, etc. This method is mostly used where only one type of production is carried out. This method cannot be used in factories, where different kinds of products are manufactured. Unit rate is the overheads for one unit. It can be calculated as the ratio of total overheads to the quantity of production during a particular period.

$$\text{Overhead/Unit} = \frac{\text{Total overheads}}{\text{Quantity of production}}$$

Space Rate Method

The amount of space occupied by a machine has a relationship to certain overhead expenses. For example, building expense, heat, light, ventilation and service equipment such as cranes and conveyors

Space rate/m^2 for a department is

$$\text{Rs.} = \frac{\text{Total overhead assigned to a department}}{\text{Total area of the production department in square metre}}$$

∴ Space charges to the individual machine for the defined period of time = Space rate × Total area with which the machine should be charged.

14. A factory has 15 lathes of same make and capacity and 5 shapers of same make and capacity. Lathes occupy 30 m^2 area while shapers occupy 15 m^2. During one calender year, factory expenses for this section area are as follows:

***(i)* Building rent and depreciation**	**Rs. 5000**
***(ii)* Indirect labour and material**	**Rs. 15000**
***(iii)* Insurance**	**Rs. 2000**
***(iv)* Depreciation charges of lathes**	**Rs. 5000**
***(v)* Depreciation charges of shapers**	**Rs. 3000**
***(vi)* Power consumption for the lathes**	**Rs. 2000**
***(vii)* Power consumption for the shapers**	**Rs. 1000**

Find out the machine hour rate for lathes and shapers work for 25000 hours and 8000 hours respectively. (16 marks) (AU N/D '12) (AU A/M '18)

Solution

(a) Lathe section

Total overheads for the lathe section will be as follows:

(i) Building rent and depreciation (charged on the basis of floor area occupied)	
	= (5000 × 30) / (30 + 15)
	= Rs. 3333.33
(ii) Indirect labour and material	= (15000 × 30) / (30 + 15)
	= Rs.10000
(iii) Insurance	= (2000 × 30) / (30 + 15)
	= Rs. 1333.33
(iv) Depreciation	= Rs. 5000
(v) Power	= Rs. 2000
∴ Total overheads	= Rs. 21666.66
∴ Machine hour rate for lathes	= 21666.66 / 25000
	= Rs. 0.87

(b) Shaper section

Total overhead for the shaper section will be as follows

(i) Building rent and depreciation	= (5000 ×15) / (30+15)
	= Rs. 1666.66
(ii) Indirect labour and material	= (15000×15) / (30+15)
	= Rs.5000

(iii) Insurance	= (2000 ×15) / (30+15)
	= Rs. 666.66
(iv) Power consumption	= Rs. 1000.00
(v) Depreciation	= Rs. 3000.00
Total overheads	= Rs. 11332.32
∴ Machine hour rate for shapers	= 11332.32/ 8000
	= Rs. 1.42

15. Calculate prime cost, factory cost, production cost, total cost and selling price per item from the data given below for the year 2003-04.

Cost of raw material in stock as on 1-04-2003	**Rs. 25,000**
Raw material purchased	**Rs. 40,000**
Direct labour cost	**Rs. 14,000**
Direct expenses	**Rs. 1,000**
Factory/Works overhead	**Rs. 9,750**
Administrative expenditure	**Rs. 6,500**
Selling and distribution expenses	**Rs. 3,250**
No. of items produced	**Rs. 650**
Cost of raw material in stock as on 31-03-2004	**Rs. 15,000**

Net profit/item is 10 percent of total cost of the product.

(16 marks) (AU N/D '14)

Solution :

For 650 units produced during 2003-04

(*i*) Direct material used = Stock of raw material on 1-04-2003 + raw material purchased – stock of raw material on 31-03-2004

= 25,000 + 40,000 – 15,000

= Rs. 50,000

(*ii*) Direct labour	= Rs. 14,000
(*iii*) Direct expenses	= Rs. 1,000
Prime cost	= 50,000 + 14,000 + 1,000
	= Rs. 65,000
Factory cost	= Prime cost + Factory expenses
	= 65,000 + 9,750
	= Rs. 74,750
Production cost	= Factory cost + Administrative expenses
	= 74,750 + 6,500
	= Rs. 81,250
Total cost	= Production cost + Selling expenses
	= 81,250 + 3,250
	= Rs. 84,500
Selling price	= 84,500 + 10 percent of 84,500
	= 84,500 × 1.10 = Rs. 92,950

$$\text{Prime cost/item} = \frac{65,000}{650} = \text{Rs. } 100$$

$$\text{Factory cost/item} = \frac{74,750}{650} = \text{Rs. } 115$$

$$\text{Production cost/item} = \frac{81,250}{650} = \text{Rs. } 125$$

$$\text{Total cost/item} = \frac{84,500}{650} = \text{Rs. } 130$$

$$\text{Selling price/item} = \frac{92,950}{650} = \text{Rs. } 143$$

16. From the following data for a sewing machine manufacturer, prepare a statement showing prime cost, Works/factory cost, production cost, total cost and profit.

	Rs.
Value of stock of material as on 1-04-2003	**26,000**
Material purchased	**2,74,000**
Wages to labour	**1,20,000**
Depreciation of plant and machinery	**8,000**
Depreciation of office equipment	**2,000**
Rent, taxes and insurance of factory	**16,000**
General administrative expenses	**3,400**
Water, power and telephone bills of factory	**9,600**
Water, lighting and telephone bills of office	**2,500**
Material transportation in factory	**2,000**
Insurance and rent of office building	**2,000**
Direct expenses	**5,000**
Commission and pay of salesman	**10,500**
Repair and maintenance of plant	**1,000**
Works Manager salary	**30,000**
Salary of office staff	**60,000**
Value of stock of material as on 31-03-2004	**36,000**
Sale of products	**6,36,000**

(16 marks) (AU N/D '13)

Solution :

(*i*) Material cost = Opening stock value + Material purchases – Closing balance
= 26,000 + 2,74,000 – 36,000
= Rs. 2,64,000

Prime cost = Direct material cost + Direct labour cost + Direct expenses
= 2,64,000 + 1,20,000 + 5,000
= Rs. 3,89,000

(*ii*) Factory overheads are :

	Rs.
Rent, taxes and insurance of factory	16,000
Depreciation of plant and machinery	8,000
Water, power and telephone bill of factory	9,600
Material transportation in factory	2,000
Repair and maintenance of plant	1,000

Work Manager salary	30,000
Factory overheads or Factory cost	**66,600**

Factory cost = Prime cost + Factory expenses
= 3,89,000 + 66,600
= Rs. 4,55,600

(*iii*) Administrative/office expenses are :

	Rs.
Depreciation of office equipment	2,000
General administrative expenses	3,400
Water, lighting and telephone bills of office	2,500
Rent, insurance and taxes on office building	2,000
Salary of office staff	60,000
Total	**69,900**

Production cost = Factory cost + Office expenses
= Rs. 4,55,600 + Rs. 69,900
= Rs. 5,25,500

(*iv*) Selling overheads are :

Commission and pay to salesmen = Rs. 10,500

Total cost = Production cost + Selling expenses
= 5,25,500 + 10,500
= Rs. 5,36,000

(*v*) Profit = Sales – Total cost
= 6,36,000 – 5,36,000
= Rs. 1,00,000

17. In a manual operation, observed time for a cycle of operation is 0.5 minute and the rating factor as observed by the time study engineer is 125%. All allowances put together is 15% of N.T. (Normal Time). Estimate the Standard Time.

(8marks) (AU N/D '2014)

Solution :

Observed time for a cycle = 0.5 min.
Rating factor = 125%
Normal time = Observed time × Rating factor
= 0.5 × 1.25
= 0.625 min.
Allowances = 15% of Normal Time
Standard Time = Normal Time + Allowances
= 0.625 min. + (0.15 × 0.625) min.
= 0.625 min. + 0.094 min.
= 0.719 min.
= 0.72 min.

18. In a manufacturing process, the observed time for 1 cycle of operation is 0.75 min. The rating factor is 110%. The following are the various allowances as % of normal time :

Personal allowance = 3%
Relaxation allowance = 10%
Delay allowance = 2%
Estimate the standard time. (8 marks) (AU N/D '2014)

Solution :

Basic time or normal time = Observed time × Rating factor
= 0.75 min × 110%
= 0.75 × 1.1
= 0.825 min.

Standard time = Normal time + All allowances
= Normal time + [3% + 10% + 2%] of normal time
= 0.825 min. + (0.15 × 0.825) min.
= 0.825 min. + 0.124 min.
= 0.949 min.
= 0.95 min.

Standard time is the basis for calculation of standard output (*i.e.,* no. of components produced) in 1 day or in 1 shift (of 8 hours). Incentive schemes are based on the standard output.

19. From the records of an oil mill, the following data are available,

***(a)* Raw materials**
Opening stock = Rs. 1,40,000
Closing stock = Rs. 1,00,000
Total purchases during the year = Rs. 2,00,000
***(b)* Finished goods**
Opening stock = Rs. 20,000
Closing stock = Rs. 30,000
Sales = Rs. 6,00,000
***(c)* Direct wages = Rs. 1,00,000**
***(d)* Factory expenses = Rs. 1,00,000**
***(e)* Non-manufacturing expenses = Rs. 85,500**

Find out what price should be quoted for a product involving an expenditure of Rs. 35,000 in material and Rs. 45,000 wages. Factory expenses to labour cost is 100%. (16marks) (AU M/J '2012)

Solution

Direct material cost = Opening stock + Total purchases – Closing stock
= 1,40,000 + 2,00,000 – 1,00,000
= Rs. 2,40,000

Direct material cost = Rs. 2,40,000

Direct wages = Rs. 1,00,000

Factory expenses = Rs. 1,00,000

Factory cost = Direct material + Direct labour + Factory overheads
= 2,40,000 + 1,00,000 + 1,00,000
= Rs. 4,40,000/-

Non-manufacturing expenses = Rs. 85,000

Total cost = Factory cost + Non-manufacturing expenses
= 4,40,000 + 85,000
= Rs. 5,25,000/-

Factory expenses of direct labour cost = 100%

Non-manufacturing expenses = 85000/4, 40,000 = 19.31%

Cost of finished goods = Opening stock + cost of goods – Closing stock
= 20,000 + 5,25,000 – 30,000
= 5,15,000

Cost of finished goods = Rs. 5,15,000/-

Total sales = Rs. 6,00,000

Profit = Rs. 6,00,000 – 5,15,000

Profit to sales cost = 85,000/5,15,000 = 16.5%

The cost of the product to be quoted is listed down as follows:

Direct material cost = Rs. 35,000

Direct labour cost = Rs. 45,000

Factory expenses = 100% of wages
= Rs. 45,000

Factory cost = Direct material cost + Labour cost + Factory expenses
= 35000 + 45000 + 45000 = 1,25,000

Factory cost = Rs. 1,25,000

Administrative and selling expenses = Non-manufacturing expenses
= 19.31% of factory cost
= Rs. 24,137.50

Total cost = 1,25,000 + 24137.50
= Rs. 1,49,137.50

Total cost = Rs. 1,49,137.50

Profit = 16.5% total cost
= Rs. 24,607.68

Profit = Rs. 24,607,68/-

Quotation price = 1,49,137.50 + 24,607.68 = 1,73,745.1875

Quotation price = Rs. 1,73,745.1875/-
Selling price = Total cost + Profit
= 3410 + 682 = Rs. 4092/-
Cost per unit = 4092 / Number of units
= 4092 / 50
= Rs. 81.84
List price = Selling price + Discount
= Selling price + 20% list price

Let us assume 'list price' be ('x/-Rs.')

Now, x = 81.84 + (20x/100)

x = 81.84 + 0.2 x
0.8 x = 81.84
x = 102.30
List price = Rs. 102.30.

20. Calculate the selling price per unit from the following data :

Direct material cost = Rs. 8,000
Direct labour cost = 60 percent of direct material cost
Direct expenses = 5 percent of direct labour cost
Factory expenses = 120 percent of direct labour cost
Administrative expenses = 80 percent direct labour cost
Sales & distribution expenses = 10 percent of direct labour cost
Profit = 8 percent of total cost
No. of pieces produced = 200 (16 marks) (AU A/M '17) (AU N/D '17)

Solution :

Direct material cost = Rs. 8,000
Direct labour cost = 60 percent of direct material cost

$$= \frac{60 \times 8.000}{100} = \text{Rs. } 4.800$$

$$\text{Direct expenses} = 5 \text{ percent of direct labour cost}$$

$$= \frac{4.800 \times 5}{100} = \text{Rs. } 240$$

$$\text{Prime cost} = 8.000 + 4.800 + 240$$

$$= \text{Rs. } 13.040$$

$$\text{Factory expenses} = 120 \text{ percent of direct labour cost}$$

$$= \frac{4.800 \times 120}{100} = \text{Rs. } 5.760$$

$$\text{Administration Expenses} = 80 \text{ percent of direct labour cost}$$

$$= \frac{4.800 \times 80}{100} = \text{Rs. } 3.840$$

$$\text{Sales and distribution expenses} = 10 \text{ percent of direct labour cost}$$

$$= \frac{10 \times 4.800}{100} = \text{Rs. } 480$$

Total cost = Prime cost + Factory expenses + Office expenses + Sales and distribution expenses

= 13,040 + 5,760 + 3,840 + 480

= Rs. 23,120

Profit = 8 percent of Total cost

$$= \frac{23{,}120 \times 8}{100} = \text{Rs. } 1{,}849.60$$

= Rs. 1,850 (say)

Selling price = Total cost + Profit
= 23,120 + 1,850
= Rs. 24,970

$$\text{Selling price 1 unit} = \frac{24{,}970}{200} = \text{Rs. } 124.85$$

= Rs. 125

21. Describe the various components of job estimate. (16 marks) (AU N/D '17)

Components of a cost estimate or job estimate

The total estimated cost of a product consists of the following cost components :

1. Cost of design.
2. Cost of drafting.
3. Cost of research and development.
4. Cost of raw materials.
5. Cost of labour.
6. Cost of inspection.
7. Cost of tools, jigs and fixtures.
8. Overhead cost.

1. Cost of Design

The cost of design of a component or product is estimated by ascertaining the expected time for the design of that component. This may be done on the basis of similar job previously manufactured but for new and complicated jobs the estimator has to consult the designer who gives the estimated time of design. The estimate design time multiplied by the salary of designer per unit time gives the estimated cost of design. If the design of the component is done by some outside agency, the total amount paid to outside agency gives the cost of design.

2. Cost of Drafting

Once the design of the component is complete, its drawings have to be prepared by draftsman. The expected time to be spent in drawing or drafting is estimated and is then multiplied by the standard drafting rate or by the salary of the draftsman per unit time to get estimated cost of drafting.

3. Cost of Research and Development Work

Before taking up the manufacturing of actual components/parts considerable time and money has to be spent on research and development. The research may be theoretical, experimental or developmental research. The cost of R and D can be estimated by considering various items of expenditure incurred during R and D work which include :

(*i*) Cost of labour involved.

(*ii*) Cost of material used.

(*iii*) Cost of special equipment used or fabricated for the prototype.

(*iv*) Depreciation, repair and maintenance cost of experimental set-up.

(*v*) Cost of services of highly qualified and trained personnel needed for experimentation.

(*vi*) Cost of preparing Test Reports, if any.

In some cases the cost of R and D may be estimated on the basis of research involved in similar products produced in the past.

4. Cost of Raw Material

The estimation of cost of materials used in production of a component/product consists of following steps:

(*i*) A list of all the materials used in the manufacture of the product is made which includes the direct as well as indirect materials.

(*ii*) The quantity (weight or volume) of all the material expected to be used in the manufacture of the product is estimated. The allowance for material wastage, spoilage and scarp are also added for each component/part.

(*iii*) Cost of each material is estimated by multiplying the estimated quantity of each material with its estimated future price. The estimate of future price of a material is made keeping in view of present prices and general trends and variations.

(*iv*) Estimated cost of all the materials is added to get the overall estimated material cost.

5. Cost of Labour

The cost of labour involved in the manufacture of a product is estimated by estimating the labour time needed to manufacture the product and multiplying it by cost of labour per hour. In order to estimate the labour time expected to be spent on a job, one must have thorough knowledge of the various operations to be performed, machines to be used, sequence of operations, tools to be used and labour rates. For this purpose, the estimator may consult engineers, supervisors or foremen from
production or industrial engineering departments.

6. Cost of Inspection

A product being manufactured is inspected at various stages during its manufacture. It may be inspection of raw material or in-process inspection or inspection of finished goods. The cost of inspection equipment, gauges and consumable involved in the inspection and testing are taken into account while estimating the cost of the product.

7. Cost and Maintenance Charges of Tools, Jigs and Fixtures

Estimated cost of a product includes the estimated cost and maintenance charges for the tools, jigs, fixtures and dies required in the production. The cost of tools, jigs, fixtures etc., is estimated considering their present prices, market trend and the number of times a particular tool can be used during its life-time. The estimated cost divided by the number of jobs, it can make, gives the tool cost per unit produced.

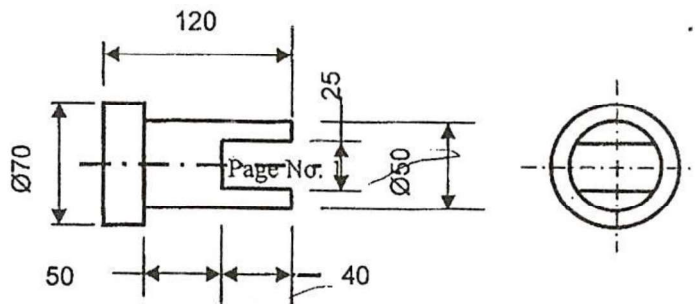
8. Overhead Costs

Overhead or indirect costs are those which are not incurred specifically for any one order or product and these cannot be charged directly to a specific order or product. The overhead costs may be estimated by referring to the records of overhead costs in similar items produced in past. The overhead cost per unit varies considerably with the volume of production *i.e.* number of components produced.

Unit – 4 Production Cost Estimation

Part – A

1. **Estimate the weight of the component shown in fig. the material is CI (AU A/M '18)**



Volume of the component = volume of A + Volume of B – Volume of C

$= (\frac{\pi}{4} d^2 l) + (\frac{\pi}{4} d^2 l) - (b \times l)$

$= \left(\frac{\pi}{4} \times 70^2 \times 30\right) + \left(\frac{\pi}{4} \times 50^2 \times 90\right) - (50 \times 25)$

= 115454 + 176715 +1250

= 290919 cm^3

Weight of the component = Volume x Density

Assume density of CI = 7.2 g/cc

Weight of the component = 290919 x 7.2

= 2094617 g = 2094.62 kg

2. **What are the causes of depreciation? (AU A/M '18)**

Depreciation due to physical condition

- Wear and tear
- Physical decay
- Accident
- Poor maintenance of equipment

Depreciation due to functional conditions

- Inadequacy
- Obsolescence

3. **Give the formula for calculating the cost of power consumed in arc welding (AU N/D '17)**

Power cost = $\frac{V \times A}{1000} \times \frac{t}{60} \times \frac{1}{\eta} \times \frac{1}{r} \times C$

V = voltage in volts

A = current in amperes

t = welding time in minutes

η = efficiency of the welding machine

r = ratio of operating time to connecting time taken by operator

C = rate of electricity per kWhr in Rs

4. **Define roll forging (AU N/D '17)**

Roll forging is used to draw out sections of bar stock, *i.e.,* reducing the cross-section and increasing the length. Special roll forging machines, with dies of decreasing cross-section are used for roll forging.

5. **List the losses to be considered in estimating the gross weight of a forging component? (AU M/J ’16) (AU N/D ’16) (AU N/D ’14) (AU N/D ’13) (AU A/M ’17)**
   - Scale loss
   - Flash loss
   - Tonghold loss
   - Sprue loss
   - Shear loss
6. **Differentiate leftward and rightward welding. (AU N/D ’16) (AU A/M ’18)**
   Leftward welding: In this method, welding is started from right hand side of the joint and proceeds towards left. This method is used for welding plates upto 5 mm thick. No edge preparation is required in case of the plates of thickness upto 3 mm.
   Rightward welding: This method is adopted for welding thicker plates. Welding proceeds from left to right. The flame is directed towards the deposited metal and rate of cooling is very slow.
7. **Brief about the procedure to calculate material cost. (AU N/D ’15)**
   Direct material cost = Gross weight × Price/kg.
   Gross weight = Net weight + Material loss in the process.
   Net weight = Volume of forging × Density of metal.
8. **How can you calculate the labour cost for a turning process in lathe? (AU N/D ’13)**
   Direct labour cost = $t \times l$
   Where t = Time for truning process per piece (in hrs)
   l = Labour rate per hour
9. **Define Flash loss (AU N/D ’13)**
   There is a certain quantity of metal which comes between the flat surfaces of the two dies after the die cavity has been filled in. This material equal to the area of the flat surface is wastage. For finding the flash loss, the circumference is determined which multiplied by cross-sectional area of flash will give the volume of the flash. The volume multiplied by material density gives the flash loss. Generally, it is taken as 3 mm thick and 2 mm wide all round the circumference.
10. **What are the various elements considered while calculating the cost of a welded joint? (AU N/D ’12)**
    The total cost of welding consists of the following elements :
    - Direct material cost.
    - Direct labour cost.
    - Direct other expenses.
    - Overheads.
11. **State any four pattern allowances. (AU N/D ’12)**
    (i) Shrinkage Allowance
    (ii) Machining Allowance
    (iii) Draft Allowance
    (iv) Distortion Allowance

12. Define production cost (AU A/M '17)

Prime cost = Direct material cost + Direct labour cost + Direct expenses (if any)

Factory cost = Prime cost + Factory overheads

Cost of production = Factory cost + Administrative overheads + Miscellaneous overheads (if any)

13. What are overhead costs? (AU A/M '17)

Overhead expenses include all expenditure incurred by the manufacturer on the product except the direct material cost, direct labour cost and direct chargeable expenses.

(a) Indirect material expenses.

(b) Indirect labour expenses.(supervisors, inspectors, foremen, store-keeper, gatekeepers, repair and maintenance staff, crane drivers, sweepers, administrative office staff and sales and distribution staff, etc.)

(c) Other indirect.(water and electricity charges, rent of factory building, licence fee, insurance premia stationery, legal expenses, audit fee etc.

Part – B

1. Market price of a CNC lathe is Rs. 50,000 and discount is 20% of market price. Here factory cost is 4 times selling cost and 1 : 4 : 2 is ratio of material, labour and overhead charges. Material cost is Rs. 4000. What is profit value?(16 marks) (AU M/J '16)

Solution

Material cost	= 4000
From ratio, Labour cost	= 16,000/-
Overheat charges	= 8000/-
Factory cost	= 4000 + 16000 + 8000
	= Rs. 28000/-
Now selling price	= 28000 / 4
Total cost	= 28000 + 7000
	= Rs. 35000/-
Selling price	= Market rate – Discount
Profit	= Selling price – Total cost
	= 40000 – 35000
	= 5000

Company incurs Rs. 5000/- as profit.

2. **Explain the different items involved in the estimation of arc welding cost of job. (6 marks) (AU M/J '16) (AU N/D '16)**

Estimation of Cost in Welding

The total cost of welding consists of the following elements:

1. Direct material cost.
2. Direct labour cost.
3. Direct other expenses.
4. Overheads.

1. Direct Material Cost

The direct material cost in a welded component consists of the following :

- Cost of base materials to be welded *i.e.,* sheet, plate, rolled section, casting or forging. This cost is calculated separately.
- Cost of electrodes/filler material used. The electrode consumption can be estimated by using the charts supplied by the suppliers. Another way to find the actual weight of weld metal deposited is to weigh the component before and after the welding and making allowance for stub end and other losses during welding.

Also the weight of weld metal = Volume of weld × Density of weld material

2. Direct Labour Cost

The direct labour cost is the cost of labour for preparation, welding and finishing operations. Preparation or pre-welding labour cost is the cost associated with preparation of job for welding, *i.e.,* the edge preparation, machining the sections to be welded etc. If gas is used in cutting/preparation of edges, its cost is also taken care of.

Cost of labour in actual welding operation is calculated considering the time in which arc is actually in operation.

The cost of labour for finishing operation is the cost of labour involved in grinding, machining, sand or shot blasting, heat treatment or painting of welded joints.

3. Direct Other Expenses

The direct other expenses include the cost of power consumed, cost of fixtures used for a particular job etc.

Cost of power : The cost of power consumed in arc welding can be calculated from the following formula :

$$\text{Power cost} = \frac{V \times A}{1{,}000} \times \frac{t}{60} \times \frac{1}{E} \times \frac{1}{r} \times C$$

Where V = Voltage

A = Current in Amperes

t = Welding time in minutes

E = Efficiency of the welding machine

= 0.6 for welding transformer

= 0.25 for welding generator

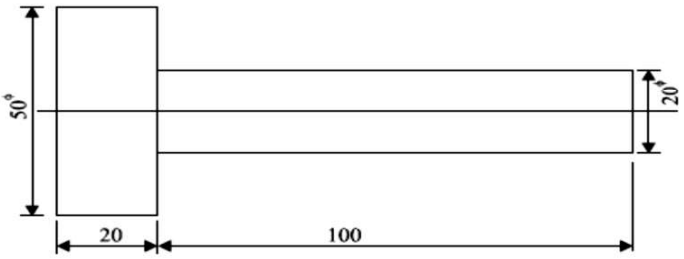
r = Ratio of operating time to connecting time taken by the operator

C = Cost of electricity per kWh *i.e.,* Unit.

Overheads

The overheads include the expenses due to office and supervisory staff, lighting charges of office and plant, inspection, transport, cost of consumables and other charges. The cost of equipment is also apportioned to the individual components in the form of depreciation.

3. **150 components, as shown in Fig. are to be made by upsetting a dia 20 mm bar. Calculate the net weight, gross weight and length of dia 20 mm bar required. The density of material may be taken as 7.86 gms/cc. (10 marks) (AU M/J '16)**



Solution :

$$\text{Net volume of material} = \frac{\pi}{4}[(5)^2 \times 2 + (2)^2 \times 10]$$

$$= \frac{\pi}{4}(50 + 40) = 70.72 \text{ cm}^3$$

$$\text{Net weight per component} = 70.72 \times 7.86 = 556 \text{ gms}$$

$$\text{Net weight for 150 components} = 556 \times 150 = 83{,}400 \text{ gms}$$

$$= 83.4 \text{ kgs}$$

Losses :

$$\text{Shear loss} = 5 \text{ percent of net weight}$$

$$= \frac{5}{100} \times 556 = 27.8 \text{ gms}$$

$$\text{Scale loss} = 6\% \text{ of net weight}$$

$$= \frac{6}{100} \times 556 = 33.4 \text{ gms}$$

$$\text{Gross weight/component} = 556 + 27.8 + 33.4$$

$$= 617 \text{ gms}$$

$$\text{Gross weight for 150 components} = 617 \times 150 = 92{,}550 \text{ gms}$$

$$= 92.550 \text{ kgs}$$

$$\text{Length of 20 mm f bar required} = \frac{92550}{\frac{\pi}{4}(2)^2 \times 7.86}$$

$$= 3744 \text{ cms} = 37.44 \text{ meters.}$$

4. **Two 1 m long M.S plates of 10 mm thickness are to be welded by a lap joint with a 8 mm electrode. Calculate the cost of welding. Assume the following data.**
   - ***(i)*** **Current used = 30 amperes**
   - ***(ii)*** **Voltage = 300 V**
   - ***(iii)*** **Welding speed = 10 m/hr**
   - ***(iv)*** **Electrode used = 0.1 kg/m of welding**
   - ***(v)*** **Labour charges = Rs. 4.00/hr**
   - ***(vi)*** **Power charges = Rs. 0.2/kWh**
   - ***(vii)*** **Cost of electrode = Rs. 40.00/kg**

(viii) **Efficiency of machine = 70% (16 marks) (AU M/J '12)**

Solution

(a) Cost of electrode required for 1 m length of welding = 0.1 kg

Cost of electrode as Rs. 40/kg = 40×0.1 = Rs. 4.

(b) Labour cost

Time required for welding 1 m length

$$= \frac{1}{10} \text{ hr}$$

Labour charge $= \frac{1}{10} \times 4 = \text{Rs. } 0.4$

(c) Power charges, as power consumed

$$= \frac{V \times I}{\text{Efficiency of the machine}}$$

$$= \frac{300 \times 30}{0.7} = 12.85 \text{ kW}$$

Energy consumed for welding 1 m length

$$= 12.85 \times \frac{1}{10} = 1.285 \text{ kWh}$$

Power charges at Rs. 0.1/kWh = 1.28×0.4

= Rs. 0.512

Total welding cost = Cost of electrode + Labour charges + Power charges

= 4 + 0.4 + 0.512 = Rs. 4.912.

5. **Generalize the meaning of Tonghold loss in forging. (6 marks) (AU N/D '16)**

This is the loss of material due to a projection at one end of the forging to be used for holding it with a pair of tongs and turning it round and round to give the required cross section in drop forging. About 1.25 cm and 2.5 cm of the size of the bar is used for tonghold. The tonghold loss is equal to the volume of the protections. For example, the tonghold loss for a bar of 2 cm diameter will be

$$= \frac{\pi}{2}(2)^2 \times 1.25 \; cu.cm$$

6. **State and explain various losses which are to be considered in a forging shop. (8 marks) (AU N/D '16) (AU N/D '17)**

Losses in Forging

It is well known that some metal is always lost in the different operations of forging and this lost metal must be added to the net weight before calculating the material cost. The different losses to be considered are:

a) Scale loss
b) Flash loss
c) Tonghold loss
d) Sprue loss
e) Shear loss

(i) Scale loss

This is the material lost because of the surface oxidation in heating and forging the piece. When iron is heated at a high temperature in atmospheric conditions a thin of iron oxide is formed all round the surface of the heated metal which goes as a waste. The iron oxide film is known as scale and it falls from the surface of the metal on being beaten up by the hammer. Scale loss depends upon the surface area, heating time and the type of material. For forgings under 5 kg loss is 7.5 per cent of the net weight, and for forgings from 5 to 12.5 kg and over an addition of 6 per cent and 5 per cent of the net weight is necessary for scale loss.

(ii) Flash loss

There is a certain quantity of metal which comes between the flat surfaces of the two dies after the die cavity has been filled in. This material equal to the area of the flat surface is a wastage. For finding the flash loss, the circumference is determined which multiplied by cross-sectional area of flash will give the volume of the flash. The volume multiplied by material density gives the flash loss. Generally, it is taken as 3 mm thick and 2 mm wide all round the circumference.

(iii) Tonghold loss

This is the loss of material due to a projection at one end of the forging to be used for holding it with a pair of tongs and turning it round and round to give the required cross section in drop forging. About 1.25 cm and 2.5 cm of the size of the bar is used for tonghold. The tonghold loss is equal to the volume of the protections. For example, the tonghold loss for a bar of 2 cm diameter will be

$$= \frac{\pi}{2}(2)^2 \times 1.25 \text{ cu.cm}$$

(iv) Sprue loss

The connection between the forging and tonghold is called the sprue or runner. The material loss due to this portion of the metal used as a contact is called sprue loss. The sprue must be heavy enough to permit lifting the workpiece out of the impression die without bending. The sprue loss is generally 7.5 per cent of the net weight.

(v) Shear loss

In forging, the long bars or billets are cut into required length by means of a sawing machine. The material consumed in the form of saw-dust or pieces of smaller dimensions left as defective pieces is called shear loss. This is usually taken as 5% of the net weight. From above we see that nearly 15 to 20% of the net weight of metal is lost during forging. And as already said these losses must be added to the net weight to get the gross weight of the material.

7. A factory produces 100 bolts and nuts per hour on a machine. Material cost is Rs. 375, labour Rs. 245 and direct expense is Rs. 80. The factory on cost is 150% and office on cost is 30%. If sales price is Rs. 11.30 find whether company incurs profit or loss. (10 marks) (AU N/D '15)

Solution

Material cost	= 375.00
Labour	= 245.00
Direct expenses	= 80.00
Factory expenses	= 150% of labour cost

= 245 × 1.5 = Rs. 367.50

Factory cost = 375 + 245 + 80 + 367.5
= Rs. 1067.50

Office on cost = 30% of factory cost
= 1067.50 X 0.3
= Rs. 320.25

Total cost = 1067.50 + 320.25
= 1387/-

Cost per nut = 1387/100
= 13.87/-

Sales price = 11.30

Hence, company incurs a loss of Rs. 2.57/-.

8. Estimate the selling price per piece of a casting component from the following data :

Net weight of cast component = 5.117 kg
Density of material = 7.2 gms/cc
Cost of molten metal at cupola spout = Rs. 20 per kg
Process scrap = 20 percent of net weight
Scrap return value = Rs. 6 per kg
Administrative overheads = Rs. 30 per hour
Sales overheads = 20 percent of factory cost
Profit = 20 percent of factory cost
Other expenditures are:

Operation	*Time (min)*	*Labour cost/hr (Rs.)*	*Shop overheads/hr (Rs.)*
Moulding and pouring	15	20	60
Shot blasting	5	10	40
Fettling	6	10	40

(16 marks) (AU N/D '13)

(*i*) *Material cost :*

Net weight of cast component = 5.117 kg
Process scrap = 20 percent of 5.117 kg
= 0.2 × 5.117 = 1.02 kg
Total metal required per component = 5.12 + 1.02 = 6.14 kg
Cost of metal poured = 6.14 × 20 = Rs. 122.8
Process return value = 1.02 × 6 = Rs. 6.12
Material cost per component = 122.8 – 6.1 = Rs. 116.7

(*ii*) *Labour cost and factory overheads :*

Labour cost = Rs. 6.83
Shop overheads = Rs. 22.33

Process	*Time per piece (Minutes)*	*Labour cost per piece (Rs.)*	*Shop overheads per piece (Rs.)*
Melting and pouring	15	5.00	15.00
Shot blast	5	0.83	3.33
Fettling	6	1.00	4.00
Total	**26 min**	**6.83**	**22.33**

(*iii*) Factory cost per component = 116.70 + 6.83 + 22.33 = Rs. 145.86

(*iv*) Administrative overheads = (30 × 26) /60 = Rs. 13

(*v*) Sales overheads = 0.2 × 145.86 = Rs. 29.17

(*vi*) Profit = 0.2 × 145.86 = Rs. 29.17

Selling price per component = Factory cost + Administrative overheads+ Sales overheads + profit

= 145.86 + 13 + 29.17 + 29.17

= Rs. 217.2

9. Calculate the net weight and gross weight for the component shown in Fig. Density of material used is 7.86 gm/cc. (6 marks)

Also calculate :

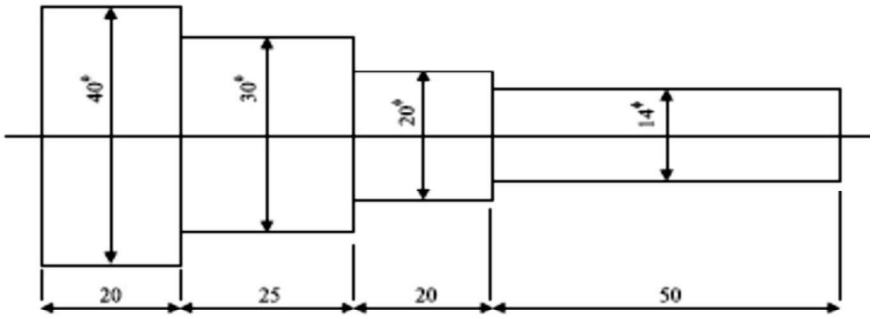
(*i*) Length of 14 mm dia bar required to forge one component. (4 marks)

(*ii*) Cost of forging/piece if: (6 marks)

Material cost = Rs. 80 per kg

Labour cost = Rs. 5 per piece

Overheads = 150 percent of labour cost. (16 marks) (AU N/D '13) (AU A/M '17)



$$\text{Net volume of forged component} = \frac{\pi}{4}\left[(4)^2 \times 2 + (3)^2 \times 2.5 + (2)^2 \times 2 + (1.4)^2 \times 5\right]$$

$$= \frac{\pi}{4}(72.3) = 56.76 \text{ cc}$$

$$\text{Net weight} = 56.76 \times 7.86 = 446 \text{ gms}$$

Losses :

Shear loss = 5 percent of net weight

$$= \frac{5}{100} \times 446 = 22.30 \text{ gms}$$

Scale loss = 6 percent of net weight

$$= \frac{6}{100} \times 446 = 26.76 \text{ gms}$$

Taking flash width = 20 mm

Flash thickness = 3 mm

Flash loss = (periphery of parting line) × 2 × 0.3 × 7.86

= [2 (2 + 2.5 + 2 + 5) + 1.4 + (2 – 1.4) + (3 – 2) + (4 – 3) + 4] × 2 × 0.3 × 7.86

= 31.0 × 2 × 0.3 × 7.86 = 146 gms

Tonghold loss = 2 × Area of cross-section of bar × 7.86

$$= 2 \times \frac{\pi}{4}(1.4)^2 \times 7.86 = 24.22 \text{ gms}$$

Sprue loss = 7 percent of net weight

$$= \frac{7}{100} \times 446 \text{ gms}$$

= 31.22 gms

Total material loss = 22.3 + 26.8 + 146 + 24.22 + 31.22

= 250 gms

Gross weight = Net weight + Losses

= 446 + 250 = 696 gms

(*i*) New length of 14 mm f bar required per piece

$$= \frac{\text{Volume of forging}}{\text{Area of X – Section of bar}}$$

$$= \frac{56.76}{\frac{\pi}{4}(1.4)^2} = 36.86 \text{ cm}$$

$$\text{Direct material cost} = \frac{696}{1{,}000} \times 8$$

= Rs. 5.57

Direct labour cost = Rs. 5 per piece

Overheads = 150 percent f labour cost

= 1.5 × 5 = Rs. 7.5

Cost per piece = 5.57 + 5 + 7.5

= Rs. 18

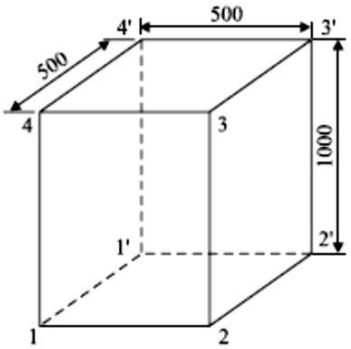
10. A container open on one side of size 0.5 m × 0.5 m × 1 m is to be fabricated from 6 mm thick plates Fig. The plate metal weighs 8 gms/cc. If the joints are to be welded, make calculations for the cost of container. The relevant data is :

Cost of plate = Rs. 10 per kg

Sheet metal scarp (wastage) = 5 percent of material

Cost of labour = 10 percent of sheet metal cost

Cost of welding material = Rs. 20 per meter of weld. (16 marks) (AU A/M '17)



Solution :

(*i*) To calculate material cost :

Net volume of material used = (4 × 50 × 100 × 0.6) + (50 × 50 × 0.6) = 13,500 cc

Net weight of container = Volume × density of material

= 13,500 × 8 = 1,08,000 gm = 108 kgs

Sheet metal scrap = 5 percent of net weight

$$= \frac{108 \times 5}{100} = 5.40 \text{ kgs}$$

Total weight of sheet metal required for fabrication of one container

= 108 + 5.4 = 113.4 kgs

Cost of sheet metal per container = 113.4 × 10 = Rs. 1134

(*ii*) To calculate labour charges :

Cost of labour = 10 percent of sheet metal cost

$$= \frac{1134 \times 10}{100} = \text{Rs. } 113$$

(*iii*) To calculate cost of welding material :

Length to be welded = (4 × 50) + (4 × 100) = 600 cm = 6 meters

Cost of welding material = 6 × 20 = Rs. 120

(*iv*) Cost of container = Cost of sheet metal material + Cost of labour + Cost of welding material

= 1134 + 113 + 120 = Rs. 1367

11. Work out the welding cost for a cylindrical boiler drum 2 ½ × 1 m diameter which is to be made from 15 mm thick m.s plates. Both the ends are closed by arc welding of circular plates to the drum. Cylindrical portion is welded along the longitudinal seam and welding is done both in inner and outer sides. Assume the following data:

(*i*) Rate of welding = 2 meters per hour on inner side and 2.5 meters per hour on outer side

(*ii*) Length of electrodes required = 1.5 m/ meter of weld length

(*iii*) Cost of electrode = Rs. 0.60 per meter

(*iv*) Power consumption = 4 kWh/meter of weld

(*v*) Power charges = Rs. 3/kWh

(*vi*) Labour charges = Rs. 40/hour

(*vii*) Other overheads = 200 percent of prime cost

(*viii*) Discarded electrodes = 5 percent

(*ix*) Fatigue and setting up time = 6 percent of welding time. (16 marks) (AU N/D '17) (AU A/M '18)

Diameter of drum = 1 meter

Length of drum = 2.5 meter

As the cylindrical portion is welded on both sides and both the ends are closed by welding circular plates, the welding on circular plates being on one side only.

Length of weld = 2 × p × dia of drum + (2 × length of drum)
= 2 × p × 1 + (2 × 2.5)
= 11.28 meters ≈11.3 meters.

(*i*) To calculate direct material cost: In this example the cost of electrodes is the direct materiel cost.

Length of electrode required = 1.5 m/m of weld
Net electrode length required for 11.3 meters weld length = 1.5 × 11.3 = 16.95 meters
Discarded electrode = 5 percent
Total length of electrodes required = 16.95 + [(5 × 16.95)/100] = 17.8 meters
Cost of electrodes = 0.6 × 17.8 = Rs. 10.68.

(*ii*) To calculate direct labour cost: To calculate the labour charges, first we have to calculate the time required for making the weld (assuming that side plates have single side welding and longitudinal seam is welded on both sides).

Length of weld on inside of drum = 2.5 meter
Length of weld on outside of drum = 2 × p × 1 + (2.5) = 8.8 meters
Time taken for inside weld = (2.5 × 1)/2 = 1.25 hrs
Time taken for outside weld = (8.8 × 1)/2.5 = 3.5 hrs
Net time required for welding = 1.25 + 3.5 = 4.75 hrs
Fatigue and setting up allowances = 4.75 × 0.06 = 0.28 hrs
Total time required = 4.75 + 0.28 = 5 hrs
Direct labour cost = 40 × 5 = Rs. 200

(*iii*) To calculate cost of power consumed

Power consumption = 4 × 11.3 = 45.2 kWh
Cost of power consumed = 45.2 × 3 = Rs. 135.6

(*iv*) To calculate the overhead charges:

Prime cost = Direct material cost + Direct labour cost + Direct other expenses
Prime cost = 10.68 + 200 + 135.60 = Rs. 346
Overheads = (200 x 346)/100 = Rs. 692
(*v*) Total cost of making boiler drum = 10.68 + 200 + 135.6 + 692 = Rs. 1038

12. List the various sections that will be normally found in a foundry shop. (4 marks) (AU N/D '17)

Generally a foundry shop has the following sections :

1. Pattern Making Section

In this section the patterns for making the moulds are manufactured. The machines involved in making the patterns are very costly and small foundries may not be able to

afford these machines. In such cases the pattern are got made for outside parties who are specialists in pattern making. Patterns are made either from wood or from a metal.

2. Sand-mixing Section

In this section raw sand is washed to remove clay etc., and various ingredients are added in the sand for making the cores and moulds.

3. Core-making Section

Cores are made in this section and used in moulds to provide holes or cavities in the castings.

4. Mould Making Section

This is the section where moulds are made with the help of patterns. The moulds may be made manually or with moulding machines.

5. Melting Section

Metal is melted in the furnace and desired composition of metal is attained by adding various constituents. Metal may be melted in a cupola or in an induction or in an arc furnace. In some cases pit furnace is also used for melting the metals.

6. Fettling Section

The molten metal after pouring in the moulds is allowed to cool and the casting is then taken out of mould. The casting is then cleaned to remove sand and extra material and is shot blasted in fettling section. In fettling operation risers, runners and gates are cut off and removed.

7. Inspection Section

The castings are inspected in the inspection section before being sent out of the factory.

Unit – 5 Machining Time Calculation

Part – A

1. **Write steps involved in cutting time calculation (AU A/M '18)**

   Step 1: Calculation of length of cut (L)

   Step 2: Calculation of feed (f) and depth of cut

   Step 3: Calculation of speed (S); [rpm (N) = 1000 S/π D]

   Step 3: Calculation of machining time by using the formula $(\frac{L}{f \times N})$

2. **What are the typical data required for cutting time calculation in shaping (AU A/M '18)**

   Shaping time T_m = [{L x B x (1+ k)} / (1000 v f)] x number of cuts

   B = width of the work

   N = Number of stroke/min

   f = Feed/stroke in mm

   V = Cutting speed m/min

   K = Return time/Cutting time

3. **Write short notes on tear down time (AU N/D '17)**

   It is the time taken to remove the tools, jigs and fixtures from the machine and to clean the machine and tools after the operation has been done on the last component of batch. The tear down time is usually small. The tear down time occurs only once for a complete lot or batch taken for machining. Standard data are available for tear down time for various machines.

4. **Give the formula for estimation of machining time for drilling (AU N/D '17)**

   Time for drilling = $\frac{\text{Depth of hole to be produced}}{\left(\frac{\text{feed}}{\text{rev}}\right) \times (\text{rpm})} = \frac{L}{f \times N}$

5. **Define cutting speed. List various factors affecting cutting speed. (AU N/D '16) (AU A/M '17)**

   Cutting speed is the speed at which the cutting edge of tool passes over the job and it is usually expressed in meters per minute. The cutting speed depends on the cutting tool material, the work piece material and the operation. Once the cutting speed has been selected, the revolutions per minute of job/machine are calculated as follows:

   $$S = \pi DN/1000 \text{ or } N = 1000\ S/\pi D$$

   Where S = Surface cutting speed in meters per minute

   D = Diameter of the job in mm

   N = r.p.m. of machine/job.

6. **What is machining time? (AU N/D '16)**

   It is the time for which the machine works on the component, i.e. from the time when the tool touches the work piece to when the tool leaves the component after completion of operation. The machining time depends on the type and extent of machining required, material being machined, speed, feed, depth of cut and number of cuts required.

7. **Derive an expression for machining time in planning machine. (AU N/D '11)**

   Planing time Tm = [(L + 250) (B + 50) (1+ k)] / (1000 v f)

   B = width of the work

   N = Number of stroke/min

f = Feed/stroke in mm
V = Cutting speed m/min
K = Return time/Cutting time

8. Derive an expression for machining time for plain turning in lathe. (AU N/D '10)

Turning, on a lathe, is the removal of excess material form the workpiece by means of a pointed tool, to produce a cylindrical or cone shaped surface. From cutting speed, r.p.m. of job are calculated by using the formula.

$$N = \frac{1000\ S}{\pi D}$$

where N = r.p.m. of job
S = Surface cutting speed in meters/minute
D = Diameter of the stock to be turned (in mm)
if f = Feed per revolution (in mm)
L = Length of stock to be turned (in mm)
T = Time required for turning (in minutes)

$$\text{Then } T = \frac{L}{f\ X\ N}$$

9. What are the different types of milling operations? (AU M/J '07)

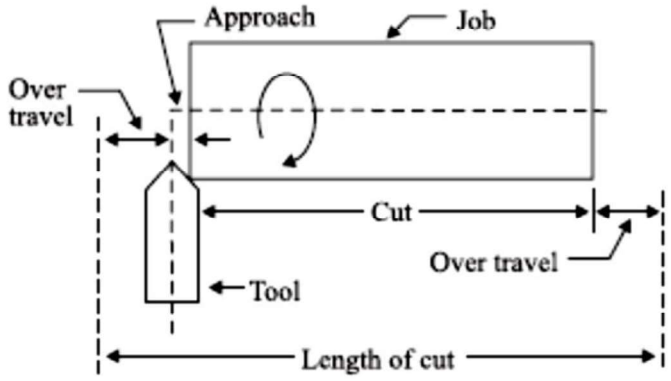
- Face milling
- Slab milling
- Profile milling
- Keyway cutting
- Slotting

10. Define tool approach and tool travel (AU A/M '17)

Length of cut : It is the distance travelled by the tool to machine the work piece and is calculated as follows :

Length of cut (L) = Approach length + Length of work piece to be machined + Over travel

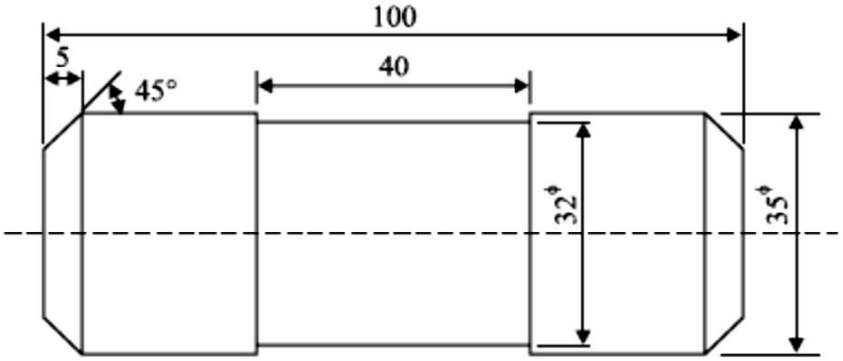
Approach is the distance a tool travels, from the time it touches the work piece until it is cutting to full depth. Over travel is the distance the tool is fed while it is not cutting. It is the distance over which the tool idles before it enters and after it leaves the cut. These terms are explained in the Fig. for a cutting operation on lathe.



Total tool travel = length of job + approach + over travel

Part – B

1. **A mild steel bar 100 mm long and 38 mm in diameter is turned to 35 mm dia. And was again turned to a diameter of 32 mm over a length of 40 mm as shown in the Fig. 5.23. The bar was machined at both the ends to give a chamfer of 45° × 5 mm after facing. Calculate the machining time. Assume cutting speed of 60 m/min and feed 0.4 mm/rev. The depth of cut is not to exceed 3 mm in any operation. (16 marks) (AU N/D'16) (AU N/D'17)**



Solution : *Ist operation* : Turning from ϕ 38 mm to ϕ 35 mm

$$S = 60 \text{ meters/min.}$$

$$D = 38 \text{ mm}$$

$$N = \frac{1{,}000\,S}{\pi D} = \frac{1{,}000 \times 60}{\pi \times 38}$$

$$= 503 \text{ r.p.m.}$$

$$\text{Time taken} = \frac{\text{Length of cut}}{\text{r.p.m.} \times \text{Feed/rev.}}$$

$$= \frac{100}{503 \times 0.4} = 0.5 \text{ min.}$$

2nd operation : External relief

$$L = 40 \text{ mm.}$$

$$D = 35 \text{ mm.}$$

$$S = 60 \text{ m/min.}$$

$$N = \frac{60 \times 1{,}000}{\pi \times 35} = 545 \text{ r.p.m.}$$

$$\text{Time taken for second operation} = \frac{\text{Length}}{\text{r.p.m.} \times \text{Feed/rev.}}$$

$$= \frac{40}{545 \times 0.4} = 0.18 \text{ min.}$$

3rd operation : Facing of both ends

$$L = \text{Length of cut} = \frac{35}{2} = 17.5 \text{ mm}$$

$$D = 35 \text{ mm}$$

$$S = 60 \text{ m/min}$$

$$N = \frac{60 \times 1{,}000}{\pi \times 35} = 545 \text{ r.p.m.}$$

$$\text{Time for facing one end} = \frac{17.5}{0.4 \times 545} = 0.08 \text{ min}$$

$$\text{Time for facing both ends} = 2 \times 0.08 = 0.16 \text{ min}$$

4th operation : Chamfering 45° × 5 mm

$$\text{Length of cut} = 5 \text{ mm}$$

$$N = 545 \text{ r.p.m.}$$

$$\text{Time taken for chamfering on one side} = \frac{5}{545 \times 0.4} = 0.02 \text{ min}$$

$$\text{Time taken for chamfering on both sides} = 0.02 \times 2 = 0.04 \text{ min}$$

$$\text{Total machining time} = 0.50 + 0.18 + 0.16 + 0.04 = 0.88 \text{ min}$$

2. **Find the time required to drill 4 holes in a cast iron flange each of 2 cm depth, if the hole diameter is 2 cm. Assume cutting speed as 21.9 m/min. and feed as 0.02 cm/rev. (8 marks) (AU N/D '16)**

Solution

Depth of hole = 2 cm = 20 mm
Diameter of hole = 2 cm = 20 mm
Cutting speed = 21.9 m/min
Feed = 0.02 cm/rev,
Depth hole = l + 0.3 d
= 2 + 0.3 (2) = 2.6
Number of holes = 4

(i) N = (1000 V) / π D
= (1000 x 21.9) / 3.14 x 20
= 350 rpm

(ii) T_m = Depth of hole / (Feed x rpm)
= 2.6 / (0.02 x 350)
= 0.3714 min

(ii) Time for drilling four holes = 0.3714 × 4 = 1.486 min.

3. **A keyway has to be cut in spindle whose dimensions are 40 cm long 4 cm diameter with a 1 cm width. The cutter diameter is 10 cm. If the cutter is revolving at 120 rpm, what time will be required to cut one cm deep keyway at a feed of 0.05 cm/rev of cutter? (8 marks) (AU N/D '16)**

$$\text{Table travel} = \sqrt{d(D-d)} + 0.5 = \sqrt{1(10-1)} + 0.5 = 3.5 \text{ cm}$$

$$\text{Total table movement} = 40 + 3.5 = 43.5 \text{ cm}$$

$$\text{Time required} = \frac{\text{Total table travel}}{N \times \text{Feed}}$$

$$= \frac{43.5}{120 \times .05} = 7.25 \text{ min.}$$

4. **A 20 × 5 cm CI surface is to be faced on a milling m/c with a cutter having a diameter of 10 cm and having 16 tooth for the cutting speed and feed are 50 m/min and 5 cm/min respectively, determine the milling time, rpm, and feed/tooth. (8 marks) (AU N/D '15)**

$$N = \frac{1000 \times V}{\pi \times D} = \frac{1000 \times 50}{\pi \times 100} = 160 \text{ rpm}$$

$$\text{Feed/min} = f_t = n \times N = f_t \times 16 \times 160$$

$$\text{Feed/tooth } f_t = \frac{50}{16 \times 160} = 0.0196 \text{ mm}$$

$$\text{Milling time T} = \frac{L + \frac{1}{2}\left[D - \sqrt{D^2 - W^2}\right] + 7}{(f_t \times n) \times N}$$

$$= \frac{200 + \frac{1}{2}\left[100 - \sqrt{100^2 - 50^2}\right] + 7}{0.0196 \times 16 \times 160}$$

$$\boxed{T = 4.27 \text{ min}}$$

5. **A T-slot is to be cut in a C.I. slab as shown in Fig. Estimate the machining time. Take cutting speed 25 m/min, feed is 0.25 mm/rev. Dia of cutter for channel milling is 80 mm. (16 marks) (AU N/D '14) (AU N/D '17)**

Solution:

The T-slot will be cut in two steps :

***Step I* :** Cut a 20 mm wide and 35 mm deep channel along the length

Dia of cutter = 80 mm

Cutting speed = 25 m/min

Length of job = 260 mm

$$\text{r.p.m. of cutter} = \frac{25 \times 1000}{\pi \times 80} = 100$$

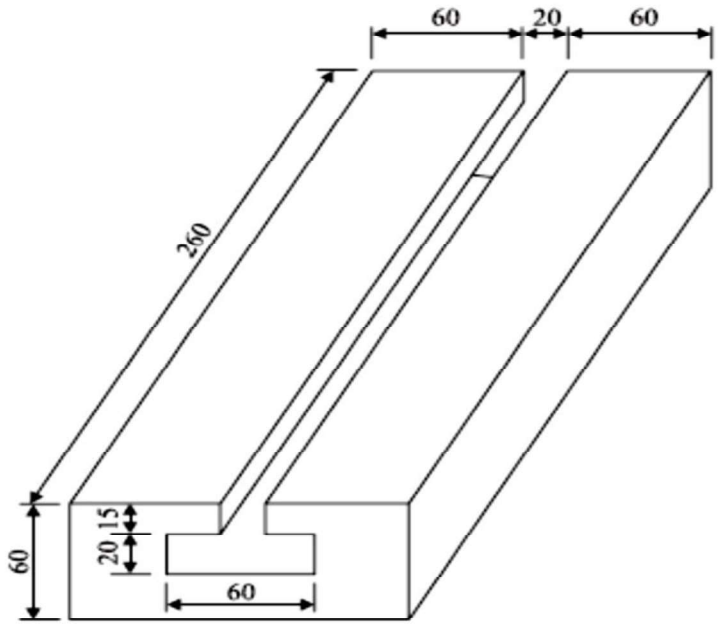
$$\text{Over travel} = \sqrt{Dd - d^2}$$

$$= \sqrt{80 \times 35 - 35^2} = 40 \text{ mm}$$

$$\text{Total tool travel} = 260 + 40 = 300 \text{ mm}$$

$$\text{Time for cutting slot} = \frac{\text{Length of cut}}{\text{Feed/min.}}$$

$$= \frac{300}{0.25 \times 100} = 12 \text{ min.}$$



Step II **:** Cut T-slot of dimensions 60 × 20 with a T-slot cutter
Here dia of cutter = 60 mm

$$\text{r.p.m. of cutter} = \frac{25 \times 1{,}000}{\pi \times 60} = 133$$

$$\text{In this case the over travel of tool} = \frac{1}{2} \text{ Dia of cutter,}$$

since dia of cutter = width of slot

$$\text{Over travel} = \frac{60}{2} = 30 \text{ mm}$$

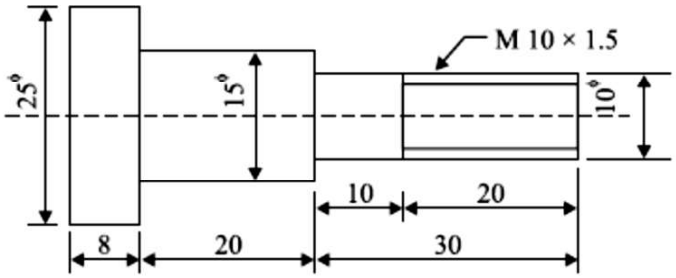
$$\text{Total tool/Table travel} = 260 + 30 = 290 \text{ mm}$$

$$\text{Time taken} = \frac{290}{0.25 \times 133} = 8.7 \text{ min}$$

Total time to cut T-slot = 12 + 8.7
= 20.7 minutes

6. Calculate the machining time required to produce one piece of the component shown in Fig. given below starting from f 25 mm bar. The following data is available. (16 marks) (AU N/D '14) (AU N/D '13)

For turning:
Cutting speed = 40 m/min.
Feed = 0.4 mm/rev.
Depth of cut = 2.5 mm/per pass
For thread cutting:
Cutting speed = 8 m/min.



Solution:

Step I **:** Time for turning to 15 mm dia from 25 mm dia.

As depth of material to be removed is

$$\frac{(25-15)}{2} = 5 \text{ mm.}$$

it will be accomplished in 2 cuts.

$$\text{Average Dia} = D_{av} = \frac{25+15}{2} = 20 \text{ mm.}$$

$$\text{Spindle r.p.m.} = \frac{40 \times 1{,}000}{20 \times \pi} = 637 \text{ rev/min.}$$

$$\text{Time taken} = \frac{50}{637 \times 0.4} = 0.2 \text{ min.}$$

For 2 cuts time taken = 0.4 min.

Step 2 **:** Turning from 15 mm to 10 mm dia over a length of 30 mm in one pass

$$N = \frac{40 \times 1{,}000}{\pi \times 15} = 850 \text{ rev/min.}$$

$$\text{Time taken} = \frac{30}{0.4 \times 850} = 0.09 \text{ min.}$$

Step 3 **:** Threading

$$N = \frac{8 \times 1{,}000}{\pi \times 10} = 255 \text{ r.p.m.}$$

$$\text{Feed} = \text{pitch} = 1.5 \text{ mm}$$

$$\text{Threads per cm} = \frac{10}{1.5} = \frac{100}{15}$$

$$\text{No. of cuts} = \frac{25}{\text{Threads per cm}}$$

$$= \frac{25 \times 15}{100} = 3.75 = 4 \text{ cuts}$$

$$\text{Time for one cut} = \frac{\text{Length of cut}}{\text{Feed/rev.} \times \text{r.p.m.}}$$

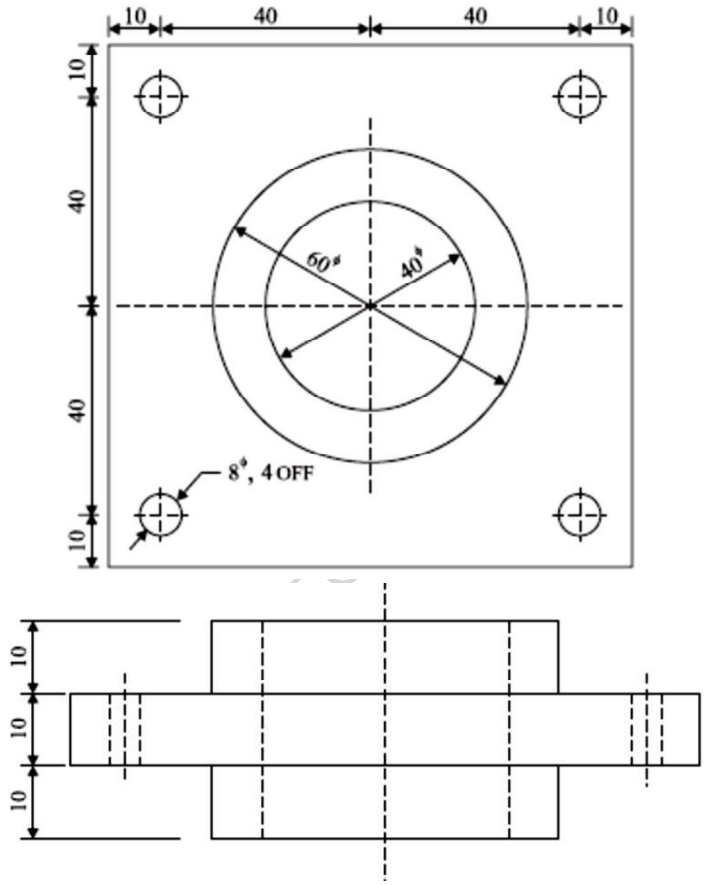
$$= \frac{20}{1.5 \times 255} = 0.05 \text{ min.}$$

Time for 4 cuts = $0.05 \times 4 = 0.2$ min.

Total time for producing one component = 0.4 + 0.09 + 0.2

= 0.69 min.

7. **Calculate the machining time to drill four 8 mm dia holes and one 40 mm dia central hole in the flange shown in Fig. 20 mm dia hole is drilled first and then enlarged to 40 mm f hole. Take cutting speed 10 m/min, feed for 8 mm drill 0.1 mm/rev, for 20 mm drill feed is 0.2 mm/rev. and for 40 mm f drill feed is 0.4 mm/rev. (16 marks) (AU A/M '17) (AU A/M '18)**



Solution :

(*i*) Time to drill four 8 mm dia holes

S = 10 m/min.

Dia of drill D = 8 mm.

L = 10 mm

f = 0.1 mm/rev.

$$N = \frac{S \times 1{,}000}{\pi D} = \frac{10 \times 1{,}000}{\pi 8}$$

$$= 398 \text{ r.p.m.}$$

$$\text{Time taken to drill one hole} = \frac{L}{f \times N} = \frac{10}{0.1 \times 398}$$

$$= 0.25 \text{ min.}$$

$$\text{Time to drill 4 holes} = 0.25 \times 4 = 1 \text{ minute.}$$

(*ii*) Time to drill one hole of 40 mm diameter :

This hole is made in two steps :

(*a*) Drill 20 mm ⌀ hole — 30 mm long

$$N = \frac{10 \times 1{,}000}{\pi \times 20} = 159 \text{ r.p.m.}$$

$$\text{Time taken} = \frac{30}{0.2 \times 159} = 0.95 \text{ min.}$$

(*ii*) Enlarge 20 mm ⌀ hole with 40 mm ⌀ drill

Here $$N = \frac{10 \times 1{,}000}{\pi \times 40} = 80 \text{ r.p.m.}$$

$$f = 0.4 \text{ mm/rev.}$$

$$\text{Time taken} = \frac{30}{0.4 \times 80} = 0.94 \text{ min.}$$

Total time taken to drill all the holes = 1.0 + 0.95 + 0.94

= 2.9 min.

11. Find the time required on a shaper to machine a plate 600 mm × 1,200 mm, if the cutting speed is 15 meters/min. The ratio of return stroke time to cutting time is 2 : 3. The clearance at each end is 25 mm along the length and 15 mm on width. Two cuts are required, one roughing cut with cross feed of 2 mm per stroke and one finishing cut with feed of 1 mm per stroke. (8 marks) (AU N/D '17)

Solution :

S = 15 m/minute

Length of stroke = L = Length of plate + clearance on both sides

= 1200 + 2 × 25 = 1,250 mm.

Cross travel of table = W = Width of job + clearance

= 600 + 2 × 15 = 630 mm.

K =2/3 = 0.67

Cross feed for rough cut = 2 mm/stroke

Cross feed for finish cut = 1 mm/stroke

$$\text{Time for one complete stroke} = \frac{L(1+K)}{1000 \times S}$$

$$= \frac{1.250\,(1+0.67)}{1.000 \times 15}$$

$$= 0.14 \text{ min}$$

$$\text{No. of strokes for roughing cut} = \frac{\text{Cross travel of table}}{\text{Feed/stroke (Roughing)}}$$

$$= \frac{630}{2} = 315$$

$$\text{No. of strokes for finishing cut} = \frac{\text{Cutting travel of table}}{\text{Feed/stroke (Finishing)}}$$

$$= \frac{630}{1} = 630$$

Total no. complete strokes required = 630 + 315 = 945

Total machining time = 945 × 0.14 = 132 min.

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Department of Mechanical Engineering

Lecture Notes

Subject Code : ME8791

Subject Name: MECHATRONICS

Sem/Year : 07/IV

Regulation : 2017

ME8791	MECHATRONICS	L	T	P	C
		3	0	0	3

OBJECTIVE:

- To impart knowledge about the elements and techniques involved in Mechatronics systemswhich are very much essential to understand the emerging field of automation.

UNIT I INTRODUCTION **9**

Introduction to Mechatronics – Systems – Concepts of Mechatronics approach – Need for Mechatronics - Emerging areas of Mechatronics - Classification of Mechatronics. Sensors and Transducers**:** Static and dynamic Characteristics of Sensor, Potentiometers - LVDT - Capacitance sensors - Strain gauges - Eddy current sensor – Hall effect sensor – Temperature sensors – Lightsensors

UNIT II MICROPROCESSOR AND MICROCONTROLLER **9**

Introduction - Architecture of 8085 - Pin Configuration - Addressing Modes - Instruction set, Timing diagram of 8085 – Concepts of 8051 microcontroller – Block diagram,.

UNIT III PROGRAMMABLE PERIPHERAL INTERFACE **9**

Introduction - Architecture of 8255, Keyboard interfacing, LED display - interfacing, ADC and DAC interface, Temperature Control - Stepper Motor Control – Traffic Control interface.

UNIT IV PROGRAMMABLE LOGIC CONTROLLER **9**

Introduction - Basic structure - Input and output processing - Programming - Mnemonics – Timers, counters and internal relays – Data handling – Selection of PLC.

UNIT V ACTUATORS AND MECHATRONIC SYSTEM DESIGN **9**

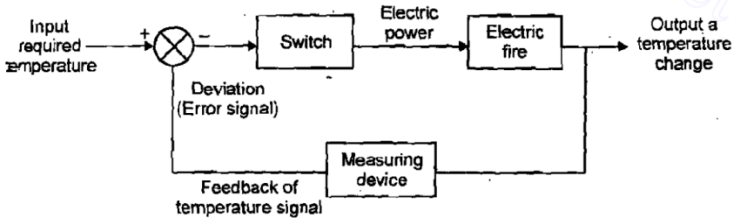
Types of Stepper and Servo motors – Construction – Working Principle – Advantages and Disadvantages. Design process-stages of design process - Traditional and Mechatronics design concepts - Case studies of Mechatronics systems - Pick and place Robot - Engine Management system – Automatic car park barrier.

TOTAL : 45 PERIODS

Unit-I Introduction

Closed loop system

If there is feedback device to compare the actual value with desired one, then the system is called closed loop control system.



Elements of Closed Loop System:

The elements of closed loop control system are Comparison Unit, Control Unit, Correction Unit, Process Unit, Measurement Device

i. **Comparision element**

This element compares the required or reference value of the variable condition being controlled with the measured value and produces an error signal.

Error signal = reference value-measured value

ii. **Control element**

This element decides the corrective action to be taken when an error signal is received by it.

iii. **Correction element**

Correction element is an actuator that produces a change in a process to correct or change the controller condition.

iv. **Process element**

An element that controls the process is known as process element.

Eg. Room temperature of a house is being controlled

v. **Measurement element**

The measurement element produces a signal related to the variable condition of the process that is being controlled.

2. Explain the static and dynamic characteristic of a sensor?

Range and Span:

- The range of a transducer defines the limits between which the input can vary.

- The difference between the limits (maximum value - minimum value) is known as span.
- For example a load cell is used to measure force. An input force can vary from 20 to 100 N. Then the range of load cell is 20 to 100 N. And the span of load cell is 80 N (i.e., 100-20)

Error:

- The algebraic difference between the indicated value and the true value of the measured parameter is termed as the error of the device.
- Error = Indicated value — true value
- For example, if the transducer gives a temperature reading of 30°C when the actual temperature is 29° C, then the error is + 1°C. If the actual temperature is 3 1° C, then the error is — 1°C.

Accuracy:

- Accuracy is defined as the ability of the instrument to respond to the true value of the measure variable under the reference conditions.
- For example, a thermocouple has an accuracy of ± 1° C. This means that reading given by the thermocouple can be expected to lie within + 1°C (or) — 1°C of the true value.
- Accuracy is also expressed as a percentage of the full range output (or) full scale deflection.
- For example, a thermocouple can be specified as having an accuracy of ±4 % of full range output. Hence if the range of the thermocouple is 0 to 200°C, then the reading given can be expected to be within + 8°C (or) — 8°C of the true reading.

Sensitivity:

- The sensitivity is the relationship showing how much output we can get per unit input.

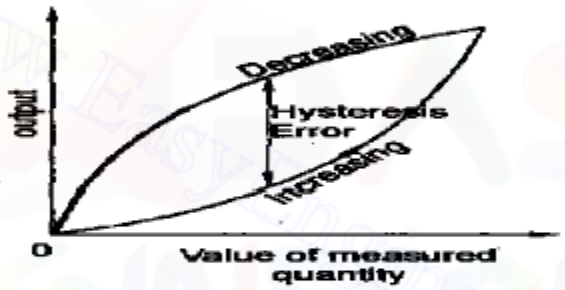
  Sensitivity = Output / Input

Precision:

- It is defined as the degree of exactness for which the instrument is intended to perform.

Hysteresis error:

- When a device is used to measure any parameter plot the graph of output Vs value of measured quantity.
- First for increasing values of the measured quantity and then for decreasing values of the measured quantity.
- The two output readings obtained usually differ from each other.



Repeatability:

- The repeatability and reproducibility of a transducer are its ability to give the same output for repeated applications of the same input value.

Reliability:

- The reliability of a system is defined as the possibility that it will perform its assigned functions for a specific period of time under given conditions.

Stability:

- The stability of a transducer is its ability to give the same output when used to measure a constant input over a period of time.

Drift:

- The term drift is the change in output that occurs over time.

Dead band:

There will be no output for certain range of input values. This is known as dead band. There will be no output until the input has reached a particular value.

Dead time:

- It is the time required by a transducer to begin to respond to a change in input value.

Resolution:

- Resolution is defined as the smallest increment in the measured value that can be detected. The resolution is the smallest change in the input value which will produce an observable change in the input.

Backlash:

- Backlash is defined as the maximum distance (or) angle through which any part of a mechanical system can be moved in one direction without causing any motion of the attached part.
- Backlash is an undesirable phenomenon and is important in the precision design of gear trains.

Dynamic characteristics

Response time:

- This is the time which elapses after a constant input is applied to the transducer up to the point at which the transducer gives an output corresponding to some specified percentage, e.g.95%, of the value of the input.

Time constant:

- This is the 63.2% response time. The time constant is a measure of the inertia of the sensor and so how fast it will react to changes in its input. The bigger the time constant, the slower the reaction to a changing input signal.

Rise time:

- This is the time for the output to rise to some specified percentage of the steady state output. Often the rise time refers to the time taken for the output to rise from 10% of the steady state value to 90 or 95% of the steady state value.

Settling time:

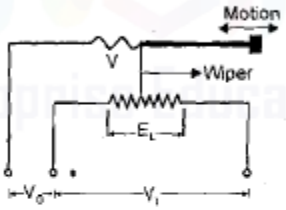
- This is the time for the output to settle to within some percentage, example 2% of the steady state value.

3. Explain the construction and working of potentiometer sensor and LVDT sensor.

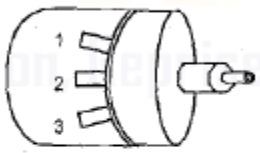
Potentiometer

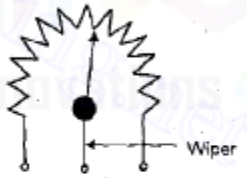
Principle:

It works on variable resistance transduction principle Linear or Rotary potentiometer is a variable resistance displacement transducer which uses the variable resistance transduction principle in which the displacement or rotation is converted into a potential difference due to the movement of sliding contact over a resistive element



Linear Potentiometer





Rotary Potentiometer

Construction & working:

- A resistor with three terminals.
- Two end terminal & one middle terminal (wiper)
- Two end terminal are connected to external input voltage
- One middle and one end terminal as output voltage

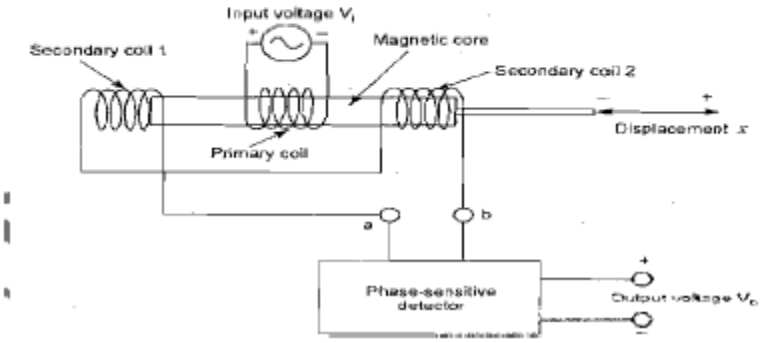
- The slider determines the magnitude of the potential difference developed

Characteristics:

- Resistance element = Precision Drawn wire with a diameter of about 25 to 50 microns, and wad over a cylindrical or a flat mandrel of ceramic, glass or Anodized Aluminium. 2mm to 500 mm in case of linear pot.
- Wipers (Sliders) = Tempered phosphor bronze, beryllium copper or other precious alloys.
- Wire Material = Strong, ductile and protected from surface corrosion by enamelling or oxidation. Materials &e alloys of copper nickel, Nickel chromium, and silver palladium.
- Resistance range = 20Ω to 200KΩ and for plastic 500Ω to 80KΩ
- Accuracy = Higher temperature coefficient of resistance than the wire and so temperature changes have a greater effect Accuracy.

Linear variable differential transformer:

- It consists of three symmetrically spaced coils.
- The centre coil is primary coil and other two are secondary coil
- Secondary coils are connected in series opposition and equally positioned with respect to primary coil
- The output voltage is proportional to the displacement of the core from null position



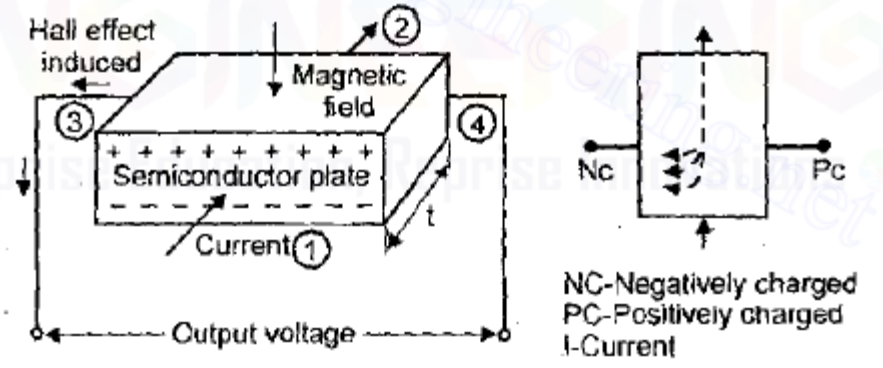
4. Explain the construction and working of eddy current and Hall Effect sensor.

Principle:

When a current carrying semiconductor plate is placed in a transverse magnetic field, it experiences a force (Lorentz force). Due to this action a beam of charged particles are forced to get displaced from its straight path. This is known as Hall Effect.

A current flowing in a semiconductor plate is like a beam of moving charged particles and thus can be deflected by a magnetic field. The side towards which the moving electron deflected becomes negatively charged and the other side of the plate becomes positively charged or the electrons moving away from it.

This charge separation produces an electrical voltage which continues until the Lorentz force on the charged particles from the electric field balances the forces produced by the magnetic field. The result is a traverse potential difference known as Hall voltage.



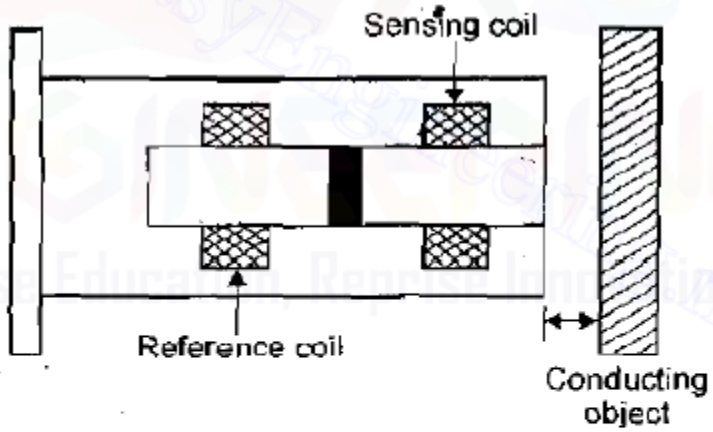
Current is passed through leads **1** and 2 of the semiconductor plate and the output leads are connected to the element faces 3 and **4**.

- These output faces are at same potential when there is no transverse magnetic field passing through the element and voltage **known** as Hall voltage appears when a transverse magnetic field is passing through the element.
- This voltage is proportional to the current and the magnetic field.
- The direction of deflection depends on the direction of applied current and the direction of magnetic field

Eddy current proximity sensor:

Principle:

When a coil is supplied with alternating current, an alternating magnetic field is produced which induces an EMF on it. If there is a metal near to this alternating magnetic field, on EMF is induced in it. The EMF cause current to flow. This current flow is eddy current.



Construction & working:

- It has two identical coils.
- One reference coil & another sensing coil which senses the magnetic current in the object.
- Eddy current start to flow due to AC(conducting object) close to sensor

- Eddy current produce a magnetic field to oppose the magnetic field generated by sensing coil.
- Due to this opposition reduction flux is created. To detect 0.001mm

5. Explain the construction and working of capacitive and strain gauge sensor.

Capacitive Sensors:

It is used for measuring, displacement, velocity, force etc.

Principle:

It is passive type sensors in which equal and opposite charges are generated on the plates due to voltage applied across the plate which is separated by dielectric material.

Formula:

The capacitance 'C' of a parallel plate capacitor is given by

$$C = \frac{\varepsilon_r \varepsilon_0 A}{d}$$

where ε_r = Permittivity of the dielectric between the plates [= 1 for air]

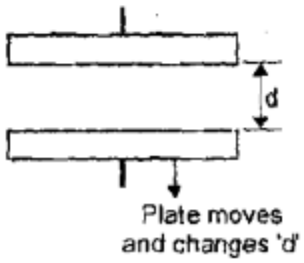
ε_0 = Permittivity of free space [= 8.854×10^{-12} F/m for air]

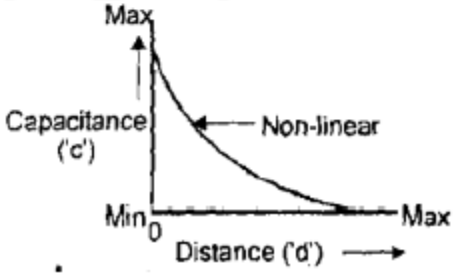
A = Area of overlap between two plates in m^2

d = Distance between two plates in m.

By Changing the Distance between Two Plates:

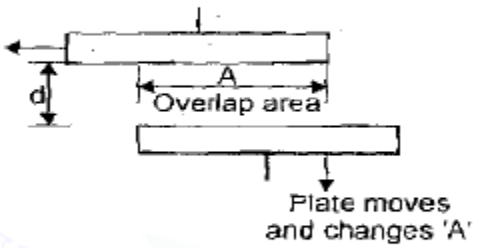
- The displacement is measured due to the change in capacitance

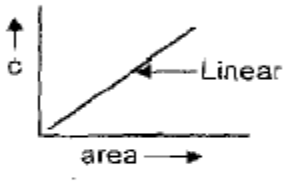




By Varying the Area of Overlap:

- The displacement causes the area of overlap to vary
- The capacitance is directly proportional to the area of the plates and varies linearly with changes in the displacement between the plates





By Varying the Dielectric Constant:

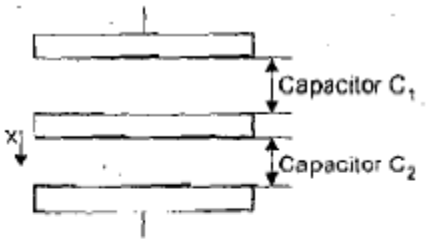
- The change in capacitance can be measured due to change in dielectric constant as a result of displacement.
- When the dielectric material is moved due to the displacement, the material causes the dielectric constant to vary in the region where the two electrodes are separated that results in a charge in capacitance

Push Pull Sensor:

- Push pull displacement sensor is used to overcome the non-linearity error.
- The sensor consists of three plates with the upper pair forming one capacitor and the lower pair forming another capacitor.
- The displacement moves central plate between the two other plates.
- If the central plate moves downwards.
- The plate separation of the upper capacitor increases and the separation of the lower one decreases.

$$\therefore C_1 = \frac{\varepsilon_0 \varepsilon_r A}{d + x}$$

$$C_2 = \frac{\varepsilon_0 \varepsilon_r A}{d - x}$$



Strain gauge:

- Strain gauges are passive type resistance sensor whose electrical resistance change when it is stretched or compressed (mechanically strained) under the application of force.
- The electrical resistance is changed due to the change in length (increases) and cross sectional area (decreases) of the strain gauge.
- This change in resistance is then usually converted into voltage by connecting one, two or four similar gauges as an arm of a Wheatstone bridge (known as Strain Gauge Bridge) and applying excitation to the bridge. The bridge output voltage is then a measure of strain, sensed by each strain gauge.

Unbonded Type Strain Gauges:

- In unbonded type, fine wire filaments (resistance wires) are stretched around rigid and electrically insulated pins on two frames.
- One frame is fixed and the other is movable.
- The frames are held close with a spring loaded mechanism.
- Due to the relative motion between two frames, the resistance wires are strained.
- This strain is then can be detected through measurement of the change in electrical resistance since they are not cemented with the surfaces, they can be detached and reused.

Bonded Type Strain Gauges:

- Bonded type strain gauges consists of resistance elements arranged in the form of a grid of fine wire, which is cemented to a thin paper sheet or very

thin Bakelite sheet, and covered with a protective sheet of paper or thin Bakelite.

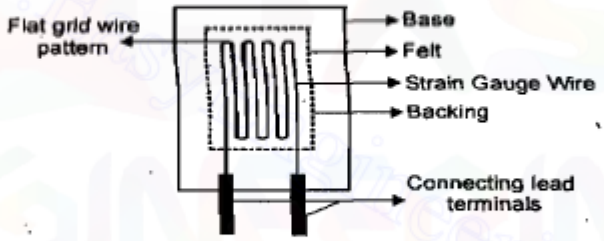
- The paper sheet is then bonded to the surface to be strained. The gauges have a bonding material which acts an adhesive material during bonding process of a surface with the gauge element.

Classification of Bonded Type Strain Gauges:

- Fine wire gauges
- Metal foil gauges
- Semiconductor filament type

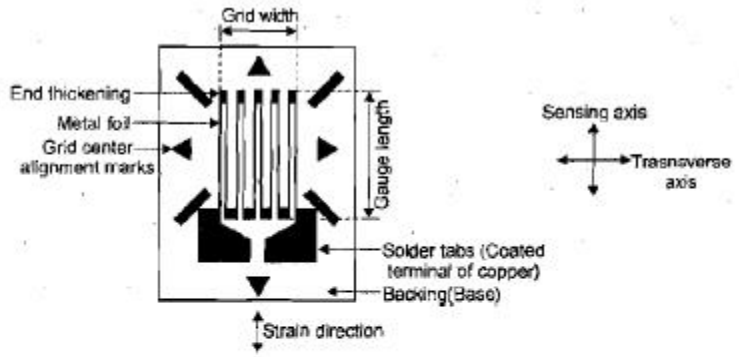
Fine Wire Gauges:

- Wire of 3 to 25 microns diameter is arranged in the form of grid consisting of parallel loops



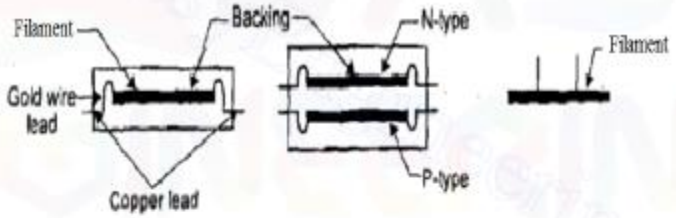
Metal Foil Gauges:

- A thin foil of metal, deposited as a grid pattern onto a plastic backing material using polyimide
- Foil pattern is terminated at both ends with large metallic pads
- Entire gauge size 5- 15mm



Semiconductor Filament Type:

- The gauges are produced in wafers from silicon or germanium crystals
- Special impurities such as boron is added
- It is mounted on an epoxy resin backing with copper on nickel leads
- Filament about 0.05mm thick 0.25mm wide and 1.25 to 12mm length

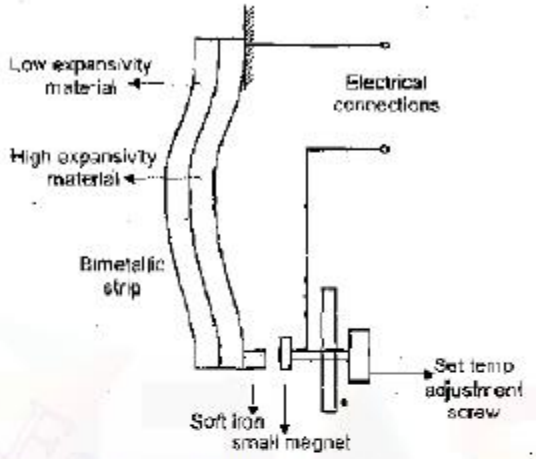


6. Explain any four temperature sensors.

Bimetallic Strips:

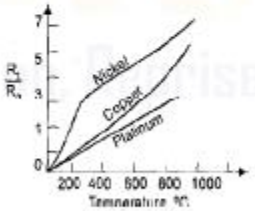
- A Bimetallic thermostat consists of two different metal strips bounded together and they cannot move relative to each other.
- These metals have different coefficients of expansion and when the temperature changes the composite strips bends into a curved strip, with the higher coefficient metal on the outside of the curve.
- The basic principle in this is all metals try to change their physical dimensions at different rates when subjected to same change in temperature.

- This deformation may be used as a temperature- controlled switch, as in the simple thermostat.



Resistance Temperature Detectors (RTDs):

- The materials used for RTDs are Nickel, Iron, Platinum, Copper, Lead, Tungsten, Mercury, Silver, etc.
- The resistance of most metals increases over a limited temperature range and the relationship between Resistance and Temperature is shown below.

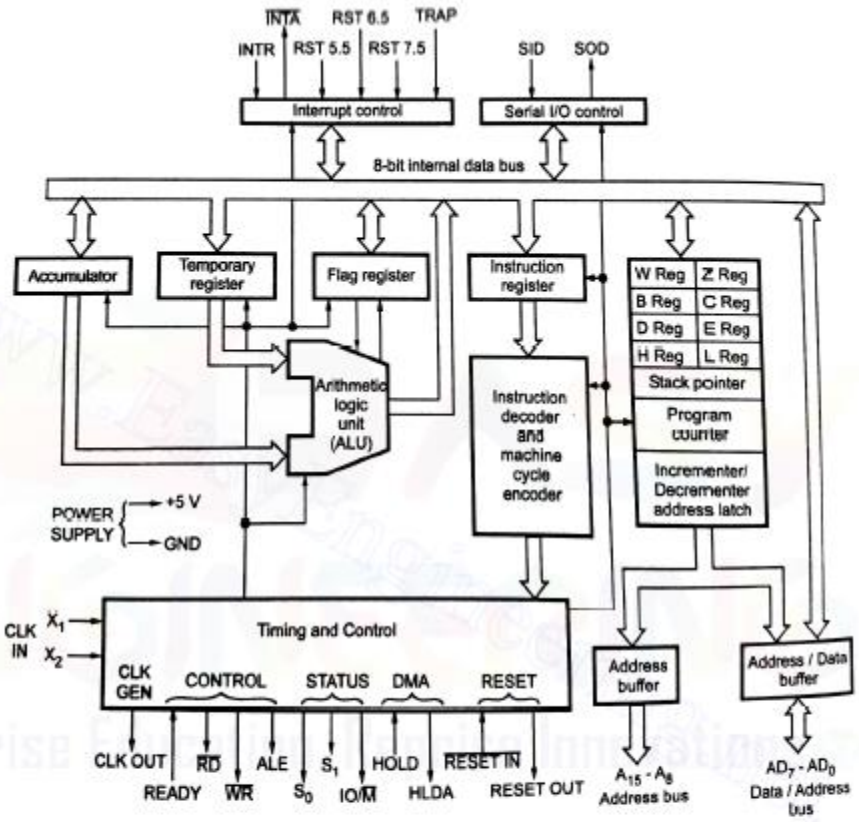


- The Resistance temperature detectors are simple and resistive elements in the form of coils of wire
- The equation which is used to find the linear relationship in RTD is

$$R_t = R_0 (1 + \alpha t)$$

Unit-II Microprocessor and Micro controller

Architecture of 8085 microprocessor



- It consists of various functional blocks.
- Registers
- Arithmetic and logic unit
- Instruction decoder and machine cycle encoder
- Address buffer
- Address/Data buffer
- Increment / Decrement address latch
- Interrupt control

- Serial control
- Serial I/O control
- Timing and control circuitry

Registers

It has eight addressable 8-bit registers A,B,C,D,E,H,L,F and two 16-bit registers PC and SP

These register can be classified as,

1. General purpose registers
2. Temporary registers
   (a) Temporary data register (b) W and Z registers
3. Special purpose registers
   (a) Accumulator (b) Flag registers (c) Instruction registers
4. 16-bit registers
   (a) Program counter (PC) (b) Stack pointer (SP)

General purpose registers:

- ✓ B,C,D,E,H,L are 8-bit general purpose registers can be used as a separate (or) as 16-bit register pairs BC, DE, HL.
- ✓ When used in register pair mode the higher order byte resides in the first register and the low order byte in the second.
- ✓ HL pair also functions as a data pointer (or) memory pointer. These are also called scratched registers as user can store data in them.
- ✓ To store and read data from these registers bus access is not required, it is an internal operation.
- ✓ Used to store intermediate results and use them when required.

Temporary registers:

(a) Temporary data register:

- ✓ The ALU has two inputs
- ✓ One input is supplied by the accumulator and other from temporary data register.

- ✓ The programmer cannot access this temporary data.

(b) W and Z registers:

- ✓ W and Z registers are temporary registers.
- ✓ These registers are used to hold 8-bit data during execution of some instructions.
- ✓ These registers are not available for programmer since 8085 uses them internally.

Special purpose registers:

(a) Register A (Accumulator)

- ✓ It is a tri state 8-bit register.
- ✓ It is extensively used in arithmetic, logic, load and store operations as well as input/output (I/O) operations.
- ✓ Most of the times the result of arithmetic and logical operations is stored in the register A.

(b) Flag register:

- ✓ It is an 8-bit register in which five of the bits carry significant information in the form of flags.
- ✓ S – Sign flag; Z – Zero flag; AC – Auxiliary carry flag; P – Parity flag; CY – carry flag.

S- Sign flag:

- ✓ After the execution of arithmetic (or) logical operations if bit D_7 of the result is 1, the sign flag is set.
- ✓ In a given byte if D_7 is 1, the number will be viewed as negative number.
- ✓ If D_7 is 0, the number will be considered as positive number.

Z – Zero flag:

- ✓ The zero flag sets if the result of operation is ALU is zero and flag resets if result is non zero.
- ✓ The zero flag is also set if certain register content becomes zero following as increment (or) decrement operation of that register.

AC – Auxiliary carry register:

- ✓ This flag is set if there is an overflow out of bit 3 i.e., carry from lower nibble to higher nibble (D_3 bit to D_4 bit).
- ✓ This flag is used for BCD operations and it is not available for the programmer.

P – Parity flag:

- ✓ Parity flag is defined as the number of one's present in the accumulator.

CY – carry flag:

- ✓ This flag is set if there is an overflow out of bit 7.
- ✓ The carry flag also serves as a borrow flag for subtraction.

© Instruction registers:

- ✓ In a typical processor operation the processor first fetches the opcode of instruction from memory.
- ✓ The CPU stores this opcode in a register called the instruction register.
- ✓ This opcode is further sent to the instruction decoder to select one of the 256 alternatives.

16-bit registers:

(a) Program counter (PC):

- ✓ Program counter is sequence of instructions
- ✓ The PC is a special purpose register which at a given time stores the address of the next instruction to be fetched.
- ✓ Program counter acts as a pointer to the next instruction.
- ✓ The Pc increments depends upon the nature of the instruction, for one byte instruction it increments program counter by one, for two byte instruction it increments PC by two and so on.

(b) Stack pointer (SP):

- ✓ The stack pointer is a reserved area of the memory in the RAM where temporary information may be stored.

- ✓ A 16-bit stack pointer is used to hold the address of the most recent stack entry.

Arithmetic logic unit (ALU):

- ✓ The 8085's ALU performs arithmetic and logical functions on 8-bit variables.
- ✓ The arithmetic unit performs addition and subtraction.
- ✓ The logic unit perform logical operations such as complement, AND, OR, EX-OR, rotate, clear etc.,
- ✓ The ALU also looks after the branching decisions.

Instruction decoder:

- ✓ The processor first fetches the opcode of instructions from memory and stores this opcode in the instruction register.
- ✓ It is then send to the instruction decoder.
- ✓ The instruction decoder decodes it and accordingly gives the timing and control signals which control the register, the data buffers, ALU etc.,
- ✓ The 8085 executes seven different types of machine cycles
- ✓ It gives the information about which machine cycle is currently executing in the encoded from on the S0, S1 and IO/$\overline{M}$ lines
- ✓ This task is done by machine cycle encoder.

Address buffer:

- ✓ This is an 8-bit unidirectional buffer.
- ✓ It is used to drive external high order address bus (A_{15} – A_8).
- ✓ It is also used to tri-state the high order address bus under certain conditions such as reset, hold, halt, and when address lines are not in use.

Address/Data buffer:

- ✓ This is an 8-bit bi-directional buffer.
- ✓ It is used to drive multiplexed address/data bus ie, lower order address bus (A_7-A_0) abd data bus (D_7-D_0).
- ✓ It is also used to tri-state the high order address bus under certain conditions such as reset, hold, halt, and when address lines are not in use.

- ✓ The address and data buffers are used to drive external address and data buses respectively.
- ✓ Due to these buffers the address and data buses can be tri-stated when they are not in use.

Increment/Decrement address latch:

- ✓ This 16-bit register is used to increment (or) decrement the contents of PC (or) AP as a part of execution of instruction related to them.

Interrupt control:

- ✓ The processor fetches, decodes and execute instructions in a sequence.

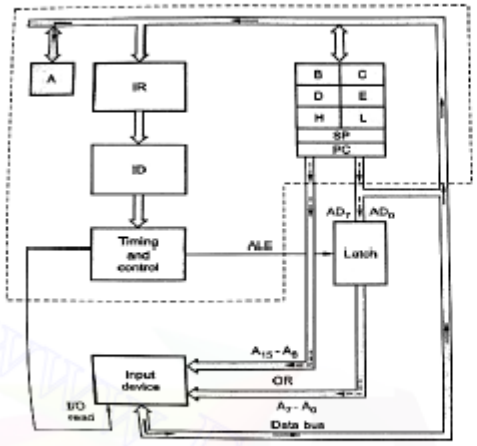
Serial I/O control:

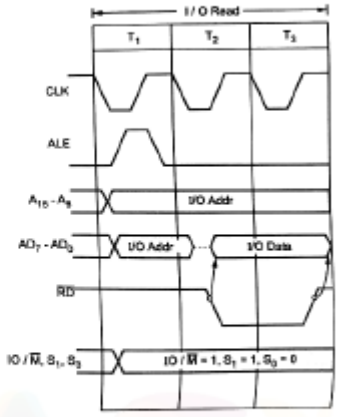
- ✓ In serial communication one bit is transferred at a time over a single line.
- ✓ The 8085 serial I/O control provides two lines, SOD and SID for serial communication.
- ✓ The serial output data (SOD) line is used to send data serially and serial input data (SID) line is used to receive data serially.

Timing and control circuitry:

- ✓ The control circuitry in the processor 8085 is responsible for all the operations.
- ✓ The control circuitry and operations in 8085 are synchronized with the help of clock signal.
- ✓ Control circuitry also generates signals required to interface external devices to the processor 8085.

2. Draw and explain the timing diagram of memory read and write operation.





Memory read cycle:

- The 8085 executes the memory read cycle to read the contents of R/W memory or ROM.
- The length of this machine cycle is 3T-states(T_1-T_3)
- In this machine cycle processor places the address on the address lines from the stack pointer, general purpose register pair or program counter and through the read process, reads the data from the addressed memory location.
- Memory read cycle is similar to the opcode fetch machine cycle.
- However they use only states T_1 to T_3 and the status signal values (IO/$\overline{M}$=0, S_1=1, S_0=0) appropriate for memory read machine cycle are issued in T_1.

The following section describes the memory read machine cycle in step by step manner.

Step 1: (State T_1)

- ✓ In T_1 state, microprocessor places the address on the address lines from the stack pointer, general purpose register pair or program counter and activates ALE signal in order to latch low-order byte of address.

- ✓ During T_1, 8085 sends status signal: IO/M=0, S_1=1, S_0=0 for memory read machine cycle.

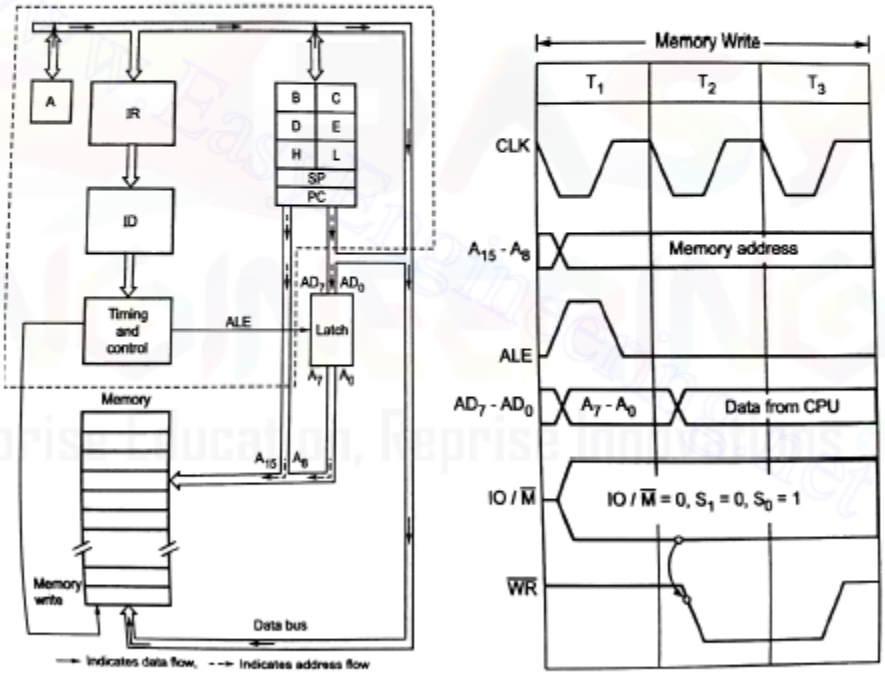
Step 2: (State T_2)

- ✓ In T_2, 8085 sends RD signal low to enable the addressed memory location.
- ✓ The memory device then places the contents of addressed memory location of the data bus (AD_0-AD_7).

Step 3: (State T_3)

During T_3, 8085 loads the data from the data bus into specified register (F, A, B, C, D, E, H and L) and raises RD to high which disables the memory device.

Memory write cycle:



- ✓ The 8085 executes the memory write cycle to store the data into data memory or stack memory.
- ✓ The length of this machine cycle is 3T-states(T_1-T_3)

- ✓ In this machine cycle processor places the address on the address lines from the stack pointer general purpose register pair and through the write process, stores the data into the addressed memory location.
- ✓ The memory write timing diagram is similar to the memory read timing diagram, except the instead of RD, WR signal goes low during T_2 and T_3.
- ✓ The status signals for memory write cycle are: $IO/\overline{M}$=0, S_1=0, S_0=1. The following section describes the memory write machine cycle in step by step manner.

Step 1: (State T_1)

- ✓ In T_1-state, the 8085 places the address on the address lines from stack pointer or general purpose register pair and activates ALE signal in order to latch low-order byte of address.
- ✓ During T_1, 8085 sends status signals: $IO/\overline{M}$ = 0, S_1=0, S_0=1 for memory write machine cycle.

Step 2: (State T_2)

- ✓ In T_2, 8085 places data on the data bus and sends WR signal low for writing into the addressed memory location.

Step 3: (State T_3)

- ✓ During T_3, WR signal goes high, which disables the memory device and terminates the write operation.

3. What are the different addressing modes in 8085 microprocessor? Explain it with an example?

Addressing mode specifies the location of operand (data). Every instruction of a program has to operate on a data. The method of specifying the data to be operated by the instruction is called Addressing. The 8085 has the following 5 different types of addressing.

a. Immediate Addressing
b. Direct Addressing
c. Register Addressing

d. Register Indirect Addressing
e. Implied Addressing

a. Immediate Addressing:

In immediate addressing mode, the data is specified in the instruction itself. The data will be a part of the program instruction. All instructions that have 'I' in their mnemonics are of immediate addressing type.

Example: MVI A, 01H- Move the data 01H given in the instruction to A register.

b. _Direct Addressing:

In direct addressing mode, the address of the data is specified in the instruction. The data will be in memory. In this addressing mode, the program instructions and data can be stored indifferent memory blocks. This type of addressing can be identified by 16-bit address present in the instruction.

Example:LDA 4500H- Load the data available in memory location 4500H in A register.

c. Register Addressing:

In register addressing mode, the instruction specifies the name of the register in which the data is available. This type of addressing can be identified by register names in the instruction.

Example: MOV A, B -Move the content of B register to A register.

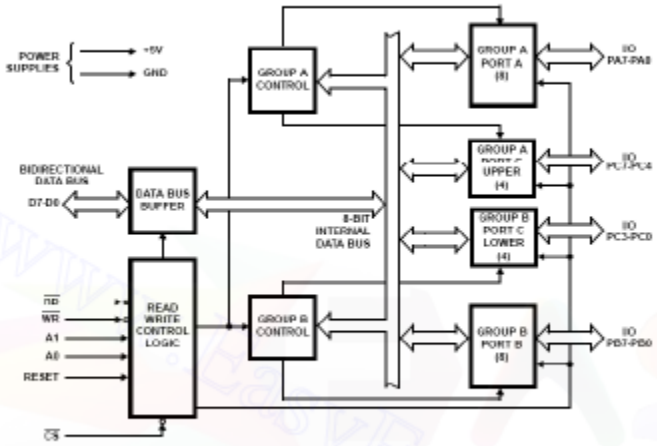
d. Register Indirect Addressing:

In register indirect addressing mode, the instruction specifies the name of the register in which the address of the data is available. The data will be in memory and the address will be in the register pair. This type of addressing can be identified by letter 'M' present in the instruction.

Example: MOV A, M - The content of memory (data) addressed by HL pair is moved to A register.

Unit III - PROGRAMMABLE PERIPHERAL INTERFACE

Block diagram of 8255 ppi



It has a 40 pins of 4 groups.

1. Data bus buffer

2. Read Write control logic

3. Group A and Group B controls

4. Port A, B and C

Data bus buffer:

This is a tri state bidirectional buffer used to interface the 8255 to system data bus. Data is transmitted or received by the buffer on execution of input or output instruction by the CPU.

- Control word and status information are also transferred through this unit.

Read/Write control logic

This unit accepts control signals (RD, WR) and also inputs from address bus and issues commands to individual group of control blocks

(Group A, Group B).It has the following pins.

a) CS – Chip select : A low on this PIN enables the communication between CPU and 8255.

b) RD (Read) – A low on this pin enables the CPU to read the data in the ports or the status word through data bus buffer.

c) WR (Write) : A low on this pin, the CPU can write data on to the ports or on to the control register through

the data bus buffer.

d) RESET: A high on this pin clears the control register and all ports are set to the input mode

e) A0 and A1 (Address pins): These pins in conjunction with RD and WR pins control the selection of one of the

3 ports.

Group A and Group B controls

These block receive control from the CPU and issues commands to their respective ports.

Group A - PA and PCU (PC7 –PC4)

Group B - PCL (PC3 – PC0)

• Control word register can only be written into no read operation of the CW register is allowed.

PORTS

a) **Port A:** This has an 8 bit latched/buffered O/P and 8bit input latch. It can be programmed in 3 modes – mode 0,

mode 1, mode 2.

b) **Port B:** This has an 8 bit latched / buffered O/P and 8 bit input latch. It can be programmed in mode 0, mode1.

c) **Port C :** This has an 8 bit latched input buffer and 8 bit out put latched/buffer. This port can be divided into two 4

bit ports and can be used as control signals for port A and port B. it can be programmed in mode 0.

Modes of Operation of 8255

These are two basic modes of operation of 8255. I/O mode and Bit Set-Reset mode (BSR).

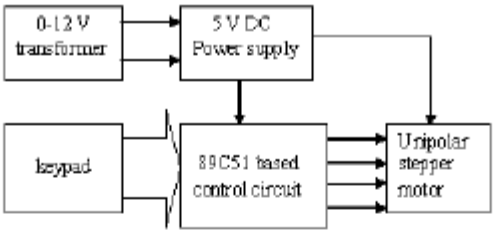
• In I/O mode, the 8255 ports work as programmable I/O ports, while in BSR mode only port C (PC0-PC7) can be used to set or reset its individual port bits.

• Under the I/O mode of operation, further there are three modes of operation of 8255, so as to support different types of applications, mode 0, mode 1 and mode 2.

BSR Mode: In this mode any of the 8-bits of port C can be set or reset depending on D0 of the control word.

2. Explain with a neat diagram the stepper motor control using 8051 microcontroller.

Stepper Motor Control using 8051 Microcontroller Circuit Design: The complete board consists of transformer, control circuit, keypad and stepper motor as shown in snap. The given figure shows the block diagram of project.



The circuit has inbuilt 5 V power supply so when it is connected with transformer it will give the supply to circuit and motor both. The 8 Key keypad is connected with circuit through which user can give the command to control stepper motor. The control circuit includes micro controller 89C51, indicating LEDs, and current driver chip ULN2003A. One can program the controller to control the operation of stepper motor. He can give different commands through keypad like, run clockwise, run anticlockwise, increase/decrease RPM, increase/decrease revolutions, stop motor, change the mode, etc. before we start with project it is must that we first understood the operation of unipolar stepper motor.

Unipolar stepper motor:-

In the construction of unipolar stepper motor there are four coils. One end of each coil is tide together and it gives common terminal which is always connected with positive terminal of supply. The other ends of each coil are given for interface. Specific color code may also be given. Like in my motor orange is first coil (L1), brown is second (L2), yellow is third (L3), black is fourth (L4) and red for common terminal.

By means of controlling a stepper motor operation we can

1. Increase or decrease the RPM (speed) of it

2. Increase or decrease number of revolutions of it

3. Change its direction means rotate it clockwise or anticlockwise

To vary the RPM of motor we have to vary the PRF (Pulse Repetition Frequency). Number of applied pulses will vary number of rotations and last to change direction we have to change pulse sequence.

So all these three things just depends on applied pulses. Now there are three different modes to rotate this motor

1. Single coil excitation

2. Double coil excitation

3. Half step excitation

The table given below will give you the complete idea that how to give pulses in each mode

Single coil excitation		Double coil excitation		Half step excitation	
Clockwise	Anticlockwise	Clockwise	Anticlockwise	Clockwise	Anticlockwise
L4 L3 L2 L1	L4 L3 L2 L1	L4 L3 L2 L1	L4 L3 L2 L1	L4 L3 L2 L1	L4 L3 L2 L1
0 0 0 1	0 0 0 1	0 0 1 1	0 0 1 1	0001	0001
0 0 1 0	1 0 0 0	0 1 1 0	1 0 0 1	0011	0011
0 1 0 0	0 1 0 0	1 1 0 0	1 1 0 0	0010	1000
1 0 0 0	0 0 1 0	1 0 0 1	0 1 1 0	0110	1001
				0100	0100
				1100	1100
				1000	0010
				1001	0110

Stepper motor has 6 pins. In these six pins, 2 pins are connected to the supply of 12V and the remaining are connected to the output of the stepper motor. Stepper rotates at a given step angle. Each step in rotation is a fraction of full cycle. This depends on the mechanical parts and the driving method.

Similar to all the motors, stepper motors will have stator and rotor. Rotor has permanent magnet and stator has coil. The basic stepper motor has 4 coils with 90 degrees rotation step. These four coils are activated in the cyclic order. The below

figure shows you the direction of rotation of the shaft. There are different methods to drive a stepper motor. Some of these are explained below.

Pulses for stepper motor module

Note:- In half step excitation mode motor will rotate at half the specified given step resolution. Means if step resolution is 1.8 degree then in this mode it will be 0.9 degree. Step resolution means on receiving on 1 pulse motor will rotate that much degree. If step resolution is 1.8 degree then it will take 200 pulses for motor to compete 1 revolution (360 degree).

Now let me give you the specification of the stepper motor that I have used.

Max rated voltage: - 5 V Max rated current per coil: – 0.5 Amp Step resolution: - 1.8 degree / pulse Max RPM: - 20 in single/double coil excitation mode and 60 in half step mode Torque: – 1.5 Kg/cm2

RPM calculation:-

One can calculate the exact RPM at which motor will run. We know that motor needs 200 pulses to complete 1 revolution. Means if 200 pulses applied in 1 second motor will complete 1 revolution in 1 second. Now 1 rev. in 1 sec means 60 rev. in 1 minute. That will give us 60 RPM. Now 200 pulses in 1 sec means the PRF is 200 Hz. And delay will be 5 millisecond (ms). Now lets see it reverse.

* If delay is 10 ms then PRF will be 100 Hz. * So 100 pulses will be given in 1 sec * Motor will complete 1 revolution in 2 second * So the RPM will be 30.

In same manner as you change delay the PRF will be changed and it will change RPM

Full Step Drive: In this method two coils are energized at a time. Thus, here two opposite coils are excited at a time.

Half Step Drive: In this method coils are energized alternatively. Thus it rotates with half step angle. In this method, two coils can be energized at a time or single coil can be energized. Thus it increases the number of rotations per cycle. It is shown in the below figure.

UNIT – IV PROGRAMMING LOGIC CONTROLLERS

Components of PLC

Definition of plc:

A programmable logic controller (PLC) Program is a specially designed digital operating microprocessor-based controller that uses a programmable memory for internal storage of instructing and for internal storage of instructing and for implementing function such as logic, sequencing, timing, counting and arithmetic in order to control machines and processes.

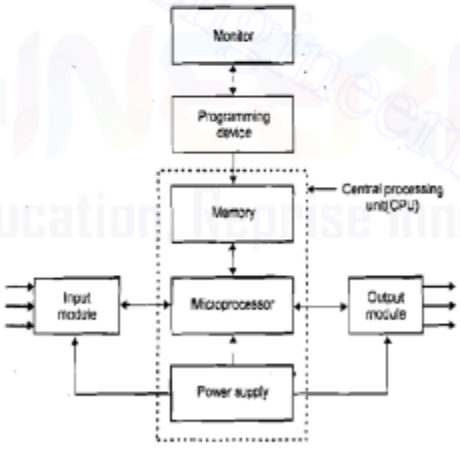
Basic components of plc:

The PLC hardware system consists of the basic components are

- Processor
- Memory
- Power Supply
- Input *I* Output modules
- Programming device
- Monitor

Processor:

- It is the heart of PLC
- He processor processes the signals from input module and generates controlling signals for the system
- It also scans and solve the logic of the user program
- It consists of ALU, microprocessor unit, memory unit and system power supply



Memory:

- The memory unit contains the program stored in it
- The programs were written with control actions to be executed by the microprocessor for the input given

- RAM is a temporary storage device used to store ladder diagram and for testing and evaluation
- Then it is stored in ROM where changes cannot done

Power Supply:

- The purpose of a power supply unit is to convert the main A.C voltage into a low – level D.C voltage (5V).
- The D.C. voltage is supplied to the processor and the circuits in the input and output interface modules.
- The power supply should be free from heavy loads, noises and voltage fluctuations.

Input / Output Modules:

- The Input module receives information from extended devices and sends to processor and communicates the processed information to the external devices through output modules.
- The Input devices are mechanical switches, photo sensors, temperature sensors, flow sensors, other type of sensors keypads etc.,
- The output devices may include solenoid valves, Relays, contactors, lights, Horns,
- Heating elements, fans, Motor starter, signal Amplifiers. Conveyor belt, lift, automatic door etc.,
- I/O devices are also called peripheral devices.

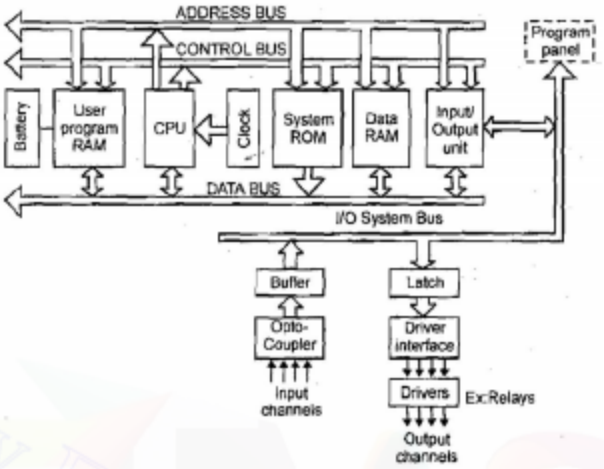
Programming Device:

- It is used to enter the required program into the memory of the CPU
- The program is developed in programming device and stored into memory unit

Central Processing Unit:

- The CPU controls and processes all the operations within the PLC.
- It is supplied with a clock with a frequency of typically between 1 to 8 MHz.
- This frequency determines the operating speed of the PLC and provides the timing and synchronization for all elements in the system.
- The information within the PLC is carried by means of digital signals.
- The processor is a microprocessor that executes a program to perform the operations specified in a ladder diagram or a set of Boolean equations.

- The CPU consists of the following units



Arithmetic and Logic Unit (ALU):

- This unit performs data manipulation and arithmetic and logical operations on input I variable data and determines the proper state of the output variables.
- The arithmetic operation includes addition, subtraction etc., and logic operations include AND, OR, AND, EXCLUSIVE - OR.

Memory Unit:

- Memory termed registers located within the microprocessor and used to store information involved in a program execution.
- These programs contain control actions to be executed by the microprocessor for the given input. There are several memory elements in a PLC system.
- System Read-only Memory (ROM) gives permanent storage for the operating system and fixed data wed by the CPU.
- RAM for the user to develop program and acts a temporary memory.
- In addition, temporary buffer stores for the I/O channels.

Control Unit:

- A control unit is used to control the timing of operations.

- The processor functions under a permanent supervisory operating system that directs the overall operations from data input and output to execution of user programs.
- The controller can perform only one operation at a time. So, it scans each of the inputs sequentially, evaluates the ladder diagram program, provide each output(s), and then repeat the whole process.
- Hence, the timing control's necessary for a PLC system.

Memory Unit:

- The sequence of instructions to be executed, programs are stored in the memory unit.
- During entering and editing including Debugging, the program is stored in the temporary storages called RAM (Random Access memory).
- Once the program is completely finished (free & from errors).
- It may be 'burned' into ROM
- When the ROM is plugged into the PLC, the device is ready to be placed into service in the industrial environment.
- For network programmed PLCs, the final PLCs program is downloaded into a special reprogrammable
- ROM (EPROM, PROM, and EEPROM) in the PLC.
- Memory may be either volatile type or Non-volatile type.

Volatile Memory:

- Volatile memory or temporary memory or Application memory is the user memory, where the user can enter and edit the program.
- Volatile memory will lose all its programmed contents if operating power is removed or lost.
- here for necessary to provide a battery backup power to all times.

Non Volatile Memory:

- Non-volatile memory or permanent memory or system memory is (used) a system memory that stores the monitor a booting programs, lookup tables etc.,
- This usually programmed and supplied by the manufacturer.
- This controls the operation of PLC.
- It does not lose its content during power failure.
- It does not require any battery.

- The ROM memory offers the CPU to use only fixed amount of data.

The Different Types of ROMS are

- Mask programmed ROM
- PROM
- EPROM
- EEPROM

Mask Programmed ROM:

- It is a special type of ROM which is programmed during manufacturing.
- The programmed content stored by this type of ROM memory cannot be altered.

PROM:

- PROM stands for programmable Read only memory.
- It is a special type of ROM usually programmed by manufacturer during manufacturing.
- It has the disadvantage of requiring special programming device and once programmed Cannot be erased or altered.

EPROM:

- EPROM stands for electrically programmable Read only Memory.
- Here, the user programs electrically.
- One can erase the program completely by shining UV light source or quartz window in package.
- After the program chip is erased completely, program changes can be made.
- When the program developed in RAM, the manufacturers usually load it in EPROM to make permanent storage.

EEPROM:

- EEPROM - Electrically Erasable programmable Read-only memory.
- Even though, it is a non-volatile memory, it offers some programming flexibility as RAM.
- One can erase the program completely by electrical signals.
- Program changes can be made very easily with the use of a PC with EEPROM software.
- It can be electrically programmable by the user.

Buses:

- A set of parallel lines that provides communication between various devices of a system is termed as a Bus.
- The bus system carries information and data's to and from the CPU, Memory and I/O units.
- The information is transmitted in binary form as 0 or 1
- Digital signals or electrical signals are flowing inside the bus.
- It might be tracks on a printed circuit board (PCB) or wires in a ribbon cable.
- The PLC system contains four buses.
- They are namely Data Bus, Address Bus, Control bus and system bus.

Data Bus:

- The data bus contains 8, 16 or 32 parallel signal lines for sending data between the various devices of a system.
- An 8-bit microprocessor has an internal data bus which can handle 8-bit numbers.

Address Bus:

- The Address bus contains 16, 20, 24 or 32 parallel signal lines to carry the Address of the memory locations for accessing stored data.
- Every memory location is given a distinct unique address to locate easily and accessed by the CPU either to read or write data.

Control Bus:

- The Control bus contains 4 to 10 parallel signal lines to carry the signals used by the CPU that are related to internal Control actions. Typical control bus signals are Memory read Memory write, I/O Read and I/O write.

I/O System Bus:

- The I/O system bus provide the communication between the I/O ports and I/O units

Input / Output Unit:

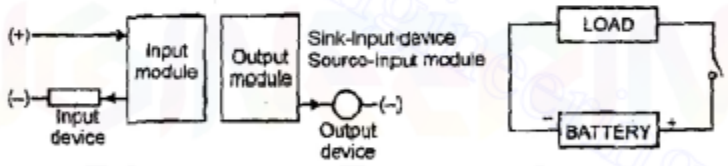
- The I/O units provide the interface between the system and the outside world, allowing for connections to be made through I/O channels to input / output devices.
- Programs are entered from a program panel through I/O unit.

2. Explain the input / output processing of plc.

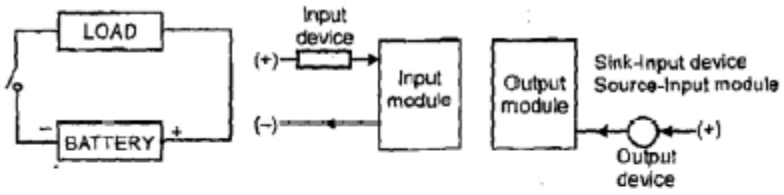
- The sourcing and sinking are used to describe the way in which DC devices are connected to PLC

Sourcing:

- If a switch is connected to the positive of the battery and current flows from positive to negative, it is said to be the sourcing the current. So, the input device receives current from the input module.
- For the PLC, input unit, hence input module is the source of the current. For the PLC output unit, output module is the source of current as it supplies current to the output devices. Sourcing output units for interfacing with solenoids.



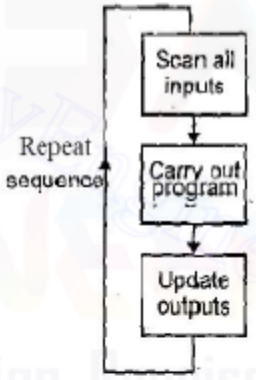
- Here, the input device supplies current to the input module. For the PLC input unit, hence the input module is the sink for the current. Sinking input units are used for interfacing with electronic equipment.
- So, if a switch is connected to the negative of the battery and current flows from positive to negative, by conventional current flow direction, it is said to be the sinking for Current. For the PLC output unit, the current flows from output device to the output module then the output module is the sink for current.



Steps involved in input / output processing:

The sequence followed by a PLC when carrying out a program can be as follows:

- Scan the inputs associated with one rung of the ladder program
- Solve the logic operation involving those inputs.
- Set / Reset the outputs for that rung
- Move on the next rung and repeat the operations 1, 2, 3



The two methods of Input/ Output processing operations are

- Continuous updating
- Mass Input / Output copying

Continuous Updating:

The sequence followed thus in continuous updating is as follows:

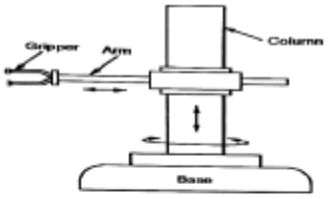
- Fetch and decode the first program instruction
- Scan there relevant inputs
- Fetch and decode the second program instruction
- Scan the relevant inputs etc. For the remaining program instructions

UNIT – V ACTUATORS AND MECHATRONIC SYSTEM DESIGN

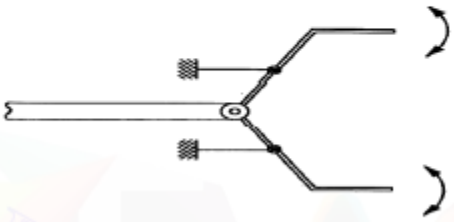
Pick and place robot

The basic from of a pick and place robot is shown in Figure. The robot has three axes about which motion can occur. The following movements are required for this robot.

1. Clock wise and anticlockwise rotation of the robot unit of its base.
2. Linear movement of the arm horizontally i.e., extension or contraction of arm.
3. Up and down movement of the arm and
4. Open and close movement of the gripper.



Basic form of a pick and place robot

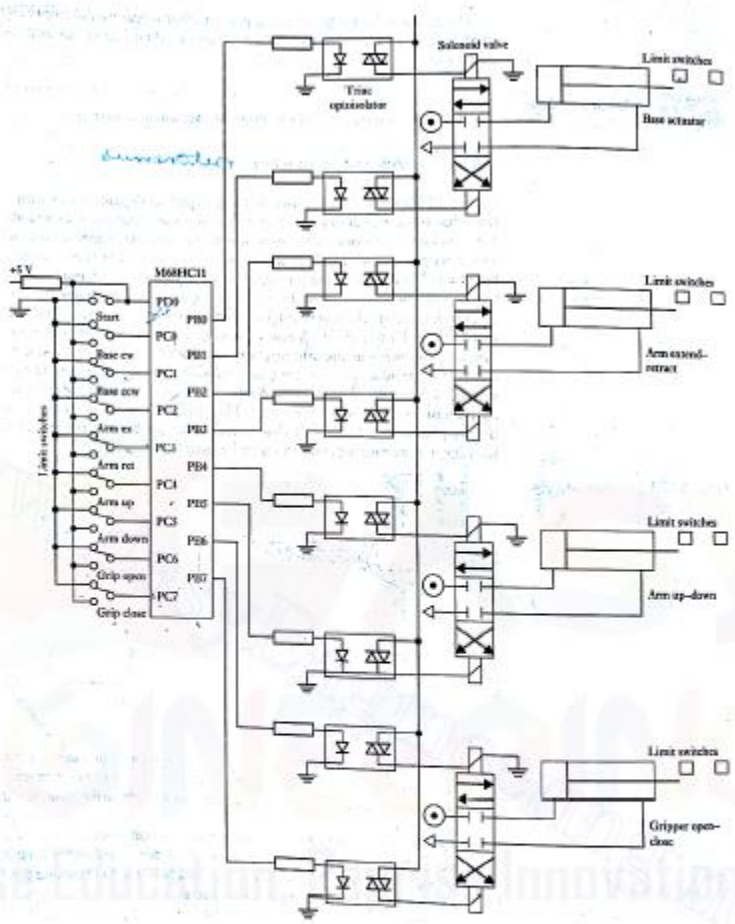


Gripper mechanism of a robot

The foresaid movements can be obtained by pneumatic cylinders which are operated by solenoid valves with limit switches. Limit switches are used to indicate when a motion is completed.

The clockwise rotation of the robot unit on its base can be obtained from a piston and cylinder arrangement during pistons forward movement. Similarly counter clockwise rotation can be obtained during backward movement of the piston in cylinder. Linear movement of the arm can result during forward and backward movement of the piston in a cylinder.

The upward movement of the arm can result from forward movement of the piston in a cylinder whereas downward movement from its retardation. The griper can also be operated in a similar way as explained above i.e., gripper is opened during forward movement of the piston and closed during backward movement of the piston in the cylinder. Figure 5.16 shows a mechanism used for this purpose.



A microcontroller used to control the solenoid valves of various cylinders is shown in Figure. The micro controller used of this purpose is M68HC11 type. A software program is used to control the robot.

TRIAC optoisolator consists of LED and TRIAC. If the input of the LED is 1, it glows and activates the TRIAC to conduct the current to the solenoid valve. Otherwise TRIAC will not conduct the current to the solenoid valve.

2. Case study on engine management system

An electronic engine management system is made up of sensors, actuators, and related wiring that is tied into a central processor called microprocessor or microcomputer (a smaller version of a computer)

Electronic management systems monitor and gather data from a number of sensors in the engine and continuously adjust the fuel supply and injection timing. This minimizes emissions and maximizes fuel efficiency and engine output at any given workload. The electronic engine management generally consists of the following basic components: An electronic control unit (ECU), a fuel delivery system (typically fuel injection), an ignition system and a number of sensors. Figure 5.21 shows the various components in the typical engine management system.

1. Electronics control unit (ECU) :

The sensors provide feedback to the ECU to indicate how the engine is running so that the ECU can make the necessary adjustments to the operation of the fuel delivery and / or ignition system.

2. Fuel delivery system :

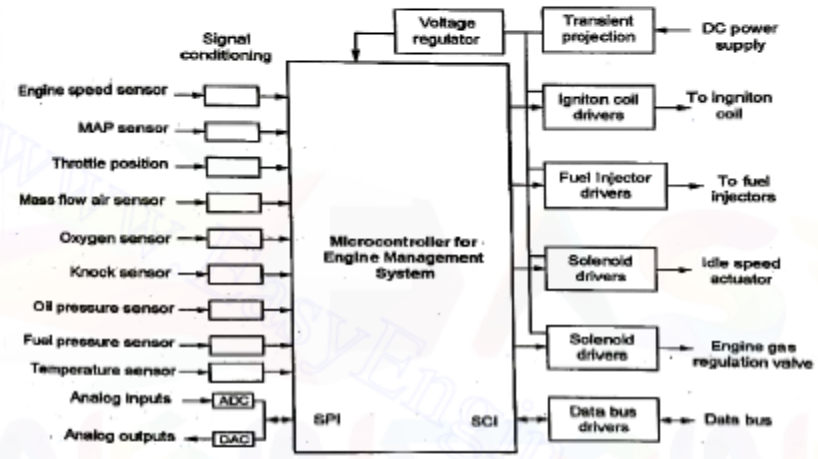
This system consist high pressure fuel pump which is mounted in or near the tank. The fuel line the pump passes through a filter before it runs forward to the engine bay. The fuel line connects to a fuel rail that feeds each of the injectors. At the end of the rail is a fuel pressure regulator, with surplus fuel heading back to the tank in the return line.

3. Ignition system :

Ignition system consists of ignition coil, distributor and spark plug. These components are connected with the ECU to receive the signal for proper timed operation.

4. Various sensors :

Engine sensors fall into five broad categories. Throttle – Position Sensors, Exhaust Gas Oxygen Sensors, Manifold Absolute Pressure Sensors, Temperature Sensors and Speed / Timing Sensors. All these sensor functions are centrally controlled by microcontroller as shown in Figure.



a. Throttle – Position Sensors :

A throttle – position sensor sends the signal to ECU about the throttle opening and the force applied by the driver. Then the ECU controls the fuel delivery and spark timing based on the throttle position. Two common throttle – position sensors are potentiometric and Hall – effect sensors.

b. Exhaust Gas Oxygen (EGO) Sensors :

Exhaust gas oxygen (EGO) sensors are places within the engine's exhaust system. The amount of oxygen in the exhaust gas indicates whether or not the ECU has directed the fuel delivery system to provide the proper air – to fuel ratio. If the relative amount of air is too high or too low, engine power, smoothness, fuel efficiency and emissions will all suffer.

c. Manifold Absolute Pressure (MAP) Sensors:

Manifold Absolute Pressure (MAP) Sensors measure the degree of vacuum in the engine's intake manifold. The amount of vacuum depends on engine rpm and throttle opening. The most common MAP sensors are piezoresistive and variable capacitor sensors.

d. Temperature Sensors:

Temperature sensors are used to report engine temperature to the driver / operator via dash panel mounted temperature gauge, report engine temperatures to the ECU to activate / de – activate cooling fans in water – cooled engines, to richen fuel mixtures for easier starting in cold weather and to lean out mixtures for maximum fuel economy. Two common temperature sensors are thermistors or thermodiodes.

e. Engine Speed / Timing Sensors :

Speed / Timing sensors provide information to the ECU regarding engine speed and the crank position. This information is used by the ECU to control fuel and ignition, as well as to make sure that engine speed does not exceed safe operating limits. It is also used to control the fuel injectors and spark plugs. Most common speed/timing sensors are variable reluctance, optical crankshaft position and Hall Effect sensors.

f. Exhaust Gas regulation (EGR) Valve Position Sensor:

The signal from EGR valve position sensor is used to adjust the air fuel mixture. The exhaust gases introduced by the EGR valve into the intake manifold reduce the available oxygen and thus less fuel is needed in order to maintain low hydro carbon level in the exhaust.

g. Mass Air flow (MAF) sensor :

MAF sensor is used to measure engine load to squirt in the right amount of petrol, and fire the spark at just the right moment. The amount of power

being developed depends on how much air the engine is breathing. Most common airlflow sensors are Hot Wire Airflow sensor and V and Airflow Meter.

h. Knock Sensor :

The knock sensor is used to identify the sounds of knocking and sends signal to ECU to avoid knocking. It is screwed into the engine block and is designed to separate out the special noise which means that knocking is occurring. Many Electronic Fuel Injection (EFI) engines run ignition timing very close to knocking.

The comparison of traditional and mechatronics approach in engine management is given in Table.

Table Traditional Vs Mechatronics approach in Engine Management

Sl.No.	Traditional approach	Mechatronics approach
1.	The cam operated rocker arm mechanism controls the valve operation. The rotation of cam is based on the crank rotation.	The valve operation is controlled by the signal received from electronic control unit. The timing of valve operation is pre programmed in the micro controller.
2.	The engine speed regulation is based on the governor controlled throttle valve. The governor is actuated by the speed of the crank shaft. The speed control has not effect on the engine temperature and air flow rate.	The engine speed regulation is based on the input signal from and MAF sensor. Based on the sensor information the throttling valve is controlled by microcontroller.
3.	Spark timing of the spark plug is controlled by the ignition coil and distributor at constant pre set	Spark timing of the spark plug is controlled by the ignition coil that receives signal from the microcontroller through a timing

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Lecture Notes

Subject Code : OML751

Subject Name: TESTING OF MATERIALS

Sem/Year : 07/IV

Regulation : 2017

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UNIT I

INTRODUCTION TO MATERIALS TESTING

SYLLABUS

Overview of materials, Classification of material testing, Purpose of testing, Selection of material, Development of testing, Testing organizations and its committee, Testing standards, Result Analysis, Advantages of testing.

1.1. OVERVIEW OF MATERIALS

❖ A material is defined as a substance (most often a solid, but other condensed phases can be included) that is intended to be used for certain applications. There are infinite number of materials around us - they can be found in anything from buildings to spacecraft.

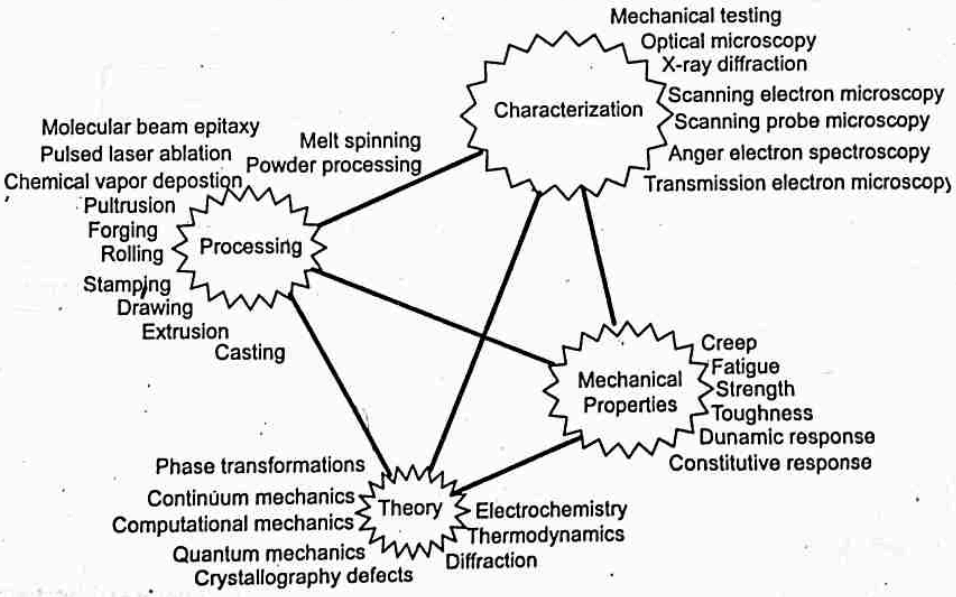


Fig. 1.1. Role of material testing

- Materials can generally be further divided into two classes: crystalline and non-crystalline. The traditional examples of materials are metals, semiconductors, ceramics and polymers. New and advanced materials that are being developed include nanomaterial, biomaterials and energy materials to name a few.
- The basis of materials science involves studying the structure of materials, and relating them to their properties.

1. CLASSIFICATION OF MATERIALS

Solid materials have been conveniently grouped into three basic categories,

- Metals
- Ceramics
- Polymers

This scheme is based primarily on chemical makeup and atomic structure, and most materials fall into one distinct grouping or another.

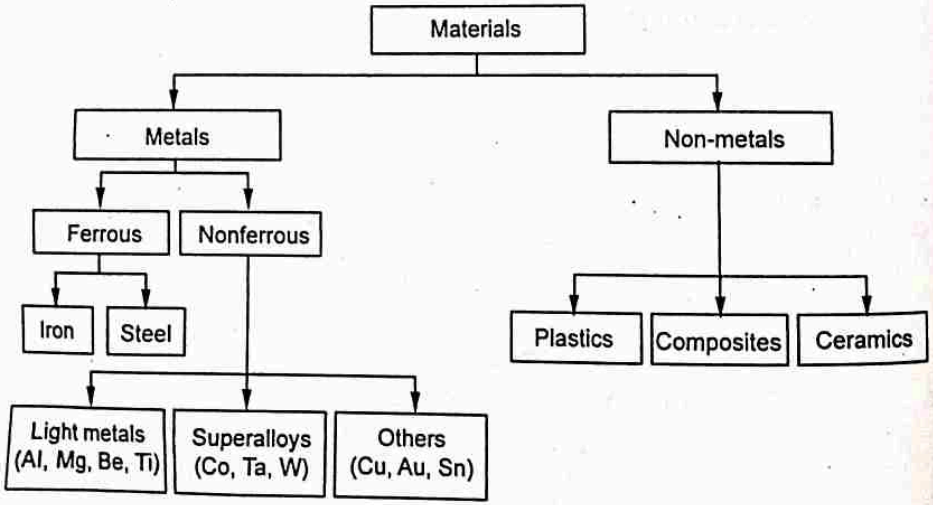
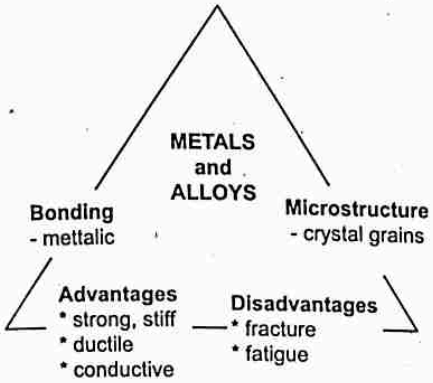


Fig. 1.2. Classification of materials

(i) Metals

- **Metals** are opaque, lustrous elements that are good conductors of heat and electricity. Most metals are malleable and ductile and are, in general, denser than the other elemental substances.

- Metals major classifications are metallic elements (e.g., iron, aluminum, copper, titanium, gold, and nickel), and often also Non-metallic elements (e.g., carbon and oxygen) in relatively small amounts.



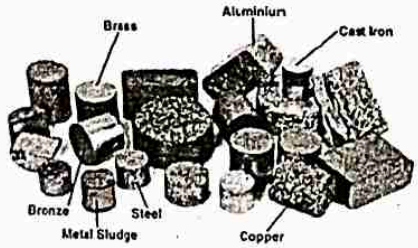


Fig. 1.3. Metal

(ii) Ceramics

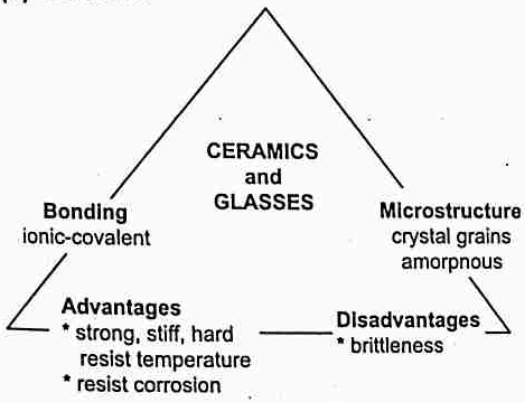


Fig. 1.4. Ceramics

- A **ceramic** is an inorganic non-metallic solid made up of either metal or non-metal compounds that have been shaped and then hardened by heating to high temperatures.
- It is compounds between metallic and nonmetallic elements; they are most frequently oxides, nitrides, and carbides.

(iii) Polymers

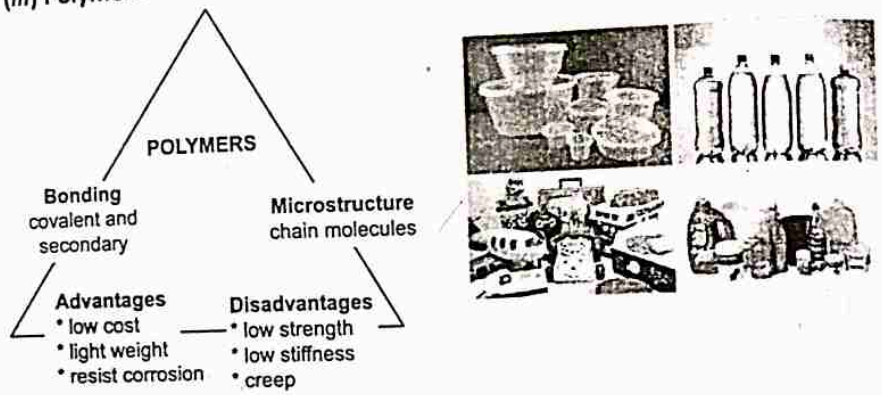


Fig. 1.5. Polymers

- A **polymer** is a large molecule, or macromolecule, composed of many repeated subunits. Due to their broad range of properties, both synthetic and natural polymers play essential and ubiquitous roles in everyday life.
- Many of them are organic compounds that are chemically based on carbon, hydrogen, and other non-metallic elements (i.e., O, N, and Si).

(iv) Composites

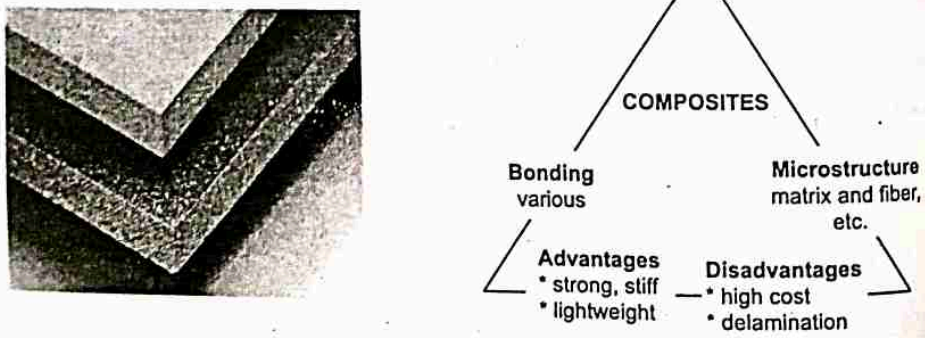


Fig. 1.6. Composites

- A **composites** is a material made from two or more constituent materials with significantly different physical or chemical properties that, when combined, produce a material with characteristics different from the individual components.
- A composite is composed of two (or more) individual materials, which come from the categories previously discussed metals, ceramics, and polymers.

(v) Advanced Materials

- Materials that are utilized in high-technology (or high-tech) applications are some- times termed advanced materials.; examples include electronic equipment (camcorders, CD/DVD players, etc.), computers, fiber-optic systems, spacecraft, aircraft, and military rocketry ,materials that are used for lasers, integrated circuits, magnetic information storage, liquid crystal displays (LCDs), and fiber optics.
- Some of the advanced materials are
  - Semiconductors
  - Biomaterials
  - Smart Materials
  - Nanomaterial

Table 1.1. Comparison between various materials

Property	Metals	Ceramics	Polymers
Bonding	Metallic (Free - Electron Cloud)	Ionic Or Covalent	Covalent
Compressive Strength (Mpa)	100 –1,500	1,000 –5,000	-
Corrosion Resistance	Low To Medium	Superior	Medium
Density (g/cm^3)	From 2 to 20	From 1 to 14	From 1 to 2.5
Ductility or Strain-to Fracture (%)	4 – 40	<1	2 - 4
Electrical Conductivity	High	Low	Low

Property	Metals	Ceramics	Polymers
Fracture Toughness ($MNm^{-3/2}$)	10 – 30	1-10	2-8
Maximum Service Temperature(°C)	1,000	1,800	250
Structure	Mostly Crystalline (Face-Centered Cubic (FCC), Body-Centered Cubic(BCC),Hexagonal Closed Packed(HCP)	Complex Crystalline Structure	Amorphous Or Semi crystalline Polymer
Tensile Strength (Mpa)	100 –1,500	100 – 400	-
Thermal Conductivity	High	Low	Low

2. Bonding in Solids

- The chemical bonds that hold atoms and molecules together in solids. There are two types bonds
  1. Primary bond
  2. Secondary bond

(*a*) Primary bond

- Primary bonds are strong and stiff and do not easily melt with increasing temperature. They are responsible for the bonding of metals and ceramics, and they provide the relatively high elastic modulus (E) in these materials.
- Three types of bonds ionic, covalent, and metallic are collectively termed primary bonds.

(*i*) Ionic bonds

- Ionic bonds occur as a result of strong electrostatic Coulomb attractive forces between positively and negatively charged ions.

(*ii*) Covalent Bonds

- Covalent bonds are often found between atoms with nearly complete outer shells. The atoms typically achieve a more stable electronic structure (lower energy state) by sharing electrons in outer shells to form structures with completely filled outer shells .

(*iii*) Metallic Bonds

- Metallic bonds are the third type of primary bond. The theory behind metallic bonding is often described as the Drude–Lorenz theory (gives relation between thermal conductivity and electrical conductivity).
- Metallic bonds can be understood as the overall effect of multiple electrostatic attractions between positively charged metallic ions.

(*b*) Secondary Bond

- Secondary or physical forces and energies are also found in many solid materials; they are weaker than the primary ones but it influence the physical properties of some materials.
- Van der Waals and hydrogen bonds, which are relatively weak, are called secondary bonds.

(*i*) Van der Waals force

- Small electrostatic attractions may develop between the atoms with slightly higher electron densities and the atoms with slightly lower electron densities. The slight deviation in the electrostatic charges on the atoms are often referred to as temporary dipole attractions or Van der Waals' forces.

(*ii*) Hydrogen Bonds

- Hydrogen bonds are induced as a result of permanent dipole forces.
- Due to the high electronegativity (power to attract electrons) of the oxygen atom, the shared electrons in the water (H_2O) molecule are more strongly attracted to the oxygen atom than to the hydrogen atoms.

3 . Structure in Crystalline Materials

- Metals and ceramics are composed of aggregations of small grains, each of which is an individual crystal. In contrast, glasses have an amorphous or non-crystalline structure.

- For example: Polymers are composed of chainlike molecules, which are sometimes arranged in regular arrays in a crystalline manner.

Basic Crystal Structures

- The arrangement of atoms (or ions) in crystals can be described in terms of the smallest grouping that can be considered to be a building block for a perfect crystal. Such a grouping, called a unit cell, can be classified according to the lengths and angles involved.
- For example: In three-dimensional space with seven major crystallographic unit cells may be better classified into 14 Bravais lattices.

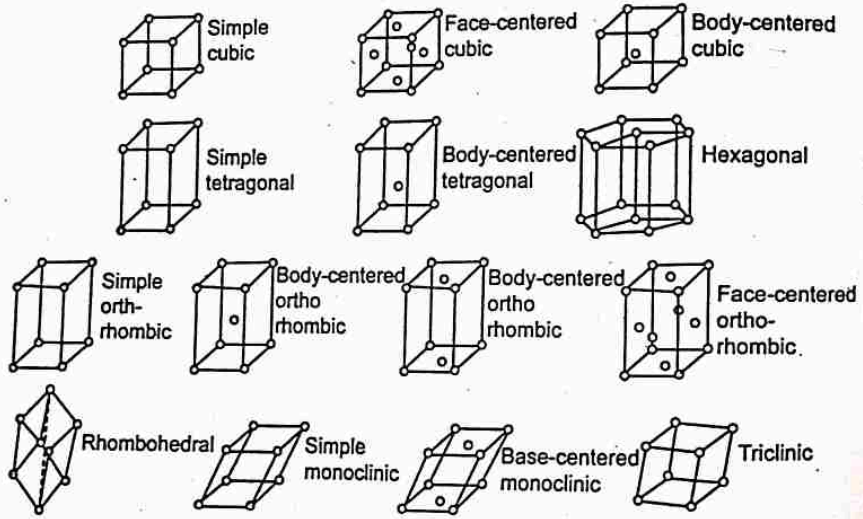


Fig. 1.7. Bravais lattices

4. DEFECTS IN CRYSTALS

- Ceramics and metals in the form used for engineering applications are composed of crystalline grains that are separated by grain boundaries.
- Even within grains, the crystals are not perfect; with defects occurring that can be classed as point defects and line defects or surface defects.
- Line defects are also called as dislocations where the edges of surfaces is relatively displaced lattice planes.
- Line defects is further classified into edge dislocation and screw dislocation.

- Grain boundaries can also be a class of surface defect where the lattice planes change orientation by a large angle.
- In point defects, where an atom is missing (or) is an irregular place in lattice structure.

1.2. MATERIAL TESTING

- Materials testing are established technique which is used to ascertain both the physical and mechanical properties of raw materials and components.
- It also measures the characteristics and behaviour of substances such as metals, ceramics, or plastics under various conditions. Testing of materials is classified for following purposes.
  - Developing standard methods and procedure for testing.
  - Test to establish properties of materials.
  - Test to establish the integrity of the material or component.

CLASSIFICATION OF MATERIAL TESTING

- Test may be classified based on loading condition-static, dynamic or long time tests, based on temperature-normal or room temperature and elevated temperature, based on special requirement on instrument- holdings or gripping, power regulation, bedding the specimen, accuracy , precision, special atmosphere like salt spray, corrosive etc.
- Materials testing classified into three major categories
  - Mechanical testing (or) Destructive testing (DT)
  - Nondestructive testing
  - Material characterization testing

1. DESTRUCTIVE TESTING

- Destructive testing (DT) is a form of object analysis that involves applying a test to break down a particular material to determine its physical properties, such as the mechanical properties of strength, toughness, flexibility, and hardness.
- It is undertaken in order to understand a specimen's performance or material behavior, procedures is carried out to the test specimen's failure.

(a) CLASSIFICATION OF DESTRUCTIVE TESTING

1. Static Testing
2. Impact Testing
3. Cyclic Testing

1. Static Testing

- Where the load is applied gradually in static testing. Different material testing methods available under static testing. They are listed below.
  - Tension Test
  - Compression Test
  - Shear Test(Torsion test)
  - Hardness Test
  - Creep Test
  - Bending test

2. Impact (Dynamic) Testing

- When the given specimen is subjected to shock loads then it is known as the impact load testing or the dynamic load testing.
  - Charpy Test
  - Izod Test
  - Drop Ball
  - Drop Dart
  - Instrumented Puncture Testing

3. Cyclic Testing

- When the load is repeatedly varied in magnitude and the direction then this test is called Impact or dynamic testing.
  - Fatigue test

(b) ADVANTAGES

- Allows a roughly identify the mechanical properties (fracture strength, elongation, modulus of elasticity etc.
- The properties of the bonding can be defined according to the different types of stresses such as tension, compression, shear, peel, dynamic forces of impact.

- The costs of equipment for destructive testing are cheaper compare with the certain equipment used in non - destructive testing.
- Verification of surface preparation, curing conditions and working conditions is minimum.
- Predict and identify the approximate nature of the failure or breakdown that may occur during the lifetime.
- Tests on a relatively cheaper cost.

(c) DISADVANTAGES

- You cannot identify internal defectology (bubbles, delaminating, pores, wrong thickness etc.)
- Need to make large number of specimens simulating the same process (surface preparation, environmental conditions) which cannot be reused once have been tested again.
- Not directly identifies the status of the failure area.

2. NON-DESTRUCTIVE TESTING (NDT)

- Nondestructive Testing (NDT) consists of a variety of non-invasive inspection techniques used to evaluate material properties, components, or entire process units. The techniques can also be utilized to detect, characterize, or measure the presence of damage mechanisms (e.g. corrosion or cracks).
- Many types of NDT techniques are capable of locating defects and determining the features of the defects such as size, shape, and orientation.
- The purpose of NDT is to inspect a component in a safe, reliable, and cost effective manner without causing damage to the equipment or shutting down plant operations. This is in contrast to destructive testing where the part being tested is damaged or destroyed during the inspection process.

Major source of NDT test

- Liquids
- Radiation
- Sound

- Magnetism
- Infrared

(a) CLASSIFICATION OF DESTRUCTIVE TESTING

- Acoustic Emission Testing (AET)
- Infrared Testing (IR)
- Leak Testing (LT)
- Liquid Penetrant Testing (PT)
- Electromagnetic Testing (ET)
- Magnetic Particle Testing (MPT)
- Radiographic Testing (RT)
- Film Radiography (FR)
- Ultrasonic Testing (UT)
- Visual Inspection (VI)

Advanced NDT Techniques

- Advanced methods tend to be understood as emerging technologies, e.g uncertain advantages or limitations, lack of technician qualification criteria, or little to no industry codification.
  - Electromagnetic Testing (ET)
    - Eddy Current Testing (ECT)
    - Magnetic Flux Leakage (MFL)
  - Laser Testing Methods (LM)
    - Holographic Testing
  - Radiographic Testing (RT)
    - Computed Radiography (CR)
    - Computed Tomography (CT)
    - Digital Radiography (DR)
  - Ultrasonic Testing (UT)

- Angle Beam
- Long Range Ultrasonic Testing (LRUT)
- Phased Array Ultrasonic Testing (PAUT)

(b) ADVANTAGES OF NDT TEST

- Most of the equipment in NDT test is portable.
- The obtaining of result is quick and reliable.
- The separate sample preparation is not requires and sample is can be reused.
- To determine the properties of the raw material.
- To check quality at intermediate stages of production processes.
- To ensuring that your infrastructure and vital equipment will provide continued production, undergo minimal degradation and are designed with optimal performance in mind.
- Many properties are found in single specimen.
- Less Waste of specimens.
- Accident Prevention.
- Identify areas of concern before failure.

(c) DISADVANTAGES OF NDT TEST

- Result interpretation is difficult.
- Skilled labor is required.
- Components needing to be cleaned before and after inspection.
- Sensitivity of inspection can sometimes be affected by the finish of a component.
- Sometimes there might be a lack of depth sizing.
- On some non-destructive test methods, only relatively non-porous surfaces can be inspected.
- Some test methods require electricity , affected by variations in magnetic permeability , only effective on materials that are conductive.

COMPARISON BETWEEN DESTRUCTIVE TEST & NON-DESTRUCTIVE TEST

Table 1.2. Destructive Test Vs Non-Destructive Test

DESTRUCTIVE TEST	NON-DESTRUCTIVE TEST
❖ Tests are usually quantitative measurements of load for failure, significant distortion or damage, or life to failure under given loading and environmental conditions.	❖ Tests are usually qualitative and rarely quantitative. They do not usually measure load for failure or life to failure even indirectly.
❖ The correlation of result is directly given by observer.	❖ Skilled judgment and test or service experience are usually required to interpret test indications.
❖ Destructive tests are not usually to apply on parts in working condition.	❖ Non-destructive tests may often be applied to parts in working assemblies without interruption or service beyond normal maintenance or idle periods.
❖ Cumulative change over a period of time cannot readily be measured on a single specimen. ❖ Eg. Concrete cube is tested for 7days, 14days and 28 days.	❖ Non-destructive tests permit repeated checks of a given same specimen over a period of time.
❖ The sample of high cost material or fabrication, the cost of replacing the parts destroyed may be difficult.	❖ Acceptable sample of very high material or fabrication costs are not lost in non-destructive testing.
❖ Tests can be made on only a fraction of the production lot to be used in building.	❖ Tests can be made on every parts to be used in building if economically justified.
❖ A single destructive test may measure only one or a few of the properties that may be critical under service conditions.	❖ Many non-destructive tests, each sensitive to different properties or regions of the material or part, may be applied simultaneously or in sequence.
❖ Tests usually simulate durability conditions. Consequently, they tend to measure serviceability directly and reliably.	❖ Tests usually involve indirect measurements of properties of no direct significance in service.

3. MATERIAL CHARACTERIZATION TESTING

- ❖ Characterization and analytical techniques are methods used to identify, isolate or quantify chemicals or materials, or to characterize their physical properties.
- ❖ Characterization of samples used for external techniques to analysis into the sample's elemental composition, internal structure and thermal, electrical, optical, magnetic properties etc.

TYPES OF MATERIAL CHARACTERIZATION TEST

Table 1.3. Types of characterization test

Major classification	Sub catagory
Microscopy	❖ Optical Microscope ❖ Scanning Electron Microscope (SEM) ❖ Transmission Electron Microscope (TEM)
Spectroscopy	❖ Ultraviolet-visible spectroscopy (UV-vis) ❖ Secondary ion mass spectrometry (SIMS) ❖ Nuclear magnetic resonance spectroscopy (NMR)
Macroscopic testing	❖ Destructive testing ❖ Ultraviolet-visible spectroscopy (UV-vis) ❖ Fourier transform infrared spectroscopy ❖ X-ray diffraction (XRD) ❖ Secondary ion mass spectrometry (SIMS) ❖ Nuclear magnetic resonance spectroscopy (NMR) ❖ Differential thermal analysis (DTA) ❖ Dielectric thermal analysis (DEA) ❖ Thermogravimetric analysis (TGA) ❖ Differential scanning calorimetry (DSC) ❖ Impulse excitation technique (IET)

(a) ADVANTAGES

- Less time is required for testing.
- Complex structures can be analyzed easily.
- Multiple properties is observed in single test.
- High resolution image processing techniques.

(b) DISADVANTAGES

- Only few of the equipment is portable.
- Cost of installation is high.
- Most of the test requires specimen preparation.
- Vacuum is needed for many tests.
- Sample size are prepared under some restrictions.
- Most of the testing methods are uncommon.
- Single method is unfit for testing all materials.

1.3. PURPOSE OF TESTING

- To maintain the quality and consistency of the finished product.
- To avoid mistakes in the first stage of the manufacturing process.
- To obtain compliance certification by following guidelines and regulations of testing and by obtaining standard limit of materials properties.
- To ensure that the materials are suitable for production and usage.
- To determine the reason behind product failure during manufacture or while in use.
- To prevent failure in usage.
- Used as a quality control check in the material manufacturing or processing. Destructive test is used to check the durability, specific requirement and non-destructive test used for finding defect.
- For the acceptance of material, the component performance would fulfill the requirement of testing.
- To check the components prior the final assemble.

- To check the component in service without damage and deterioration
- Used for research and development of existing and new materials.

1.4. SELECTION OF MATERIAL

- Material selection is one of the foremost functions of effective engineering design as it determines the reliability of the design in terms of industrial and economical aspects.
- Generally, it is in Iterative nature. There is a strong element of trial and error where an initial design is done and then analyzed, tested, and subjected to trial production. Changes may be made at any stage of the process to satisfy requirements not previously considered or problems just discovered.

(a) STEPS TO BE CONSIDERED FOR SELECTION OF MATERIALS

Step 1: Identify the design requirements.

- Each step involves a synthesis process in which all of the various concerns and requirements are considered together. Compromises between conflicting requirements are usually necessary and continual effort.
- The design requirements include the following items
  - Performance requirements
  - Simplicity and practicability
  - Reliability requirements
  - Size, shape, and mass requirements
  - Cost requirements
  - Manufacturing and assembly requirements
  - Industry standards
  - Sustainability requirements
- Identifying as many of the requirements as possible is critical. For many products, some of these requirements are not applicable, making the information gathering will make the process easier.

Step 2: Identify materials selection criteria

- The materials selection criteria are specific materials properties derived from the requirements identified during pervious step.

- For example, for a component that must support a specific load, the minimum yield stress that is required for the component's material can be determined. This will be one of the material selection criteria.

Step 3: Identify candidate materials

- Use the materials selection criteria to rule out materials that will not satisfy all the materials selection criteria. When evaluating whether a material might be appropriate for the application, be sure to consider the materials range of values for the properties of interest.

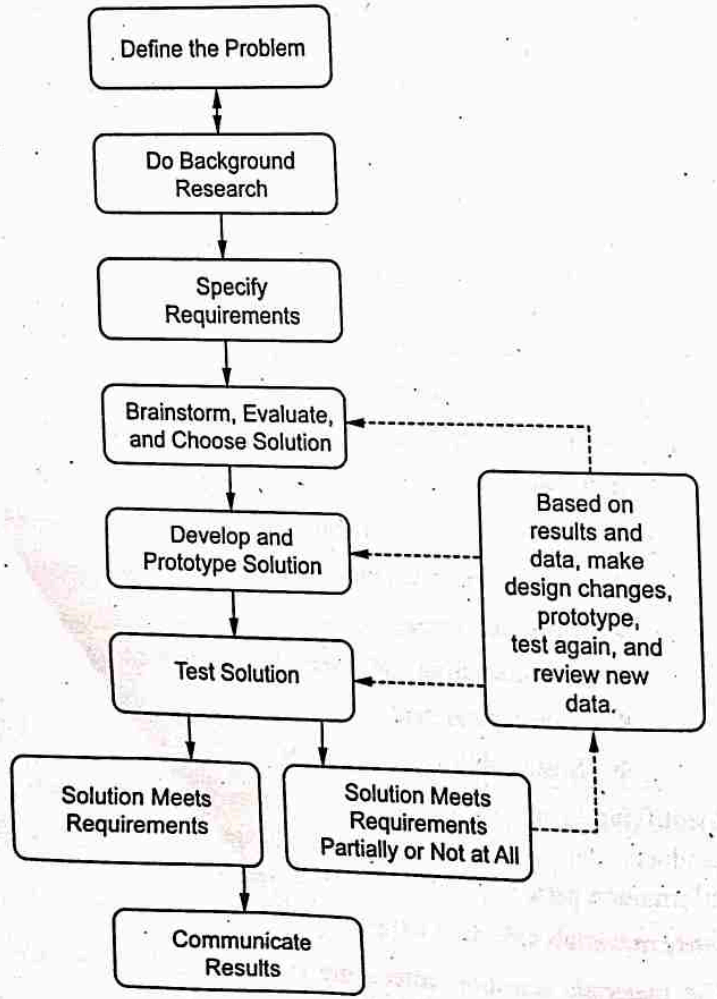


Fig. 1.8. Failure analysis

Step 4: Evaluate candidate materials

- There may be candidate materials for which there insufficient data available to indicate whether the materials satisfy certain selection criteria. These materials will have to be analyzed and tested to determine whether they do meet the selection criteria by creating a prototype.

Step 5: Select materials

- Select the materials that satisfy all the materials selection criteria at the lowest cost. Remember, cost includes the cost of the material and the cost to fabricate a component or form a joint between components.

Step 6: Failure Analysis

- The selection of materials is finalized with help of failure analysis mode which is given in Fig. 1.8.

Step 7: Service Experience

- Design changes may also be made as a result of experience with a limited production run of a new product. Purchasers of the product may also use it in a way not anticipated by the designer, resulting in failure.
- The design process often continues even after a product is established and widely distributed.

(b) FACTORS AFFECTING SELECTION OF MATERIALS

1. Performance

- This characteristic refers to those properties that are required for the product to satisfy its functional requirements.
- Materials typically perform one or more functions in a product such as carrying loads, providing heat conduction or thermal insulation, providing electrical conduction or insulation, or containing fluids.

(i) Mechanical properties

- The material must possess a certain strength and stiffness. Selected materials are examined for strength and stiffness values, and then potential materials are further inspected for other desired properties.

(ii) Wear of materials

- Wear is a problem when the materials are contacting each other in a product. So it must be ensured that the selected materials have sufficient wear resistance.

(iii) Corrosion

- It is an important engineering design criterion for designs open to the environment for a longer period of time. Some materials are very likely to be corroded in the service depending on the service environment.
- Metals like iron are heavily prone to corrosion if it not prepared to resist corrosion. Painting or any other surface coating method, cathodic protection, etc. are possible ways to minimize the effect and increase the service life.

(iv) Ability to manufacture

- Although the material is well capable of using for the design, it may be difficult to manufacture.
- If this selection criteria is neglected the manufacture process might be very costly making it unprofitable as a commercial product.

(v) Cost

- Cost is a critical fact to consider when selecting materials for a certain design for most products because they are facing a severe competition in the market.
- The cost factor can be neglected when performance is given the top priority. When estimating costs, all the associated cost factors must be considered to get a more reasonable value. It may involve the transportation, processing costs, etc.

2. Reliability and Environmental Resistance

- This characteristic relates to the durability of a material, which is its ability to resist deterioration in the environment in which it will be used. It includes such properties as fatigue resistance and resistance to radiation, chemical solvents, and corrosive agents.
- Critical characteristics that are needed to satisfy the functional requirements and their constraints.

3. Reducibility

- Material selection cannot be made independently of the selection of the manufacturing process, since the manufacturing process will affect the performance properties of the material.
- Furthermore, the selection of the manufacturing process will depend on certain properties of the materials. Material properties that can dictate the choice of a manufacturing process include ductility, toughness, formability, and castability. In addition, one must take into account the geometric attributes of the production.

1.5. DEVELOPMENT OF TESTING

- **Materials testing**, measurement of the characteristics and behavior of such substances as metals, ceramics, or plastics under various conditions by a full- or small-scale model of a proposed machine or structure may be tested.
- Alternatively, investigators may construct mathematical models that predict capabilities of the structure.
- Standard test methods have been established by such national and international bodies as the International Organization for Standardization (ISO).

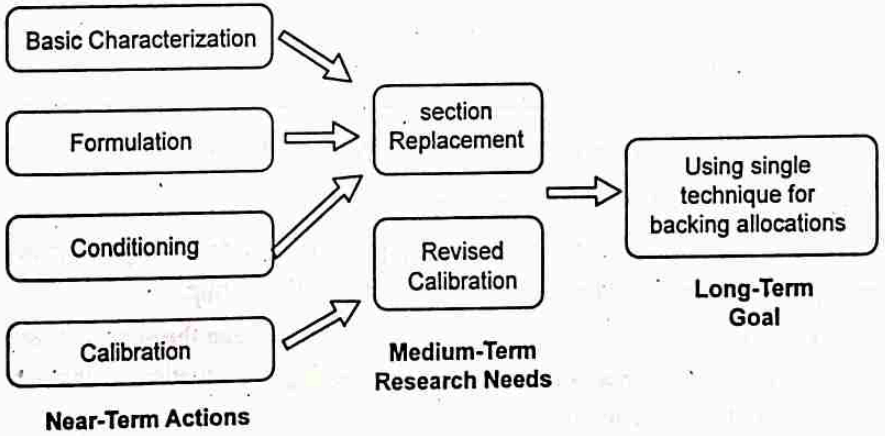


Fig. 1.9. Formulation in test development

(a) STAGES IN DEVELOPMENT OF TESTING

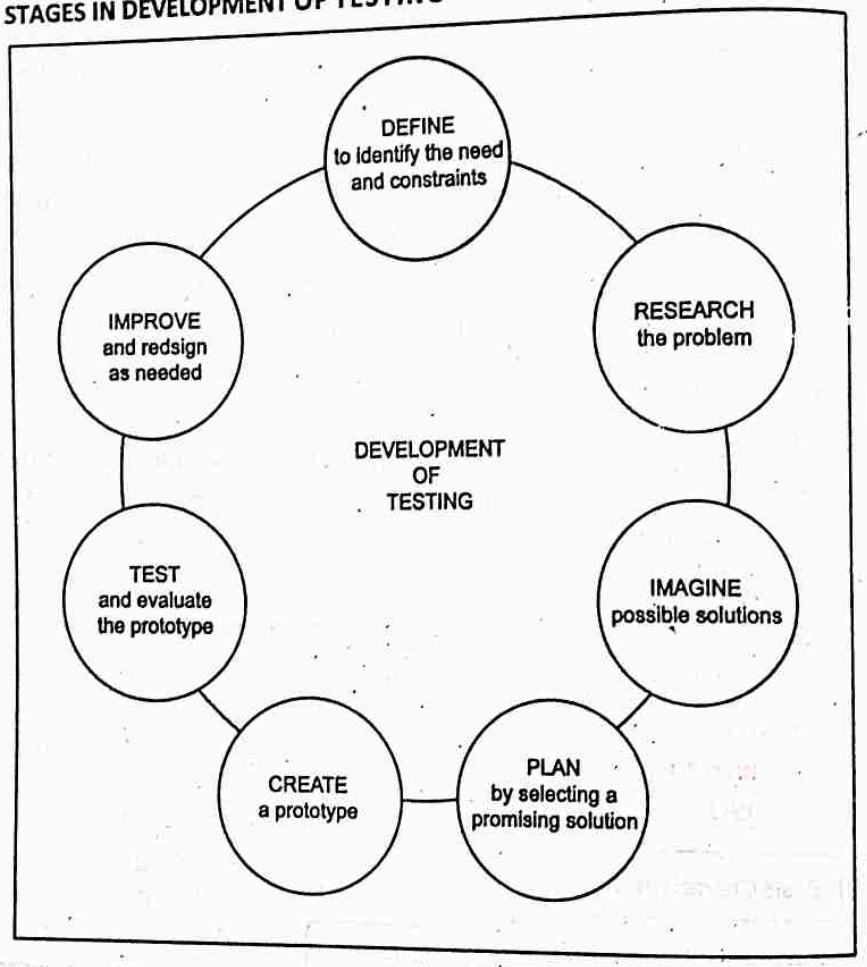


Fig. 1.10. Stages in development of testing

(a) Identify the Need & Define the Problem

The first step is to identify and define the problem. The following major problem, which needs to consider during development of material testing.

- A problem can be regarded as a difference between the actual situation and the desired situation. It involves diagnosing the situation so that the focus on the real problem.
- Development of varies time, cost, sample and labor minimizing test techniques.

- Development of a new manufacturing / processing line or making changes to an existing one, needs an improvement of testing methods under different conditions and in different applications.
- Improvement of Troubleshooting, to determine what is causing issues during processing.
- Scale-up of a testing technology.
- Increase fundamental understanding of materials.
- Improvement of the process/product performance relative to the needs and demands of customers.
- Reduction of existing process spread, which leads to poor capability.

(b) Research the Problem

- Some possible ways to identify potential process by using knowledge of the process, historical data, cause-and-effect analysis and brainstorming, etc.,
- The research of problem may concern of a condition to be improved, a difficulty to be eliminated, or a troubling question that exists in literature or testing techniques , specific issue, contradiction or gap between present and future testing techniques in that need of meaningful understanding and deliberate investigation.
- If important factors are left out during development of testing experiment, then the results of the experiment will not be accurate which must be take care.

(c) Develop possible testing methods

- The size of the testing is dependent on the number of factors or interactions to be studied, the number of levels of each factor, budget and resources allocated for carrying out the experiment, etc.
- The development testing plan methods is done using various techniques of graphical presentation, such as Auto cad, simulation techniques methods, etc.
- During the design stage, it is quite important to consider the confounding structure and resolution of the design.

- The material testing code book gives the basics of testing development standards, which is based on environment, material specification and result analysis methods etc.

(d) Evaluate the Alternatives & Select Most Promising methods

- The various possible method is developed and stimulated in softwares to ensure the theoretical acceptance.
- Pre presenting the information of testing methods are deciding criteria of effective method.
- The testing methods need to satisfy the basic criteria like cost and time.
- The combination of different testing methods is also selected for the effectiveness.

(e) Initial Design

- The initial design is often made on the basis of avoiding stresses that exceed the yield strength of the material. Then the design is checked by more refined analysis, and changes are made as necessary to avoid more subtle modes of material failure, such as fatigue, brittle fracture, and creep.
- In making design decisions that involve safety and durability, the concept of a safety factor is often used. The safety factor in stress is the ratio of the stress that causes failure to the stress expected to occur in the actual service of the component. That is,

$$X1 = \text{stress causing failure/stress in service}$$

(f) Construct a prototype

- The materials that will be used in final testing methods may be expensive or difficult to fabricate, so prototypes may be made from different materials than the final product. In some cases, the final production materials may still be undergoing development themselves.
- A prototype, or trial model, is often made and subjected to simulated service testing to demonstrate whether it is functions properly.
- Prototypes are generally made with much closer individual inspection and the assumption that some adjustment or rework will be part of the fabrication process.

- Prototypes may also be exempted from some requirements that will apply to the final product.

(g) Test and Evaluate the Prototype

- It is important to test and evaluate your prototype along the way for functionality, usefulness, and safety. The final product may be subject to a number of quality assurance tests to verify conformance with drawings or specifications.
- These tests may involve custom inspection fixtures, statistical sampling methods, and other techniques appropriate for ongoing production of a large quantity of the final product.

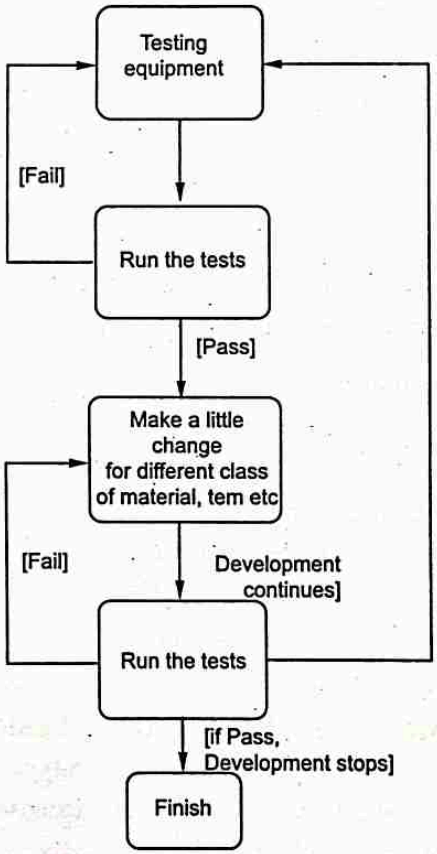


Fig. 1.11. Evaluation of prototype

- The failure of prototype leads to choosing alternatives and redesign the section.
- The early estimate of loads may have been quite uncertain. A prototype may also be subjected to simulated service testing until either a mechanical failure occurs, perhaps by fatigue, creep, wear, or corrosion, or the design is proven to be reliable. This is called durability testing.
- For very large items, it may be impractical or uneconomical to test a prototype of the entire item. A part of the item, that is, a component, may then be tested.

(h) Communicate the Design

- Communication design is a mixed discipline between design and information-development which is concerned with such as printed, crafted, electronic media or presentations to communicate with people for overcoming some unreliable problems.

(i) Redesign

- The redesign is approached existing testing techniques is outdated for the present materials and to minimizing the calibration.

Example for development of testing

- **DEVELOPMENT OF MECHANICAL TESTING**-Structures and machines, or their components, fail because of fracture or excessive deformation. In attempting to prevent such failure, the designer estimates how much stress (load per unit area) can be anticipated, and specifies materials that can withstand expected stresses.
- Test machine grips are designed to transfer load smoothly into the test piece without producing local stress concentrations.
- **DEVELOPMENT OF STATIC COMPRESSION** - Tests determine a material's response to crushing, or support-type loading (such as in the beams of a house). Testing machines and extensometers for compression tests resemble those used for tension tests.
- **DEVELOPMENT OF STATIC SHEAR AND BENDING TESTS** - In plane shear tests indicate the deformation response of a material to forces

applied tangentially. Shear strength of rivets and other fasteners also can be measured.

- **DEVELOPMENT OF MEASURES OF DUCTILITY**- Ductility is the capacity of a material to deform permanently in response to stress. Ductility can be expressed as strain, reduction in area, or toughness. Reduction in area (change in area per unit area) may be measured, for example, in the test section of a steel bar that necks when stressed.
- **DEVELOPMENT OF HARDNESS TESTING**-Based on the idea that a material's response to a load placed at one small point is related to its ability to deform permanently (yield), the hardness test is performed by pressing a hardened steel ball (Brinell test) or a steel or diamond cone (Rockwell test) into the surface of the test piece.
- **DEVELOPMENT OF IMPACT TEST**-Many materials, sensitive to the presence of flaws, cracks, and notches, fail suddenly under impact.
- **DEVELOPMENT OF FRACTURE TOUGHNESS TESTS**-The criterion for failure became sudden propagation of a crack rather than fracture. Tests have shown that cracks occur by opening, when two pieces of material part in vertical plane, one piece going up, the other down; by edge sliding, where the material splits in horizontal plane, one piece moving left, the other right; and by tearing, where the material splits with one piece moving diagonally upward to the left, the other moving diagonally downward to the right.
- **DEVELOPMENT OF CREEP TEST**-Creep is the slow change in the dimensions of a material due to prolonged stress; most common metals exhibit creep behavior. In the creep test, loads below those necessary to cause instantaneous fracture are applied to the material, and the deformation over a period of time (creep strain) under constant load is measured, usually with an extensometer or strain gauge.
- **DEVELOPMENT OF FATIGUE TEST**- Materials that survive a single application of stress frequently fail when stressed repeatedly. This phenomenon, known as fatigue, is measured by mechanical tests that involve repeated application of different stresses varying in a regular cycle from maximum to minimum value.

1.6. TESTING ORGANIZATIONS AND ITS COMMITTEE

(a) INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)

- The International Organization for Standardization (ISO) is an international standard-setting body composed of representatives from various national standards organizations.
- ISO is a voluntary organization whose members are recognized authorities on standards, each one representing one country. Members meet annually at a General Assembly to discuss the strategic objectives of ISO. The organization is coordinated by a central secretariat based in Geneva.

(b) ASTM INTERNATIONAL

- ASTM International, formerly known as American Society for Testing and Materials, is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services.

(c) BUREAU OF INDIAN STANDARDS (BIS)

- BIS is the National Standard Body of India established under the BIS Act 2016 for the harmonious development of the activities of standardization, marking and quality certification of goods and for matters connected therewith or incidental there to.
- BIS has been providing traceability and tangibility benefits to the national economy in a number of ways
  - Providing safe reliable quality goods
  - Minimizing health hazards to consumers
  - Promoting exports and imports substitute
  - Control over proliferation of varieties etc. Through standardization, certification and testing

(i) Organization OF BIS

- The organization of BIS consists of following members,
  - Governing Council Members
  - Executive Committee
  - Administrative Structure

(ii) Organization chart

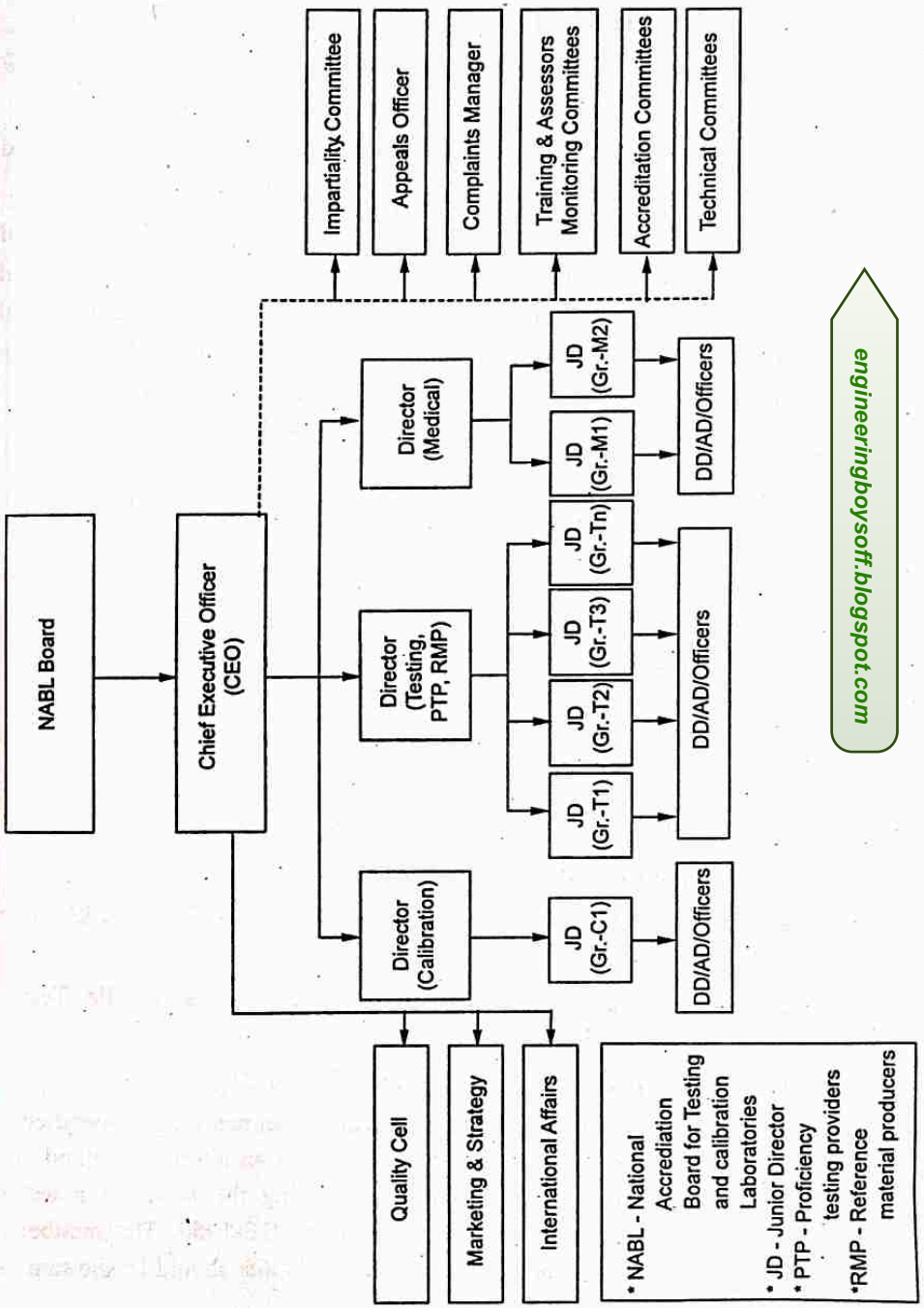


Fig. 1.12. Organization chart

(iii) OTHER TESTING ORGANIZATIONS

- The National Metrological Institutes (NMIs) namely National Physical Laboratory (NPL) and Bhabha Atomic Research Centre (BARC).
- The Standards Bodies namely Bureau of Indian Standards (BIS) and Standardization, Testing and Quality Certification (STQC).
- Council for Industrial and Scientific Research (CSIR), the other Boards of Quality Council of India (QCI), the other organizations under nodal department of QCI i.e. Department for Promotion of Industry and Internal Trade, the other Departments / organizations under nodal Ministry i.e. Ministry of Industry and Commerce are the bodies related to NABL.

(iv) Codes for TEST procedure

- Some of the testing standards codes followed in India
  1. Rockwell hardness test (IS: 1586-2000)
  2. Brinell and Vickers hardness tests (IS: 2281-2005 RA-2011)
  3. Impact tests (Charpy V-Notch and Izod tests) (IS: 1757-1988 and IS: 1598-1977 RA-2009))
  4. Tensile Test (IS: 1608-2005 RA-2011)
  5. Compression Test (IS: 1608-2005 / ISO 4506-1979)
  6. Bend test for metal products(IS:1599-1985 RA-2011)
  7. Shear Test (IS: 5242-1979 RA-2006)
  8. Beam or flexural bending test (IS: 16-1959)
  9. Torsion test and Fatigue test (IS:5074-1969 RA-2001 and IS: 5075-1985 RA-2001)
  10. Indian Standard Mechanical Testing of Metals Tensile Testing (IS:1608-1995)
  11. Metallic materials - Bend test (IS 1599 - 2012)
- For all the tests described in this section, the method as specified in relevant ISO standard may also be followed as an alternate method. The final value, observed or calculated, expressing the result of a test or analysis, is rounded off in accordance with IS:2-1960. The number of significant places retained in the rounded off value should be the same as that of the specified value in the code.

1.7. BENEFITS OF TESTING

(i) Safety issues can be identified

- The tests are carried out to ensure product safety, and also to make sure the person carrying out the work on any machinery or components is safe too. In mechanical testing, the equipment testing area is covered with glass plate to present from shattering of test piece out of equipment.
- Most non-destructive tests are harmless to humans, although tests involving radiographic must be carried out under strict settings. All tests must ensure that products are left completely undamaged.
- Its main aim, when used properly, and the results of the tests accurately acted upon is to identify and resolve problems that could otherwise be disastrous.

(ii) It provides reliability

- If workers in industry want reliable and accurate results, all material testing will offer stability.
- The testing technique are accurate way of inspection since it is repeatable and used to correlate results.
- Any given piece of equipment or machinery can undergo a range of non-destructive tests which will remove the risk of any inaccuracy of result, or oversight for long range. The testing equipment needs calibration for better result.

(iii) It is cost effective

- These types of tests can also give insights that can result in the effective replacement or repair of components or equipment before a real malfunction or breakdown occurs, which will save more money in the long term.

(iv) It offers reassurance

- Reassurance is such a simple thing, but it can sometimes be the most important advantage to testing methods.
- The operation of testing equipment being harmless and it also help to prevent injury (or) fatalities by structures, machinery (or) components etc.

- When workers know they are safe, they feel more secure and this is something that can benefit productivity and output, overall.

1.8. PRESENTATION OF RESULT

- It is very important by sharing the knowledge of result or development with others which leads to the various development of test result by other scientist or researchers.
- The steps to be followed for description of test report
  - Statement of the problems
  - Materials, methods and procedure used during testing
  - Result analysis
  - Summary, conclusion and discussion
  - Appendices to support findings

(*i*) Statement of the problems

- Statement of the problems describes the objectives of testing which intends about problem.

(*ii*) Materials, methods and procedure used during testing

- Materials, methods and procedure used during testing section includes the material to be tested, the conditions of testing specimen, important apparatus used for testing and the major procedure followed by testing which is referenced from the Indian standard code books.

(*iii*) Data presentation and Result analysis

- The result data presented by plotting it in various methods with proper units assigned or listed in clear and meaningful manner. In every method of result presentation, the statement of result is summarized with the significance of materials.
- The result analysis is done by various methods,
  - Charts
  - Graphs
  - Tabulation
  - Statement
  - Analytic Software

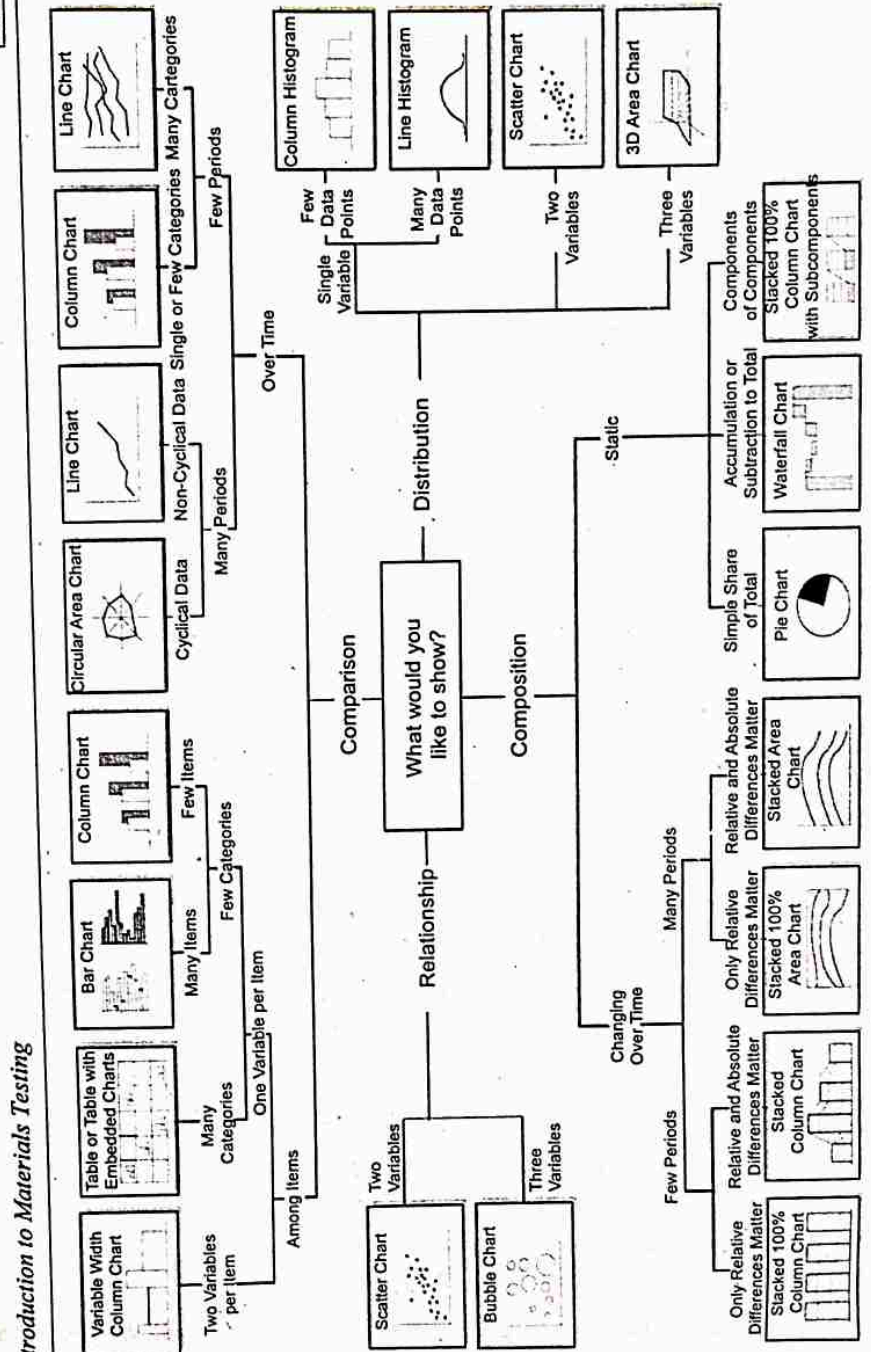


Fig. 1.13. Types of graphs and charts

(a) CHARTS & GRAPHS

- A chart displays schematic processes based on the outcome, validity or answer to a previous variable. Graphs, used to display comparisons between 2 variables. For example: line graphs involve an x-axis horizontally and a y-axis vertically on a grid

(b) TABULATION

- Tabulation is a systematic & logical presentation of numeric data in rows and columns, to facilitate comparison and statistical analysis accompanying with summarizing result.

Major Objectives of Tabulation

- To Simplify the Complex Data
- To Bring Out Essential Features of the Data
- To Facilitate Comparison
- To Facilitate Statistical Analysis
- Saving of Space

(c) STATEMENT

- Statement statistics is a form of mathematical analysis that uses quantified models, representations and synopses for a given set of experimental data or real-life studies. Statistics statement studies methodology to gather, review, analyze and draw conclusions from data.
- **Example:** The result of 28 days strength of silicon mixed cube is 25% greater than the conventional concrete.

(d) ANALYTIC SOFTWARE

- Software analysis is the analytics specific to the domain of software systems taking into account source code, static and dynamic characteristics (e.g., software metrics) as well as related processes of their development and evolution.

Example:

- ***BIOVIA* MATERIALS STUDIO-** Materials Studio allows you to easily build, modify, visualize and simulate a wide range of materials.

- **LAS X MATERIALS SCIENCE MODULES-** LAS X can be enhanced with a range of advanced modules and applications to form a powerful microscopy imaging environment.
- **MATLAB** - Computation and plotting.
- **AUTO CAD** - Designing of outline element, 2Dand 3D element.
- **STADD PRO** - Designing of structures.
- **ABACUS** - Finite element analysis.
- **ANSYS ELECTRONICS** – It is the premier solution for electromagnetic field, circuit, systems and multi physics simulation and analysis for electronic design.

(iv) SUMMARY, CONCLUSION AND DISCUSSION

- It describes about the general findings of test or experiment and summarizes the important point. Also gives the view about the various error or difficulties occurred during testing. It gives new view and opinion about material, projected view and acceptability for use in market and environment.

(v) APPENDICES TO SUPPORT FINDINGS

- It gives supporting data for testing the materials like code books, past material testing history and data for better clarity for testing.

1.9. TESTING VS INSPECTION

- Testing is the physical performance of an operation series aimed at providing quantitate data regarding the properties of a material. It provides the information about the quality of material.
- Inspection is the observance of a material to determine the presence or absence of a desired one. It aimed about the controlling the quality of materials by establishing criteria of acceptance or rejection.

1.10. PRECISION VS ACCURACY

- The **accuracy** of an experiment, object, or value is a measurement of how closely results agree with accepted value. The degree of conformity and

correctness of something when compared to a true or absolute value. Single factor or measurement.

- The **precision** of an experiment, object, or value is a measure of the reliability and consistency. A state of strict exactness - how often something is strictly exact. Multiple measurements or factors are needed.

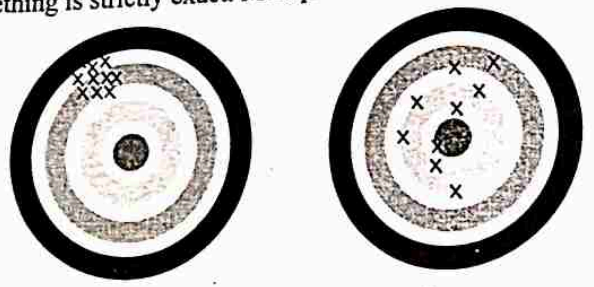


Fig. 1.14. Precision vs. Accuracy

TWO MARK QUESTIONS WITH ANSWERS

1. ***What are the major types of materials?***

Solid materials have been conveniently grouped into three basic categories,

- Metals
- Ceramics
- Polymers

2. ***Define line defects.***

- Line defects are called dislocations and are the edges of surfaces where there is a relative displacement of lattice planes. One type is an edge dislocation, and the other is a screw dislocation.

3. ***What are the benefits of testing?***

- Safety issues can be identified
- It provides reliability
- It is cost effective
- It offers reassurance

4. ***What are types of material testing?***

- Materials testing classified into three major categories
  - Mechanical testing (or) Destructive testing (DT)
  - Nondestructive testing.
  - Material characterization testing

5. ***Define NDT.***

- Nondestructive Testing (NDT) consists of a variety of non-invasive inspection techniques used to evaluate material properties, components, or entire process units. The techniques can also be utilized to detect, characterize, or measure the presence of damage mechanisms (e.g. corrosion or cracks).

6. ***Write contrast between NDT and destructive testing.***

DESTRUCTIVE TEST	NON-DESTRUCTIVE TEST
❖ Tests are usually quantitative measurements of load for failure, significant distortion or damage, or life to failure under given loading and environmental conditions.	❖ Tests are usually quantitative and rarely quantitative. They do not usually measure load for failure or life to failure even indirectly.
❖ The correlation of result is directly given by observer.	❖ Skilled judgment and test or service experience are usually required to interpret test indications.
❖ Destructive tests are not usually to apply on parts in working condition.	❖ Non-destructive tests may often be applied to parts in working assemblies without interruption or service beyond normal maintenance or idle periods.

7. ***What is the test used to test metals?***

- Major test used for testing metals are destructive one i.e., Test, Shear(Torsion test),Test, Creep Test, Bending test etc

8. ***Why more concentration is needed for selection of materials?***

- Material selection is one of the foremost functions of effective engineering design as it determines the reliability of the design in terms of industrial and economical aspects.
- It is Iterative in nature, there is a strong element of trial and error where an initial design is done and then analyzed, tested, and subjected to trial production. Changes may be made at any stage of the process to satisfy requirements not previously considered or problems just discovered.

9. ***What are factors to be considered during selection materials?***

- Performance
- Mechanical properties
- Wear of materials
- Corrosion
- Ability to manufacture
- Cost
- Reliability and Environmental Resistance
- Reducibility

10. ***What are stages in development of testing?***

- Identify the Need & Define the Problem
- Research the Problem
- Develop possible testing methods
- Evaluate the Alternatives & Select Most Promising methods
- Initial Design
- Construct a prototype
- Test and Evaluate the Prototype
- Communicate the Design
- Redesign

11. ***Define prototype.***

- A prototype, or trial model, is often made and subjected to simulated service testing to demonstrate whether or not a machine or vehicle functions properly.

12. ***Differentiate precision and accuracy.***

S.No.	ACCURACY	PRECISION
1.	The accuracy of an experiment, object, or value is a measurement of how closely results agree with accepted value.	The precision of an experiment, object, or value is a measure of the reliability and consistency.
2.	The degree of conformity and correctness of something when compared to a true or absolute value. Single factor or measurement.	A state of strict exactness — how often something is strictly exact. Multiple measurements or factors are needed.

13. ***Why development of testing is necessary?***

- A problem can be regarded as a difference between the actual situation and the desired situation. It involves diagnosing the situation so that the focus on the real problem.
- Development of various time, cost, sample and labor minimizing testing techniques.
- The destruction of material reduction technique.
- Scale-up of a testing technology.
- Increase fundamental understanding of materials.
- Improvement of the process/product performance relative to the needs and demands of customers.
- Reduction of existing process spread, which leads to poor capability.

14. ***Define ISO.***

- The International Organization for Standardization (ISO) is an international standard-setting body composed of representatives from various national standards organizations.
- ISO is a voluntary organization whose members are recognized authorities on standards, each one representing one country. Members meet annually

at a General Assembly to discuss the strategic objectives of ISO. The organization is coordinated by a central secretariat based in Geneva.

15. ***What is the testing standard organization followed in India?***

- ❖ BIS is the National Standard Body of India established under the BIS Act 2016 for the harmonious development of the activities of standardization, marking and quality certification of goods and for matters connected therewith or incidental there to.

REVIEW QUESTIONS

1. Write a review on types of materials.

   Ans: Section No. 1.1 **Page No:** 1.1

2. What are aspects that you understand from testing of materials?

   Ans: Section No. 1.2 **Page No:** 1.9

3. Write the classification of various material testing.

   Ans: Section No. 1.2 **Page No:** 1.9

4. What are the advantages and disadvantages encountered by various material testing?

   Ans: Section No. 1.2 **Page No:** 1.10

5. Differentiate between NDT and Destructive testing.

   Ans: Section No. 1.2 **Page No:** 1.14

6. Why testing of materials are important?

   Ans: Section No. 1.3 **Page No:** 1.16

7. What are steps to be followed during selection of materials?

   Ans: Section No. 1.4 **Page No:** 1.17

8. What are criteria that affect the selection of materials?

   Ans: Section No. 1.4 **Page No:** 1.19

9. Explain various stages in development of testing in detail.

   Ans: Section No. 1.5 **Page No:** 1.22

10. What are the purpose of developing a test? Explain with few examples.

    Ans: Section No. 1.5 **Page No:** 1.26

11. What is BIS? Explain its organization.

    Ans: Section No. 1.6 **Page No:** 1.28

12. Explain various benefits of testing.

    Ans: Section No. 1.7 **Page No:** 1.31

13. How will you represent the result analysis of testing?

    Ans: Section No. 1.8 **Page No:** 1.32

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UNIT II

MECHANICAL TESTING

SYLLABUS

Introduction to mechanical testing, Hardness test (Vickers, Brinell, Rockwell), Tensile test, Impact test (Izod, Charpy) - Principles, Techniques, Methods, Advantages and Limitations, Applications. Bend test, Shear test, Creep and Fatigue test - Principles, Techniques, Methods, Advantages and Limitations, Applications.

2.1. INTRODUCTION TO MECHANICAL TESTING

- Mechanical testing reveals the properties of a material under dynamic or static force which is also known as destructive testing.
- Designed to ensure that materials are suitable for their intended applications, mechanical testing includes methods such as tensile strength, compression strength, impact resistance, fracture toughness and fatigue.
- Materials testing study reveals the behavior of materials under different loads. In particular, the relationship between the acting forces and the resulting deformation is found, in which the limit stresses that lead to failure of components are considered.
- To assure performance, safety, and durability, it is necessary to avoid excess deformation i.e. bending, twisting, or stretching of the components (parts) of the machine, vehicle, or structure. In addition, cracking in components must be avoided entirely, or strictly limited, so that it does not progress to the point of complete fracture.
- **The study of deformation and fracture in materials is called mechanical behavior of materials.** Knowledge of this area provides the basis for avoiding these types of failure in engineering applications. One aspect of the subject is the physical testing of samples of materials by applying.

1. MECHANICAL PROPERTIES OF MATERIAL

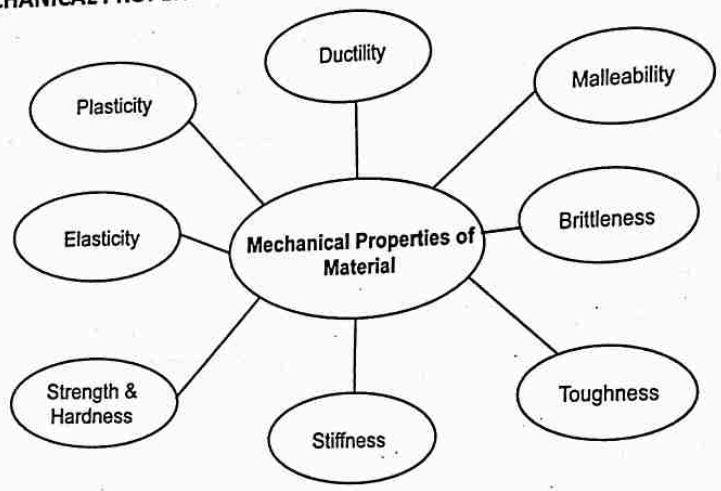


Fig. 2.1. Mechanical properties

1. Strength & Hardness

- Strength is the ability of a material to resist the externally applied forces without breaking or yielding. The internal resistance offered by a part to an externally applied force is called stress.
- Hardness is a very important property of the metals and it also embraces many different properties such as resistance to wear, scratching, deformation and machinability etc.

2. Stiffness

- Stiffness is the ability of a material to resist deformation under stress. The modulus of elasticity is the measure of stiffness.

3. Elasticity

- It is the property of a material to regain its original shape after deformation when the external forces are removed. This property is desirable for materials used in tools and machines than rubber.

4. Plasticity

- Plasticity is a property of a material which retains the deformation produced under load permanently. This property of the material is necessary for forgings, in stamping images on coins and in ornamental work.

5. Ductility

- Ductility is the property of a material enabling it to be drawn into a wire with the application of a tensile force. A ductile material must be both strong and plastic. The ductility is usually measured by the terms, percentage elongation and percentage reduction in area. The ductile material commonly used in engineering practice are mild steel, copper, aluminum, nickel, zinc, tin and lead.

5. Brittleness

- It is the property of breaking of a material with little permanent distortion. Brittleness of a material is opposite to ductility property.
- Brittle materials are withstanding compression load. When subjected to tensile loads snap off without giving any sensible elongation. Cast iron is a brittle material.

6. Malleability

- It is a special case of ductility which permits materials to be rolled or hammered into thin sheets, making wire. A malleable material should be plastic in nature but it is not essential to be so strong. The malleable materials commonly used in engineering practice are lead, soft steel, wrought iron, copper, and aluminum.

7. Toughness

- Toughness is the property of a material to resist fracture due to high impact. It is measured by the amount of energy that a unit volume of the material has absorbed after being stressed up to the point of fracture.
- This property is desirable in parts subjected to shock and impact loads.

8. Resilience

- It is the property of a material to absorb energy and to resist shock and impact loads. It is measured by the amount of energy absorbed per unit volume within elastic limit. This property is essential for designing the spring materials.

2. PROPERTY BASED TESTING METHODS

- The characteristic values obtained from the testing process are used for materials development, designing components and in quality assurance.

- There is a range of standardized testing methods to characterize the mechanical properties of materials as precisely as possible

Table 2.1. Mechanical Property vs. test

Mechanical Property	Destructive Testing Method
❖ Elasticity, Plasticity	❖ Tensile Test, Compression Test, Bending Test, Torsion Test
❖ Stiffness, Material Behaviour Under Static Load	
❖ Creep Behaviour	❖ Creep Rupture Test
❖ Hardness	❖ Brinell, Rockwell, Vickers
❖ Toughness	❖ Impact Test
❖ Fatigue Behaviour, Fatigue Strength	❖ Wöhler Fatigue Test

3. MATERIAL FAILURE

- **Material failure** is the loss of load carrying capacity of a **material** unit. This definition introduces to the fact that **material failure** can be examined in different scales. The material failure happens due to two major phenomena,
  - Deformation failure
  - Fracture failure

(a) DEFORMATION FAILURE

- A deformation failure is a change in the physical dimensions or shape of a component that is sufficient for its function to be lost or impaired.
- **Elastic deformation & Plastic deformation** - Deformation that appears quickly upon loading can be classed as either elastic deformation or plastic deformation. Elastic deformation is recovered immediately upon unloading, whereas plastic deformation is permanent.
- **Creep-**It is deformation that accumulates with time. Depending on the magnitude of the applied stress and its duration, when deformation may become so large that a component can no longer perform its function.

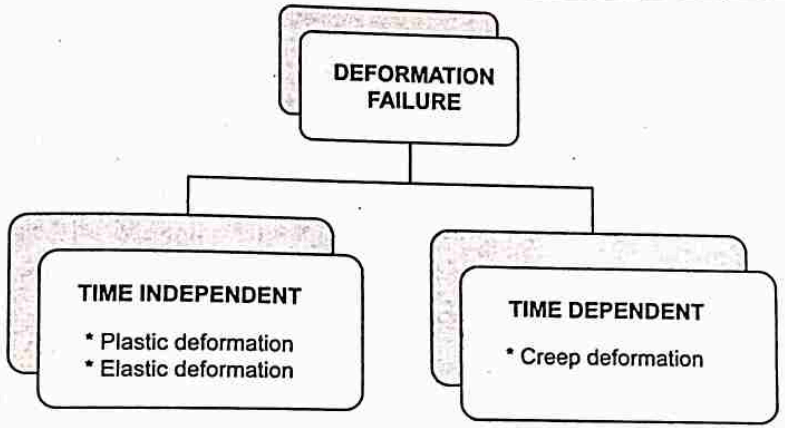


Fig. 2.2. Types of demoformartion failure

(b) FRACTURE FAILURE

- Cracking to the extent that a component is separated into two or more pieces is termed fracture.

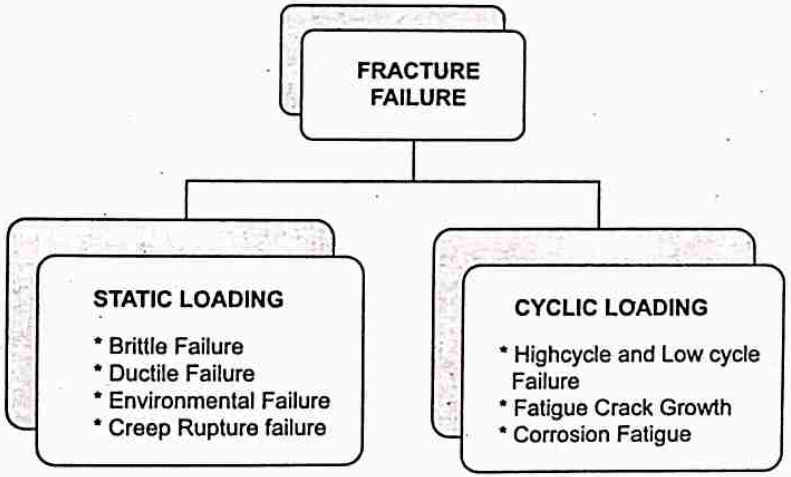


Fig. 2.3. Fracture failure

- **Brittle or Ductile fracture-**The possible growth of the cracks by fatigue, as this can lead to a brittle or ductile fracture once the cracks are sufficiently large. Such situations are identified by the term fatigue crack growth and may also be analyzed.

- **Environmental cracking failure**-Fracture may occur as a result of a combination of stress and chemical effects, and this is called environmental cracking failure.
- **Corrosion fatigue**-It is the combination of cyclic loading and corrosion. It is often a problem in cyclically loaded
- **Fatigue crack growth** -Creep deformation may proceed to the point that separation into two pieces occurs. This is called creep rupture and is similar to ductile fracture, except that the process is time dependent.
- **Creep rupture** -The common cause of fracture is fatigue, which is failure due to repeated loading. In general, one or more tiny cracks start in the material, and these grow until complete failure occurs.
- **High-cycle fatigue & low-cycle fatigue** -If the number of repetitions (cycles) of the load is large, say millions then the situation is termed high-cycle fatigue. Conversely, low-cycle fatigue is caused by a relatively small number of cycles; say tens, hundreds, or thousands. Low-cycle fatigue is generally accompanied by significant amounts of plastic deformation whereas high-cycle fatigue is associated with relatively small deformations that are primarily elastic.

2.2. HARDNESS TEST

1. HARDNESS

- The term 'hardness' is a structure-sensitive mechanical property of materials, primarily associated with the surface. If a material is uniform in composition and structure, the hardness measured on the surface layer will represent the hardness of the bulk of the material.
- The hardness is defined as the resistance of a material to permanent or plastic deformation of its surface, usually by indentation, under static or dynamic load

2. CLASSIFICATION OF HARDNESS

- Depending on the manner in which the hardness test is conducted, hardness may be classified as follows
  - Indentation hardness
  - Rebound hardness
  - Scratch hardness
  - Wear or abrasion hardness
  - Cutting hardness

(a) Indentation hardness

- It is the resistance of a material to permanent indentation under static or dynamic load. The types of indentation hardness test is given below,

  (*i*) Brinell; (*ii*) Meyer; (*iii*) Vickers (macro- and micro-hardness); (*iv*) Rockwell (regular and superficial); (*v*) Knoop (micro hardness); (*vi*) Nano hardness (mostly by Vickers and Berkovich indenters) etc.
- Classification based on scale of indenter used which is describe in the table with testing methods.

Table 2.2. Types of indenter hardness test

Major group	Testing methods	Force applied
Macro-Hardness Tests (Rapid routine hardness measurements)	Rockwell test Brinell test Vickers test	50N To 30000N
Micro-Hardness Tests (Hardness of coatings, surface hardness, or hardness of different phases in the multi-phase material is measured)	Micro-Vickers test Knoop test	10 To 1000gf.
Nano-Hardness Test	-	1 Nano-Newton

(b) Rebound hardness

- It is the resistance offered by a material to strike and absorb energy for plastic deformation under impact loads, causing the hammer to rebound.
- Most common example is the 'Shore scleroscope hardness test' which measures the hardness in terms of the rebound height of the indenter. It is virtually an indentation test.

(c) Scratch hardness

- It is the resistance of a material to scratch by another material, for example Mohs scale of hardness which is discussed after.

(d) Wear or abrasion hardness

- It is the resistance of a material to abrasion and wear, when subjected to rotational or sliding motion, for example file hardness test.

(e) Cutting hardness

- It is the resistance of a material to various cutting or drilling operations. This hardness is a measure of machinability of a material.
- 'Bauer drill test' is one of the various tests employed to determine the cutting hardness or machinability of materials

4. MOHS SCALE

- Mohs scale of hardness is widely used in the field of mineralogy but rarely applied for the testing of metals and alloys; it is a qualitative ordinal scale characterizing scratch resistance of various minerals through the ability of harder material to scratch softer material.

Table 2.3. Mohs scale of hardness

Mohs scale	Material
1	Talc
2	Gypsum
3	Calcite
4	Fluorite
5	Apatite
6	Orthoclase feldspar
7	Quartz
8	Topaz
9	Corundum
10	Diamond

5. INDENTER

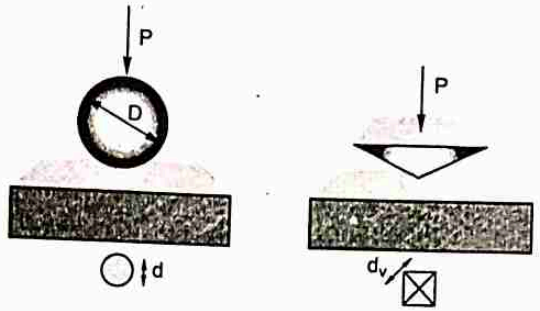


Fig. 2.4. Steel ball & pyramid indenter

- Indenter is the tool of material which causes deformation or indentation on the surface of the specimen to be tested which must be harder than the test piece.
- When the indenter is forced into the test piece, the indenter will be subjected to varying amount of elastic deformation depending on the magnitude of the applied load and the hardness of the test piece.
- The deformation mark or impression on the surface of the test piece is called indentation.

Table 2.4. Types of indenter

Indenter Type	Test
Hard Metal Ball	Brinell Hardness Test
Right Pyramid with a Square Base	Vickers Hardness Test
Diamond Or Ball Type	Rockwell Hardness Test

6. SELECTION CRITERIA OF HARDNESS TESTER

Main elements to consider before choosing a hardness tester

(a) Test load

- This is determined by the hardness of the material. Metals such as steel or alloys, for example, require test loads of up to 3,000 kgf, while soft metals require only 500 kgf. The higher the load, the higher the accuracy. It is important to note that the impression should not exceed 1/10 of the thickness of the sample.

(b) Hardness range

- It determines the material of the indenter. Over 650 HB/30 hardness, you should favor a diamond indenter. Below this value, steel or hard metal indenters are suitable.

(c) Accuracy level

- It depends on the surface to be measured (cleanliness, flat surface, static or dynamic system, etc.).

(d) Adaptability of the device

- It is importance varies according to the shape and size of the samples to be tested.

6. BENEFITS OF HARDNESS TEST

- Easy
- Inexpensive
- Quick
- Non-destructive
- May be applied to the samples of various dimensions and shapes
- May be performed in-situ

2.3. BRINELL HARDNESS TEST

- The standardized method for quantitative determination of indentation hardness, which was the first widely accepted indentation hardness test known as 'Brinell hardness' test
- **The Brinell hardness test consists of forming an indentation by forcing a standard spherical ball indenter into the surface of the material.**
- In this test a hardened steel ball of 2.5, 5 or 10 mm in diameter is used as indenter.
- The loading force is in the range of 300N to 30000N (300N for testing lead alloys, 5000N for testing aluminum alloys, 10000N for copper alloys, 30000N for testing steels).

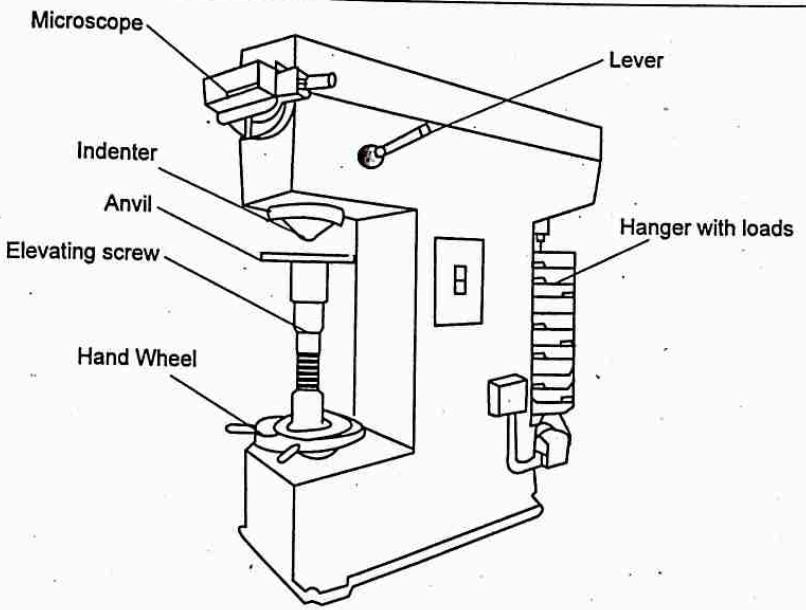


Fig. 2.5. Brinell tester with components

1. PRINCIPLE

- An indenter (hard metal ball with diameter) is forced into the surface of a test piece and the diameter of indentation, '*d*' left in the surface after removal of the surface, 'F' is measured under a definite static load applied for a standard period of time.
- The standard Brinell hardness tester operates usually under hydraulic pressure that applies force.

2. MAJOR COMPONENTS

- Brinell hardness tester
- Brinell microscope
- Indenters and Plunger
- Anvil

3. INDENTERS

- The diameters of spherical steel ball indenters used in the standard Brinell hardness test are either 5 or 10 mm. The ball indenter normally used is

made from heat treated hard high carbon steel, known as 'Hultgren ball' (made from tungsten carbide).

4. LOAD APPLICATION

- In Brinell hardness tester, load application and time duration is based the materials tested.

Table 2.5. Load application of metal

Load application	Diameter of ball	Duration	Metals
3000 kg	10-mm	10 Seconds	Iron, Steel and Alloys Having Hardness Similar to Steel
750 kg	5-mm		
500 kg	10-mm	30 Seconds	Copper, Annealed Brass and Magnesium Alloys etc.,
1000 kg	10-mm	15 Seconds	Gun Metal/Bronze and Cold-Worked Brass, etc

4. WORKING

- The surface of the test specimen must be either machined, ground, lapped or polished.
- The specimen is placed on the anvil of the testing machine, and the anvil is raised by rotating the hand wheel so that the specimen surface is brought in tight contact with the apex of the indenter
- Place the specimen on the test table and, apply a minor load to bringing both the pointers on the dial gauge to the 'set' positions.
- Apply the major load (remaining part of the test load) on the specimen by turning the loading lever backward.
- Maintain the load on the specimen exactly for the specified dwell time (15 seconds) and then release it by turning the loading lever forwards.
- Take out the specimen and measure the diameter of the indentation formed on it by using the Brinell Microscope.

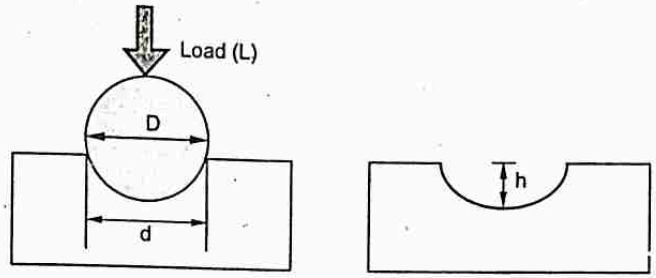


Fig. 2.6. Indentator impression

5. BRINELL HARDNESS NUMBER (BHN)

- The Brinell hardness number (BHN), expressed in units of kilograms per square millimeter , is defined as the ratio of the applied load (F in kilograms) to the curved surface area of the elastically recovered indentation(Area in square millimeters).

Brinhell hardness number (BHN) H_b = F/Area

$$\text{Area} = \frac{\pi D}{2}\left[D - \sqrt{(D^2 - d^2)}\right]$$

$$H_B = \frac{2F}{\pi D\left[D - \sqrt{D^2 - d^2}\right]}$$

$$h = \frac{1}{2}\left[\frac{D}{D^2 - d^2}\right]$$

H_b = Brinell hardness number (BHN)

h = Depth of Indentation (h)

D = Diameter of Ball in mm

L = Applied load in kg

d = Diameter of indentation in mm.

Table 2.6. Brinell hardness number for varies materials

Recommended Materials	Brinell Hardness Number (BHN)
Steel and similarly hard ferrous and other alloys	140–600
Harder Non-ferrous metals and alloys like gun metal/bronze, cold-worked brass	50–200

Recommended Materials	Brinell Hardness Number (BHN)
Non-ferrous metals and alloys like copper, annealed brass, magnesium alloys	25 – 100
Softer Non-ferrous metals and alloys like aluminum, lead, tin and their alloys	10 – 50

6. BEHAVIOUR OF DEFORMATION

Two types of anomalous behaviour, as illustrated schematically in cross-sections of Brinell indentation

- ❖ 'Ridging' or 'Piling up' which there is a formation of a lip or a raised ridge of material around the periphery of the indentation. This condition is observed with cold-worked materials having little ability to strain-harden.
- ❖ 'Sinking in' in which a depressed surface of the material is formed around the periphery of the indentation. This type of behaviour is frequently observed with annealed materials having a high rate of strain hardening.

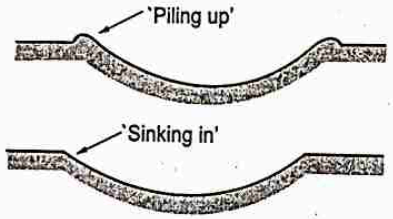


Fig. 2.7. deformation behaviour

7. ERROR IN READING

- ❖ Errors in reading the diameter of the indentation may arise from the following two causes ,
  - (*i*) Error in reading from the microscope
  - (*ii*) The boundary of the indentation is not distinct.

8. ADVANTAGES

- ❖ Simple, robust and low-cost indenters.
- ❖ The Brinell method can be used for testing non-homogeneous materials.
- ❖ A choice can be made between a large numbers of test forces.
- ❖ The influence of surface scratches and roughness will be less in the Brinell test than other hardness tests.
- ❖ The specimen surface can be rough.
- ❖ Suitable for hardness tests on large blanks such as forged pieces, castings and hot-rolled etc
- ❖ Measurement is usually not affected by movement of the specimen.

9. DISADVANTAGES

- ❖ Restriction of application range to a maximum Brinell hardness of 650 HBW.
- ❖ Restriction when testing small and thin-walled specimens.
- ❖ The test location must be prepared.
- ❖ High risk of deforming the material to be in test.
- ❖ Good illumination of the test indent is important for ensuring correct evaluation of the test indent.
- ❖ Limitation in applying the method on thin specimens of very hard materials.
- ❖ The process is slow (by comparison with the Rockwell method).
- ❖ Due to the larger size of the indentation, the application of Brinell hardness test is not possible on small jobs or critically stressed portions which would crack during the indentation.

2.4. ROCKWELL HARDNESS TEST

- ❖ In the Rockwell test the depth of the indenter penetration into the specimen surface is measured. Each time a test is performed two loads are applied to the sample being tested.

1. PRINCIPLE

- ❖ Rockwell hardness test is to determine the hardness of a metal by 'differential depth' measurement test. This hardness testing method

involved the measurement of the increment of depth of an indenter force into the metal by a primary and a secondary load.

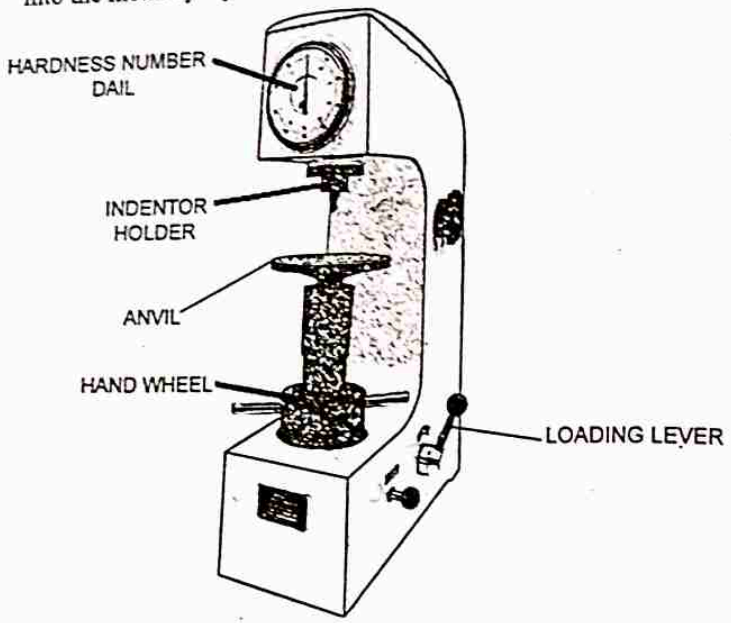


Fig. 2.8. Rockwell hardness tester

2. COMPONENTS

- Rockwell hardness tester
- Indenter

3. INDENTER

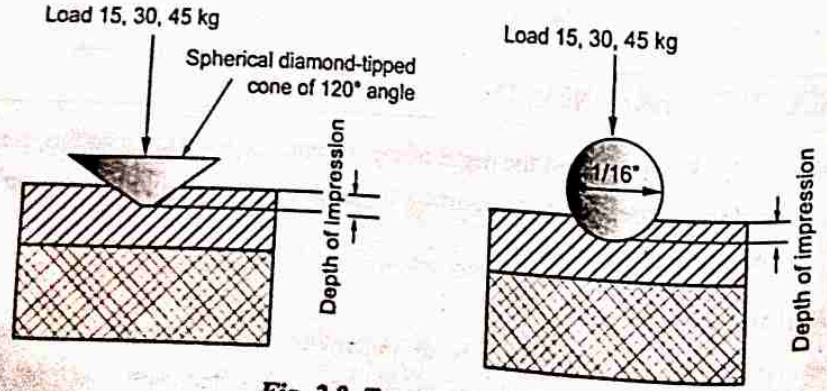


Fig. 2.9. Types of indenter

- The indenter or 'penetrator' is either made of hardened steel with shape of a spherical ball or made of diamond with shape of a cone having a spherical tip called the 'Brale'.
- The indenter may be either a diameter 1/16", 1/8" or a spherical diamond cone of 120° angle.

4. LOADING CONDITION

- Loads during testing are applied in two stages
  - Minor static load
  - Major static load

(a) Minor Static Load

- Minor static load of 10 kg is applied to form a very shallow indentation on the surface of the specimen through compression of a calibrated coiled spring placed within the machine between the indenter shaft and the dial.
- The purpose of applying minor load is as follows:
  - To eliminate the error that may arise due to variable contacts between the indenter and the surface of the specimen.
  - To set the indenter on the specimen and hold it in position.
  - To eliminate the error that may arise due to slight surface imperfections, i.e. to minimize the surface preparation of the specimen.
  - To reduce the tendency for 'ridging' or 'sinking in' caused by the indenter.

(b) Major Static Load

- Major static load of either 50, 90 or 140 kg is applied on the surface of the specimen through a system of weights and levers by means of an operating handle in the machine that enlarges the initially formed indentation under minor load.
- The total static load applied for indentation on the test piece is the summation of the minor load and the major load, which is equal to either 60 or 100 or 150 kg.

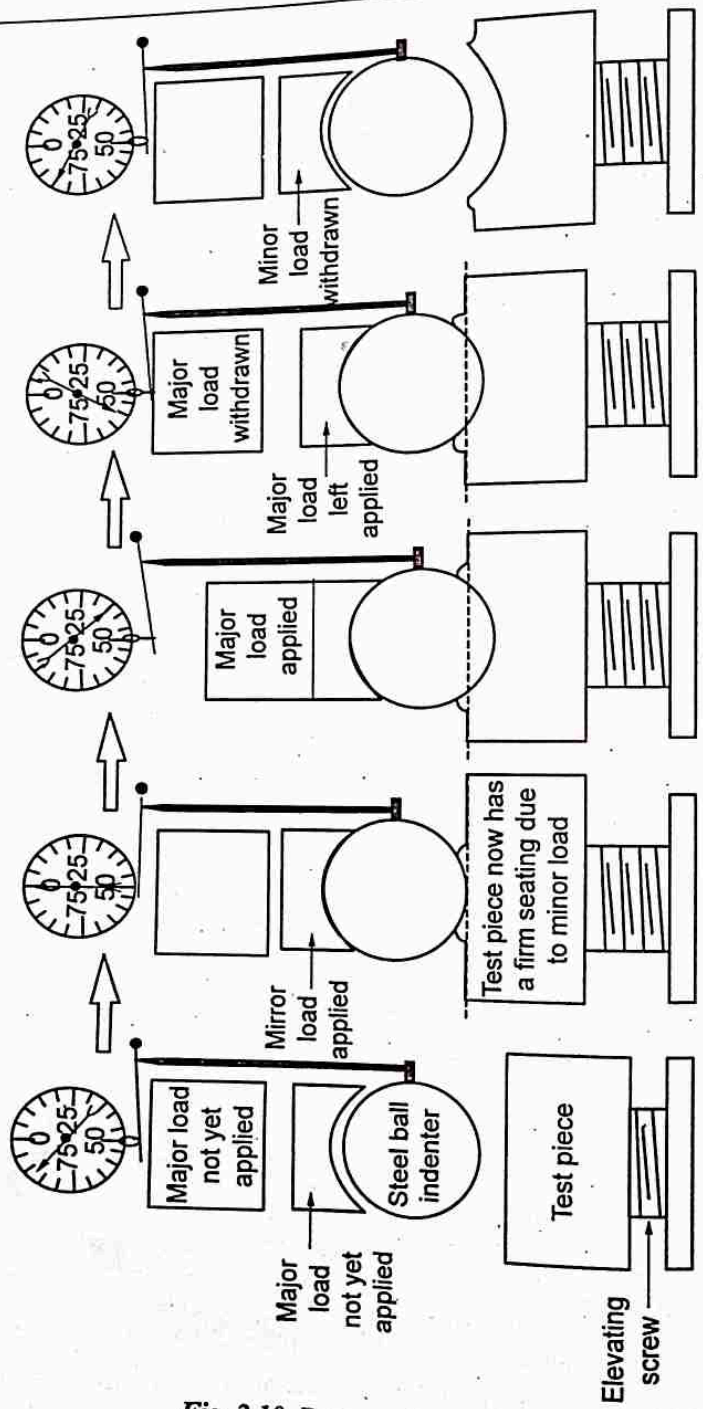


Fig. 2.10. Process of loading

5. WORKING

- The specimen to be tested is made flat by grinding and then roughly polished because any surface irregularities will be taken care of by the minor load.
- The application of the minor load becomes effective when the surface of the specimen kept on the anvil is brought in contact with the indenter by rotating the anvil elevating wheel.
- First, the indenter is forced into the test material under a preliminary minor load and this depth is recorded.
- With the minor load still applied an additional load is introduced known as the major load which increases the depth of penetration on the sample.
- The major load is then removed, and the force on the sample is returned to the minor load.
- The increase in the depth of penetration that results from applying and removing the major load is used to calculate the Rockwell hardness value.

6. ROCKWELL HARDNESS SCALE

- The Rockwell hardness value obtained for materials of different hardness with different combinations of total or major load and indenter are employed during the tests.

Table 2.7. Rockwell hardness scale

Rockwell Hardness Scale				
Scale	**Indenter**	**Load (kg)**	**Dial number**	**Typical material**
A	Diamond cone	60	Black	Cemented carbide, case hardened surface, thin steel
B	1.5 mm ball	100	Red	Copper, aluminium, brass, cast iron
C	Diamond cone	150	Black	Hard cost iron, hardened steel
D	Diamond cone	100	Black	Thin steel specimens

E	3 mm ball	100	Red	Soft aluminium and alloys, magnesium alloy, bearing metals
F	1.5 mm ball	60	Red	Bearing alloy, anneled copper and alloy

7. APPLICATIONS

- It is widely applied in the industry of Cemented carbides, Copper alloys Thin steel and medium case hardened steel, Cast iron, aluminum etc due to the rapidity and simplicity

8. ADVANTAGES

- High accuracy is achieved.
- Relatively low procurement costs for the testing machine because no optical measuring device is necessary.
- Relatively short test time because the hardness value is automatically displayed immediately following the indentation process.
- Relatively short time needed to train operator.
- Only small size of the impressions produced and lot of trails is followed in same specimen.
- It is generally used for testing of larger samples.
- It can be used for advanced tests.
- There was no special surface preparation.
- No measurements of indentation profiles as with other hardness tests.

9. DISADVANTAGES

- The main limitations are due to the fact that between maximum and minimum load there is only a 10:1 ratio.
- There has a possibility of errors due to the shifting of samples under test loads during the test cycle.
- The quality of the indenter and the surface has a strong influence on the test results.

- Possibility of measurement errors due to movement of the test piece and poorly seated or worn machine components during the application of the test forces.
- Sensitivity of the diamond indenter is high. If any damage in diamond indenter, thus producing a risk of incorrect measurements.
- Relatively low sensitivity on the difference in hardness.

10. ADVANTAGES OVER VICKER AND BRINELL HARDNESS TEST

- Its advantage over the Brinell test is that it can measure the hardness of harder materials that is beyond the scope of the Brinell test.
- It is faster because arbitrary hardness values can be read directly from the dial of the machine.
- It differs from the Brinell test in that the indentation and the loads are smaller, and hence, the resulting indentation is smaller and shallower, which is less objectionable in the finished parts.
- Due to application of minor load, the surface preparation of the specimen is minimized in comparison to the Brinell as well as Vickers hardness tests. Only rough grinding of specimen surface may be adequate for Rockwell hardness test.

2.5. VICKER HARDNESS TEST

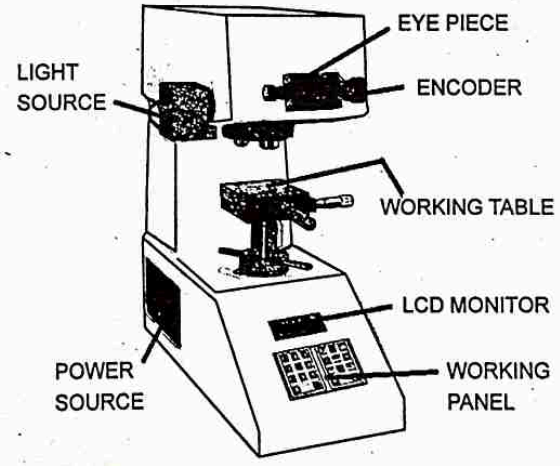


Fig. 2.11. Vickers hardness tester

❖ The Vickers hardness test, used to determine quantitatively the indentation hardness of material under the application of a constant static load, is a widely accepted method for research work because it is capable of measuring hardness from very soft materials to extremely hard materials without changing the load or indenter.

1. PRINCIPLE

❖ A diamond indenter in the form of a right pyramid with a square base and with a specified angle between opposite faces at the vertex is forced into the surface of a test piece followed by measurement of the diagonal length of the indentation left in the surface after removal of the test force F.

❖ The Vickers hardness test is a static hardness test method, used for both macro and micro hardness testing. It is an optical method of testing where the size of the indentation left by the indenter is measured to determine the hardness value of a test specimen.

2. COMPONENTS

❖ Vickers hardness tester

❖ Intender

3. INTENDER

❖ It is made of diamond in the form of a square-based pyramid with an included angle of 136° between opposite faces.

4. LOADING CONDITION

❖ The loads that can be applied to the indenter in Vickers hardness tester are 1, 2.5, 5, 10, 20, 30, 50, 100 and 120 kg through appropriate selection of weights.

5. WORKING

❖ Place the specimen carefully on the testing table.

❖ Turn the hand wheel slowly in the clockwise direction so that the specimen gets focused on the front screen sharply.

❖ Now bring the inventor to the "set" position and turn on the loading, dwell-unloading cycle.

❖ The indentation is now projected on the front focusing screen.

❖ Measure the diagonals along both the axis of the impression and record them.

6. VICKERS HARDNESS NUMBER

❖ Vickers hardness number is frequently called as the diamond pyramid hardness number.

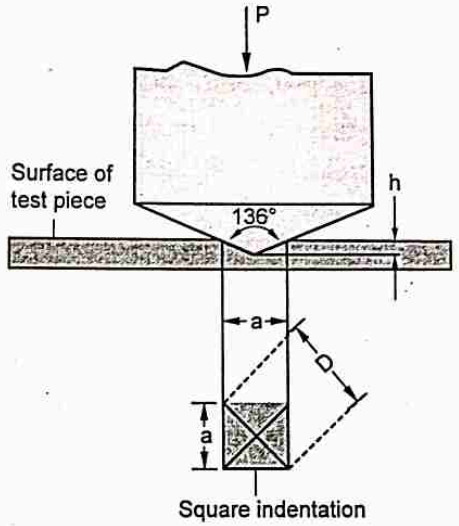


Fig. 2.12. Vickers diamond indenter

❖ The Vickers hardness number (VHN) is defined as the ratio of the applied load, P (kilogram) to the surface area of the elastically recovered pyramidal indentation (A_s in square millimeters).

$$VHN = \frac{P}{A_s} \text{ kg/mm}^2$$

$$VHN = \frac{P}{D^2 / 1.854}$$

$$= 1.854 \times \frac{P}{D^2}$$

P = Applied load in (kg)

A_s = Lateral area of elastically recovered pyramidal indentation (mm^2)

D = Average diagonal length of square indentation in (mm)

7. ADVANTAGES

- The Vickers method can be used with any & all materials and test specimens, from soft to hard, as it covers the entire hardness range.
- Testing thin sheets, small test pieces or test surfaces, thin-walled tubes, thin, hard and plated coatings is possible.
- There is only one type of indenter, which can be used for all Vickers methods.
- Non-destructive testing is possible, so the test specimen can be used for other purposes
- The small indentation has no influence on the function or appearance of tested materials or products.
- Useful for finding stress values.

8. DISADVANTAGES

- The test location must be prepared (ground and polished), otherwise precise evaluation is difficult.
- The process is rather slow (compared with the Rockwell method). The test cycle takes somewhere between 30 and 60 seconds, not including the time taken to prepare the specimen.
- Relatively long test time due to the measurement of the diagonal lengths.
- Due to the need to conduct optical indent evaluation, Vickers hardness testers must be equipped with an optical system, which makes them more expensive to purchase than Rockwell testers.
- Sensitivity of the diamond indenter to damage.
- Very sensitive to effects of vibration, especially in the micro hardness range.

2.6. KNOOP HARDNESS TEST

- The quantitative determination of hardness on materials over a very small area under the application of a constant static load, the diamond indenter known as the 'Knoop' indenter and hardness test is called Knoop hardness test (Micro hardness).

2.7. MONOTRON HARDNESS TEST

- The Monotron hardness test also operates on the depth of the indentation is fixed or predetermined under the application of variable static loads during hardness measurements of different materials, whereas different sizes of the indentations are formed under an applied constant load in other hardness tests.

2.8. NANO HARDNESS TESTS

- Nano hardness tests or Nano indentation tests, in which the magnitudes of applied forces are usually in the milli-newton range, may be as low as 0.1 mN. Majority of nano indentation tests aim to obtain Young's modulus along with measurement of hardness of the specimen material from the load–displacement data obtained in tests.

2.9. COMPARISON BETWEEN ROCKWELL TEST, BRINELL TEST AND VICKERS TEST

Properties	Brinell	Rockwell	Vicker
Indenters	Hard metal	Steel ball or diamond cone	Square-based pyramid diamond indenter with a 136° included angle
Load	Typically 1kg to 3000kg	30-100 kg	Typically 10g to 1,000g
Duration	15- 30sec	10-15 sec	30-60 sec
Advantages	Simple surface preparation, easy measurement	Higher speed, immediate reading, shallow imprint.	The test specimen can be used for other purposes.
Disadvantages	Impression is large with visible trace	Possibility of cone breakage	Surface preparation is needed

2.10. TENSILE TEST

❖ Tensile test is a measurement of the ability of a material to withstand forces that tend to pull it apart and to determine to what extent the material stretches before breaking. Tensile modulus, an indication of the relative stiffness of a material, can be determined from a stress–strain diagram.

❖ The tension test is the most common method for determining the mechanical properties of materials, such as strength, ductility, toughness, elastic modulus, and strain- hardening capability.

1. PRINCIPLE

❖ A standardized specimen with a known cross section is loaded uniformly with relatively low increasing force in the longitudinal direction.

❖ A uniaxial stress state prevails in the specimen until contraction commences. The ratio of stress to strain can be shown from the plotted load-extension diagram.

2. EQUIPMENT

❖ Universal Testing Machine (UTM), Extensometer, Scale Vernier Calipers, Punching tools.

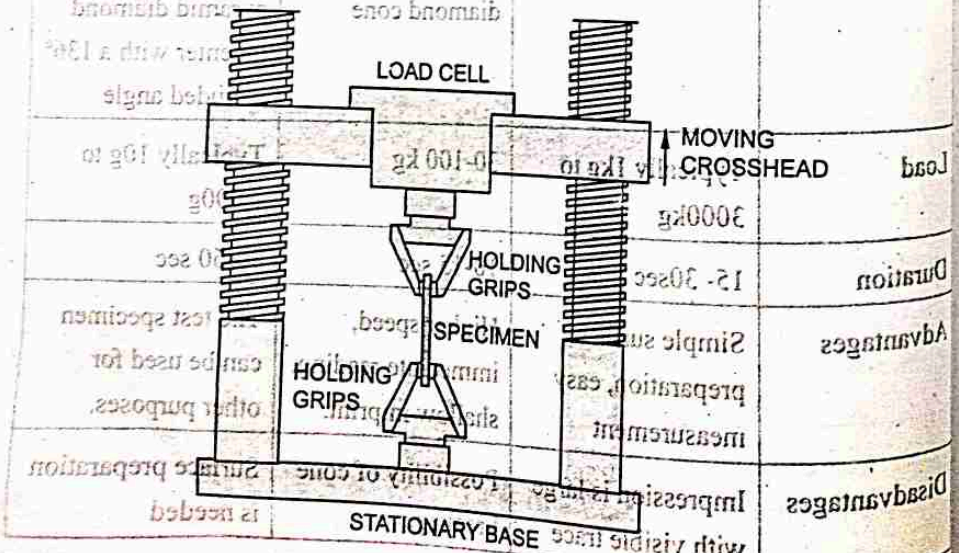


Fig. 2.13. Tensile testing apparatus

3. UNIVERSAL TESTING MACHINE

❖ Universal testing machine has two crossheads with one is adjusted for the length of the specimen and the other is hydraulic powered driven to apply tension and compression to the test specimen.

❖ It is capable of force capacity from 500N to 1MN.The strain measurements are measured with an extensometer.

4. EXTENSOMETER

❖ The accurate measurement of dimensional change achieved by attaching the sensitive measurement device to test piece. The devices used to measure longitudinal strain are termed as extensometer.

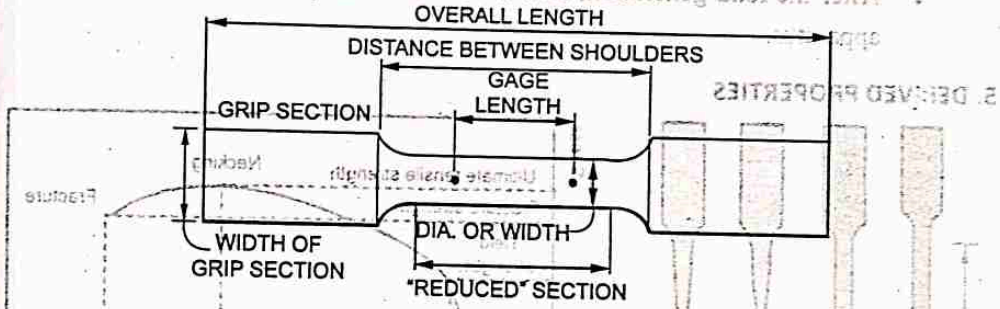


Fig. 2.14. Sample Tensile Specimen

4. WORKING

❖ **Preparation of Specimen:** Initially, the steel rod specimen is cleaned and gauge length is marked on it. The ultimate load range to be fixed.

❖ **Placing the Specimen:** Once the specimen is placed, the jaws are locked.

❖ **Placing Extensometer:** Fix the extensometer on the specimen and set the reading to zero.

❖ **Load Application:** When the specimen is under load, slowly unclamp the locking handle. Note the extension at a convenient load increment. Extensometer must be removed before reaching the yield point.

❖ **Important Load Points:** With the increase in load at some point, the load pointer remains stationary this indicates the yield point. With further increase in load, the pointer goes backward and specimen breaks. The load

before this breaking is the ultimate load. The load at the breaking of the specimen is called as the breaking load.

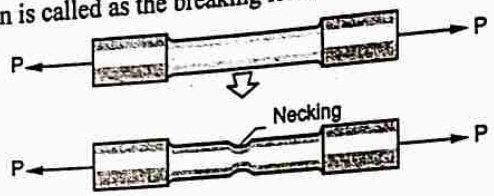


Fig. 2.15. neck formation

- Necking is a large reduction caused in the cross-sectional area of the steel rod. Measure the diameter of the specimen at the neck.
- After the load generation, load is reversed and specimen is removed from apparatus.

5. DERIVED PROPERTIES

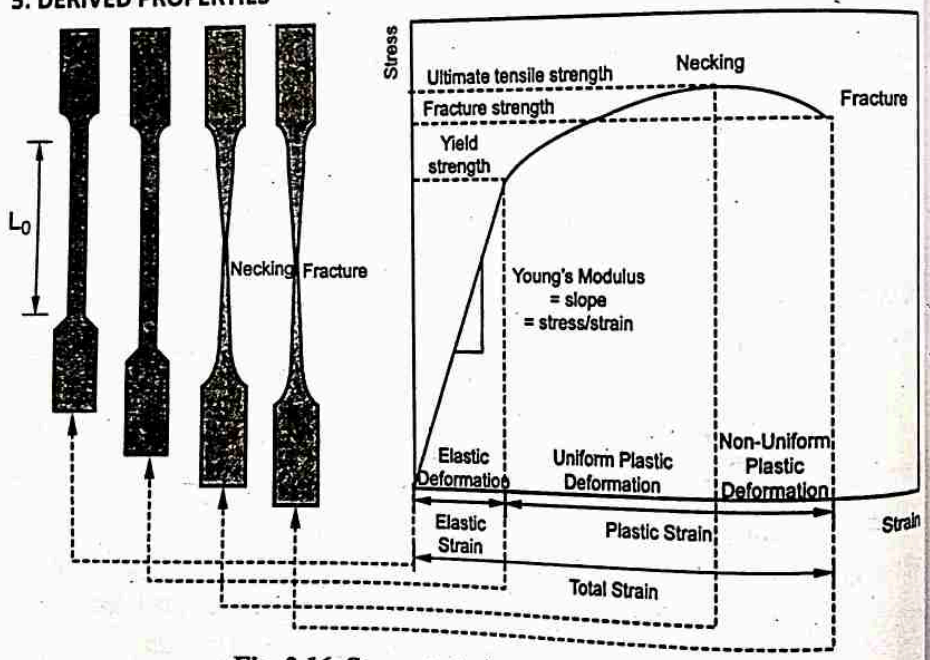


Fig. 2.16. Stress strain curve of mild steel

- **Proportional Limit:** The material is capable of sustaining the applied load without any deviation, it is defined as proportionality of stress to strain within elastic limit (Hooke's Law).

- **Elastic Limit** - The lowest stress at which permanent deformation can be measured.
- **Engineering Stress:** Stress (nominal stress) is defined as the ratio of the applied load to the original cross-sectional area of the specimen

$$\text{Stress } (\sigma) = \frac{\text{Applied load}}{\text{Original cross-sectional area}}$$

- **Engineering Strain:** Strain is defined as change in length to original length

$$\text{Strain } (e) = \frac{\text{Change in length}}{\text{Original length}}$$

$$\text{Percentage of elongation} = \frac{[\text{Final length(at fracture)} - \text{Original length}]}{\text{Original length}}$$

$$\text{Percentage of Reduction in area} = \frac{[\text{Original area} - \text{Area at fracture}]}{\text{Original area}}$$

- **Tensile strength:** Tensile strength is stress obtained at highest applied force is the tensile strength which is the maximum stress on curve.

$$\text{Tensile strength} = \frac{\text{Force (load)}}{\text{Cross-section area}}$$

- **Ultimate tensile strength:** The ultimate tensile strength at yield and at break is calculated.

$$\text{Tensile strength at yield} = \frac{\text{Maximum load}}{\text{Cross-section area}}$$

$$\text{Tensile strength at break} = \frac{\text{Break load}}{\text{Cross-section area}}$$

- **Tensile Modulus (Modulus of elasticity or Young's modulus):** Tensile Modulus and Elongation are derived from a stress strain curve. The extensometer is magnifies the actual stretch of the specimen.

$$\text{Tensile modulus} = \frac{\text{Difference in stress}}{\text{Difference in corresponding strain}}$$

- **Yield strength:** The yield strength (YS) is the stress required to produce a small specified amount of plastic deformation.

$$\text{Yield point} = \frac{\text{Load at sharp discontinuity}}{\text{Original cross sectiona area}}$$

❖ **Upper Yield Point and Lower Yield Point**

(*a*) Upper Yield Point is beyond elastic limit a ductile material has plastic properties. Upper yield point is the point at which maximum external load or stress is required to initiate plastic deformation inside the material.

(*b*) Lower Yield Point is material length will increase with a very small increase in external load (stress). In other words it is the point at which minimum load is required to maintain the plastic behavior of the material

❖ **Ductility:** Ductility is the extent of plastic deformation that the material undergoes before fracture.

❖ **Elasticity:** Elasticity is the property of the material which enables the material to return to its original form after the external force is removed.

❖ **Necking:** In stress strain curve when the specimen reaches its ultimate stress then diameter of portion starts decreasing because of local instability. This phenomenon is called necking.

❖ **Plasticity:** It is a property that allows the material to remain deformed without fracture even after the force is removed.

❖ **Strain hardening:** The increase in the tensile strength of the material is due to strain hardening which is due to the increased dislocations interactions during the deformation of the tensile test. This is called Strain-hardening.

❖ **Proof Stress:** The stress that causes a percentage increase in gauge length. It can be found by drawing a line parallel to the straight part of the graph. A value can be taken from the vertical axis.

6. FACTORS AFFECTING TENSILE TESTING

❖ Specimen Preparation and Specimen Size
❖ Rate of Straining
❖ Temperature
❖ Hydrostatic Pressure Effects
❖ Radiation Effects

7. VARIES FORMS OF TENSILE TEST

1. Tensile adhesion
2. Tensile shear
3. Tensile grab
4. Tensile pulling
5. Tension fatigue
6. Tensile creep.

8. ADVANTAGES

❖ The main advantages of this test are to check yield strength, tensile strength and ductile property of material.
❖ Used for selecting materials for an application based.
❖ It provides safety and integrity of materials.
❖ It determines batch quality.

9. DISADVANTAGES

❖ It does not provide information about the material at different temperatures.
❖ It does not identify the strength of the material at differing strain rates.
❖ It does not identify any possible asymmetry in the material strength.
❖ It provides no information about the strength of the material in different environments.
❖ It provides no information about changes in the material strength due to the process of forming the material. (A casting will have different properties than a forging or a sintered metal part.
❖ Since it is destructive testing, the material gets wasted every time. The test is mainly restricted to ductile materials.
❖ Tensile test is a destructive testing, where sample is made in Standard size.
❖ It is done under constant strain rate and constant temperature.

2.11. IMPACT TEST

- Impact testing is a very popular and fast method for evaluating the fracture toughness of materials. One of the purposes of this method is to evaluate the energy absorbed by a standard specimen during tests at a very high strain rates.
- The impact test is a dynamic test, carried out with notched specimen and known as notched-bar impact test.

1. METHODS OF IMPACT TESTING

- Impact blow may be applied by means of dropping weight, a swinging pendulum and a rotating flywheel.
- Specimen is ruptured in impact test by a single blow, repeated blows of constant magnitude and repeated blows of increasing magnitude.
- Impact tests may be carried out with different types of loading, Flexural loading, Tensile loading, Compressive loading and Torsional loading.
- Based on the loading condition, impact blow pattern and rupturing blow, the impact test is classified as follow

1. Single-Blow Pendulum Impact Test
   - (*i*) Charpy Notched-Bar Impact Test
   - (*ii*) Izod Notched-Bar Impact Test
2. Drop Weight Test (DWT)
3. Robertson Crack-Arrest Test
4. Dynamic Tear (DT) Test
5. Instrumented Puncture Testing
6. Tensile Impact test.

2. PURPOSE OF IMPACT TESTING

- The purpose of an impact test is to determine the ability of the material to absorb energy during a collision.

- This energy may be used to determine the
  - Toughness
  - Impact Strength
  - Fracture Resistance
  - Impact resistance or fracture resistance of the material

2.12. THE IZOD AND CHARPY TEST

- **The Charpy V- notch** impact test is the most common fracture toughness test. A notched specimen is broken by a swinging pendulum and the amount of energy required to break the specimen is recorded.
- **The Izod impact** strength test is a standard method of determining the impact resistance of materials. A pivoting arm is raised to a specific height (constant potential energy) and then released. The arm swings down hitting a notched sample, breaking the specimen.

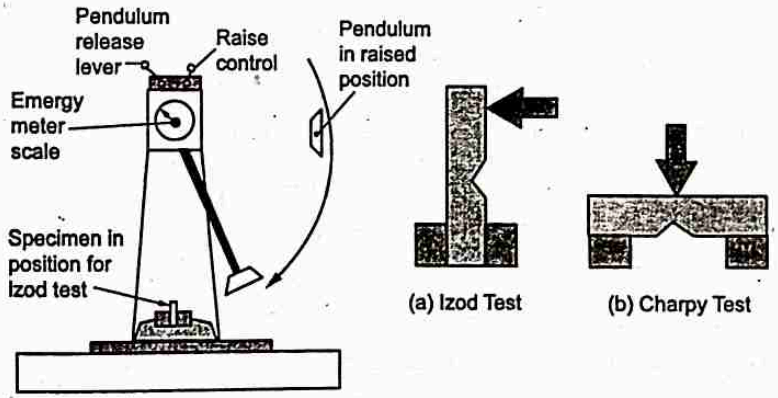


Fig. 2.17. Pendulam impact machine and notch position

1. PRINCIPLE OF IMPACT TESTING

- The sample is placed into a holding fixture with the geometry and orientation determined by the shape of a pendulum is released from a known height so that it collides with the specimen with a sudden force.

- This collision between the weight and specimen generally results in the destruction of the specimen but the transfer of energy between the two is used to determine the fracture mechanics of the material.

2. WORKING

- The test piece is held in the anvil, prior to the release of the pendulum by are lease mechanisms from its fixed starting point.
- A Charpy V-notch specimen is placed across parallel jaws in the impact testing machine and for Izod test specimen is placed perpendicular to jaws.
- The pointer is set up to its maximum value (300 J).
- Initially before release, the pendulum will have a potential energy that depends on the weight of the pendulum and its height off all. Upon release, the pendulum strikes and breaks the test piece by a single blow, which consumes part of the energy of the pendulum depending on the toughness of the test material.
- The energy consumed to break the specimen is measured, usually in joule, from the position of a pointer on a dial attached to the impact tester.
- Observations of the energy absorbed are recorded.

3. APPLICATIONS OF IMPACT TEST

- The impact test also indicates the notch sensitivity of a material resulting from the presence of internal stress raisers such as grain boundary inclusions, internal cracks, and second phases.
- The impact test is often used to assess the transition temperature from the ductile to brittle state which occurs as the temperature is lowered.

4. ADVANTAGES

- The chief merit is that comparatively in expensive small-sized test specimens are used in these tests, which are also comparatively simple to carry out.
- The higher the impact value of a material is, the higher the toughness or tenacity of the material.

- Tests can easily be performed over a wide range of sub ambient temperatures.
- Tests can be applied to study and compare the effects of heat treatments and alloy additions on the notch tough-ness of a material.
- Tests are well suited for quality control and material acceptance purposes.
- The impact value can be used for determining the load bearing capacity of a material against momentary stress from impact strength and fracture energy.

5. DISADVANTAGES

- Impact tests are of little value for most wrought nonferrous metals such as aluminum, copper, and their alloys since there is no transition to brittle behavior.
- The main problem is that the results obtained from these tests cannot be readily used in design.
- The notched-bar impact properties are remarkably influenced by the size, shape and sharpness of the flaw.
- Variation in result if improper placement of the test piece in the impact tester.

2.13. COMPARISON BETWEEN IZOD IMPACT TEST AND CHARPY IMPACT TEST

Parameter	Izod impact test	Charphy impact test
Specimen position	Specimen held at vertical	Specimen held at horizontal
Point of strike	At Upper tip of specimen	At Point of notch but in opposite direction
Types of notch	V-notch	V-notch and U-notch
Type of hammer	Farming hammer	Ball pin hammer
Specimen dimension	75 × 10 × 10 mm	55 × 10 × 10mm

Parameter	Izod impact test	Charphy impact test
Notch face	Facing the striker, fastened in pendulum	Face is positioned away from the striker
Materials used	Plastics and metals	Metals
Holding	It imitates cantilever beam	It imitates simply supported beam
Temperature	It is largely affected by temperature changes	It shows minimum error to temperature changes
Calculation	The Izod impact value (J/m, kJ/m^2) is calculated by dividing the fracture energy by the width of the specimen.	The Charpy impact value (kJ/m^2) is calculated by dividing the fracture energy by the cross-section area of the specimen.
Energy	The fracture energy is determined from the swing-up angle of the hammer and its swing-down angle	The fracture energy is determined from the swing-up angle of the hammer and its swing-down angle.

2.14. BEND TEST

- Bending tests is standard test method for material of smooth bars like flat metal spring, concrete, natural stone, wood, plastics, glass and ceramics.
- It also called as flexural test (particularly to evaluate tensile strength of brittle material which is difficult to under estimate in uniaxial tension test).

1. PRINCIPLE

- Bending tests are conducted by placing a length of material across a span and pushing down along the span to bend the material causing a concave surface or a bend to form without the occurrence of fracture and are typically performed to determine the ductility or resistance to fracture of

that material, the elastic modulus of bending, flexural stress, and flexural strain of a material.

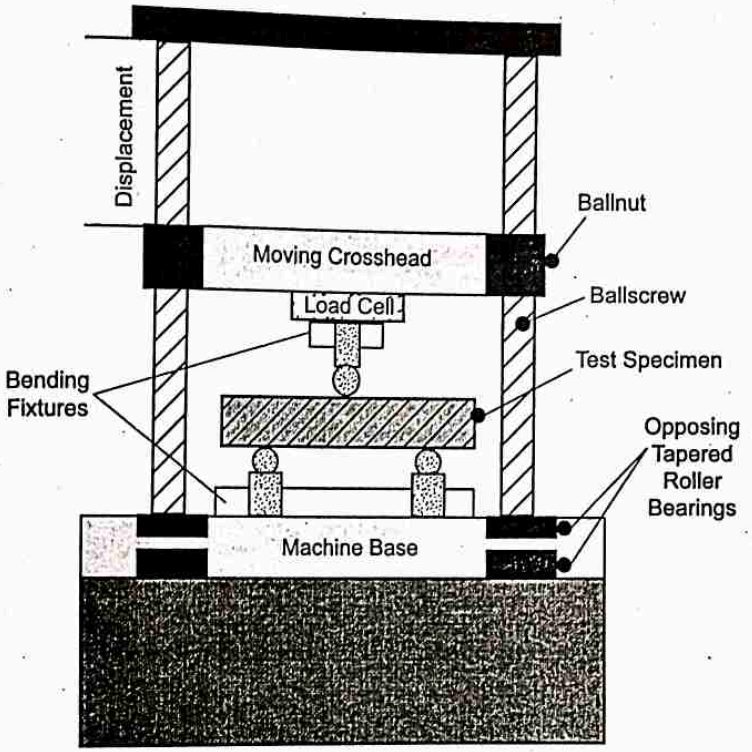


Fig. 2.18. Bending test equipment

METHODS OF BEND TEST BASED ON LOAD POSITION

- **Single-point loading at the free end of a cantilever beam** - A cantilevered beam is fixed at one end and the other end is free. In cantilever beam tests, a load is applied to the free end of the beam until failure occurs
- **Centre point loading (or) Three-point bending test** - Three-point bend fixtures configuration of flexural strength testing, where a specimen is loaded at a location midway between two supports bearings
- **Four-point bending test**-Four-point bend fixtures configuration of flexural strength testing where a specimen is symmetrically loaded at two locations

that are situated one quarter of the overall span, away from the outer two support bearings.

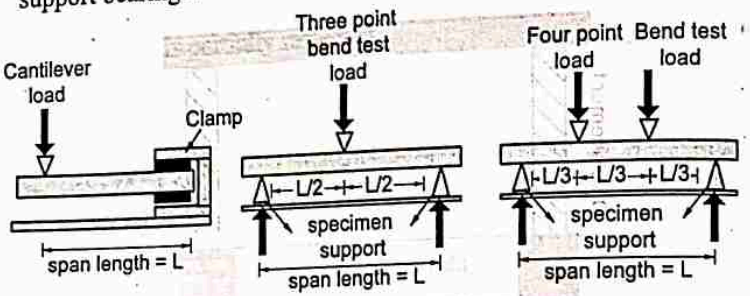


Fig. 2.19. Cantilever, 3-point and 4point Load position

Bend Testing Universal Testing Systems

- Material testing systems accurately and reliably measure the flexural properties of metals, concrete, plastics, medical devices and other products and components. The machines can calculate flexural modulus, flexural strength, and yield point at maximum capacities.

Bend Fixtures

- Bend fixtures are used to determine the flexural properties of rigid and semi-rigid materials. They are available in a variety of capacities, spans, and support diameters and widths. It consists of default adjustable load pointer based on loading position.

3. WORKING

- The bending fixture is supported on the platform of hydraulic cylinder of the UTM.
- A loading beam that rests on two rollers on the top of beam to be tested is used to apply the loads. Accurate spacing of the supports and loading points is necessary.
- A load is applied to the loading beam accurately at the mid-point between its two supporting rollers for three-point loading (or) four-point loading.
- The supports are generally knife-edge or convex. The load applicator is a rounded knife-edge with an included angle of 60°, applied either at mid span (for three-point testing) or symmetrically placed from the supports (for four-point testing).

- These rollers in turn must be spaced accurately at equal distances from the supporting rollers for the beam to be tested.
- If the distance between the supporting rollers of the test-beam is L; the supporting rollers of the loading beam are often located at L/3 or L/4 distances from the test-beam supports, although any equal location distances can be used.
- Load and either deflection or strain are usually recorded in the test.
- Using this method, a beam mounted on supports is studied under a applied force to the beam.
- The bending test demonstrates the relationship between the load of a bending beam and its elastic deformation.
- The loading is held in the middle cross head.
- At a particular load the deflection at the center of the beam is determined by using a dial gauge.

4. DERIVED PROPERTIES

(*a*) Flexural strength, also known as modulus of rupture or bend strength or transverse rupture strength is a material property, defined as the stress in a material just before it yields in a flexure test.

1. For three point bending test (rectangular cross section)

$$\sigma_f = \frac{3FL}{2bd^2}$$

2. For four point bending test where the loading span is 1/2 of the support span (rectangular cross section)

$$\sigma_f = \frac{FL}{bd^2}$$

3. For four point bending test where the loading span is 1/3 of the support span (rectangular cross section)

$$\sigma_f = \frac{3FL}{4bd^2}$$

σ_f = Stress in outer fibers at midpoint, (MPa)

= load at a given point on the load deflection curve, (N)

L = Support span, (mm)

b = Width of test beam, (mm)

d = Depth or thickness of tested beam, (mm)

(b) Deflection is the degree to which a element is displaced under a flexural load (due to its deformation).Deflection for three point bending test,

$$\delta_C = \frac{FL^3}{48EI}$$

E = Modulus of Elasticity (or) Young's modulus

I = Area moment of inertia of cross section

4. FACTORS AFFECTING THE MODULUS OF RUPTURE

1. Types of loading
2. Length of span
3. Shape of the cross-section of a beam
4. Cross-sectional dimensions of a beam
5. Rate of loading, i.e. speed of testing

5. ADVANTAGES

- Simpler sample geometries.
- Minimum sample machining is required.
- Simple test fixture.
- Possibility to use as-fabricated materials
- The bend test is a simple and inexpensive qualitative test that can be used to evaluate both the ductility and soundness of a material.
- It is often used as a quality control test for butt-welded joints, having the advantage of simplicity of both test piece and equipment.
- The main advantage of a three point flexural test is the ease of the specimen preparation and testing.

6. DISADVANTAGES

- The results of the testing method are sensitive to specimen and loading geometry and strain rate.
- More complex stress distributions through the sample.

2.15. SHEAR TEST

- In Shear test, the shear force is the load that causes two contiguous parts of the body to slide relative to each other in a direction parallel to their plane of contact.

1. PRINCIPLE

- Shear strength measures a material's ability to resist forces that cause the material to slide against it. The Specimen is loaded in shear fixtures, load in applied perpendicular to specimen through plunger. The phenomenon of shear applies through the shear fixtures (coupling device) is known as shear test.

2. TYPES OF SHEAR TEST

1. Single shear test
2. Double shear test

3. COMPONENTS

- Universal testing machine
- Vernier caliper
- Shear fixtures

4. SHEAR FIXTURES

- Two coupling braces which is used for both single or double shear connection. Both are at similar position with certain distance apart. For single shear, specimen is routed to single brace and for double shear, specimen is routed fully.

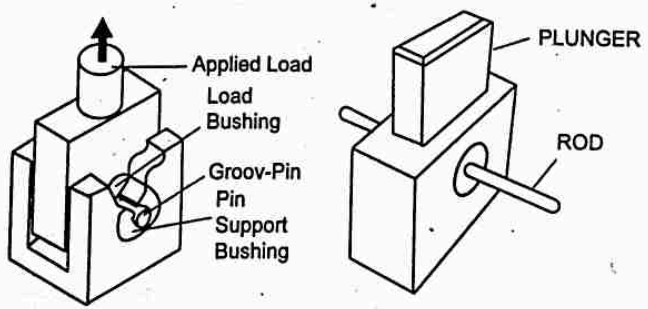


Fig. 2.20. Layout of shear fixtures

5. SINGLE & DOUBLE SHEAR TEST

- In the double-shear method, the specimen is sheared off at two cross sections. In the single-shear process, the specimen only shears away at one cross section. Calculating the shear strength in the two processes differs in the cross-sectional area to be applied. The shear strength determined in the shear test is important in the design of bolts, rivets and pins, as well as for calculating the force required for shears and presses.

6. WORKING

- The diameter is measured using the vernier caliper
- Mount the shear fixtures on UTM and load the specimen in shear fixture accordance to need of shear test. Operate (push) buttons for driving the motor to drive the pump.

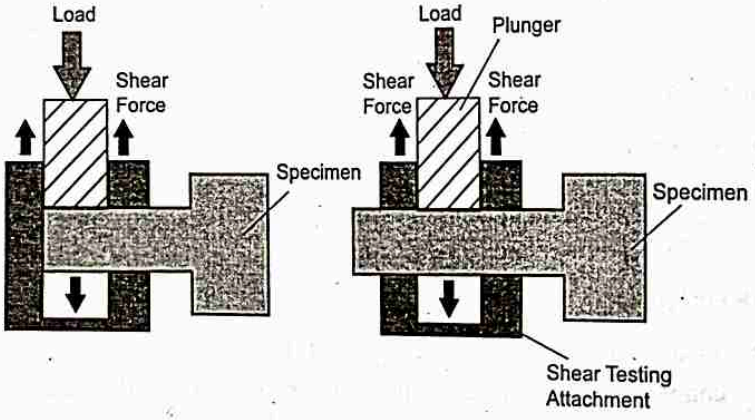


Fig. 2.21. Single and double shear loading

- Gradually move the head control level direction till the specimen shears. Take the load at which the specimen shears.

$$\text{Shear Stress } (\tau) = \frac{F}{2A}$$

where, F = Force at breaking shear

A = Shearing Surface

7. ADVANTAGES

- The time of testing is small

- The adhesion capacity also can be found.
- Result evaluations is direct manner
- No skilled labor is requires

8. LIMITATIONS

- Due to limitation in diameter of hole, size of testing rod is limited.
- If Error in measurement of the diameter of the specimen gives large variation in results.
- For sheet metal, thickness is restricted.

2.16. CREEP

- The material is stressed with static load at increased temperature. The material fails before yield point and without an increase in load lead to a slow but steady irreversible plastic deformation, also known as creep. After a sufficiently long, even load time, this leads to fracture of the specimen.
- The creep is viscoelasticity process.
- Stress relaxation is closely related to creep. In stress relaxation, the stresses resulting from loading of a structural component decrease in magnitude over a period, even though the dimensions of the component remain constant.

1. CREEP TEST

- In the creep rupture test, a specimen is subjected to load at constant stress and constant temperature.
- This experiment is performed multiple times with different temperature, but always at static loading. The plastic deformations are measured in continuous intervals.
- All measured values can then be transferred to a creep diagram. The measured elongation shows a characteristic curve, which is known as the creep curve.
- The creep rupture test determines the characteristic values for the creep strength and the various strain values

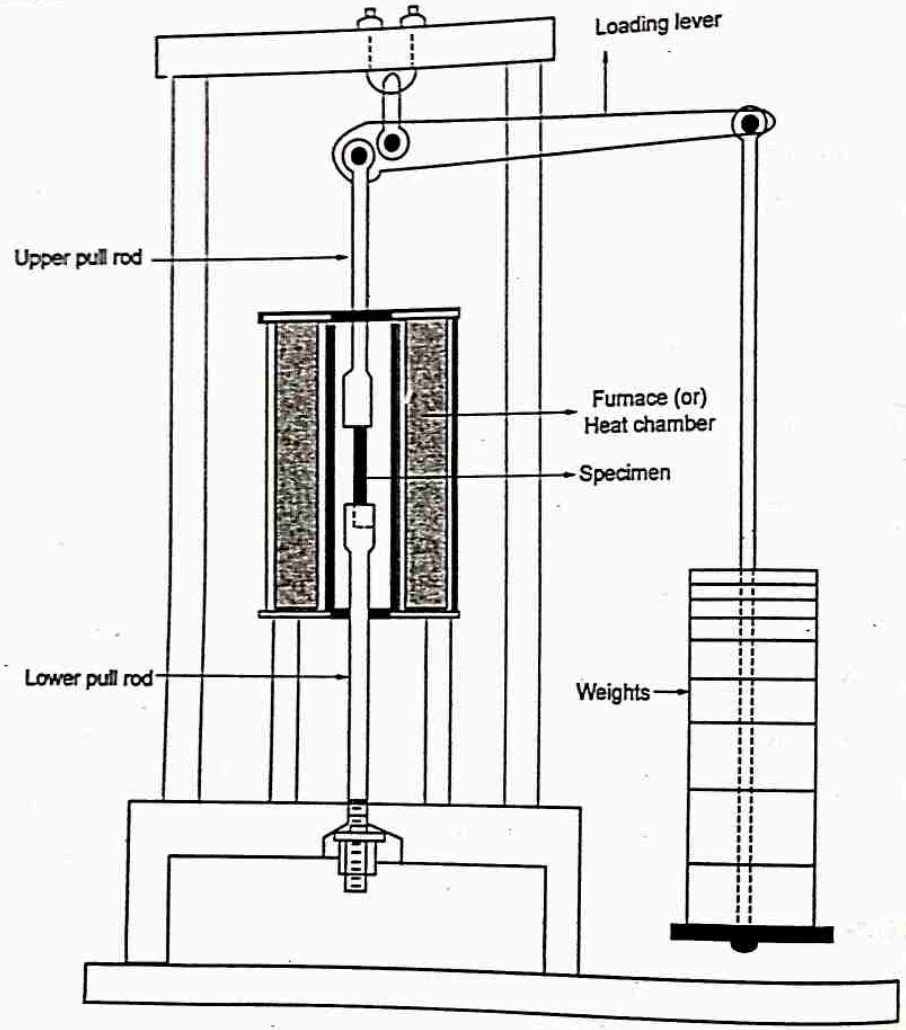


Fig. 2.22. Constant loading creep

2. Procedure

- Mark the sample for the reduced gauge length (uniform width), **Heating Chamber** is what surrounds the object and maintain the temperature that the object is subjected to gradually elevated temperature.
- Measure the dimensions (gauge length and width by Vernier caliper and thickness by screw gauge) of the given lead sample.
- Fix the ends of the sample up to mark in the jaws of the machine

- Adjust the extensometer position on the load such that needle on dial is at '0' position
- The value of change dimension with respect to time for increased temperature with static loading is noted until the specimen fails.

The final result will be done in following steps,

- Calculation of stress
- Plot strain vs. time
- Calculate the creep rate as a function of time and identify the various stages of creep
- Finding the minimum creep rate at each stage

3. Stages of Creep

(a) Primary Creep

- Primary creep or transient creep the initial creep stage where the slope is rising rapidly at first in a short amount of time.
- After a certain amount of time has elapsed, the slope will begin to slowly decrease from its initial rise.

(b) Secondary creep

- Steady-state creep or secondary creep after the primary creep, the creep rate reaches essentially a steady state, in which the creep rate changes little with time. This region of approximately constant creep rate.
- During this stage, the steady state is achieved because of an approximate balance between two opposing factors: the strain hardening that tends to reduce the creep rate and the softening or recovery process that tends to increase it.
- The creep rate is constant so the line on the curve shows a straight line that is a steady rate.

(c) Tertiary Creep

- The last stage of creep when the object that is being subjected to pressure is going to reach its breaking point.

- In this stage, the object's creep continuously increases until the object breaks. The slope of this stage is very steep for most materials. During this stage, high stresses or/and at high temperatures.
- The creep rate is greater and increases continuously till the material undergoes fracture.
- Tertiary creep occurs when the effective cross-sectional area of the specimen is reduced remarkably either due to localized necking or internal void formation.

(d) Ultimate ductile failure

- It which takes place when the crack becomes sufficiently long so that the remaining cross-section can no longer sustain the applied load.

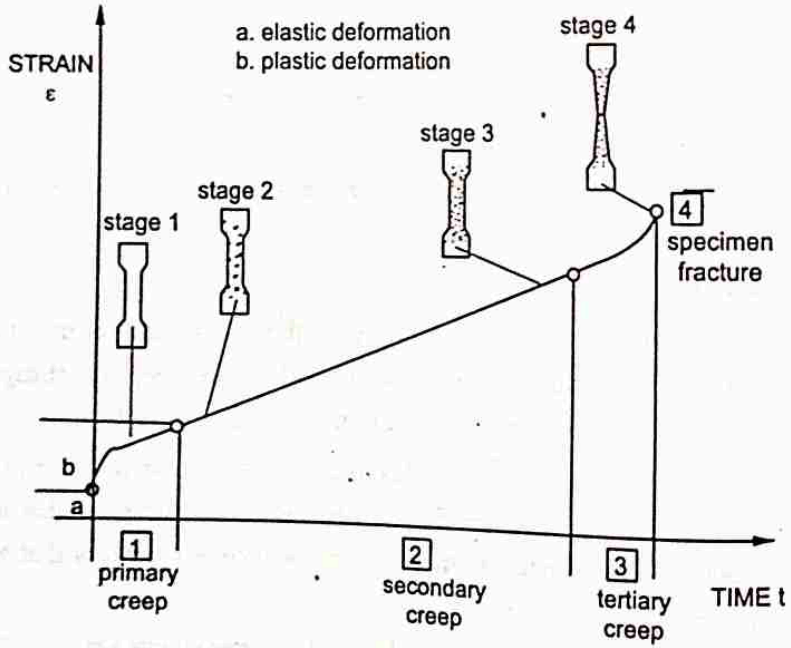


Fig. 2.23. Stages of creep

4. MECHANISM OF DEFORMATION

- **Dislocation creep:** At high stresses (relative to the shear modulus), creep is controlled by the movement of dislocations. That involves dislocation glide and climb.

- **Diffusional creep :** That involves stress-assisted diffusional flow of atoms and vacancies
- **Grain-boundary sliding:** It is a shear process occurring in the direction of grain boundary, causing the movement of grains relative to each other in polycrystals.

5. METHODS TO REDUCE CREEP

- Solid solution strengthening
- Particle dispersion strengthening
- Precipitation hardening
- Increasing grain size

6. ADVANTAGES

- To determine the stability of a material and its behaviour when it is put through ordinary stresses like crcep test.
- The understanding of their properties and advantages of one material's use over another.

7. LIMITATION

- Intermediate stopping of instrument cause error in result
- The size must be precise or else it cause error
- As costliness and long testing times.
- It also demands large sample material out take which often involve weld repair.

2.17. FATIGUE TEST

- When the component is subjected to repeated cyclic stress (due to rotation, bending or vibration) leads to failure even though the stress below the yield strength of material.
- This progressive failure of the material at a stress much lower than that required to cause fracture on a single application of load is called a fatigue failure.

1. PRINCIPLE

- A fatigue test is used for the determination of the maximum load that a sample can withstand for a specified number of cycles. Cyclic fatigue tests produce repeated loading and unloading in tension, compression, bending, torsion or combinations of these stresses.
- These tests are used to generate fatigue life and crack growth data, identify critical locations or demonstrate the safety of a structure that may be susceptible to fatigue.

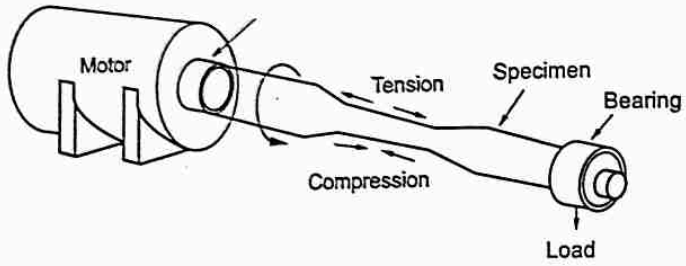


Fig. 2.24. The cantilever type fatigue testing

2. METHODS TO DETERMINE FATIGUE LIFE

Following methods to determine the fatigue life of a material

(a) The stress-life method: A mechanical part is often exposed to a complex, often random of sequence of loads values of large and small range.

Types of stress life method

- Rainflow analysis
- Fatigue damage spectrum
- S-N curve
- Miner's rule.

(b) The strain-life method: When strains are no longer elastic, such as in the presence of stress concentrations, the total strain can be used instead of stress as a similitude parameter. This is known as the strain-life method

(i) The crack growth method: An estimate of the fatigue life of a component can be made using a crack growth equation by summing up the width of each increment of crack growth for each loading cycle

(ii) Probabilistic methods: It is based on either life or crack growth methods.

WORKING

- In the fatigue strength test, a rotating, cantilever-mounted specimen is subjected to a bending moment.
- In the cylindrical specimen, this creates an alternating stress due to rotary bending. After a certain number of load cycles, the specimen fractures because of material fatigue.
- Polish the sample surface as smooth as possible and observe for any surface defects and deep scratch/machining marks. Reject the sample if you find any defects.
- Measure dimensions of the given specimen of mild steel.
- The equipment is mounted with motor driven chuck. The load is suspended in the opposite end of motor.
- Fit the specimen is in the sample holder such that it passes through the opening provided in the rod on which the loads are seated.
- After fitting the sample, keep the desired load on the seat .
- At the top end the tension is applied and bottom end compression is provided with rotating of specimen.
- Switch on the instrument to conduct the fatigue test by rotating specimen at 90° with compression and tension and rotate to 180° with same cycle loads. Repeat the cycle of stress upto of on a rotating shaft in four-point bending.
- Record the time for the failure, when it occurs.
- Note the appearance of the fractured surface in each case.

4. STAGES IN FATIGUE FAILURE

(a) Stage 1-Crack initiation

- Crack initiates at which are pre-existing flaws or generated during the cyclic straining process.
- The minor crack initiates at the surface of material which occurs after loading for a while. The crack develops by grain to grain of material. The growth of crack is slow in this stage.

(b) Stage 2-Crack propagation

- Slip-band crack growth, where the initial crack grows along slip planes, i.e. planes of high shear stress.
- The minor crack is gradually propagates to major one as cyclic stress to continues. This Crack propagation in a specimen is also determined by the grain size. The larger the grains are, the rougher the crack surfaces will be. In case of unloading, these stresses cause an opposite plastic deformation and close the crack even at the crack tip.

(c) Stage 3-Sudden fracture

- Finally the sudden fracture occurs in material due to stress that is not supported by the materials section planes of high tensile stress, where a well-defined crack propagates in a direction normal to the maximum applied tensile stress.

5. S-N CURVE

- Fatigue test involve testing the specimens under various cycles of stress, usually in a combination of tension, bending and rotation.
- The test is conducted with variation of stress amplitudes (S); the number of cycles (N), the point of total failure in the specimen is recorded.
- S-N curves are derived from tests on samples of the material to be characterized (often called coupons) where a regular sinusoidal stress is applied by a testing machine which also counts the number of cycles to failure. This process is sometimes known as coupon testing.
- Stress amplitude is defined as the maximum stress, in tension and compression, to which the specimen is subjected.
- The resulting diagram is called a stress-cycle (or S-N) diagram (sometimes also stress-life or Wöhler diagram)
- To determine an S–N curve, a group of fatigue specimens is tested at different stress levels and at each of the several stress levels the loaded specimen is rotated until it fractures.
- The sudden bend of curve indicates the endurance limit. The maximum endurance limit for S-N curve is nearly 108 cycles. S-N curve calculated in semi log graph

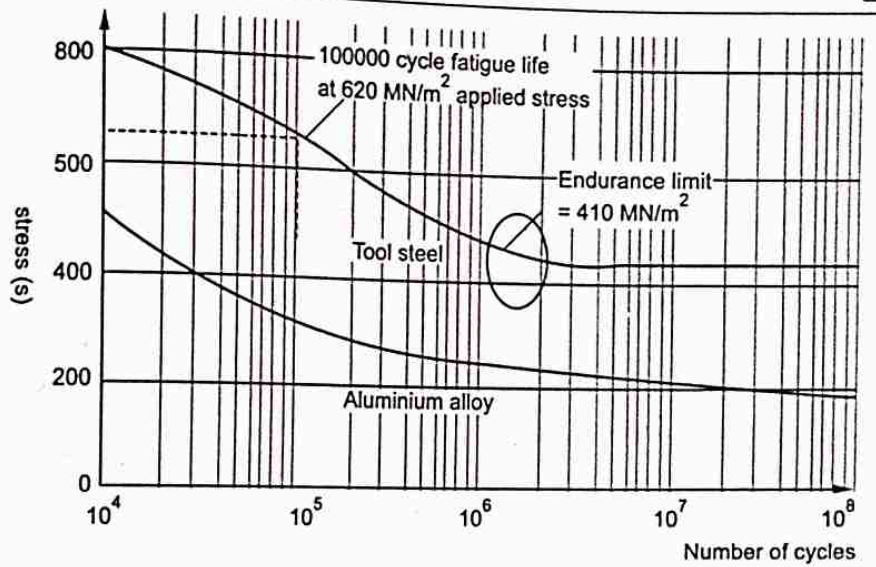


Fig. 2.25. S-N curve for steel and aluminum alloy

6. DERIVED PROPERTIES

- **Maximum stress** is calculated by

$$\sigma = \frac{10.18\, lF}{d^3}$$

σ = Maximum fatigue stress
l = Length of specimen
F = Fatigue failure load
d = Diameter of rod

- **Endurance limit (fatigue limit)** is the maximum fatigue stress applied to material without failure. It is 50% of fatigue failure load which is preferred for design criteria
- **Fatigue life** is the survival of component on particular stress.
- The fatigue strength defines the load limit up to which a material that is loaded dynamically withstands without breaking.
- **Endurance ratio** is ratio of Endurance limit and Tensile strength. It is nearly half of tensile strength. It allows calculating the fatigue strength from the tensile strength. For most materials it is in the range of 0.4-0.5.

- **Stress amplitude** (σ_a) is half the difference between the maximum stress (σ_{max}) and minimum stress (σ_{min}).

$$\sigma_a = \frac{\sigma_{max} - \sigma_{min}}{2}$$

- **Mean Stress** (σ_m) is half the sum between the maximum stress (σ_{max}) and minimum stress (σ_{min}).

$$\sigma_m = \frac{\sigma_{max} + \sigma_{min}}{2}$$

- **Stress ratio R** is the defined as ratio of minimum stress (σ_{min}) and maximum stress (σ_{max}).

$$R = \frac{\sigma_{min}}{\sigma_{max}}$$

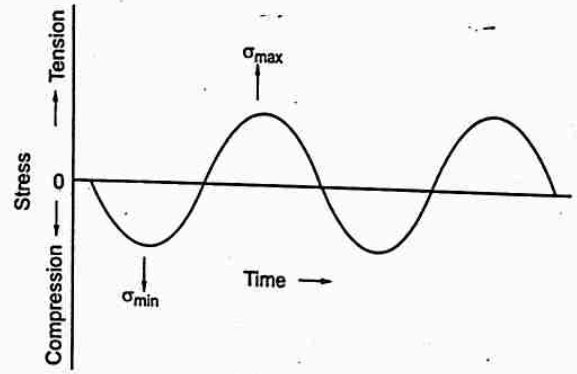


Fig. 2.26. Compression and tension flow cycle

7. TYPES OF FATIGUE CYCLE

(a) High-cycle fatigue

- When fatigue tests are conducted with a fixed cycle of load or stress limits, it is called a stress-controlled fatigue. It is a high-cycle fatigue (often simply termed as fatigue) because fatigue failure takes place at high numbers of stress cycles, usually more than 10^4 cycles (about 10^4 to 10^8 cycles). Since majority of the fatigue failures in service occurs at $N > 10^4$ cycles, the fatigue in the high-cycle region (stress-controlled fatigue) has received an engineering importance.

- A load-controlled servo-hydraulic test rig is commonly used in these tests, with frequencies of around 20–50 Hz. Other sorts of machines - like resonant magnetic machines - can also be used, to achieve frequencies up to 250 Hz.

6. Low-cycle fatigue

- When fatigue tests are conducted with a fixed cycle of elastic plus plastic strain limits, it is called a strain-controlled fatigue or a low-cycle fatigue because fatigue failure takes place when the number of cycles necessary to cause fatigue failure, $N < 10^3$ cycles. Testing is conducted with constant strain amplitudes typically at 0.01 – 5 Hz.

8. FACTORS INFLUENCE THE FATIGUE LIMIT

- Mean stress
- Size of specimen
- Surface condition
- Stress ratio
- Corrosion
- strain range
- Surface finish and quality
- Surface treatments
- Load sequence and overload
- Temperature

9. METHODS TO REDUCE FATIGUE

- Changes in the materials
- Peening
- Deep cryogenic treatment
- Re-profiling.

10. ADVANTAGES

- Demonstrate the safety of a structure that may be susceptible to fatigue.
- Generate fatigue data.

- Identify critical locations.
- Fatigue tests can also be used to determine the extent that widespread fatigue damage may be a problem.

11. LIMITATIONS

- It fails to recognize the probabilistic nature of fatigue and there is no simple way to relate life predicted by the rule with the characteristics of a probability distribution.
- It does not consider the effect of an overload or high stress which may result in a compressive residual stress that may retard crack growth.

TWO MARK QUESTIONS WITH ANSWERS

1. ***What is advantage of charpy test on izod test?***
   - More suitable for low-temperature tests which must be completed within a few seconds from the time of removal of the test piece from the coolant. This is due to easier placement of the Charpy specimen in the tester compared to the Izod.
   - Free from compressive stresses around the notch, while gripping of the Izod specimen inside the clamp device produces the compressive stresses around the notch.
2. ***Define true stress–strain and engineering stress–strain.***
   - True Stress is Stress value obtained by dividing the instantaneous area into applied load
   - True Strain is Provides a more realistic assessment of "instantaneous" elongation per unit length

$$\varepsilon = \int_{L_0}^{L} \frac{dL}{L} = ln\frac{L}{L_0}$$

   - **Engineering Stress:** Stress (nominal stress) is defined as the ratio of the applied load to the original cross-sectional area of the specimen

Stress (σ) = applied load / original cross-sectional area

- **Engineering Strain**: Strain is defined as change in length to original length

Strain (e) = change in length / original length

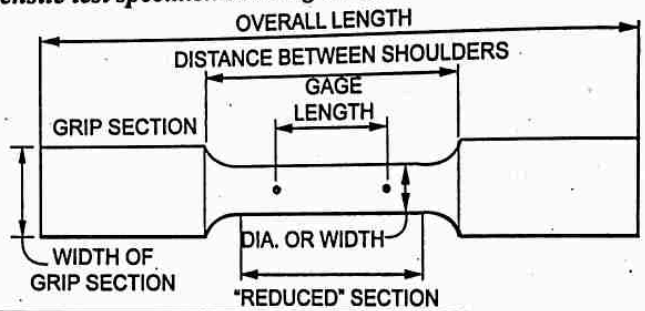
3. ***What are the major mechanical properties of material and its test to determine it?***

Mechanical Property	Destructive Testing Method
❖ Elasticity, Plasticity	❖ Tensile Test, Compression Test, Bending Test, Torsion Test
❖ Stiffness, Material Behaviour Under Static Load	
❖ Creep Behaviour	❖ Creep Rupture Test
❖ Hardness	❖ Brinell, Rockwell, Vickers
❖ Toughness	❖ Impact Test
❖ Fatigue Behaviour, Fatigue Strength	❖ Wöhler Fatigue Test

4. ***What are various failure modes of materials?***
   - Material failure is the loss of load carrying capacity of a material unit. The material failure happens due to two major phenomena,
     - Deformation failure
     - Fracture failure
5. ***How the hardness influence the material properties?***
   - 'Hardness' is a structure-sensitive mechanical property of materials, primarily associated with the surface. It is the resistance of a material to permanent or plastic deformation of its surface.
6. ***List out the different types of Hardness testing machines.***
   - (*i*) Brinell; (*ii*) Meyer; (*iii*) Vickers (macro - and micro-hardness); (*iv*) Rockwell (regular and superficial); (*v*) Knoop (micro hardness); (*vi*) Nano hardness (mostly by Vickers and Berkovich indenters)
7. ***What property of metal does the impact test measure? Give its significance.***
   - The purpose of an impact test is to determine the ability of the material to absorb energy during a collision.

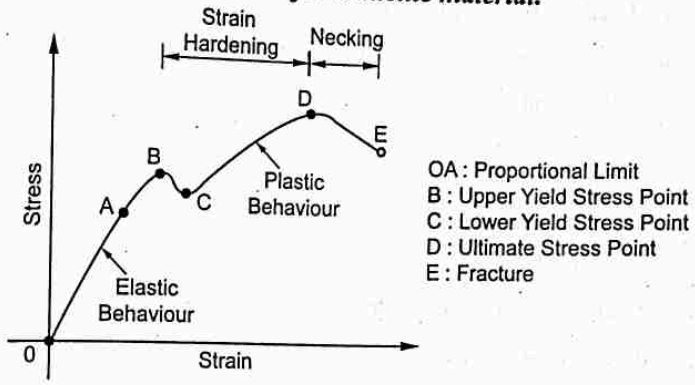
- This energy may be used to determine the
  - Toughness
  - Impact Strength
  - Fracture Resistance
  - Impact resistance or fracture resistance of the material

8. *Sketch a tensile test specimen showing all dimensions in inch.*



All values in inches	Plate type (1.5 in. wide)	Sheet type (0.5 in. wide)	Sub-size specimen (0.25 in. wide)
Gauge length	8.00 ± 0.01	2.00 ± 0.005	1.000 ± 0.003
Width	1.5 + 0.125 – 0.25	0.500 ± 0.010	0.250 ± 0.005
Thickness	0.188 ≤ T	0.005 ≤ T ≤ 0.75	0.005 ≤ T ≤ 0.25
Fillet radius (min.)	1	0.25	0.25
Overall length (min.)	18	8	4
Length of reduced section (min.)	9	2.25	1.25
Length of grip section (min.)	3	2	1.25
Width of grip section (approx.)	2	0.75	3/8

9. *Neatly draw stress–strain curve for a ductile material.*



10. *Give the dimensions of Charpy and Izod impact test samples.*

Parameter	Izod impact test	Charphy impact test
Specimen dimension	Length-75 mm Width-10 mm Thickness-10 mm	Length-55 mm Width-10 mm Thickness-10 mm

11. *What are advantages made the choice of Brinell hardness test?*

- A choice can be made between a large numbers of test forces.
- The influence of surface scratches and roughness will be less in the Brinell test than other hardness tests.
- The specimen surface can be rough.
- Suitable for hardness tests on large blanks such as forged pieces, castings and hot-rolled etc
- Measurement is usually not affected by movement of the specimen

12. *What kind of indenter suitable for Vickers hardness?*

- It is made of diamond in the form of a square-based pyramid with an included angle of 136° between opposite faces.

13. *What are properties can be determined from tensile testing?*

- The tension test is the most common method for determining the mechanical properties of materials, such as strength, ductility, toughness, elastic modulus, and strain- hardening capability.

14. ***Define strain hardening and proof stress.***

- **Strain hardening**: This increase in the tensile strength of the material is due to strain hardening which is due to the increased dislocations interactions during the deformation of the tensile test. This is called Strain - hardening.
- **Proof Stress:** The stress that causes a percentage increase in gauge length. It can be found by drawing a line parallel to the straight part of the graph. A value can be taken from the vertical axis.

15. ***Write the classification of impact test based on load application.***

- Impact test classified based on load application applied by means of dropping weight, a swinging pendulum and a rotating flywheel.

16. ***What is the basic principle involved in Charpy and Izod impact test?***

- The Charpy V- notch impact test is the most common fracture toughness test. A notched specimen is broken by a swinging pendulum and the amount of energy required to break the specimen is recorded.
- The Izod impact strength test is a standard method of determining the impact resistance of materials. A pivoting arm is raised to a specific height (constant potential energy) and then released. The arm swings down hitting a notched sample, breaking the specimen.

17. ***Compare Charpy and Izod impact test based on specimen position & point of strike?***

Parameter	Izod impact test	Charphy impact test
Specimen position	Specimen held at vertical	Specimen held at horizontal
Point of strike	At Upper tip of specimen	At Point of notch but in opposite direction

18. ***Define deflection.***

- **Deflection** is the degree to which a element is displaced under a flexural load (due to its deformation).Deflection for three point bending test,

$$\delta_C = \frac{FL^3}{48EI}$$

E = Modulus of Elasticity (or) Young's modulus

I = Area moment of inertia of cross section

19. ***What is modulus of rupture in bending nature?***

- Flexural strength, also known as modulus of rupture or bend strength or transverse rupture strength is a material property, defined as the stress in a material just before it yields in a flexure test.
- For three point bending test (rectangular cross section)

$$\sigma_f = \frac{3FL}{2bd^2}$$

- For four point bending test where the loading span is 1/2 of the support span (rectangular cross section)

$$\sigma_f = \frac{FL}{bd^2}$$

20. ***What is mean by shear relaxation in creep mechanism?***

- Stress relaxation is closely related to creep. In stress relaxation, the stresses resulting from loading of a structural component decrease in magnitude over a period, even though the dimensions of the component remain constant.

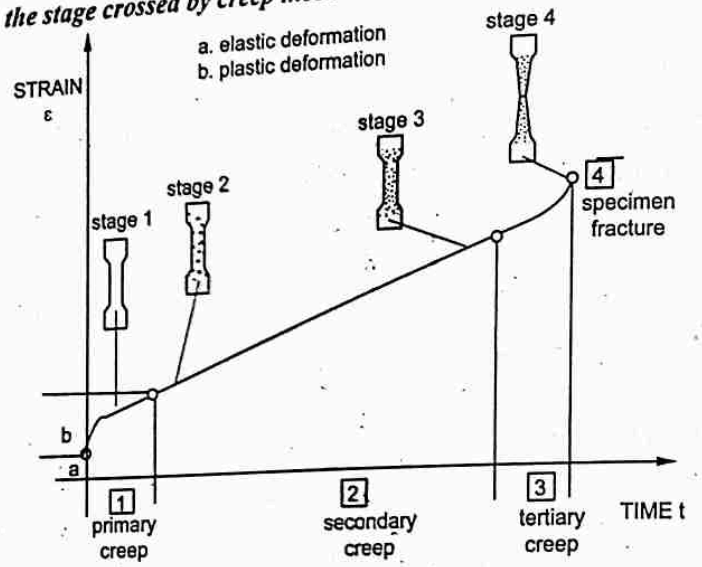
21. ***How the steady state creep mechanism will works?***

- Steady-state creep or secondary creep after the primary creep, the creep rate reaches essentially a steady state, in which the creep rate changes little with time. This region of approximately constant creep rate. The steady state is achieved because of an approximate balance between two opposing factors: the strain hardening that tends to reduce the creep rate and the softening or recovery process that tends to increase it.

22. ***How will control the creep?***

- Solid solution strengthening
- Particle dispersion strengthening
- Precipitation hardening
- Increasing grain size

23. *Sketch the stage crossed by creep mechanism.*



24. *Define the property of fatigue.*

- When the component is subjected to repeated cyclic stress (due to rotation, bending or vibration) leads to failure even though the stress below the yield strength of material.

25. *What is principle involved in fatigue testing?*

- A fatigue test is used for the determination of the maximum load that a sample can withstand for a specified number of cycles. Cyclic fatigue tests produce repeated loading and unloading in tension, compression, bending, torsion or combinations of these stresses.

26. *What are the methods available to calculate the fatigue life?*

- The stress-life method
- The strain-life method
- The crack growth method
- Probabilistic methods

27. *What is role of SN curve in fatigue mechanism?*

- S-N curves are derived from tests on samples of the material to be characterized, where a regular sinusoidal stress is applied by a testing machine which also counts the number of cycles to failure.

28. *Define Endurance limit.*

- Endurance limit (fatigue limit) is the maximum fatigue stress applied to material without failure. It is 50% of fatigue failure load which is preferred for design criteria

REVIEW QUESTIONS

1. State the working principle of the machine used for tension test. What care should be taken while performing a test on UTM?

   Ans: Refer Section No. 2.10 **Page No.** 2.26

2. Explain the various mode load application in the Rockwell hardness test.

   Ans: Refer Section No. 2.4 **Page No.** 2.15

3. Explain the working principles of machines used to conduct Charpy and Izod impact test. How specimens are put–up in both the tests? Why?

   Ans: Refer Section No. 2.12 **Page No.** 2.33

4. Discuss the factors considered for selection of hardness testing machine. What care must be taken while selecting specimens for hardness test?

   Ans: Refer Section No. 2.2 **Page No.** 2.19

5. Sketch the various types of fatigue cycles. How is S–N curve constructed? Explain the significance of endurance limit.

   Ans: Refer Section No. 2.17 **Page No.** 2.47

6. With a neat sketch, explain the various stages of creep curve.

   Ans: Refer Section No. 2.16 **Page No.** 2.43

7. What are properties arrived from the bending test? How do you relate with failure of section?

   Ans: Refer Section No. 2.14 **Page No.** 2.36

8. What are the test available for testing following material and explain with working procedure

   - Plastic

- ❖ Wood
- ❖ Steel Plate

Ans: Refer Section No. 2.14, 2.15 **Page No.** 2.36, 2.41

9. What are the various destructive tests available and which is more suitable to the hardness of material?

Ans: Refer Section No. 2.2 **Page No.** 2.4, 2.6

10. What are major contrasts of nature between izod and charpy test?

Ans: Refer Section No. 2.11 **Page No.** 2.35

11. How could you determine the fatigue life of material with the cyclic stresses?

Ans: Refer Section No. 2.17 **Page No.** 2.47

12. In the steel industry, iron rod is manufactured. Now, the iron rod is need to quality check. What is the quickest test available for testing various properties?

Ans: Refer Section No. 2.10 **Page No.** 2.26

13. In the construction site of steel cell phone tower, the quality engineer need to the check bold quality used for connection purpose. What is better test used for checking bold that used in connection? Explain with experimental procedure with advantages and limitation.

Ans: Refer Section No. 2.15 **Page No.** 2.41

□□

UNIT III

NON DESTRUCTIVE TESTING

SYLLABUS

Visual inspection, Liquid penetrant test, Magnetic particle test, Thermography test – Principles, Techniques, Advantages and Limitations, Applications. Radiographic test, Eddy current test, Ultrasonic test, Acoustic emission- Principles, Techniques, Methods, Advantages and Limitations, Applications.

3.1. OVERVIEW OF NDT

- ❖ Non-destructive testing (NDT) is a testing and analysis technique used by industry to evaluate the properties of a material, component, structure or system for characteristic differences or defects and discontinuities without causing damage to the original part.
- ❖ NDT also known as non-destructive examination (NDE), non-destructive inspection (NDI) and non-destructive evaluation (NDE).

1. IMPORTANCE OF NDT

- ❖ To Accident prevention and to reduce cost.
- ❖ For routine or periodic determination of quality of the plants and structures during service.
- ❖ To determine acceptance to a given requirement.
- ❖ To give information on repair criteria.
- ❖ To ensure product reliability.
- ❖ To ensure the safety of operation.
- ❖ To ensure customer satisfaction and to maintain the manufacturer's reputation.
- ❖ To control manufacturing processes and lower manufacturing costs.

- To maintain uniform quality level.

2. ADVANTAGES

(i) Reusable

- There are a number of distinct advantages, the most obvious of which is that the pieces being tested are left undamaged by the process, allowing for an item to be repaired rather than replaced should any problems be found.

(ii) Safe

- It is also a very safe testing method for operators, with most techniques being harmless to humans, although some types of test - such as radiographic testing - still need to be conducted under strict conditions.
- This testing technique can also help prevent injury or fatalities by ensuring structures, components and machinery is safe.
- This testing technique also offers operators peace of mind, knowing that equipment is functioning as it should, preventing future accidents and determining any measures that can be taken for life extension.

(iii) Accurate

- Non-destructive testing is also a very accurate way of inspection since the tests are repeatable and a number of tests can be used together to correlate results.

(iv) Cost effective

- These testing methods are also economical. Unlike destructive testing, NDT is cost effective as it can prevent the need to replace an item before malfunction occurs without destroying the piece itself.

(v) Quality control

- It is also useful for testing of welds and verification of welding procedures to ensure that a welding process has been completed to the correct specification within the bounds of quality control, for example to make sure that the base metal has reached the correct temperature, cooled at the specific rate and that compatible materials have been used to prevent welding defects.

4. STAGES OF WORKING IN NDT

1. Testing

- The first step testing involves in preparation of test material. With help of primary source (dye, ac source, loading), probe, receiver etc. the material is surveyed.

2. Recording & Reporting

- The most of output is displayed in computer.

3. Interpretation &Evaluation

- Based the output report, remedial action is take place and service life is also determined.

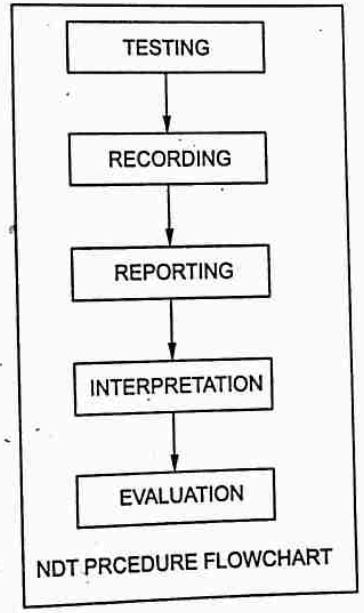


Fig. 3.1. NDT work flow chart

3.2. NON-DESTRUCTIVE TESTING METHODS

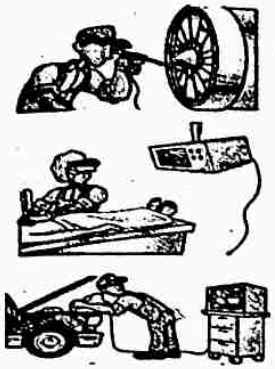
- Acoustic Emission Testing (AE)
- Electromagnetic Testing (ET)
- Ground Penetrating Radar (GPR)

- Laser Testing Methods (LM)
- Leak Testing (LT)
- Liquid Penetrant Testing (PT)
- Magnetic Flux Leakage (MFL)
- Magnetic Particle Testing (MT)
- Radiographic Testing (RT)
- Thermal/Infrared Testing (IRT)
- Ultrasonic Testing (UT)
- Visual Testing (VT)

Table 3.1. Comparison of NDT Capabilities

Technique	Capabilities	Limitations
Visual Inspection	Macroscopic surface flaws	Small flaws are difficult to detect, no subsurface flaws.
Radiography	Subsurface flaws	Smallest defect detectable is 2% of the thickness; Need radiation protection.
Dye penetrate	Surface flaws	No subsurface flaws; Not used for porous materials
Ultrasonic	Subsurface flaws	Material must be good conductor of sound.
Magnetic Particle	Surface / near surface and layer flaws	Limited subsurface capability, only for Ferromagnetic materials.
Eddy Current	Surface and near surface flaws	Difficult to interpret in some applications; only for metals.
Acoustic emission	Can analyze entire structure	Difficult to interpret, expensive equipment.

3.2.1. VISUAL TESTING (VT)



- Visual testing also known as visual inspection or Optical testing is one of the most common techniques which involve the operator looking at the test piece.
- This can be aided by the use of optical instruments such as magnifying glasses or computer-assisted systems (known as 'Remote Viewing').
- This method allows for the detection of corrosion, misalignment, damage, cracks and more.
- Visual testing is inherent in most other types of NDT as they will generally require an operator to look for defects.

1. PRINCIPLE

- The basic procedure used in visual NDT involves illumination of test specimen with light, usually in the visible region.
- The specimen is then examined with eye or by light sensitive device such as photo cells. The surface of the specimen should be adequately cleaned before being inspected.

2. ENVIRONMENT FOR VISUAL INSPECTION

- Inspection must take place in a clean, comfortable environment with adequate lighting. Lighting is very important and can greatly affect the results. It includes Natural daylight, Bright sunlight and Artificial light.

3. TYPES OF VISUAL INSPECTION

- Unaided Visual Inspection
- Aided Visual Inspection

(I) Unaided visual inspection

- It is also known as Direct Visual Inspection. It can be accomplished with the help of naked eye
- It can do without the help of optical aids.

(a) Defects can be detected are

- Absence of cracks
- Corrosion layer
- Surface porosity
- Misalignment of mated parts

(b) Aids of Unaided Visual Inspection

The eyes

- Human eye is the most valuable NDT Tool. Sensitivity of the human eye varies according to the light source.
- Human eye has an excellent visual perception. Yellow green light of wavelength 5560°A is the most suitable light for human eye at normal condition

(ii) Unaided Visual Inspection

- It is also known as indirect Visual Inspection.
- It can be accomplished with the help of some external equipment accomplished with direct visual. It can do with the help of optical aids.

Fig. 3.2. Aids of visual testing

Types of unaided viewing is,

- Direct viewing - Viewing of an object in the operator's immediate presence. This can be unaided or by using equipment
- Remote viewing - Viewing of an object not in the operator's immediate presence. This can only be done using special equipment

The commonly using visual aids are,

- **Magnifying glasses** - It consists of lens with magnification power which can used inspecting area of not accessible. Some types of magnifier incorporate a small battery-powered bulb to provide illumination of the test-surface.
- **Fillet weld gauge** - It usually uses a leaf-type fillet weld gauge to measure the size of fillet welds for standard size.
- **Microscopes** - Microscopes come in a wide variety of magnification ranges, microscope is a multiple element magnifier for proving high magnified image of small defect
- **Computer equipment (remote viewing)** - A modern videoscopes, due to their small size and flexibility, can provide access to internal areas inaccessible to Borescope.
- **Illuminated magnifier** - Inspection Magnifier is highly useful for inspection of small parts and also for online visual quality evaluation.
- **Holography** - Holography is name given to the method of obtaining an accurate 3-D image of a given object. It is used for the NDT of surfaces of highly complicated and precision components without the dis-advantages of having to use a high power microscope. It can provide a record of the image of an entire surface which can be readily compared with that of a standard defect free surface.
- **Borescope** - It is optical instrument for remote viewing of objects. Borescope can have various angles of view: 0° direct, 45° fore-oblique, 90° lateral and 110° retro. Borescope consist of precision illumination system. The size of the visual field usually varies with the diameter, for a given magnification system. The size of the visual field usually varies with the diameter, for a given magnification system.

- **Magnifying Mirrors** - When inspection is not easily accessible, a magnifying mirror can be used.
- **Periscope** - It is an instrument used for remote observation of inaccessible areas. In simple periscope, two right angle reflecting prisms are utilized in combination with a series of lenses.
- **Endoscope** - It is bit superior than Borescope. Magnification factor of 10X is obtained. Available up to smaller dia of 1.7 mm and length upto 100-150mm

4. MATERIAL FACTORS THAT AFFECT VISUAL TESTING

- **Surface Condition**
  - Cleanliness
  - Colour
  - Texture
- **Physical Conditions**
  - Specimen Condition
  - Shape and Size
  - Temperature
- **Environmental Factors**
  - Atmosphere
  - Humidity and Temperature
  - Safety
- **Physiological Factors**
  - Physical Comfort
  - Health , mental attitude, fatigue and test item position

5. ADVANTAGES

- Simple method to perform
- Examination can be performed quickly
- Low-cost method
- Minimal training

- Minimal equipment
- Virtually any component can be examined anywhere on the surface.
- Speed
- Applicability to irregular shapes
- Field mobility

6. DISADVANTAGES

- Inspector training necessary.
- Good eyesight required or eyesight corrected to 20/40.
- Can miss internal defects.
- Report must be recorded by inspector.
- Open to human error.
- Providing adequate viewing angles, sensitivity, resolution, and illumination may be costly.
- Visual testing requires a line of sight to the test surface and lighting adequate to detect and interpret anomalies of interest.
- Visual testing is sometimes limited to component geometry: size, contour, surface roughness, complexity, and discontinuity orientation.

7. APPLICATIONS

- Examining the surface condition of a component
- Examining alignment of mating surfaces
- Checking presence of leaks

8. EXAMPLE OF SOME APPLICATION VISUAL TESTING

Visual test of welds in connections

- In majority of industries for testing of welds, fillet weld gauge is used. The safety limit is checked in limits by using codes
- Surface is cleaned well to ensure free from rust, dirt etc.
- By inspecting irregularities, depth of penetration of weld and discontinuity the detected.

3.2.2. LIQUID PENETRANT TEST

- It also known as liquid penetrant inspection (LPI) or dye penetrant testing is based on the properties of surface wetting and capillary action, which causes a liquid to rise when confined to a small opening. After applying the penetrant and wiping away the excess, the penetrant that rises to the surface can indicate surface-breaking.
- Dye Penetrant Inspection (DPI), also called Liquid Penetrant Inspection (LPI) or Penetrant Testing (PT).
- It is used to detect any surface-connected discontinuities such as cracks from fatigue, quenching, and grinding, as well as fractures, porosity, incomplete fusion, and flaws in joints.

1. PRINCIPLE

- Liquid penetrant testing involves the application of a fluid with low viscosity on the material to be tested.
- This fluid seeps into any defects such as cracks or porosity before a developer is applied which allows the penetrant liquid to seep upwards and create a visible indication of the flaw.
- Liquid penetrant tests can be conducted using solvent removable penetrants, water washable penetrants or post-emulsifiable penetrants.

2. Basic Processing Steps of a Liquid Penetrant Inspection

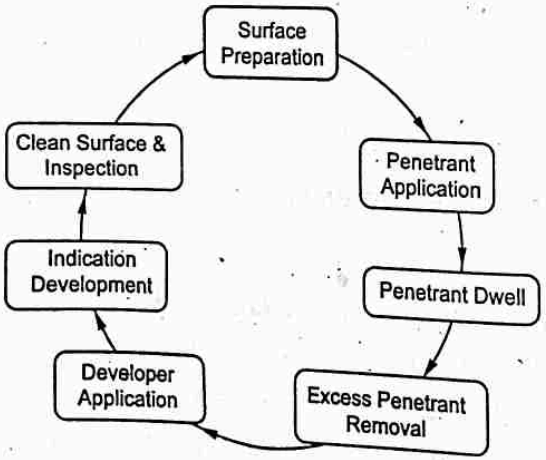


Fig. 3.3. Flow chart in basic process of Liquid Penetrant Inspection

(a) Surface Preparation

- One of the most critical steps of a liquid penetrant inspection is the surface preparation.
- The surface must be free of oil, grease, water, or other contaminants that may prevent penetrant from entering flaws.
- The sample may also require etching if mechanical operations such as machining, sanding, or grit blasting have been performed. These and other mechanical operations can smear metal over the flaw opening and prevent the penetrant from entering.

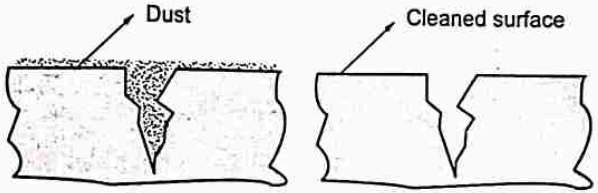


Fig. 3.4. Surface Preparation

(b) Penetrant Application

- Once the surface has been thoroughly cleaned and dried, the penetrant material is applied by spraying, brushing, or immersing the part in a penetrant bath.

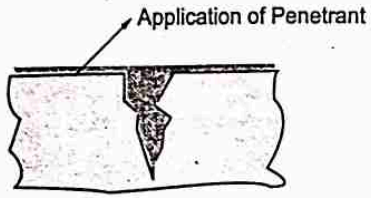


Fig. 3.5. Penetrant Application

(c) Penetrant Dwell

- The penetrant is left on the surface for a sufficient time to allow as much penetrant as possible to be drawn from or to seep into a defect.
- The times vary depending on the application, penetrant materials used, the material, the form of the material being inspected, and the type of defect being inspected for.

- Minimum dwell times typically range from five to 60 minutes. Generally, there is no harm in using a longer penetrant dwell time as long as the penetrant is not allowed to dry.

(d) Excess Penetrant Removal

- This is the most delicate part of the inspection procedure because the excess penetrant must be removed from the surface of the sample while removing as little penetrant as possible from defects.
- Depending on the penetrant system used, this step may involve cleaning with a solvent, direct rinsing with water, or first treating the part with an emulsifier and then rinsing with water.

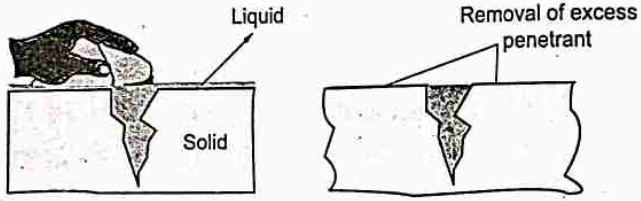


Fig. 3.6. Excess Penetrant Removal

(e) Developer Application

- A thin layer of developer is then applied to the sample to draw penetrant trapped in flaws back to the surface where it will be visible.
- Developers come in a variety of forms that may be applied by dusting (dry powdered), dipping or spraying (wet developers).

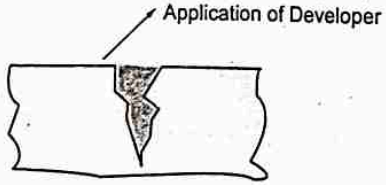


Fig. 3.7. Application of developer

(f) Indication Development

- The developer is allowed to stand on the part surface for a period of time sufficient to permit the extraction of the trapped penetrant out of any surface flaws.
- This development time is usually a minimum of 10 minutes. Significantly longer times may be necessary for tight cracks.

(g) Inspection

- Inspection is then performed under appropriate lighting to detect indications from any flaws which may be present.

(h) Clean Surface

- The final step in the process is to thoroughly clean the part surface to remove the developer from the parts that were found to be acceptable.

3. ADVANTAGES

- High sensitivity to small surface discontinuities.
- Easy inspection of parts with complex shapes.
- Quick and inexpensive inspection of large areas and large volumes of parts/materials.
- Few material limitations (metallic and nonmetallic, magnetic and nonmagnetic, and conductive and nonconductive can all be inspected).
- A visual representation of the flaw are indicated directly on the part surface.
- It is easy and requires minimal amount of training.
- Suitable for parts with complex shapes.
- Portable (materials are available in aerosol spray cans).
- Low cost (materials and associated equipment are relatively inexpensive).

4. DISADVANTAGES

- Only surface breaking defects can be detected.
- Only materials with a relatively nonporous surface can be inspected.
- Pre-cleaning is critical since contaminants can mask defects.
- The surface finish of the specimen after the test is difficult.
- The compatibility of the materials with the specimen.
- The sensitivity required.
- The size, shape and accessibility of the area to be inspected.
- The inspector must have direct access to the surface being inspected.
- Surface finish and roughness can affect inspection sensitivity.
- Multiple process operations must be performed and controlled.

- Post cleaning of acceptable parts or materials is required.
- Chemical handling and proper disposal is required.

5. APPLICATION

- **Aerospace:** Typical Components that are checked by this method include Turbine, rotor disc, blades, aircraft wheels, Casting, forged parts and welded assemblies
- **Automobiles:** Many automotive parts particularly aluminum castings and forging including pistons and cylinder heads are subjected to this form of quality checks before assembly
- **Railways:** LPI to detect fatigue cracking is also used for the regular in service examination of the bogie frames of railway locomotive and the rolling stock
- **Tool and dies:** Field drilling rays, drill pipes, castings and drilling equipment's inspected by this methods.
- **Inspection on reactors and tank:** Tanks, vessels, reactors, piping, dyers in the chemical, petro-chemical industries.

3.2.3. PENETRANTS

- It is used for detection of surface imperfections in non-porous materials and basically consists of applying a flow of liquid to the surface of the material to be tested.
- The liquid, by capillary action, will penetrate the discontinuities and the excess remaining on the surface will be removed by a suitable cleaning system. It will be highly visible or fluoresce brightly to produce easy to see indications.

1. Types of Penetrants

- **Fluorescent Penetrants:** They contain a dye or several dyes that fluoresce when exposed to ultraviolet radiation.
- **Visible Penetrants:** They contain a red dye that provides high contrast against the white developer background.

2. Methods used for excess removal of Penetrants

- Water washable

- Solvent removable
- Post-Emulsifiable
  - Lipophilic
  - Hydrophilic

3.2.4. DEVELOPERS

- The role of the developer is to pull the trapped penetrant material out of defects and spread it out on the surface of the part so it can be seen by an inspector.

1. The six standard forms of developers are

- Dry Powder
- Water Soluble
- Water Suspendable
- Non aqueous
  - Type 1: Fluorescent (Solvent Based)
  - Type 2: Visible Dye (Solvent Based)

3.2.5. MAGNETIC PARTICLE TESTING (MT)

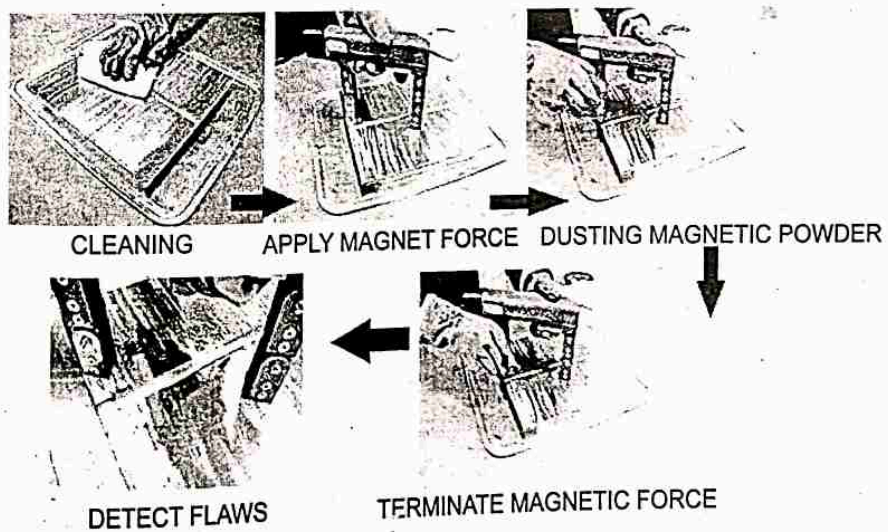


Fig. 3.8. Demo of magnetic particle testing

- A magnetic field is established in a component made from ferromagnetic material. The magnetic lines of force travel through the material and exit and reenter the material at the poles.
- Defects such as crack or voids cannot support as much flux, and force some of the flux outside of the part.
- Magnetic particles distributed over the component will be attracted to areas of flux leakage and produce a visible indication.

1. PRINCIPLE

- This NDT process uses magnetic fields to find discontinuities at or near the surface of ferromagnetic materials. The magnetic field can be created with a permanent magnet or an electromagnet, which requires a current to be applied.
- The magnetic field will highlight any discontinuities as the magnetic flux lines produce leakage, which can be seen by using magnetic particles that are drawn into the discontinuity.

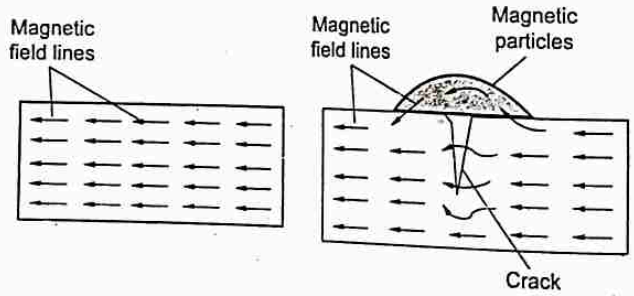


Fig. 3.9. Principle of working

2. MAGNETIC PROPERTIES OF MATERIALS

(a) HYSTERESIS LOOP

- A hysteresis loop shows the relationship between the induced magnetic flux density B and the magnetizing force H. It is often referred to as the B-H loop
- From the hysteresis loop, a number of primary magnetic properties of a material can be determined.
- Retentivity, Residual Magnetism or Residual Flux, Coercive Force, Permeability and Reluctance.

(b) PERMEABILITY

- Permeability describes how easily a material can be magnetized; a material with a high permeability is easier to magnetise than a material with a low permeability
- A material's permeability is determined by dividing the magnetising force applied to a material into the magnetic flux density achieved in the material – permeability has no units.
- There are three material categories that are related to permeability: diamagnetic ,paramagnetic and ferromagnetic

(a) Diamagnetic materials: It have a permeability value slightly less. It will slightly repel a magnetic field.

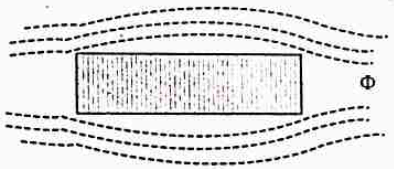


Fig. 3.10. Repel of diamagnetic

(b) Paramagnetic materials: It have a permeability value slightly greater .It is slightly easier for the magnetic flux to pass through the paramagnetic material than to travel through the vacuum

Fig. 3.11. Repel of paramagnetic

(c) Ferromagnetic materials: It have a permeability value much higher, that it is much easier for the magnetic flux to pass through the ferromagnetic material than to pass through the vacuum. Ferromagnetic materials are very strongly attracted by a magnetic field.

Fig. 3.12. Ferromagnetic material

3. TYPES OF MAGNETISATION

- **Circular magnetization** - Circular magnetic field will be produced around the component at right angles to the direction of the electric current which produced it.

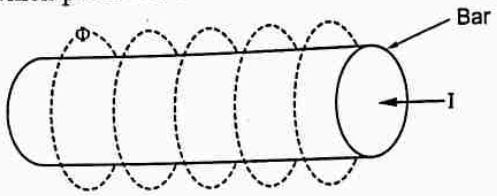


Fig. 3.13. Circular magnetism

- **Longitudinal magnetization** - The magnetic flux flows from pole to pole, we call this longitudinal magnetisation. Discontinuities will be detectable once more at 90° (±45°) to the flux direction.

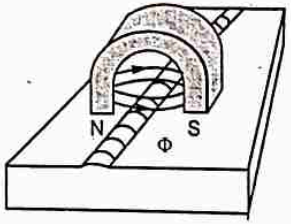


Fig. 3.14. Longitudinal magnetization

4. COMPONENTS IN MAGNETIC PARTICLE INSPECTION (MPI)

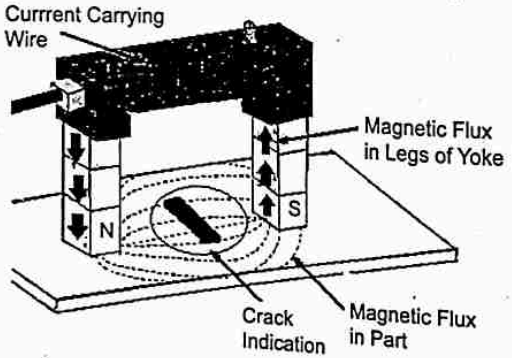


Fig. 3.15. Components of magnetic particle testing

(*a*) Permanent magnet
(*b*) Electromagnetic Yoke

(*c*) Current flow probes
(*d*) Flexible coil
(*e*) Adjacent cable

(*a*) Permanent magnets

- Permanent magnets are sometimes used for magnetic particle inspection as the source of magnetism. The two primary types of permanent magnets are bar magnets and horseshoe (yoke) magnets.

(*b*) Electromagnetic Yoke

- An electromagnetic yoke is a very common piece of equipment that is used to establish a magnetic field. It is basically made by wrapping an electrical coil around a piece of soft ferromagnetic steel.

(*c*) Current flow probes

- Probes are handheld electrodes that are pressed against the surface of the component being inspected to make contact for passing electrical current through the metal.

(*d*) Adjacent cable

- Coils and conductive cables are used to establish a longitudinal magnetic field within a component. When a preformed coil is used, the component is placed against the inside surface on the coil. Coils typically have three or five turns of a copper cable within the molded frame.

(*e*) Portable Power Supplies

- Portable power supplies are used to provide the necessary electricity to the prods, coils or cables. Power supplies are commercially available in a variety of sizes.

5. WORKING OF MAGNETIC PARTICLE TESTING

(*a*) Pretreatment

- The surface must be free of grease, oil or other moisture that could keep particles from moving freely.
- A thin layer of paint, rust or scale will reduce test sensitivity but can sometimes be left in place with adequate results.

(b) Apply the magnetizing force (magnetic particle)

- Use permanent magnets, an electromagnetic yoke, prods, a coil or other means to establish the necessary magnetic flux.

(c) Dust on the dry magnetic particles

- Dust on a light layer of magnetic particles.

(d) Gently blow off the excess powder

- With the magnetizing force still applied, remove the excess powder from the surface with a few gentle puffs of dry air.
- The force of the air needs to be strong enough to remove the excess particles but not strong enough to dislodge particles held by a magnetic flux leakage field.

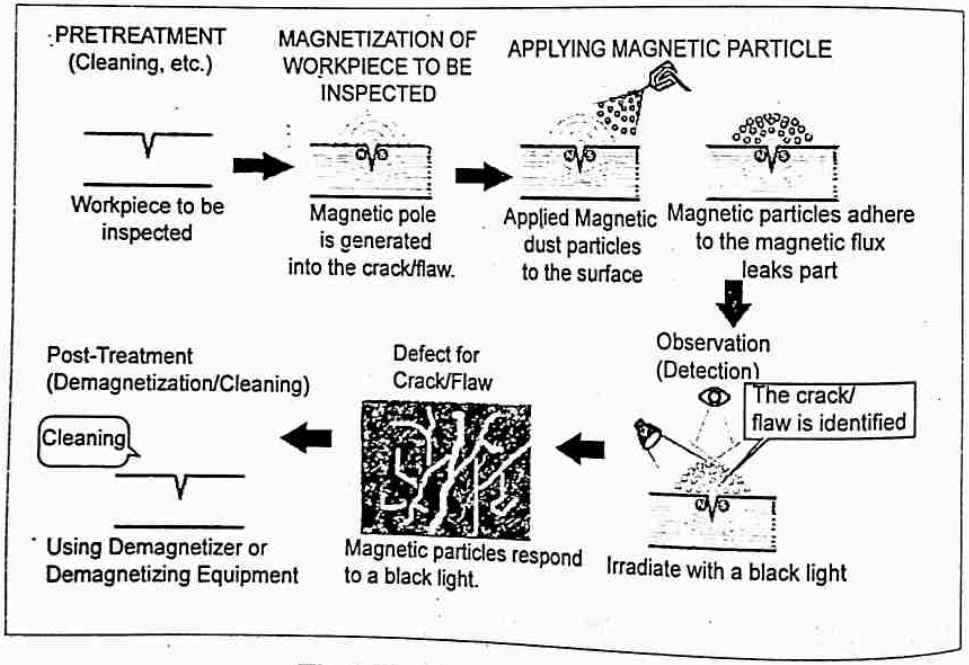


Fig. 3.16. Nature of finding flaws

(e) Terminate the magnetizing force

- If the magnetic flux is being generated with an electromagnet or an electromagnetic field, the magnetizing force should be terminated. If permanent magnets are being used, they can be left in place.

(f) Detect the defects

- Look for areas where the magnetic particles are clustered with the help of visual aids like illuminating light, microscope, naked eyes and magnifying glass etc.,

(g) Post Treatment

- The surface of material should be demagnetized (or) cleaned using demagnetizer (or) demagnetizing equipment.

6. ADVANTAGES

- Can find both surface and near sub-surface defects.
- This inspection formats are extremely portable and low cost.
- Rapid inspection with immediate results.
- Indications are visible to the inspector directly on the specimen surface.
- Can detect defects that have been smeared over.
- Can inspect parts with irregular shapes (external splines, crankshafts, connecting rods, etc.).
- The method can be adapted for site or workshop use.
- It is inexpensive compared to radiography.
- Large or small objects can be examined.

7. LIMITATIONS

- The specimen must be ferromagnetic (e.g. steel, cast iron)
- Paint thicker than about 0.005" must be removed before inspection
- Post cleaning and post demagnetization is often necessary
- Maximum depth sensitivity is typically adopted as 0.100" (deeper under perfect conditions)
- Alignment between magnetic flux and defect is important
- Insensitive to internal defects
- Require magnetization and demagnetization of materials to be inspected
- Require power supply for magnetization
- Coating may mask indication
- Material may be burned during magnetization

8. APPLICATIONS

- Magnetic particle testing or inspection (MT or MPI testing) is used for quality control and materials testing in all major industries. This includes castings, forgings, plates, extruded components, weld joints, electrical and electronic component manufacturing, production of steel, pressure vessels, ships, bridges, motor vehicles, machinery and jet engines.
- The flaws to be detected include cracks, inclusions, pipe, laminations, bursts and flakes.
- Testing effective in detecting fatigue cracks during in-service maintenance inspection of power plants, cement plants, sugar plants, petroleum refinery machinery components and structures

Mainly used to find,

- Fatigue Cracks
- Grinding Cracks
- Inclusions in aerospace blooms, billets, and bars
- Quenching Cracks
- Shrink Cracks
- Stress Corrosion Cracking
- Welding Defects

3.2.6. THERMOGRAPHY TEST

- Infrared testing or thermography uses sensors to determine the wavelength of infrared light emitted from the surface of an object, which can be used to assess its condition.
- A thermographer views an object with a thermal imager to measure the infrared emitted from the surface. However, to confuse matters, heat sources behind the imager can reflect from the surface making the object appear hotter than it really is. Even the heat from the body of the thermographer can cause this effect on objects at ambient temperature

1. PRINCIPLE

- Thermography is a technique of obtaining an image of the heat distribution over the surface of an object. The usual method is to use a special

television camera with an infrared sensitive detector and a lens which transmits infrared radiation. Such cameras can operate at normal video rates.

2. TYPES OF THERMOGRAPHY

- **Passive thermography** uses sensors to measure the wavelength of the emitted radiation and if the emissivity is known or can be estimated, the temperature can be calculated and displayed as a digital reading or as a false Colour image.
- **Active thermography** induces a temperature gradient through a structure. Features within it that affect the heat flow result in surface temperature variations that can be analyzed to determine the condition of a component. Often used to detect near surface delamination or bonding defects in composites.
- **The external excitations/optical excitations** or may be the external energy says so generally this energy is delivered to the surface and then propagated through the material until it encounters flaw examples photographic classes for heat pulsed simulations, halogen lamps for periodic heating.
- **Internal excitations/mechanical excitations** so generally the energy is injected into the specimen in order to stimulate exclusively the defects

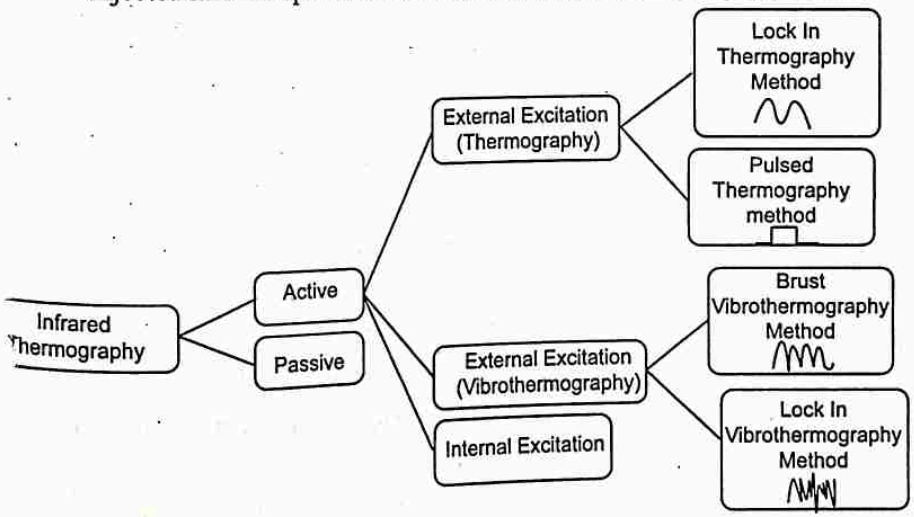


Fig. 3.17. Types of Thermography

3. BASIC AIDS OR COMPONENTS IN THERMOGRAPHY

- **Thermographic camera** so it is also known as infrared camera or maybe the thermal imaging camera. It is a device that forms a heat zone image using infrared radiation it operates in wavelengths as long as 14,000 nanometer.
- There are two basic types of thermographic camera. One is called the cooled infrared detectors another one is called the uncooled infrared detectors.
- **Control unit** is which sets the level of adjustment for halogen lamp and heater.
- **Pc/image processing unit** which displays the defect unit after deep proceess of unit.

4. WORKING OF VARIOUS THERMOGRAPHY TESTING METHODS

(a) Burst Vibrothermography Method

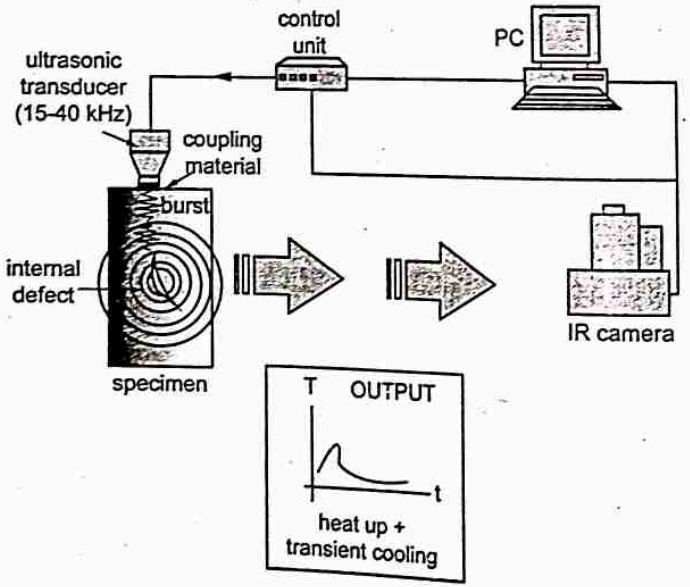


Fig. 3.18. Burst Vibrothermography Method

- Ultra-sonic burst phase thermography is also employed when short ultrasonic bursts are used.
- In this method an ultrasonic transducer with a fixed resonance frequency typically at 20 or 40 kHz has been used to excite high amplitudes of

vibration which rise surface temperature around defect, is large enough to be detected by an infrared camera.

(b) Lock In Vibrothermography Method

- The Lock-In method is suitable for testing components with a low thermal diffusivity Pulse thermography (pulse method).

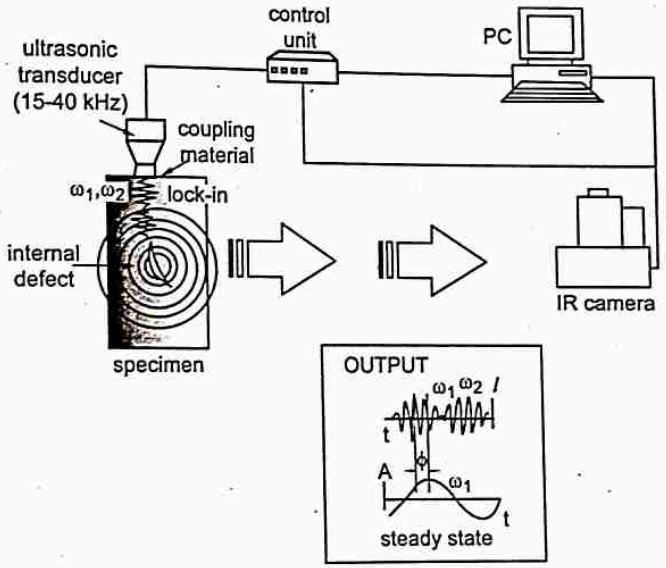


Fig. 3.19. Lock In Vibrothermography Method

- A very short pulse – usually in the units of milliseconds – is used to excite the object.
- A ultrasonic transducer is typically used as an excitation source.
- The advantage of this method is the speed of the analysis and a possibility to estimate the defects depth.
- The disadvantage is a limited to of detection capabilities based on geometrical orientation of defects.

Lock In Thermography Method

- Lock-In thermography is a periodic excitation method). When the input energy (Halogen lamps) wave penetrates the object's surface, it absorbed.
- The reflected portion of the wave causing an interference pattern in the local surface temperature.

- When the input wave reaches areas within the object when thermo physical properties are not same (due to defect) compared to surrounding the input wave is partially reflected.
- It has the advantage that it can be used on large surfaces and it puts a low thermal energy on the part being inspected.
- The disadvantage is a longer measurement time and dependence of detection capabilities on a geometrical orientation of defects

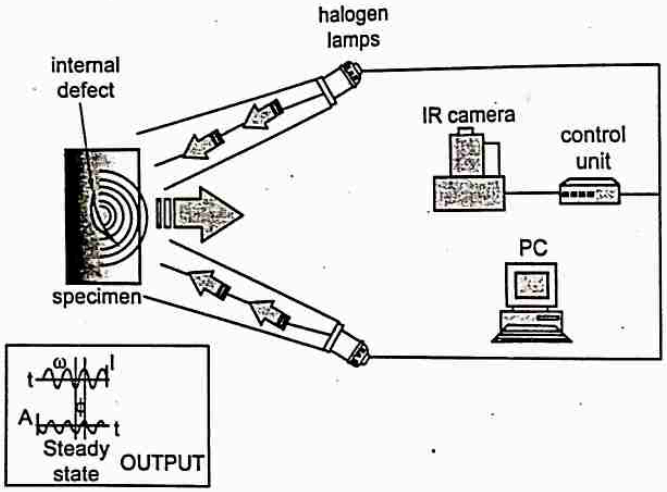


Fig. 3.20. Lock In Thermography Method

(d) Pulsed Thermography method

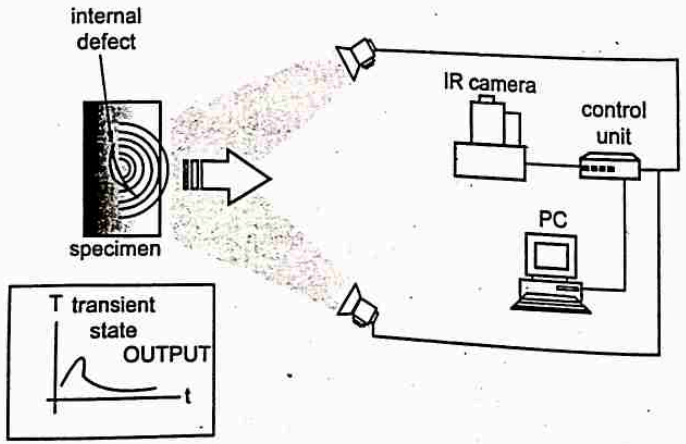


Fig. 3.21. Pulsed Thermography method

- Pulsed thermography is a classical optical excitation thermography technique. In pulsed thermography, high-energy lamps are often used to produce a uniform heating source on the specimen surface.
- The heat transmits through the inspected specimen to the subsurface defects or damages, and then returns to the specimen surface.
- A uniform temperature rise will be recorded if there are no defects in the specimen. If there are defects such as voids or delamination, a localized high-temperature zone will be observed above the defect due to the insulation effect.

5. ADVANTAGES

- Data collection system can record temperature changes with time
- High-speed, portable, and non-contact
- Ability to inspect large areas
- Effective prevention of test scrap
- Contactless testing with low thermal stress
- Simple analysis of large, uneven surfaces
- Categorization of different types of defects

6. DISADVANTAGES

- Risk of damage the sample(e.g., overheating)
- Limitations of inspected thickness
- Variable emissivity of materials
- Dependence from thermal contrast
- Expensive instrumentation require qualified personnel accuracy

7. APPLICATIONS

- Used largely in Aerospace industry ,Automotive industry and Power industry.
- Quality assurance for bonded, welded, soldered and other joints by means of cavity detections (e.g. on vehicle interior parts).
- Localization of defects in joints such as cavities, defective welding seams/points.
- Testing of metallic and non-metallic materials/material compounds.
- Tests of internal structures, such as fractures or impacts in honeycomb lightweight constructions.

3.2.7. RADIOGRAPHIC TESTING

- Radiographic Testing (RT) is a non-destructive testing (NDT) method which uses either x-rays or gamma rays to examine the internal structure of manufactured components identifying any flaws or defects.

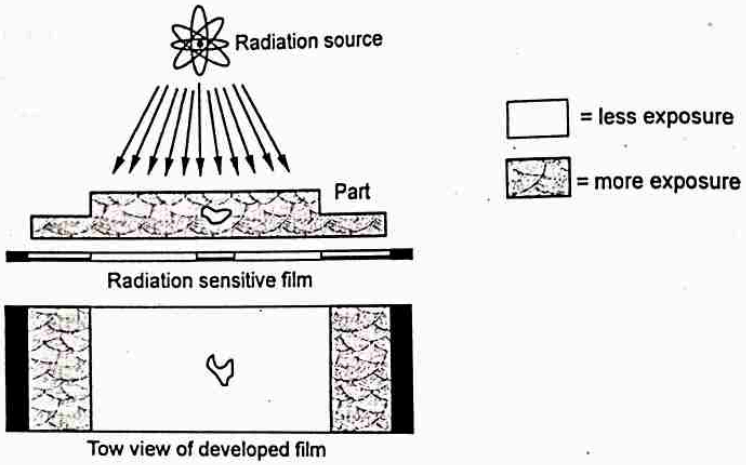


Fig. 3.22. Radiographic Testing

- X-rays are commonly used for thin or less dense materials while gamma rays are used for thicker or denser items.
- The term radiography usually implies a radiographic process that produces a permanent image on film (conventional radiography) or paper (paper radiography or xeroradiography), although, in a broad sense, it refers to all forms of radiographic inspection.
- When inspection involves viewing of a real-time image on a fluorescent screen or image intensifier, the radiographic process is termed real-time inspection. When electronic, non-imaging instruments are used to measure the intensity of radiation, the process is termed radiation gaging.
- Neutron radiography refers to radiographic inspection using neutrons rather than electromagnetic radiation.

1. PRINCIPLE

- In Radiography Testing the test-part is placed between the radiation source and film (or detector). The radiation passed through a test piece to detect defects.

- The results can be processed using film radiography, computed radiography, computed tomography or digital radiography. The method is used, the radiation will show discontinuities in the material due to the strength of the radiation.

2. TYPES OF RADIOGRAPHIC TESTING

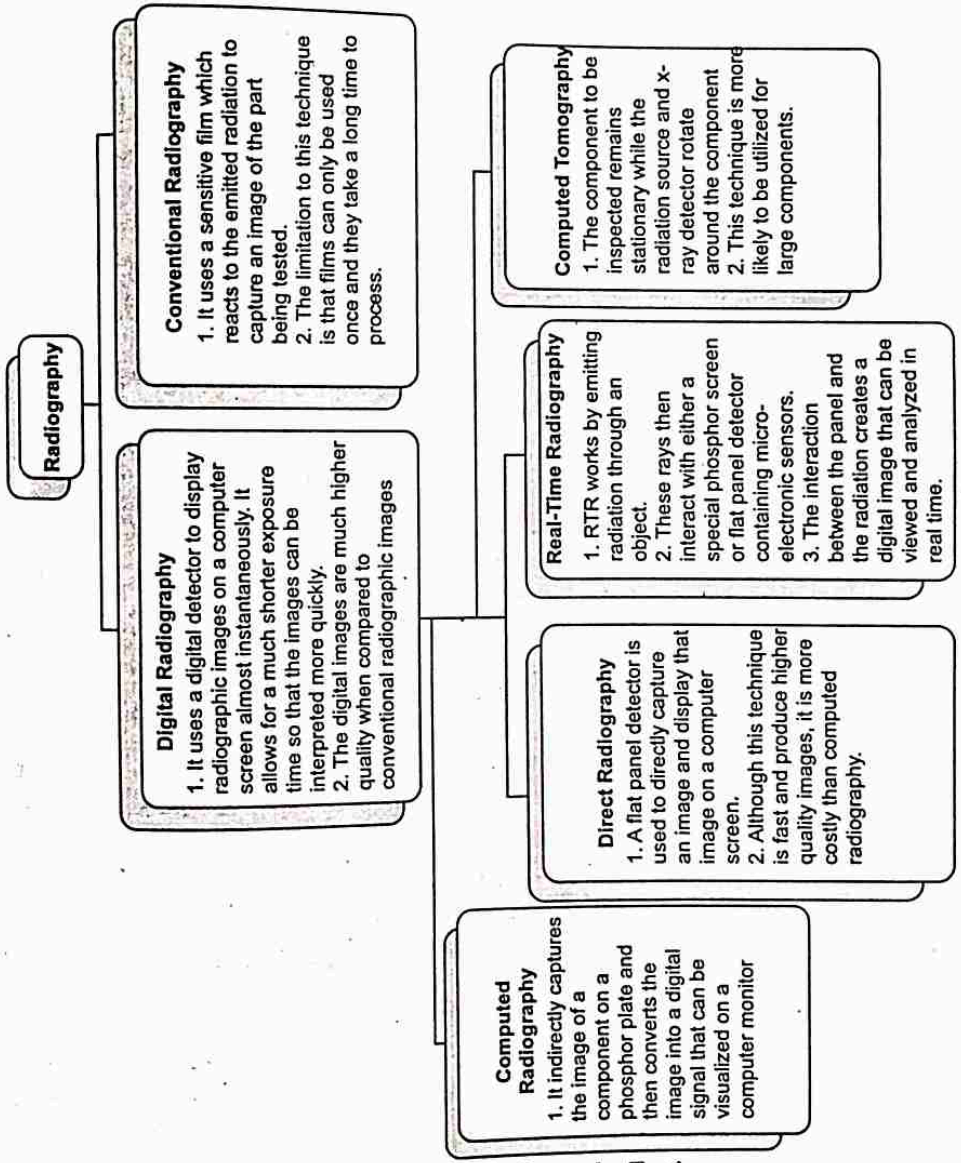


Fig. 3.23. Types of Radiography Testing

3. BASIC COMPONENTS OF RADIOGRAPHIC TESTING

(a) Source

- X-rays are generated by directing a stream of high speed electrons at a target material such as tungsten, which has a high atomic number. When the electrons are slowed or stopped the interaction with the atomic particles of the target, X-radiation is produced.
- The neutron, energy is released in the form of gamma rays. Two of the most common industrial gamma-ray sources for industrial radiography are Iridium-192 and Cobalt-60.

(b) Radiographic Film

- When X-rays or gamma-rays or light strike the film, some of the halogen atoms are liberated from the silver halide crystal and thus leaving the silver atoms alone.
- This change is detected by a method is called a "latent (hidden) image". When the film is exposed to a chemical solution (developer) the reaction results in the formation of black.

4. WORKING PRINCIPLE OF RADIOGRAPHIC TESTING

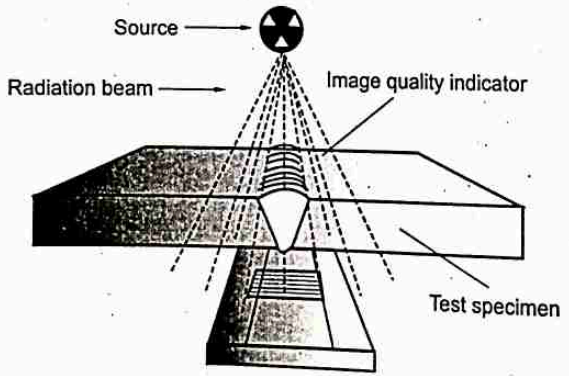


Fig. 3.24. Working principle of radiographic testing

- The testing specimen part to be placed between the radiation source (x-ray or gamma source) and a piece of film which records the defect data.
- The undefeated part will stop some of the radiation. Thicker and denser area will allow less radiation to pass through. The discontinuity allows rays to pass.

- The property of the film will vary with the amount of radiation reaching the film through the test object. These differences in "absorption" can be recorded on film, or electronically. The energy of the radiation affects its penetrating power.
- Higher energy radiation can penetrate thicker and denser materials.
- The radiation energy and exposure time must be controlled to properly image the region of interest.

5. RADIOGRAPH FILM ANALYSIS

- If an object has a high density, ie a thicker object, it absorbs more radiation causing less radiation to hit the film, which produces a lighter image.
- If an object has a low density, ie when the through section is reduced or there is a lower-density material such as slag (compared to the surrounding material), it will absorb less radiation causing more radiation to hit the film, producing a darker image.
- The image on the film cannot initially be seen; this is called the latent image and can only be seen when the film is developed. The quality of this image mainly depends upon two properties;
- Density- This is the degree of blackness on the radiograph. There will be minimum and maximum amounts of density to make the radiograph readable and give the required sensitivity.
- Contrast- Radiographic contrast is the degree of difference between density fields on a radiograph. If there are only blacks and whites on a radiograph, this would be high contrast. If only tones of a similar density are on the graph, this would be low contrast.

6. SAFETY ASPECTS OF RADIATION TEST

- **Film badges/TLDs** (thermoluminescent dosemeters)

  The detectors worn by all industrial radiographers that measure the dose a radiographer receives over a period of time, usually one month.

- **Survey meters** (dose rate meters)

  The instruments that can measure dose rates per unit time.

- **Audible alarms**

  These are alarm/warning devices that should always be worn by radiographers working with gamma radiation.

- **Pocket dosemeters (exposure meters)**

  These meters record an accumulative amount of radiation and can be used for measuring the dose received, for instance over one day, instead of waiting for the monthly badge results.

- **Audio/visual alarms**

  These are alarms, such as the 'Gamma Alert', that are placed inside the radiation area and normally have an amber flashing light

7. ADVANTAGES

- Both surface and internal discontinuities can be detected.
- Significant variations in composition can be detected.
- Can be used for inspecting hidden areas (direct access to surface is not required).
- Permanent test record is obtained.
- Good portability especially for gamma-ray sources.
- Minimum surface preparation required.
- Verify internal flaws on complex structures.
- Isolate and inspect internal components.
- Automatically detect and measure internal flaws.
- Measure dimensions and angles within the sample without sectioning.
- Sensitive to changes in thickness, corrosion, flaws and material density changes.

8. DISADVANTAGES

- Hazardous to operators and other nearby perscnnel.
- High degree of skill and experience is required for exposure and interpretation.
- The equipment is relatively expensive (especially for x-ray sources).
- The process is generally slow

- Highly directional (sensitive to flaw orientation).
- Depth of discontinuity is not indicated.
- It requires a two-sided access to the component.
- Many safety precautions for the use of high intensity radiation.
- Many hours of technician training prior to use.
- Access to both sides of sample required.
- Orientation of equipment and flaw can be critical.
- Determining flaw depth is impossible without additional angled exposures.
- Expensive initial equipment cost.

9. APPLICATIONS

- Industrial Radiographic testing is used extensively on castings and weldments.
- Radiography is also well suited for testing of semiconductor devices for cracks, broken wires, unsoldered connections, foreign material and misplaced components.
- Sensitivity of radiography to various types of flaws depends on many factors, including type of material, type of flaw and product form.
- Both ferrous alloys can be radiographed, as well as non-metallic materials and composites.

Used in fields of,

- Aerospace industries
- Military defense
- Offshore industries
- Marine industries
- Power-gen industries
- Petrochem industries
- Waste Management
- Automotive industries
- Manufacturing industries
- Transport industries

3.2.8. ELECTROMAGNETIC TESTING (ET) OR EDDY CURRENT TESTING

- This testing method uses an electric current or magnetic field which is passed through a conductive part.
- Eddy current testing uses an alternating current coil to induce an electromagnetic field into the test piece, alternating current field measurement and remote field testing both uses a probe to introduce a magnetic field, with RFT generally used to test pipes.

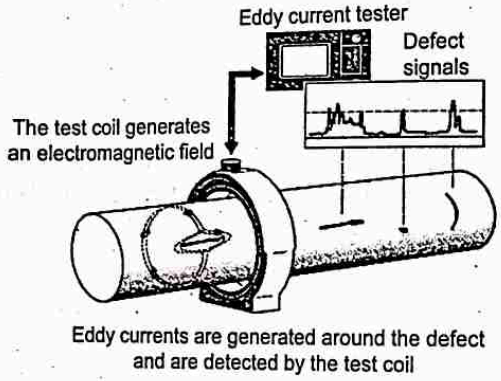


Fig. 3.25. Eddy current tester

1. PRINCIPLE

- An electromagnetic inductor is used to generate a magnetic field. When this field is introduced in the surface of the test piece, it generates so called "eddy currents" in the material.

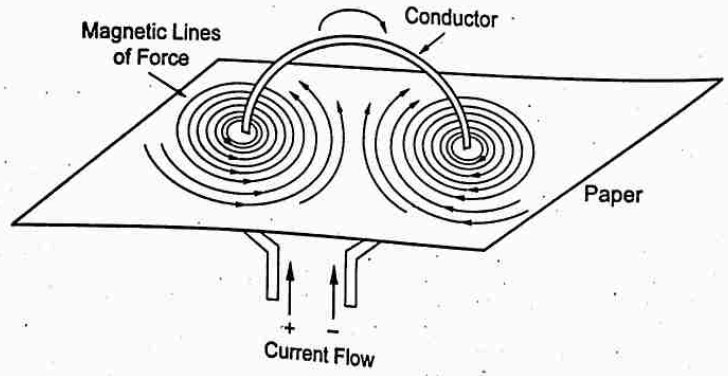


Fig. 3.26. Principle of eddy current flowing

- These currents generate their own magnetic field which resists the initial field created by the inductor. When a discontinuity disturbs the eddy currents, this can be registered by measuring the resulting change in impedance of the coil.

2. METHODS OF EDDY CURRENT TESTING

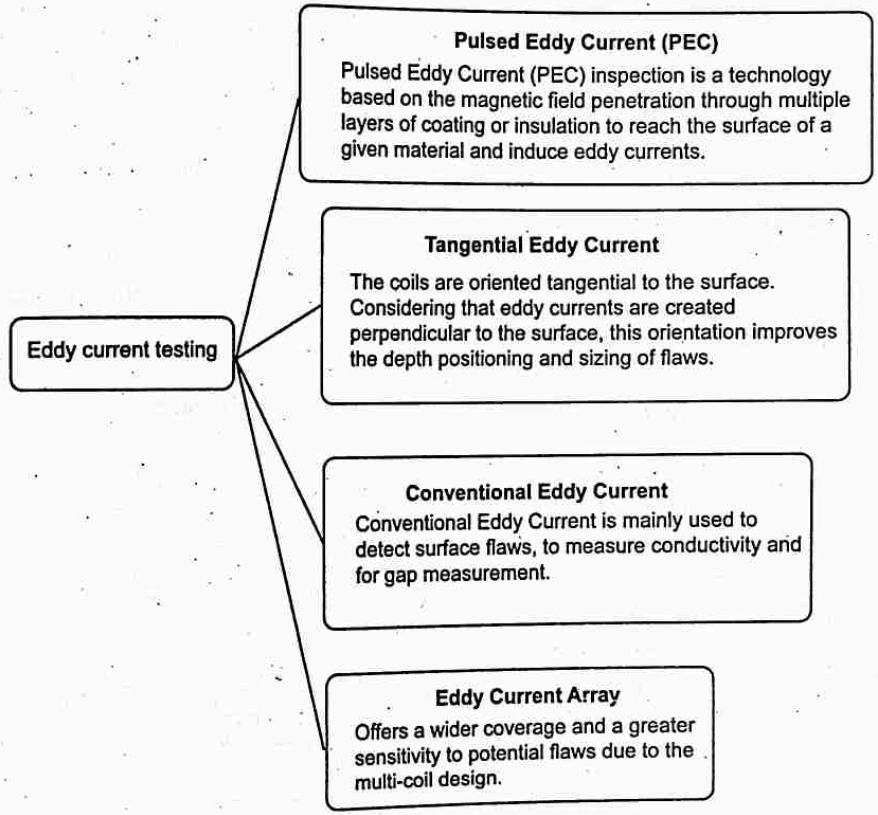


Fig. 3.27. Types of eddy current testing

3. COMPONENTS OF EDDY CURRENT TESTING

- **Eddy probe (AC source, Electromagnetic coil, Display unit, Receiver coil, Exciting coil, Display unit)** - AC voltage source for the purpose of the test can generate a primary electromagnetic alternating field. The exciter coil and the receiver coil normally have coil axes parallel to each other, so that the primary alternating magnetic field of the exciter coil induces an AC voltage in the receiver coil.

4. WORKING OF EDDY CURRENT TESTING

- When eddy current probe brought close to the testing material, an alternating current flows through a wire coil and generates an oscillating magnetic field.
- The electrical currents are called eddy currents because the flow in circles at and just below the surface of the material. The Eddy Current generates a new superposed magnetic field. This field is detected by a receiver coil.
- Interruptions in the flow of eddy currents, caused by imperfections, dimensional changes, or changes in the materials conductive and permeability properties, can be detected with the proper equipment like probs.
- Eddy current testing can be used on all electrically conducting materials with a reasonably smooth surface. The figure shows the difference in flawless and flaw surface with impedance graph

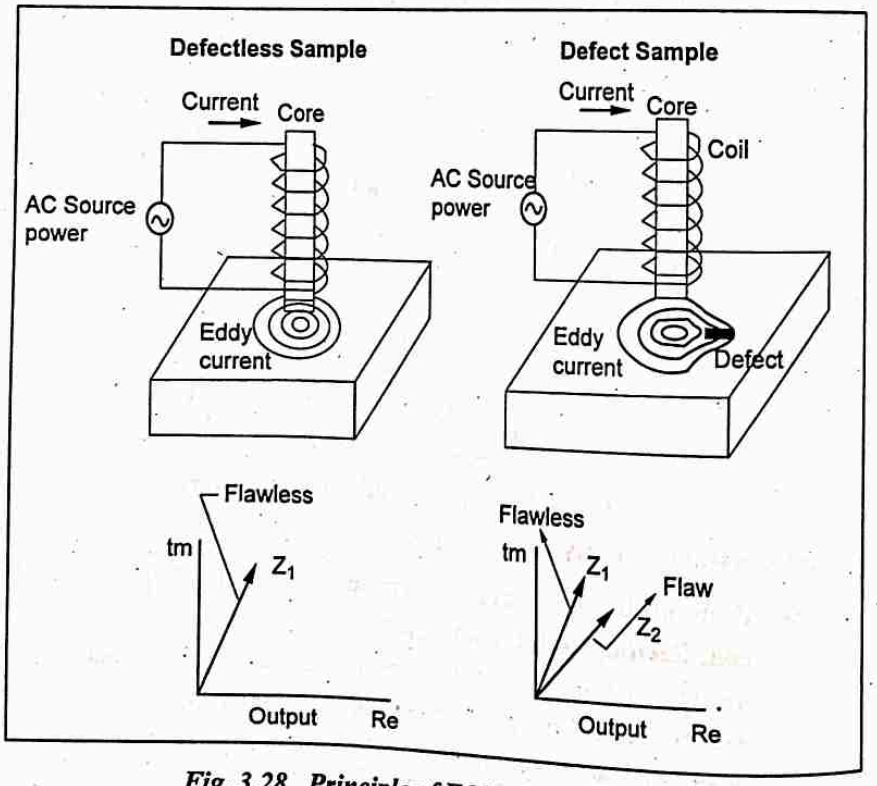


Fig. 3.28. Principle of Eddy current testing

- The test equipment consists of a generator (AC power supply), a test coil and recording equipment, e.g. a galvanometer or an oscilloscope
- Used for crack detection, material thickness measurement (corrosion detection), sorting materials, coating thickness measurement, metal detection, etc.

4. THE STRENGTH OF THE EDDY CURRENTS PRODUCED DEPENDS ON

- Electrical conductivity of the specimen
- Magnetic permeability (for a ferromagnetic specimen)
- Stand-off distance between the specimen and coil.
- AC frequency used in the exciting coil dimensions of the coil and specimen.

5. FACTORS THAT AFFECT EDDY CURRENT INSPECTION

- Material conductivity
- Permeability
- Frequency
- Geometry
- Proximity/Lift-Off
- Depth of Penetration
- Eddy Current Testing and Industry

6. ADVANTAGES

- Sensitive to small cracks and other defects
- Detects surface and near surface defects
- Inspection gives immediate results
- Equipment is very portable
- Method can be used for much more than flaw detection
- Minimum part preparation is required
- Test probe does not need to contact the part
- Inspects complex shapes and sizes of conductive materials
- Able to detect surface and near-surface cracks as small as 0.5mm

- Able to detect defects through several layers, including non-conductive surface coatings, without interference from planar defects
- Effective on test objects with physically complex geometries
- Provides immediate feedback

7. LIMITATIONS

- Can only be used on conductive materials
- The depth of penetration is variable
- Very susceptible to magnetic permeability changes .
- Unable to detect defects that are parallel to the test object's surface
- Only conductive materials can be inspected
- Surface must be accessible to the probe
- Skill and training required
- Surface finish and roughness may interfere
- Reference standards needed for setup
- Depth of penetration is limited
- Flaws such as delamination that lie parallel to the probe coil winding and probe scan direction are undetectable.

8. APPLICATIONS

- It is often applied for surface crack detection and material sorting. Material sorting is used to ensure that the proper materials are in use and to verify component materials or assembly features (such as the orientation or position of a subcomponent in an assembly).
- **Weld Inspection** - To scan the surface for open surface cracks on weld caps and in heat affected zones.
- **Conductivity Testing** - Eddy current testing's ability to measure conductivity can be used to identify and sort ferrous & nonferrous alloys, and to verify heat treatment.
- **Surface Inspection** - Surface cracks in machined parts and metal stock can be readily identified with eddy current.

- **Corrosion Detection** - Low frequency probes can be used to locate corrosion on second and third layers of metal that cannot be inspected ultrasonically.
- **Bolt Hole Inspection** - Cracking inside bolt holes can be detected using bolt hole probes, often with automated rotary scanners.
- **Tubing inspection** - Both in-line inspection of tubing at the manufacturing stage and field inspection of tubing like heat exchangers are common eddy current applications. Both cracking and thickness variations can be detected.

3.2.9. EDDY PROBE

- A coil of conductive wire is excited with an alternating electrical current. This wire coil produces an alternating magnetic field around itself.
- This wire coil produces an alternating magnetic field around itself. The magnetic field oscillates at the same frequency as the current running through the coil. When the coil approaches a conductive material, currents opposite to the ones in the coil are induced in the material eddy currents.
- An eddy current probe is arranged at a small distance (test distance) to a surface of a test specimen to be tested, which consists at least in the region of the surface of an electrically conductive material.

1. TYPES OF EDDY CURRENT PROBE

- Surface probes - Used for identifying flaws on and below metal surfaces, usually large diameter to accommodate lower frequencies for deeper penetration, or for scanning larger areas.
- Pencil probes - Smaller diameter probes housing coils built for high frequencies for high resolution of near surface flaws.
- Bolt hole probes - Designed to inspect the inside of a bolt hole. These probes can be rotated by hand or automatically using a rotary scanner.
- Donut probes - Designed to inspect aircraft fastener holes with fasteners in place.
- Sliding probes - Also used in testing aircraft fastener holes, offering higher scan rates than donut probes.

- ID probes - Used for inspection of heat exchangers and similar metal tubing from the inside, available in a variety of sizes.
- OD probes - Used for inspection of metal tubing and bars from the outside, with the test piece passing through the coil

2. DESIGN OF PROBES

The probe material must be chemically compatible with the component. In brief, probe design is usually done considering the following,

- Geometry of the component e.g. rod, tube, plate etc.
- Type of discontinuity expected e.g. fatigue cracks, conductivity variation etc.
- Likely location of defect e.g. surface, sub-surface
- Coil impedance and its matching with the bridge circuit of the EC instrument
- Frequency range of the probe i.e. for simultaneous multi-frequency excitation
- Inspection requirement e.g. detection, evaluation of length, depth etc.
- Material characteristics e.g. ferromagnetic or non-ferromagnetic
- Coil response to a notch, drilled hole or other reference discontinuity
- Field distribution in space and eddy current flow distribution in the material
- Shape and dimensions of core, coil /coils and lift-off characteristics
- Environmental characteristics such as wear, temperature and chemical attack

3.2.10. ULTRASONIC TESTING (UT)

- **Ultrasonic testing (UT)** is a non-destructive testing techniques based on the propagation of ultrasonic waves (high frequency sound waves) are transmitted into materials to detect internal flaws or to characterize materials.
- The sound frequencies used to perform ultrasonic testing with range of 0.1 to 20 MHz and the wavelength in the range 1 to 10 mm. The velocity depends on the material and is in the range 1000-6000 m/s.

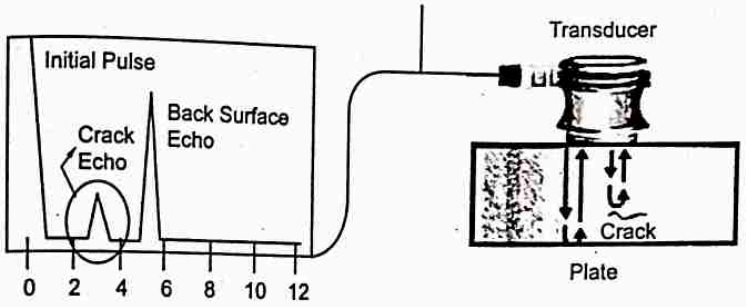


Fig. 3.29. Ultrasonic testing set up

1. PRINCIPLE

- Ultrasonic methods of NDT use beams of mechanical waves (vibrations) of short wavelength and high-frequency, transmitted from a small probe and detected by the same or other probes. Such mechanical waves can travel large distances in fine-grain metal, in the form of a divergent wave with progressive attenuation.

2. BASIC COMPONENTS IN ULTRASONIC TESTING

(a) Ultrasonic waves

- Ultrasonic waves are sound wave is very similar to light waves in that they can be reflected, refracted, and focused.
- Reflection and refraction occurs when sound waves interact with interfaces of differing acoustic properties.

(b) Probe

- Sound beam is emitted through a probe. The probe is made up of a piezoelectric material. Piezoelectric material has the ability of converting mechanical energy into electrical energy. It is reversible; hence an electrical energy can be converted into mechanical energy or sound energy. Sometimes the probe will act as transducer and receiver.
- Three types of probes are generally used in industries;
  - Normal Probe
  - TR probe
  - Angle Probe

(c) Transducer

- Transducer converts it to sound beam, these sound beam travels into the test object.
- A couplant is a material (usually liquid) that facilitates the transmission of ultrasonic energy from the transducer into the test specimen. Couplant is generally necessary because the acoustic impedance mismatch between air and solids (i.e. such as the test specimen) is large.

(d) Receiver

- Receiver receives 'crack echo'/'back surface echo' from the material.

(e) Display unit

- The received signals can be displayed as visual signals on cathode ray tube (CRT) or liquid crystal display (LCD) screen of the machine.
- The reflected signal strength is displayed versus the time from signal generation to when an echo was received.

3. DATA INTERPERTATION

There are three main types of display for flaw detectors: the A-scan, the B-scan and the C-scan presentation.

- An **A-scan presentation** is the most common display used in ultrasonic testing. It shows returning signal amplitudes vertically and the elapsed time or distance horizontally (depth).

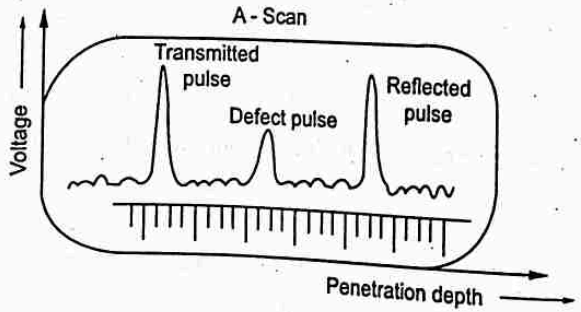


Fig. 3.30. A-scan presentation

- With **B-scan displays**, a cross-sectional view of the component under test is seen. The display shows the depth of reflectors and is used to determine

the cross-sectional size, location (both position and depth) and, with large discontinuities, can show the shape and orientation to a certain degree.

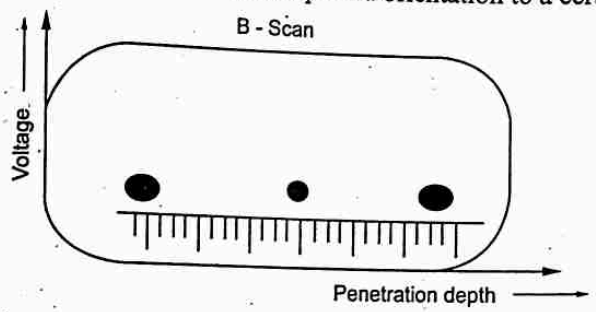


Fig. 3.31. B-scan

- A **C-scan display** is built up using raster scanning (X versus Y) over the component surface. It is mainly used with automated immersion equipment and is well suited for use with through-transmission systems.

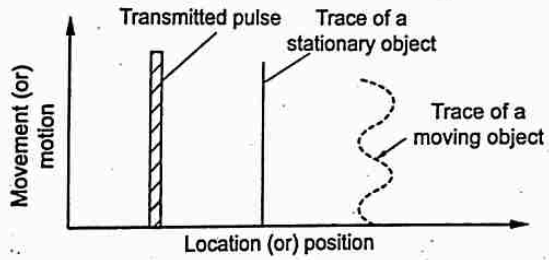


Fig. 3.32. C-scan display

4. METHODS IN ULTRASONIC TESTING

- Ultrasonic testing is a very versatile inspection method, and inspections can be accomplished in a number of different ways.
- Ultrasonic inspection techniques are commonly divided into three primary classifications.
  - Pulse-echo and Through Transmission
  - Contact and Immersion
  - Normal Beam and Angle Beam

(a) Pulse-echo method

- This is the method most commonly utilized in the ultrasonic testing of materials.

- The transmitter and receiver probes are on the same side of the specimen and the presence of a defect is indicated by the reception of an echo before that of the back wall echo.

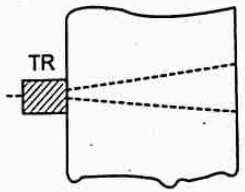


Fig. 3.33. Pulse-echo method probe

(b) Through Transmission method

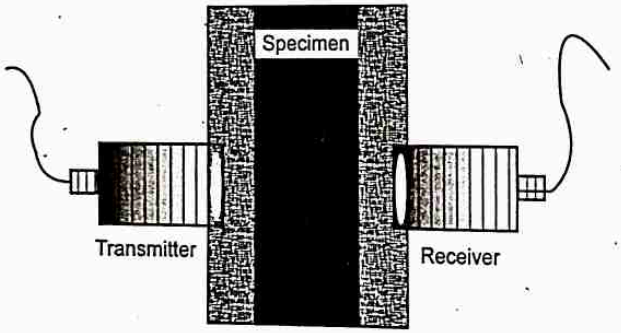


Fig. 3.34. Through Transmission method

- Transmitted and receiving probes are on the opposite side of the specimen. Presence of defect is indicated by variation in transmission signal. Method not shows exact location of damage.

(c) Contact type

- In the contact type, the probe is placed in direct contact with the test specimen with a thin liquid film used as a couplant for better transmission of ultrasonic waves in to the test specimen. Contact type subdivided into normal and angle beam technique
- In the **normal beam technique** the ultrasonic beam is projected perpendicularly in to the test specimen. This technique may use single, double or SE normal beam probes. With the single probe, the transducer of the probe acts as both transmitter and receiver.

- **The angle beam technique** is used to transmit ultrasonic waves in to a test specimen at a predetermined angle to the test surface.

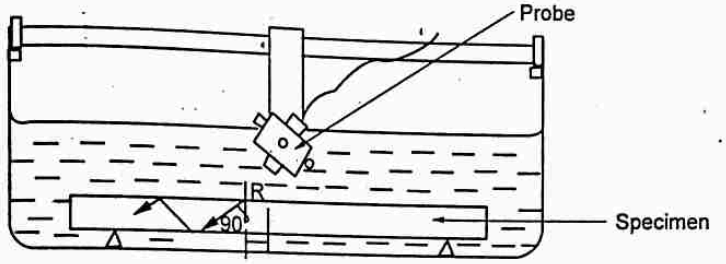


Fig. 3.35. The angle beam technique

D. IMMERSION TYPE

- In the immersion type, a waterproof probe is used at some distance from the test specimen and the ultrasonic beam is transmitted in to the material through a water path or water column.

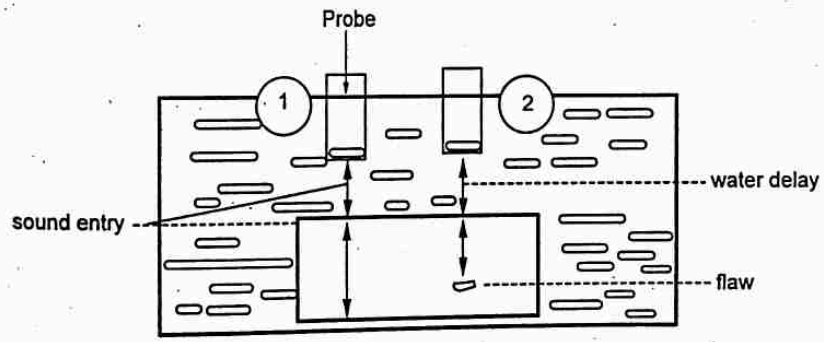


Fig. 3.36. immersion type

5. WORKING OF ULTRASONIC TESTING

- The technique detects internal, hidden discontinuities that may be deep below the surface.
- The sound energy is introduced and propagates through the materials in the form of waves.
- When there is a discontinuity (such as a crack) in the wave path, part of the energy will be reflected back from the flaw surface.
- The reflected wave signal is transformed into an electrical signal by the transducer and is displayed on a screen.

- Knowing the velocity of the waves, travel time can be directly related to the distance that the signal traveled.
- From the signal, information about the reflector location, size, orientation and other features can sometimes be gained.

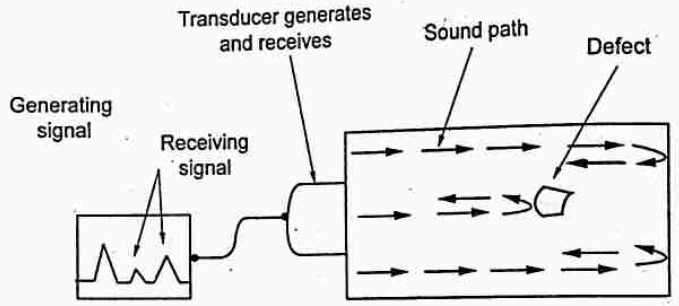


Fig. 3.37. Working of Ultrasonic testing

6. ADVANTAGES

- Capable of portable or highly automated operation.
- Can be performed on all types of materials.
- High accuracy and reproducibility in flaws detection.
- Generally only one surface needs to be accessible.
- Detection of surface and subsurface defects.
- Superior depth of penetration compared to other test methods.
- Minimal specimen preparation is required.
- Instantaneous results produced by using electronic equipment. Detailed images can be produced with automated systems.
- Non-hazardous to operations or nearby personnel.

7. DISADVANTAGES

- Surface must be accessible to probe and couplant.
- Skill and training required is more extensive than other technique.
- Surface finish and roughness can interfere with inspection.
- Thin parts may be difficult to inspect.
- Linear defects oriented parallel to the sound beam can go undetected.

- Cast iron and other coarse grained materials are difficult to inspect due to low sound transmission and high signal noise
- Linear flaws oriented parallel to the direction of the sound beam may go undetected
- Reference standards are required for equipment calibration and for the characterization of flaws.

8. APPLICATIONS

- Checking the quality of welds in pipes for the offshore oil industry
- Flaw detection and evaluation of materials
- Used in industries, Military defence, Offshore and marine industries
- Flaw detection (cracks, inclusions, porosity, delamination etc.)
- Corrosion/erosion wall thickness gauging
- Bond integrity assessment
- Estimation of grain size in metals
- Estimation of void content in composites and plastics

3.2.11. ACOUSTIC EMISSION

- This is a passive NDT technique, which relies on detecting the short bursts of ultrasound emitted by active cracks under a load. Sensors dispersed over the surface the structure detect the AE.
- It is even possible to detect from plasticization in highly stressed areas before a crack forms.

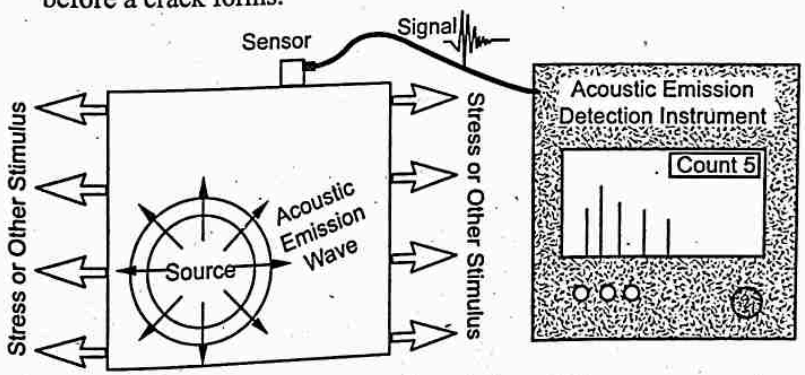


Fig. 3.38. Acoustic emission setup

- Frequently a method for use during proof tests of a pressure vessel; AE testing is also a continuous Structural Health Monitoring (SHM) method, for example on bridges. Leaks and active corrosion are detectable AE sources too.

1. PRINCIPLE

- Acoustic Emission (AE) refers to the generation of transient elastic waves produced by a sudden redistribution of stress in a material. When a structure is subjected to an external stimulus (change in pressure, load, or temperature), localized sources trigger the release of energy, in the form of stress waves, which propagate to the surface and are recorded by sensors.

2. BASIC COMPONENTS IN ACOUSTIC EMISSION TESTING

(a) Source

- The transient elastic waves that result from a sudden strain energy release within a material due to the occurrence of microstructural changes.
- Preamplifier is amplifies the initial signal.

(b) Sensor

- It is sensitivity in low ultrasonic frequency.
- The sensor can hear breaking of a single grain in metal, single fiber in fiber reinforced concrete and burst of tiny glass bubble in glass. It is made up of ceramic.

(c) Cable

- It transmit data Acoustic Emission device. Typically coaxial is used.

(d) Data acquisition device

- It performs filtration of signals parameter evaluation, data analysis and charting.

3. WORKING OF ACOUSTIC EMISSION

- Acoustic emission testing works by mounting small sensors onto a component under test.
- The component is stressed; the built-up state of stress spontaneously discharges at a leak, thereby generating sound impulses. As the damage grows in the component, there is a greater release of energy.

- The energy thus discharged is received by sensors applied on the surface of the tested object. The rates in which the acoustic emission is detected, the activity, and the intensity of the acoustic emission, the loudness, are monitored and used for assessing structural integrity and for health monitoring of components.
- The signals are received at different times by different sensors. By measuring these differences in time, the sound source can be located.

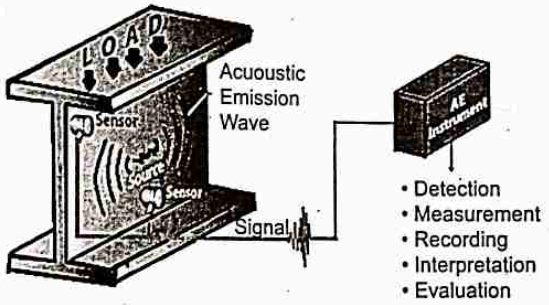


Fig. 3.39. Working of Acoustic Emission

3. ADVANTAGES

- High sensitivity.
- Early and rapid detection of defects, flaws, cracks etc.
- Real time monitoring.
- Cost Reduction test.
- Defective area location: only critical defects provide sustainable Acoustic Emission sources.
- Minimization of plant downtime for inspection, no need for scanning the whole structural surface. Minor disturbance of insulation.
- Ability to detect a range of damage mechanisms including, but not limited to, fiber breakages, friction, impacts, cracking, delamination and corrosion in their early stages, before they become significant issues.
- Can be conducted during operation, during qualification (proof) testing or development testing.
- Operational in hazardous environments, including high temperatures, high pressures and corrosive and nuclear environments.

- Can detect damages in defects that are difficult to access with conventional non-destructive testing techniques.

4. DISADVANTAGE

- Limited to assessing structural integrity or machine health by locating issues, further inspection is usually required to fully diagnose issues.
- Cannot detect defects that may be present, but that do not move or grow.
- Can be slower than other non-destructive testing techniques.

5. APPLICATION

- Continuous structural health monitoring (SHM) - bridges, metallic structures, mines, etc.
- Periodic testing - pressure vessels, pipelines, bridges, cables, storage tanks
- Transformer reliability monitoring
- Tube leak monitoring
- Structural integrity evaluation
- Tank bottom testing
- Corrosion detection
- Tube trailers & high pressure gas cylinders
- Reactor & high energy piping testing
- Aging aircraft evaluation

3.2.12. SELECTION OF NDT PROCESS

When planning an NDT inspection, following factors should made in account

- Cost.
- Economic criteria.
- Feasibility of NDT methods available.
- Quality assurance level achieved.
- The minimum detectable flaw size, shape, and orientation of the defect.
- The sensitivities and limitations of the NDT method.
- The type of damage (flaw, defect, discontinuity) mechanism to be inspected.

- Type of material to be tested.
- Where the defect is located (surface or internal).
- Working conditions and location.

1. RELIABILITY OF NONDESTRUCTIVE TESTING METHODS

- A simplified breakdown of the complexity and relative requirements of the five most frequently used NDT techniques is shown in table 3.2.

Table 3.2. Relative uses and merits of various nondestructive testing methods

Test method	Ultrasonics	X-ray	Eddy current	Magnetic particle	Liquid penetrant
Capital cost	Medium to high	High	Low to medium	Medium	Low
Consumable cost	Very low	High	Low	Medium	Medium
Time of results	Immediate	Delayed	Immediate	Short delay	Short delay
Effect of geometry	Important	Important	Important	Not too important	Not too important
Access problems	Important	Important	Important	Important	Important
Type of defect	Internal	Most	External	External	Surface breaking
Relative sensitivity	High	Medium	High	Low	Low
Formal record	Expensive	Standard	Expensive	Unusual	Unusual
Operator skill	High	High	Medium	Low	Low
Operator training	Important	Important	Important	Important	Less important

Test method	Ultrasonics	X-ray	Eddy current	Magnetic particle	Liquid penetrant
Training needs	High	High	Medium	Low	Low
Portability of equipment	High	Low	High to medium	High to medium	High
Dependent on material composition	Very	Quite	Very	Magnetic only	Little
Ability to automate	Good	Fair	Good	Fair	Fair
Capabilities	Thickness gaging; Some composition testing	Thickness gaging	Thickness gaging; Grade sorting	Defects only	Defects only

2. COMPARISON OF MAJOR NDT TEST

Table 3.3. Comparison of NDT test

Application	Characteristics detected	Advantages	Limitations	Example of use
Ultrasonic	Changes in acoustic impedance caused by cracks, non-bonds, inclusions, or interfaces	Can penetrate thick materials; excellent for crack detection; can be automated	Normally requires coupling to material either by contact to surface or immersion in a fluid such as water. Surface needs to be smooth.	Adhesive assemblies for bond integrity; laminations; hydrogen cracking

Application	Characteristics detected	Advantages	Limitations	Example of use
Radiography	Changes in density from voids, inclusions, material variations; Placement of internal parts is detected	Can be used to inspect wide range of materials and thicknesses; Versatile; Film provides record of inspection	Radiation safety requires precautions; Expensive; Detection of cracks can be difficult unless perpendicular to x-ray film.	Pipeline welds for penetration, inclusions, and voids; Internal defects in castings
Visual optical	Surface characteristics such as finish, scratches, cracks, or color; strain in transparent materials; Corrosion	Often convenient; Can be automated	Can be applied only to surfaces, through surface openings or to transparent material	Paper, wood, or metal for surface finish and uniformity
Eddy current	Changes in electrical conductivity caused by material variations, cracks, voids, or inclusions	Readily automated; Moderate cost	Limited to electrically conducting materials; limited penetration depth	Heat exchanger tubes for wall thinning and cracks
Liquid penetrant	Surface openings due to cracks, porosity, seams, or folds	Inexpensive, Easy to use, readily portable,	Flaw must be open to surface. Not useful on porous	Turbine blades for surface cracks or porosity;

Application	Characteristics detected	Advantages	Limitations	Example of use
		Sensitive to small surface flaws	materials or rough surfaces	Grinding cracks
Magnetic particle	Leakage magnetic flux caused by surface or near-surface cracks, voids, inclusions, or material or geometry changes	Inexpensive or moderate cost, both to surface and near- surface flaws sensitive	Limited to ferromagnetic material; Surface preparation and post-inspection demagnetization may be required	Railroad wheels for cracks; large castings

3.2.13. DISCONTINUITIES

- **Discontinuities:** Any imperfection or interruption in the normal physical structure or configuration of a product (cracks, laps, inclusion, etc). Discontinuity may or may not affect the usefulness of the product
- **Defect:** A discontinuity whose size, shape, orientation, location or properties makes it detrimental to the useful service of the product in which it occurs or exceeds the accept/reject criteria for the given design. Defect is a type of discontinuity.
- **Flaw:** It is defined as "an imperfection or discontinuity that may be detectable by nondestructive testing and is not necessarily rejectable." A flaw is also something that can occur in various sizes, shapes, orientations, locations, and can even only be isolated to a tiny portion of the material properties within a material volume.

Types of Discontinuities

- Inherent discontinuities - The discontinuities that originate during the initial casting process (when the metal is casted into ingots for further processing) and also it includes the discontinuities that are produced when metal is casted as parts of any given shape.
- Primary processing discontinuities - The discontinuities that originate during hot or cold forming processes (extrusion, forging, rolling, drawing, welding, etc.).
- Secondary procession discontinuities- The discontinuities that originate during grinding, machining, heat treating, plating and related finishing operations.
- Service discontinuities - The discontinuities that originate or develop while the component is in service. The service conditions (loading, mechanical and chemical environment, maintenance) of a component affect its expected life.

3.2.14. FACTORS INFLUENCING SENSITIVITY OF INSPECTION

The things can influence the sensitivity of inspections, but some of the main items to consider are: geometrical complexity, material density, surface roughness, and accessibility.

- **Geometrical complexity** - The simple rod, bar, or panel, something that can access from just about any direction, then flaw detection method will not be driven by geometrical complexity. The irregular shapes is largely affected during testing.
- **Material density** - Density and thickness of material can be critical to flaw sensitivity. Distinguishing a very small flaw can be nearly impossible in this situation.
- **Surface roughness** - The surface is where many of the inspections need to contact, so a rough surface makes for a difficult inspection, or no inspection at all.
- **Accessibility** - As with surface roughness, accessibility can quickly rule out UT and ET because you have to be able to have adequate probe contact. PT and MT are usually pretty good at limited areas of accessibility.

TWO MARK QUESTION WITH ANSWER

1. ***Define NDT.***
   - ❖ Non-destructive testing (NDT) is a testing and analysis technique used by industry to evaluate the properties of a material, component, structure or system for characteristic differences or defects and discontinuities without causing damage to the original part.
2. ***Write importance of NDT.***
   - ❖ To ensure product reliability
   - ❖ To ensure the safety of operation
   - ❖ To ensure customer satisfaction and to maintain the manufacturer's reputation
   - ❖ To control manufacturing processes and lower manufacturing costs
   - ❖ To maintain uniform quality level
3. ***What are the advantages of using NDT?***
   1. Reusable
   2. Safe
   3. Accurate
   4. Cost effective
   5. Quality control
4. ***What are the major 5 NDT methods?***

   The major 5 NDT Methods are:
   - ❖ Ultrasonic Testing
   - ❖ Radiography Testing
   - ❖ Magnetic Particle Testing
   - ❖ Dye Penetrant Testing
   - ❖ Eddy Current Testing
5. ***What are stages in NDT testing?***
   1. Testing
   2. Recording & Reporting
   3. Interpretation & Evaluation

6. ***Define Borescope.***
   - ❖ It is optical instrument for remove viewing of objects. Borescope can have various angles of view: 0° direct, 45° fore-oblique, 90° lateral and 110° retro.
   - ❖ Borescope consist of precision illumination system.
   - ❖ The size of the visual field usually varies with the diameter, for a given magnification system. The size of the visual field usually varies with the diameter, for a given magnification system.
7. ***What are the factors affecting the choice of NDT method***
   - ❖ Cost
   - ❖ Economic criteria.
   - ❖ Feasibility of NDT methods available.
   - ❖ Quality assurance level achieved.
   - ❖ The minimum detectable flaw size, shape, and orientation of the defect
   - ❖ The sensitivities and limitations of the NDT method
   - ❖ The type of damage (flaw, defect, discontinuity) mechanism to be inspected.
   - ❖ Type of material to be tested
8. ***What aids used for visual testing?***
   - ❖ Magnifying glasses
   - ❖ Fillet weld gauge-
   - ❖ Microscopes
   - ❖ Computer equipment (remote viewing)
   - ❖ Illuminated magnifier
   - ❖ Holography
9. ***Define liquid penetrant inspection***
   - ❖ It is based on the properties of surface wetting and capillary action, which causes a liquid to rise when confined to a small opening. After applying the penetrant and wiping away the excess, the penetrant that rises to the surface can indicate surface-breaking.

10. ***What is purpose penetrant in liquid penetrant inspection?***
    - ❖ The liquid, by capillary action, will penetrate the discontinuities and the excess remaining on the surface will be removed by a suitable cleaning system. It will be highly visible or fluoresce brightly to produce easy to see indications.
11. ***What is the role of developer in liquid penetrant inspection?***
    - ❖ The role of the developer is to pull the trapped penetrant material out of defects and spread it out on the surface of the part so it can be seen by an inspector.
12. ***Write the principle of working in magnetic particle testing?***
    - ❖ This NDT process uses magnetic fields to find discontinuities at or near the surface of ferromagnetic materials. The magnetic field can be created with a permanent magnet or an electromagnet, which requires a current to be applied.
    - ❖ The magnetic field will highlight any discontinuities as the magnetic flux lines produce leakage, which can be seen by using magnetic particles that are drawn into the discontinuity.
13. ***What are type of magnetization in magnetic particle testing?***

    Longitudinal magnetization- the magnetic flux flows from pole to pole, we call this longitudinal magnetisation. Discontinuities will be detectable once more at 90° (± 45°) to the flux direction.

    Circular magnetization - Circular magnetic field will be produced around the component at right angles to the direction of the electric current which produced it.
14. ***What are limitations of using magnetic particle testing?***
    - ❖ The specimen must be ferromagnetic (e.g. steel, cast iron)
    - ❖ Paint thicker than about 0.005" must be removed before inspection
    - ❖ Post cleaning and post demagnetization is often necessary
    - ❖ Insensitive to internal defects
    - ❖ Require magnetization and demagnetization of materials to be inspected
    - ❖ Require power supply for magnetization

- ❖ Coating may mask indication
- ❖ Material may be burned during magnetization

15. ***What are the major components used in thermography Method?***
    - ❖ Thermographic camera
    - ❖ Control unit
    - ❖ Pc/image processing unit
16. ***Define Pulsed thermography***

    It is a classical optical excitation thermography technique. In pulsed thermography, high-energy lamps are often used to produce a uniform heating source on the specimen surface.
17. ***What are the advantages of thermography Method compared to other NDT?***
    - ❖ Data collection system can record temperature changes with time
    - ❖ High-speed, portable, and non-contact
    - ❖ Ability to inspect large areas
    - ❖ Effective prevention of test scrap
    - ❖ Contactless testing with low thermal stress
18. ***Define Radiographic Testing.***
    - ❖ Radiographic Testing (RT) is a non-destructive testing (NDT) method which uses either x-rays or gamma rays to examine the internal structure of manufactured components identifying any flaws or defects.
19. ***How densities of material influence the radiographic testing?***
    1. If an object has a high density, ie a thicker object, it absorbs more radiation causing less radiation to hit the film, which produces a lighter image.
    2. If an object has a low density, ie when the through section is reduced or there is a lower-density material such as slag (compared to the surrounding material), it will absorb less radiation causing more radiation to hit the film, producing a darker image.
20. ***Define eddy current.***
    - ❖ An electromagnetic inductor is used to generate a magnetic field. When this field is introduced in the surface of the test piece, it generates so called "eddy currents" in the material.

21. *Difference between Digital Radiography and Conventional Radiography.*

Digital Radiography	Conventional Radiography
It uses a digital detector to display radiographic images on a computer screen almost instantaneously.	It uses a sensitive film which reacts to the emitted radiation to capture an image of the part being tested.
It allows for a much shorter exposure time so that the images can be interpreted more quickly.	The limitation to this technique is that films can only be used once and they take a long time to process.

22. *What are the types of Eddy current testing?*

- ❖ Pulsed Eddy Current (PEC)
- ❖ Tangential Eddy Current
- ❖ Conventional Eddy Current
- ❖ Eddy Current Array

23. *How the eddy current used for finding defects in the material?*

- ❖ The electrical currents are called eddy currents because the flow in circles at and just below the surface of the material.
- ❖ Interruptions in the flow of eddy currents, caused by imperfections, dimensional changes, or changes in the materials conductive and permeability properties, can be detected with the proper equipment like probs.

24. *What are the factors affecting eddy current inspection?*

- ❖ Material conductivity
- ❖ Permeability
- ❖ Frequency
- ❖ Geometry
- ❖ Proximity/Lift-Off
- ❖ Depth of Penetration
- ❖ Eddy Current Testing and Industry

25. *What are various application of eddy current testing?*

- ❖ Weld Inspection

- ❖ Conductivity Testing
- ❖ Surface Inspection
- ❖ Corrosion Detection

26. *Define ultrasonic testing.*

- ❖ Ultrasonic testing (UT) is a non-destructive testing techniques based on the propagation of ultrasonic waves (high frequency sound waves) are transmitted into materials to detect internal flaws or to characterize materials

27. *What is the principle of working in acoustic emission test?*

- ❖ Acoustic Emission (AE) refers to the generation of transient elastic waves produced by a sudden redistribution of stress in a material.
- ❖ When a structure is subjected to an external stimulus (change in pressure, load, or temperature), localized sources trigger the release of energy, in the form of stress waves, which propagate to the surface and are recorded by sensors.

28. *Differentiate between Radiography, Eddy current and Ultrasonic.*

Parameter	Radiography	Eddy current	Ultrasonic
Source	X ray , δ ray	Magnetic field	Ultrasonic wave made by piezoelectric or laser
Material	All types of engineering materials that do not absorb the whole wavelength of the ray	Only conductive materials, not cellular materials	All type of engineering materials (metals or plastics)
Geometry	Suitable for complex weld geometry	Need for special probes for different geometries	Need for special probes for different geometries

Parameter	Radiography	Eddy current	Ultrasonic
Type of defects and position	Surface and subsurface defects, all types of flaws. Not suitable for very fine defects	Surface and subsurface defects. Not suitable for deep flaws. All types of flaws	Surface and subsurface defects. Suitable for deep flaws. All types of flaws
Advantages	Determine the position and type of defects, ability for automation	Portable. Suitable for poor access areas. No need for paint or coat removing. No consumable Materials	Determine the length, location and type of defects. Portable.
Limitations	Poor resolution. Access to both sides of the part is required. The size of defect is not accurate	Defect direction, conductive materials, clean and smooth enough surface required	Defect direction Sometimes access to both sides or ends of the detail is required
Applications	Crack detection in weld pipeline	Crack detection of coated weld pipeline, inspecting of fatigue crack	Spot welding control, inspection of SAW in pipeline
Weld process (Example)	Electric resistance welding Laser beam welding Electron beam welding Gas metal arc welding	Laser beam welding Gas metal arc welding Gas tungsten arc welding	Resistance spot welding Gas metal arc welding Friction stir welding Laser beam welding Electron beam welding

29. *Define Inherent discontinuities.*

- The discontinuities that originate during the initial casting process (when the metal is casted into ingots for further processing) and also it includes the discontinuities that are produced when metal is casted as parts of any given shape.

30. *What are the advantages of using acoustic emission test?*

- High sensitivity.
- Early and rapid detection of defects, flaws, cracks etc.
- Real time monitoring
- Cost Reduction
- Defective area location: only critical defects provide sustainable Acoustic Emission sources.

REVIEW QUESTIONS

1. What are the varies advantages of using NDT test?
   Ans: Section No. 3.1 **Page No:** 3.2
2. Compare and contrast the major NDT test with various parameters.
   Ans: Section No. 3.2.12 **Page No:** 3.52
3. Explain the visual test with aids used, advantages and disadvantages.
   Ans: Section No. 3.2.1 **Page No:** 3.5
4. Explain the penetration test with step process and its application.
   Ans: Section No. 3.2.2 **Page No:** 3.10
5. What do you understand by NDT test? And explain the role of Nondestructive testing in manufacture process.
   Ans: Section No. 3.1 **Page No:** 3.1
6. What do you understand by magnetic hysteresis? Explain different magnetization technique using magnetic particle testing with their advantages and disadvantages.
   Ans: Section No. 3.2.5 **Page No:** 3.16
7. Classify the NDT methods. Justify any three methods.
   Ans: Section No. 3.2 **Page No:** 3.3

8. What is ultrasonic testing? Explain types of transducer.

   Ans: Section No. 3.2.10 **Page No:** 3.43

9. Write principle of radiography testing. Explain the working in detail.

   Ans: Section No. 3.2.7 **Page No:** 3.27

10. With output line diagram explain the ultrasonic flaw detector in detail.

    Ans: Section No. 3.2.10 **Page No:** 3.45

11. What is meant by thermography? Explain in detail.

    Ans: Section No. 3.2.6 **Page No:** 3.22

12. Why couplant used in Ultrasonic testing? Explain test with advantages and disadvantages.

    Ans: Section No. 3.2.10 **Page No:** 3.42, 3.46

13. Define eddy probe. Describe types and design of probes.

    Ans: Section No. 3.2.9 **Page No:** 3.39

14. Explain the radiography with safety measures.

    Ans: Section No. 3.2.7 **Page No:** 3.31

15. Write short note on

    - Eddy current testing
    - Acoustic emission testing

    Ans: Section No. 3.2.8, 3.2.11 **Page No:** 3.34, 3.47

16. Write a case study on NDT test used in welding industry.

17. The steel deck truss bridge in Trichy was 90-year-old, constructed across Kollidam river that connects Srirangam with mainland Tiruchirapalli. Use proper NDT test for monitoring bridge condition and explain step procedure of using NDT in bridge for structural health monitoring.

UNIT IV

MATERIAL CHARACTERIZATION TESTING

SYLLABUS

Macroscopic and Microscopic observations, Optical and Electron microscopy (SEM and TEM) - Principles, Types, Advantages and Limitations, Applications. Diffraction techniques, Spectroscopic Techniques, Electrical and Magnetic Techniques - Principles, Types, Advantages and Limitations, Applications.

4.1. OVERVIEW

- Characterization, when used in materials science, refers to the broad and general process by which a material's structure and properties are probed and measured. It is a fundamental process in the field of materials science, without this no scientific understanding of engineering materials could be determined.
- The Materials Characterization has a wide variety of characterization techniques in the areas of Microscopy, Spectroscopy, and Macroscopic techniques which help to increase the different degrees of understanding why different materials show different properties and behaviour.
- Materials characterizing are aimed at the features of materials quantitatively; this is often closely related to the analysis, modelling and simulation, and the qualitative characterization of materials through testing.
- **"Characterization describes those features of composition and structure (including defects) of a material that are significant for a particular preparation, study of properties, or use, and suffice for reproduction of the material."**

Material Characterization used for identification of,

- Contaminants

- Purity
- Active ingredients
- Polymer additives
- Fillers
- Solvents
- Failure Analysis
- Identification of Unknown Substances and Contaminants
- De-formulation and Reverse Engineering
- Material Comparisons
- Specialized Method Development

METHODS OF MATERIALS CHARACTERIZATION

- Chemical Characterization
- Toxicological Characterization
- Physical Characterization
- Electrical Characterization
- Morphological Characterization
- Mechanical Characterization

4.1.1. OBJECTIVES OF MATERIALS CHARACTERIZATION

- To measure accurately the physical properties of materials
- To measure accurately the chemical properties of materials
- To determine accurately the structure of a material at atomic and microscopic level structures

4.1.2. COMMON APPLICATIONS OF MATERIALS CHARACTERIZATION

- Surface Chemical Analysis
- Near Surface Chemical Analysis
- Atomic & NanoScale Chemical Analysis
- Surface Imaging

- Defect Analysis
- Analytical Imaging
- Non-Destructive Internal Imaging

4.1.3. CLASSIFICATION BASED ON APPLICATION

- From a realization of application, a classification of materials characterization methods can be outlined in a simplified manner.

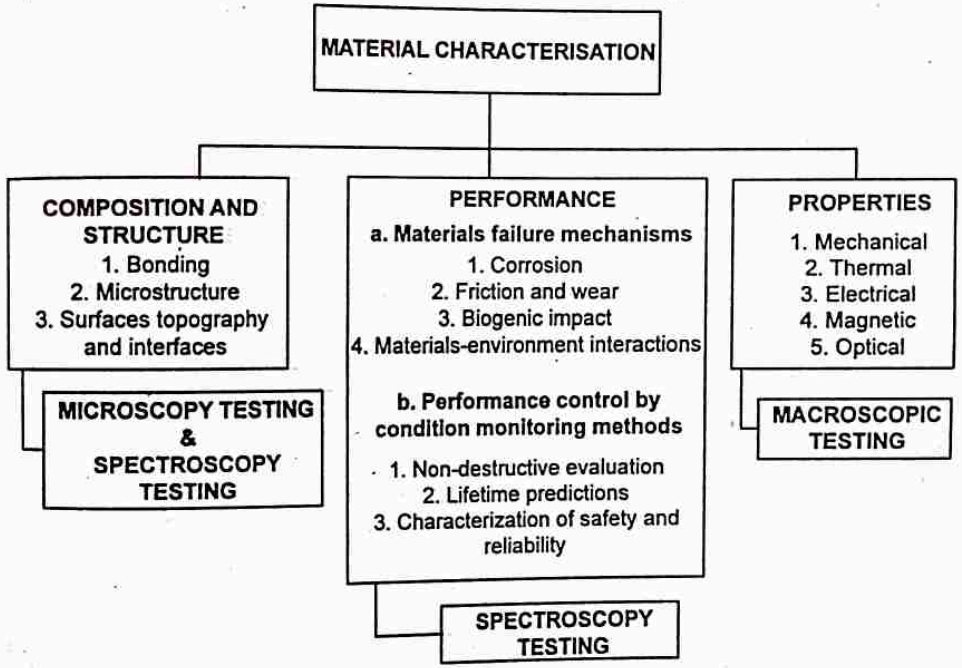


Fig. 4.1. Materials characterization chart

4.2. SCALE

- The scale of the structures observed in materials characterization ranges from angstroms, such as in the imaging of individual atoms and chemical bonds, up to centimeters, such as in the imaging of coarse grain structures in metals.
- The geometric length scale of materials has more than twelve orders of magnitude.

Table 4.1. Ranges of scale

Scale	Range
Nano scale	1 to 100 nanometers
Micro scale (Micro-devices and micro systems)	1 to 1000 micro- meters
Macro scale	Millimeter to the kilometer scale

4.3. MATERIAL CHARACTERIZATION TESTING

- Material characterization is the process of measuring and determining physical, chemical, mechanical and microstructural properties of materials.
- Based on scale of testing, there are two types,
  - Microscopy testing
  - Macroscopic testing
- Based on testing of composition, there are two types,
  - Spectroscopy & Nuclear spectroscopy

4.3.1. MICROSCOPY

- Microscopy is a technique that allows the determination of both the composition and the structure of a material.
- It is essentially the process of viewing the structure on a much finer scale not possible with the naked eye
- The properties of materials with extremely fine features and defects those are only possible to observe using microscopy techniques.

MICROSCOPIC PROPERTIES OF MATERIALS

- Contaminants & Purity
- Ingredients
- Chemical bonding
- Molecular pattern
- Crystal structure & lattice bonding
- Nano Size
- Ions etc.,

COMMON MICROSCOPY INSTRUMENTS INCLUDE

- **Optical Microscope**
- **Scanning Electron Microscope (SEM)**
- **Transmission Electron Microscope (TEM)**
- Field Ion Microscope
- Scanning Tunneling Microscope
- Scanning probe microscopy
- Atomic Force Microscope
- X-ray diffraction topography

4.3.2. SPECTROSCOPY & NUCLEAR SPECTROSCOPY

- This group of techniques uses a range of principles to reveal the chemical composition, composition variation, crystal structure and photoelectric properties of materials. Some common instruments include:
  - Ultraviolet-visible spectroscopy
  - Fourier transform infrared spectroscopy
  - Thermoluminescence
  - Photoluminescence
  - Energy-dispersive X-ray spectroscopy
  - Wavelength dispersive X-ray spectroscopy
  - Electron energy loss spectroscopy
  - X-ray photoelectron spectroscopy
  - Auger electron spectroscopy
  - X-ray Photon Correlation Spectroscopy

4.3.3. MACROSCOPIC

- In which some physical and chemical changes are observed. In this, changes can be observed by the naked eye.
- This simple process can yield a large amount of information about the material such as the colour of the material, its luster (does it display a metallic luster), its shape (whether it displays a regular, crystalline form), its composition (is it made up of different phases), its structural features (does it contain porosity) etc.

MACROSCOPIC PROPERTIES OF MATERIALS

- Density
- Volume
- Strength
- Hardness
- Roughness etc.,

COMMON MACROSCOPIC INSTRUMENTS INCLUDE

- Mechanical testing, including tensile, compressive, torsional, creep, fatigue, toughness and hardness testing
- Differential thermal analysis
- Dielectric thermal analysis
- Thermo gravimetric analysis
- Differential scanning calorimetry
- Impulse excitation technique
- Ultrasound techniques, including resonant ultrasound spectroscopy and time domain ultrasonic testing methods

4.4. BASIC TERMINOLOGY

4.4.1. MAGNIFICATION

- Magnification on a microscope refers to the amount or degree of visual enlargement of an observed object or enlargement of image.

Table 4.2. Methods of magnification

Method	Purpose	Examples
Relative Size Magnification	Increasing the actual size of the object being viewed	Larger print material
Relative Distance Magnification	Reducing the distance between the object and the eye	Move object closer to the eye
Angular Magnification	Increasing angular subtense of the image being viewed	Telescope, magnifier

- Magnification is measured by multiples, such as 2x, 4x and 10x, indicating that the object is enlarged to twice as big, four times as big or 10 times as big, respectively.
  - Magnification = Image ÷ Object

Table 4.3. Magnification vs instrument

Magnification	Instrument
1x	Naked eye
2x to 5x	Magnifying glass
10x to 20x	Stereoscopic microscope
50x to 1500 x	Upright/inverted microscope
2,000x to 1,000,000x	Electron microscope

4.4.2. RESOLUTION

- Resolution is defined as the ability to distinguish two very small and closely-spaced objects as separate entities.
- Resolution is determined by certain physical parameters that include the wavelength of light, and the light-gathering power of the objective and condenser lenses.

4.4.3. LENS

- The observation magnification is the product of the magnifications of each of the lenses. This generally ranges from 10x to 1,000x with some models even reaching up to 2000x magnification. Common types of lens include,

1. OBJECTIVE LENS

- The objective lens consists of several lenses to magnify an object and project a larger image. According to the difference of the focal distance, lenses of different magnifications are available, such as 4x, 10x, 40x, and 50x.
  - Achromatic lens
  - Semi-apochromatic lens (fluorite lens)
  - Apochromatic lens

- Plan lens
- Immersion lens

2. OCULAR LENS (EYEPIECE)

- A lens to be mounted on the observer side. The image magnified by the objective lens is further magnified by the ocular lens for observation. An ocular lens consists of one to three lenses and is also provided with a mechanism, called a field stop, which removes unnecessary reflected light and aberration.
- Different types are available according to the magnification they provide, such as 7x and 15x.
  - Huygens lens
  - Ramsden lens
  - Periplan lens
  - Compensation lens
  - Wide-field lens
  - Super-field lens

3. CONDENSER LENS

- A lens to be mounted under the stage. This lens can adjust the amount of light to uniformly illuminate objects. It is useful for observation at high magnification.
- There are various types of condenser lenses, ranging from general "abbe condensers" to "achromatic condensers" that correct color aberration.
  - Abbe condenser
  - Achromatic condenser
  - Universal condenser

4.4.4. ABERRATION

- Aberration is a property of optical systems such as lenses that causes light to be spread out over some region of space rather than focused to a point.
- Aberrations cause the image formed by a lens to be blurred or distorted, with the nature of the distortion depending on the type of aberration

- Chromatic aberration
- Spherical aberration.

4.4.5. NUMERICAL APERTURE

- The numerical aperture of a microscope objective is a measure of its ability to resolve fine specimen detail. The value for the numerical aperture is given by,
  - Numerical Aperture (NA) = $n \sin \alpha$

4.4.6. DEPTH OF FIELD

- Depth of field is the axial depth of the space on both sides of the object plane within which the object can be moved without detectable loss of sharpness in the image, and within which features of the object appear acceptably sharp in the image while the position of the image plane is maintained.

4.4.7. DEPTH OF FOCUS

- Depth of focus is the axial depth of the space on both sides of the image plane within which the image appears acceptably sharp while the positions of the object plane and of the objective are maintained.

4.5. OPTICAL MICROSCOPE

- The optical microscope, also referred to as a light microscope, is a type of microscope that commonly uses visible light and a system of lenses to generate magnified images of small objects.

1. PRINCIPLE

- The functioning of the light microscope is based on its ability to focus a beam of light through a specimen, which is very small and transparent, to produce an image. The image is then passed through one or two lenses for magnification for viewing. The transparency of the specimen allows easy and quick penetration of light.

2. CONSTRUCTION

- The object is placed on a stage and may be directly viewed through one or two eyepieces on the microscope.

3. TYPES OF MICROSCOPE

1. **Bright field microscope:** Transparent objects can be illuminated from below but the solid objects can be illuminated with light coming through and to produce a quality image. It is also known as a compound light microscope. Common types are,
   (*a*) **Simple microscope:** A simple microscope is a microscope that uses only one lens for magnification, and is the original light microscope. It is used to obtain small magnifications. A single biconvex lens magnifies the size of the object to get an enlarged virtual image
   (*b*) **Compound microscope:** The compound microscope uses a set of many lenses in order to maximize magnification. It magnifies the size of the object by a complex system of lens arrangement. It has a series of two lenses; the objective lens and the ocular lens, to magnify the size of the object.
2. **Dark field microscope:** The object is illuminated against a dark background.
3. **Polarized light microscope:** Polarized light may be used to determine crystal orientation of metallic objects.
4. **Phase-contrast microscope:** Phase-contrast imaging can be used to increase image contrast by highlighting small details of differing refractive index.
5. **Fluorescence Microscope:** It is used to view material stained with fluorescent dyes for specific purposes.
6. **Digital microscope:** A digital microscope is a microscope equipped with a digital camera allowing observation of a sample via a computer.

OTHER MICROSCOPE TYPES

There are many variants of the compound optical microscope design for specialized purposes. Some of these are physical design differences allowing specialization for certain purposes:

- **Stereo microscope,** a low-powered microscope which provides a stereoscopic view of the sample, commonly used for dissection.
- **Comparison microscope,** which has two separate light paths allowing direct comparison of two samples via one image in each eye.

- **Inverted microscope,** for studying samples from below; useful for cell cultures in liquid, or for metallography.
- **Epifluorescence microscope,** designed for analysis of samples which include fluoro phores.
- **Confocal microscope,** a widely used variant of epifluorescent illumination which uses a scanning laser to illuminate a sample for fluorescence.

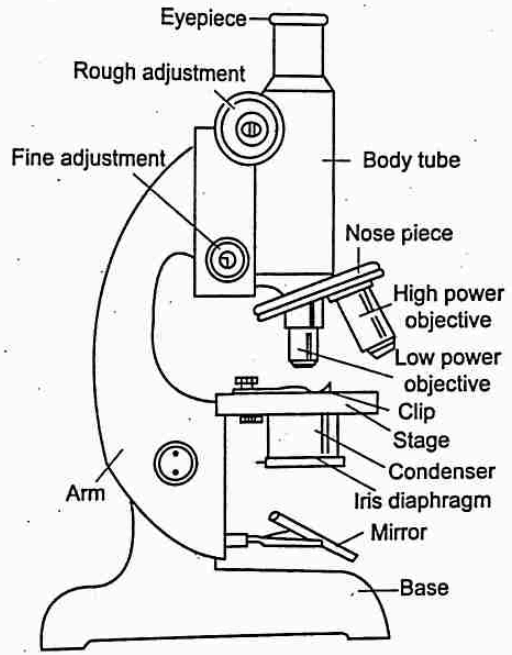


Fig. 4.2. Typical cross section of optical microscope

4. PREPARATION OF SPECIMEN

Basically preparation of specimen for optical microscopy is done by respective processes.

- Cut required part of specimen.
- Mount the specimen in mounting press.
- Grind the specimen as per to requirements.
- Polish the specimen.
- Etching.

5. COMPONENTS

- **Eyepiece (ocular lens):** It is a cylinder containing two or more lenses; its function is to bring the image into focus for the eye.
- **Objective turret** (or) revolver or revolving nose piece (to hold multiple objective lenses)
- **Objective lenses:** There will be around three objective lenses screwed. These arrangements are designed to be parfocal, which means that when one changes from one lens to another on a microscope, the sample stays in focus.
- **Diaphragm and condenser:** The condenser is a lens designed to focus light from the illumination source onto the sample.
- **Focus knobs** (to move the stage)
  - Coarse adjustment knob
  - Fine adjustment knob
- **Stage** (to hold the specimen)
- **Light source** (a light or a mirror)

6. WORKING

- The stage moves up and down when you turn a thumb wheel on the side of the microscope. By raising and lowering the stage, you move the lenses closer to or further away from the object you're examining, adjusting the focus of the image to see.
- The slide is held in place by two metal clips, one on either side.
- Light traveling up from the mirror passes through the glass slide, specimen, and cover slip to the objective lens (the one closest to the object). This makes the first magnification; it works by spreading out light rays from the specimen so they appear to come from a bigger object. The objective "lens" usually consists of more than one lens.
- A selection of other objective lenses can be used to magnify the specimen by more or less.
- The eyepiece lens (the one closest to your eye) magnifies the image from the objective lens, rather like a magnifying glass.

- On some microscopes, you can move the eyepiece up and down by turning a wheel. This gives you fine control or "fine tuning" of the focus.

7. MAGNIFICATION

- The maximum magnification power of optical microscopes is typically limited to around 1000x because of the limited resolving power of visible light.
- The magnification of a compound optical microscope is the product of the magnification of the eyepiece (say 10X) and the objective lens (say 100x), to give a total magnification of 1,000X.

8. ADVANTAGES

- Measuring microscopes are used for precision measurement.
- It is relatively easy to use.
- It is small and lightweight.
- It offers high levels of observational quality.
- It is unaffected by electromagnetic fields.
- It does not require radiation to operate.
- It requires very little training.
- It allow you to observe living organisms.
- It have a minor maintenance cost compared to other models.
- It can use fluorescent lights to display a sample visually.
- It is fully adjustable to the comfort level of the user.

9. DISADVANTAGES

- Resolution limit of optical microscopes .Due to diffraction, even the best classic optical microscope is limited to a resolution of 0.2 micro meters.
- Low magnification
- Separate sample Preparation
- Poor surface view
- Light microscopes cannot operate in darkness.
- Light microscopes cannot provide three-dimensional renderings.

10. APPLICATION

- Optical microscopy is used extensively in microelectronics, nanophysics, biotechnology, pharmaceutical research, mineralogy and microbiology.
- Optical microscopy is used for medical diagnosis.
- In industrial use, binocular microscopes are common.
- In certain applications, long-working-distance or long-focus microscopes are beneficial.
- An item may need to be examined behind a window, or industrial subjects may be a hazard to the objective.

4.6. ELECTRON MICROSCOPY

- An **electron microscope** is a microscope that uses a beam of accelerated electrons as a source of illumination.
- As the wavelength of an electron can be up to 100,000 times shorter than that of visible light photons, electron microscopes have a higher resolving power than light microscopes and can reveal the structure of smaller objects.

TYPES OF ELECTRON MICROSCOPE

- Transmission Electron Microscope
- Scanning Electron Microscope

4.6.1. SCANNING ELECTRON MICROSCOPE (SEM)

- A scanning electron microscope (SEM) uses a focused electro probe to extract structural and chemical information point by point on the specimen. It use wide range of scale from nanometer to micrometer.

1. PRINCIPLE

- A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons.
- The electrons interact with atoms in the sample, producing various signals that contain information about the surface topography and composition of the sample.

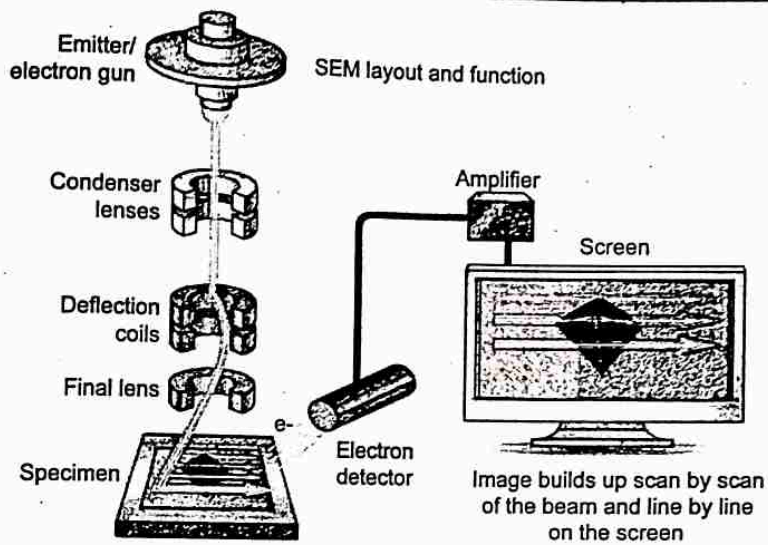


Fig. 4.3. Working nature of SEM

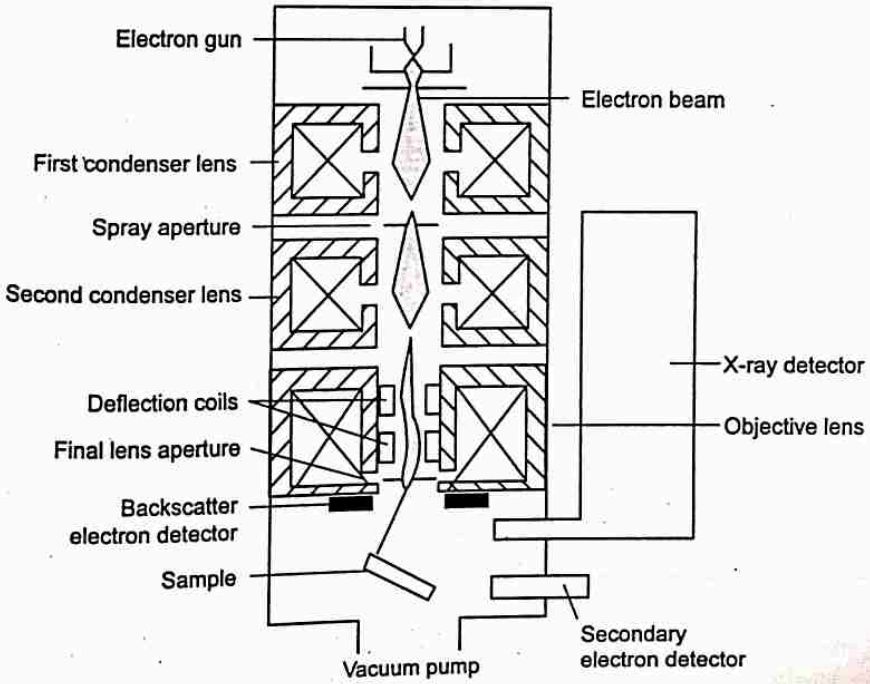


Fig. 4.4. Sectional view of SEM

2. COMPONENTS OF SEM

- **Electron gun:** It produces the high energy electron. Tungsten is normally used in guns because it has the highest melting point thereby allowing it to be electrically heated for electron emission, and its low cost.
- **Condenser lens:** It placed below electron gun. It is used to adjust the width (intensity) of the electron beam as per requirement. The main purpose is focusing the electron beam.
- **Vacuum chamber:** SEMs require a vacuum to operate. Without a vacuum, the electron beam generated by the electron gun would meet at constant interference from air particles in the atmosphere. The specimen chamber must be kept at a high vacuum of 10^{-3} to 10^{-4} Pa.
- **Deflector coils:** The scanning coils deflect the electron beam horizontally and vertically over the specimen surface. This is also called rastering.
- **Secondary electron detector:** A fluorescent substance (scintillator) is coated on the tip of the detector and a high voltage of about 10 kV is applied to it. The secondary electrons from the specimen are attracted to this high voltage and then generate light when they hit the scintillator. Then, the light is converted to electrons, and these electrons are amplified as an electric signal.
- **Image Display and Recording:** The output signals from the secondary electron detector are amplified and then transferred to the display unit.
- **Specimen stage** - The platform on which a specimen sits while being imaged.

3. CONSTRUCTION

- It consists of an electron gun. A magnetic condensing lens is used to condense the electron beam. The scanning coil is arranged in-between magnetic condensing lens and the sample.

4. SPECIMEN LOADING STAGES

- The specimen must meet the following requirements before it is loaded to the SEM stage:
  - Surface preparation
  - Mounting specimen
  - Specimen coating

(a) SURFACE PREPARATION

- **Fracturing-** When a specimen is a structural object, such as semiconductor device fracturing the specimen in this specific direction enables you to obtain a flat cross section.
- **Cutting-** If a specimen is soft like a polymer, it can be cut.
- **Mechanical polishing-** For many metal or mineral specimens, mechanical polishing is applied.
- **Milling by the ion beam-** A focused ion beam (FIB) system enables you to obtain a cross section with a high positional accuracy of a few hundreds of nanometers
- **Contrast enhancement-** Surfaces of cross sections are chemically or physically etched to form irregularity on the surface and internal structures are observed using secondary electron images.

(b) MOUNTING SPECIMEN

- **Bulk specimens-** Bulk specimens are fixed to the specimen mount by conductive paste or conductive double-sided adhesive tape. If a bulk specimen has a relatively uniform shape, it is clamped with an exclusive specimen holder.
- **Powders and particles-** These specimens are dusted on conductive paste or double-sided adhesive tape

(c) SPECIMEN COATING

- If a specimen is nonconductive, its surface needs to be coated with a thin metal film so that the surface has conductivity.

5. WORKING OF SEM

- In SEM an electron beam is emitted from an electron gun fitted with a tungsten filament cathode.
- The electron beam, which typically has an energy ranging from 0.2 keV to 40 keV, is focused by one or two condenser lenses to a spot about 0.4 nm to 5 nm in diameter.

- The beam passes through pairs of scanning coils or pairs of deflector plates in the electron column, which deflect the beam in the x and y axes so that it scans in a raster fashion (rectangular area) of the sample surface.
- When the primary electron beam interacts with the sample, the electrons lose energy by repeated random scattering and absorption.
- The energy exchange between the electron beam and the sample results in the reflection of high-energy electrons by elastic scattering, emission of secondary electrons, backscattered electrons and characteristic X-rays by inelastic scattering and the emission of electromagnetic radiation, each of which can be detected by specialized detectors.
- The beam current absorbed by the specimen can also be detected and used to create images of the distribution of specimen current.
- Electronic amplifiers of various types are used to amplify the signals, which are displayed as variations in brightness on a computer monitor.

6. OUTPUT-TYPES SCATTERED ELECTRONS

(a) X-RAYS

- X-rays, emitted from beneath the sample surface, can provide element and mineral information.

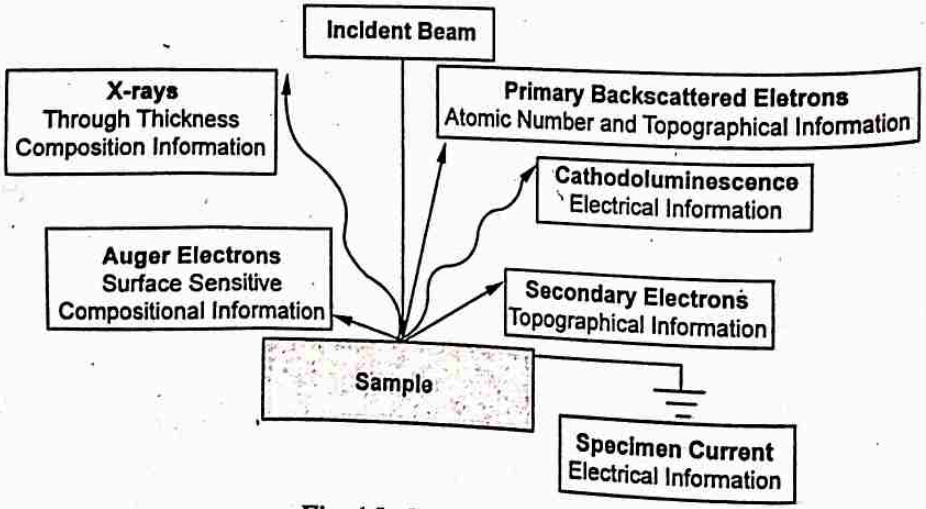


Fig. 4.5. Scattering Electrons

(b) SECONDARY ELECTRONS

- When the incident electron beam enters the specimen, secondary electrons are produced from the emission of the valence electrons of the constituent atoms in the specimen.
- Secondary electron image information used for surface morphology

(c) BACKSCATTERED ELECTRONS

- Backscattered electrons are those scattered backward and emitted out of the specimen, when the incident electrons are scattered in the specimen.
- This feature can be used to observe the topography of the surface.

7. MAGNIFICATION

- Magnification in an SEM can be controlled over a range of about 6X orders of magnitude from about 10 to 3,000,000 times.
- Magnification is therefore controlled by the current supplied to the scanning coils, or the voltage supplied to the deflector plates, and not by objective lens power.

8. APPLICATIONS

1. THE SEM ALSO EXCELS IN PRODUCING

- Detailed surface topography images
- Failure analysis
- Dimensional analysis
- Process characterization
- Reverse engineering
- Particle identification
- Surface 3D
- Elemental analysis

2. IDEAL USES

- High resolution surface topography images.
- Elemental microanalysis and particle characterization

9. ADVANTAGES

- Rapid, high-resolution imaging.

- Quick identification of elements present
- Excellent depth of field (~100X that of optical microscopy)
- Versatile platform that supports many other analysis techniques
- Low vacuum mode enables imaging of insulating and hydrated samples

10. LIMITATIONS

- Size restrictions may require cutting the sample.
- The size is not portable.
- SEMs are expensive and large.
- Maintenance involves keeping a steady voltage, currents to electromagnetic coils and circulation of cool water.
- SEMs are limited to solid, inorganic samples small enough to fit inside the vacuum chamber that can handle moderate vacuum pressure.
- SEMs carry a small risk of radiation exposure
- Training is required to operate.

4.6.2. TRANSMISSION ELECTRON MICROSCOPY (TEM)

- A **Transmission Electron Microscope** (TEM) utilizes energetic electrons to provide morphologic, compositional and crystallographic information on samples. The transmitted electrons that have passed through the thin sample are detected to form images, which is the reason to call it "transmission" electron microscopy.
- At a maximum potential magnification of 1 nanometer, TEMs are the most powerful microscopes.

1. PRINCIPLE

- An image is formed from the interaction of the electrons with the sample as the beam is transmitted through the specimen. The image is then magnified and focused onto an imaging device, such as a fluorescent screen, a layer of photographic film, or a sensor such as a scintillator attached to a charge-coupled device.

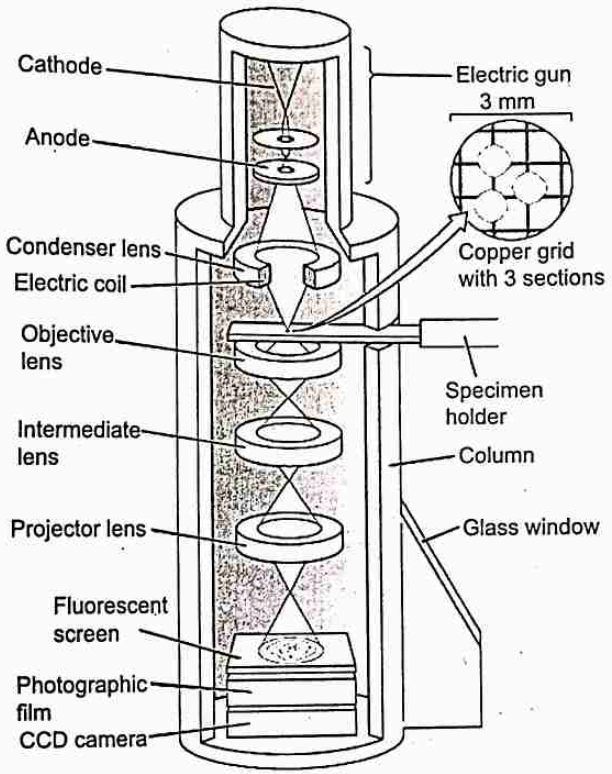


Fig. 4.6. Working of TEM

2. METHOD OF SPECIMEN PREPARATION

- **Ultra microtome:** Specimens must be very thin so that electrons are able to pass. This may be done by cutting very thin slices of a specimen's using an ultra-microtome.
- **Ultrasonic disk cutting:** For most electronic materials, it is a common sequence of preparation technique.
- **Dimpling**: Dimpling is a preparation technique that produces a specimen with a thinned central area and an outer rim of sufficient thickness to permit ease of handling.
- **Ion milling:** Ion milling is traditionally the final form of specimen preparation. In this process, charged argon ions are accelerated to the specimen surface by the application of high voltage. The ion impingement upon the specimen surface removes material as a result of momentum transfer.

- **Mechanical milling:** Mechanical polishing is also used to prepare samples for imaging on the TEM. A diamond, or cubic boron nitride polishing compound Polishing needs to be done to a high quality, to ensure constant sample thickness and to remove any scratches across the region of interest.
- **Chemical etching:** Certain samples may be prepared by chemical etching, particularly metallic specimens. These samples are thinned using a chemical etchant, such as an acid, to prepare the sample for TEM observation.
- **Ion etching:** Ion etching is a sputtering process that can remove very fine quantities of material. Ion etching uses an inert gas passed through an electric field to generate a plasma stream that is directed to the sample surface.
- **Replication:** It common use is for examining the fresh fracture surface of metal alloys.

3. CONSTRUCTION

- It consists of an electron gun. The specimen is placed in between the condensing lens and the objective lens. The magnetic projector lens is placed above the fluorescent screen.

4. COMPONENTS OF TEM

- **Electron Source** - The emission source or cathode, which may be a tungsten filament or needle. The gun is connected to a high voltage source (typically ~100 – 300 kV) and it emit electrons either by thermionic or field electron emission into the vacuum.
- **Electromagnetic lenses** - Electron lenses are designed to act similar like optical lens, by focusing parallel electrons at some constant focal distance. These focuses selected magnetic properties, such as magnetic saturation, hysteresis and permeability.
- **Vacuum chamber** - To increase the mean free path of the electron gas interaction, it is evacuated to low pressures, typically on the order of 10^{-4} Pa

- **Condensers** – Condensers consists of condenser lenses, the objective lenses, and the projector lenses. The condenser lenses are responsible for primary beam formation, while the objective lenses focus the beam that comes through the sample itself. The projector lenses are used to expand the beam onto the phosphor screen or other imaging device, such as film.
- **Sample stage** - Stage designs include specimen holder into the vacuum with minimal loss of vacuum in other areas of the microscope.

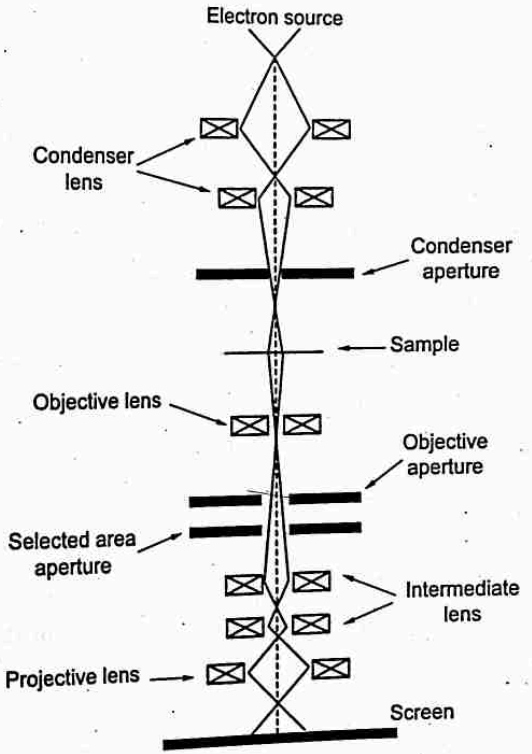


Fig. 4.7. Cross sectional view of TEM

- **Phosphor or fluorescent screen** - Imaging systems in a TEM consist of a phosphor screen, which may be made of fine (10 – 100 μm) particulate zinc sulfide, for direct observation by the operator and optionally an image recording system such as photographic film
- **Condenser lens** - The first electromagnetic lens that the electron beam encounters. Focuses the electrons onto the specimen.

- **Objective aperture** - A small laser-bored hole in a flat strip of molybdenum placed near the objective lens. Adjustment of this aperture strip can aid in adjustment of contrast of the image.

5. WORKING

- TEMs employ a high voltage electron beam in order to create an image.
- An electron gun at the top of a TEM emits electrons that travel through the microscope's vacuum tube.
- Rather than having a glass lens focusing the light, it employs an electromagnetic lens which focuses the electrons into a very fine beam.
- This beam then passes through the specimen, which is very thin (typically, sample thickness is less than 200 nm, depending on the composition of sample and the expected information from TEM characterization) and the electrons either scatter or hit a fluorescent screen at the bottom of the microscope.
- During transmission, the speed of electrons directly correlates to electron wavelength; the faster electrons move, the shorter wavelength and the greater the quality and detail of the image.
- An image of the specimen with its assorted parts shown in different shades according to its density appears on the screen. The image becomes visible when the electron beam hits a fluorescent screen at the base of the machine. This is analogous to the phosphor screen at the front of an old-fashioned TV.

6. OPERATION MODES OF TEM

- After interaction with the sample, on the exit surface of the specimen two types of electrons exist – unscattered (which will correspond to the bright central beam on the diffraction pattern) and scattered electrons (which change their trajectories due to interaction with the material).
- The two basic operation modes of TEM
  - Imaging mode
  - Diffraction mode

7. RESOLUTION

- TEMs can produce images with resolution down to 0.2nm. This resolution is smaller than the size of most atoms and therefore shows the true structural arrangement of atoms in the sample material.

8. LIMITATIONS

- Significant sample preparation time (1-4hrs)
- Small sampling volumes and samples are typically ~100nm thick.
- Some materials are not stable in the high energy electron beam
- TEMs are large and very expensive
- Laborious sample preparation
- Operation and analysis requires special training
- Samples are limited to those that are electron transparent, able to tolerate the vacuum chamber and small enough to fit in the chamber
- Images are black and white
- Electron microscopes are sensitive to vibration and electromagnetic fields and must be housed in an area that isolates them from possible exposure.
- A Transmission Electron Microscope requires constant upkeep including maintaining voltage, currents to the electromagnetic coils and cooling water.

9. ADVANTAGES

- The highest spatial resolution elemental mapping of any analytical technique (0.2nm (2Å) image resolution)
- Small area crystallographic information
- Strong contrast between crystalline vs amorphous materials without chemical staining.
- TEMs offer the most powerful magnification, potentially over one million times or more
- TEMs have a wide-range of applications and can be utilized in a variety of different scientific, educational and industrial fields
- TEMs provide information on element and compound structure

- Images are high-quality and detailed
- TEMs are able to yield information of surface features, shape, size and structure

10. APPLICATIONS

- Metrology at 0.2nm resolution
- Identification of nm-sized defects on integrated circuits, including embedded particles and via residues
- Determination of crystallographic phases at the nanometer scale
- Catalyst studies
- Nanometer scale elemental maps
- Super lattice characterization
- Crystal defect characterization (dislocations, grain boundaries, voids, stacking faults)
- Microstructure and nanostructure: size and morphology
- Crystal structure determination through electron diffraction
- Chemical information – composition and bonding (EDS, EELS) from single points, line scans or maps
- Energy filtered imaging (EFTEM)
- TEMs can be used in semiconductor analysis and production and the manufacturing of computer and silicon chips.
- Colleges and universities can utilize TEMs for research and studies.

4.6.3. COMPARISON BETWEEN SEM AND TEM

Table 4.4. Contrast Nature of SEM and TEM

Category	SEM	TEM
Source electrons	Scattered electrons	Transmitted electrons
Process of working	Scattering absorption	Diffraction
Energy	1-30kV	60-300kV

Category	SEM	TEM
Environment	Air/vacuum	Vacuum
Specimen thickness	Any thickness	Typically less than 150nm
Output	3D image formation	2D projection image of inner structure
Property identification	Roughness or contamination detection	Structural defects or impurities
Magnification	2 million level magnification	50 million level magnification.
Field of view	Large	Limited
Optimum resolution	0.4 nanometer resolution	0.5 angstroms resolution
Image formation	Electron are captured and countered by detector image on PC	Direct image on fluorescent screen or PC screen with LCD
Operation	Little sample preparation.	Laboratory sample preparation.
Amount of sample	Huge amount of sample	Minimum sample amount
Cost	Cost is low	Cost is 2 to 3 times higher than SEM
Sample usage	Invasive	Non-invasive, sample can used again

4.7. DIFFRACTION TECHNIQUES

4.7.1. DIFFRACTION

- Diffraction refers to various phenomena that occur when a wave encounters an obstacle or a slit. It is defined as the bending of waves around the corners of an obstacle or through an aperture into the region of geometrical shadow of the obstacle/aperture.

1. FUNDAMENTALS OF DIFFRACTION

- **Refraction** the change in direction of a wave passing from one medium to another caused by its change in speed.
- **Interference** the net effect of the combination of two or more wave trains moving on intersecting or coincident paths. The effect is that of the addition of the amplitudes of the individual waves at each point affected by more than one wave.
- **Reflection**, abrupt change in the direction of propagation of a wave that strikes the boundary between different mediums.
- **A diffraction grating** is an arrangement equivalent to a large number of parallel slits of equal widths and separated from one another by equal opaque spaces. They are two types reflection and transmission gratings.

2. DIFFRACTION PRINCIPLE

- **Bragg's law** is which determines the angles of coherent and incoherent scattering from a crystal lattice. When X-rays are incident on a particular atom, they make an electronic cloud move just like an electromagnetic wave.

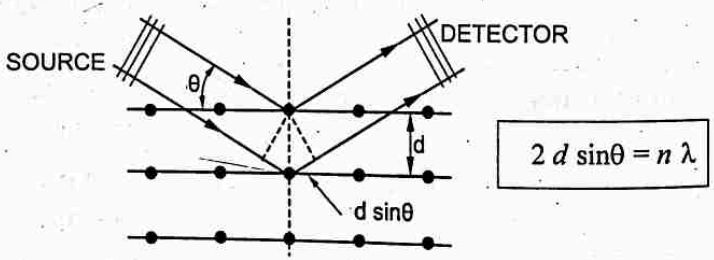


Fig. 4.8. Bragg's law

There are two conditions for constructive interference of waves:

1. The angle of incidence must equal the angle of reflection
2. The difference in path length must be an integral number of wavelengths

3. PATTERN OF DIFFRACTION

- **Fresnel's Diffraction:** Forms cylindrical wave front with source of screen at finite distance.

- **Fraunhofer diffraction:** Forms plane wave fronts with observation distance at infinite distance.

4. COMMON METHODS OF DIFFRACTION

1. Electron diffraction
2. Neutron diffraction
3. X-ray diffraction

5. FACTORS AFFECTING INTENSITY OF DIFFRACTION

1. Structure factor
2. Polarization factor
3. Lorentz factor
4. Multiplicity factor
5. Temperature factor
6. Absorption factor

6. ADVANTAGES, LIMITATION AND APPLICATION FOR COMMON METHODS OF DIFFRACTION

(a) ADVANTAGES

- Data generation is quick.
- Testing is cheap but equipment installation is costlier

(b) LIMITATION

- Sample preparation is complex.
- May have chance of absorption of radiation.
- Source is costlier.
- Most of diffraction method need vacuum.

(c) APPLICATION

- Diffraction methods offer a unique way to measure micro stresses in crystalline materials, because each phase will have its own diffraction pattern giving information on the stresses in that phase .
- It is also the measurement of changes in crystal plane spacing in different directions with respect to the specimen surface.

TERMS	X-RAY DIFFRACTION	NEUTRON DIFFRACTION	ELECTRON DIFFRACTION
ENERGY	❖ X-ray have energy, E=104 e V	❖ Neutrons have the energy, E =0.08 e V	❖ Electrons have the energy , E = 40 e V
ECONOMY	❖ X-ray is the cheapest the most convenient and widely used method.	❖ Neutron sources in the world are limited so neutron diffraction is a very special tool and very expensive.	❖ Electron beam can easily produce by cathode tube, and easily available.
INTERACTION	❖ X-rays interact with the spatial distribution of the valence electrons.	❖ Neutrons are scattered by the atomic nuclei through the strong nuclear forces.	❖ Electrons are charged particles and interact with matter through the Coulomb forces (positively charged atomic nuclei).
SCATTERING	❖ Atomic scattering power decreases as scattering angle increase.	❖ Atomic scattering power decreases as increases angle.	❖ Atomic scattering power is change erratically with angle.
METHODS	❖ 1. Powder Diffraction ❖ 2. Single-Crystal Diffraction	❖ 1.Nuclear Scattering ❖ 2.Magnetic Scattering	❖ 1. Diffraction/ Elastic Scattering ❖ 2. Inelastic Scattering

COMMON METHODS OF DIFFRACTION TECHNIQUES

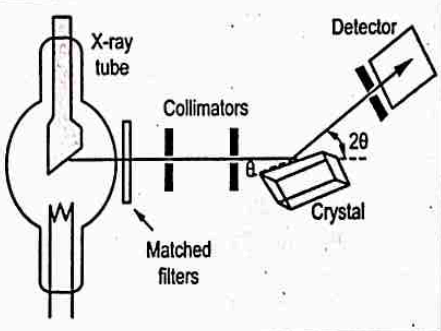
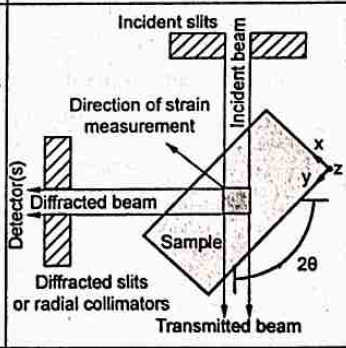
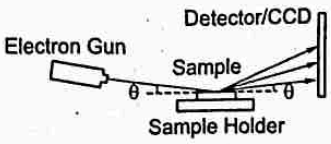
Table 4.5. methods of diffraction techniques

TERMS	X-RAY DIFFRACTION	NEUTRON DIFFRACTION	ELECTRON DIFFRACTION
DEFINITION	❖ X-ray diffraction (XRD) OR X-ray crystallography (XRC) is the determination of the atomic and molecular structure of a crystal, in which the crystalline structure causes a beam of incident X-rays to diffract into many specific directions. ❖ It produce a three-dimensional picture of the density of electrons within the crystal.	❖ Neutron diffraction or elastic neutron scattering is the application of neutron scattering to the determination of the atomic and/or magnetic structure of a material. ❖ A sample to be examined is placed in a beam of thermal or cold neutrons to obtain a diffraction pattern that provides information of the structure of the material.	❖ Electron diffraction is similar to X-ray diffraction (XRD) is the phenomenon resulting from the interaction between electrons and crystalline materials, producing a pattern of rings or spots that characterize the sample
WAVELENGTH	❖ Wavelength needed for crystal diffraction of the order of λ=1Å which is same size as an atom	❖ Wavelength needed for crystal diffraction of the order of λ = 2Å	❖ Wavelength needed for crystal diffraction of the order of λ = 1Å

TERMS	X-RAY DIFFRACTION	NEUTRON DIFFRACTION	ELECTRON DIFFRACTION
STRENGTHS	❖ Powerful and rapid (< 20 min) technique for identification of an unknown mineral ❖ Useful for unambiguous mineral determination ❖ Minimal sample preparation is required ❖ XRD units are widely available ❖ Data interpretation is relatively straight forward ❖ Measurement under atmosphere pressure. ❖ X-ray are not observed very much by air, so the specimen need not be in evacuated chamber	❖ Momentum transfer around interatomic distance ❖ Highly penetrating: measure bulk properties, can benefit from large samples, extreme sample environment (high/low temperature, magnetic field, pressure etc.,) ❖ Polarization is possible ❖ Neutrons interact with unpaired electrons. ❖ Magnetic structure and spin excitations can be studied	❖ Crystal cell symmetry ,cell parameters can be easily extracted from electron diffraction patterns ❖ Diffracted beam have high intensity. ❖ Can handle nano -size crystals. ❖ Small amount of material needed.
LIMITATIONS	❖ Gives better result only for homogeneous and single phase material	❖ Low intensity or resolution, large samples, and statistical noise.	❖ Sample size and preparation is tedious. ❖ The material must be less

TERMS	X-RAY DIFFRACTION	NEUTRON DIFFRACTION	ELECTRON DIFFRACTION
WORKING	❖ X-rays are generated in a cathode ray tube by heating a filament to produce electrons ❖ When electrons have sufficient energy to dislodge inner shell electrons of the target material, characteristic X-ray spectra are produced. ❖ As the sample and detector are rotated, the intensity of the reflected X-rays is recorded.	❖ The sample is placed within a neutron beam and the angles at which the neutrons are deflected or scattered by the material are recorded to generate a "diffraction pattern" from which structural information can be extracted.	❖ This experiment involves directing a beam of electrons through a carbon target, scattering the electrons, and analyzing the pattern produced on a luminescent screen.
ELEMENTS	❖ X-Ray Tube (Source) ❖ Sample Holder ❖ X-Ray Detector	❖ Neutron Generator ❖ Vacuum Pump. ❖ Sample Holder Quartz ❖ Detector	❖ The Electron Gun ❖ Carbon Target ❖ Luminescent Screen
			❖ 3. Small Angle Scattering ❖ 4.Reflectometry Diffraction

TERMS	X-RAY DIFFRACTION	NEUTRON DIFFRACTION	ELECTRON DIFFRACTION
	widely used for the identification of unknown crystalline materials (e.g. minerals, inorganic compounds). ❖ Determining lattice mismatch between film and substrate and to inferring stress and strain ❖ Determining dislocation density and quality of the film by rocking curve measurements ❖ Measuring super lattices in multilayered epitaxial structures ❖ Determining the thickness, roughness and density of the film using glancing incidence x-ray reflectivity measurements ❖ Make textural measurements, such as the orientation of grains, in a polycrystalline sample	structure ❖ Locating Light atoms ❖ Heavy atoms that absorb x-ray strongly ❖ Similar atomic no / Isotopes are studied ❖ Magnetic properties and single crystal study analysis	density

TERMS	X-RAY DIFFRACTION	NEUTRON DIFFRACTION	ELECTRON DIFFRACTION
	❖ Requires standard reference for inorganic compounds ❖ Requires tenths of a gram of material which must be ground into a powder. ❖ For mixed materials, detection limit is ~ 2% of sample ❖ Non-isometric crystal is complicated ❖ Peak overlay may occur	❖ Penetrating background hard to control and need large samples ❖ Some elements strongly absorb ❖ Hard to manipulate, accelerate, detect, etc.,	than 200 nm thick in order to pass the electron beam through. ❖ Observation of very small portion of the material.
			
APPLICATION	❖ X-ray powder diffraction is most	❖ Used for determination of	❖ It is used to assess the defect

4.8. SPECTROSCOPY TECHNIQUES

1. SPECTRUM

- Spectrum is a plot of the response as a function of wavelength or more commonly frequency.

2. SPECTROSCOPY

- Spectroscopy deals with the production, measurement, and interpretation of spectra arising from the interaction of electromagnetic radiation with matter.
- Spectroscopic methods are very informative and widely used for both quantitative and qualitative analysis.

3. SPECTROMETRY

- It is the measurement of these **Spectrum** responses and an instrument which performs such measurements is a spectrometer or spectrograph.

4. SPECTROPHOTOMETRY

- Spectrophotometry is a quantitative approach of measuring the relative energy i.e. emitted, transmitted or reflected in the visible or UV regions as a function of wave length or wave number.

5. ELECTROMAGNETIC SPECTRUM

- Electromagnetic radiation is a form of energy that is transmitted through space at enormous velocities. Electromagnetic radiation, or light, is described by the properties of both waves and particles nature.
- In dealing with phenomena such as reflection, refraction, interference, and diffraction, but electromagnetic radiation is conveniently modeled as waves.
- An electromagnetic wave is characterized by several fundamental properties, including its frequency, velocity, amplitude, phase angle, polarization, and direction of propagation.
- The entire electromagnetic spectrum, from the lowest to the highest frequency (longest to shortest wavelength), includes all **radio waves (e.g., commercial radio and television, microwaves, radar), infrared radiation, visible light, ultraviolet radiation, X-rays, and gamma rays.**

Nearly all frequencies and wavelengths of electromagnetic radiation can be used for spectroscopy.

Table 4.6. Distinct feature of electromagnetic radiation

Name of Spectroscopy	Type of Radiation used	Wavelength	Relative Energy	What it does to the molecule/atom	What it tells us about the atom/molecule
Photoelectron Spectroscopy	X-rays	0.01 to 10 nm	Very high	Removes core electrons	In Atomic structure, it gives information about how tightly the electrons are held by the nucleus
UV-visible Spectroscopy	Ultraviolet	50-400 nm	High	Excites valence electrons	Identify of a molecular element
UV-Visible Spectroscopy	Visible light	400 - 800 nm	Medium	Excites valence electrons	Concentration of a molecule
IR (vibrational) Spectroscopy	Infrared	2.5-50 μm	Low	Changes the vibrations in covalent bonds	Types of bonds/atoms/ functional groups within a molecule
Microwave (rotational) Spectroscopy	Microwave	0.3 mm - 0.5 m	Very low	Changes the rotations of the atoms in covalent bonds	Location of hydrogen atoms within a molecule

6. PRINCIPLE OF SPECTROSCOPY

- The beam of electromagnetic radiation onto a sample, and observe how it responds to such a stimulus. The response is usually recorded as a function of radiation wavelength. A plot of the response as a function of wavelength is referred to as a spectrum.

- The Beer-Lambert law states that the quantity of light absorbed by a substance dissolved in a fully transmitting solvent is directly proportional to the concentration of the substance and the path length of the light through the solution.

7. COMMON METHODS OF SPECTROSCOPY

- The method of Spectroscopy differ with respect to the species to be analyzed (such as molecular or atomic spectroscopy), the type of radiation–matter interaction to be monitored (such as absorption, emission, or diffraction), and the region of the electromagnetic spectrum used in the analysis.
- Spectroscopic methods based on the absorption or emission of radiation in the ultraviolet (UV), visible (VIS), infrared (IR), and radio (nuclear magnetic resonance, NMR)
- Each of these methods is distinct in that it monitors and different types of molecular or atomic transitions.

8. COMMON TYPE OF SPECTROSCOPY

- Ultraviolet-visible spectroscopy (UV-vis)
- Electron Spin Resonance spectroscopy
- Atomic spectroscopy
- Infrared spectroscopy and Raman spectroscopy
- Mass spectrometry
- Nuclear spectroscopy(nuclear magnetic resonance)

9. APPLICATION OF SPECTROSCOPIC ANALYSIS

- Understanding constitution of matter from atoms to complex molecules
- Studies on diverse materials existing in nature from deep sea studies to space missions
- Investigations of crime samples
- Analysis and development of whole range of man-made materials of human consumption
- Studies on environmental samples
- Mineralogy

10. ADVANTAGES OF SPECTROSCOPIC ANALYSIS

- Cure monitoring of composites using optical fibers.
- Estimate weathered wood exposure times using near infrared spectroscopy.
- Measurement of different compounds in food samples by absorption spectroscopy both in visible and infrared spectrum.
- Measurement of toxic compounds in blood samples
- Non-destructive elemental analysis
- Electronic structure research with various spectroscopes.
- Quantitative and qualitative analysis

11. DISADVANTAGES OF SPECTROSCOPIC ANALYSIS

- The radiation may be easily contaminated
- Cost of spectroscopy equipment is high.
- Not suitable for all kind of material.
- Need low working temperature at certain condition.

4.8.1. TYPES OF SPECTROSCOPY

4.8.1.1. ATOMIC SPECTROSCOPY OR FLAME SPECTROSCOPY

- Atomic spectroscopy is based upon the absorption or emission of electromagnetic radiation by atomic particles. Spectroscopic determination of atomic species can only be performed on a gaseous medium in which the individual atoms or elemental ions. This method is widely applied to a wide range of metals and nonmetals.
- Energy transitions of outer electrons of atoms after volatilization in a flame
- Liquid solution saimples are aspirated into a burner or nebulizer/burner combination, desolvated, atomized, and sometimes excited to a higher energy electronic state.
- Atomic spectroscopy is the study of the electromagnetic radiation absorbed and emitted by atoms.

1. PRINCIPLE

- The electrons of the atoms in the atomizer can be promoted to higher orbitals for a short amount of time by absorbing a set quantity of energy (i.e. Light of a given wavelength).

- This amount of energy is specific to a particular electron transition in a particular element, and in general, each wavelength corresponds to only one Element. This gives the technique its elemental selectivity.

2. TYPES

- **Absorption** - Light of a wavelength characteristic of the element of interest radiates through the atom vapor. The atoms absorb some of the light. The amount absorbed is measured.
- **Emission** - Sample is heated to excitation/ionization of the sample atoms. Excited and ionized atoms decay to a lower energy state through emission. Intensity of the light emitted is measured.
- **Fluorescence** – A short wavelength is absorbed by the sample atoms, a longer wavelength (lower energy) radiation characteristic of the element is emitted and measured.

3. COMPONENTS

- Lamp source - Hollow cathode lamp or diode laser source
- Nebulizer - The nebulizer forms a mist or aerosol of the sample; this is done by forcing the sample at high velocities through a narrow tube
- Atomizer- Atomize sample to atomic state
- Monochromator - Responsible for production of narrow band of radiation
- Detector - Photo sensitive element

Table 4.7. Comparative of AAS and AES

Activities	Atomic absorption spectroscopy	Atomic emission spectroscopy
Process measured	Absorption (light absorbed by unexcited atoms)	Emission (light emitted by exited atoms)
Use of flame	Atomization	Atomization and excitation
Instrumentation	Uses light source	Do not use light source (independent of light source)

4. CONSTRUCTION & WORKING

- The first step in all atomic spectroscopic procedures is atomization, a process in which a sample is volatilized and decomposed to produce gas-phase atoms and ions.
- Atomization is a critical step in all atomic spectroscopy. Several methods are used to atomize samples for atomic spectroscopic studies. E.g. inductively coupled plasmas, flames, and electro thermal atomizers; Flames and electro thermal atomizers are widely used in atomic absorption spectrometry, while the inductively coupled plasma is employed in optical emission and in atomic mass spectrometry.

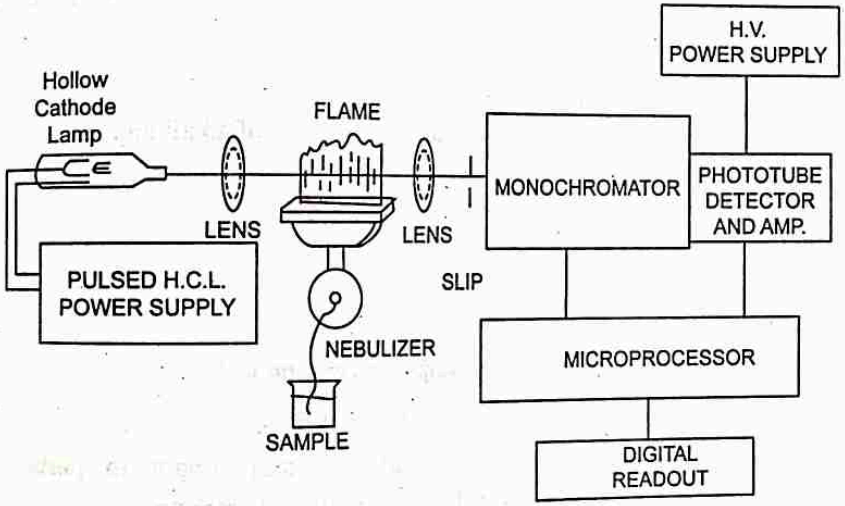


Fig. 4.9. Working of flame spectroscopy

- In the components of an atomic absorption or flame absorption apparatus, the flame can be considered to be a dilute gaseous solution of the atomized sample held in place by the aspirator-burner. Radiation from a suitable source is passed through the atomized sample and into the slit of a photometer or spectrophotometer.
- Radiation of specific wavelength is emitted by the hollow cathode lamp onto the gaseous atoms in the atomizer
- The monochromator focuses the specific wavelengths onto the detector.
- The detector finds the amount of light absorbed.
- The concentration of atoms in the sample is directly proportional to the absorbance.

5. APPLICATIONS

- Level of metals could be detected in tissue samples like Aluminum in blood and Copper in brain tissues
- Presence of metals as an impurity or in alloys could be found easily
- Determination of elements in the agricultural and food products
- Determination of lead in petrol
- Determination of calcium and magnesium in cement.
- AAS is an analytical technique used for the qualitative and quantitative
- Determination of the elements present in different samples like food, water and wastewater sample, nanomaterial, biomaterials, forensics (blood sample), and industrial wastes.
- Qualitative and quantitative analysis of metals.
- Emission techniques are for routine determination of alkali metals.

6. ADVANTAGES

- High sensitivity
- Easy to use
- Inexpensive
- The method of analysis is very simple and economical.
- It is quick, convenient, selective and sensitive analysis.
- Even very low concentrations (parts per million/ppm to parts per billion/ppb range) of metals in the sample can be determined.
- This method compensates for any unexpected interfering material present in the sample solution.
- This method can be used to estimate elements which are rarely analysed.

7. DISADVANTAGES

- Different cathode lamp for different elements
- Can detect only metals and some non-metals
- Only one element detected
- The elements such as carbon, hydrogen and halides cannot be detected due to their non-radiating nature.
- The accurate concentration of the metal ion in the solution cannot be measured.

- It cannot directly detect and determine the presence of inert gases.
- It does not provide the information about the molecular structure of the metal present in the sample.
- Only liquid samples may be used.

4.8.1.2. UV/VISIBLE SPECTROSCOPY

- UV-V is Spectrometry is based upon absorption of electromagnetic radiation in the visible and ultraviolet regions of the spectrum resulting in changes in the electronic structure of ions and molecules. The wavelength of UV and visible light are substantially shorter than the wavelength of infrared radiation. The UV–V is spectrum ranges from 200 to 700 nm. When a molecule or ion absorbs ultraviolet or visible radiation it undergoes a change in its valence electron transition.

1. PRINCIPLE

- Diminution of a beam of light after it passes through a sample or after reflection from a sample surface. Absorption measurements can be at a single wavelength or over an extended spectral range.
- Energy transitions of bonding and non-bonding outer electrons and molecules, usually delocalized electrons.

2. COMPONENTS

- Light Source - Tungsten filament lamps (or) Hydrogen-Deuterium lamps
- Monochromator- Monochromators generally is composed of prisms and slits. The radiation emitted from the primary source is dispersed with the help of rotating prisms. The various wavelengths of the light source which are separated by the prism are then selected by the slits such the rotation of the prism results in a series of continuously increasing wavelength to pass through the slits for recording purpose. The beam selected by the slit is monochromatic and further divided into two beams with the help of another prism.
- Detector-One of the photocell receives the beam from sample cell and second detector receives the beam from the reference.
- Recording devices- Computer stores all the data generated and produces the spectrum of the desired compound.

3. WORKING

- Polychromatic light from the source is focused on the entrance slit of a monochromator, which selectively transmits a narrow band of light. This light then passes through the sample area to the detector. The absorbance of a sample is determined by measuring the intensity of light reaching the detector without the sample (the blank) and comparing it with the intensity of light reaching the detector after passing through the sample.

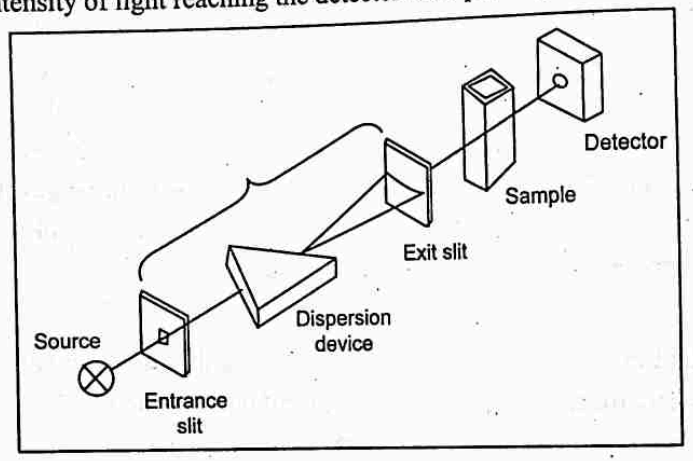


Fig. 4.10. Working of UV spectroscopy

4. APPLICATION

- Routine qualitative and quantitative measurement.
- Used to find relative purity of a solution.
- Widely applicability to both organic and inorganic compounds.

5. ADVANTAGES

- Minimum damage to sample.
- Better result at lower concentration.
- Very rapid calibration.
- High sensitivity
- Good accuracy

6. DISADVANTAGES

- Lack of sensitivity.
- Instrument is expansive.
- Have limited application to identify the functional group or particular molecule as a result of absorption spectra.

Table 4.8. Common methods of spectroscopy

Method	Definition & Principle of Working	Application	Advantages	Disadvantages
Infrared (IR) spectroscopy	❖ Infrared (IR) spectroscopy or vibrational spectroscopy is an analytical technique that takes advantage of the vibrational transitions of a molecule. ❖ When light impinges upon a molecule and interacts with the electron cloud & the bonds of that molecule. The incident photon excites the molecule einto a virtual state.	❖ NanoScale semiconductor analysis ❖ Identification of compounds ❖ Quantitative analysis ❖ Information regarding functional groups of molecules and constitution of molecules can be deduced from IR spectrum ❖ Qualitative analysis and fingerprinting of purified molecules of intermediate size.	❖ The crystalline structures can be obtained for smaller molecules ❖ Used for microscopic analysis ❖ Comparatively cheaper	❖ Molecular structures are too complex to study. ❖ The radiation deforms easily. ❖ The low operation temperature of 15 - 90 K. ❖ Lower ,sensitivity, because scattering effect is weaker ❖ Not suited for aqueous solutions. ❖ Sample preparation necessary

Mass spectroscopy	❖ The sample is converted to rapidly moving positive ions by electron bombardment and charged particles are separated according to their masses. ❖ Determination of the abundance of positively ionized molecules and fragments.	❖ Mainly used in research, but has high potential in metallurgy field. ❖ To find surface analysis of components.	❖ Small sample size. ❖ Fast method. ❖ Nondestructive ion detection. ❖ It does not absorb or emit light. ❖ High sensitivity.	❖ Difficult to non-volatile component. ❖ It does not provide structural information. ❖ Expansive equipment
Nuclear Magnetic Resonance spectroscopy	❖ The alignment (polarization) of the magnetic nuclear spins is applied in an constant magnetic field. ❖ Detection of magnetic moment associated with an odd number	❖ To study molecular physics, crystals and non-crystalline materials. ❖ Good choice for analyzing dangerous samples. ❖ The prediction results are provided to	❖ Easy to find 3d structure. ❖ The motion of domains can be examined. ❖ Used to find dielectric constant, the polarity and other properties.	❖ Not suitable for high molecular weight component. ❖ Very less resolving power. ❖ Cost of investigation increases with more accuracy .

	❖ Atomic vibrations involving a change in dipole moment and a change in polarizability, respectively.	❖ Mainly used in research. ❖ To detect explosives ❖ The technique is used is to study changes in chemical bonding ❖ To find crystallographic orientation of sample		
Electron Spin Resonance spectroscopy	❖ In this method, electron spins that are excited instead of the spins of atomic nuclei ❖ Detection of magnetic moment associated with unpaired electrons.	❖ Detection of changes in the environment of free radicals introduced into biological assemblies, e.g. membranes. ❖ EPR sspectroscopy is particularly useful for studying metal complexes or organic radicals	❖ It is highly specific. ❖ It is very sensitive. ❖ Less period of testing. ❖ Used for low concentration upto 1μM	❖ Not suitable for all materials ❖ For paramagnetic materials need low temperature

	of protons in an atomic nucleus.	control systems via analogue or digital outputs from the spectrometer.		
Spectrofluorimetry	❖ It is a type of electromagnetic spectroscopy which analyzes fluorescence from a sample. ❖ It involves using a beam of light, usually ultraviolet light, that excites the electrons in molecules of certain compounds and causes them to emit light of a lower energy ❖ Absorbed radiation emitted at longer wavelengths.	❖ Fluorescence spectroscopy is used in, among others, biochemical, medical, and chemical research fields for analyzing organic compounds.	❖ More sensitive at even low concentration. ❖ More precision is obtained. ❖ Applied even for non-fluorescent material.	❖ Not useful for all type of component. ❖ Contamination may happen in fluorescence.

4.9. ELECTRICAL AND MAGNETIC TECHNIQUES

4.9.1. ELECTRICAL TECHNIQUES

❖ Electrical properties are a key physical property of conducting materials. It is often necessary to accurately measure the resistivity of materials.

COMMON METHODS

❖ Dielectric strength
❖ Electrochemical Impedance Spectroscopy (EIS)
❖ Arc resistance
❖ EMF shielding test
❖ Two-probe method and four-probe method

4.9.1.1. ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY

❖ Electrochemical Impedance Spectroscopy (EIS) is a highly sensitive characterization technique used to establish the electrical response of chemical systems in a nondestructive manner. It is an electrochemical technique to measure the impedance of a system in dependence of the AC potentials frequency.

1. PRINCIPLE

❖ An electrochemical cell is used to house the chemical reaction and is electrically connected to the electrochemical spectrometer to obtain the electrical response of an electrolytic solution. EIS systems are operated using computer programs specifically designed for EIS testing. Therefore, prior to conducting an EIS experiment it is essential that all components of the system be attained.

2. COMPONENTS

❖ Three electrodes (working electrode, counter electrode, reference electrode)
❖ Electrolytic solution
❖ Insulating material
❖ Display unit

3. CONSTRUCTION AND WORKING

- EIS studies utilize a three electrode mode which is comprised of a working electrode (the sample material), a counter electrode (commonly graphite or platinum), and a reference electrode.
- While electrode geometries may vary the general experimental setup remains similar to the procedure outlined below.

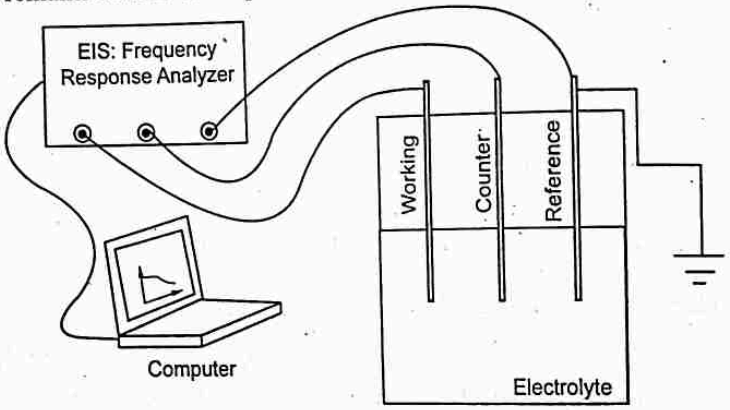


Fig. 4.11. Working of Electrochemical Impedance Spectroscopy (EIS)

- The three electrodes are mounted on an electrode stage and secured. The electrolytic solution is prepared and transferred to the sample container.
- A metallic sample container would provide additional pathways for electrons during experimentation leading to a reduction in the EIS current response as electrons move into the metal rather than the reference electrodes.
- Therefore, the sample container should be composed of an insulating material, such as glass or plastic, which will not interfere with the transfer of electrons during testing. The electrode mount is then placed on the sample container such that a portion of each electrode is submerged in the electrolytic solution.
- Four leads are used to attach the three electrodes to the EIS frequency response analyzer.
- A working lead and a counter lead is used to carry current, whereas the working sense lead and reference leads are used to sense voltage.

- The Electrochemical Impedance Spectroscopy (EIS) working sense lead connects the exposed end of the electrode to the EIS. The reference lead is attached to the reference electrode and the counter lead is connected to the counter electrode.
- The fourth lead is recommended to ground the system during testing. Once all leads are connected and by stimulus the data is collected from computer generated data.
- The impedance produced during electrochemical experimentation can be evaluated through use of one or more equivalent circuits.

4. ADVANTAGES

- Useful on high resistance materials such as paints and coatings.
- Time dependent data is available
- Non- destructive.
- Quantitative data available.
- Use service environments.

5. DISADVANTAGES

- Expensive.
- Complex data analysis for quantification.

6. APPLICATION

- It provides information about the corrosion kinetics and coatings evaluation.
- It is an accurate and reproducible technique suitable for highly resistive environments.
- It provides data about the electrochemical control mechanism, indicating if corrosion occurs by activation, concentration or diffusion.
- It characterizes the state of the rebar and the morphology of the corrosion.
- It allows for monitoring of the evolution of the passive or active state over time.

4.9.2. MAGNETIC TECHNIQUES

- Magnetic methods are potential methods for evaluation of surface manifestations such as microstructural degradation, residual stresses,

surface roughness and defect detection in surface coatings of magnetic substrates.

COMMON METHODS

- **Magnetic Adhesive Force Method:** Magnetic adhesive force method uses the distance dependency of the magnetic attractive force between a ferromagnetic substrate and a permanent magnet touching the surface of coating, which must be made from a non-magnetic material. Used to find holding power of magnet.
- **Magnetically Inductive Method:** Another popular method is the magnetically inductive method which is based on measuring the magnetic flux that passes through a non-ferro magnetic coating into a ferromagnetic substrate.
- **Magnetic Barkhausen Emission Method:** Magnetic flux perturbations and acoustic emissions are generated when an induced magnetic field is swept in a hysteresis loop in ferromagnetic materials. This is referred to as Magnetic Barkhausen Emissions (MBE). Surface characteristics such as hardness, residual stress and fatigue damage have been shown to influence Barkhausen activity and MBE technique is routinely used for evaluation of these characteristics both on production-line and in operating components.

4.9.3. ELECTROMAGNETIC TECHNIQUE

- Electromagnetic methods have very high potential for material characterization and well known nondestructive testing.
- Electromagnetic techniques are able to indicate nondestructively and quickly changes of residual stresses, texture, microstructure states, and mechanical properties, and are, therefore, very useful tools for materials characterization and damage assessment of in-service engineering components.

1. PRINCIPLE

- Magnetic hysteresis occurs when an external magnetic field is applied to a ferromagnetic such as iron and the atomic dipoles align themselves with it.

Even when the field is removed, part of the alignment will be retained: the material has become magnetized.

ELECTROMAGNETIC METHODS

- Magnetic Barkhausen noise
- Incremental permeability
  - Non-resonant Methods (transmission/reflection method)
  - Resonant Method
- Upper harmonics
- Incremental permeability

1. ADVANTAGES

- Nondestructive technique
- Used for Nano material characterization
- Immediate result.
- Accuracy in measurement of dielectric losses

2. DISADVANTAGES

- Limitation of lateral resolution.
- Need very thin samples
- Characterization limited to dielectric permittivity.
- Multiple steps
- Need technical knowledge
- Presence of air gaps may reduce the accuracy.

3. APPLICATIONS

- Used for purpose of finding micro structure, texture, hardness depth, phase content, residual stress, aging and grain size.

TWO MARK QUESTIONS WITH ANSWERS

1. ***Difference between microscopic and macroscopic observation.***

Microscopic Observation	Macroscopic Observation
Microscopic system is the one with objects or phenomena not visible with the naked eye and magnification instrument is necessary	**Macroscopic** system is the one with objects or phenomena visible with the naked eye and sometimes with magnifying instruments.
Scale of 1 to 100 nanometers and 1 to 1000 micro- meters	Scale of Millimeter to the kilometer scale
Needs very high magnification power	Needs very low magnification of 10x
The structural arrangement of atoms and bonds etc are observed	The appearance and physical arrangement is viewed by naked eye
This simple process can yield a large amount of information about the material such as ❖ The colour of the material ❖ Its lustre (does it display a metallic lustre) ❖ Its shape (whether it displays a regular, crystalline form) ❖ Its composition (is it made up of different phases) ❖ Its structural features (does it contain porosity) etc.	It is necessary because many of the properties of materials are dependent on extremely fine features and defects that are only possible to observe using one of the following techniques in this field.

2. ***Define magnification***

❖ Magnification on a microscope refers to the amount or degree of visual enlargement of an observed object or enlargement of image.

❖ Magnification is measured by multiples, such as 2x, 4x and 10x, indicating that the object is enlarged to twice as big, four times as big or 10 times as big, respectively.

Magnification = Image ÷ Object

3. ***Define resolution.***

❖ Resolution is defined as the ability to distinguish two very small and closely-spaced objects as separate entities.

❖ Resolution is determined by certain physical parameters that include the wavelength of light, and the light-gathering power of the objective and condenser lenses.

4. ***What are the types lenses used in microscope?***

❖ Objective lens

❖ Ocular lens (eyepiece)

❖ Condenser lens

5. ***Difference between optical and electron microscope.***

Optical Microscope	Electron Microscope
It uses the source of light.	The light source is replaced by a beam of very fast moving electrons
The minor work in specimen preparation	The specimen usually has to be specially prepared and held inside a vacuum air has been pumped out (because electrons do not travel very far in air).
Lens ,light source and reflective mirror is used	The lenses are replaced by a series of coil- shaped electromagnets through which the electron beam travels.
Low resolution and magnification (500x to 1000x)	High resolution and magnification (10000x app.)
Operation type is mechanical	Operation type is electrical
Relatively easy to carry and inexpensive	Relatively large and expensive

6. ***Give some common method of microscopic observation and macroscopic observation.***

Microscopic observation

- Optical Microscope
- Scanning Electron Microscope (SEM)
- Transmission Electron Microscope (TEM)
- Field Ion Microscope
- Scanning Tunneling Microscope

Macroscopic observation

- Mechanical testing, including tensile, compressive, torsional, creep, fatigue, toughness and hardness testing
- Differential thermal analysis
- Dielectric thermal analysis

7. ***Write major contrast between SEM and TEM***

Category	SEM	TEM
Source electrons	Scattered electrons	Transmitted electrons
Process of working	Scattering absorption	Diffraction
Energy	1-30kV	60-300kV
Environment	Air/vacuum	Vacuum
Specimen thickness	Any thickness	Typically less than 150nm
Output	3D image formation	2D projection image of inner structure
Magnification	2 million level magnification	50 million level magnification.
Image formation	Electron are captured and countered by detector image on PC	Direct image on fluorescent screen or PC screen with LCD
Amount of sample	Huge amount of sample	Minimum sample amount

8. ***Write principle of SEM and TEM***

- A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning the surface with a focused beam of electrons.
- In **TEM,** an image is formed from the interaction of the electrons with the sample as the beam is transmitted through the specimen. The image is then magnified and focused onto an imaging device, such as a fluorescent screen, a layer of photographic film, or a sensor such as a scintillator attached to a charge-coupled device.

9. ***Why specimen preparation is important in microscopic technique.***

- Specimen preparation is important in any microscopic technique with proper preparation methods facilitating examination and interpretation of microstructural features.
- Improper preparation methods may obscure features, and even create artifacts that may be misinterpreted.

10. ***State the uses of scattered electrons in TEM .***

- **X-rays**-element and mineral information.
- **Secondary Electrons**-Secondary electron image for surface morphology
- **Backscattered Electrons**-This feature can be used to observe the topography of the surface.

11. ***State Difference between Diffraction and Inference.***

Inference	Diffraction
Interference is due to the super position of two different waves from coherent source	Diffraction is super position of secondary wavelets
Fringes width is constant	Fringes width are vary
Have same intensity	Have varying intensity

12. ***State Diffraction Principle.***

- **Bragg's law** is which determines the angles of coherent and incoherent scattering from a crystal lattice. When X-rays are incident on a particular atom, they make an electronic cloud move just like an electromagnetic wave.

13. ***Write the methods of Diffraction.***

1. Electron diffraction
2. Neutron diffraction
3. X-ray diffraction

14. ***Define spectroscopy.***

- Spectroscopy deals with the production, measurement, and interpretation of spectra arising from the interaction of electromagnetic radiation with matter.
- Spectroscopic methods are very informative and widely used for both quantitative and **qualitative analyses.**

15. ***What are the methods of Spectroscopy?***

- Ultraviolet-visible spectroscopy (UV-vis)
- Electron Spin Resonance spectroscopy
- Atomic spectroscopy
- infrared spectroscopy and Raman spectroscopy
- Mass spectrometry
- Nuclear spectroscopy(nuclear magnetic resonance)

16. ***Difference between Raman and IR spectroscopy.***

Raman spectroscopy	Infrared spectroscopy
It is due to the scattering of light by vibrating molecules	It is the result of absorption of light by vibrating molecules.
The vibration is active if it causes to change in polarizability	The vibration is active if it causes to change in dipole moment
The molecule need not possess a permanent dipole moment	The vibration concerned change in dipole moment due to vibration
Water can be used as solvent	Water cannot be used as intense absorption of IR
Sample preparation is not elaborate. Any state of sample is used	Sample preparation is elaborate. Gaseous sample can be rarely used. It diffused in

Raman spectroscopy	Infrared spectroscopy
Gives an indication of covalent character of molecule	Gives an ionic character in the molecule
Cost of instrument is high	Comparatively inexpensive
Weak in intensity	Strong in intensity
Optical system: Glass, quartz	Optical system: NaCl, KBr
Record by using a beam of monochromatic radiation	Record by using a beam of radiation having a large number of frequencies

17. ***Write about types in IR spectroscopy.***

There are four types of instruments for infrared absorption measurements available:

- Dispersive grating spectrophotometers for qualitative measurements .
- Non dispersive photometers for quantitative determination of organic species in the atmosphere .
- Reflectance photometers for analysis of solids .
- Fourier transform infrared (FT-IR) instruments for both qualitative and quantitative measurements.

18. ***Write about sample preparation in IR spectroscopy.***

- Sampling techniques for IR spectroscopy
- Gas sample - In sample tube of 10 cm length fitted with IR transparent holder
- Liquids - The think film formed between NaCl plates
- Solid - Pellet or as a Nujol mull (Nujol is a viscous mineral oil (hydrocarbon)) in which the solid is finely suspended

19. ***Write objectives of material characterization.***

- To measure accurately the physical properties of materials
- To measure accurately the chemical properties of materials
- To determine accurately the structure of a material at atomic and microscopic level structures

20. *Define scale.*

- The scale of the structures observed in materials characterization ranges from angstroms, such as in the imaging of individual atoms and chemical bonds, up to centimeters, such as in the imaging of coarse grain structures in metals.

REVIEW QUESTIONS

1. Explain various methods of microscopic technique with neat sketch.
   Ans: Section No. 4.3 **Page No:** 4.4
2. Explain SEM with principle of working.
   Ans: Section No. 4.6.1 **Page No:** 4.14
3. Write about advantages and limitation of TEM.
   Ans: Section No. 4.6.2 **Page No:** 4.25
4. What is optical microscope and how it is working?
   Ans: Section No. 4.5 **Page No:** 4.9
5. Write short note on various method of sample preparation in SEM and TEM.
   Ans: Section No. 4.6 **Page No:** 4.17, 4.21
6. Write comparison between X ray diffraction and electron diffraction.
   Ans: Section No. 4.7 **Page No:** 4.30
7. Explain diffraction techniques with principle of working.
   Ans: Section No. 4.7 **Page No:** 4.28
8. How spectroscopy is working with different principles of electromagnetic radiation?
   Ans: Section No. 4.8 **Page No:** 4.39
9. Write short note on
   (*a*) IR spectroscopy
   (*b*) UV spectroscopy
   (*c*) Mass spectroscopy
   Ans: Section No. 4.8 **Page No:** 4.45
10. Explain in detail about electrical and magnetic techniques.
    Ans: Section No. 4.9 **Page No:** 4.49

❑❑

UNIT V

OTHER TESTING

SYLLABUS

Thermal Testing: Differential scanning calorimetry, Differential thermal analysis. Thermo- mechanical and dynamic mechanical analysis: Principles, Advantages, Applications. Chemical Testing: X-Ray Fluorescence, Elemental Analysis by Inductively Coupled Plasma-Optical Emission Spectroscopy and Plasma-Mass Spectrometry.

5.1. OVERVIEW

- **Materials testing**, measurement of the characteristics and behaviour of such substances as metals, ceramics, or plastics etc. under various conditions.
- Investigators may construct mathematical models that utilize known material characteristics and behaviour to predict capabilities of the structure.

Materials testing breaks down into major categories

- Mechanical testing & Non destructive testing
  - Testing for physical & chemical properties
  - Testing for thermal properties
  - Testing for electrical properties
  - Testing for resistance to corrosion, Radiation and Biological deterioration

5.2. THERMAL ANALYSIS

- Thermal analysis is a form of analytical technique most commonly used in the branch of materials science where changes in the properties of materials are examined with respect to temperature.

- It is a group of techniques in which changes of physical or chemical properties of the sample are monitored against time or temperature, while the temperature of the sample is programmed.
- The temperature program may involve heating or cooling at a fixed rate, holding the temperature constant (isothermal), or any sequence of these.
- The sample is subjected to a predefined heating or cooling program.
- The sample is usually in the solid state and the changes that occur on heating include melting, phase transition, sublimation, and decomposition.

5.2.1. THERMAL PROPERTIES

- Thermal properties of material decide how it reacts when it is subjected to heat fluctuation (excessive heat or very low heat, for example). The major thermal properties are described in table 5.1.

Table 5.1. Thermal properties

S. No	Properties	Description
1.	Thermal conductivity	It is determining temperatures as a function of time along the length of a bar or across the surface
2.	Specific heat	It is defined as heat absorbed per unit mass per degree change in temperature
3.	Thermal expansion	Expansion due to heat is usually measured in linear fashion as the change in a unit length of a material caused by a one-degree change in temperature.
4.	Thermal stress	The stress experienced by a body due to either thermal expansion or contraction is called thermal stress.
5.	Thermo-Elastic Effect	When a solid is subjected to a load, work is done on it and it changes in volume. This will appear in the form of rise of temperature of solid when it is in stretched. Similarly when the solid is rapidly relaxed, it will cool. This warming or cooling phenomenon is called thermo elastic effect.

S. No	Properties	Description
6.	Thermal Shock	The ability of material to withstand thermal stresses due to sudden and severe changes in the temperature at the surface of a solid body.
7.	Melting point or heat resistance	Melting point or softening point is a significant temperature level as it represents transition point between solid and liquid phases.
8.	Emissivity of Materials	The emissivity (ε) of the surface of a material is its effectiveness in emitting energy as thermal radiation and varies between 0.0 and 1.0.
9.	Latent Heat of Fusion of Materials	Latent heat is the amount of heat added to or removed from a substance to produce a change in phase.
10.	Latent Heat of Vaporization of Materials	Certain amount of energy is involved in this change of phase, When a material changes phase from solid to liquid or from liquid to gas.

5.2.2. THERMAL TESTING

- Thermal Testing involves testing a product at the extremes of its intended use thermal environment for heating rate, temperature and airflow or gaseous atmosphere or vacuum with measuring case temperatures on individual components to determine the effect on product performance and long-term reliability.
- It measures based on dynamic relationships between temperature, Mass, Volume and Heat of reaction.

Major methods of Thermal testing,

- Differential thermal analysis
- Dilatometer
- Differential scanning calorimetry
- Dynamic mechanical analysis
- Thermogravimetric analysis

- Thermo mechanical analysis
- Thermo optical analysis

Other common methods of thermal methods

- Dielectric thermal analysis
- Evolved gas analysis
- Laser flash analysis
- Derivatography

Table 5.2. Parameters of thermal testing

S.No	Method	Parameter testing
1.	Thermogravimetric Analysis	Mass changes
2.	Differential Thermal Analysis	Temperature Difference
.3.	Differential Scanning Calorimetry	Heat Difference
4.	Evolved Gas Analysis	Gas Decomposition
5.	Thermo Mechanical Analysis	Deformation And Dimension
6.	Dilatometer	Volume
7.	Dielectric thermal analysis	Electrical properties
8.	Thermo optical analysis	Optical properties

5.2.3. THERMOGRAVIMETRIC ANALYSIS (TGA)

- The Thermogravimetric analysis (TGA) is a type of thermo analytical testing performed on materials to determine changes in weight in relation to changes in temperature.
- The TGA relies on a high degree of precision in three measurements: weight, temperature and temperature change.
- The TGA is commonly employed in research and testing to determine characteristics of materials, to determine degradation temperatures, absorbed moisture content of materials, the level of inorganic and organic components in materials, decomposition points of explosives and solvent residues.

5.2.4. DIFFERENTIAL SCANNING CALORIMETRY

- DSC measures the energy absorbed or released from a sample as a function of time or a temperature profile.
- DSC is useful to make the measurements for melting points, heats of reaction, glass transition, and heat capacity

1. PRINCIPLE

- Differential scanning calorimetry (DSC) is based on the principle; sample and reference are maintained at the same temperature, even during a thermal event (in the sample). The energy required maintaining zero temperature different between the sample and the reference is measured.
- By calibrating the standard material(reference material), the unknown sample quantitative measurement is achievable.

2. TYPES

There are four different types of DSC instrument

- Heat flux DSC
- Power compensated DSC
- Modulated DSC
- Hyper DSC
- Pressure DSC

The most common methods are Heat flux DSC and Power compensated DSC

3. POWER COMPENSATION DSC

- A technique in which difference of thermal energy that is applied to the sample and the reference material separately per unit of time is measured as a function of the temperature.

(a) Components

- Separate sensors and heaters are used for the sample and reference
- **Sample holder:** Al or Platinum pans
- **Sensors:** Platinum resistance thermocouples
- **Furnace:** Separate blocks for sample and reference cells

- **Temperature controller:** Differential thermal power is supplied to the heaters to maintain the temperature of the sample and reference at the program value

(b) Working

- The power needed to maintain the sample temperature equal to the reference temperature is measured.
- In power compensation DSC two independent heating units are employed.
- These heating units are quite small, allowing for rapid rates of heating, cooling and equilibration. The heating units are embedded in a large temperature- controlled heat sink.
- The sample and reference holders have platinum resistance thermometers to continuously monitor the temperature of the materials.
- The instrument records the power difference needed to maintain the sample and reference at the same temperature as a function of the programmed temperatures.
- Power compensated DSC has lower sensitivity than heat flux DSC, but its response time is more rapid. It is also capable of higher resolution then heat flux DSC .
- This makes power compensated DSC well suited for kinetics studies in which fast equilibrations to new temperature settings are needed.

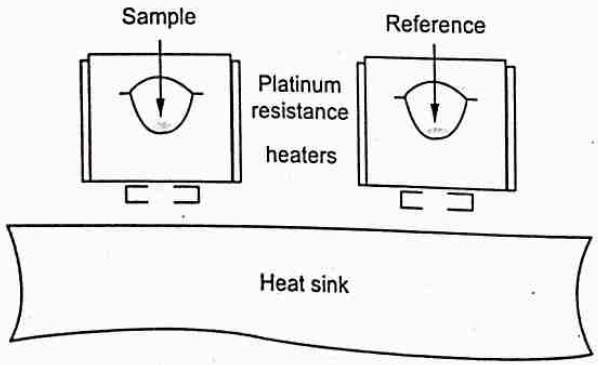


Fig. 5.1. Typical arrangement of Power compensated DSC

4. HEAT FLUX DSC

- In heat flux DSC, the difference in heat flow into the sample and reference is measured while the sample temperature is changed at the constant rate
- Sample and reference are connected by a low resistance heat flow path (a metal disc).The assembly is enclosed in a single furnace.

(a) Components

One blocks for both sample and reference cells

- **Sample holder:** Sample and reference are connected by a low- resistance heat flow path.Al or Platinum pans placed on constantan disc.
- **Sensors:** Chromel alumel thermocouples Furnace are used.

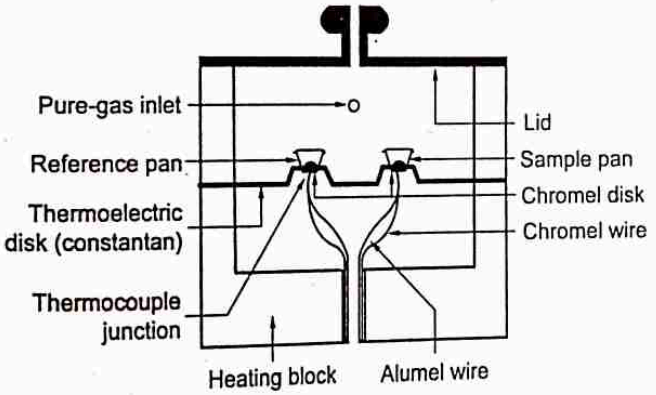


Fig. 5.2. Typical arrangement of heat flux DSC

(b) Working

- The main assembly of the DSC cell is enclosed in a cylindrical, silver heating black, which dissipates heat to the specimens via a constantan disc which is attached to the silver block.
- The disk has two raised platforms on which the sample and reference pans are placed.
- A chromel disk and connecting wire are attached to the underside of each platform, and the resulting chromel-constantan thermocouples are used to determine the differential temperatures of interest.

- Alumel wires attached to the chrome discs provide the chromel-alumel junctions for independently measuring the sample and reference temperature.

5. DSC MEASURES

- Glass transitions
- Melting and boiling points
- Crystallization time and temperature
- Percent crystallinity
- Heats of fusion and reactions
- Specific heat capacity
- Oxidative/thermal stability
- Reaction kinetics
- Purity

6. DSC Curve

- DSC Curve is plot between heat flow and temperature. It shows various peaks of measurement

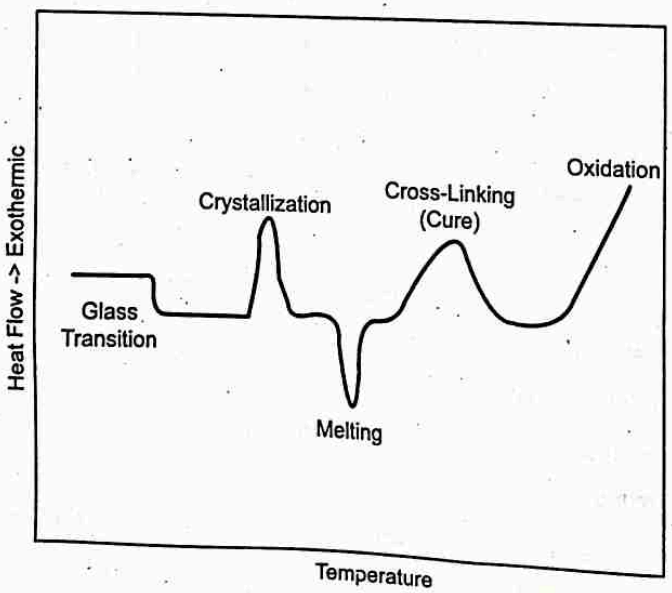


Fig. 5.3. DSC Curve

Factors Affecting DSC Curve

Table 5.3. Factors Affecting DSC Curve

Instrumental Factors	Sample Characteristic Factors
❖ Furnace heating rate ❖ Recording or chart speed ❖ Furnace atmosphere ❖ Geometry of sample holder/location of sensors ❖ Sensitivity of the recording system ❖ Composition of sample containers	❖ Amount of sample ❖ Nature of sample ❖ Sample packing ❖ Solubility of evolved gases in the sample ❖ Particle size ❖ Heat of reaction ❖ Thermal conductivity

7. APPLICATION OF DSC

- To observe fusion and crystallization events as well glass transition temperature
- To study oxidation, as well as other chemical reactions
- The transition from amorphous to crystalline is known.
- The ability to determine transition temperature and enthalpies.
- Rapid optimization of purification and manufacturing conditions

8. SOURCES OF ERRORS

- Calibration
- Contamination
- Sample preparation - how sample is loaded into a pan
- Residual solvents and moisture.
- Thermal lag
- Heating/Cooling rates
- Sample mass

9. ADVANTAGES OF DSC

- Instruments can be used at very high temperatures

- Instruments are highly sensitive
- Flexibility in sample volume/form
- Characteristic transition or reaction temperatures can be determined
- High resolution obtained
- High sensitivity
- Stability of the material.

10. LIMITATIONS OF DSC

- DSC generally unsuitable for two-phase mixtures
- Difficulties in test cell preparation in avoiding evaporation of volatile Solvents
- DSC is generally only used for thermal screening of isolated intermediates and products
- Does not detect gas generation
- Uncertainty of heats of fusion and transition temperatures

5.2.5. DIFFERENTIAL THERMAL ANALYSIS

- Differential thermal analysis (DTA) is a thermo-analytical technique which is used for thermal analysis where thermal changes can be studied. It is used to determine the oxidation process, decomposition, and loss of water or solvent.

1. PRINCIPLE

- In DTA, the sample material and an reference material are made to undergo identical thermal cycles, (i.e., same cooling or heating programme) while recording any temperature difference between sample and reference. This differential temperature is then plotted against time, or against temperature (DTA curve, or thermogram). Changes in the sample, either exothermic or endothermic, can be detected relative to the inert reference.

2. COMPONENTS

- **Furnace** - This is device for heating the sample(Nickel and chromium alloy furnace)

- **Sample holder** - This is used to contain the sample as well as the reference material (Platinum alloy holder)
- **DC amplifier** - Generally a low level DC amplifier is employed.
- **Differential Temperature Detector (Thermogram)** - The function of this detector is to measure differential temperature.
- **Furnace Temperature Programme** - The main function of this is to increase the temperature of the furnace at a steady rate.
- **Recorder** - This is to record the DTA curve(automatic electronic recorder)
- **Control Equipment**- Its function is to maintain a suitable atmosphere in the furnace & sample holder.

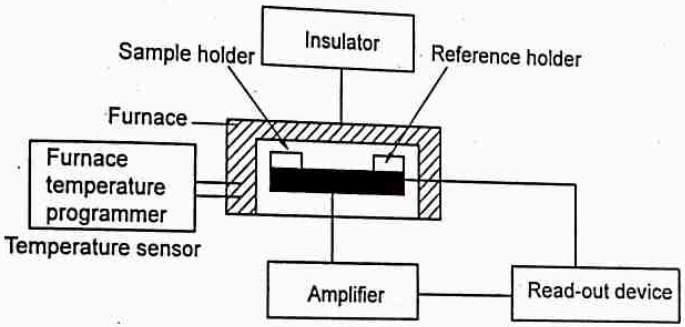


Fig. 5.4. Cross section of DTA

3. WORKING

- The sample under investigation is loaded into a container.
- This container is then placed onto the sample pan and it is marked as S (means sample). Same quantity of reference sample is placed in another container which is then placed onto the reference pan and it is marked as R (means reference).
- In order to heat the sample pan and the reference pan at an identical rate, the dimensions of these two pans should be nearly identical; moreover, the sample and the reference should have equal weights, thermally matched and should be arranged symmetrically with the furnace.
- The metal block which surrounds the pans acts as a heat sink whose temperature is increased slowly by using an internal heater.
- The sink then heats the sample and reference material simultaneously.

- Two pairs of thermocouples are used, one pair is in contact with the sample and the second pair is in contact with the reference.
- Thermocouple is attached with an amplifier which amplifies the result of differential thermocouple and sent this result to the read-out device which displays the results in the form of DTA curve or thermogram as a function of the sample temperature, reference temperature or time.
- No signal is generated if no temperature difference is observed even though the actual temperatures of both the sample and reference are increasing.
- When there is a physical change in the sample then heat is absorbed or released. For example, when a metal carbonate is decomposed then carbon dioxide is released. This is an endothermic reaction where the heat is absorbed and the temperature of the sample is decreased. Now the sample is at a lower temperature than that of the reference. This temperature difference between sample and reference produces a net signal, which is then recorded.

4. DTA Curve

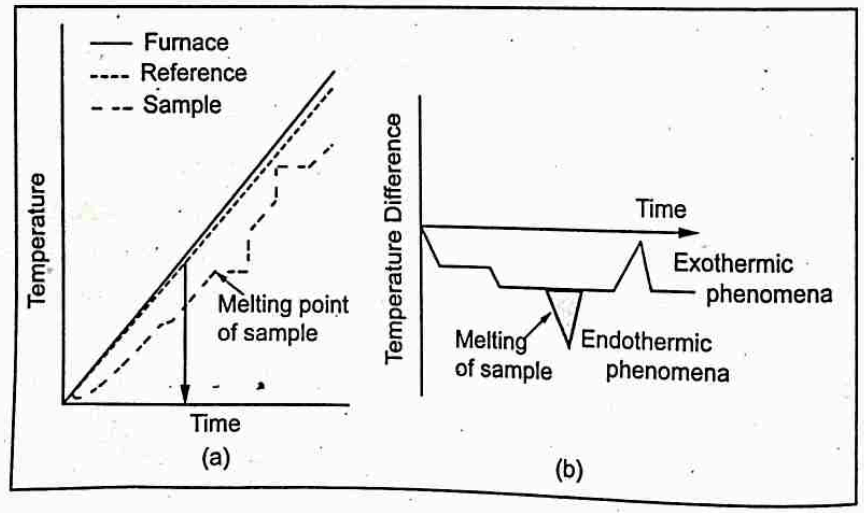


Fig. 5.5. (a) The DTA curve or thermo gram is a plot between differential temperature and Time. (b) DTA curve may be endothermic (downward plot) or exothermic (upward plot).

Factors affecting DTA curve

Table 5.4. Factors affecting DTA curve

Sample factors	Instrumental factors	Physical factors
❖ Amount of the sample. ❖ Packing density. ❖ Particle size of the sample material. ❖ Degree of crystallinity. ❖ Heat capacity. ❖ Thermal conductivity. ❖ Dilutes of the diluents. ❖ Swelling of the sample. ❖ Shrinkage of the sample.	❖ Size or shape of the holders. ❖ Material of the sample holder. ❖ Recording system sensitivity. ❖ Rate of heating of the sample. ❖ Atmosphere around the sample. ❖ Thermocouple location in the sample. ❖ Instrumental design.	❖ Adsorption. ❖ Change in the crystal structure. ❖ Crystallization. ❖ Desorption. ❖ Change in the crystal structure. ❖ Vaporization. ❖ Sublimation. ❖ Melting.

5. ADVANTAGES

- It can be operated at very high temperature ranges.
- Highly sensitive technique.
- Flexibility in crucible volume
- Both exothermic and endothermic reactions can be determined accurately.

6. DISADVANTAGES

- There is lot of uncertainty in transition reactions and heat of fusions upto 20-50%
- Destructive limited range of samples time consuming usually not qualitative.

7. APPLICATIONS

- Used to identify the minerals both qualitatively and quantitatively.
- Rapid identification of the compositions of mixed clays
- Polymers characteristics can be easily characterized.
- Degree of crystallinity can be measured.
- Degree of polymerization can be assessed.
- Many of the biological materials can be analyzed.
- DTA offers a wide spectrum of useful investigations related to reaction kinetics, polymerization, solvent retention, phase-transformations, solid-phase reactions and curing or drying properties of a product
- Melting point, boiling point, and temperatures of decomposition of organic compounds can be determined.
- Have wide applications for the quality control (QC) of many substances such as soil, cement, glass, etc.
- Also used to determine the thermal stability of many inorganic compound s and complexes.

5.2.6. THERMO- MECHANICAL ANALYSIS

- A technique in which a deformation of the sample under non-oscillating stress is monitored against time or temperature while the temperature of the sample, in a specified atmosphere, is programmed. Thermo mechanical analysis (TMA) easily and rapidly measures sample displacement (growth, shrinkage, movement, etc.) as a function of temperature, time and applied force.

1. PRINCIPLE

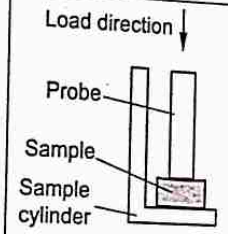
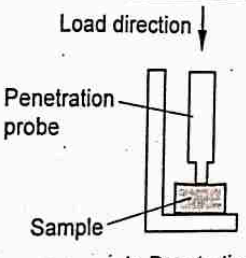
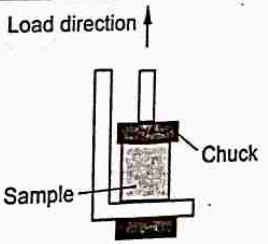
- Thermo mechanical analysis (TMA) is used to measure the dimensional changes of a material as a function of temperature by applying stress. The stress may be compression, tension, flexure or torsion.

2. COMPONENTS

- Transducer (Linear Variable Displacement Transducer (LVDT) , laser , optoelectronic etc.,

- Probe (made up of quartz glass)
- Thermocouple Furnace
- Force generator

3. PROBES ON DIFFERENT LOADING CONDITION

Loading Condition	Load Application	Purpose
(a) Expansion / Compression Probe	 a. Expansion/Compression	It is used for the measurement of the deformation by the thermal expansion and the transition of the sample under the compressed force is applied.
(b) Penetration Probe	 b. Penetration	It is used for the measurement of the softening temperature.
(c) Tension Probe	 c. Tension	It is used for the measurement of the thermal expansion and the thermal shrinkage of the sample such as the film and the fiber.

4. CONSTRUCTION AND WORKING

- The sample is inserted into the furnace and is touched by the probe which is connected with the Length Detector and the Force Generator. The construction of the pushrod and sample holder depends on the mode of the measurements.

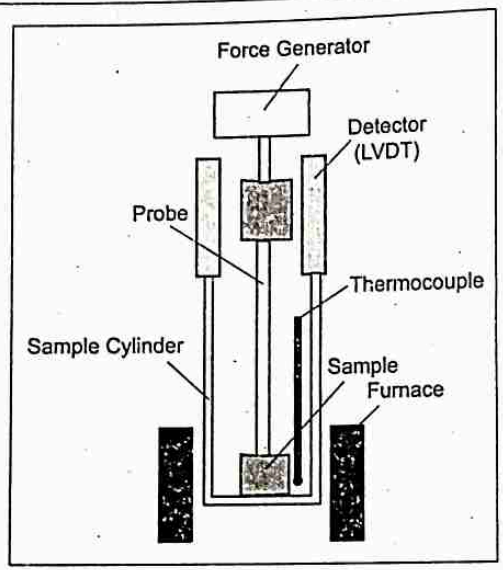


Fig. 5.6. Working of Thermo mechanical analyser

- The thermocouple for temperature measurement is located near the sample. The rate of 5° C/min is usually the maximum recommended value for good temperature equilibration across the specimen
- The sample temperature is changed in the furnace by applying the force onto the sample from the Force Generator via probe.
- The sample deformation such as Thermal Expansion and Softening with changing temperature is measured as the probe displacement by the Length Detector. Linear Variable Differential Transformer (LVDT) is used for Length Detection sensor.
- Every displacement of the pushrod is trans-formed into an analog signal by the LVDT, converted to digital form and then recorded in the computer system, and finally presented by the software as a dimensional change versus time or temperature.

5. APPLICATION

- Measurement of Dimensional Change
- Coefficient of Linear Thermal Expansion
- Determination of Material Anisotropy

- Softening Temperatures and Glass Transition
- Linear Thermal Expansion

6. ADVANTAGES

- Compactness and lightness
- Low operation voltage
- Measures large deformation
- Large actuation force
- Measures measure relaxation effects

7. LIMITATION

- Used only for solid samples.
- Creep occurring concurrently with normal dimensional changes.
- Usage of proper probe.
- Low operational speed

5.2.7. THERMO MECHANICAL DYNAMIC ANALYSIS

- **Thermo mechanical dynamic analysis**, otherwise known as Dynamic Mechanical Analysis (DMA), is a technique where a small deformation is applied to a sample in a cyclic manner. This allows the materials response to stress, temperature, frequency and other values to be studied. The term is also used to refer to the analyzer that performs the test.
- Dynamic mechanical analysis (DMA) is an important technique used to measure the mechanical and viscoelastic properties of materials such as thermoplastics, thermosets, elastomers, ceramics and metals.

1. PRINCIPLE

- A sinusoidal stress is applied and the strain in the material is measured, allowing one to determine the complex modulus. The temperature of the sample or the frequency of the stress are often varied, leading to variations in the complex modulus; this approach can be used to locate the temperature of the material, as well as to identify transitions corresponding to other molecular motions.

2. TYPES OF THERMO MECHANICAL DYNAMIC ANALYZER

- Forced resonance analyzers - Analyzers force the sample to oscillate at a certain frequency and are reliable for performing a temperature sweep.
- Free resonance analyzers- Free resonance analyzers measure the free oscillations of damping of the sample being tested by suspending and swinging the sample

3. MODE OF ANALYZER

- Stress (force) control - The structure of the sample is less likely to be destroyed and longer relaxation times/ longer creep studies can be done.
- Strain (displacement) control-The better short time response for materials of low viscosity and experiments of stress relaxation are done with relative ease

4. COMPONENTS

- **Transducer Sensor (Linear Variable Displacement Transducer (LVDT)** – It is which measures a change in voltage.
- **Drive shaft or probe** - It is a support and guidance system to act as a guide for the force from the motor to the sample.
- **Drive motor** - A linear motor for probe loading which provides load for the applied force.
- **Stepper motor** - It controls the specimen dimension and measurement.

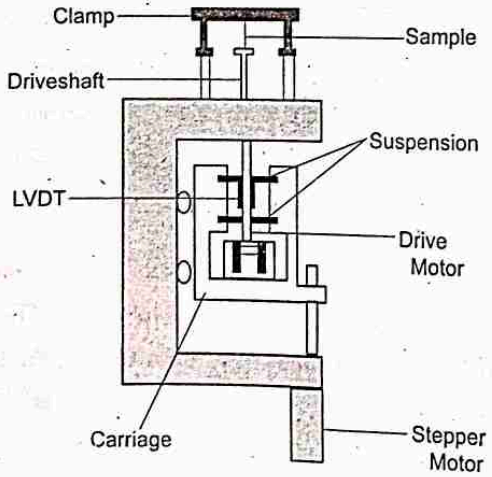
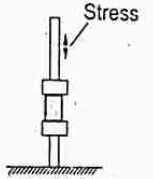
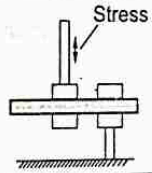
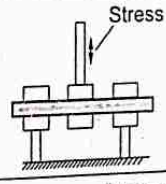
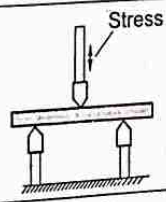
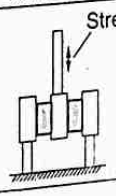


Fig. 5.7. Cross section of Thermo mechanical dynamic analyser

5. WORKING

- The sample is clamped in the measurement head of the DMA instrument. During measurement, sinusoidal force is applied to the sample via the probe or driving shaft.
- Deformation caused by the sinusoidal force is detected and the relation between the deformation and the applied force is measured.
- Properties such as elasticity and viscosity are calculated from the applied stress and strain plotted as a function of temperature or time.

Table 5.5. different loading condition

Modes	Stress application	Purpose
Shear mode		Used for evaluation of thin fibers or films or bundle of single fiber
3- point bending mode		Best for medium to high modulus materials.
Dual cantilever mode		Highly damped materials can be measured.
Single cantilever mode		Suited best for thermoplastics
Tension or compression mode		Used for low to medium moduius materials

6. DIFFERENT LOADING MODES

- The most suitable type should be selected depending on the sample shape, modulus and measurement purpose.

7. ADVANTAGES

- It is an essential analytical technique to determining the viscoelastic properties of polymers.
- Very soft and hard samples are measured.
- Allows accurate temperature measurement.
- It can provide major and minor transitions of materials
- It is also more sensitive.
- It is able to quickly scan and calculate the modulus for a range of temperatures.
- It is the only technique that can determine the basic structure of a polymer system
- This analytical method is able to accurately predict the performance of materials in use.

8. LIMITATIONS

- It leads to calculation inaccuracies.
- The large inaccuracies are introduced if dimensional measurements of samples are slightly inaccurate.
- The oscillating stress converts mechanical energy to heat and changes the temperature of the sample.
- The maintaining an exact temperature is important in temperature scans, this also introduces inaccuracies.
- The final source of measurement uncertainty comes from computer error.

9. DMA MEASURES

- Displacement and force
- Wide range of force 1mN to 40N
- Wide range of frequency 0.001 to 1000Hz.
- Wide stiffness range.

- Coefficient of Thermal Expansion (CTE)
- Glass Transition Temperature
- Compression Modulus of Polymeric Materials
- Viscoelastic properties such as:
  - Storage modulus (purely elastic component)
  - Loss modulus (purely viscous component)
  - Loss tangent

10. APPLICATION

- Measurement of the glass transition temperature of polymers
- Varying the composition of monomers
- Effectively evaluate the miscibility of polymers
- To characterize the glass transition temperature of a material.
- Mechanical properties in the relevant frequency range
- Modulus information
- Measurement of different relaxations
- Molecular interaction
- Nonlinear properties
- Damping behaviour

5.3. CHEMICAL ANALYSIS

- Chemical analysis is used to identify the contents, composition and quality of the materials used in product development, manufacturing and testing.

5.3.1. CHEMICAL PROPERTY

- A chemical property is a characteristic or behavior of a substance that may be observed when it undergoes a chemical change or reaction.

S.No	Property	Description
1.	**Toxicity**	Toxicity is a very important chemical property because it gives the harm of a substance can bring to other organisms.

S.No	Property	Description
2.	**Reactivity**	Reactivity is the tendency of a substance to undergo chemical reaction, either by itself or with other materials, and to release energy.
3.	**Types of chemical bonds formed**	Chemical bonds include covalent, polar covalent and ionic bonds.
4.	**Coordination number**	The coordination number of an atom in a molecule is the number of atoms bonded to the atom, the coordination number describes the number of neighbor atoms with respect to a central atom
5.	**Oxidation states**	The oxidation state is the charge of an atom if all bonds it formed were ionic bonds.
6.	**Flammability**	Flammable is a property of a material relating how easily the material ignites or sustains a combustion reaction.
7.	**Heat of combustion**	A combustion reaction involves oxygen and releases energy as heat.
8.	**Enthalpy of formation**	The heat of formation is the heat released or absorbed (enthalpy change) during the formation of a pure substance from its elements at constant pressure (in their standard states). Heat of formation is also called enthalpy of formation kilojoules per mole (kJ/mol).
9.	**Chemical stability under specific conditions**	Stability occurs when a system is in its lowest energy state, or chemical equilibrium with its environment

S.No	Property	Description
10.	**Acidity or basicity**	Acidity is the extent to which a substance will donate a proton/hydrogen ion. Basicity is the extent to which a substance will accept a proton/hydrogen ion.
11.	**Radioactivity**	Radioactive decay is a property of several naturally occurring elements as well as of artificially produced isotopes of the elements

5.3.2. CHEMICAL TESTING

- Chemical Testing provides a variety of quantitative and qualitative services for verification, identification and component analysis of ferrous and non-ferrous metals.

5.3.3. PURPOSE OF CHEMICAL TESTING

- Chemical Trace Analysis
- Elemental Trace Analysis
- Failure Analysis
- Contamination Analysis
- Materials Analysis and Testing
- Material Verification
- Material Identification
- Chemical Composition Analysis

5.3.4. CHEMICAL COMPOSITION TECHNIQUE AND TESTS

(a) Chromatography Technique

- Gas Chromatography
- Ion Chromatography
- Liquid Chromatography

(b) Mass Spectroscopy Technique

- Gas Chromatography Mass Spectroscopy
- Inductively Coupled Plasma

(c) Spectroscopy Technique

- Fourier-transform infrared spectroscopy (Solution & Pellet)
- X-Ray - EDS & XRF Analysis
- Inductively Coupled Plasma (ICP-AES)
- Atomic Absorption Graphite Furnace (GF-AAS)
- Spark Atomic Emissions (Spark-AES)

(d) Wet Chemistry Technique

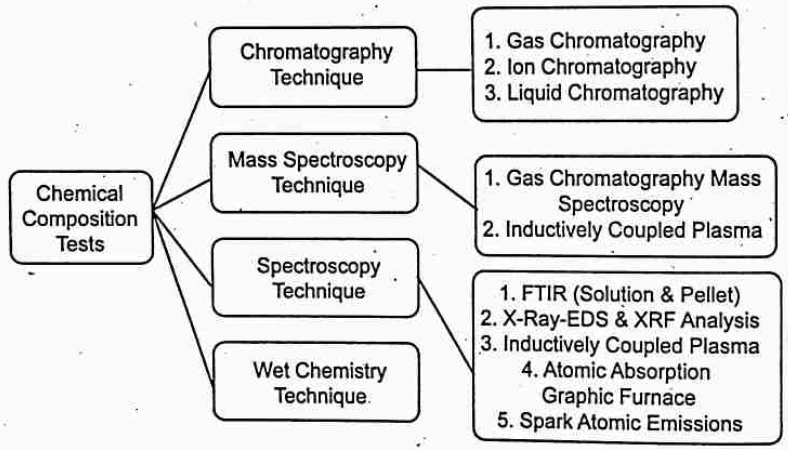


Fig. 5.8. Types of chemical composition test

5.3.5. X-RAY FLUORESCENCE

- XRF (X-ray fluorescence) is a non-destructive analytical technique used to determine the elemental composition of materials. XRF analyzers determine the chemistry of a sample by measuring the fluorescent X-ray emitted from a sample when it is excited by a primary X-ray source.
- The phenomenon is widely used for elemental analysis and chemical analysis, particularly in the investigation of metals, glass, ceramics and building materials, and for research in geochemistry.

1. PRINCIPLE

- **X-ray fluorescence (XRF)** is the emission of characteristic "secondary" (or fluorescent) X-rays from a material that has been excited by being bombarded with high-energy X-rays or gamma rays.

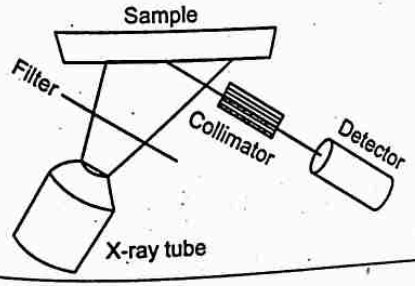
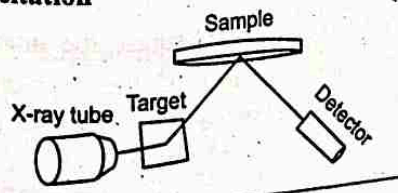
2. COMPONENTS OF A TYPICAL XRF SPECTROMETER

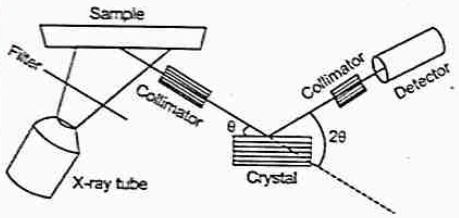
- Source of X-rays used to irradiate the sample. Wavelengths are typically in the range 0.01 to 10 nm, which is equivalent to energies of 125 keV to 0.125 keV.
- Detection equipped by Gas-filled detectors, semiconductor detector, scintillation detector, a photographic plate.

3. TYPES OF XRF SPECTROSCOPY.

The XRF spectroscopy differs primarily by detection and analyzing.

- Energy Dispersive XRF (Direct and polarized excitation)
- Wavelength Dispersive XRF

Methods	Description
Energy Dispersive X-ray fluorescence with direct excitation 	An energy dispersive detection system directly measures the different energies of the emitted X-rays from the sample. By counting and plotting the relative numbers of X-rays at each energy an XRF spectrum is generated
Energy Dispersive X-ray fluorescence with polarized excitation 	The detector must be perpendicular to the plane determined by the tube, target and sample. The most important effect is that by deflecting the X-ray radiation by 90°, the radiation is polarized and the spectral background in the spectrum is reduced.

Methods	Description
Wavelength Dispersive X-ray fluorescence 	The X-rays are directed to a crystal, which diffracts the X-rays in different directions according to their wavelengths (energies).On a sequential system a detector is placed at a fixed position, and the crystal is rotated so that different wavelengths are picked up by the detector.

4. WORKING OF X-RAY FLUORESCENCE

1. A solid or a liquid sample is irradiated with high energy X-rays from a controlled X-ray tube.
2. When an atom in the sample is struck with an X-ray of sufficient energy, an electron from one of the atom's inner orbital shells is removed.
3. The atom regains stability, filling the vacancy left in the inner orbital shell with an electron from one of the atom's higher energy orbital shells.
4. The electron drops to the lower energy state by releasing a fluorescent X-ray. The energy of this X-ray is equal to the specific difference in energy between two quantum states of the electron. The measurement of this energy is the basis of XRF analysis.
5. The intensity of each characteristic radiation is directly related to the amount of each element in the material.

5. APPLICATIONS

- It is a method of elemental (metal and Nonmetal) analysis with atomic number greater than 12.
- Quantitative analysis can be carried out by measuring the intensity of fluorescence at the wavelength characteristics of the element being determined, especially applicable to most of the element in the periodic table.

- Research in igneous, sedimentary, and metamorphic petrology, Soil surveys, Mining (e.g., measuring the grade of ore),Cement production, Ceramic and glass manufacturing
- Metallurgy (e.g., quality control)
- Environmental studies (e.g., analyses of particulate matter on air filters)
- Petroleum industry (e.g., sulfur content of crude oils and petroleum products)
- Field analysis in geological and environmental studies (using portable, hand-held XRF spectrometers)
- Bulk chemical analyses of major elements and trace elements

6. ADVANTAGES

- Simple spectra analysis
- XRF is a versatile and rapid technique
- Easily analysis of the element among the same family elements
- It is non-destructive method of chemical analysis
- Important as in case of samples in limited amounts, or valuable or irreplaceable
- It is precise and with skilled operations it is accurate
- Applicable to a wide variety of samples from powders to liquids
- It is convenient and economical to use
- The instruments have few moving parts, tend to be low-maintenance, and on a regular basis consume only liquid nitrogen and electricity
- Spectral positions are almost independent of the chemical state of the analyses
- Applicable over a wide range of concentrations

7. ADVANTAGES

- It fairly high limits of detection when compared to other methods
- Possibility of matrix effects, although these can usually be accounted for using software-based correction procedures

- It is limited in their ability to precisely and accurately measure the abundances of elements with Atomic number <11 in most natural earth materials
- XRF analyses cannot distinguish variations among isotopes of an element
- XRF analyses cannot distinguish ions of the same element in different valence states
- Instrumentation is fairly expensive

5.4. ELEMENTAL ANALYSIS BY INDUCTIVELY COUPLED PLASMA

5.4.1. ELEMENTAL ANALYSIS

- **Elemental analysis** is a process where a sample of some material (e.g., soil, waste or drinking water, bodily fluids, minerals, chemical compounds) is analyzed for its elemental and sometimes isotopic composition. Elemental analysis can be qualitative (determining what elements are present), and it can be quantitative (determining how much of each are present). Elemental analysis falls within the ambit of analytical chemistry, the set of instruments involved in deciphering the chemical nature of our world.

5.4.2. METHODS OF ELEMENTAL ANALYSIS

- CHNX analysis
- Quantitative analysis
- Qualitative analysis

1. **CHNX analysis** - The determination of the mass fractions of carbon, hydrogen, nitrogen and heteroatoms (X) (halogens, sulfur) of a sample.
   - The varies CHNX analysis are
     - NMR (Nuclear Magnetic Resonance)
     - Mass spectrometry chromatographic
     - Combustion analysis
2. **Quantitative analysis** - Quantitative analysis is the determination of the mass of each element or compound present. The quantitative analysis are
   - Gravimetery analysis

   - Optical atomic spectroscopy(Flame atomic absorption, Graphite furnace atomic absorption, and Inductively coupled plasma atomic emission spectroscopy)
   - Neutron activation analysis
3. **Qualitative analysis** - To qualitatively determine which elements exist in a sample
   - Mass spectrometric (atomic spectroscopy)
   - Inductively coupled plasma mass spectrometry
   - X-ray fluorescence
   - Particle-induced X-ray emission
   - X-ray photoelectron spectroscopy
   - Auger electron spectroscopy
   - Sodium fusion test

5.4.3. EXCITING SOURCE OF MASS AND EMISSION SPECTROMETRY

- The excitation source must desolvate, atomize, and excite the analyte atoms. A variety of excitation sources are flame, arc/spark and plasma.

5.4.3.1. PLASMA

- Plasma is an electrical conducting gaseous mixture containing significant amounts of cations and electrons (net charge approaches zero).

1. ADVANTAGES OF PLASMA

- Increased atomization/excitation
- Wider range of elements
- Simultaneous multi element analysis
- Wide dynamic range

2. TYPES OF PLASMA

- **Direct-current plasma (DCP)** - In a DCP, a dc current passing between two electrodes heats the plasma gas, again typically argon, and produces a discharge. The most common version is the three- electrode system.

- **Microwave-induced plasma (MIP)** - A MIP is an electrode less discharge generated in a glass or quartz capillary discharge tube, often in a resonant cavity.
- **Capacitively Coupled Microwave Plasmas (CMP)** - A CMP is formed using a magnetron to produce microwave energy at 2.45 GHz.
- **Inductively-coupled plasma (ICP)**

5.4.3.2. Inductively-Coupled Plasma (ICP)

- An **inductively coupled plasma (ICP)** or **transformer coupled plasma (TCP)** is a type of plasma source in which the energy is supplied by electric currents which are produced by electromagnetic induction, that is, by time-varying magnetic fields.
- The most commonly used ion source for plasma spectrometry, the ICP, is produced by flowing an inert gas, typically argon, through a water-cooled induction coil which has a high-frequency field (typically 27 MHz) running through it .
- An inductively coupled plasma (ICP) is a very high temperature (7000-8000K) excitation source. ICP sources are used to excite atoms for atomic-emission spectroscopy and to ionize atoms for mass spectrometry.

1. PRODUCTION OF PLASMA

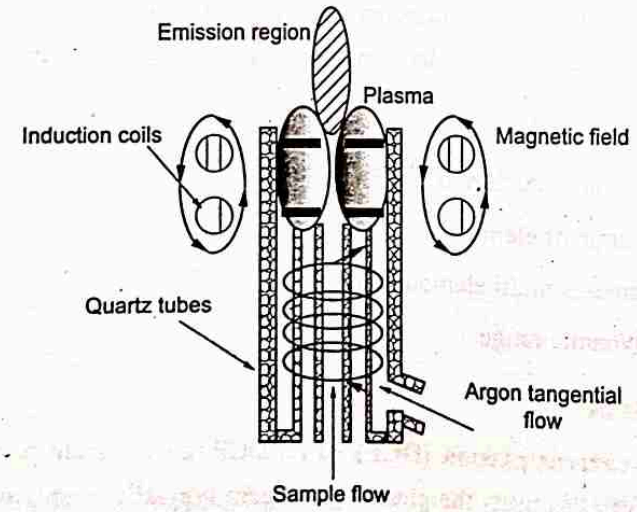


Fig. 5.9. Production process of plasma

- Inductively coupled discharge also uses RF power supply like capacitively coupled discharge.
- A radiofrequency (RF) generator (typically 1-5 kW @ 27 MHz) produces an oscillating current in an induction coil that wraps around the tubes.
- For a commonly used cylindrical plasma chamber shown below, antenna is usually wrapped around the electrically insulating chamber wall.
- RF generator drives high alternating current through coil antenna, which creates an alternating magnetic field within the plasma chamber.
- Oscillating magnetic field will generate an oscillating electric field in the plasma chamber.
- Eventually, the electric field will accelerate the electrons and generate plasma.
- The magnetic field in turn sets up an oscillating current in the ions and electrons of the support gas (argon). As the ions and electrons collide with other atoms in the support gas.
- Since the excitation force is delivered through magnetic field, inductively coupled discharge is also called "H-discharge". For some applications, it is described as "electrode less discharge" because there is no cathode or anode required for inductively coupled discharge.

2. CHARACTERISTICS OF OPTICALLY COUPLED PLASMA

- High temperature (7000 – 8000 K)
- High electron density (1014–1016cm)
- Appreciable degree of ionization for many elements
- Simultaneous multielement capability (over 70 elements including P and S)
- Low background emission and relatively low chemical interference
- High stability leading to excellent accuracy and precision
- Excellent detection limits for most elements (0.1 –100 ng mL-1)
- Wide linear dynamic range (LDR) (four to six orders of magnitude)
- Applicable to the refractory elements cost-effective analyses

5.4.4. OPTICAL EMISSION SPECTROSCOPY

- Optical Emission Spectroscopy, or OES analysis, is a rapid method for determining the elemental composition of a variety of metals and alloys.

Based on excitation source Optical Emission Spectroscopy is classified as,

- Inductively Coupled Optical Emission Spectroscopy
- Glow Discharge Optical Emission Spectrometry (GD-OES) or Glow Discharge MS (GD-MS)
- Arc spark Optical Emission Spectroscopy
- Flame emission spectroscopy

5.4.5. INDUCTIVELY COUPLED PLASMA OPTICAL EMISSION SPECTROMETRY

- The Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES) analysis method uses high-frequency inductively coupled plasma as the light source, and is ideal for the element analysis of sample solutions.

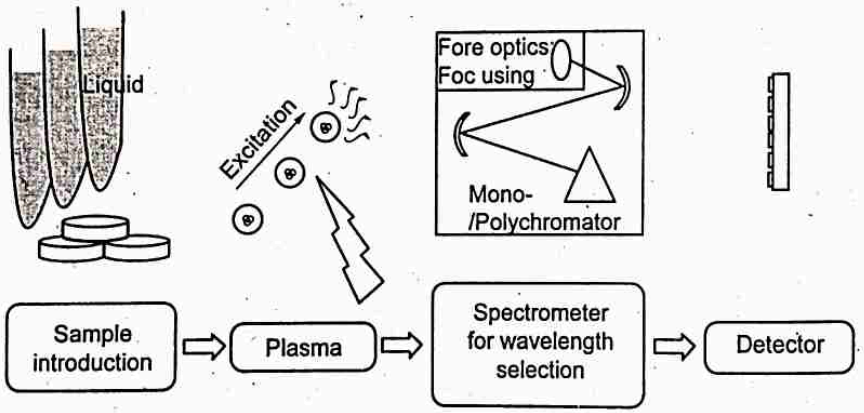


Fig. 5.10. Flow diagram of ICP-OES

1. PRINCIPLE

- When plasma energy is given to an analysis sample from outside, the component elements (atoms) is excited. When the excited atoms return to low energy position, emission rays (spectrum rays) are released and the emission rays that correspond to the photon wavelength are measured.

2. COMPONENTS

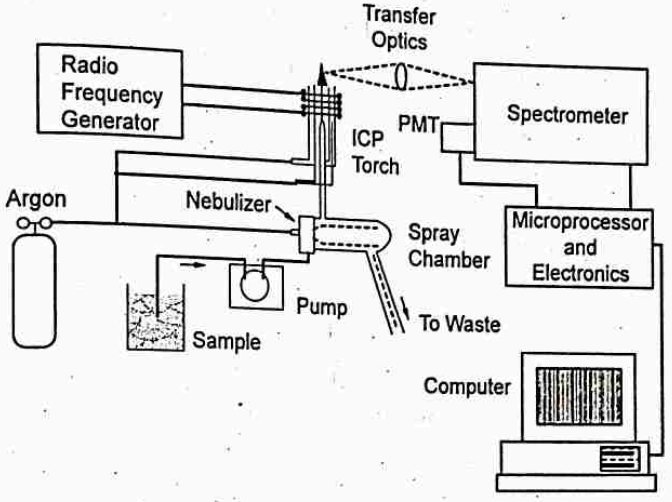


Fig. 5.11. A representation of the layout of a typical ICP-OES instrument.

3. CONSTRUCTION

- Sample introduction
- Production of emission
- Collection and detection of emission
- Signal processing and instrument control

(a) SAMPLE INTRODUCTION

1. Nebulizer

- With a nebulizer, the sample liquid is converted into an aerosol and transported to the plasma.

2. Pump

- It require for the solution to be pumped into the nebulizer, the Peristaltic pumps are almost exclusively the choice for ICP-OES applications. These pumps utilize a series of rollers that push the sample solution through the tubing using a process known as peristalsis.

3. Spray chambers

- A spray chamber is placed between the nebulizer and the torch. Only very small droplets in the aerosol are suitable for injection into the plasma, it can be injected into the plasma by spray chamber.

4. Drains

- The drain carries excess sample from the spray Chamber to a waste container can have an impact on the performance of the ICP instrument.

(b) Production of Emission

1. Torches

- It contains a ring-shaped toroidal plasma is formed, where the sample aerosol passes centrally through the hot plasma.
- The burner consists of three concentric quartz tubes. The aerosol is led with its carrier gas through the central tube.
- Between the outer and the intermediate tube a gas flow is introduced tangentially. It takes up the high-frequency energy and also prevents the torch from melting.

2. Radio Frequency Generators

- The radio frequency (RF) Generator is the device that provides the power for the generation and sustainment of the plasma discharge.
- The plasma with the energy of a high-frequency generator (in the frequency range of around 6 –100 MHz) is transferred to a gas flow at atmospheric pressure (mostly argon) in a quartz tube system with the aid of a working coil.
- The electrons take up energy and collide with atoms, by which a plasma with a temperature of up to 6000 K is formed.

(c) Collection and Detection of Emission

1. Transfer Optics

- The emission radiation from the region of the plasma known as the normal analytical zone (NAZ) is sampled for the spectrometric measurement.

2. Wavelength Dispersive Devices

- The next step in ICP-OES is the differentiation of the emission radiation from one element from the radiation emitted by other elements and molecules. The physical dispersion of the different wavelengths is done by

- Diffraction gratings
- Prisms
- Filters

- To separate polychromatic light the grating is incorporated in an optical instrument called a spectrometer. The spectrometer receives white light or polychromatic radiation and disperses it into monochromatic radiation. One or more exit slits on the exit plane or circle are then used to allow certain wavelengths to pass to the detector while blocking out other Wavelengths.
- The monochromatic radiation which is diffracted from the grating is composed primarily of wavelengths representative of the light emitted by a particular elemental or molecular species in the ICP.

3. Detectors

- Once the proper emission line has been isolated by the Spectrometer, the detector and its associated electronics are used to measure the intensity of the emission line. The most common detector is photomultiplier tube.
- A photomultiplier tube (PMT) consists of a photosensitive cathode, several dynodes and a collection anode. The dynodes are responsible for the increase in signal by electron multiplication.

(d) Signal Processing and Instrument Control

1. Signal Processing

- The electrical current measured at the anode of the PMT is converted into information that can be used by a computer.

2. Computers and Processors

- The computer to control the spectrometer and to collect, manipulate, and report analytical data, the amount of computer control over other functions of the instrument varies widely from model to model.

3. Software

- ICP-OES instrument would be that it could prepare the standards and samples, develop the analytical method, analyze the samples, report the

results, and make decisions based on those results all from a single keystroke.

4. WORKING OF ICP-OES

- The first step in an analysis is to prepare the samples and Standards for introduction to the ICP. This step depends on the physical and chemical characteristics of the samples and from simple dilution to a complex series of chemical reactions and other preparation steps.
- The next step in the analysis concerns the sample introduction method and hardware to be used. For most ICP-OES analyses, the standard sample introduction system provided with the instrument will be sufficient.
- In inductively coupled plasma-optical emission spectrometry, the sample is usually transported into the instrument as a stream of liquid sample. Inside the instrument, the liquid is converted into an aerosol through a process known as nebulization.
- The sample aerosol is then transported to the plasma where it is desolvated, vaporized, atomized, and excited and/or ionized by the plasma.
- The excited atoms and ions emit their characteristic radiation which is collected by a device that sorts the radiation by wavelength.
- The radiation is detected and turned into electronic signals that are converted into concentration information for the analyst.
- The next step in the development of an analysis methodology is to program the instrument, using the computer software provided with the instrument, to perform the data collection and processing steps.
- To do this, decisions must be made concerning the operating conditions, wavelength selection, instrument calibration, emission measurement, and the actual sample analysis.

5. Advantages

- Extremely high sensitivity
- Almost full elemental coverage without need for specific excitation sources
- Linear range of several orders of magnitude

- Very accurate quantification at low concentrations
- By using bulk samples a true bulk analysis is obtained (this is often difficult or impossible for many other methods)
- The ability to analyze most any sample type even with limited availability (most commonly samples are about 0.1-1 g but can be as small as a few milligrams)
- Even gases may be analyzed when introduced into the torch using methods such as gas chromatography.
- High sample throughput enabling the efficient analysis of large batches
- Simultaneous determination of multiple elements in each sample
- Complementary analysis to techniques like XRF
- Large dynamic linear range
- Low chemical and matrix interference effects

6. DISADVANTAGES

- Cumbersome sample preparation
- The need to generate calibration curves from samples as similar in all respects as the samples under investigation
- Initial progress is often time consuming and tedious
- In the case of failure analyses method development will often be necessary each time a new sample type is encountered
- Relatively long analysis times
- The method is inherently destructive

7. APPLICATIONS

- Trace analysis of environmental soil and water samples
- Assessment of metal ores for mass balances and process control
- Trace metal analysis of any material that can be digested into an aqueous matrix
- Boron and Lithia in glasses
- Forensic analysis

- Trace analysis of food and drink samples such as; metals in wine; and elements bound to proteins
- Metal release testing of tableware.
- Determination of toxic, trace and major constituents in coal and slags
- Analysis of low alloy steels for As, B, Bi, Ce, La, P, Sn and Ta; High-precision determination of Si in steels.
- Determination of contaminants in high-purity Al.
- Analysis of superconducting materials for trace.

5.4.6. INDUCTIVELY COUPLED PLASMA MASS SPECTROMETRY

- Inductively coupled plasma mass spectrometry (ICP-MS) is an instrumental analytical technique based on the use of a high temperature ionisation source (ICP) coupled to a mass spectrometer.
- It is an elemental analysis technology capable of detecting most of the periodic table of elements at milligram to Nano gram levels per liter.
- It is used in a variety of industries including, but not limited to, environmental monitoring, geochemical analysis, metallurgy, pharmaceutical analysis, and clinical research.

1. PRINCIPLE

- It is a type of mass spectrometry that uses an inductively coupled plasma to ionize the sample. It atomizes the sample and creates atomic and small polyatomic ions, which are then detected.
- It is known and used for its ability to detect metals and several non-metals in liquid samples at very low concentrations. It can detect different isotopes of the same element, which makes it a versatile tool in isotopic labeling.

2. SAMPLE PREPARATION

- This internal standard consists primarily of deionized water, with nitric or hydrochloric acid, and Indium and/or Gallium. Depending on the sample type, usually 5 mL of the internal standard is added to a test tube along with 10 - 500 microliters of sample.

3. COMPONENTS

- **Peristaltic Pump** - Ensures constant flow of liquid irrespective of differences in viscosity between samples, standards and blanks. Sample pumped at 1ml/min
- **Nebulizer and spray chamber** - It uses supersonic expansion of gas to turn the liquid into a fine mist, and the spray chamber then removes any droplets that are too large to be processed in the plasma. This occurs at the sample interface of the instrument.
- **Torch** - The plasma torch consists of three concentric quartz tubes through which streams of argon flow. The nebulizer gas which carries the analyte into the plasma flows in the central tube. The auxiliary gas flows around the central tube and adjusts the position of the plasma relative to the torch. The coolant gas streams tangentially through the outer tube, serving to cool the inside walls and center of the torch, and stabilizes the plasma.
- **Plasma Ionization Source** - Inductively coupled plasmas are formed by coupling energy produced by a Radio Frequency generator to the plasma support gas with an electromagnetic field. The field is produced by applying an RF power (typically 700-1500 W) to a load coil.
- **Interface Region (Skimmer cone & Sampler cone)** - A section that connects the ionizing section at ambient pressure to the mass spectrometer at high vacuum. Function is to export the ions produced in argon plasma and transport them to the mass spectrometer.
- **Ion Focusing Region** - One or more electrostatically controlled lens component made up of series of metallic plates or cylinders having a voltage placed on them Ions are separated from Photons & Neutrals
- **Mass Analyzer (Mass spectroscopy)** - Quadrupole is a sequential mass filter, which separates ions based on their m/z. Measurement of the m/z of the ion allows qualitative identification of the isotope or molecule. Magnitude of the ion current is used to provide quantitation of the amount of the analyze in the original sample.
- **Spectral Interferences** - Polyatomic or molecular Spectral Interferences severely compromise detection capability of certain elements by ICP-MS

using the Quadrupole mass analyzer technology. Generated by combination of Plasma/nebulizer Gas, solvent and matrix derived ions

- **Collision Reaction Cell (CRC)** - The CRC devices in commercial instruments have been designed to remove polyatomic species.
- **Ion Detectors**-Detector is an Electron Multiplier Device which can generate a measurable signal pulse from the impact of a single ion. Each electron which strikes a dynode releases several electrons from that surface and hence the device is called "electron multiplier".

4. WORKING OF ICP-MS

- The sample solution is introduced into the device by means of a peristaltic pump.
- There it becomes nebulized in a spray chamber.
- The resulting aerosol is injected into an argon-plasma that has a temperature of 6000-8000 K.
- Inside the plasma torch, solution is removed from the sample and also atomization and ionization occur.

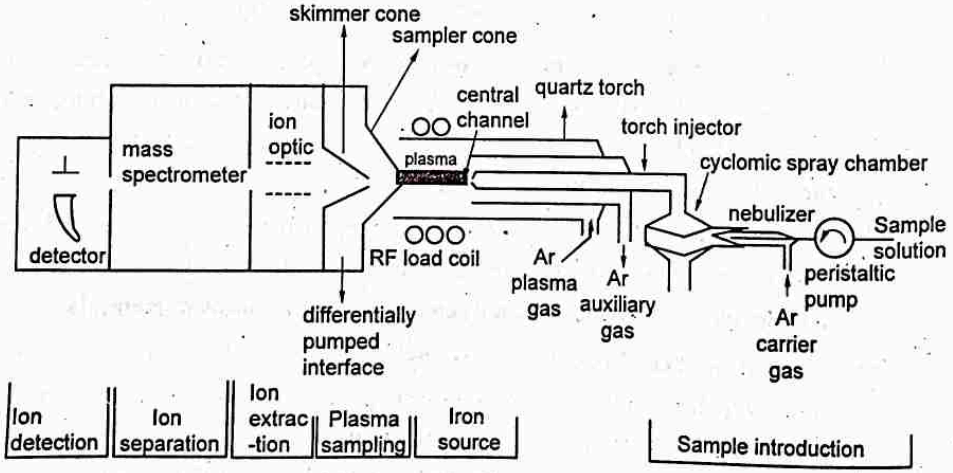


Fig. 5.12. Working flow of ICP-MS

- To be processed efficiently in the plasma, samples must be in either gas or vapor (aerosol) form. So, while gases can be analyzed directly by the plasma (e.g., when separated by gas chromatography), solids and liquids

have to be converted to aerosol form using either a nebulizer (for liquids) or an ablation device (for solids).

- Only a small amount part of the ions produced in the plasma further penetrate to the mass-spectrometer part.
- After mass separation, ions must be detected and amplified in order to determine their intensities.
- Electron multipliers (also known as secondary electron multiplier, or SEM, detectors) can detect extremely small ion currents, including even single ions, coming from the mass analyzer. They operate on the principle of secondary electron emission, in which charged particles with sufficient energy incident on a 'dynode' stimulate the emission of electrons from the surface.

5. MAINTENANCE OF ICP-MS

- Pump tubing has the tendency to stretch, which changes the amount of sample being delivered to the nebulizer
- Tip of the nebulizer should not get blocked.
- Microscopic particles can build up on the tip of the nebulizer without the operator noticing, which, over time, can cause a loss of sensitivity, imprecision, and poor long-term stability.
- Drain of spray chamber must function properly. Malfunctioning or leaking drain can produce changes in the spray chamber backpressure, producing fluctuations in the analyte signal, resulting in erratic and imprecise data
- Staining and discoloration of the outer tube of the quartz torch because of heat and the corrosiveness of the liquid sample can cause electrical arcing
- The most common types of problems associated with the interface are blocking or corrosion of the sampler cone & skimmer cone

6. ADVANTAGES

- Quantitative analysis is the fundamental tool used to determine analyte concentrations in unknown samples.
- Increased sensitivity and wide dynamic range
- Extremely low detection limits

- A large linear range
- Possibilities to detect isotope composition of elements
- Wide Elemental Coverage
- Extremely Low Detection Limits (ppt/ppm) or (ng/L to mg/L)
- Fast Analysis times (all elements at once)
- Simple Spectra
- Isotopic Information
- High Throughput & Productivity

7. APPLICATION

- Simple metal analysis during metal based drug development
- Impurity limit tests
- Metals present in Active Pharmaceutical Ingredients
- Quality Control Tests of natural products for toxic impurities testing
- Monitoring metabolites of an administered drug
- Detection of metal impurities from leachable packaging material
- For elemental speciation
- Pharmaceutical Waste Water monitoring

8. DISADVANTAGE

- The high capital cost of the instrumentation.
- Lower precision compared with atomic absorption spectrometry (AAS)
- The total dissolved salts should be less than 1000 ppm
- Severe matrix effects
- Heavier elements, such as lead, are well-suited for ICP-MS analysis, whereas lighter elements are prone to more interference.

TWO MARK QUESTIONS WITH ANSWERS

1. ***Define thermal analysis***

Thermal analysis is a form of analytical technique most commonly used in the branch of materials science where changes in the properties of materials are examined with respect to temperature.

2. ***List out various thermal properties***

- Thermo-Elastic Effect
- Specific heat
- Thermal expansion
- Thermal stress
- Thermal conductivity

3. ***What is meant by Dilatometer?***

A dilatometer is a scientific instrument that measures volume changes caused by a physical or chemical process. A familiar application of a dilatometer is the mercury-in-glass thermometer, in which the change in volume of the liquid column is read from a graduated scale.

4. ***Define Thermogravimetric analysis***

The Thermogravimetric analysis (TGA) is a type of thermo analytical testing performed on materials to determine changes in weight in relation to changes in temperature.

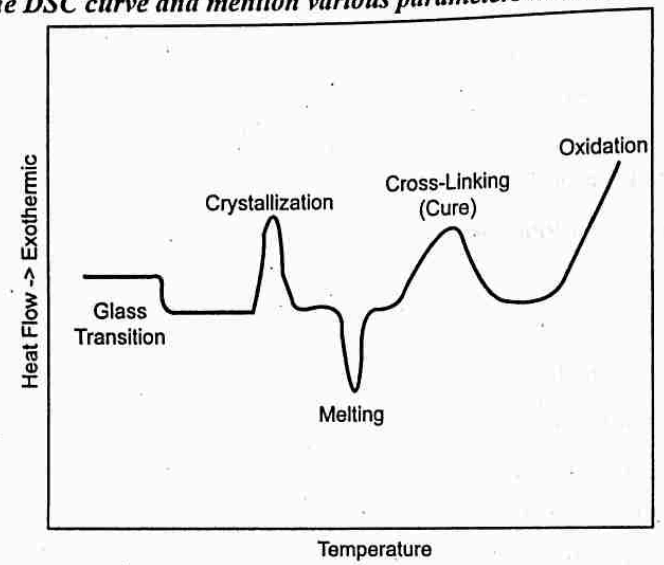
5. ***What is principle of working in Differential scanning calorimetry?***

Differential scanning calorimetry (DSC) is based on the principle; sample and reference are maintained at the same temperature, even during a thermal event (in the sample). The energy required maintaining zero temperature different between the sample and the reference is measured.

6. ***Write the methods of Differential scanning calorimetry***

- Heat flux DSC
- Power compensated DSC
- Modulated DSC
- Hyper DSC
- Pressure DSC

7. ***Draw the DSC curve and mention various parameters in curve.***



8. ***Define Differential thermal analysis.***

Differential thermal analysis (DTA) is a thermo-analytical technique which is used for thermal analysis where thermal changes can be studied. It is used to determine the oxidation process, decomposition, and loss of water or solvent.

9. ***Write about detector used in Differential thermal analysis.***

Differential Temperature Detector (Thermogram), the main function of this detector is to measure differential temperature.

10. ***Write limitation of Differential Temperature Detector***

1. There is lot of uncertainty in transition reactions and heat of fusions upto 20-50%
2. Destructive limited range of samples time consuming usually not qualitative.

11. ***Define LVDT.***

Linear Variable Differential Transformer is a common type of electromechanical transducer that can convert the rectilinear motion of an object to which it is coupled mechanically into a corresponding electrical signal.

12. ***Write the usage of LVDT in Differential thermal analysis***

Every displacement in pushrod of Differential thermal analysis is transformed into an analog signal by the LVDT, converted to digital form and then recorded in the computer system, and finally presented by the software as a dimensional change versus time or temperature.

13. ***Compare the merits and demerits of TMA, DSC, TGA.***

Technique	Employed for	Merits	Demerits
Thermomechanical analysis	Glass transition temperature, softening point, coefficient of linear thermal expansion	Straightforward method with high accuracy and applicable for all polymers	High cost
Differential scanning calorimetry	Crystalllinity, oxidation time, glass transition temperature	Limited for chlorinated polymers	High cost, qualitative result
Thermogravimetric analysis	Polymer additives, ash content, carbon black content, decomposition temperature	Straightforward method with high accuracy for all polymers	Qualitative

14. ***Write various advantages in Differential thermal analysis***

- Compactness and lightness
- Low operation voltage
- Measures large deformation
- Large actuation force
- Measures measure relaxation effects

15. ***Mention the various components of Dynamic Mechanical Analyser***

- Transducer Sensor (Linear Variable Displacement Transducer (LVDT)
- Drive shaft or probe

- Drive motor
- Stepper motor

16. *Difference between Drive motor and Stepper motor of DMA*

- Drive motor is a linear motor for probe loading which provides load for the applied force
- Stepper motor is controls the specimen dimension and measurement

17. *What are benefits of using DMA?*

- Very soft and hard samples are measured.
- Allows accurate temperature measurement.
- It can provide major and minor transitions of materials
- It is also more sensitive.
- It is able to quickly scan and calculate the modulus for a range of temperatures.

18. *Differentiate between TGA, DTA, DSC*

TGA	DTA	DSC
TGA is Thermogravimetric analysis	DTA is Differential thermal analysis	DSC is Differential scanning calorimetry
The change mass with change of temperature is analysed.	Temperature difference developed between the sample and reference is measured identically.	Heat flow is measured against temperature at particular time
Sample can be used as solid substance.	Sample can be used as solid substance.	Sample can be used as liquid substance.

19. *What are purposes of chemical analysis*

- Chemical Trace Analysis
- Elemental Trace Analysis
- Failure Analysis
- Contamination Analysis
- Materials Analysis and Testing
- Material Verification

20. *Define chromatography technique*

Chromatography is a technique for the separation of a mixture. The mixture is dissolved in a fluid called the mobile phase, which carries it through a structure holding another material called the stationary phase. The various constituents of the mixture travel at different speeds, causing them to separate.

21. *Define Wet Chemistry*

Wet Chemistry, also called wet chemical analysis, generally refers to chemistry performed on samples in the liquid phase. Since wet chemistry analysis is performed on liquid samples, this type of element analysis can often be performed on samples too small for other instrumental methods.

22. *How X Ray is utilized in XRF spectroscopy?*

X-ray fluorescence (XRF) is the emission of characteristic "secondary" (or fluorescent) X-rays from a material that has been excited by being bombarded with high-energy X-rays or gamma rays.

23. *What are the types of XRF spectroscopy?*

- Energy Dispersive XRF (Direct and polarized excitation)
- Wavelength Dispersive XRF

24. *What are the limitations of XRF spectroscopy?*

- XRF analyses cannot distinguish variations among isotopes of an element.
- XRF analyses cannot distinguish ions of the same element in different valence states.
- Instrumentation is fairly expensive

25. *Define inductively coupled plasma.*

An inductively coupled plasma (ICP) or transformer coupled plasma (TCP) is a type of plasma source in which the energy is supplied by electric currents which are produced by electromagnetic induction, that is, by time-varying magnetic fields.

26. *Define Nebulizer*

Nebulizers are devices that convert a liquid into an aerosol that can be transported to the plasma. This process is one of the critical steps in ICP-OES. The ideal sample introduction system would be one that delivers the

entire sample to the plasma in a form that the plasma could reproducibly desolvate, vaporize, atomize and ionize, and excite. Types of Nebulizers,

- Pneumatic nebulizer
- Babington nebulizer
- Ultrasonic nebulizer

27. ***Compare contrast between ICP OES and ICP MS***

ICP OES	ICP MS
Inductively coupled plasma optical emission spectroscopy (ICP-OES)	Inductively coupled plasma mass spectrometry (ICP-MS)
Measurement of excited atoms and ions at the wavelength characteristics for the specific elements being measured	Measures an atom's mass by mass spectrometry
Detection limit for ICP-MS can extend to parts per trillion (ppt)	Detection limit for ICP-OES is parts per billion (ppb)
ICP-OES has much higher tolerance for TDS (up to 30%)	ICP-MS has much lower tolerance for TDS (about 0.2%) although there are ways to increase the tolerance.

28. ***Define Torches in ICP OES***

- It contains a ring-shaped toroidal plasma is formed, where the sample aerosol passes centrally through the hot plasma.
- The burner consists of three con- centric quartz tubes. The aerosol is led with its carrier gas through the central tube.

29. ***List out types of dispersing unit.***

- **Prism or diffraction gratings** - The grating provides dispersion of the wavelength range of interest over a given angular range.
- **Monochromators** - Multi-element determinations using a monochromator must be sequential, as the monochromator can observe only one line at a time owing to single secondary slit.

- **Polychromators** - Polychromators have a permanently fixed secondary slit for certain individual wavelengths (individual elements).

REVIEW QUESTIONS

1. Explain differential scanning calorimetry with working principle and write its applications.

   Ans: Section No. 5.2.4 **Page No:** 5.5

2. Explain the types of differential scanning calorimetry with neat sketch.

   Ans: Section No. 5.2.4 **Page No:** 5.5

3. Describe the various components of differential thermal analysis with working.

   Ans: Section No. 5.2.5 **Page No:** 5.10

4. What are the benefits and limitation of differential thermal analysis?

   Ans: Section No. 5.25 **Page No:** 5.13

5. Compare the curve of DTA and DSC.

   Ans: Section No. 5.2.4, 5.2.5 **Page No:** 5.8, 5.12

6. Explain the various loading condition in thermo mechanical analysis.

   Ans: Section No. 5.26 **Page No:** 5.15

7. Write short note on
   - DTA
   - DSC
   - DMA
   - TMA

   Ans: Section No. 5.2.4 to 5.2.7 **Page No:** 5.5 to 5.17

8. Explain in detail about thermo mechanical dynamic analysis.

   Ans: Section No. 5.2.7 **Page No:** 5.17

9. What are the various applications, advantages, disadvantages of x-ray fluorescence?

Ans: Section No. 5.3.5 **Page No:** 5.24

10. Describe the process of production of plasma in ICP.

Ans: Section No. 5.4.3 **Page No:** 5.30

11. Explain the various components working in Inductively Coupled Plasma Optical Emission Spectroscopy.

Ans: Section No. 5.4.5 **Page No:** 5.32

12. Write comparison between various features of ICP OES and ICP MS.

Ans: Section No. 5.4.5, 5.4.6 **Page No:** 5.32, 5.38

13. Write short note on

- ICP
- ICP OES
- ICP MS

Ans: Section No. 5.4.3.2, 5.4.5, 5.4.6 **Page No:** 5.30, 5.32, 5.38

14. Explain the working condition, advantages and disadvantages of ICP MS.

Ans: Section No. 5.4.6 **Page No:** 5.38

MODEL QUESTION PAPER - 1

B.E./B.Tech., DEGREE EXAMINATIONS,

Electronics and Communication Engineering,

OML751 - TESTING OF MATERIALS

(Regulation 2017)

Time: Three Hours **Maximum: 100 marks**

Answer ALL questions

PART A (2 × 10 = 20 Marks)

1. ***Why more concentration is needed for selection of materials?***

Material selection is one of the foremost functions of effective engineering design as it determines the reliability of the design in terms of industrial and economical aspects.

Iterative in nature, there is a strong element of trial and error where an initial design is done and then analyzed, tested, and subjected to trial production. Changes may be made at any stage of the process to satisfy requirements not previously considered or problems just discovered.

2. ***Define prototype.***

A proto type, or trial model, is often made and subjected to simulated service testing to demonstrate whether or not a machine or vehicle functions properly.

3. ***Define strain hardening and proof stress.***

Strain hardening: This increase in the tensile strength of the material is due to strain hardening which is due to the increased dislocations interactions during the deformation of the tensile test. This is called Strain-hardening.

Proof Stress: The stress that causes a percentage increase in gauge length. It can be found by drawing a line parallel to the straight part of the graph. A value can be taken from the vertical axis.

4. ***What are advantages made the choice of Brinell hardness test?***

- A choice can be made between a large numbers of test forces.
- The influence of surface scratches and roughness will be less in the Brinell test than other hardness tests.
- The specimen surface can be rough.

- Suitable for hardness tests on large blanks such as forged pieces, castings and hot-rolled etc
- Measurement is usually not affected by movement of the specimen

5. ***How densities of material influence the radiographic testing?***

(*a*) If an object has a high density, i.e., a thicker object, it absorbs more radiation causing less radiation to hit the film, which produces a lighter image.

(*b*) If an object has a low density, i.e., when the through section is reduced or there is a lower-density material such as slag (compared to the surrounding material), it will absorb less radiation causing more radiation to hit the film, producing a darker image.

6. ***What aids used for visual testing?***

(*i*) Magnifying glasses
(*ii*) Fillet weld gauge
(*iii*) Microscopes
(*iv*) Computer equipment (remote viewing)
(*v*) Illuminated magnifier
(*vi*) Holography

7. ***Why specimen preparation is important in microscopic technique?***

- Specimen preparation is important in any microscopic technique with proper preparation methods facilitating examination and interpretation of micro structural features.
- Improper preparation methods may obscure features, and even create artifacts that may be misinterpreted.

8. ***Difference between Raman and IR spectroscopy.***

Raman spectroscopy	Infrared spectroscopy
It is due to the scattering of light by vibrating molecules	It is the result of absorption of light by vibrating molecules.
The vibration is active if it causes to change in polarizability	The vibration is active if it causes to change in dipole moment
The molecule need not possess a permanent dipole moment	The vibration concerned change in dipole moment due to vibration

9. ***Define inductively coupled plasma.***

An inductively coupled plasma (ICP) or transformer coupled plasma (TCP) is a type of plasma source in which the energy is supplied by electric currents which are produced by electromagnetic induction, that is, by time-varying magnetic fields.

10. ***How x ray is utilized in XRF spectroscopy?***

X-ray fluorescence (XRF) is the emission of characteristic "secondary" (or fluorescent) X-rays from a material that has been excited by being bombarded with high-energy X-rays or gamma rays.

PART B (5 × 13 = 65 Marks)

11. (*a*) (*i*) What are the advantages and disadvantages encountered by various material testing? (7)

Ans: Refer Section No. 1.2 Page No.1.10

(*ii*) What are criteria that affect the selection of materials? (6)

Ans: Refer Section No. 1.4 Page No. 1.19

[OR]

(*b*) What are steps to be followed during selection of materials? Explain each step in detail. (13)

Ans: Refer Section No. 1.4 Page No. 1.17

12. (*a*) Explain the working principles of machines used to conduct Charpy and Izod impact test. How specimens are put–up in both the tests? (13)

Ans: Refer Section No. 2.12 Page No. 2.32

[OR]

(*b*) Write short note following terms

(*i*) True stress - strain and engineering stress - strain. (3)
(*ii*) Stages of creep (5)
(*iii*) S-N curve (5)

Ans: Refer Page No.2.53, 2.59

13. (*a*) What do you understand by NDT test? Explain the role of Nondestructive testing in manufacturing process. (13)

Ans: Refer Section No. 3.1 Page No. 3.1

[OR]

(*b*) Write short note on

(*i*) Eddy current testing. (5)

(*ii*) Acoustic emission testing. (3)

(*iii*) Liquid penetration Test. (5)

Ans: Refer Section No. 3.2.8, 3.2.11 & 3.2.2 Page No. 3.34, 3.47 & 3.10

14. (*a*) Explain SEM with principle of working, advantages, limitation and various applications.

Ans: Refer Section No. 4.6.1 Page No. 4.14

[OR]

(*b*) (*i*) Write short note on various method of sample preparation in SEM and TEM. (5)

Ans: Refer Section No. 4.6 Page No. 4.17 & 4.21

(*ii*) What is optical microscope and how it is working? (8)

Ans: Refer Section No. 4.5 Page No. 4.9

15. (*a*) Describe the various components of differential thermal analysis with working. (13)

Ans: Refer Section No. 5.2.5 Page No. 5.10

[OR]

(*b*) Write short note on (13)

- ❖ DTA
- ❖ DSC
- ❖ DMA
- ❖ TMA

Ans: Refer Section No. 5.2.4 to 5.2.7 Page No. 5.5 to 5.17

PART C (1 × 15 = 15 Marks)

16. (*a*) The steel deck truss bridge in Trichy is 90-year-old, constructed across Kollidam River that connects Srirangam with mainland Tiruchirapalli. Use proper NDT test for monitoring bridge condition and explain step procedure of using NDT in bridge.

[OR]

(*b*) Write an case study on NDT test used in inspection on welding works.

MODEL QUESTION PAPER - 2

B.E./B.Tech., DEGREE EXAMINATIONS,

Electronics and Communication Engineering,

OML751 - TESTING OF MATERIALS

(Regulation 2017)

Time: Three Hours **Maximum: 100 marks**

Answer ALL questions

PART A (2 × 10 = 20 Marks)

1. ***What are the benefits of testing?***
   - Safety issues can be identified
   - It provides reliability
   - It is cost effective
   - It offers reassurance
2. ***What are the tests used to testing metals?***

   Major test used for testing metals are destructive one i.e., Test, Shear (Torsion test),Test, Creep Test, Bending test etc.
3. ***Define Endurance limit.***

   Endurance limit (fatigue limit) is the maximum fatigue stress applied to material without failure. It is 50% of fatigue failure load which is preferred for design criteria
4. ***What is role of SN curve in fatigue mechanism?***

   S-N curves are derived from tests on samples of the material to be characterized, where a regular sinusoidal stress is applied by a testing machine which also counts the number of cycles to failure.
5. ***Define NDT.***

   Non-destructive testing (NDT) is a testing and analysis technique used by industry to evaluate the properties of a material, component, structure or system

for characteristic differences or welding defects and discontinuities without causing damage to the original part.

6. ***What is purpose penetrant in liquid penetrant inspection?***

The liquid, by capillary action, will penetrate the discontinuities and the excess remaining on the surface will be removed by a suitable cleaning system. It will be highly visible or fluoresce brightly to produce easy to see indications.

7. ***State Diffraction Principle.***

Bragg's law is which determines the angles of coherent and incoherent scattering from a crystal lattice. When X-rays are incident on a particular atom, they make an electronic cloud move just like an electromagnetic wave.

8. ***What are the methods of Spectroscopy?***

- Ultraviolet-visible spectroscopy (UV-vis)
- Electron Spin Resonance spectroscopy
- Atomic spectroscopy
- infrared spectroscopy and Raman spectroscopy
- Mass spectrometry
- Nuclear spectroscopy(nuclear magnetic resonance)

9. ***Define Nebulizer.***

- Nebulizers are devices that convert a liquid into an aerosol that can be transported to the plasma. This process is one of the critical steps in ICP-OES. The ideal sample introduction system would be one that delivers the entire sample to the plasma in a form that the plasma could reproducibly desolvate, vaporize, atomize and ionize, and excite

10. ***What is meant by Dilatometer?***

A dilatometer is a scientific instrument that measures volume changes caused by a physical or chemical process. A familiar application of a dilatometer is the mercury-in-glass thermometer, in which the change in volume of the liquid column is read from a graduated scale.

PART B (5 × 13 = 65 Marks)

11. (*a*) Explain various stages in development of testing in detail. What is the purpose of developing a test? Explain with few examples.

Ans: Refer Section No. 1.5 Page No. 1.22

[OR]

(*b*) (*i*) How will you represent the result analysis of testing? (8)

Ans: Refer Section No. 1.8 Page No. 1.32

(*ii*) Differentiate between NDT and destructive testing. (5)

Ans: Refer Section No. 1.2 Page No. 1.14

12. (*a*) What are the various destructive tests available and which is more suitable to the hardness of material? (13)

Ans: Refer Section No. 2.2 Page No. 2.4, 2.6

[OR]

(*b*) What are properties arrived from the bending test? How do you relate with failure of section? (13)

Ans: Refer Section No. 2.36 Page No. 2.38

13. (*a*) (*i*) Differentiate between Radiography, Eddy current and Ultrasonic testing. (7)

Ans: Refer Page No. 3.61

(*ii*) What is ultrasonic testing? Explain types of transducer. (6)

Ans: Refer Section No. 3.2.10 Page No. 3.43

[OR]

(*b*) Explain the penetration test with step process and its application. What are the various advantages and disadvantages of penetration test. (13)

Ans: Refer Section No. 3.2.2 Page No. 3.10

14. (*a*) (*i*) Difference between optical and electron microscope.

(*ii*) Write about advantages and limitation of TEM.

Ans: Refer Section No. 4.6.2 Page No. 4.25, 4.55

[OR]

(*b*) (*i*) Write short note on Mass spectroscopy. (5)

Ans: Refer Section No. 4.8 Page No. 4.45

(*ii*) Write major contrast between SEM and TEM (8)

Ans: Refer Section No. 4.6.3 Page No. 4.26

15. (*a*) Explain the types of differential scanning calorimetry with neat sketch. (13)

Ans: Refer Section No. 5.2.4 Page No. 5.5

[OR]

(*b*) Write short note on (13)

- ICP
- ICP OES
- ICP MS

Ans: Refer Section No. 5.4.3.2, 5.4.5 & 5.4.6 Page No. 5.30, 5.32 & 5.38

PART C (1 × 15 = 15 Marks)

16. (*a*) In the steel industry, iron rod is manufactured. Now, the iron rod is need to quality check. What is the quickest test available for testing various properties?

Ans: Refer Section No. 2.10 Page No. 2.25

[OR]

(*b*) In the construction site of steel cell phone tower, the quality engineer need to the check bold quality used for connection purpose. What is better test used for checking bold that used in connection? Explain with experimental procedure with advantages and limitation.

Ans: Refer Section No. 2.15 Page No. 2.40

****

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MADHA
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Department of Mechanical Engineering

Lecture Notes

Subject Code : ME8097

Subject Name: NON DESTRUCTIVE TESTING AND EVALUATION

Sem/Year : 07/IV

Regulation : 2017

ME8097	NON DESTRUCTIVE TESTING AND EVALUATION	L	T	P	C
		3	0	0	3

OBJECTIVE:

- To study and understand the various Non Destructive Evaluation and Testing methods,theory and their industrial applications.

UNIT I OVERVIEW OF NDT **9**

NDT Versus Mechanical testing, Overview of the Non Destructive Testing Methods for the detection of manufacturing defects as well as material characterisation. Relative merits and limitations, Various physical characteristics of materials and their applications in NDT., Visual inspection – Unaided and aided.

UNIT II SURFACE NDE METHODS **9**

Liquid Penetrant Testing - Principles, types and properties of liquid penetrants, developers, advantages and limitations of various methods, Testing Procedure, Interpretation of results. Magnetic Particle Testing- Theory of magnetism, inspection materials Magnetisation methods, Interpretation and evaluation of test indications, Principles and methods of demagnetization, Residual magnetism.

UNIT III THERMOGRAPHY AND EDDY CURRENT TESTING (ET) **9**

Thermography- Principles, Contact and non contact inspection methods, Techniques for applying liquid crystals, Advantages and limitation - infrared radiation and infrared detectors, Instrumentations and methods, applications. Eddy Current Testing-Generation of eddy currents, Properties of eddy currents, Eddy current sensing elements, Probes, Instrumentation, Types of arrangement, Applications, advantages, Limitations, Interpretation/Evaluation.

UNIT IV ULTRASONIC TESTING (UT) AND ACOUSTIC EMISSION (AE) **9**

Ultrasonic Testing-Principle, Transducers, transmission and pulse-echo method, straight beam and angle beam, instrumentation, data representation, A/Scan, B-scan, C-scan. Phased Array Ultrasound, Time of Flight Diffraction. Acoustic Emission Technique – Principle, AE parameters, Applications

UNIT V RADIOGRAPHY (RT) **9**

Principle, interaction of X-Ray with matter, imaging, film and film less techniques, types and use of filters and screens, geometric factors, Inverse square, law, characteristics of films - graininess, density, speed, contrast, characteristic curves, Penetrameters, Exposure charts, Radiographic equivalence. Fluoroscopy- Xero-Radiography, Computed Radiography, Computed Tomography

TOTAL : 45 PERIODS

ME8097- NON DESTRUCTIVE TESTING AND EVALUATION

UNIT-1 OVERVIEW OF NDT

Introduction

In **destructive testing**, or (Destructive Physical Analysis DPA) tests are carried out to the specimens failure, in order to understand a specimens performance or material behaviour under different loads. These tests are generally much easier to carry out, yield more information, and are easier to interpret than nondestructive testing. Destructive testing is most suitable, and economic, for objects which will be mass-produced, as the cost of destroying a small number of specimens is negligible. It is usually not economical to do destructive testing where only one or very few items are to be produced (for example, in the case of a building). Analyzing and documenting the destructive failure mode is often accomplished using a high-speed camera recording continuously (movie-loop) until the failure is detected. Detecting the failure can be accomplished using a sound detector or stress gauge which produces a signal to trigger the high-speed camera. These high-speed cameras have advanced recording modes to capture almost any type of destructive failure.[2] After the failure the high-speed camera will stop recording. The capture images can be played back in slow motion showing precisely what happen before, during and after the destructive event, image by image.
Some types of destructive testing:

- Stress tests
- Crash tests
- Hardness tests
- Metallographic tests

1.1 Materials Testing

Prior to manufacturing, many material, design, and production decisions are made to ensure product reliability and proper performance. To validate these decisions, a variety of testing methods are employed. The methods are grouped into two major categories:
Mechanical Testing
Non-Destructive Testing (NDT)
Mechanical testing, which is also known as destructive testing, is accomplished by forcing a part to fail by the application of various load factors. In contrast, non-destructive testing does not affect the part's future usefulness and leaves the part and its component materials in tact.

1.2 Mechanical Testing

Typically mechanical testing involves such attributes as hardness, strength, and impact toughness. Additionally, materials can be subjected to various types of loads such as tension or compression. Mechanical testing can occur at room temperatures or in either high or low temperature extremes.
Hardness
The resistance to indentation and to scratching or abrasion. The two most common hardness tests are the Bri nell test and the Rockwell test.
In the Brinell hardness test, a known load is applied for a given period of time to a specimen surface using a hardened steel or tungsten-carbide ball, causing a permanent indentation. Standard ball diameter is 10 millimeters, or approximately four-tenths of an inch. The diameter of the resulting permanent indentation is then measured and converted to a Brinell hardness number. The Rockwell hardness test involves the use of an indentor for penetrating the surface of a material first by applying a minor, or initial load, and then applying a major, or final load under specifi conditions. The difference between the minor and major penetration depths is then noted as a hardness value directly from a dial or digital

readout. The harder the material the higher the number.

Tensile Test

Tensile – Force is applied perpendicular to the cross sectional area of the test item. Two of the primary material properties that tensile tests determine are:
Yield Strength, which is the stress required to permanently elongate, or deform, a material a specific amount, commonly 0.2% of total elongation.

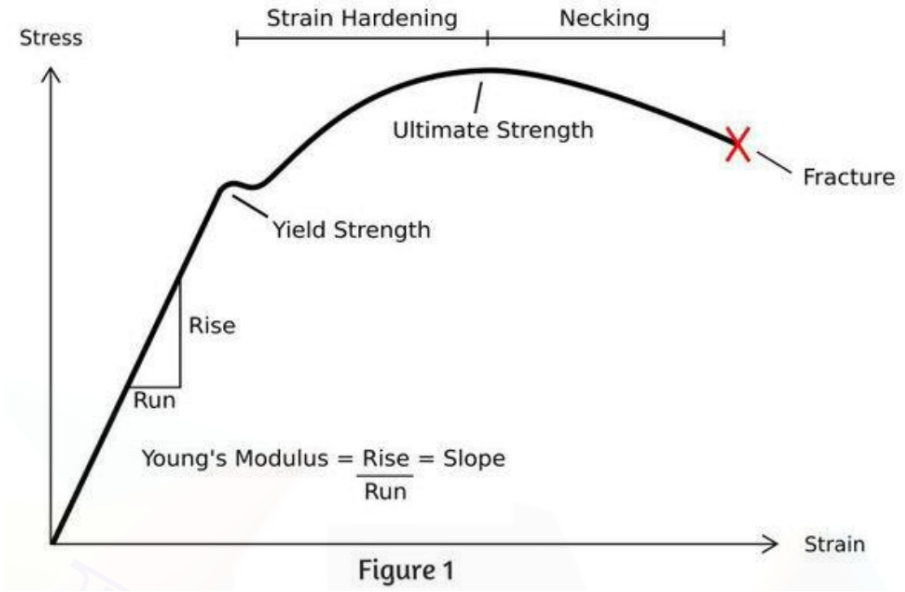
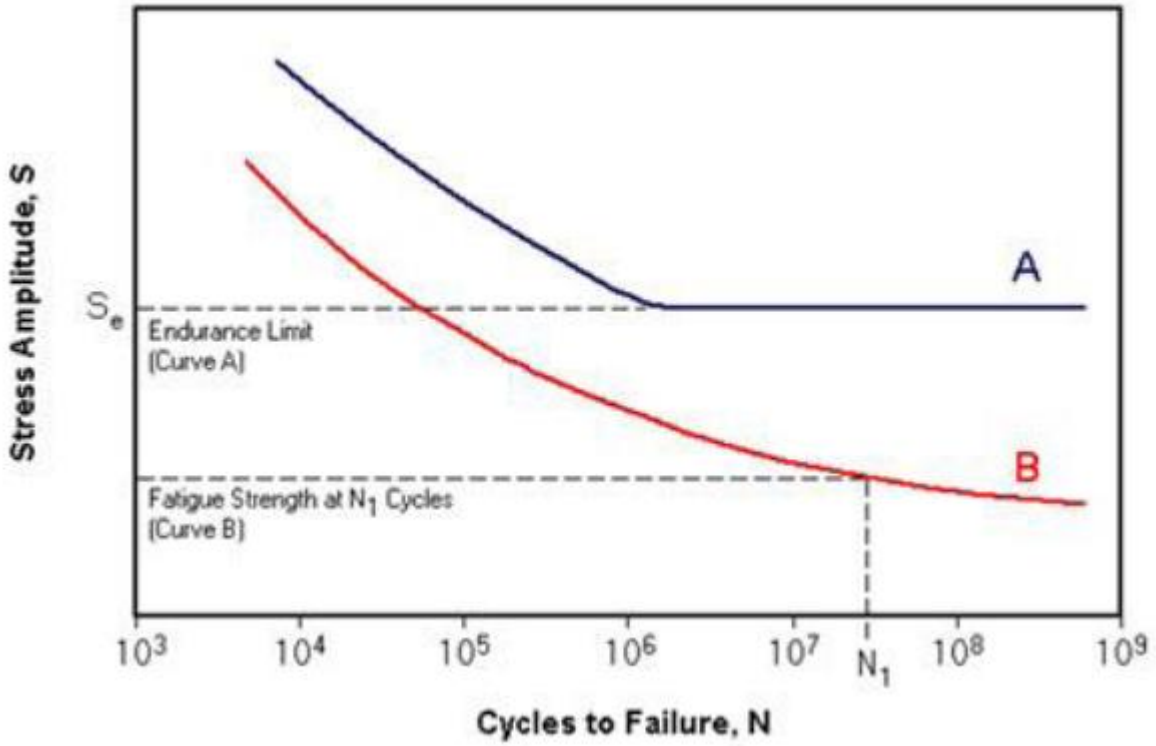


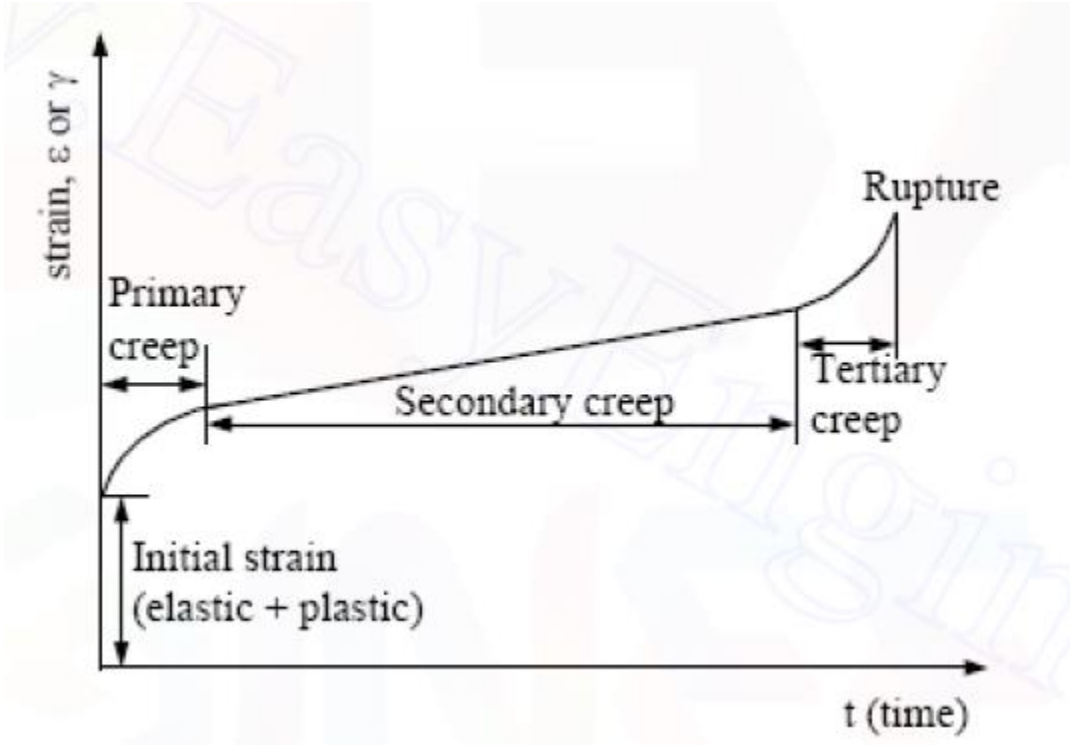
Figure 1

Ultimate Tensile Strength, which is the maximum stress a material can withstand just prior to fracturing.
Compression – Compressive loads are applied to a point just beyond the yield strength of the material and measured at that point or continued to the point of failure if required.
Impact – Impact tests measure resistance to shock loading or impact by determining the amount of energy absorbed by the test specimen. There are two basic types of impact tests:
Pendulum
Drop Weight
Most common pendulum impact tests are the Charpy notched-bar impact test and the Izod notched-bar impact test. In both tests, the specimen is fractured and the energy absorbed is documented. The chief differences between these two impact tests are the way the test specimen is held and in the pendulum hammer design. In the dropped weight test, a known weight is dropped from a specified height. Such tests have advantages in that the impact is unidirectional with failure beginning at the weakest point and propagating from there. A principle advantage over the pendulum impact tests is that the drop weight impact test can define failure by either deformation, crack initiation, or complete failure of the specimen.
Fracture Toughness - Measures a material's resistance to brittle fracture and can be quantified by linear elastic fracture mechanics.
Fatigue – Measures material failure under repeated loading below the yield strength. Stresses measured below failure is referred to as the 'endurance limit' while the number of repeating cycles the material can withstand above this limit is known as 'fatigue life.'



Creep test

Measures a material's continuing dimensional change while under timed stress load. Creep tests are usually performed at elevated temperatures and can last for a thousand hours or longer.



Properties

- Brittleness: Ability of a material to break or shatter without significant deformation when under stress; opposite of plasticity
- Compressive strength: Maximum stress a material can withstand before compressive failure (MPa)
- Creep: The slow and gradual deformation of an object with respect to time
- Ductility: Ability of a material to deform under tensile load (% elongation)
- Elasticity: Ability of a body to resist a distorting influence or stress and to return to its original size and shape when the stress is removed
- Fatigue limit: Maximum stress a material can withstand under repeated loading (MPa)
- Fracture toughness: Ability of a material containing a crack to resist fracture (J/m^2)
- Hardness: Ability to withstand surface indentation and scratching (e.g. Brinnell hardness number)
- Plasticity: Ability of a material to undergo irreversible or permanent deformations without breaking or rupturing; opposite of brittleness
- Poisson's ratio: Ratio of lateral strain to axial strain (no units)
- Resilience: Ability of a material to absorb energy when it is deformed elastically (MPa); combination of strength and elasticity

- Stiffness: Ability of an object resists deformation in response to an applied force; rigidity; complementary to flexibility
- Tensile strength: Maximum tensile stress a material can withstand before failure (MPa)
- Toughness: Ability of a material to absorb energy (or withstand shock) and plastically deform without fracturing (or rupturing); a material's resistance to fracture when stressed; combination of strength and plasticity

1.4 NON-DESTRUCTIVE TESTING

Up to this point we have learnt various testing methods that somehow destruct the test specimens. These were, tensile testing, hardness testing, etc. In certain applications, the evaluation of engineering materials or structures without impairing their properties is very important, such as the quality control of the products, failure analysis or prevention of the engineered systems in service. This kind of evaluations can be carried out with Non destructive test (NDT) methods. It is possible to inspect and/or measure the materials or structures without destroying their surface texture, product integrity and future usefulness. The field of NDT is a very broad, interdisciplinary field that plays a critical role in inspecting that structural component and systems perform their function in a reliable fashion. Certain standards has been also implemented to assure the reliability of the NDT tests and prevent certain errors due to either the fault in the equipment used, the miss-application of the methods or the skill and the knowledge of the inspectors. Successful NDT tests allow locating and characterizing material conditions and flaws that might otherwise cause planes to crash, reactors to fail, trains to derail, pipelines to burst, and variety of less visible, but equally troubling events. However, these techniques generally require considerable operator skill and interpreting test results accurately may be difficult because the results can be subjective. These methods can be performed on metals, plastics, ceramics, composites, cermets, and coatings in order to detect cracks, internal voids, surface cavities, delamination, incomplete crack defective welds and any type of flaw that could lead to premature failure. Commonly used

Visual inspection:

VI is particularly effective detecting macroscopic flaws, such as poor welds. Many welding flaws are macroscopic: crater cracking, undercutting, slag inclusion, incomplete penetration welds, and the like. Like wise, VI is also suitable for detecting flaws in composite structures and piping of all types. Essentially, visual inspection should be performed the way that one would inspect a new car prior to delivery, etc. Bad welds or joints, missing fasteners or components, poor fits, wrong dimensions,

improper surface finish, delaminations in coatings, large cracks, cavities, dents, inadequate size, wrong parts, lack of code approval stamps and similar proofs of testing.

Radiography:
Radiography has an advantage over some of the other processes in that the radiography provides a permanent reference for the internal soundness of the object that is radiographed. The x-ray emitted from a source has an ability to penetrate metals as a function of the accelerating voltage in the x-ray emitting tube. If a void present in the object being radiographed, more x-rays will pass in that area and the film under the part in turn will have more exposure than in the non-void areas. The sensitivity of x-rays is nominally 2% of the materials thickness. Thus for a piece of steel with a 25mm thickness, the smallest void that could be detected would be 0.5mm in dimension. For this reason, parts are often radiographed in different planes. A thin crack does not show up unless the x-rays ran parallel to the plane 0 the crack. Gamma radiography is identical to x-ray radiography in function. The difference is the source of the penetrating electromagnetic radiation which is a radioactive material such m Co 60. However this method is less popular because of the hazards of handling radioactive materials.

Liquid (Dye) penetrant method:
Liquid penetrant inspection (LPI) is one of the most widely used nondestructive evaluation (NDE) methods. Its popularity can be attributed to two main factors, which are its relative ease of use and its flexibility.
The technique is based on the ability of a liquid to be drawn into a "clean" surface breaking flaw by capillary action. . This method is an inexpensive and convenient technique for surface defect inspection. The limitations of the liquid penetrant technique include the inability to inspect subsurface flaws and a loss of resolution on porous materials. Liquid penetrant testing is largely used on nonmagnetic materials for which magnetic particle inspection is not possible. Materials that are commonly inspected using LPI include the following; metals (aluminum, copper, steel, titanium, etc.), glass, many ceramic materials, rubber, plastics. Liquid penetrant inspection is used to inspect of flaws that break the surface of the sample. Some of these flaws are listed below; fatigue cracks, quench cracks grinding cracks, overload and impact fractures, porosity, laps seams, pin holes in welds, lack of fusion or braising along the edge of the bond line.

Magnetic particles:
Magnetic particle inspection is one of the simple, fast and traditional nondestructive testing methods widely used because of its convenience and low cost. This method uses magnetic fields and small magnetic particles, such as iron filings to detect flaws in components. The only requirement from an inspect ability standpoint is that the component being inspected must be made of a ferromagnetic material such iron, nickel, cobalt, or some of their alloys, since these materials are materials that can be magnetized to a level that will allow the inspection to be effective. On the other hand, an enormous volume of structural steels used in engineering is magnetic. In its simplest application, an electromagnet yoke is placed on the surface of the part to be examined, a kerosene-iron filling suspension is poured on the surface and the electromagnet is energized. If there is a discontinuity such as a crack or a flaw on the surface of the part, magnetic flux will be broken and a new south and north pole will form at each edge of the discontinuity. Then just like if iron particles are scattered on a cracked magnet, the particles will be attracted to and cluster at the pole ends of the magnet, the iron particles will also be attracted at the edges of the crack behaving poles of the magnet. This cluster of particles is much easier to see than the actual crack and this is the basis for magnetic particle inspection. For the best sensitivity, the lines of magnetic force should be perpendicular to the defect.

Eddy current testing:
Eddy currents are created through a process called electromagnetic induction. When alternating current is applied to the conductor, such as copper wire, a magnetic field developsin and around the conductor. This magnetic field expands as the alternating current rises to maximum and collapses as the current is reduced to zero. If another electrical conductor is brought into the close proximity to this changing magnetic field, current will be induced in this second conductor. These currents are influenced by the nature of the material such as voids, cracks, changes in grain size, as well as physical distance between coil and material. These currents form an impedance on a second coil which is used to as a sensor. In practice a probe is placed on the surface of the part to be inspected, and electronic equipment monitors the eddy current in the work piece through the same probe. The sensing circuit is a part of the sending coil. Eddy currents can be used for crack detection, material thickness measurements, coating thickness measurements, conductivity measurements for material identification, heat damage detection, case depth determination, heat treatment monitoring. Some of the advantages of eddy current inspection include; sensitivity to small cracks and other defects, ability to detect surface and near surface defects, immediate results, portable equipment, suitability for many different applications, minimum part preparation, no necessity to contact the part under inspection, ability to inspect complex shapes and sizes of conductive materials. Some limitation of eddy current inspection; applicability just on conductive materials, necessity for an accessible surface to the probe, skillful and trained personal, possible interference of surface finish and roughness, necessity for reference standards for setup, limited depth of penetration, inability to detect of the flaws lying parallel to the probe coil winding and probe scan direction.

Ultrasonic Inspection:
Ultrasonic Testing (UT) uses a high frequency sound energy to conduct examinations and make measurements. Ultrasonic inspection can be used for flaw detection I evaluation, dimensional measurements, material characterization, and more. A typical UT inspection system consists of several functional units, such as the pulser/receiver, transducer, and display devices. A pulser/receiver is an electronic device that can produce high voltage electrical pulse. Driven by the pulser, the transducer of various types and shapes generates high frequency ultrasonic energy operating based on the piezoelectricity technology with using quartz, lithium sulfate, or various ceramics. Most inspections are carried out in the frequency rang of 1 to 25MHz. Couplants are used to transmit the ultrasonic waves from the transducer to the test piece; typical couplants are water, oil, glycerin and grease. The sound energy is introduced and propagates through the materials in the form of waves and reflected from the opposing surface. An internal defect such as crack or void interrupts the waves' propagation and reflects back a portion of the ultrasonic wave. The amplitude of the energy and the time required for return indicate the presence and location of any flaws in the work-piece. The ultrasonic inspection method has high penetrating power and sensitivity. It can be used from various directions to inspect flaws in large parts, such as rail road wheels pressure vessels and die blocks. This method requires experienced personnel to properly conduct the inspection and to correctly interpret the results. As a very useful and versatile NDT method, ultrasonic inspection method has the following advantages; sensitivity to both surface and subsurface discontinuities, superior depth of penetration for flaw detection or measurement, ability to single-sided access for pulse-echo technique, high accuracy in determining reflector position and estimating size and shape, minimal part preparation, instantaneous results with electronic equipment, detailed imaging with automated systems, possibility for other uses such as thickness measurements.
Its limitations; necessity for an accessible surface to transmit ultrasound, extensive skill and training, requirement for a coupling medium to promote transfer of sound energy into test specimen, limits for roughness, shape irregularity, smallness, thickness or not homogeneity, difficulty to inspect of coarse grained materials due to low sound transmission and high signal noise, necessity for the linear defects to be oriented parallel to the sound beam, necessity for reference standards for both equipment calibration, and characterization of flaws.

Acoustic Method:
There are two different kind of acoustic methods: (a) acoustic emission; (b) acoustic impact technique.

Acoustic emission:
This technique is typically performed by elastically stressing the part or structure, for example, bending a beam, applying torque to a shaft, or pressurizing a vessel and monitoring the acoustic responses emitted from the material. During the structural changes the material such as plastic deformation, crack initiation, and propagation, phase transformation, abrupt reorientation of grain boundaries, bubble formation during boiling in cavitation, friction and wear of sliding interfaces, are the source of acoustic signals. Acoustic emissions are detected with sensors consisting of piezoelectric ceramic elements. This method is particularly effective for continuous surveillance of load-bearing structures.

Acoustic impact technique:
This technique consists of tapping the surface of an object and listening to and analyzing the signals to detect discontinuities and flaws. The principle is basically the same as when one taps walls, desktops or countertops in various locations with a finger or a hammer and listens to the sound emitted. Vitrified grinding wheels are tested in a similar manner to detect cracks in the wheel that may not be visible to the naked eye. This technique is easy to perform and can be instrumented and automated. However, the results depend on the geometry and mass of the part so a reference standard is necessary for identifying flaws

Test	Application	Limitation
Visual Inspection	Macroscopic surface flaws Small flaws are difficult to detect, no subsurface flaws.	Microscopy surface flaws Not applicable to larger structures; no subsurface flaws.
Dye penetrate	Surface flaws No subsurface	flaws not for porous materials
Magnetic Particle	Surface / near surface and layer flaws	Limited subsurface capability, only for ferromagnetic materials
Ultrasonic	Subsurface flaws Material must be good conductor of sound.	
Eddy Current	Surface and near surface flaws	Difficult to interpret in some applications; only for metals
Radiography	Subsurface flaws Smallest defect detectable is 2% of the thicknes;	radiation protection No subsurface flaws not for porous materials
Acoustic emission	Can analyze entire structure	Difficult to interpret, expensive equipments.

NON-DESTRUCTIVE TESTING – VISUAL TESTING – GENERAL PRINCIPLES

Direct visual testing
Direct visual testing may usually be made for local visual testing when access is sufficient to place the eye within 600 mm of the surface to be tested and at an angle not less than 30° to the surface to be tested. Mirrors may be used to improve the angle of vision, and aids such as a magnifying lens, endoscope and fibre optic may be used to assist testing.
Direct visual testing may also be made at greater distances than 600 mm specifically for general visual testing. A viewing distance appropriate to the test shall be used. The specific part,

component, vessel, or section thereof, under immediate test, shall be illuminated, if necessary, with auxiliary lighting, to attain a minimum of 160 lx for general visual testing and a minimum of 500 lx for local visual testing.
Consideration shall be given to the application of illuminance to maximize the effectiveness of the test by:
a) using the optimum direction of light with respect to the viewing point;
b) avoiding glare;
c) optimizing the colour temperature of the light source;
d) using an illumination level compatible with the surface reflectivity.

Remote visual testing
When direct visual testing cannot be utilized, remote visual testing may have to be substituted. Remote visual testing uses visual aids such as endoscopes and fibre optics, coupled to cameras or other suitable instruments. The suitability of the remote visual testing system to perform the designated task shall be proven.

Personnel

Personnel who carry out tests according to this standard shall be shown to:
a) be familiar with relevant standards, rules, specifications, equipment procedures/instructions;
b) be familiar with the relevant manufacturing procedure used and/or with the operating conditions of the component to be tested;
c) have satisfactory vision in accordance with EN 473. In addition, when performing general visual testing far vision shall be checked using the standard optotype in
All visual tests shall be evaluated in terms of the acceptance criteria specified (e.g. product standard, contract).

Post-test documentation

When required (e.g. product standard, contract) a written test report shall be provided detailing the following:
a) date and place of test;
b) method used according to clauses 5 or 6;
c) acceptance criteria and/or written procedure/instruction reference;
d) equipment and/or system utilized including set-up;
e) reference to customer's order;
f) name of organization carrying out test;
g) description and identification of test object;
h) details of test findings with respect to the acceptance criteria (e.g. size, location);
i) extent of test coverage;
j) name and signature of person conducting test with date;
k) name and signature of person supervising test with date, if required;
l) marking of component tested, when appropriate;
m) results.
This may be accomplished by referencing the visual testing written procedure and/or the instruction.
Records
Records shall be maintained as required (e.g. product standard, contract).

UNIT II SURFACE NDE METHODS

Liquid penetrant method:
In this method the surfaces to be inspected should be free from any coatings, paint, grease. dirt, dust, etc., therefore, should be cleaned with an appropriate way. Special care should be taken not to give additional damage to the surface to be inspected during the cleaning process. Otherwise, the original nature of surface could be disturbed and the results could be erroneous with the additional interferences of the surface features formed during the cleaning process. Surface cleaning can be performed with alcohol. Special chemicals like cleaner-remover can also be applied if needed. In the experiment, only cleaner remover will be sufficient. Subsequent to surface cleaning, the surface is let to dry for 2 minutes. Commercially available cans of liquid penetrant dyes with different colors are used to reveal the surface defects.

Steps used in the experiment
:
 Clean the surface with alcohol and let surface dry for 5 min.
 Apply the liquid penetrant spray (red can) to the surface and brush for further penetration. Then, wait for 20 min.
 Wipe the surface with a clean textile and subsequently apply remover spray (blue can) to remove excess residues on the surface and wait for a few min.
 Apply the developer spray (yellow can) at a distance of about 30cm from the surface. Thedeveloper will absorb the penetrant that infiltrated to the surface features such as cracks, splits, etc., and thenreacted with it to form a geometric shape which is the negative of the
 geometry of the surface features from which the penetrant is sucked.
 The polymerized material may be collected on a sticky paper for futureevaluation and related documentation, if needed

Penetrants
Penetrants are carefully formulated to produce the level of sensitivity desired by the inspector. The penetrant must possess a number of important characteristics:
- spread easily over the surface of the material being inspected to provide complete and even coverage.
- be drawn into surface breaking defects by capillary action.
- remain in the defect but remove easily from the surface of the part.
- remain fluid so it can be drawn back to the surface of the part through the drying and developing steps.
- be highly visible or fluoresce brightly to produce easy to see indications.
- not be harmful to the material being tested or the inspector.

Penetrant materials are not designed to perform the same. Penetrant manufactures have developed different formulations to address a variety of inspection applications. Some applications call for the detection of the smallest defects possible while in other applications, the rejectable defect size may be larger. The penetrants that are used to detect the smallest defects will also produce the largest amount of irrelevant indications. Standard specifications classify penetrant materials according to their physical characteristics and their performance.

Penetrant materials come in two basic types:

Type 1 - Fluorescent Penetrants: they contain a dye or several dyes that fluoresce when exposed to ultraviolet radiation.
Type 2 - Visible Penetrants: they contain a red dye that provides high contrast against the white

developer background.

Fluorescent penetrant systems are more sensitive than visible penetrant systems because the eye is drawn to the glow of the fluorescing indication. However, visible penetrants do not require a darkened area and an ultraviolet light in order to make an inspection.
Penetrants are then classified by the method used to remove the excess penetrant from the part. The four methods are:

Method A - Water Washable: penetrants can be removed from the part by rinsing with water alone. These penetrants contain an emulsifying agent (detergent) that makes it possible to wash the penetrant from the part surface with water alone.Water washable penetrants are sometimes referred to as self-emulsifying systems.

Method B - Post-Emulsifiable, Lipophilic: the penetrant is oil soluble and interacts with the oil-based emulsifier to make removal possible.

Method C - Solvent Removable: they require the use of a solvent to remove the penetrant from the part.

Method D - Post-Emulsifiable, Hydrophilic: they use an emulsifier that is a water soluble detergent which lifts the excess penetrant from the surface of the part with a water wash.
Penetrants are then classified based on the strength or detectability of the indication that is produced for a number of very small and tight fatigue cracks. The five sensitivity levels are:
Level ½ - Ultra Low Sensitivity
Level 1 - Low Sensitivity
Level 2 - Medium Sensitivity
Level 3 - High Sensitivity
Level 4 - Ultra-High Sensitivity
The procedure for classifying penetrants into one of the five sensitivity levels uses specimens with small surface fatigue cracks. The brightness of the indication produced is measured using a photometer.

Developers
The role of the developer is to pull the trapped penetrant material out of defects and spread it out on the surface of the part so it can be seen by an inspector. Developers used with visible penetrants create a white background so there is a greater degree of contrast between the indication and the surrounding background. On the other hand, developers used with fluorescent penetrants both reflect and refract the incident ultraviolet light, allowing more of it to interact with the penetrant, causing more efficient fluorescence.
According to standards, developers are classified based on the method that the developer is applied (*as a drypowder, or dissolved or suspended in a liquid carrier*). The six standard forms of developers are:

Form a - Dry Powder
Form b - Water Soluble
Form c - Water Suspendable
Form d - Nonaqueous Type 1: Fluorescent (Solvent Based)
Form e - Nonaqueous Type 2: Visible Dye (Solvent Based)
Form f - Special Applications

Dry Powder
Dry powder developers are generally considered to be the least sensitive but they are inexpensive to use and easy to apply. Dry developers are white, fluffy powders that can be applied to a thoroughly dry surface in a number of ways; by dipping parts in a container of developer, by using a puffer to dust parts

with the developer, or placing parts in a dust cabinet where the developer is blown around. Since the powder only sticks to areas of indications since they are wet, powder developers are seldom used for visible inspections.

Water Soluble

As the name implies, water soluble developers consist of a group of chemicals that are dissolved in water and form a developer layer when the water is evaporated away. The best method for applying water soluble developers is by spraying it on the part. The part can be wet or dry. Dipping, pouring, or brushing the solution on to the surface is sometimes used but these methods are less desirable. Drying is achieved by placing the wet, but well drained part, in a recirculating warm air dryer with a temperature of 21°C. Properly developed parts will have an even, light white coating over the entire surface.

Water Suspendable

Water suspendable developers consist of insoluble developer particles suspended in water. Water suspendable developers require frequent stirring or agitation to keep the particles from settling out of suspension. Water suspendable developers are applied to parts in the same manner as water soluble developers then the parts are dried using warm air.

Nonaqueous

Nonaqeous developers suspend the developer in a volatile solvent and are typically applied with a spray gun. Nonaqueous developers are commonly distributed in aerosol spray cans for portability. Th solvent tends to pull penetrant from the indications by solvent action. Since the solvent is highly volatile, forced drying is not required

Steps of Liquid Penetrant Testing

The exact procedure for liquid penetrant testing can vary from case to case depending on several factors such as the penetrant system being used, the size and material of the component being inspected, the type of discontinuities being expected in the component and the condition and environment under which the inspection is performed. However, the general steps can be summarized as follows:

1. *Surface Preparation*: One of the most critical steps of a liquid penetrant testing is the surface preparation. The surface must be free of oil, grease, water, or other contaminants that may prevent penetrant from entering flaws. The sample may also require etching if mechanical operations such as machining, sanding, or grit blasting have been performed. These and other mechanical operations can smear metal over the flaw opening and prevent the penetrant from entering.

2. *Penetrant Application*: Once the surface has been thoroughly cleaned and dried, the penetrant material is applied by spraying, brushing, or immersing the part in a penetrant bath.

3. *Penetrant Dwell*: The penetrant is left on the surface for a sufficient time to allow as much penetrant as possible to be drawn or to seep into a defect. Penetrant dwell time is the total time that the penetrant is in contact with the part surface. Dwell times are usually recommended by the penetrant producers or required by the specification being followed. The times vary depending on the application, penetrant materials used, the material, the form of the material being inspected, and the type of discontinuity being inspected for. Minimum dwell times typically range from 5 to 60 minutes. Generally, there is no harm in using a longer penetrant dwell time as long as the penetrant is not allowed to dry. The ideal dwell time is often determined by experimentation and may be very specific to a particular application.

4. *Excess Penetrant Removal*: This is the most delicate step of the inspection procedure because the excess penetrant must be removed from the surface of the sample while removing as little penetrant as

possible from defects Depending on the penetrant system used, this step may involve cleaning with a solvent, direct rinsing with water, or first treating the part with an emulsifier and then rinsing with water.

5. *Developer Application*: A thin layer of developer is then applied to the sample to draw penetrant trapped in flaws back to the surface where it will be visible. Developers come in a variety of forms that may be applied by dusting (*dry powders*), dipping, or spraying (*wet developers*

6. *Indication Development*: The developer is allowed to stand on the part surface for a period of time sufficient to permit the extraction of the trapped penetrant out of any surface flaws. This development time is usually a minimum of 10 minutes. Significantly longer times may be necessary for tight cracks.

7. *Inspection*: Inspection is then performed under appropriate lighting to detect indications from any flaws which may be present.

8. *Clean Surface*: The final step in the process is to thoroughly clean the part surface to remove the developer from the parts that were found to be acceptable.

Advantages
 High sensitivity (*small discontinuities can be detected*).
 Few material limitations (*metallic and nonmetallic, magnetic and nonmagnetic, and conductive and nonconductive materials may be inspected*).
 . Rapid inspection of large areas and volumes.
 Suitable for parts with complex shapes.
 Indications are produced directly on the surface of the part and constitute a visual representation of the flaw.
 Portable (materials are available in aerosol spray cans)
 Low cost (materials and associated equipment are relatively inexpensive)

Disadvantages
 Only surface breaking defects can be detected.
 Only materials with a relatively nonporous surface can be inspected.
 Pre-cleaning is critical since contaminants can mask defects.
 Metal smearing from machining, grinding, and grit or vapor blasting must be removed.
 The inspector must have direct access to the surface being inspected.
 Surface finish and roughness can affect inspection sensitivity.
 Multiple process operations must be performed and controlled.
 Post cleaning of acceptable parts or materials is required.
 Chemical handling and proper disposal is required

Magnetic Particle Testing

Magnetic particle testing is one of the most widely utilized NDT methods since it is fast and relatively easy to apply and part surface preparation is not as critical as it is for some other methods. This mithod uses magnetic fields and small magnetic particles (*i.e.iron filings*) to detect flaws in components. The only requirement from an inspectability standpoint is that the component being inspected must be made of a ferromagnetic material (*a materials that can be magnetized*) such as iron, nickel, cobalt, or some of their alloys.The method is used to inspect a variety of product forms including castings, forgings, and weldments. Many different industries use magnetic particle inspection such as structural steel, automotive, petrochemical, power generation, and aerospace industries. Underwater inspection is another area where magnetic particle inspection may be used to test items such as offshore structures and underwater pipelines.

Basic Principles

In theory, magnetic particle testing has a relatively simple concept. It can be considered as a combination of two nondestructive testing methods:

1. Magnetic flux leakage testing and
2. visual testing.

For the case of a bar magnet, the magnetic field is in and around the magnet. Any place that a magnetic line of force exits or enters the magnet is called a "pole" (*magnetic lines of force exit the magnet from north pole and enter from the south pole*).When a bar magnet is broken in the center of its length, two complete bar magnets with magnetic poles on each end of each piece will result. If the magnet is just cracked but not broken completely in two, a north and south pole will form at each edge of the crack.
The magnetic field exits the North Pole and reenters at the south pole. The magnetic field spreads out when it encounters the small air gap created by the crack because the air cannot support as much magnetic field per unit volume as the magnet can. When the field spreads out, it appears to leak out of the material and, thus is called a flux leakage field.

If iron particles are sprinkled on a cracked magnet, the particles will be attracted to and cluster not only at the poles at the ends of the magnet, but also at the poles at the edges of the crack. This cluster of particles is much easier to see than the actual crack and this is the basis for magnetic particle inspectioThe first step in a magnetic particle testing is to magnetize the component that is to be inspected. If any defects on or near the surface are present, the defects will create a leakage field. After the component has been magnetized, iron particles, either in a dry or wet suspended form, are applied to the surface of the magnetized part. The particles will be attracted and cluster at the flux leakage fields, thus forming a visible indication that the inspector can detect.

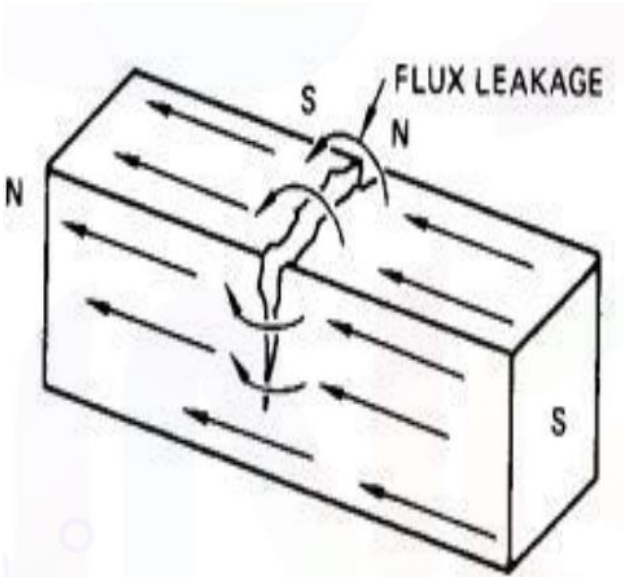


Fig.Flux leakage

Advantages

- High sensitivity (*small discontinuities can be detected*).
- Indications are produced directly on the surface of the part and constitute a visual representation of flaw.

- Minimal surface preparation (*no need for paint removal*)
- Portable (*small portable equipment & materials available in spray cans*)
- Low cost (*materials and associated equipment are relatively inexpensive*)

Disadvantages
- Only surface and near surface defects can be detected.
- Only applicable to ferromagnetic materials.
- Relatively small area can be inspected at a time.
- Only materials with a relatively nonporous surface can be inspected.

Magnetism

The concept of magnetism centers around the magnetic field and what is known as a dipole. The term "*magnetic field*" simply describes a volume of space where there is a change in energy within that volume.
The location where a magnetic field exits or enters a material is called a magnetic pole. Magnetic poles have never been detected in isolation but always occur in pairs, hence the name dipole. Therefore, a dipole is an object that has a magnetic pole on one end and a second, equal but opposite, magnetic pole on the other. A bar magnet is a dipole with a north pole at one end and south pole at the other.The source of magnetism lies in the basic building block of all matter, the atom. Atoms are composed of protons, neutrons and electrons. The protons and neutrons are located in the atom's nucleus and the electrons are in constant motion around the nucleus. Electrons carry a negative electrical charge and produce a magnetic field as they move through space. A magnetic field is produced whenever an electrical charge is in motion.
The strength of this field is called the magnetic moment.nWhen an electric current flows through a conductor, the movement of electrons through the conductor causes a magnetic field to form around the conductor. The magnetic field can be detected using a compass. Since all matter is comprised of atoms, all materials are affected in some way by a magnetic field; however, materials do not react the same way to the magnetic field.

Reaction of Materials to Magnetic Field

When a material is placed within a magnetic field, the magnetic forces of the material's electrons will be affected. This effect is known as Faraday's Law of Magnetic Induction. However, materials can react quite differently to the presence of an external magnetic field. The magnetic moments associated with atoms have three origins: the electron motion, the change in motion caused by an external magnetic field, and the spin of the electrons. In most atoms, electrons occur in pairs where these pairs spin in opposite directions.
The opposite spin directions of electron pairs cause their magnetic fields to cancel each other. Therefore, no net magnetic field exists. Alternately, materials with some unpaired electrons will have a net magnetic field and will react more to an external field.

According to their interaction with a magnetic field, materials can be classified as:

Diamagnetic materials
Diamagnetic materials have a weak, negative susceptibility to magnetic fields. Diamagnetic materials are slightly repelled by a magnetic field and the material does not retain the magnetic properties when the external field is removed. In diamagnetic materials all the electrons are paired so there is no permanent net magnetic moment per atom. Most elements in the periodic table, including copper, silver, and gold, are diamagnetic.

Paramagnetic materials
Paramagnetic materials have a small, positive susceptibility to magnetic fields. These materials are slightly attracted by a magnetic field and the material does not retain the magnetic properties when the external field is removed. Paramagnetic materials have some unpaired electrons. Examples of paramagnetic materials include magnesium, molybdenum, and lithium.

Ferromagnetic materials
Ferromagnetic materials have a large, positive susceptibility to an external magnetic field. They exhibit a strong attraction to magnetic fields and are able to retain their magnetic properties after the external field has been removed. Ferromagnetic materials have some unpaired electrons so their atoms have a net magnetic moment. They get their strong magnetic properties due to the presence of magnetic domains. In these domains, large numbers of atom's moments are aligned parallel so that the magnetic force within the domain is strong (*this happens during the solidification of the material where the atom moments are aligned within each crystal "i.e., grain" causing a strong magnetic force in one direction*). When a ferromagnetic material is in theunmagnetized state, the domains are nearly randomly organized (*since the crystals are in arbitrary directions*) and the net magnetic field for the part as a whole is zero. When a magnetizing force is applied, the domains become aligned to produce a strong magnetic field within the part. Iron, nickel, and cobalt are examples of ferromagnetic materials. Components made of these materials are commonly inspected using the magnetic particle method.

Magnetic Field Characteristics
Magnetic Field In and Around a Bar Magnet
The magnetic field surrounding a bar magnet can be seen in the magnetograph below. A magnetograph can be created by placing a piece of paper over a magnet and sprinkling the paper with iron filings. The particles align themselves with the lines of magnetic force produced by the magnet. It can be seen in the magnetograph that there are poles all along the length of the magnet but that the poles are concentrated at the ends of the magnet (*the north and south poles*).

Magnetic Fields in and around Horseshoe and Ring Magnets
Magnets come in a variety of shapes and one of the more common is the horseshoe (U) magnet. The horseshoe magnet has north and south poles just like a bar magnet but the magnet is curved so the poles lie in the same plane. The magnetic lines of force flow from pole to pole just like in the bar magnet. However, since the poles are located closer together and a more direct path exists for the lines of flux to travel between the poles, the magnetic field is concentrated between the poles.

General Properties of Magnetic Lines of Force
Magnetic lines of force have a number of important properties, which include:
They seek the path of least resistance between opposite magnetic poles (*in a single bar magnet shown, they attempt to form closed loops from pole to pole*).
They never cross one another.
They all have the same strength.
Their density decreases with increasing distance from the poles.
Their density decreases (*they spread out*) when they move from an area of higher permeability to an area of lower permeability.
They are considered to have direction as if flowing, though no actual movement occurs.
They flow from the south pole to the north pole within a material and north pole to south pole in air.

Electromagnetic Fields
Magnets are not the only source of magnetic fields. The flow of electric current through a conductor generates a magnetic field. When electric current flows in a long straight wire, a circular magnetic field is

generated around the wire and the intensity of this magnetic field is directly proportional to the amount of current carried by the wire. The strength of the field is strongest next to the wire and diminishes with distance. In most conductors, the magnetic field exists only as long as the current is flowing However, in ferromagnetic materials the electric current will cause some or all of the magnetic domains to align and a residual magnetic field will remain. Also, the direction of the magnetic field is dependent on the direction of the electrical current in the wire. The direction of the magnetic field around a conductor can be determined using a simple rule called the "*right-hand clasp rule*". If a person grasps a conductor in one's right hand with the thumb pointing in the direction of the current, the fingers will circle the conductor in the direction of the magnetic field.

Magnetic Field Produced by a Coil

When a current carrying wire is formed into several loops to form a coil, the magnetic field circling each loop combines with the fields from the other loops to produce a concentrated field through the center of the coil (*the field flows along the longitudinal axis and circles back around the outside of the coil*). When the coil loops are tightly wound, a uniform magnetic field is developed throughout the length of the coil. The strength of the magnetic field increases not only with increasing current but also with each loop that is added to the coil. A long, straight coil of wire is called a *solenoid* and it can be used to generate a nearly uniform magnetic field similar to that of a bar magnet. The concentrated magnetic field inside a coil is very useful in magnetizing ferromagnetic materials for inspection using the magnetic particle testing method.

Quantifying Magnetic Properties

The various characteristics of magnetism can be measured and expressed quantitatively. Different systems of units can be used for quantifying magnetic properties. SI units will be used in this material. The advantage of using SI units is that they are traceable back to an agreed set of four base units; meter, kilogram, second, and Ampere. The unit for magnetic *field strength* **H** is *ampere/meter* (*A/m*). A magnetic field strength of *1 A/m* is produced at the center of a single circular conductor with a *1 meter* diameter carrying a steady current of *1 ampere*.

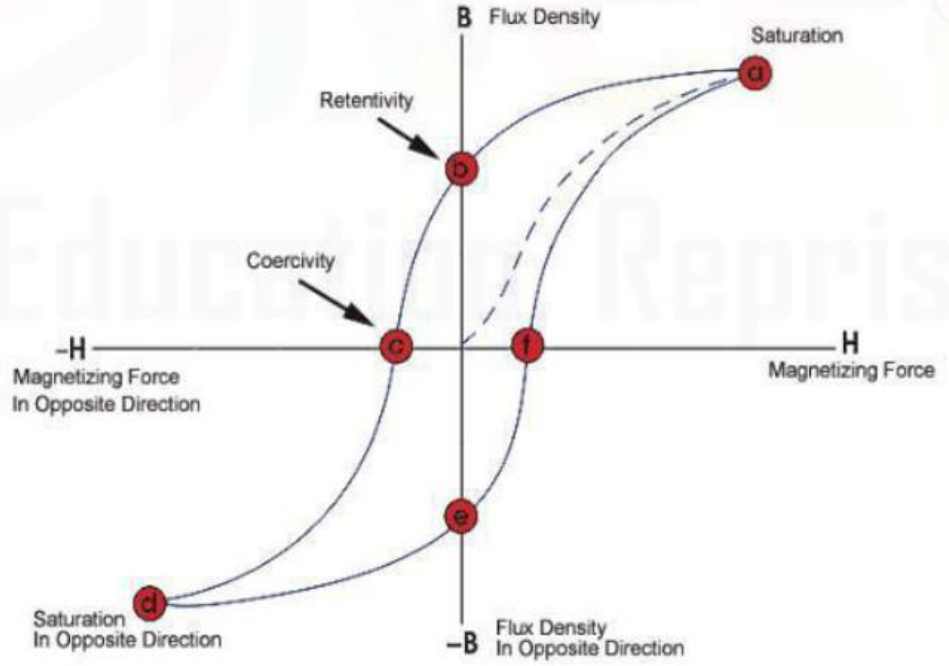
The number of magnetic lines of force cutting through a plane of a given area at a right angle is known as the magnetic *flux density*, **B**. The flux density or magnetic induction has the *Tesla* as its unit. One *Tesla* is equal to *1 Newton/(A/m)*. From these units, it can be seen that the flux density is a measure of the force applied to a particle by the magnetic field.

The total number of lines of magnetic force in a material is called magnetic *flux*, **ϕ**. The strength of the flux is determined by the number of magnetic domains that are aligned within a material. The *total flux* is simply the flux density applied over an area. Flux carries the unit of a *weber*, which is simply a *Teslameter* ^{2}.

The *magnetization* **M** is a measure of the extent to which an object is magnetized. It is a measure of the magnetic dipole moment per unit volume of the object. Magnetization carries the same units as a magnetic field *A/m*

The Hysteresis Loop and Magnetic Properties

A great deal of information can be learned about the magnetic properties of a material by studying its hysteresis loop. A hysteresis loop shows the relationship between the induced magnetic flux density (**B**) and the magnetizing force (**H**). It is often referred to as the *B-H* loop. An example hysteresis loop is shown below.



The loop is generated by measuring the magnetic flux of a ferromagnetic material while the magnetizing force is changed. A ferromagnetic material that has never been previously magnetized or has been thoroughly demagnetized will follow the dashed line as **H** is increased. As the line demonstrates, the greater the amount of current applied (***H+***), the stronger the magnetic field in the component (***B+***). At point "***a***"almost all of the magnetic domains are aligned and an additional increase in the magnetizing force will produce very little increase in magnetic flux. The material has reached the point of magnetic saturation. When **H** is reduced to zero, the curve will move from point "***a***" to point "***b***". At this point, it can be seen that some magnetic flux remains in the material even though the magnetizing force is zero.

This is referred to at the point of retentivity on the graph and indicates the level of residual magnetism in the material (*Some of the magnetic domains remain aligned but some have lost their alignment*). As the magnetizing force is reversed, the curve moves to point "***c***", where the flux has been reduced to zero. This is called the point of coercivity on the curv (*the reversed magnetizing force has flipped enough of the domains so that the net flux within the material is zero*). The force required to remove the residual magnetism from the material is called the coercive force or coercivity of the material. As the magnetizing force is increased in the negative direction, the material will again become magnetically saturated but in the opposite direction, point "***d***". Reducing **H** to zero brings the curve to point "***e***". It will have a level of residual magnetism equal to that achieved in the other direction. Increasing **H** back in the positive direction will return **B** to zero. Notice that the curve did not return to the origin of the graph because some force is required to remove the residual magnetism. The curve will take a different path from point "***f***" back to the saturation point where it with complete the loop.

From the hysteresis loop, a number of primary magnetic properties of a material can be determined:

1. ***Retentivity*** - A measure of the residual flux density corresponding to the saturation induction of a magnetic material. In other words, it is a material's ability to retain a certain amount of residual magnetic field when the magnetizing force is removed after achieving saturation (The value of **B** at point ***b*** on the hysteresis curve).

2. ***Residual Magnetism or Residual Flux*** - The magnetic flux density that remains in a material when the magnetizing force is zero. Note that residual magnetism and retentivity are the same when the material has been magnetized to the saturation point. However, the level of residual magnetism may be lower than the retentivity value when the magnetizing force did not reach the saturation level.

3. ***Coercive Force*** - The amount of reverse magnetic field which must be applied to a magnetic material to make the magnetic flux return to zero (The value of **H** at point ***c*** on the hysteresis curve).

4. Permeability, μ - A property of a material that describes the ease with which a magnetic flux is established in the material.

5. ***Reluctance*** - Is the opposition that a ferromagnetic material shows to the establishment of a magnetic field. Reluctance is analogous to the resistance in an electrical circuit.

Permeability

As previously mentioned, permeability (μ) is a material property that describes the ease with which a magnetic flux is established in a component. It is the ratio of the flux density (B) created within a material to the magnetizing field (H) and it is represented by the following equation:

$\mu = B/H$

This equation describes the slope of the curve at any point on the hysteresis loop. The permeability value given in letrature for materials is usually the maximum permeability or the maximum relative permeability. The maximum permeability is the point where the slope of the B/H curve for the unmagnetized material is the greatest. This point is often taken as the point where a straight line from the origin is tangent to the B/H curve. The shape of the hysteresis loop tells a great deal about the material being magnetized. The hysteresis curves of two different materials are shown in the graph.

Relative to other materials, a material with a narrower hysteresis loop has:
- Higher Permeability
- Lower Retentivity
- Lower Coercivity
- Lower Reluctance
- Lower Residual Magnetism

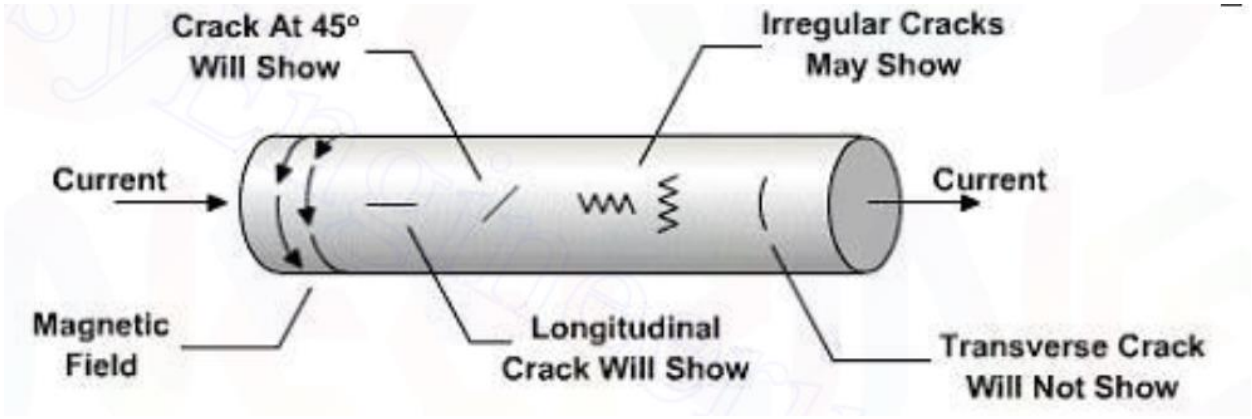
In magnetic particle testing, the level of residual magnetism is important. Residual magnetic fields are affected by the permeability, which can be related to the carbon content and alloying of the material. A component with high carbon content will have low permeability and will retain more magnetic flux than a material with low carbon content.

Magnetic Field Orientation and Flaw Detectability

To properly inspect a component for cracks or other defects, it is important to understand that the orientation of the crack relative to the magnetic lines of force determinies if the crack can or cannot be detected. There are two general types of magnetic fields that can be established within a component.
A longitudinal magnetic field has magnetic lines of force that run parallel to the long axis of the part. Longitudinal magnetization of a component can be accomplished using the longitudinal field set up by a coil or solenoid. It can also be accomplished using permanent magnets or electromagnets.
A circular magnetic field has magnetic lines of force that run circumferentially around the perimeter of

a part. A circular magnetic field is induced in an article by either passing current through the component or by passing current through a conductor surrounded by the component.

The type of magnetic field established is determined by the method used to magnetize the specimen.



Being able to magnetize the part in two directions is important because the best detection of defects occurs when the lines of magnetic force are established at right angles to the longest dimension of the defect.
This orientation creates the largest disruption of the magnetic field within the part and the greatest flux leakage at the surface of the part. If the magnetic field is parallel to the defect, the field will see little disruption and no flux leakage field will be produced An orientation of 45 to 90 degrees between the magnetic field and the defect is necessary to form an indication. Since defects may occur in various and unknown directions, each part is normally magnetized in two directions at right angles to each other.
If the component shown is considered, it is known that passing current through the part from end to end will establish a circular magnetic field that will be 90 degrees to the direction of the current.
Therefore, defects that have significant dimension in the direction of the current
(*longitudinal defects*) should be detectable, while transverse-type defects will not be detectable
with circular magnetization.

Magnetization of Ferromagnetic Materials

There are a variety of methods that can be used to establish a magnetic field in a component for evaluation using magnetic particle inspection. It is common to classify the magnetizing methods as either direct or indirect.
Magnetization Using Direct Induction (Direct Magnetization) With direct magnetization, current is passed directly through the component. The flow of current causes a circular magnetic field to form in and around the conductor. When using the direct magnetization method, care must be taken to ensure that good electrical contact is established and maintained between the test equipment and the test component to avoid damage of the the component (*due to arcing or overheating at high resistance ponts*).

There are several ways that direct magnetization is commonly accomplished.
One way involves *clamping the component between two electrical contacts* in a special piece of equipment. Current is passed through the component and a circular magnetic field is established in and around the component. When the magnetizing current is stopped, a residual magnetic field will remain within the component. The strength of the induced magnetic field is proportional to the amount of current passed through the component.

- A second technique involves using *clamps or prods*, which are attached or placed in contact with the component. Electrical current flows through the component from contact to contact. The current sets up a circular magnetic field around the path of the current.

Magnetization Using Indirect Induction (Indirect Magnetization)

Indirect magnetization is accomplished by using a strong external magnetic field to establish a magnetic field within the component. As with direct magnetization, there are several ways that indirect magnetization can be accomplished. The use of *permanent magnets* is a low cost method of establishing a magnetic field. However, their use is limited due to lack of control of the field strength and the difficulty of placing and removing strong permanent magnets from the component.
Electromagnets in the form of an adjustable horseshoe magnet (*called a yoke*) eliminate the problems associated with permanent magnets and are used extensively in industry. Electromagnets only exhibit a magnetic flux when electric current is flowing around the soft iron core. When the magnet is placed on the component, a magnetic field is established between the north and south poles of the magnet.Another way of indirectly inducting a magnetic field in a material is by using the magnetic field of a current carrying conductor. A circular magnetic field can be established in cylindrical components by using a *central conductor*. Typically, one or more cylindrical components are hung from a solid copper bar running through the inside diameter. Current is passed through the copper bar and the resulting circular magnetic field establishes a magnetic field within the test components. The use of *coils and solenoids* is a third method of indirect magnetization. When the length of a component is several times larger than its diameter, a longitudinal magnetic field can be established in the component. The component is placed longitudinally in the concentrated magnetic field that fills the center of a coil or solenoid. This magnetization technique is often referred to as a "*coil shot*".

Types of Magnetizing Current
As mentioned previously, electric current is often used to establish the magnetic field in components during magnetic particle inspection. Alternating current (AC) and direct current (DC) are the two basic types of current commonly used. The type of current used can have an effect on the inspection results, so the types of currents commonly used are briefly discussed here.

Direct Current
Direct current (DC) flows continuously in one direction at a constant voltage. A battery is the most common source of direct current. The current is said to flow from the positive to the negative terminal, though electrons flow in the opposite direction. DC is very desirable when inspecting for subsurface defects because DC generates a magnetic field that penetrates deeper into the material. In ferromagnetic materials, the magnetic field produced by DC generally penetrates the entire cross-section of the component.

Alternating Current
Alternating current (AC) reverses its direction at a rate of 50 or 60 cycles per second. Since AC is readily available in most facilities, it is convenient to make use of it for magnetic particle inspection. However, when AC is used to induce a magnetic field in ferromagnetic materials, the magnetic field will be limited to a thin layer at the surface of the component. This phenomenon is known as the "*skin effect*" and it occurs because the changing magnetic field generates eddy currents in the test object. The eddy currents produce a magnetic field that opposes the primary field, thus reducing the net magnetic flux below the surface. Therefore, it is recommended that AC be used only when the inspection is limited to surface defects.

Rectified Alternating Current

Clearly, the skin effect limits the use of AC since many inspection applications call for the detection of subsurface defects. Luckily, AC can be converted to current that is very much like DC through the process of rectification. With the use of rectifiers, the reversing AC can be converted to a one directional current. The three commonly used types of rectified current are described below.

Half Wave Rectified Alternating Current (HWAC)

When single phase alternating current is passed through a rectifier, current is allowed to flow in only one direction. The reverse half of each cycle is blocked out so that a one directional, pulsating current is produced. The current rises from zero to a maximum and then returns to zero. No current flows during the time when the reverse cycle is blocked out. The HWAC repeats at same rate as the unrectified current (50 or 60 Hz). Since half of the current is blocked out, the amperage is half of the unaltered AC. This type of current is often referred to as *half wave DC or pulsating DC*. The pulsation of the HWAC helps in forming magnetic particle indications by vibrating the particles and giving them added mobility where that is especially important when using dry particles. HWAC is most often used to power electromagnetic yokes.

Full Wave Rectified Alternating Current (FWAC) (Single Phase)

Full wave rectification inverts the negative current to positive current rather than blocking it out. This produces a pulsating DC with no interval between the pulses. Filtering is usually performed to soften the sharp polarity switching in the rectified current. While particle mobility is not as good as half-wave AC due to the reduction in pulsation, the depth of the subsurface magnetic field is improved.

Three Phase Full Wave Rectified Alternating Current

Three phase current is often used to power industrial equipment because it has more favorable power transmission and line loading characteristics. This type of electrical current is also highly desirable for magnetic particle testing because when it is rectified and filtered, the resulting current very closely resembles direct current. Stationary magnetic particle equipment wired with three phase AC will usually have the ability to magnetize with AC or DC (*three phase full wave rectified*), providing the inspector with the advantages of each current form

Magnetic Fields Distribution and Intensity

Longitudinal Fields

When a long component is magnetized using a solenoid having a shorter length, only the material within the solenoid and about the same length on each side of the solenoid will be strongly magnetized. This occurs because the magnetizing force diminishes with increasing distance from the solenoid. Therefore, a long component must be magnetized and inspected at several locations along its length for complete inspection coverage.

Circular Fields

When a circular magnetic field forms in and around a conductor due to the passage of electric current through it, the following can be said about the distribution and intensity of the magnetic field:

- The field strength varies from zero at the center of the component to a maximum at the surface.
- The field strength at the surface of the conductor decreases as the radius of the conductor increases (*when the current strength is held constant*).
- the field strength inside the conductor is dependent on the current strength, magnetic permeability of the material, and, if ferromagnetic, the location on the B-H curve.
- The field strength outside the conductor is directly proportional to the current strength and it decreases with distance orom the conductor.

The images below show the magnetic field strength graphed versus distance from the center of the conductor when current passes through a solid circular conductor.
In a nonmagnetic conductor carrying DC, the internal field strength rises from zero at the center to a maximum value at the surface of the conductor.
In a magnetic conductor carrying DC, the field strength within the conductor is much greater than it is in the nonmagnetic conductor. This is due to the permeability of the magnetic material. The external field is exactly the same for the two materials provided the current level and conductor radius are the same
When the magnetic conductor is carrying AC, the internal magnetic field will be concentrated in a thin layer near the surface of the conductor (*skin effect*). The external field decreases with increasing distance from the surface same as with DC.
a hollow circular conductor there is no magnetic field in the void area. The magnetic field is zero at the inner surface and rises until it reaches a maximum at the outer surface.
Same as with a solid conductor, when DC current is passed through a magnetic conductor, the field strength within the conductor is much greater than in nonmagnetic conductor due to the permeability of the magnetic material. The external field strength decreases with distance from the surface of the conductor.

The external field is exactly the same for the two materials provided the current level and conductor radius are the same.
When AC current is passed through a hollow circular magnetic conductor, the skin effect concentrates the magnetic field at the outside diameter of the component. As can be seen from these three field distribution images, the field strength at the inside surface of hollow conductor is very low when a circular magnetic field is established by direct magnetization. Therefore, the direct method of magnetization is not recommended when inspecting the inside diameter wall of a hollow component for shallow defects (*if the defect has significant depth, it may be detectable using DC since the field strength increases rapidly as one moves from the inner towards the outer surface*).

A much better method of magnetizing hollow components for inspection of the ID and OD surfaces is with the use of a central conductor. As can be seen in the field distribution image, when current is passed through a nonmagnetic central conductor (copper bar), the magnetic field produced on the inside diameter surface of a magnetic tube is much greater and the field is still strong enough for defect detection on the OD surface.

Demagnetization

After conducting a magnetic particle inspection, it is usually necessary to demagnetize the component. Remanent magnetic fields can:
- affect machining by causing cuttings to cling to a component.
- interfere with electronic equipment such as a compass.
- create a condition known as "*arc blow*" in the welding process. Arc blow may cause the weld arc to wonder or filler metal to be repelled from the weld
- cause abrasive particles to cling to bearing or faying surfaces and increase wear.

Removal of a field may be accomplished in several ways. The most effective way to demagnetize a material is by heating the material above its curie temperature (*for instance, the curie temperature for a low carbon steel is 770°C*). When steel is heated above its curie temperature then it is cooled back down, the the orientation of the magnetic domains of the individual grains will become randomized again and thus the component will contain no residual magnetic field. The material should also be placed with its long axis in an east-west orientation to avoid any influence of the Earth's magnetic field However, it is often inconvenient to heat a material above its curie temperature to demagnetize it, so another method that returns the material to a nearly unmagnetized state is commonly used Subjecting the component to a reversing and decreasing magnetic field will return the dipoles to a nearly random orientation throughout

the material. This can be accomplished by pulling a component out and away from a coil with AC passing through it. With AC Yokes, demagnetization of local areas may be accomplished by placing the yoke contacts on the surface, moving them in circular patterns around the area, and slowly withdrawing the yoke while the current is applied. Also, many stationary magnetic particle inspection units come with a demagnetization feature that slowly reduces the AC in a coil in which the component is placed.
A field meter is often used to verify that the residual flu x has been removed from a component. Industry standards usually require that the magnetic flux be reduced to less than 3 Gauss (*3x10-4 Tesla*) after completing a magnetic particle inspectio**n.**

Measuring Magnetic Fields
When performing a magnetic particle inspection, it is very important to be able to determine the direction and intensity of the magnetic field. The field intensity must be high enough to cause an indication to form, but not too high to cause nonrelevant indications to mask relevant indications. Also, after magnetic inspection it is often needed to measure the level of residual magnetezmSince it is impractical to measure the actual field strength within the material, all the devices measure the magnetic field that is outside of the material. The two devices commonly used for quantitative measurement of magnetic fields n magnetic particle inspection are the field indicator and the Hall-effect meter, which is also called a gauss meter.

Field Indicators
Field indicators are small mechanical devices that utilize a soft iron vane that is deflected by a magnetic field. The vane is attached to a needle that rotates and moves the pointer on the scale. Field indicators can be adjusted and calibrated so that quantitative information can be obtained. However, the measurement range of field indicators is usually small due to the mechanics of the device (*the one shown in the image has a range from plus 20 to minus 20 Gauss*). This limited range makes them best suited for measuring the residual magnetic field after demagnetization.

Hall-Effect (Gauss/Tesla) Meter
A Hall-effect meter is an electronic device that provides a digital readout of the magnetic field strength in Gauss or Tesla units. The meter uses a very small conductor or semiconductor element at the tip of the probe. Electriccurrent is passed through the conductor. In a magnetic field, a force is exerted on the moving electrons which tends to push them to one side of the conductor. A buildup of charge at the sides of the conductors will balance this magnetic influence, producing a measurable voltage between the two sides of the conductor. The probe is placed in the magnetic field such that the magnetic lines of force intersect the major dimensions of the sensing element at a right angle.

Magnetization Equipment for Magnetic Particle Testing
To properly inspect a part for cracks or other defects, it is important to become familiar with the different types of magnetic fields and the equipment used to generate them. As discussed previously, one of the primary requirements for detecting a defect in a ferromagnetic material is that the magnetic field induced in the part must intercept the defect at a 45 to 90 degree angle. Flaws that are normal (90 degrees) to the magnetic field will produce the strongest indications because they disrupt more of the magnet flux. Therefore, for proper inspection of a component, it is important to be able to establish a magnetic field in at least two directions. A variety of equipment exists to establish the magnetic field for magnetic particle testing. One way to classify equipment is based on its portability. Some equipment is designed to be portable so that inspections can be made in the field and some is designed to be stationary for ease of inspection in the laboratory or manufacturing facility.

Portable Equipment
Permanent Magnets
Permanent magnets can be used for magnetic particle inspection as the source of magnetism (*bar magnets*

or horseshoe magnets). The use of industrial magnets is not popular because they are very strong (*they require significant strength to remove them from the surface, about 250 N for some magnets*) and thus they are difficult and sometimes dangerous to handle. However, permanent magnets are sometimes used by divers for inspection in underwater environments or other areas, such as explosive environments, where electromagnets cannot be used. Permanent magnets can also be made small enough to fit into tight areas where electromagnets might not fit.

Electromagnetic Yokes

An electromagnetic yoke is a very common piece of equipment that is used to establish a magnetic field. A switch is included in the electrical circuit so that the current and, therefore, the magnetic field can be turned on and off. They can be powered with AC from a wall socket or by DC from a battery pack.

This type of magnet generates a very strong magnetic field in a local area where the poles of the magne touch the part being inspected. Some yokes can lift weights in excess of 40 pounds.

Prods

Prods are handheld electrodes that are pressed against the surface of the component being inspected to make contact for passing electrical current (*AC or DC*) through the metal. Prods are typically made from copper and have an insulated handle to help protect the operator. One of the prods has a trigger switch so that the current can be quickly and easily turned on and off. Sometimes the two prods are connected by any insulator, as shown in the image, to facilitate one hand operation. This is referred to as a dual prod and is commonly used for weld inspections.

However, caution is required when using prods because electrical arcing can occur and cause damage to the component if proper contact is not maintained between the prods and the component surface. For this reason, the use of prods is not allowed when inspecting aerospace and other critical components. To help prevent arcing, the prod tips should be inspected frequently to ensure that they are not oxidized, covered with scale or other contaminant, or damaged.

Portable Coils and Conductive Cables

Coils and conductive cables are used to establish a longitudinal magnetic field within a component. When a preformed coil is used, the component is placed against the inside surface on the coil. Coils typically have three or five turns of a copper cable within the molded frame. A foot switch is often used to energize the coil. Also, flexible conductive cables can be wrapped around a component to form a coil.

The number of wraps is determined by the magnetizing force needed and of course, the length of the cable. Normally, the wraps are kept as close together as possible. When using a coil or cable wrapped into a coil, amperage is usually expressed in ampere-turns. Ampere-turns is the amperage shown on the amp meter times the number of turns in the coil.

Portable Power Supplies

Portable power supplies are used to provide the necessary electricity to the prods, coils or cables. Power supplies are commercially available in a variety of sizes. Small power supplies generally provide up to 1,500A of half-wave DC or AC. They are small and light enough to be carried and operate on either 120V or 240V electrical service. When more power is necessary, mobile power supplies can be used. These units come with wheels so that they can be rolled where needed. These units also operate on 120V or 240V electrical service and can provide up to 6,000A of AC or half-wave DC.

Stationery Equipment

Stationary stationary system is the wet horizontal (bench) unit. Wet horizontal units are designed to allow for batch inspections of a variety of components. The units have head and tail stocks (*similar to a lathe*) with electrical contact that the part can be clamped between. A circular magnetic field is produced with direct magnetization.

Most units also have a movable coil that can be moved into place so the indirect magnetization can be used to produce a longitudinal magnetic field. Most coils have five turns and can be obtained in a variety of sizes.
The wet magnetic particle solution is collected and held in a tank. A pump and hose system is used to apply the particle solution to the components being inspected. Some of the systems offer a variety of options in electrical current used for magnetizing the component (*AC, half wave DC, or full wave DC*). In some units, a demagnetization feature is built in, which uses the coil and decaying AC. magnetic particle inspection equipment is designed for use in laboratory or production environment.

Magnetic Field Indicators

The most common Magnetic Field Indicators Determining whether a magnetic field is of adequate strength and in the proper direction is critical when performing magnetic particle testing. There is actually no easy-to-apply method that permits an exact measurement of field intensity at a given point within a material. Cutting a small slot or hole into the material and measuring the leakage field that crosses the air gap with a Hall-effect meter is probably the best way to get an estimate of the actual field strength within a part. However, since that is not practical, there are a number of tools and methods that are used to determine the presence and direction of the field surrounding a component.

Hall-Effect Meter (Gauss Meter)

As discussed earlier, a Gauss meter is commonly used to measure the tangential field strength on the surface of the part. By placing the probe next to the surface, the meter measures the intensity of the field in the air adjacent to the component when a magnetic field is applied. The advantages of this device are: it provides a quantitative measure of the strength of magnetizing force tangential to the surface of a test piece, it can be used for measurement of residual magnetic fields, and it can be used repetitively. The main disadvantage is that such devices must be periodically calibrated.

Quantitative Quality Indicator (QQI)

The Quantitative Quality Indicator (QQI) or *Artificial Flaw Standard* is often the preferred method of assuring proper field direction and adequate field strength (*it is used with the wet method only*). The QQI is a thin strip (*0.05 or 0.1 mm thick*) of AISI 1005 steel with a specific pattern, such as concentric circles or a plus sign, etched on it. The QQI is placed directly on the surface, with the itched side facing the surface, and it is usually fixed to the surface using a tape then the component is then magnetized and particles applied. When the field strength is adequate, the particles will adhere over the engraved pattern and provide information about the field direction.

Pie Gage

The pie gage is a disk of highly permeable material divided into four, six, or eight sections by nonferromagnetic material (*such as copper*). The divisions serve as artificial defects that radiate out in different directions from the center. The sections are furnace brazed and copper plated. The gage is placed on the test piece copper side up and the test piece is magnetized. After particles are applied and the excess

removed, the indications provide the inspector the orientation of the magnetic field. Pie gages are mainly used on flat surfaces such as weldments or steel castings where dry powder is used with a yoke or prods. The pie gage is not recommended for precision parts with complex shapes, for wet-method applications, or for proving field magnitude. The gage should be demagnetized between readings.

Slotted Strips

Slotted strips are pieces of highly permeable ferromagnetic material with slots of different widths. These strips can be used with the wet or dry method. They are placed on the test object as it is inspected. The indications produced on the strips give the inspector a general idea of the field strength in a particular area.

Magnetic Particles

As mentioned previously, the particles that are used for magnetic particle inspection are a key ingredient as they form the indications that alert the inspector to the presence of defects. Particles start out as tiny milled pieces of iron or iron oxide. A pigment (*somewhat like paint*) is bonded to their surfaces to give the particles color. The metal used for the particles has high magnetic permeability and low retentivity. High magnetic permeability is important because it makes the particles attract easily to small magnetic leakage fields from discontinuities, such as flaws. Low retentivity is important because the particles themselves never become strongly magnetized so they do not stick to each other or the surface of the part. Particles are available in a dry mix or a wet solution.

Dry Magnetic Particles

Dry magnetic particles can typically be purchased in red, black, gray, yellow and several other colors so that a high level of contrast between the particles and the part being inspected can be achieved. The size of the magnetic particles is also very important. Dry magnetic particle products are produced to include a range of particle sizes. The fine particles have a diameter of about 50 μm while the course particles have a diameter of 150 μm (*fine particles are more than 20 times lighter than the coarse particles*).
This makes fine particles more sensitive to the leakage fields from very small discontinuities. However, dry testing particles cannot be made exclusively of the fine particles where coarser particles are needed to bridge large discontinuities and to reduce the powder's dusty nature. Additionally, small particles easily adhere to surface contamination, such as remnant dirt or moisture, and get trapped in surface roughness features.
It should also be recognized that finer particles will be more easily blown away by the wind; therefore, windy conditions can reduce the sensitivity of an inspection. Also, reclaiming the dry particles is not recommended because the small particles are less likely to be recaptured and the "once used" mix will result in less sensitive inspections. The particle shape is also important. Long, slender particles tend to align themselves along the lines of magnetic force. However, if dry powder consists only of elongated particles, the application process would be less than desirable since long particles lack the ability to flow freely. Therefore, a mix of rounded and elongated particles is used since it results in a dry powder that flows well and maintains good sensitivity. Most dry particle mixes have particles with L/D ratios between one and two.

Wet Magnetic Particles

Magnetic particles are also supplied in a wet suspension such as water or oil. The wet magnetic particle testing method is generally more sensitive than the dry because the suspension provides the particles with more mobility and makes it possible for smaller particles to be used (*the particles are*

typically 10 μm and smaller) since dust and adherence to surface contamination is reduced or eliminated. The wet method also makes it easy to apply the particles uniformly to a relatively large area.
Wet method magnetic particles products differ from dry powder products in a number of ways. One way is that both visible and fluorescent particles are available. Most non-fluorescent particles are ferromagnetic iron oxides, which are either black or brown in color. Fluorescent particles are coated with pigments that fluoresce when exposed to ultraviolet light. Particles that fluoresce green-yellow are most common to take advantage of the peak color sensitivity of the eye but other fluorescent colors are also available.
The carrier solutions can be water or oil-based. Water-based carriers form quicker indications, are generally less expensive, present little or no fire hazard, give off no petrochemical fumes, and are easier to clean from the part.
Water-based solutions are usually formulated with a corrosion inhibitor to offer some corrosion protection. However, oil-based carrier solutions offer superior corrosion and hydrogen embrittlement protection to those materials that are prone to attack by these mechanisms. Also, both visible and fluorescent wet suspended particles are available in aerosol spray cans for increased portability and ease of application.

Dry Particle Inspection

In this magnetic particle testing technique, dry particles are dusted onto the surface of the test object as the item is magnetized. Dry particle inspection is well suited for the inspections conducted on rough surfaces. When an electromagnetic yoke is used, the AC current creates a pulsating magnetic field that provides mobility to the powder. Dry particle inspection is also used to detect shallow subsurface cracks. Dry particles with half wave DC is the best approach when inspecting for lack of root penetration in welds of thin materials.

Steps for performing dry particles inspection:

Surface preparation - The surface should be relatively clean but this is not as critical as it is with liquid penetrant inspection. The surface must be free of grease, oil or other moisture that could keep particles from moving freely. A thin layer of paint, rust or scale will reduce test sensitivity but can sometimes be left in place with adequate results. Specifications often allow up to 0.076 mm of a nonconductive coating (*such as paint*) or 0.025 mm of a ferromagnetic coating (*such as nickel*) to be left on the surface. Any loose dirt, paint, rust or scale must be removed.o Some specifications require the surface to be coated with a thin layer of white paint in order to improve the contrast difference between the background and the particles (*especially when gray color particles are used*).

Applying the magnetizing force - Use permanent magnets, an electromagnetic yoke, prods, a coil or other means to establish the necessary magnetic flux.

Applying dry magnetic particles - Dust on a light layer of magnetic particles.

Blowing off excess powder - With the magnetizing force still applied, remove the excess powder from the surface with a few gentle puffs of dry air. The force of the air needs to be strong enough to remove the excess particles but not strong enough to remove particles held by a magnetic flux leakage field.

Terminating the magnetizing force - If the magnetic flux is being generated with an electromagnet or an electromagnetic field, the magnetizing force should be terminated. If permanent magnets are being used, they can be left in place.

Inspection for indications - Look for areas where the magnetic particles are clustered.

Wet Suspension Inspection

Wet suspension magnetic particle inspection, more commonly known as wet magnetic particle inspection, involves applying the particles while they are suspended in a liquid carrier. Wet magnetic particle inspection is most commonly performed using a stationary, wet, horizontal inspection unit but suspensions
are also available in spray cans for use with an electromagnetic yoke. A wet inspection has several advantages over a dry inspection. First, all of the surfaces of the component can be quickly and easily covered with a relatively uniform layer of particles. Second, the liquid carrier provides mobility to the particles for an extended period of time, which allows enough particles to float to small leakage fields to form a visible indication. Therefore, wet inspection is considered best for detecting very small discontinuities on smooth surfaces. On rough surfaces, however, the particles (*which are much smaller in wet suspensions*) can settle in the surface valleys and lose mobility, rendering them less effective than dry powders under these conditions.

Steps for performing wet particle inspection:

Surface preparation - Just as is required with dry particle inspections, the surface should be relatively clean. The surface must be free of grease, oil and other moisture that could prevent the suspension from wetting the surface and preventing the particles from moving freely. A thin layer of paint, rust or scale will reduce test sensitivity, but can sometimes be left in place with adequate results. Specifications often allow up to 0.076 mm of a nonconductive coating (*such as paint*) or 0.025 mm of a ferromagnetic coating (*such as nickel*) to be left on the surface. Any loose dirt, paint, rust or scale must be removed. Some specifications require the surface to be coated with a thin layer of white paint when inspecting using visible particles in order to improve the contrast difference between the background and the particles (*especially when gray color particles are used*).

Applying suspended magnetic particles - The suspension is gently sprayed or flowed over the surface of the part. Usually, the stream of suspension is diverted from the part just before the magnetizing field is applied.

Applying the magnetizing force - The magnetizing force should be applied immediately after applying the suspension of magnetic particles. When using a wet horizontal inspection unit, the current is applied in two or three short busts (*1/2 second*) which helps to improve particle mobility.

Inspection for indications - Look for areas where the magnetic particles are clustered. Surface discontinuities will produce a sharp indication. The indications from subsurface flaws will be less defined and lose definition as depth increases.

UNIT-III THERMOGRAPHY AND EDDY CURRENT TESTING (ET)

Introduction

Thermographic inspection refers to the nondestructive testing of parts, materials or systems through the imaging of the thermal patterns at the object's surface. Strictly speaking, the term thermography alone, refers to all thermographic inspection techniques regardless of the physical phenomena used to monitor the thermal changes. For instance, the application of a temperature sensitive coating to a surface in order to measure its temperature is a thermographic inspection contact technique based on heat conduction where there is no infrared sensor involved. Infrared thermography on the other hand, is a nondestructive, nonintrusive, noncontact mapping of thermal patterns or "thermograms", on the surface of objects through the use of some kind of infrared detector.
In addition, there are two approaches in thermographic inspection:
1. Passive, in which the features of interest are naturally at a higher or lower temperature than the background, for example: the surveillance of people on a scene; and
2.Active, in which an energy source is required to produce a thermal contrast between the feature of interest and the background, for example: an aircraft part with internal flaws.
When compared with other classical nondestructive testing techniques such as ultrasonic testing or radiographic testing, thermographic inspection is safe, nonintrusive and noncontact, allowing the detection of relatively shallow subsurface defects under large surfaces)and in a fast manner There are many other terms widely used all referring to infrared thermography, the adoption of one or other term depends on the author's background and preferences. For instance, video thermography and thermal imaging draw attention to the fact that a sequence of images is acquired and is possible to see it as a movie. Pulse-echo thermography and thermal wave imaging are adopted to emphasize the wave nature of heat. Pulsed video thermography, transient thermography, and flash thermograph are used when the specimen is stimulated using a short energy pulse

Technique

A wide variety of energy sources can be used to induce a thermal contrast between defective and non-defective zones that can be divided in external, if the energy is delivered to the surface and then propagated through the material until it encounters a flaw; or internal, if the energy is injected into the specimen in order to stimulate exclusively the defects. Typically, external excitation is performed with optical devices such as photographic flashes or halogen lamp, whereas internal excitation can be achieved by means of mechanical oscillations, with a sonic or ultrasonic transducer [13] for both burst and amplitude modulated stimulation. As depicted in the figure, there are three classical active thermographic techniques based on these two excitation modes
Thermography and pulsed thermography, which are optical techniques applied externally; and vibrothermography, which uses ultrasonic waves to excite internal features. In vibrothermography, an external mechanical energy source induces a temperature difference between the defective and nondefective
areas of the object. In this case, the temperature difference is the main factor that causes the emission of a broad electromagnetic spectrum of infrared radiation, which is not visible to the human eye. The locations of the defects can then be detected by infrared cameras through the process of mapping temperature distribution on the surface of the object
Infrared vision is the capability of biological or artificial systems to detect infrared radiation. The terms thermal vision and thermal imaging, are also commonly used in this context since infrared emissions from a body are directly related to their temperature: hotter objects emit more energy in the infrared spectrum than colder ones. The human body, as well as many moving or static objects of military or civil interest, are normally warmer than the surrounding environment. Since hotter objects emit more

infrared energy than colder ones, it is relatively easy to identify them with an infrared detector, day or night. Hence, the term night vision is also used (sometimes misused) in the place of "infrared vision", since one of the original purposes in developing this kind of systems was to locate enemy targets at night. However, night vision concerns the ability to see in the dark although not necessarily in the infrared spectrum. In fact, night vision equipment can be manufactured using one of two technologies light intensifiers or infrared vision. The former technology uses a photocathode to convert light to electrons, amplify the signal and transform it back to photons. Infrared vision on the other hand, uses an infrared detector working at mid or long wavelengths (invisible to the human eye) to capture the heat emitted by an object
Infrared vision is used extensively by the military for night
vision, navigation, surveillance and targeting. For years, it developed slowly due to the high cost of the equipment and the low quality of available images. Since the development of the first commercial infrared cameras in the second half of the 1960s, however, the availability of new generations of infrared cameras coupled with growing computer power is providing exciting new civilian (and military) applications, to name only a few buildings and infrastructure,[12] works of art, aerospace components[14] and processes, maintenance defect detection and characterization, law enforcement, surveillance and public services, medical and veterinary thermal imaging. The electronic technique that uses infrared vision to "see" thermal energy, to monitor temperatures and thermal patterns is called infrared thermography.

3.4 Infrared thermography (IRT), thermal imaging, and thermal video are examples
of infrared imaging science. Thermographic camerasusually detect radiation in the long-infrared range of the electromagnetic spectrum and produce images of that radiation, called thermograms. Since infrared radiation is emitted by all objects with a temperature above absolute zero according to the black body radiation law, thermography makes it possible to see one's environment with or without visibleillumination. The amount of radiation emitted by an object increases with temperature; therefore, thermography allows one to see variations in temperature. When viewed through a thermal imaging camera, warm objects stand out well against cooler backgrounds; humans and other warmblooded
animals become easily visible against the environment, day or night. As a result, thermography is particularly useful to the military and other users of surveillance cameras.

3.4.1 Thermogram of a cat
Some physiological changes in human beings and other warm-blooded animals can also be monitored with thermal imaging during clinical diagnostics. Thermography is used in allergy detection and veterinary medicine. It is also used for breast screening, though primarily by alternative practitioners as it is considerably less accurate and specific than competing techniques. Government and airport personnel used thermography to detect suspected swine flu cases during the 2009 pandemic.

3.4.2 Thermal imaging camera and screen. Thermal imaging can detect elevated body temperature, one of the signs of the virus H1N1 (Swine influenza).

3.4.3 Thermography has a long history, although its use has increased dramatically with the commercial and industrial applications of the past fifty years. Firefighters use thermography to see through smoke, to find persons, and to localize the base of a fire. Maintenance technicians use thermography to locate overheating joints and sections of power lines, which are a sign of impending failure. Building construction technicians can see thermal signatures that indicate heat leaks in faulty thermal insulation and can use the results to improve the efficiency of heating and air-conditioning units. The appearance and operation of a modern thermographic camera is often similar to a camcorder. Often the live thermogram reveals temperature variations so clearly that a photograph is not necessary for analysis. A recording module is therefore not always built-in.

Non-specialized CCD and CMOS sensors have most of their spectral sensitivity in the visible light wavelength range. However, by utilizing the "trailing" area of their spectral sensitivity, namely the part of the infrared spectrum called near-infrared (NIR), and by using off-the-shelf CCTV camera it is possible under certain circumstances to obtain true thermal images of objects with temperatures at about 280 °C and higher.

Specialized thermal imaging cameras use focal plane arrays that respond to longer wavelengths

The most common types are InSb, InGaAs, HgCdTe and QWIP FPA. The newest technologies use lowcost,

uncooled microbolometers as FPA sensors. Their resolution is considerably lower than that of optical cameras, mostly 160x120 or 320x240 pixels, up to 1024×768 for the most expensive models.

Thermal imaging cameras are much more expensive than their visible-spectrum counterparts, and higherend

models are often export-restricted due to the military uses for this technology. Older bolometers or more sensitive models such as InSb require cryogenic cooling, usually by a miniature Stirling cycle refrigerator or liquid nitrogen.

Advantages

- It shows a visual picture so temperatures over a large area can be compared
- It is capable of catching moving targets in real time
- It is able to find deteriorating, i.e., higher temperature components prior to their failure
- It can be used to measure or observe in areas inaccessible or hazardous for other methods
- It is a non-destructive test method
- It can be used to find defects in shafts, pipes, and other metal or plastic parts
- It can be used to detect objects in dark areas
- It has some medical application, essentially in physiotherapy

Disadvantages

- Quality cameras often have a high price range
- Many models do not provide the irradiance measurements used to construct the output image; the loss of this information without a correct calibration for emissivity, distance, and ambient temperature and relative humidity entails that the resultant images are inherently incorrect measurements of temperature
- Images can be difficult to interpret accurately when based upon certain objects, specifically objects with erratic temperatures, although this problem is reduced in active thermal imaging
- Accurate temperature measurements are hindered by differing emissivities and reflections from other surfaces
- Most cameras have ±2% accuracy or worse in measurement of temperature and are not as accurate as contact methods
- Only able to directly detect surface temperatures

Applications

- Condition monitoring
- Low Slope and Flat Roofing Inspections
- Building diagnostics including building envelope inspections, moisture inspections, and energy losses in buildings
- Thermal Mapping

3.5 Thermochromic Liquid Crystals (TLC)

Materials that change their reflected color as a function of temperature when illuminated by white light. Hence, reflect visible light at different wavelengths.

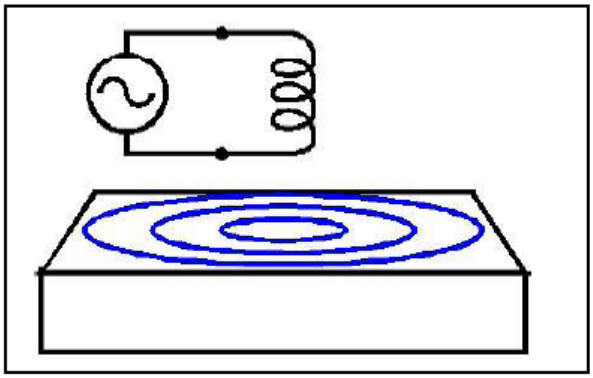
Liquid Crystal Thermography (LCT) in a Nutshell Simplest Implementation, household temperature indicator

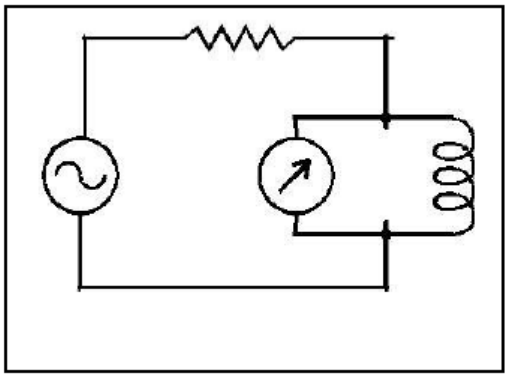
Process:

A heated surface and A liquid crystal with a known color-to-temperature response Example Fishtank

thermometers, Mood rings, Color sensitive coffee cup, etc.!
Liquid Crystal Thermography
Process Specimen preparation and Light source
To ensure good measurement, the goal is to have a smooth and contaminant free calibration and the test specimen surfaces.
Results are brilliant colors and accurate measurement. Preparation Process
Clean calibration and the test specimen surfaces (if possible) with alcohol and ensure that surfaces are dry.
Apply a “thin and uniform” coat of black paint to the test specimen and the calibration surface
Dry the surfaces with a hot air gun at a mild temperature.
Spray or apply the desired TLC material to both surfaces simultaneously.
Measurement Process
A bright and stable white light source is required to obtain accurate and reliable reflected light intensity from a TLC coated surface
The light source must be void of infrared (IR) and ultra-violet (UV) radiation.
Any IR energy present in the incident light will cause radiant heating of the test surface.
Extended exposure to UV radiation can cause rapid deterioration of the TLC surface. This causes the surface to produce unreliable color-temperature response performance.
Consistent light source settings and lighting-viewing arrangements between calibration and actual testing are essential to minimize color-temperature interpretation errors

3.6 EDDY CUURENT TESSTING





When an AC current flows in a coil in close proximity to a conducting surface the magnetic field of the coil will induce circulating (eddy) currents in that surface. The magnitudeand phase of the eddy currents will affect the loading on thecoil and thus its impedance.As an example, assume that there is a deep crack in the surface immediately underneath the coil. This will interrupt or reduce the eddy current flow, thus decreasing the loading on the coil and increasing its effective impedance. This is the basis of eddy current testing, by monitoring the voltage across the coil in such an arrangement we candetect changes in the material of interest. Note that cracks must interrupt the surface eddy current flow to be detected. Cracks lying parallel to the current path will not cause any significant interruption and may not be d etected Crack parallel to eddy currents - not detected Crack interrupts eddy currents – detected

3.6.1 Factors affecting eddy current response
A number of factors, apart from flaws, will affect the eddy current response from a probe. Successful assessment of flaws or any of these factors relies on holding the othersconstant, or somehow eliminating their effect on the results. It is this elimination of undesired response that forms the basis of much of the technology of Eddy current inspection.

The main factors are:

Material conductivity

The conductivity of a material has a very direct effect on the eddy current flow: the greater the conductivity of a material the greater the flow of eddy currents on the surface. Conductivity if often measured by an eddy current technique, and inferences can then be drawn about the different factors affecting conductivity, such as material composition, heat treatment, work hardening etc.

Permeability

This may be described as the ease with which a material can be magnetised. For non-ferrous metals such as copper, brass, aluminium etc., and for austenitic stainless steels the permeability is the same as that of 'free space', i.e. the relative permeability(mr) is one. For ferrous metals however the value of mr may be several hundred, and this has a very significant influence on the eddy current response, in addition it is not uncommon for the permeability to vary greatly within a metal part due to localised stresses, heating effects etc.

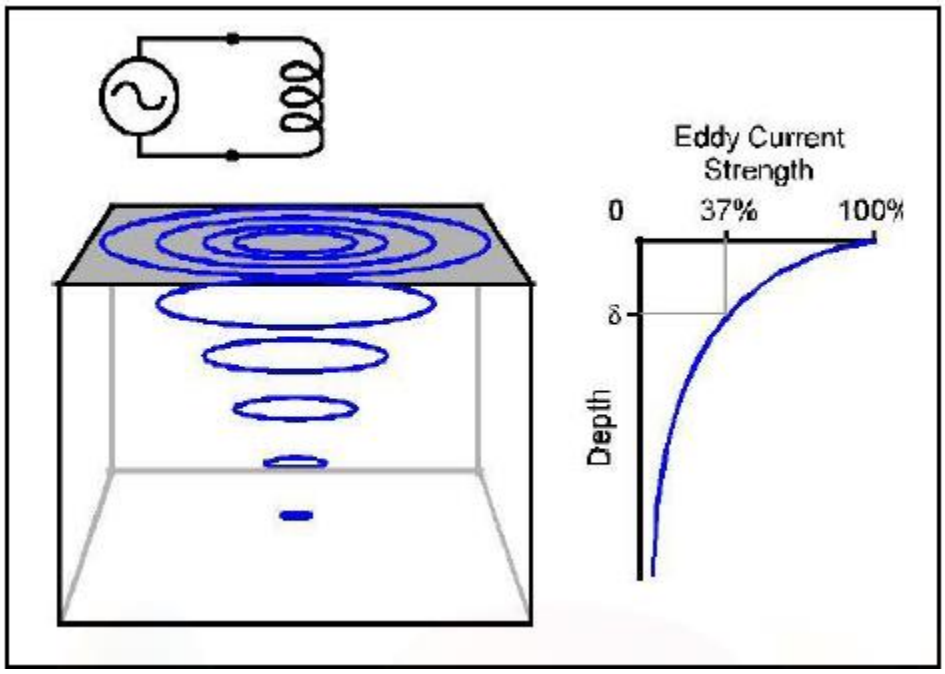
Frequency

As we will discuss, eddy current response is greatly affected by the test frequency chosen, fortunately this is one property we can control.

Geometry

In a real part, for example one which is not flat or of infinite size, Geometrical features such as curvature, edges, grooves etc. will exist and will effect the eddy current response. Test techniques must recognise this, for example in testing an edge for cracks the probe will normally be moved along parallel to the edge so that small changes may be easily seen. Where the material thickness is less than the effective depth of penetration (see below) this will also effect the eddy current response.

Proximity / Lift-off



The closer a probe coil is to the surface the greater will be the effect on that coil. This has two main effects:

· The "lift-off" signal as the probe is moved on and off the surface.

· A reduction in sensitivity as the coil to product spacing increases.

Depth of Penetration

The eddy current density, and thus the strength of the response from a flaw, is greatest on the surface of the metal being tested and declines with depth. It is mathematically convenient to define the "standard depth of penetration" where the eddy current is 1/e (37%) of its surface value.

Coil Configurations

Appropriate coil selection is the most important part of solving an eddy current application, no instrument can achieve much if it doesn't get the right signals from the probe.
Coil designs can be split into three main groups:
1. Surface probes used mostly with the probe axis normal tothe surface, in addition to the basic 'pancake' coil this includes pencil probes and special-purpose surface probes such as those used inside a fastener hole.
2.Encircling coils are normally used for in-line inspection of round products, The product to be tested is inserted though
3.a circular coil. ID probes are normally used for in-service inspection of heat exchangers. The probe is inserted into the tube. Normally ID probes are wound with the coil axis along the centre of the tube. These categories are not exhaustive and there are obviously overlaps, for example between noncircumferential
wound IDprobes and internal surface probes. To this point we have only discussed eddy current probes consisting on a single coil, These are commonly used in many applications and are commonly known as absolute probes because they give an 'absolute' value of the condition at the test point. Absolute probes are very good for metal sorting and detection of cracks in many situations, however they are sensitive also to material variations, temperature changes etc.
4. Differential prob: Another commonly used probe type is the 'differential' probethis has two sensing elements looking at different areas of the material being tested. The instrument responds to the difference between the eddy current conditions at the two points. Differential probes are particularly good for detection of small defects, and are relatively unaffected by lift-off (although the sensitivity is reduced in just the same way), temperature changes and (assuming the instrument circuitry operates in a "balanced" configuration) external interference

3.7 Practical Testing
Any practical Eddy current test will require the following:
A suitable probe
- An instrument with the necessary capabilities.
- A good idea of size, location and type of the flaws it is desired to find
- A suitable test standard to set up the equipment and verify correct operation
- A procedure or accept/reject criteria based on the above.
- The necessary operator expertise to understand and interpret the results.

Typical Instrumentation
There are a number of basic groups of eddy current instrumentation
Special purpose equipment:
Coating thickness meters, conductivity meters (e.g. Hocking AutoSigma) Generally designed to give a digital readout without the operator needing to understand much about the internal technology, except as needed to give reliable test conditions)
"Crack detectors"
fairly simple equipment, generally operates at a restricted number of frequencies typically several hundred kHz, Meter or Bar-graph display. Suitable for surface crack detection and simple sorting

applications only. e.g. Hocking Locator and QuickCheck Normally have some means of compensating for lift-off (e.g. phase rotation and/or fine frequency adjustment) so that only crack-like indications give a reading on the meter or bargraph. An alarm threshold is usually included.
Portable impedance plane
Eddy current Flaw detectors Give a real impedance plane display on a CRT or other electronic display (LCD, plasma etc.) Generally have fairly extensive capabilities: Wide frequency ranges from around a hundred hertz to several megahertz, extensive alarm facilities, general purpose units may have rate filtering (see below) some instruments may be capable of multifrequency operation, allowing combination of results at two or more test frequencies in order to reduce or eliminate specific interfering effects. "Systems" eddy current units. Intended for factory operation, often in Automatic or Semi-Automatic inspection machines. Generally similar operation to impedance plane portables but usually have extensive input and output facilities such as relays and photocell inputs. May be custom built for a specific purpose, in which case features not needed for the intended application are often omitted.

Meter/CRT Instruments
Typical examples (simplified). Hocking NDT Locator UH
Typical Application:
Surface crack detection in aircraft parts using absoluteprobe.
Controls
Meter display indicates 'crack severity' - imbalance from zero point.
Zero - balance internal circuitry
Zero Offset - shift zero point, useful for sorting/material

3.8 Applications
3.8.1Surface crack detection.
Normally carried out with pencil probes or 'pancake' type probes on ferrous or non-ferrous metals. Frequencies from 100 kHz to a few MHz are commonly used. Depending on surface condition it is usually possible to find cracks as small as 0.1 mm or so deep. Differential probes are sometimes used, particularly in automated applications, care must be taken to ensure tha the orientation of flaws is correct for detection.
3.8 .2 Non-ferrous metal sorting
This is essentially conductivity testing and for dedicated applications a conductivity meter may be a better choicFrom the impedance plane diagram it will be seen that the indication from a conductivity change is essentially the same as from a crack, and both meter and impedance plane type crack detectors can be successfully used to sort similar metals using a suitable absolute probe. It should be remembered that widely different metals may have similarconductivity and that the allowable values for sim my overlap, so conductivity measurement should only be used as an indication that a metal is of correct composition or heat-treatment.
3.8 .3 Sub-surface crack/corrosion detection.
Primarily used in Airframe inspection. By using a low frequency and a suitable probe eddy currents can penetrate aluminium or similar structures to a depth of 10mm or so, allowing the detection of second and third layer cracking, which is invisible from the surface, or thinning of any of the different layers making up the structure.

Heat exchanger tube testing
Heat exchangers used for petrochemical or power generation applications may have many thousands of tubes, each up to 20m long. Using a differential ID 'bobbin' probe these tubes can be tested at high speed (up to 1 m/s or so with computerized data analysis.) and by using phase analysis defects such as pitting can be assessed to an accuracy of about 5% of tube wall thickness. This allows accurate estimation of the remaining life of the tube allowing operators to decide on appropriate action such as

tube plugging, tube replacement or replacement of the complete heat exchanger. The operating frequency is determined by the tube material and wall thickness, ranging from a few kHz for thick-walled copper tube up around 600 kHz for thin-walled titanium. Tubes up to around 50mm diameter are commonly inspected with this technique. Inspection of ferrous or magnetic stainless steel tubes is not possible using standard eddy current inspection equipment. Dual or multiple frequency inspections are commonly used for tubing inspection. In particular for suppression of unwanted responses due to tube support plates.. By subtracting the result of a lower frequency test (which gives a proportionately greater response from the support) a mixed signal is produced showing little or no support plate indication, thus allowing the assessment of small defects in this area.

3.8 .5 In-Line inspection of Steel tubing

Almost all high-quality steel tubing is eddy current inspected using encircling coils . When the tube is made of a magnetic material there are two main problems:

1. Because of the high permeability there is little or no penetration of the eddy current field into the tube at practical test frequencies.
2. Variations in permeability (from many causes) cause eddy current responses which are orders of magnitude greater than those from defects.

These problems may be overcome by magnetically saturating the tube using a strong DC field. This reduces the effective permeability to a low value, allowing effective testing.

Tubes up to around 170mm diameter are commonly testedusing magnetic saturation and encircling coils. When tubes are welded this is usually where the problems occur, and so welded tubes are commonly tested in-line using sector coils which only test the weld zone.

Ferrous weld inspection

The geometry and heat-induced material variations around welds in steel would normally prevent inspection with a conventional eddy current probe, however a special purpose “WeldScan” probe has been developed which allows inspection of welded steel structures for fatigue-induced cracking, the technique is particularly useful as it may be used in adverse conditions, or even underwater, and will operate through paint and other corrosion-prevention coatings. Cracks around 1mm deep and 6mm long can be found in typical welds.

Instrument set-up

While the precise details of setting up an instrument will vary depending on the type and application the general procedure is usually the same, obviously one the application has been tried the required values for many test parameters will be known, at least approximately, Connect up the appropriate probe and set any instrument configuration parameters.(mode of operation, display type etc.)

- Set the frequency as required for the test.
- Set gain to an intermediate value,

Move the probe on/on/over the calibration test piece and set phase rotation as desired (e.g. lift-off or wobble horizontal on a CRT)

- Move over the defects and adjust gain (and horizontal/vertical gain ratio if fitted) to obtain the desired trace size/meter indication. It may be necessary to rebalance after changing gain. Further optimise phase rotation as required. Use filters etc. to further optimise signal to noise ratio.
- Set alarms etc. as required.
- Run over the calibration test piece again and verify that all flaws are clearly detected.
- Perform the test, verifying correct operation at regular intervals using the calibration test piece.

3.9 Pulsed eddy current

Conventional ECT uses sinusoidal alternating current of a particular frequency to excite the probe. Pulsed eddy current (PEC) testing uses a step function voltage to excite the probe. The advantage of using a step function voltage is that such a voltage contains a range of frequencies. As a result, the electromagnetic response to several different frequencies can be measured with just a single step. Since depth of penetration depends on the excitation frequency, information from a range of depths can be obtained all at once. If measurements are made in the time domain (that is, by looking at the strength of the signal as a function of time), indications produced by defects and other features near the inspection coil can be seen first and more distant features will be seen later in time.

When comparing PEC testing with the conventional ECT, ECT must be regarded as a continuouswave method where propagation takes place at a single frequency or, more precisely, over a very narrowfrequency bandwidth. With pulse methods, the frequencies are excited over a wide band, the extent of which varies inversely with the pulse length; this allows multi-frequency operation. The total amount of energy dissipated within a given period of time is considerably less for pulsed waves than for continuous waves of the same intensity, thus allowing higher input voltages to be applied to the exciting coil for PEC than conventional ECT. One of the advantage of this type of testing is that there is no need for direct contact with the tested object. Testing can be performed through coatings, sheathings, corrosion products and insulation materials.This way even high-temperature inspections are possible.

3.10 Eddy current array

Eddy current array (ECA) and conventional ECT share the same basic working principles. ECA technology provides the ability to electronically drive an array of coils (multiple coils) arranged in specific pattern called a topology that generates a sensitivity profile suited to the target defects. Data acquisition is achieved by multiplexing the coils in a special pattern to avoid mutual inductance between the individual coils. The benefits of ECA are

- Faster inspections
- Wider coverage
- Less operator dependence — array probes yield more consistent results compared to manual raster scans
- Better detection capabilities
- Easier analysis because of simpler scan patterns
- Improved positioning and sizing because of encoded data

Array probes can easily be designed to be flexible or shaped to specifications, making hard-to-reach areas easier to inspect

Lorentz force eddy current testing

A different, albeit physically closely related challenge is the detection of deeply lying flaws and inhomogeneities in electrically conducting solid materials.

In the traditional version of eddy current testing an alternating (AC) magnetic field is used to induce eddy currents inside the material to be investigated. If the material contains a crack or flaw which make the spatial distribution of the electrical conductivity nonuniform, the path of the eddy currents is perturbed and the impedance of the coil which generates the AC magnetic field is modified. By measuring the impedance of this coil, a crack can hence be detected. Since the eddy currents are generated by an AC magnetic field, their penetration into the subsurface region of the material is limited by the skin effect. The applicability of the traditional version of eddy current testing is therefore limited to the analysis of the immediate vicinity of the surface of a material, usually of the order of one millimeter. Attempts to overcome this fundamental limitation using low frequency coils and superconducting magnetic field sensors have not led to widespread applications.

A recent technique, referred to as Lorentz force eddy current testing (LET), exploits the advantages of applying DC magnetic fields and relative motion providing deep and relatively fast testing

of electrically conducting materials. In principle, LET represents a modification of the traditional eddy current testing from which it differs in two aspects, namely (i) how eddy currents are induced and (ii) how their perturbation is detected. In LET eddy currents are generated by providing the relative motion between the conductor under test and a permanent magnet(see figure). If the magnet is passing by a defect, the Lorentz force acting on it shows a distortion whose detection is the key for the LET working principle. If the object is free of defects, the resulting Lorentz force remains constant.

Advantages:

Sensitivity to surface defects. Able to detect defects of 0.5mm in length under favourable conditions.

Can detect through several layers. The ability to detect defects in multi-layer structures (up to about 14 layers), without interference from the planar interfaces.

Can detect through surface coatings. Able to detect defects through non-conductive surface coatings in excess of 5mm thickness.

Accurate conductivity measurements. Dedicated conductivity measurement instruments operate using eddy currents.

Can be automated. Relatively uniform parts can be inspected quickly and reliably using automated or semi-automated equipment, e.g. wheels, boiler tubes and aero-engine disks.

Little pre-cleaning required. Only major soils and loose or uneven surface coatings need to be removed, reducing preparation time. as small as a video cassette box and weighing less than 2kg.

Disadvantages

Very susceptible to magnetic permeability changes. Small changes in permeability have a pronounced effect on the eddy currents, especially in ferromagnetic materials. This makes testing of welds and other ferromagnetic materials difficult but, with modern digital flaw detectors and probe design, not impossible.

Only effective on conductive materials. The material must be able to support a flow of electrical current. This makes testing of fibre reinforced plastics unfeasible.

Will not detect defects parallel to surface. The flow of eddy currents is always parallel to the surface. If a planar defect does not cross or interfere with the current then the defect will not be detected.

Not suitable for large areas and/or complex geometries. Large area scanning can be accomplished, but needs the aid of some type of area scanning device, usually supported by a computer, both of which are not inexpensive. The more complex the geometry becomes, the more difficult it is to differentiate defect signals from geometry effect signals.

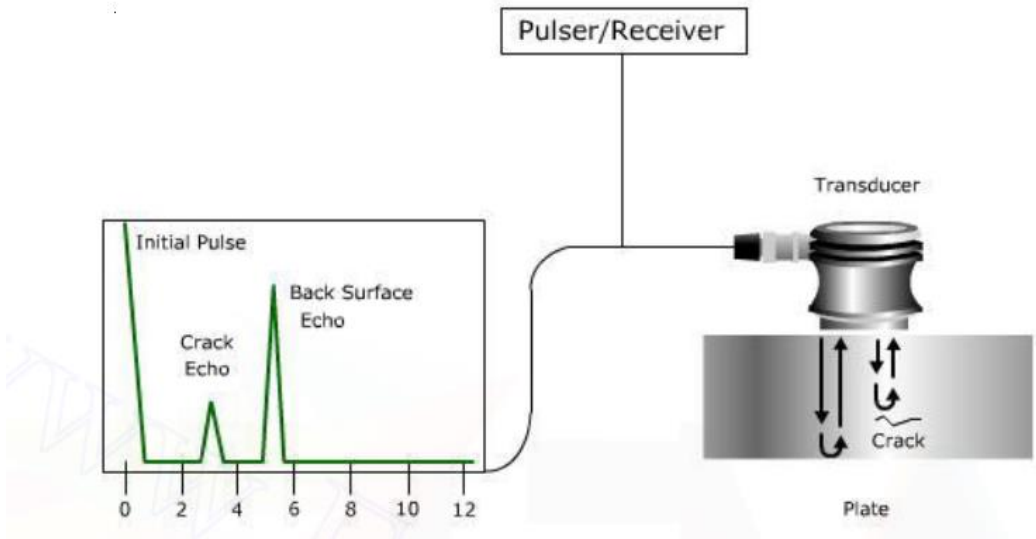
Signal interpretation required. Due to the many factors which affect eddy currents, careful interpretation of signals is needed to distinguish between relevant and non-relevant indications.

No permanent record (unless automated). Normally the only permanent record will be a paper print out or computer file when using automated systems.

UNIT – IV Ultrasonic Testing

Ultrasonic Testing (UT) uses high frequency sound waves (*typically in the range between 0.5 and 15 MHz*) to conduct examinations and make measurements. Besides its wide use in engineering applications (*such as flaw detection/evaluation, dimensional measurements, material characterization, etc.*), ultrasonics are also used in the medical field (*such as sonography, therapeutic ultrasound, etc.*). In general, ultrasonic testing is based on the capture and quantification of either the reflected waves (*pulseecho*)
or the transmitted waves (*through-transmission*). Each of the two types is used in certain applications, but generally, pulse echo systems are
more useful since they require one-sided access to the object being inspected.

4.1.1 Basic Principles



A typical pulse-echo UT inspection system consists of several functional units, such as the pulser/receiver, transducer, and a display device. A pulser/receiver is an electronic device that can produce high voltage electrical pulses. Driven by the pulser, the transducer generates high frequency ultrasonic energy. The sound energy is introduced and propagates through the materials in the form of waves. When there is a discontinuity (*such as a crack*) in the wave path, part of the energy will be reflected back from the flaw surface. The reflected wave signal is transformed into an electrical signal by the transducer and is displayed on a screen. Knowing the velocity of the waves, travel time can be directly related to the distance that the signal traveled. From the signal, information about the reflector location, size, orientation and other features can sometimes be gained.

4.1.2 Advantages and Disadvantages

Advantages

It is sensitive to both surface and subsurface discontinuities.
The depth of penetration for flaw detection or measurement is superior to other NDT methods
Only single-sided access is needed when the pulse-echo technique is used.
It is highly accurate in determining reflector position and estimating size and shape.
Minimal part preparation is required.
It provides instantaneous results.
Detailed images can be produced with automated systems.

It is nonhazardous to operators or nearby personnel and does not affect the material being tested.
It has other uses, such as thickness measurement, in addition to flaw detection.
Its equipment can be highly portable or highly automated.
Disadvantages
Surface must be accessible to transmit ultrasound.
Skill and training is more extensive than with some other methods.
It normally requires a coupling medium to promote the transfer of sound energy into test specimen.
Materials that are rough, irregular in shape, very small, exceptionally thin or not homogeneous are difficult to inspect.
Cast iron and other coarse grained materials are difficult to inspect due to low sound transmission and high signal noise.
Linear defects oriented parallel to the sound beam may go undetected.
Reference standards are required for both equipment calibration and the characterization of flaws.

PHYSICS OF ULTRASOUND

Wave Propagation

Ultrasonic testing is based on the vibration in materials which is generally referred to as acoustics. All material substances are comprised of atoms, which may be forced into vibrational motion about their equilibrium positions. Many different patterns of vibrational motion exist at the atomic level; however, most are irrelevant to acoustics and ultrasonic testing. Acoustics is focused on particles that contain many atoms that move in harmony to produce a mechanical wave. When a material is not stressed in tension or compression beyond its elastic limit, its individual particles perform elastic oscillations. When the particles of a medium are displaced from their equilibrium positions, internal restoration forces arise. These elastic restoring forces between particles, combined with inertia of the particles, lead to the oscillatory motions of the medium.

In solids, sound waves can propagate in four principal modes that are based on the way the particles oscillate. Sound can propagate as longitudinal waves, shear waves, surface waves, and in thin materials as plate waves. Longitudinal and shear waves are the two modes of propagation most widely used in ultrasonic testing. The particle movement responsible for the propagation of longitudinal and shear waves is illustrated in the figure
In *longitudinal waves*, the oscillations occur in the longitudinal direction or the direction of wave propagation. Since compression and expansion forces are active in these waves, they are also called pressure or compression waves. They are also sometimes called density waves because material density fluctuates as the wave moves. Compression waves can be generated in gases, liquids, as well as solids because the energy travels through the atomic structure by a series of compressions and expansion movements.
oscillate at a right angle or transverse to the direction of propagation. Shear waves require an acoustically solid material for effective propagation, and therefore, are not effectively propagated in materials such as liquids or gasses. Shear waves are relatively weak when compared to longitudinal waves. In fact, shear waves are usually generated in materials using some of the energy from longitudinal waves.

Modes of Sound Wave Propagation

In air, sound travels by the compression and rarefaction of air molecules in the direction of travel. However, in solids, molecules can support vibrations in other directions. Hence, a number of different types of sound waves are possible. Waves can be characterized by oscillatory patterns that are capable of maintaining their shape and propagating in a stable manner. The propagation of waves is often described in terms of what are called "*wave modes*"As mentioned previously, longitudinal and transverse (shear) waves are most often used in ultrasonic inspection. However, at surfaces and interfaces, various types of elliptical or complex vibrations of the particles make other waves possible.

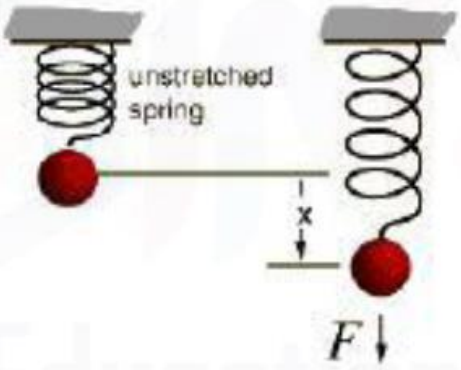
Some of these wave modes such as Rayleigh and Lamb waves are also useful for ultrasonic inspection.Though there are many different modes of wave propagation, the table summarizes the four types of waves that are used in NDT

Since longitudinal and transverse waves were discussed previously, surface and plate waves are introduced here.
Surface (or Rayleigh) waves travel at the surface of a relatively thick solid material penetrating to a depth of one wavelength. A surface wave is a combination of both a longitudinal and transverse motion which results in an elliptical motion as shown in the image. The major axis of the ellipse is perpendicular to the surface of the solid. As the depth of an individual atom from theincreases, the width of its elliptical motion decreases. Surface waves are generated when a longitudinal wave intersects a surface slightly larger than the second critical angle and they travel at a velocity between .87 and .95 of a shear wave. Rayleigh waves are useful because they are very sensitive to surface defects (*and other surface features*) and they follow the surface around curves. Because of this, Rayleigh waves can be used to inspect areas that other waves might have difficulty reaching.
Plate (or Lamb) waves are similar to surface waves except they can only be generated in materials a few wavelengths thick (*thin plates*). Lamb waves are complex vibrational waves that propagate parallel to the test surface throughout the thickness of the material. They are influenced a great deal by the test wave frequency and material thickness. Lamb waves are generated when a wave hits a surface at an incident angle such that the parallel component of the velocity of the wave (in the source) is equal to the velocity of the wave in the test material. Lamb waves will travel several meters in steel and so are useful to scan plate, wire, and tubes. With Lamb waves, a number of modes of particle vibration are possible, but the two most common are symmetrical and asymmetrical. The complex motion of the particles is similar to the elliptical orbits for surface waves. Symmetrical Lamb waves move in a symmetrical fashion about the median plane of the plate. This is sometimes called the "*extensional mode*" because the wave is stretching and compressing the plate in the wave motion direction. The asymmetrical Lamb wave mode is often called the "*flexural mode*" because a large portion of the motion is in a normal direction to the plate, and a little motion occurs in the direction parallel to the plate. In this mode, the body of the plate bends as the two surfaces move in the same direction.

4.4 Sound Propagation in Elastic Materials
It was mentioned previously that sound waves propagate due to the vibrations or oscillatory motions of particles within a material. An ultrasonic wave may be visualized as an infinite number of oscillating masses or particles connected by means of elastic springs. Each individual particle is influenced by the motion of its nearest neighbor and both inertial and elastic restoring forces act upon each particle. A mass on a spring has a single resonant frequency (*natural frequency*) determined by its spring constant $\boldsymbol{k}$ and its mass $\boldsymbol{m}$. Within the elastic limit of any material, there is a linear relationship between the displacement of a particle and the force attempting to restore the particle to its equilibrium position. This linear dependency is described by *Hooke's Law*. In terms of the spring model, the relation between force and displacement is written as $\boldsymbol{F = k\,x}$.

The Speed of Sound
Hooke's Law, when used along with Newton's Second Law, can explain a few things about the speed of sound. The speed of sound within a material is a function of the properties of the material and is independent of the amplitude of the sound wave. Newton's Second Law says that the force applied to a particle will be balanced by the particle's mass and the acceleration of the particle. Mathematically, Newton's Second Law is written as $\boldsymbol{F = m\,a}$. Hooke's Law then says that this force will be balanced by a force in the opposite direction that is dependent on the amount of displacement and the spring constant. Therefore, since the applied force and the restoring force are equal, $\boldsymbol{m\,a = k\,x}$ can be written. Since the mass $\boldsymbol{m}$ and the spring constant $\boldsymbol{k}$ are constants for any given material, it can be seen that the acceleration $\boldsymbol{a}$ and the displacement $\boldsymbol{x}$ are the only variables. It can also be seen that they are directly

proportional. For instance, if the displacement of the particle increases, so does its acceleration. It turns out that the time that it takes a particle to move and return to its equilibrium position is independent of the force applied. So, within a given material, sound always travels at the same speed no matter how much force is applied when other variables, such as temperature, are held constant.



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4.5Material Properties Affecting the Speed of Sound

Of course, sound does travel at different speeds in different materials. This is because the mass of the atomic particles and the spring constants are different for different materials. The mass of the particles is related to the density of the material, and the spring constant is related to the elastic constants of a material. The general relationship between the speed of sound in a solid and its density and elastic constants is given by the following equation:

$$V = \sqrt{\frac{C}{\rho}}$$

Where;
V: speed of sound (m/s)
C: elastic constant "in a given direction" (N/m^2)
ρ: density (kg/m^3)

This equation may take a number of different forms depending on the type of wave (*longitudinal or shear*) and which of the elastic constants that are used. It must also be mentioned that

the subscript " " attached to " " in the above equation is used to indicate the directionality of the elastic constants with respect to the wave type and direction of wave travel. In isotropic materials, the elastic constants are the same for all directions within the material. However, most materials are anisotropic and the elastic constants differ with each direction. For example, in a piece of rolled aluminum plate, the grains are elongated in one direction and compressed in the others and the elastic constants for the longitudinal direction differs slightly from those for the transverse or short transverse directions.
For longitudinal waves, the speed of sound in a solid material can be found as:

For longitudinal waves, the speed of sound in a solid material can be found as:

$$V_L = \sqrt{\frac{E(1-\upsilon)}{\rho(1+\upsilon)(1-2\upsilon)}}$$

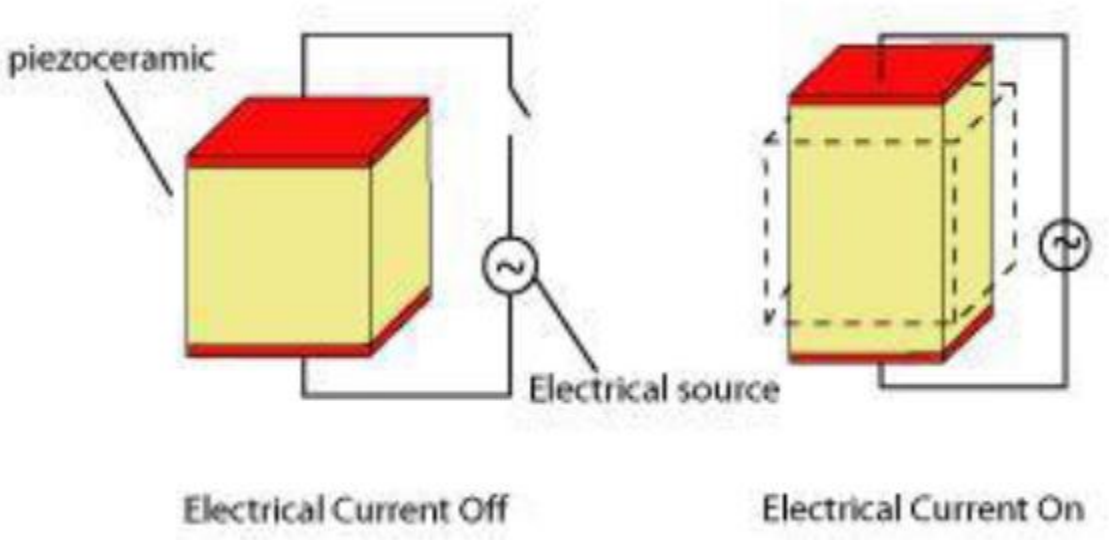
where;
V_L: speed of sound for longitudinal waves (*m/s*)
E: Young's modulus (N/m^2)
υ: Poisson's ratio
While for shear (*transverse*) waves, the speed of sound is found as:

$$V_T = \sqrt{\frac{G}{\rho}}$$

Where;
VT: speed of sound for shear waves (*m/s*)
G: Shear modulus of elasticity (N/m_2);

Attenuation of Sound Waves
When sound travels through a medium, its intensity diminishes with distance. In idealized materials, sound pressure (*signal amplitude*) is reduced due to the spreading of the wave. In natural materials, however, the sound amplitude is further weakened due to the scattering and absorption. Scattering is the reflection of the sound in directions other than its original direction of propagation. Absorption is the conversion of the sound energy to other forms of energy. The combined effect of scattering and absorption is called attenuation. Attenuation is generally proportional to the square of sound frequency. The amplitude change of a decaying plane wave can be expressed as:

EQUIPMENT & TRANSDUCERS
Piezoelectric Transducers
The conversion of electrical pulses to mechanical vibrations and the conversion of returned mechanical vibrations back into electrical energy is the basis for ultrasonic testing. This conversion is done by the transducer using a piece of piezoelectric material (*a polarized material having some parts of the molecule positively charged, while other parts of the molecule are negatively charged*) with electrodes attached to two of its opposite faces. When an electric field is applied across the material, the polarized molecules will align themselves with the electric field causing the material to change dimensions.

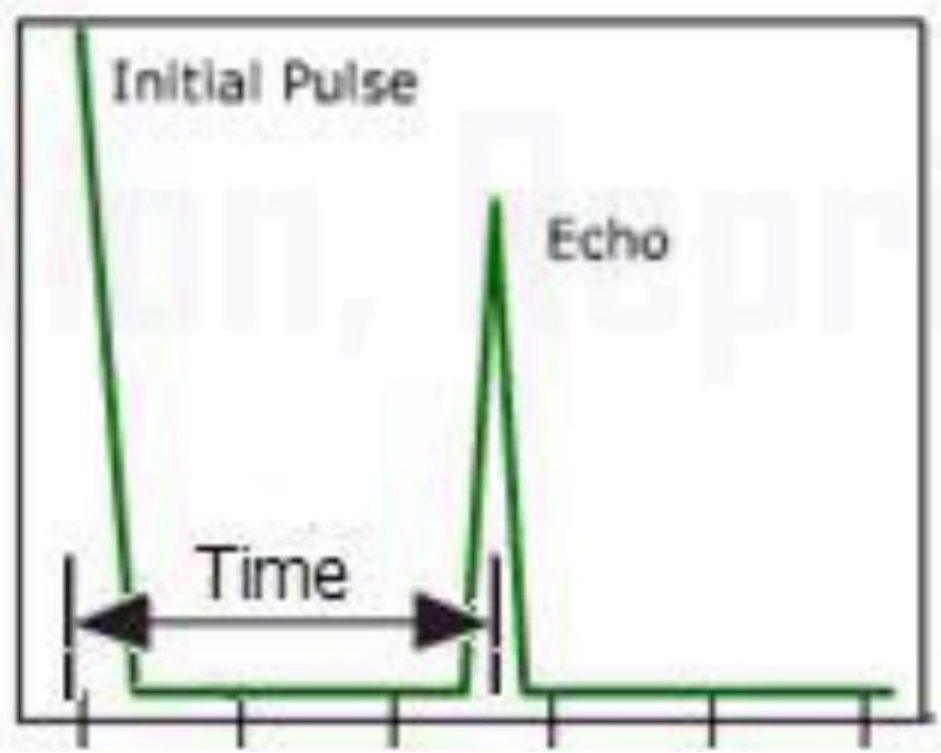


In addition, a permanently-polarized material such as quartz (SiO_2) or barium titanate ($BaTiO_3$) will produce an electric field when the material changes dimensions as a result of an imposed mechanical force. This phenomenon is known as the piezoelectric effect.
The active element of most acoustic transducers used today is a piezoelectric ceramic, which can be cut in various ways to produce different wave modes. A large piezoelectric ceramic element can be seen in the image of a sectioned low frequency transducer. The most commonly employed ceramic for making transducers is lead zirconate titanate. The thickness of the active element is determined by the desired frequency of the transducer. A thin wafer element vibrates with a wavelength that is twice its thickness.

MEASUREMENT AND CALIBRATION TECHNIQUES

Normal Beam Inspection

Pulse-echo ultrasonic measurements can determine the location of a discontinuity in a part or structure by accurately measuring the time required for a short ultrasonic pulse generated by a transducer to travel through a thickness of material, reflect from the back or the surface of a discontinuity, and be returned to the transducer. In most applications, this time interval is a few microseconds or less. The two-way transit time measured is divided by two to account for the down-and-back travel path and multiplied by the velocity of sound in the test material. The result is expressed in the well-known relationship:
Where is the distance from the surface to the discontinuity in the test piece, is the velocity of sound waves in the material, and is the measured round-trip transit time. Precision ultrasonic thickness gages usually operate at frequencies between 500 kHz and 100 MHz, by means of piezoelectric transducers that generate bursts of sound waves when excited by electrical pulses.



Typically, lower frequencies are used to optimize penetration when measuring thick, highly attenuating or highly scattering materials, while higher frequencies will be recommended to optimize resolution in thinner, non-attenuating, nonscattering materials. It is possible to measure most engineering materials ultrasonically, including metals, plastic, ceramics, composites, epoxies, and glass as well as liquid levels and the thickness of certain biological specimens. On-line or in-process measurement of extruded plastics or rolled metal often is possible, as is measurements of single layers or coatings in multilayer materials.

Distance Amplitude Correction (DAC)
Acoustic signals from the same reflecting surface will have different amplitudes at different distances from the transducer. A distance amplitude correction (DAC) curve provides a means of establishing a graphic "reference level sensitivity" as a function of the distance to the reflector (*i.e., time on the A-scan display*). The use of DAC allows signals reflected from similar discontinuities to be evaluated where signal attenuation as a function of depth has been correlated.
DAC will allow for loss in amplitude over material depth (time) to be represented graphically on the Ascan
display. Because near field length and beam spread vary according to transducer size and frequency, and materials vary in attenuation and velocity, a DAC curve must be established for each different situation. DAC may be employed in both longitudinal and shear modes of operation as well as either contact or immersion inspection techniques.

Acoustic Testing

Acoustic Emission

Acoustic emission (AE) is one of the most promising methods for structural health monitoring (SHM) of materials and structures. Because of its passive and non-invasive nature, it can be used

during the operation of a structure and supply information that cannot be collected in real time through other techniques. It is based on the recording and study of the elastic waves that are excited by irreversible processes, such as crack nucleation and propagation. These signals are sensed by transducers and are transformed into electric waveforms that offer information on the location and the type of the source. This chapter intends to present the basic principles, the equipment, and the recent trends and applications in aeronautics, highlighting the role of AE in modern non-destructive testing and SHM. The literature in the field is vast; therefore, although the included references provide an idea of the basics and the contemporary interest and level of research and practice , they are just a fraction of the total possible list of worthy studies published in the recent years.

Introduction

The safety of structures is of paramount importance. Operational loads, environmental influences and random phenomena such as impacts accumulate damage and compromise the durability of structures. To avoid human casualties as well as loss of capital, structural health monitoring (SHM) procedures are implemented in all fields
of engineering, including aeronautics. These procedures involve detection, geometric localization and characterization of damage that allows proper engineering decisions concerning maintenance or replacement of the component. Because of the deterioration of materials and structures, the necessity for suitable inspection and
maintenance is crucial. In addition, AE is a valuable tool in any platform for investigation and development of materials in laboratory conditions. It can be applied in intervals or continuously to supply the information in real time as well as a reliable evaluation of the damage condition in materials and structures .

AE is a monitoring technology that offers certain advantages in the evaluation of materials as well as structures. Some of the basic features include the high sensitivity, which leads to the detection of the actual onset of micro-cracking and the possibility of characterization of the failure mode based on the recorded waveform.

In addition, it offers the localization of the sources in one, two or three dimensions.

The sensitivity of AE is demonstrated if we consider that the absolute energy of AE signals is measured with the unit of atto-Joule (or 10_18J!). Therefore, the method allows the detection of the actual initiation of micro-cracking or any other event that would be impossible to detect through other techniques.

It is characteristic that a common mosquito of mass 2.5 mg, flying at a speed of 10 cm/s obtains a kinetic energy of approximately 1.25 _ 10_8 J, which is already 10 orders of magnitude higher than the limit of the technique.

Advantage

Another advantage is the potential to characterise the fracture mode or generally the source or excitation type. This may seem to some as a ‘detail’, since for many people, the fact that damage exists is important, disregarding the actual mode.

However, for composites the mode of the crack in a matrix or the type of failure, such as delamination or fiber pull-out is indicative of the current deterioration stage, and thus, it allows projections on the useful life of the component. This mode characterization is due to the fact that

distinct processes involve different motions of the crack tips and emit elastic waveforms with different characteristics.
A common example is the fracture of fibrous composite materials.
At low load or fatigue cycles, the matrix is expected to crack first. Then, as loading progresses, the density of debonding and pull-out events will increase, whereas eventually, fiber rupture is also possible. The analysis of the waveforms recorded at each loading stage enables the classification of the signals to the different original sources and the evaluation of the current operation stage.

Source localization is an additional strong feature of AE. By applying multiple sensors, the coordinates of the active sources can be defined with good engineering accuracy in one, two or three dimensions, which means that even if a crack is inside the volume of the material and not visible, its location can be evaluated.
The localization in most cases is based on the delay of recording of successive signals of the same source event at the different sensors. Considering the material's wave speed, which can be measured using the same sensors, the location of the source can be determined. Certainly, the different wave modes excited in plate components
typical in aeronautics structures, complicate the assessment, but there are strategies to overcome the difficulties, which will be explained in the corresponding section.

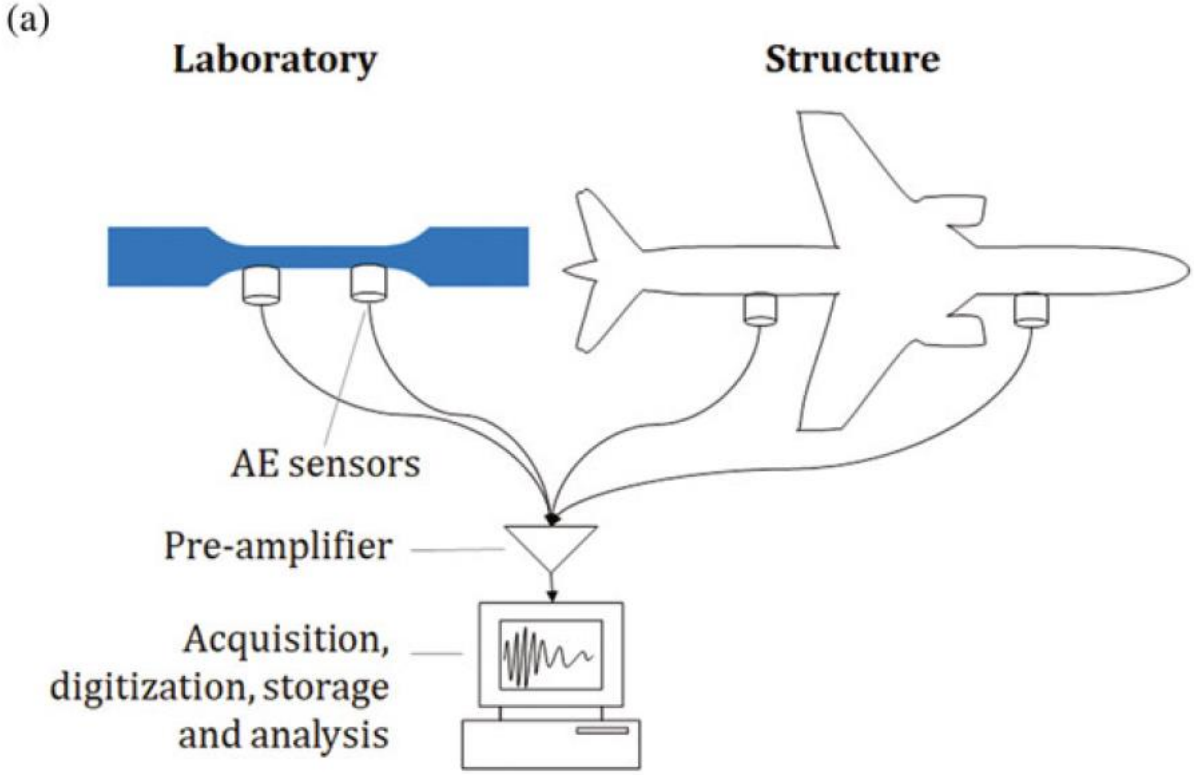
Because of the extensive use of AE technology in fracture monitoring studies, some people hesitate to call it a non-destructive testing technique. However, it should be clear that the AE sensors themselves do not inflict any damage (they do not even excite elastic waves as happens in ultrasonics). AE is a 'passive' technique.

It is similar to filming an impact or a blast by a high-resolution camera. The camera monitors a destructive process, but it is just the monitoring tool, not the cause of damage. Because of the aforementioned advantages, AE is used for fracture monitoring, which is a very demanding and dynamic process, but it is also used for problems of different nature, e.g. the detection of gas leakage from a pipe network or corrosion development in industrial settings.

Basic Experimental Details and Parameters

The AE technique detects and monitors the transient elastic waves that are emitted after an irreversible phenomenon or process in the material. In most cases, piezoelectric transducers are placed on the surface of the material under test. A layer of 'couplant' or viscous liquid is applied between the sensor and the material surface to
ensure adequate wave transmission.
The couplant may well be petroleum jelly, or roller bearing grease. The sensors transform the pressure on their surface into electric signals.
These signals are pre-amplified and are led to the digitization and acquisition board to obtain the signal as a function of time.
Apart from recording the full signals, which is always an option in most contemporary systems, the basic parameters of each signal (waveform) are measured and stored as well. Figure a shows

a typical AE system with the main elements, and Fig. b presents some indicative photographs of measurements.



Therefore, considering the expected sequence of occurrence of the different fracture mechanisms, being able to identify the dominant one in real time offers information on the current structural condition and allows projections to the useful life span.

As understood, fracture in composites is a fairly complicated and stochastic process because of several mechanisms as well as their possible overlap in time.

This complexity is inevitably transferred to the AE signal making the interpretation less than straightforward. Still, some basic indicative principles can be mentioned as the starting point of the effort to understand the connection between AE signals and the original event.

As Fig. shows, a crack propagation event extending vertical to the axis of the plate results in waveform with different characteristics from a similar crack in the parallel direction. In the case of plates, the reason can be sought in the different amount of energy forming the ‘symmetric’ and ‘antisymmetric’ wave modes ,depending on each case.

When a vertical crack is extended (Fig. a top), this motion excites mostly symmetric components that have higher propagation velocities than antisymmetric, as already discussed in Chap. 5.2. A waveform containing stronger symmetric component is expected to have higher energy in the opening part rather than the later part; see example of Fig. . By contrast, when a horizontal crack (delamination in the case of laminated plates) is extended (Fig. 7.6a bottom), the transient motion gives rise to the antisymmetric wave mode. Thus, it is reasonable that for the extreme cases of event orientation, differences are noticed in the waveform shape, practically

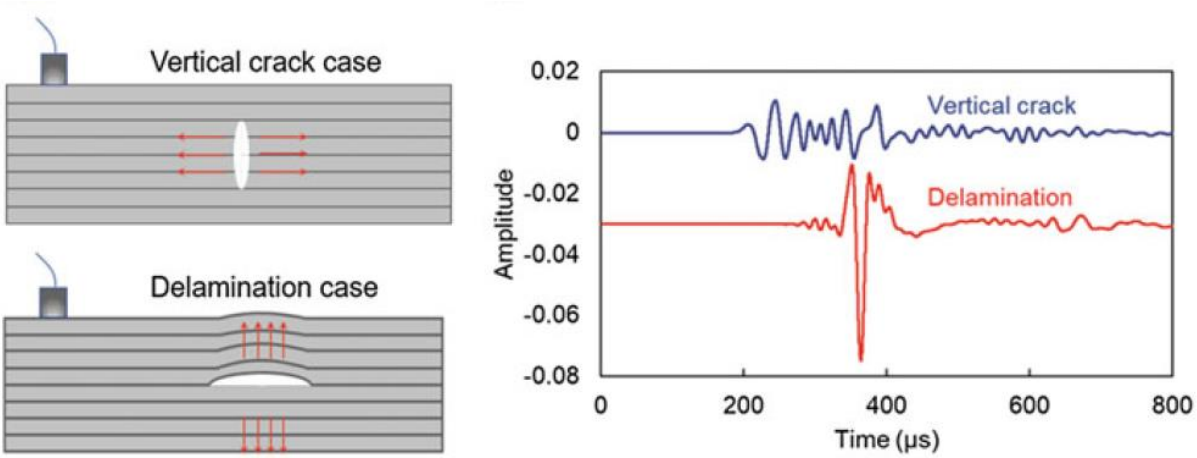


Fig. 7.6 (**a**) Representation of vertical crack (top) and delamination (bottom) in a laminated composite plate and (**b**) typical AE waveforms from the two events

resulting in shorter rise time for vertical cracks and longer durations for delaminations. Possible single fiber or fiber bundle rupture is expected to obtain even shorter duration characteristics and higher frequency content, as the fracture incident is usually shorter in time due to the limited fiber cross section to be fractured in one
step and the higher speed of crack propagation within the high modulus fiber.

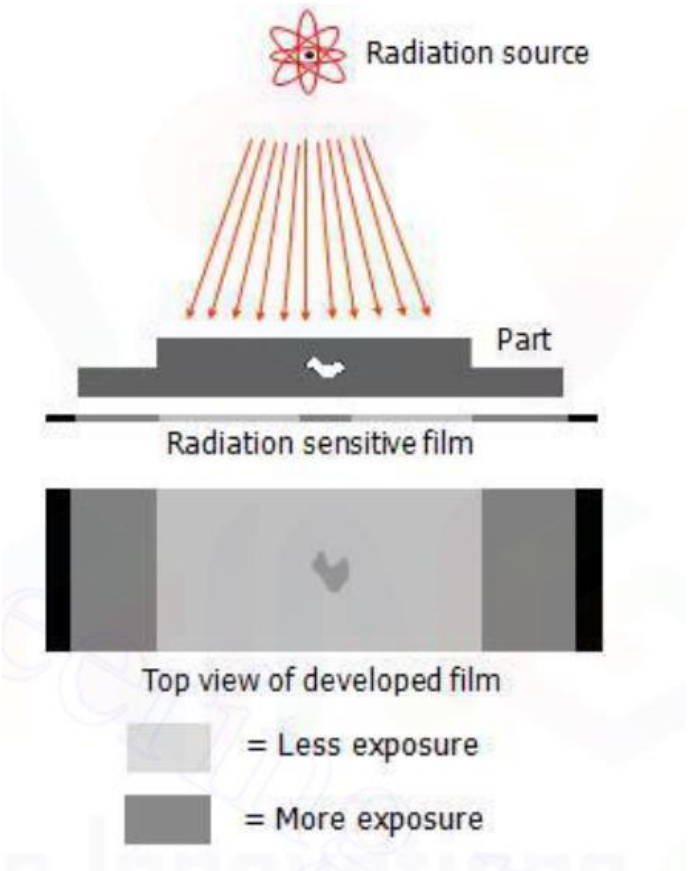
The final waveform shape will be influenced by a number of aforementioned factors apart from the orientation, such as the position of the crack in the thickness (non-central sources will yield combination of modes instead of a single one), their displacement increment and speed and the propagation distance to the sensor and sensor characteristics as mentioned below.

UNIT-V RADIOGRAPHY TESTING

Introduction

Radiography is used in a very wide range of aplications including medicine, engineering, forensics, security, etc. In NDT, radiography is one of the most important and widely used methods. Radiographic testing (RT) offers a number of advantages over other NDT methods, however, one of its major disadvantages is the health risk associated with the radiation.
In general, RT is method of inspecting materials for hidden flaws by using the ability of short wavelength electromagnetic radiation (high energy photons) to penetrate various materials. The intensity of the radiation that penetrates and passes through the material is either captured by a radiation sensitive film (*Film Radiography*) or by a planer array of radiation sensitive sensors (*Real-time Radiography*). Film radiography is the oldest approach, yet it is still the most widely used in NDT.

5.1.1 Basic Principles



In radiographic testing, the part to be inspected is placed between the radiation source and a piece of radiation sensitive film.
The radiation source can either be an X ray machine or a radioactive source (*Ir-192, Co-60, or in rare cases Cs-137*).
The part will stop some of the radiation where thicker and more dense areas will stop more of the radiation.
The radiation that passes through the part will expose the film and forms a shadowgraph of the part.

The film darkness (*density*) will vary with the amount of radiation reaching the film through the test object where darker areas indicate more exposure (*higher radiation intensity*) and lighter areas indicate less exposure (low*er radiation intensity*).
This variation in the image darkness can be used to determine thickness or composition of material and would also reveal the presence of any flaws or discontinuities inside the material.

Advantages and Disadvantages

The primary advantages and disadvantages in comparison to other NDT methods are:

Advantages

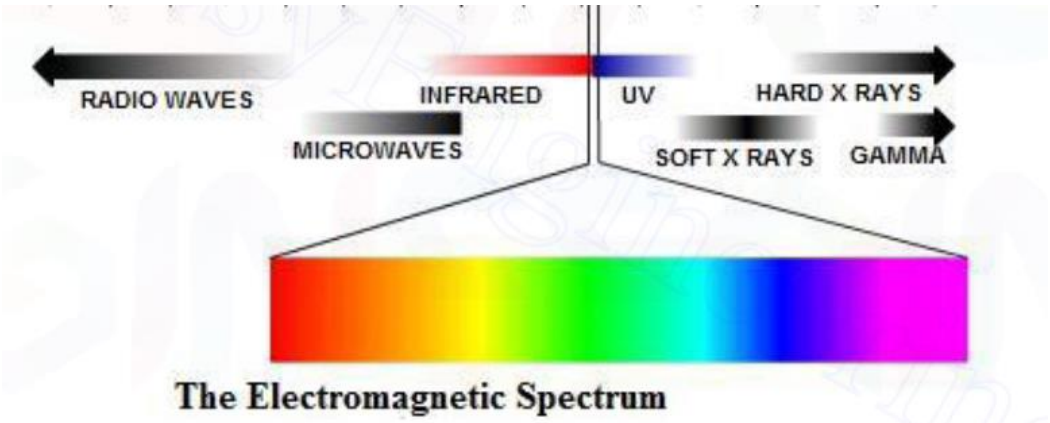
Both surface and internal discontinuities can be detected.
Significant variations in composition can be detected.
It has a very few material limitations.
Can be used for inspecting hidden areas (*direct access to surface is not required*)
Very minimal or no part preparation is required.
Permanent test record is obtained.
Good portability especially for gamma-ray sources.

Disadvantages

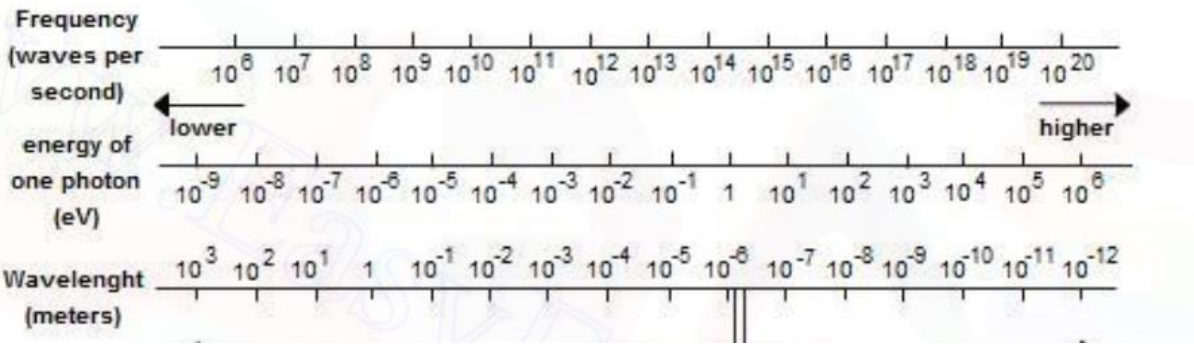
Hazardous to operators and other nearby personnel.
High degree of skill and experience is required for exposure and interpretation.
The equipment is relatively expensive (*especially for x-ray sources*).
The process is generally slow.
Highly directional (*sensitive to flaw orientation*).
Depth of discontinuity is not indicated.

Nature of Penetrating Radiation

Both X-rays and gamma rays are electromagnetic waves and on the electromagnetic spectrum they ocupy frequency ranges that are higher than ultraviolate radiation. In terms of frequency, gamma rays generaly have higher frequencies than X-rays as seen in the figure. The major distenction between X-rays and gamma rays is the origion where X-rays are usually artificially produced using an X-ray generator and gamma radiation is the product of radioactive materials. Both X-rays and gamma rays are waveforms, as are light rays, microwaves, and radio waves. X-rays and gamma rays cannot been seen, felt, or heard. They
possess no charge and no mass and, therefore are not influenced by electrical and magnetic fields and will generally travel in straight lines. However, they can be diffracted (bent) in a manner similar to light.



The Electromagnetic Spectrum



Electromagentic radiation act somewhat like a particle at times in that they occur as small "packets" of energy and are referred to as "*photons*". Each photon contains a certain amount (*or bundle*) of energy, and all electromagnetic radiation consists of these photons. The only difference between the various types of electromagnetic radiation is the amount of energy found in the photons.
Due to the short wavelength of X-rays and gamma rays, they have more energy to pass through matter than do the other forms of energy in the electromagnetic spectrum. As they pass through matter, they are scattered and absorbed and the degree of penetration depends on the kind of matter and the energy of the rays.

Properties of X-Rays and Gamma Rays
They are not detected by human senses (cannot be seen, heard, felt, etc.).
They travel in straight lines at the speed of light.
Their paths cannot be changed by electrical or magnetic fields.
They can be diffracted, refracted to a small degree at interfaces between two different materials, and in some cases be reflected.
They pass through matter until they have a chance to encounter with an atomic particle.
Their degree of penetration depends on their energy and the matter they are traveling through.
They have enough energy to ionize matter and can damage or destroy living cells.

X Radiation

X-rays are just like any other kind of electromagnetic radiation. They can be produced in packets of energy called photons, just like light. There are two different atomic processes that can produce X-ray photons. One is called *Bremsstrahlung* (*a German term meaning "braking radiation"*) and the other is called *K-shell emission*. They can both occur in the heavy atoms of tungsten which is often the material chosen for the target or anode of the X-ray tube.
Both ways of making X-rays involve a change in the state of electrons. However, Bremsstrahlung is easier to understand using the classical idea that radiation is emitted when the velocity of the electron shot at the tungsten target changes. The negatively charged electron slows down after swinging around the nucleus of a positively charged tungsten atom and this energy loss produces X-radiation. Electrons are scattered elastically or inelastically by the positively charged nucleus. The inelastically scattered electron loses energy, and thus produces X-ray photon, while the elastically scattered electrons generally change their direction significantly but without loosing much of their energy.

Bremsstrahlung Radiation

X-ray tubes produce X-ray photons by accelerating a stream of electrons to energies of several hundred kiloelectronvolts with velocities of several hundred kilometers per hour and colliding them into a heavy target material.
The abrupt acceleration of the charged particles (electrons) produces Bremsstrahlung photons. X-ray radiation with a continuous spectrum of energies is produced with a range from a few *keV* to a maximum of the energy of the electron beam.
The Bremsstrahlung photons generated within the target material are attenuated as they pass through, typically, 50 microns of target material. The beam is further attenuated by the aluminum or beryllium vacuum window. The results are the elimination of the low energy photons, *1 keV* through *15 keV*, and a significant reduction in the portion of the spectrum from *15 keV* through *50 keV*. The spectrum from an Xray tube is further modified by the filtration caused by the selection of filters used in the setup.

K-shell Emission Radiation

Remember that atoms have their electrons arranged in closed "shells" of different energies. The K-shell is the lowest energy state of an atom. An incoming electron can give a K-shell electron enough energy to knock it out of its energy state. About *0.1%* of the electrons produce K-shell vacancies; most produce heat. Then, a tungsten electron of higher energy (from an outer shell) can fall into the Kshell.
The energy lost by the falling electron shows up as an emitted X-ray photon. Meanwhile, higher energy electrons fall into the vacated energy state in the outer shell, and so on. After losing an electron, an atom remains ionized for a very short time (about 10^{-14} second) and thus an atom can be repeatedly ionized by the incident electrons which arrive about every 10^{-12} second. Generally, K-shell emission produces higher-intensity X-rays than Bremsstrahlung, and the X-ray photon comes out at a single wavelength

Gamma Radiation

Gamma radiation is one of the three types of natural radioactivity. Gamma rays are electromagnetic radiation just like X-rays. The other two types of natural radioactivity are alpha and beta radiation, which are in the form of particles. Gamma rays are the most energetic form of electromagnetic radiation. Gamma radiation is the product of radioactive atoms. Depending upon the ratio of neutrons to protons within its nucleus, an isotope of a particular element may be stable or unstable. When the binding energy is not strong enough to hold the nucleus of an atom together, the atom is said to be unstable. Atoms with unstable nuclei are constantly changing as a result of the imbalance of energy within the nucleus. Over time, the nuclei of unstable isotopes spontaneously disintegrate, or transform, in a process known as "*radioactive decay*" and such material is called "*radioactive material*".

5.4 Types of Radiation Produced by Radioactive Decay

When an atom undergoes radioactive decay, it emits one or more forms of high speed subatomic particles ejected from the nucleus or electromagnetic radiation (gamma-rays) emitted by either the nucleus or orbital electrons.

Alpha Particles

Certain radioactive materials of high atomic mass (*such as Ra-226, U-238, Pu-239*), decay by the emission of alpha particles.
These alpha particles are tightly bound units of two neutrons and two protons each (*He-4 nucleus*) and have a positive charge.
Emission of an alpha particle from the nucleus results in a decrease of two units of atomic number (*Z*) and four units of mass number (*A*).
Alpha particles are emitted with discrete energies characteristic of the particular transformation from which they originate. All alpha particles from a particular radionuclide transformation will have identical energies.

Beta Particles

A nucleus with an unstable ratio of neutrons to protons may decay through the emission of a high speed electron called a beta particle. In beta decay a neutron will split into a positively charged proton and a negatively charged electron. This results in a net change of one unit of atomic number (*Z*) and no change in the mass number (*A*). Beta particles have a negative charge and the beta particles emitted by a specific radioactive material will range in energy from near zero up to a maximum value, which is characteristic of the particular transformation.

Gamma-rays

A nucleus which is in an excited state (*unstable nucleus*) may emit one or more photons of discrete energies. The emission of gamma rays does not alter the number of protons or neutrons in the nucleus but instead has the effect of moving the nucleus from *a higher to a lower energy state* (*unstable to stable*). Gamma ray emission frequently follows beta decay, alpha decay, and other nuclear decay processes.

Activity (*of Radioactive Materials*)

The quantity which expresses the radiation producing potential of a given amount of radioactive material is called "*Activity*". The *Curie* (***Ci***) was originally defined as that amount of any radioactive material that disintegrates at the same rate as one gram of pure radium. The International System (SI) unit for activity is the *Becquerel* (***Bq***), which is that quantity of radioactive material in which one atom is transformed per second. The radioactivity of a given amount of radioactive material does not depend upon the mass of material present. For example, two one-curie sources of the same radioactive material might have very different masses depending upon the relative proportion of non-radioactive atoms present in each source.

The concentration of radioactivity, or the relationship between the mass of radioactive material and the activity, is called "*specific activity*". Specific activity is expressed as the number of *Curies* or *Becquerels* per unit mass or volume. Each gram of Cobalt-60 will contain approximately *50 Ci*. Iridium-192 will contain *350 Ci* for every gram of material. The higher specific activity of iridium results in physically smaller sources. This allows technicians to place the source in closer proximity to the film while maintaining the sharpness of the radiograph

Radiation Energy, Intensity and Exposure

Different radioactive materials and X-ray generators produce radiation at different energy levels and at different rates. It is important to understand the terms used to describe the energy and intensity of the radiation.

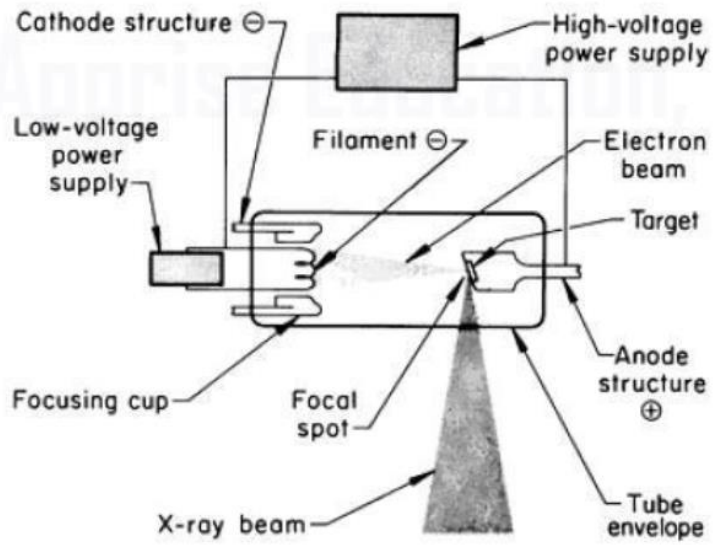
Radiation Energy

The energy of the radiation is responsible for its ability to penetrate matter. Higher energy radiation can penetrate more and higher density matter than low energy radiation. The energy of ionizing radiation is measured in *electronvolts* (***eV***). One electronvolt is an extremely small amount of energy so it is common to use kiloelectronvolts (***keV***) and megaelectronvolt (***MeV***). An electronvolt is a measure of energy, which is different from a volt which is a measure of the electrical potential between two positions. Specifically, an electronvolt is the kinetic energy gained by an electron passing through a potential difference of one volt. X-ray generators have a control to adjust the radiation energy, *keV* (or *kV*).The energy of a radioisotope is a characteristic of the atomic structure of the material. Consider, for example, Iridium-192 and Cobalt-60, which are two of the more common industrial Gamma ray sources. These isotopes emit radiation in two or three discreet wavelengths. Cobalt-60 will emit *1.17 and 1.33 MeV* gamma rays, and Iridium-192 will emit *0.31, 0.47, and 0.60 MeV* gamma rays. It can be seen from these values that the energy of radiation coming from Co-60 is more than twice the energy of the radiation coming from the Ir-192. From a radiation safety point of view, this difference in energy is important because the Co-60 has more material penetrating power and, therefore, is more dangerous and requires more shielding

EQUIPMENT & MATERIALS

X-ray Generators

The major components of an X-ray generator are the tube, the high voltage generator, the control console, and the cooling system. As discussed earlier in this material, X-rays are generated by directing a stream of high speed electrons at a target material such as tungsten, which has a high atomic number. When the electrons are slowed or stopped



by the interaction with the atomic particles of the target, X-radiation is produced. This is accomplished in an X-ray tube such as the one shown in the figure. The tube cathode (*filament*) is heated with a low-voltage current of a few amps.
The filament heats up and the electrons in the wire become loosely held. A large electrical potential is created between the cathode and the anode by the high-voltage generator.
Electrons that break free of the cathode are strongly attracted to the anode target. The stream of electrons between the cathode and the anode is the tube current.
The tube current is measured in milliamps and is controlled by regulating the low-voltage heating current applied to the cathode. The higher the temperature of the filament, the larger the number of electrons that leave the cathode and travel to the anode. The milliamp or current setting on the control console regulates the filament temperature, which relates to the intensity of the X-ray output.
The high-voltage between the cathode and the anode affects the speed at which the electrons travel and strike the anode. The higher the kilovoltage, the more speed and, therefore, energy the electrons have when they strike the anode. Electrons striking with more energy result in X-rays with more penetrating power.

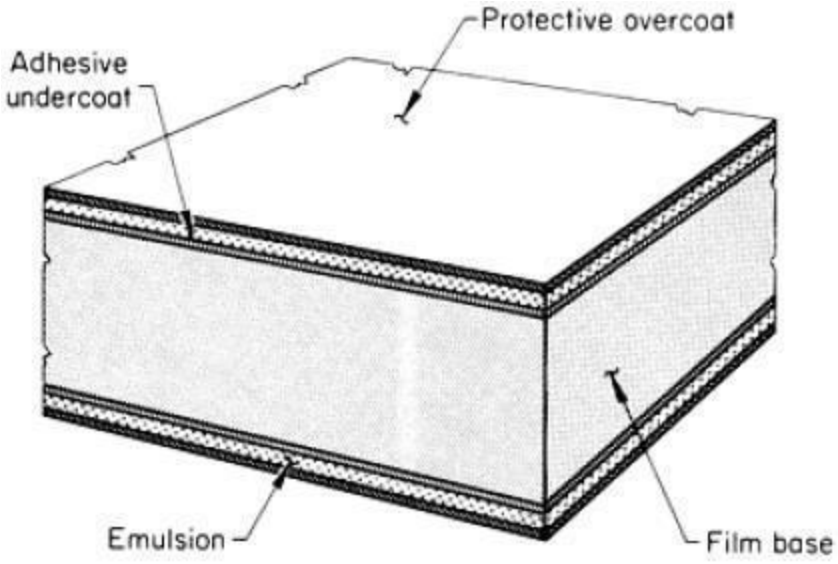
The highvoltage potential is measured in kilovolts, and this is controlled with the voltage or kilovoltage control on the control console. An increase in the kilovoltage will also result in an increase in the intensity of the radiation.
The figure shows the spectrum of the radiated X-rays associated with the voltage and current settings. The top figure shows that increasing the kV increases both the energy of X-rays and also increases the intensity of radiation (*number of photons*). Increasing the current, on the other hand, only increases the intensity without shifting the spectrum.

A focusing cup is used to concentrate the stream of electrons to a small area of the target called the "*focal spot*". The focal spot size is an important factor in the system's ability to produce a sharp image. Much of the energy applied to the tube is transformed into heat at the focal spot of the anode. As mentioned above, the anode target is commonly made from tungsten, which has a high melting point in addition toa high atomic number. However, cooling of the anode by active or passive means is necessary. Water or oil re-circulating systems are often used to cool tubes. Some low power tubes are cooled simply with the use of thermally conductive materials and heat radiating fins.

In order to prevent the cathode from burning up and to prevent arcing between the anode and the cathode, all of the oxygen is removed from the tube by pulling a vacuum. Some systems have external vacuum pumps to remove any oxygen that may have leaked into the tube. However, most industrial X-ray tubes simply require a warm-up procedure to be followed. This warm-up procedure carefully raises the tube current and voltage to slowly burn any of the available oxygen before the tube is operated at high power.
In addition, X-ray generators usually have a filter along the beam path (*placed at or near the x-ray port*). Filters consist of a thin sheet of material (*often high atomic number materials such as lead, copper, or brass*) placed in the useful beam to modify the spatial distribution of the beam. Filtration is required to absorb the lower-energy X-ray photons emitted by the tube before they reach the target in order to produce a cleaner image (*since lower energy X-ray photons tend to scatter more*).

The other important component of an X-ray generating system is the control console. Consoles typically have a keyed lock to prevent unauthorized use of the system. They will have a button to start the generation of Xrays and a button to manually stop the generation of X-rays. The three main adjustable controls regulate the tube voltage in *kilovolts*, the tube amperage in *milliamps*, and the exposure time in *minutes and seconds*.Some systems also have a switch to change the focal spot size of the tube X-ray films for general radiography basically consist of an emulsion-gelatin containing radiation-sensitive silver halide crystals (*such as silver bromide or silver chloride*). The emulsion is usually coated on both sides of a flexible, transparent, blue-tinted base in layers about *0.012 mm* thick. An adhesive undercoat

fastens the emulsion to the film base and a very thin but tough coating covers the emulsion to protect it against minor abrasion. The typical total thickness of the X-ray film is approximately *0.23 mm*.
Though films are made to be sensitive for X-ray or gamma-ray, yet they are also sensitive to visible light. When X-rays,vgamma-rays, or light strike the film, some of the halogen atoms are liberated from the silver halide crystal and thus leaving the silver atoms alone. This change is of such a small nature that it cannot be detected by ordinary physical methods and is called a "*latent (hidden) image*". When the film is exposed to a chemical solution (*developer*) the reaction results in the formation of black, metallic silver.



Film Selection
Selecting the proper film and developing the optimal radiographic technique for a particular component depends on a number of different factors;
Composition, shape, and size of the part being examined and, in some cases, its weight and location.
Type of radiation used, whether X-rays from an X-ray generator or gamma rays from a radioactive source.
Kilovoltage available with the X-ray equipment or the intensity of the gamma radiation.
Relative importance of high radiographic detail or quick and economical results.

Film Packaging
Radiographic film can be purchased in a number of different packaging options and they are available in a variety of sizes. The most basic form is as individual sheets in a box. In preparation for use, each sheet must be loaded into a cassette or film holder in a darkroom to protect it from exposure to light. Industrial X-ray films are also available in a form in which each sheet is enclosed in a light-tight envelope. The film can be exposed from either side without removing it from the protective packaging. A rip strip makes it easy to remove the film in the darkroom for processing. Packaged film is also available in the form of rolls where that allows the radiographer to cut the film to any length. The ends of the packaging are sealed with electrical tape in the darkroom. In applications such as the radiography of circumferential welds and the examination of long joints on an aircraft fuselage, long lengths of film offer great economic advantage.

Film Handling
X-ray film should always be handled carefully to avoid physical strains, such as pressure, creasing, buckling, friction, etc. Whenever films are loaded in semi-flexible holders and external clamping devices are used, care should be taken to be sure pressure is uniform. Marks resulting from contact with fingers

that are moist or contaminated with processing chemicals, as well as crimp marks, are avoided if large films are always grasped by the edges and allowed to hang free. Use of envelope-packed films avoids many of these problems until the envelope is opened for processing.

5.10 RADIOGRAPHY CONSIDERATIONS & TECHNIQUES

Radiographic Sensitivity

The usual objective in radiography is to produce an image showing the highest amount of detail possible. This requires careful control of a number of different variables that can affect image quality. Radiographic sensitivity is a measure of the quality of an image in terms of the smallest detail or discontinuity that may be detected. Radiographic sensitivity is dependant on the contrast and the definition of the image.

Radiographic contrast is the degree of density (*darkness*) difference between two areas on a radiograph. Contrast makes it easier to distinguish features of interest, such as defects, from the surrounding area. The image to the right shows two radiographs of the same stepwedge.

The upper radiograph has a high level of contrast and the lower radiograph has a lower level of contrast. While they are both imaging the same change in thickness, the high contrast image uses a larger change in radiographic density to show this change. In each of the two radiographs, there is a small dot, which is of equal density in both radiographs. It is much easier to see in the high contrast radiograph.

5.11RADIATION SAFETY

Radiation Health Risks

As mentioned previously, the health risks associated with the radiation is considered to be one the major disadvantages of radiogaphy. The amount of risk depends on the amount of radiation dose received, the time over which the dose is received, and the body parts exposed. The fact that X-ray and gamma-ray radiation are not detectable by the human senses complicates matters further. However, the risks can be minimized and controlled when the radiation is handled and managed properly in accordance to the radiation safety rules.

The active laws all over the world require that individuals working in the field of radiography receive training on the safe handling and use of radioactive materials and radiation producing devices.
Today, it can be said that radiation ranks among the most thoroughly investigated (and somehow understood) causes of disease. The primary risk from occupational radiation exposure is an increased risk of cancer. Although scientists assume low-level radiation exposure increases one's risk of cancer, medical studies have not demonstrated adverse health effects in individuals exposed to small chronic radiation doses.

The occurrence of particular health effects from exposure to ionizing radiation is a complicated function of numerous factors including:

Type of radiation involved. All kinds of ionizing radiation can produce health effects. The main difference in the ability of alpha and beta particles and gamma and X-rays to cause health effects is the amount of energy they have. Their energy determines how far they can penetrate into tissue and how much energy they are able to transmit directly or indirectly to tissues.

Size of dose received. The higher the dose of radiation received, the higher the likelihood of health effects.

Rate at which the dose is received. Tissue can receive larger dosages over a period of time. If the dosage occurs over a number of days or weeks, the results are often not as serious if a similar dose was received in a matter of minutes.

Part of the body exposed. Extremities such as the hands or feet are able to receive a greater amount of radiation with less resulting damage than blood forming organs housed in the upper body.

The age of the individual. As a person ages, cell division slows and the body is less sensitive to the effects of ionizing radiation. Once cell division has slowed, the effects of radiation are somewhat less damaging than when cells were rapidly dividing.

Biological differences. Some individuals are more sensitive to radiation than others. Studies have not been able to conclusively determine the cause of such differences.