Pure Substance → A pure substance is a substance which is

i) homogeneous in composition
ii) homogeneous in chemical aggregation
iii) Invariable in chemical aggregation

The chemical elements must be combined chemically in same way everywhere

The state of chemical combination of the system does not change with time

Saturation Pressure → It is the pressure at which phase change will occur for a given temperature.

Saturation Temperature → It is the temperature at which phase change will occur for a given pressure.

Ideal Gas Law →

$$PV = nR_uT$$

where,
P = Pressure ; V = Volume
n = No. of moles ; T = Temperature
R_u = Universal gas constant = 8.314 kJ/k-mol·K → Constant

It can also be written as

$$PV = \frac{m}{M} R_uT$$

where, $n = \frac{m}{M} = \frac{\text{Mass}}{\text{Molecular mass}}$

$$PV = m \cdot \frac{R_u}{M} T$$

$$PV = mRT$$

where,
R = Characteristics Gas Constant → Depends upon the molecular mass of ideal gases

~~Boyle's law~~

Law's of Ideal gas equation →

1) **Boyle's law** → $P \propto \frac{1}{V}$ (for a given mass)

if T = Constant

$$P_1 \propto \frac{1}{V_1}$$

$$\boxed{P_1 V_1 = P_2 V_2}$$

2) **Charle's Law** → $V \propto T$ (for a given mass)

if P = Constant

$$\boxed{\frac{V_1}{T_1} = \frac{V_2}{T_2}}$$

3) **Gay Lussac's law** → $P \propto T$ (for a given mass)

if V = Constant

$$\boxed{\frac{P_1}{T_1} = \frac{P_2}{T_2}}$$

4) **Avogadro's law** → $V \propto n$ (for a given mass of ideal gas)

if P & T are constant

5) **Regnoult's Law** → The specific heat at constant pressure (C_p) & specific heat at constant volume (C_v) do not change with change in pressure and temperature.

6) **Joule's law** → This law states that 'The internal energy of a given quantity of a gas depends on the temperature.

$U \propto T$ $U = f(T)$

Air Compressor

An air compressor is a machine to compress the air and to raise its pressure. The air compressor sucks air from atmosphere, compresses it and then delivers the same under high pressure to a storage vessel.

Main Components of Compressed air systems →

- Intake air filters
- Inter-stage coolers
- After coolers
- Air dryers
- Moisture drain traps
- Receivers

Classification of Compressor →

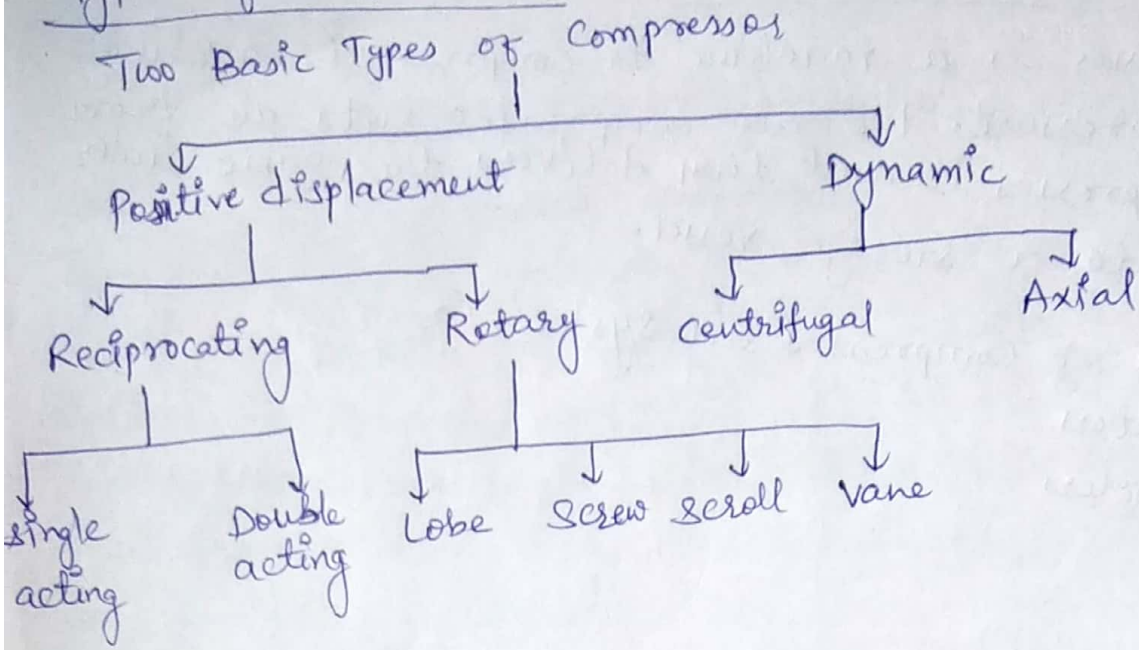
1) Method of Compression :-
   a) Reciprocating compressor
   b) Rotary compressor
   c) Centrifugal compressor

2) Principle of opesation :-
   a) Positive displacement
   b) Rotodynamic or steady flow compressor

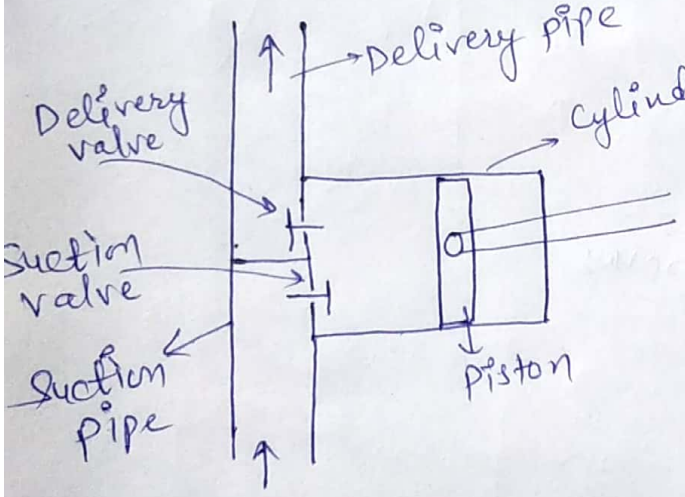
3) Numbes of stages
   a) Single stage
   b) Multi stage

4) Numbes of cylinder
   a) Single cylinder
   b) Multi Cylinder

Types of Compressors →



Positive Displacement Compressor → These compressors causes movement by trapping a fixed amount of air then forcing (displacing) that trapped volume into discharge pipe, that's why called Positive displacement



→ Reciprocating Compressor

Dynamic Compressor → It is continuous flow compressor Characterised by rotating impellers to add velocity and thus pressure to fluid.

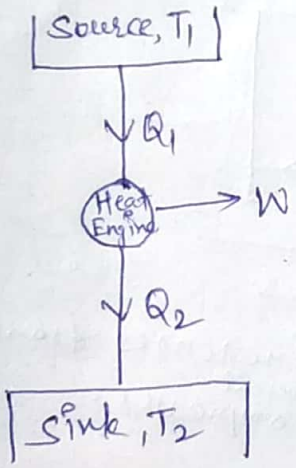
Refrigerator & Heat Pump

Refrigerator →

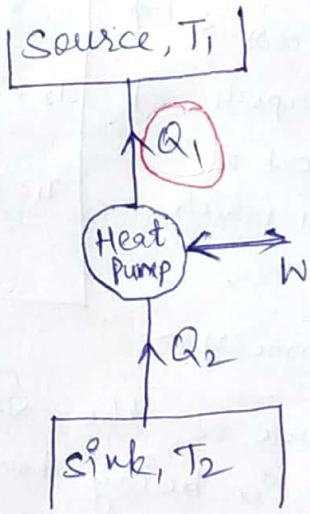
- The term refrigeration is used for the process of removing heat (i.e. cooling) from a substance.
- Theoretically, the refrigeration is a reversed heat engine, or a heat pump which pumps heat from a cold body and delivers it to hot body.
- The substance which works in a heat pump to extract heat from a cold body and to delives it to a hot body is called refrigerant.

Coefficient of performance of a refrigerator →

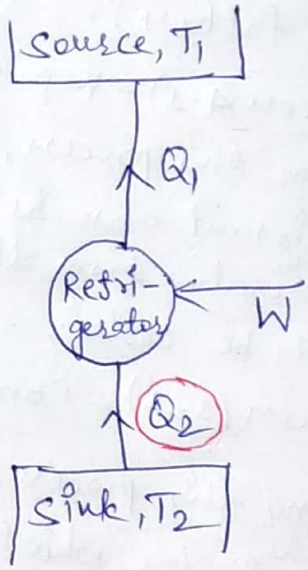
$$COP = \frac{\text{Amount of heat extracted}}{\text{work input}} = \frac{Q}{W}$$



$$\eta_{H.E.} = \frac{W}{Q_1}$$



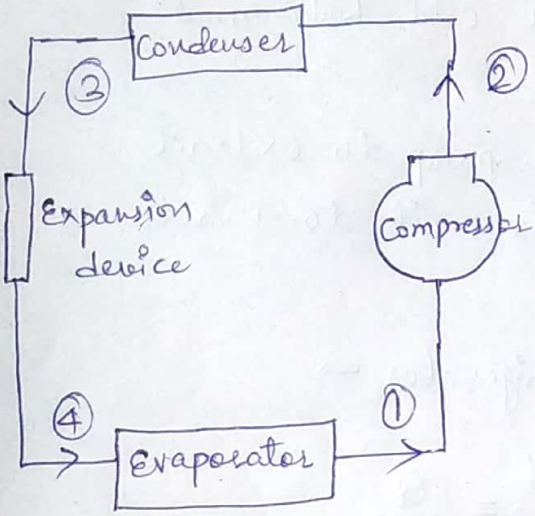
$$COP_{HP} = \frac{Q_1}{W}$$

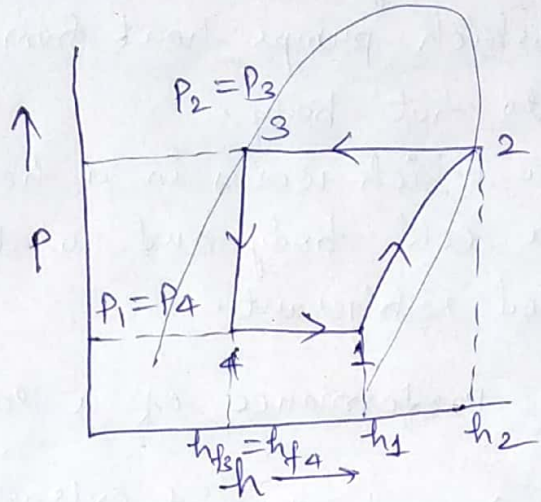


$$COP_R = \frac{Q_2}{W}$$

Vapour Compression Refrigeration System →

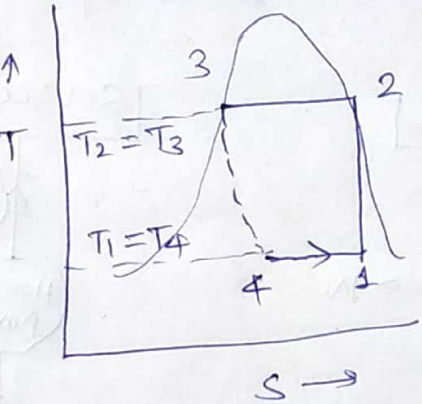
This system uses a suitable working substance, termed as refrigerant which condenses & evaporates at temperature and pressure close to atmospheric conditions.





The four process of cycle are as follows :-

1) Process (4-1) – Vaporising process →
During this process, liquid-vapour refrigerant absorbs latent heat of vaporisation from the medium which is to be cooled.



2) Process (1-2) – Compression process →
During this process, the pressure of the vapour refrigerant increases from P_1 to P_2 for which W work is being done on compressor.

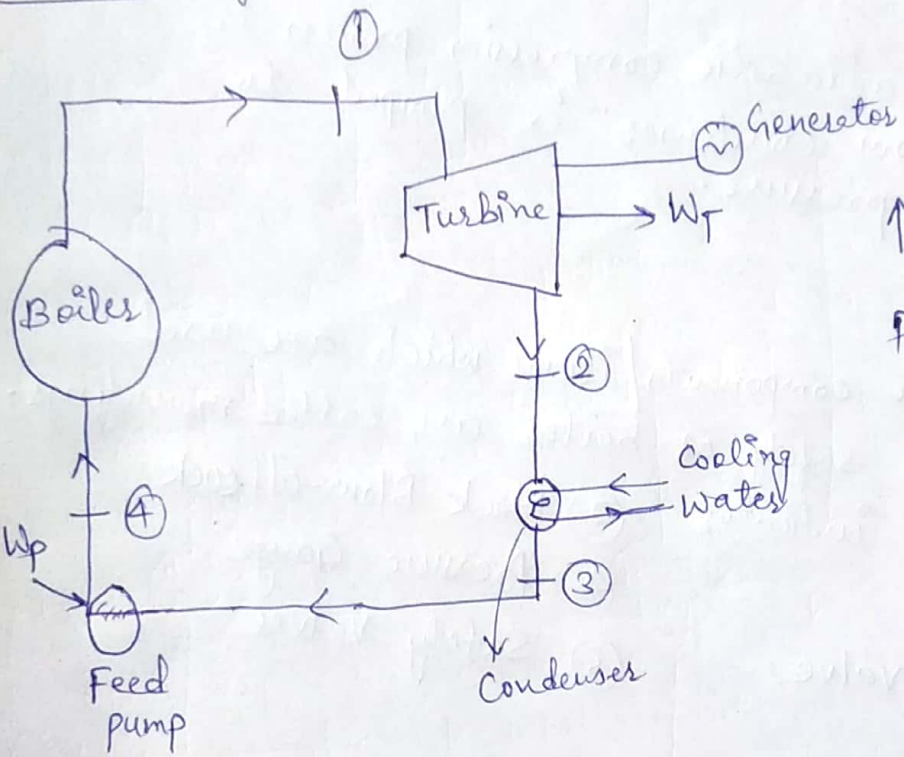
3) Process (2-3) – Condensation process →
During this process, the vapour refrigerant is changed into liquid refrigerant while exchanging heat with the surrounding.

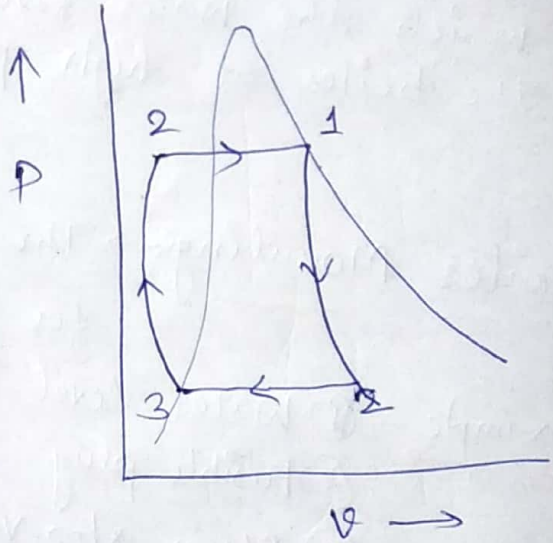
4) Process (3-4) – Expansion process →
The liquid refrigerant is expanded by throttling process and pressure of liquid refrigerant changes from P_3 to P_4.

Steam Power Plant

- Steam Power Plant is used to produce mechanical or Electrical (in generator) power by the thermal energy of the steam.
- The steam is produced in a boiler by burning coal at a suitable temperature.
- Steam power plant is also known as thermal power plant.
- Steam power plant uses Rankine cycle for power generation.

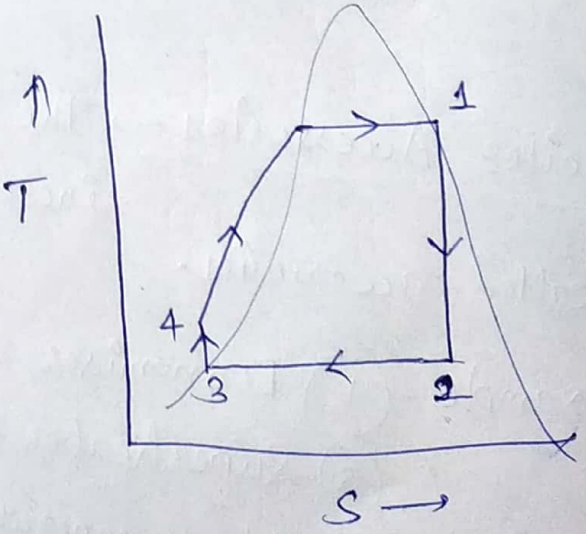
Rankine Cycle →





Process (4-1) – Boiler →

- Here liquid converts into vapour after gaining the heat from the Combustion of coal.
- It is a constant pressure heat addition process.



Process (1-2) – Turbine →

- It is a reversible adiabatic expansion process.
- Mechanical work (W_T) is produced in it at the expause of thermal energy of steam.

Process (2-3) – Condenser →

- During this process, heat is lost at constant pressure to the outside.
- It is known as constant pressure heat rejection process.

Process (3-4) – Feed Pump →

- It is a reversible adiabatic compression process in which the water from condenser is pumped to the boiler at high pressure.

Boiler Mountings → The components/items which are used for safety of boiler are called mountings.

Example – (1) Water level indicator (2) Blow-off cock
(3) Fusible plug (4) Pressure Gauge
(5) Steam stop valve (6) Safety valves

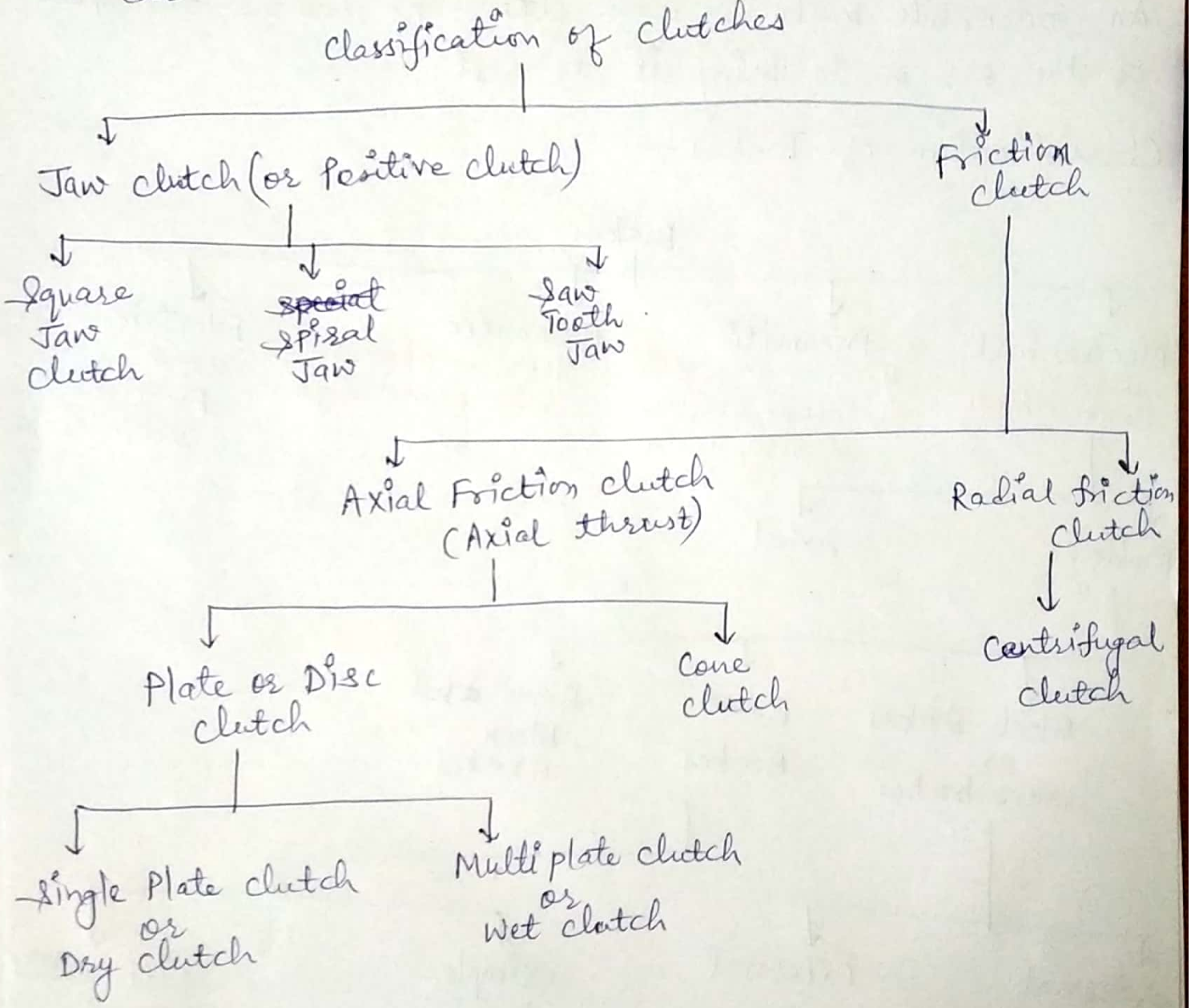
Boiler Accessories → The items which are used for increasing the boiler efficiency are called accessories.

Example – (1) Economiser (2) Preheater
(3) Superheater (4) Injector
(5) Steam seperator (6) Feed Pump

Module - 3

Sub - BME

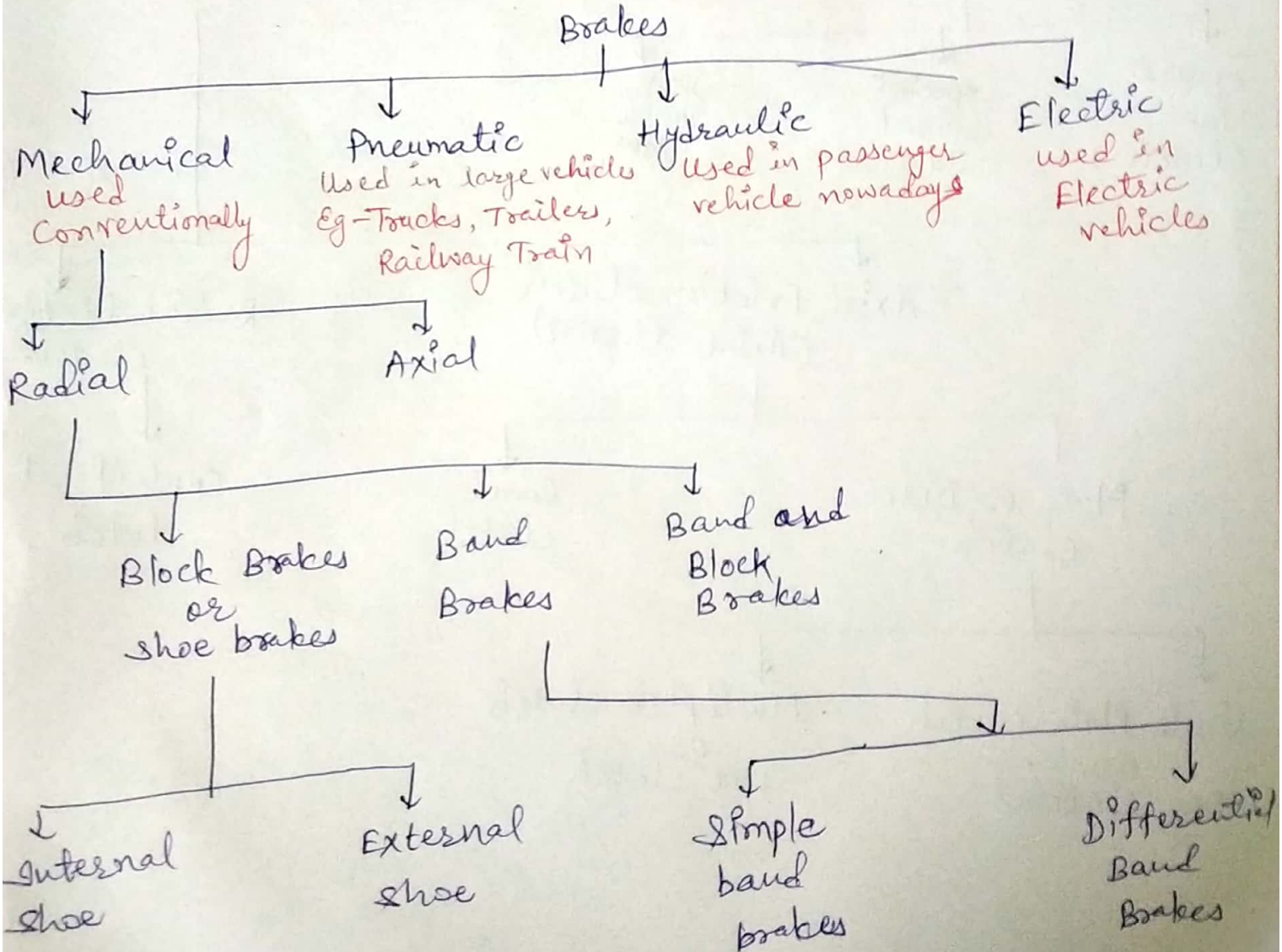
Clutch → It is a mechanical device, which is used to connect or disconnect the source of power from the remaining parts of the power transmission system at the will of operator. An automotive clutch can permit the engine to run without driving the car.



Brakes → A brake is defined as a mechanical device, which is used to absorb the energy possessed by a moving system or mechanism by means of friction. The primary purpose of the brake is to slow down or completely stop the motion of a moving system such as a rotating drum, machine or vehicle.

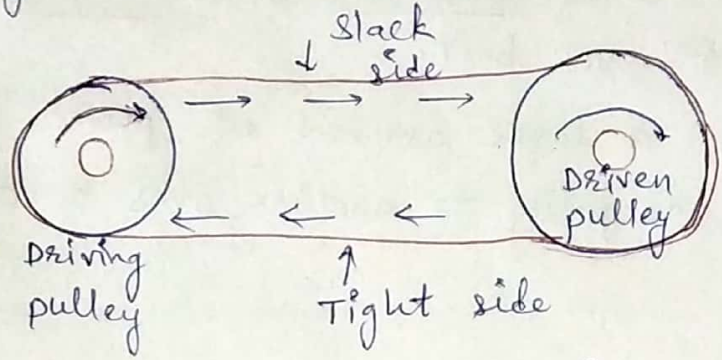
An automobile brake is used either to reduce the speed of the car or to bring it to rest.

Classification of Brakes →



Belt drive

Belt drives → These are used to transfer rotational motion from one shaft to another. Both shafts may rotate at same or variable speed.



A simple belt pulley system consist of a driver pulley and driven pulley. When drives pulley is rotated, it causes pulling action due to friction. This pulling action rotates the driven pulley in the same direction of driver pulley. This pulling action will results in tight side & slack side on belt pulley system.

Types of Belt drives →

1) Open belt drive
2) Closed or crossed belt drive
3) Fast or loose cone pulley
4) Stepped cone pulley
5) Jockey pulley drive

Rope drive

Rope Drive → A rope drive is a form of belt drive, used for mechanical power transmission.

Rope drives use a number of circular section ropes, rather than a single flat or vee belt.

It is widely used when a large amount of power is to be transmitted from one pulley to another, over a considerable distance.

Types of Rope drives →

1) Fibre Ropes
2) Wire Ropes

Gear

Gears → Gears are used to transmit motion from one shaft to another shaft or between a shaft and a slide. Gears use no intermediate link or connector and transmit the motion by direct contact. In this method, the surfaces of 2 bodies make a tangential contact. The gear drive is used when distance between the driver and follower is very small.

Classification of gear -

Based on position of axis of shafts

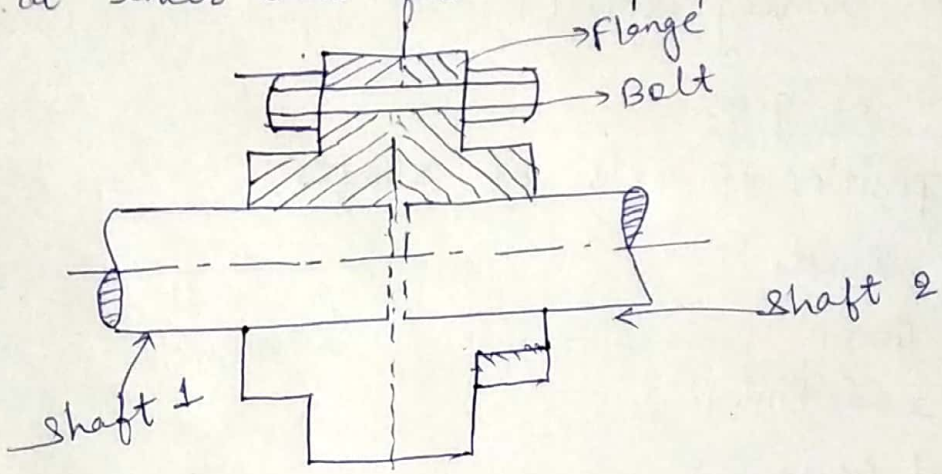
1) Parallel shafts
   a) Spur Gears
   b) Rack and Pinion
   c) Helical Gears
   d) Double-helical or herringbone gear
2) Intersecting shafts
   a) Spiral bevel Gear
   b) Zero bevel Gear
3) Skew shafts (Neither parallel nor intersecting shafts)
   a) Crossed helical gears
   b) Worm gears

Coupling

Coupling → These are mechanical elements that couples two drive elements (shafts) which enables motion to be transfered from one element to another element.

or

A coupling is a device used to connect 2 shafts together at their ends for the purpose of transmitting power.



Types of coupling →

1) **Rigid Coupling** - It is used to connect 2 shafts which are perfectly alligned.

Types of rigid coupling :- i) Sleeve or muff coupling
ii) Clamp or Compression coupling
iii) Flange coupling

2) **Flexible Coupling** - These are used when the 2 shafts are having both lateral or angular misalignment.

Types of Flexible coupling :- i) Universal coupling
ii) Oldham coupling

Robot → Came from Czech word: Robota which means forced or slave labores
→ In 1921 Karel Capek used a robot in drama.
→ First commercial, Digital & Programmable robot was built by George Devol (1954).
→ According to International Organization for Standardization (ISO) :-
An automatically controlled, Reprogrammable, multipurpose manipulator programmable in three or more axes, which can be either fixed in place or mobile for use in Industrial automation applications.

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

Note :- A CNC machine is not a robot
→ CNC machine can do more than one task at a time but robot can do only one task at a time.
→ CNC machine have generally 2 or 3 degree of freedom but robot has 6 degree of freedom.
→ In CNC machine coding are done by G code and M code but in robot the method of programing is different.
→ CNC machine is more rigid in comparision with robot.

Robotics → It is a science, which deals with the issues related to design, manufacturing & usages of robot.
→ In robotics we try to copy 3H of humans
H : Hand → In form of manipulator (mech. hand)
H : Head → Intelligence
H ; Heart → Emotion
→ We use robots in manufacturing industries because to
• To Increase productivity
• To Reduce product cost
• Improve product Quality

→ Industrial Robot :-

- An Industrial robot is a robot system used for manufacturing. Industrial robots are automated, programmable and capable of movement on three or more axis.
- Typical applications of robots include welding, painting, assembly, pick & place, packaging, product inspection & testing. All are done with high endurance, speed & precision.

laws of Robot :-

Issac Asimov's Three laws of Robotics :-

→ A robot may not injure the Human Being.

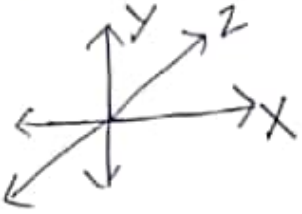
→ A robot must obey the order given by Human except it should not conflict with the 1st Law.

→ A robot must protect its own existence as long as it should not conflict with the 1st & 2nd law.

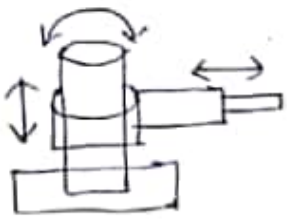
Classification of robots :-

I) According to Geometric classification :-

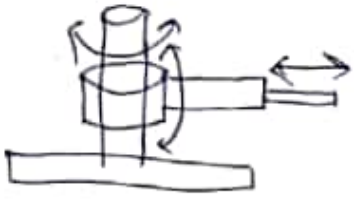
(i) Cartesian/Rectilinear: It moves in X, Y & Z direction. It has three degree of freedom in linear motion only.



(ii) Cylindrical robot : This type of robot is used for round workpiece.
It don't rotate the complete cycle.
→ Work on 2 linear and 1 rotary motion.



(iii) Spherical robot : This type of robot is also used for round workpiece where cylindrical robots are not used.
→ It consist of 2 rotary & 1 linear motion.



Basic Components of Robot →

a) **Manipulator Linkage :-**
- It is a set of links connected by joints either rotating or sliding.
- Best link — end effector
  → Eg. Gripper

b) **Actuators :-**
- It actually help to give motion to all links (joints) or Component of robots.
- Linear or rotating actuator.
- Electrical, Pneumatic or hydraulic power
  Eg. Motors

c) **Transmission :-**
- Element between Actuator & Manipulator linkage

Why we use it

a) Maintain speed of motors
   3000 rpm → 30 rpm (using gears)

b) Convert linear to Rotatory motion or vice-versa.

d) **Sensors :-**

i) Position Sensor ii) Velocity Sensor iii) Acceleration Sensor
iv) Torque Sensor v) Pressure Sensor vi) Vision Sensor
vii) Touch Sensor
[All efficient for control Robots]

e) **Controllers :-**

Provides intelligence to control the whole system
- Memory to store control program
- CPU → Control Commands
- Hardware for use interface & external work
  Eg:- Sensor in TV Remote

f) User Interface :-

- It must have
  - → Display (show status)
  - → I/p Device (Enter command to Robots)

Eg → It may be PC (Personal computer)

g) Power Conversion :-

- Lower power to higher power or vice-versa
- DC to AC or vice-versa.

advantages of robots are listed below:

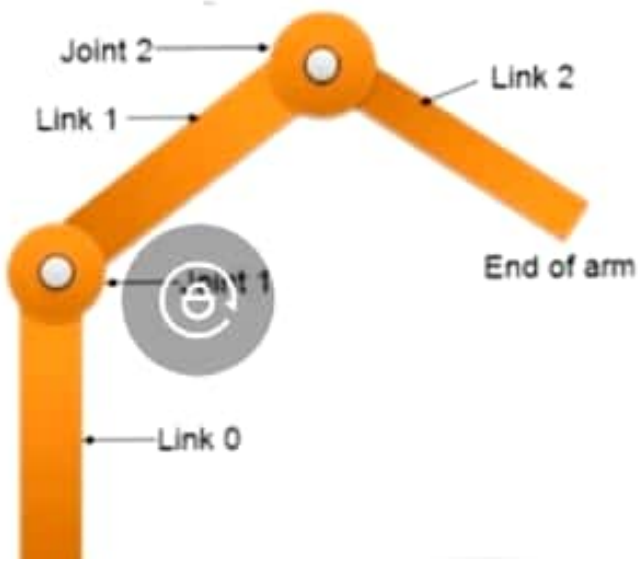
- Robots are good substitutes to the human beings in hazardous or uncomfortable work environments.
- A robot performs its work cycle with a consistency and repeatability which is difficult for human beings to attain over a long period of continuous working.
- Robots can be reprogrammed. When the production run of the current task is completed, a robot can be reprogrammed and equipped with the necessary tooling to perform an altogether different task.
- Robots can be connected to the computer systems and other robotics systems. Nowadays robots can be controlled with wire-less control technologies. This has enhanced the productivity and efficiency of automation industry.

2. Robot anatomy and related attributes

2.1 Joints and Links

The manipulator of an industrial robot consists of a series of joints and links. Robot anatomy deals with [redacted] ulator's physical construction. A robotic joint provides relative motion between two links of the robot. Each joint, or axis, provides a certain degree-of-freedom (dof) of motion. In most of the cases, only one degree-of-freedom is associated with each joint. Therefore the robot's complexity can be classified according to the total number of degrees-of-freedom they possess.

Each joint is connected to two links, an input link and an output link. Joint provides controlled relative movement between the input link and output link. A robotic link is the rigid component of the [redacted] base, such as the floor. From this base, a joint-link numbering scheme may be recognized as shown in Figure 7.5.1. The robotic base and its connection to the first joint are termed as link-0. The first joint in the sequence is joint-1. Link-0 is the input link for joint-1, while the output link from joint-1 is link-1—which leads to joint-2. Thus link 1 is, simultaneously, the output link for joint-1 and the input link for joint-2. This joint-link-numbering scheme is further followed for all joints and links in the robotic systems.



Nearly all industrial robots have mechanical joints that can be classified into following five types as shown in Figure 7.5.2.

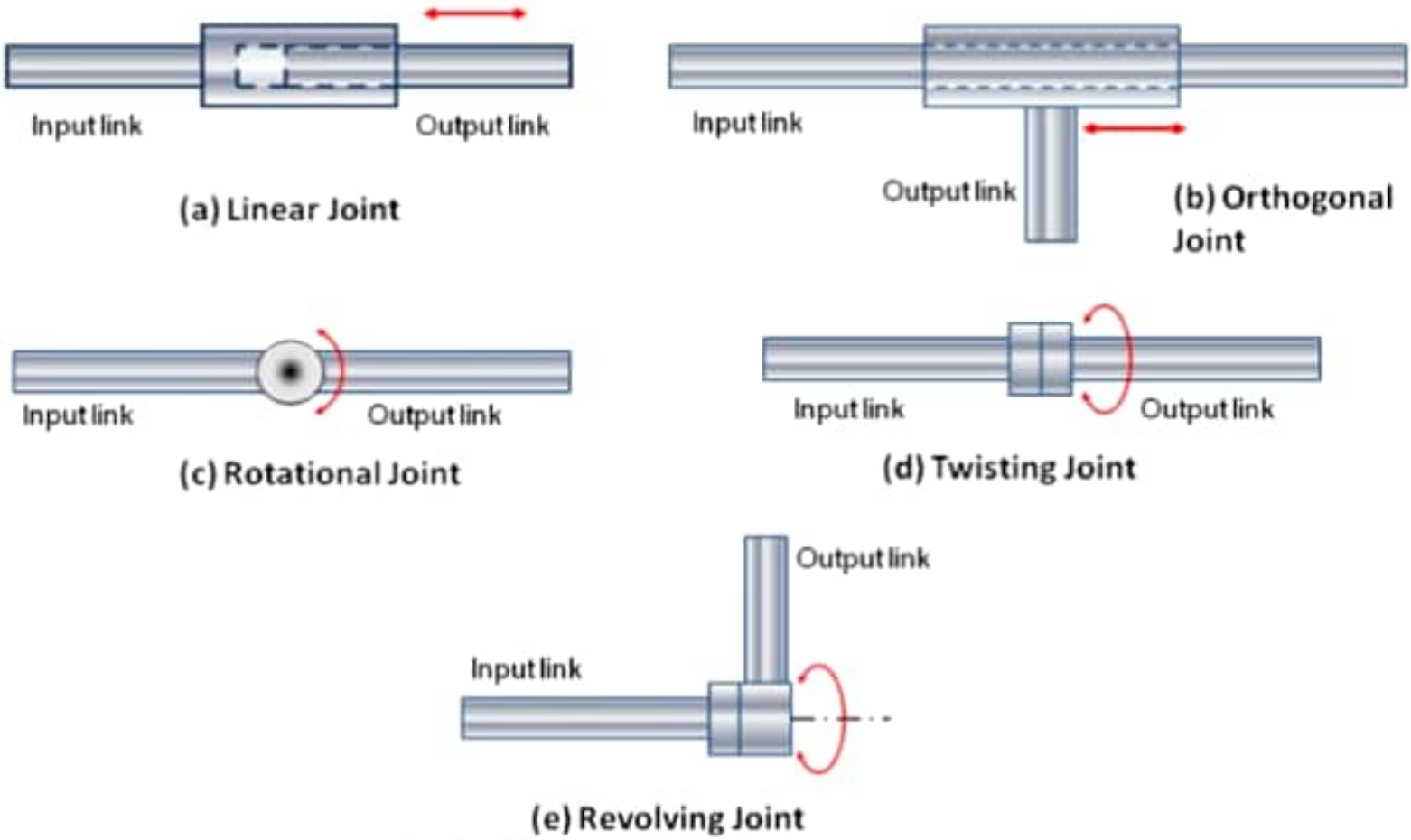


Fig. 7.5.2 Types of Joints

a) Linear joint (type L joint)

The relative movement between the input link and the output link is a translational sliding motion, with the axes of the two links being parallel.

b) Orthogonal joint (type U joint)

This is also a translational sliding motion, but the input and output links are perpendicular to each other during the move.

c) Rotational joint (type R joint)

This type provides rotational relative motion, with the axis of rotation perpendicular to the axes of the input and output links.

d) Twisting joint (type T joint)

This joint also involves rotary motion, but the axis or rotation is parallel to the axes of the two links.

e) Revolving joint (type V-joint, V from the "v" in revolving)

In this type, axis of input link is parallel to the axis of rotation of the joint. However the axis of the output link is perpendicular to the axis of rotation.

→ Industrial Robot :-

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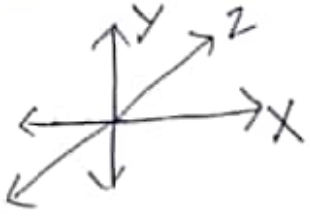

(ii) Cylindrical robot : This type of robot is used for round workpiece.
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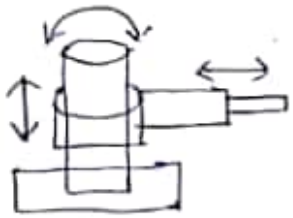
→ Work on 2 linear and 1 rotary motion.



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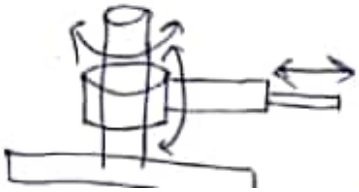
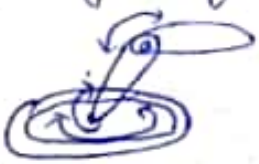


(iv) Joined Arm robot :- This type of robot only perform rotary motion. This type of robot have 3 rotary motion.



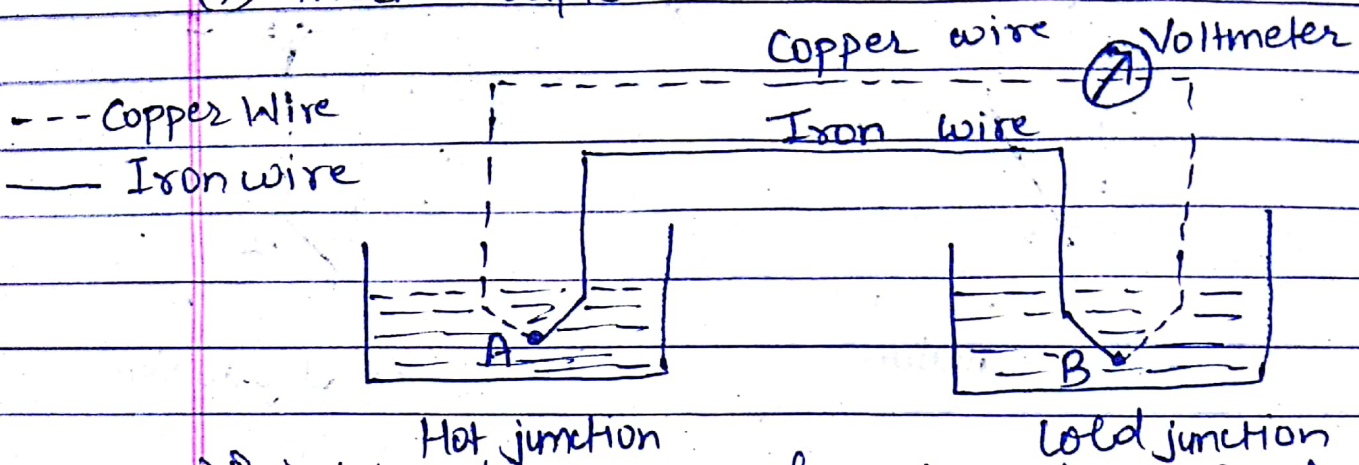
(v) SCARA robot :- SCARA Robot has 3 rotary motion & 1 linear motion. It is mainly use for pick & place of any object.

⇒ According to the usage in different fields.

(i) Industrial Robot :- Used in welding, material handling, productivity
(ii) Educational Robot → Used in education. Ex:- Robolab, Lego etc.
(iii) Domestic robot → Used in home such as modern programmed toys which can talk, dance etc.

Temperature Measurement:-

(i) Thermocouple



→ Principle of Thermocouple is based on Seebeck effect
→ Thermocouple converts thermal energy into electrical energy.
→ Thermocouple is used to measure temperature of a given substance.
→ According to Seebeck effect, when the temperature at the junction of two different metals differ, then an EMF is generated in the closed loop.
→ In figure temperature of junction B is known and we have to determine the temperature at junction A.

$$V \propto (T_1 - T_2)$$
$$V = S(T_1 - T_2)$$

where, S = Overall seebeck coefficient.

(ii) Resistance Temperature Devices :- (RTD)

→ It work on the principle that the electrical resistance of a material changes with its temperature.
→ As the temperature of metal increases the

flow of electrons increases, current also increases. So, resistance decreases.

→ The variation of resistance R with temperature T(°K) can be represented by

$$R = R_0(1 + \alpha_1 T + \alpha_2 T^2 + \alpha_3 T^3 + \cdots \alpha_n T^n)$$

where, R_0 = Resistance at temperature, T = 0K

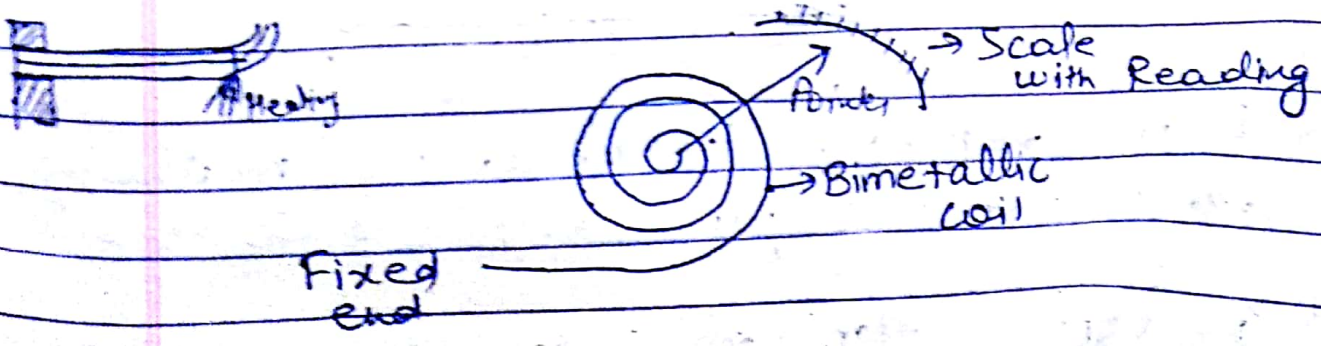
$\alpha_1, \alpha_2, \alpha_3 \cdots \alpha_n$ = Constants

→ Resistance thermometer uses the change in electrical resistance of conductors to determine the temperature.

(iii) Infrared Temperature Measurement Devices :

Infrared sensors are non-contacting devices. They measure the temperature by measuring the thermal radiation emitted by a material.

(iv) Bimetallic Temperature Measurement Devices :



→ It works on the principle that different materials have different rate of thermal expansion.

→ Deflection is directly proportional to the temperature.

→ As temperature increases or decreases there is deflection in the bimetallic coil and temperature can be measured by the help of pointer..

→ It is not so much accurate as Thermocouple and Resistance temperature Devices..

(v) Fluid - expansion Temperature Measurement Devices :

→ Fluid - expansion devices can be divided into two main classes:- the mercury type and the organic - liquid type (consist of one or more carbon atom joined to other atoms via covalent bond.)

→ Mercury thermometer is based on the principle that mercury expand with increase in temperature.

→ Fluid expansion temperature measuring devices don't require any electric power.

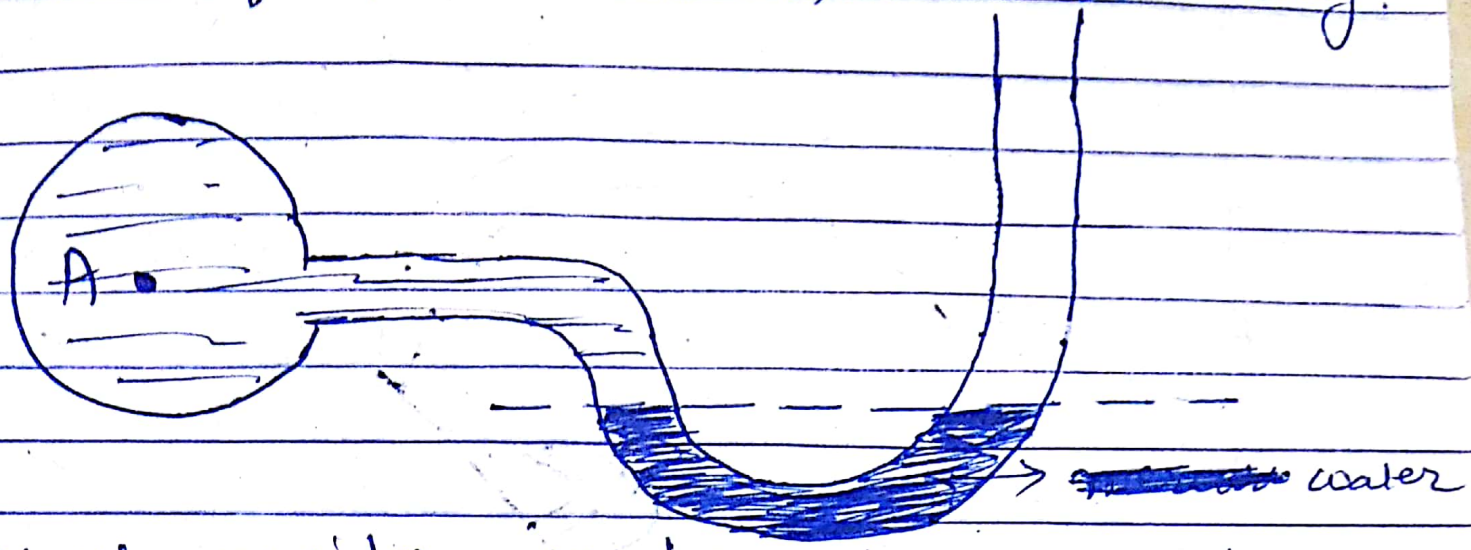
Pressure Measurement devices :

(i) Manometers :

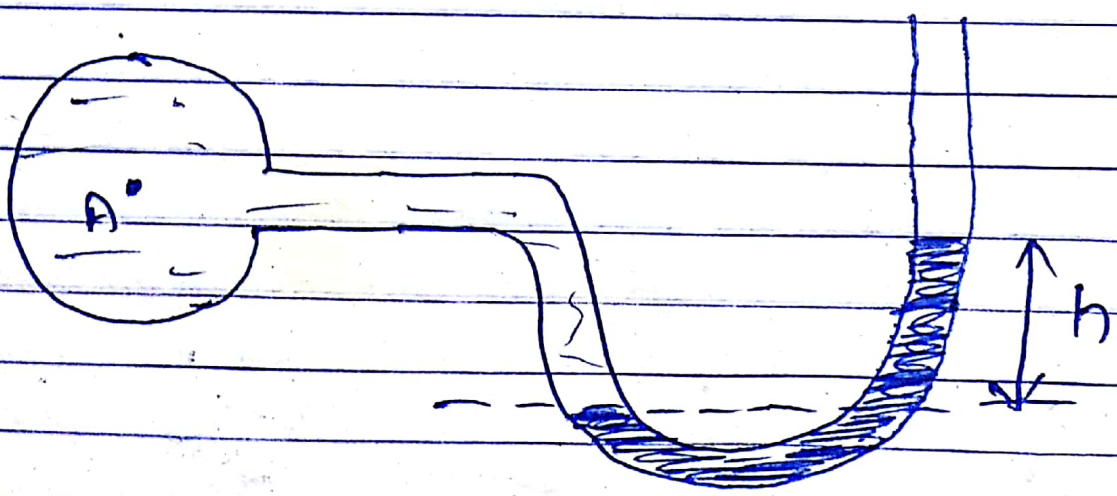
Manometer consist of a clear glass or plastic tube. ~~shaped into the~~ The tube is partially filled

DATE:

with a liquid, such as water, alcohol or mercury.



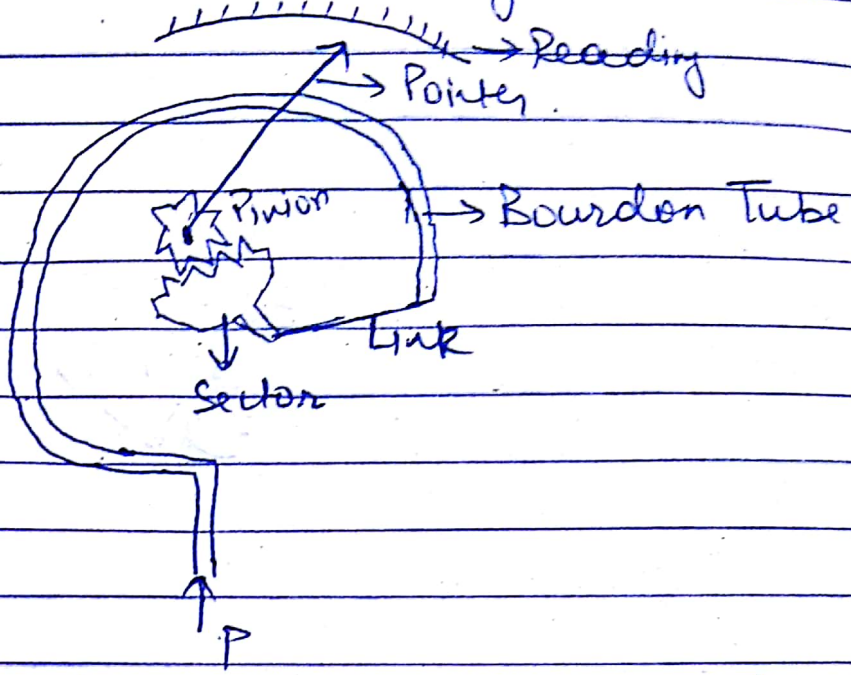
Let us consider we have to measure pressure of fluid in container A by using water in manometer. When the level of water is same then the pressure of container A is at atmosp. pressure.



When container A gains pressure more than that of atm. pressure then the level of water rises and then we can calculate the pressure of fluid in container A by the help of raise in height of water i.e, $P = \rho g h$

where, ρ = Density of water

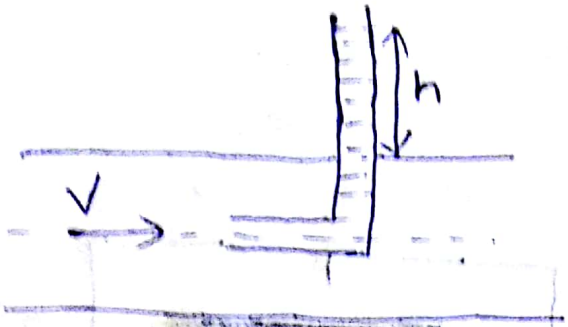
(ii) Bourdon Tube Pressure Gauge :-

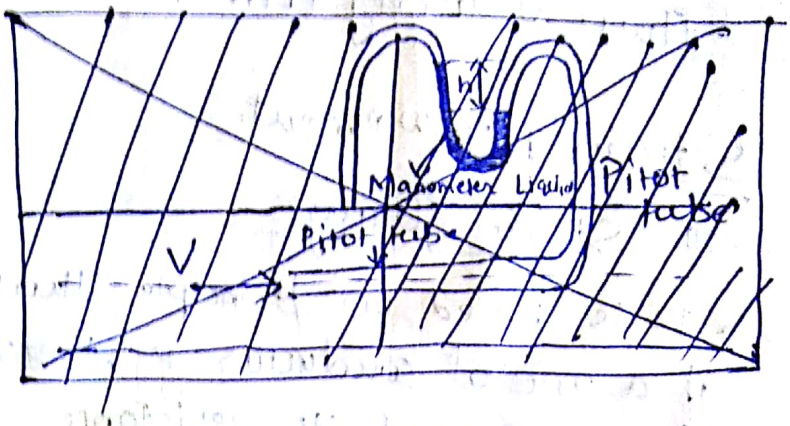


Bourdon Tube pressure gauge consist of C-shape hollow tube which is called Bourdon Tube. When hot fluid entered the hollow tube then Bourdon Tube expand due to which pinion rotate by the help of sector & link. Due to rotation of pinion pointer show the pressure reading in the closed container. Bourdon Tube is made of metal alloy such as stainless steel or brass. It is used in boilers of thermal power plant.

Velocity Measurement:

(i) Velocity Measurement of fluid with Pitot tube:-





→ Pitot tube is a flow measurement device used to measure fluid flow velocity.

→ Pitot tube consists of a tube pointing directly into the fluid flow. ~~Due to velocity of fluid, some~~ Fluid obtain some height in the tube due to velocity of fluid. By the help of height of fluid we can find the flow velocity.

$$(P_{\blacksquare} - P_0) = \frac{1}{2}\rho V^2$$

P = Pressure sense by Pitot tube $= \rho g h$

P_0 = Static pressure

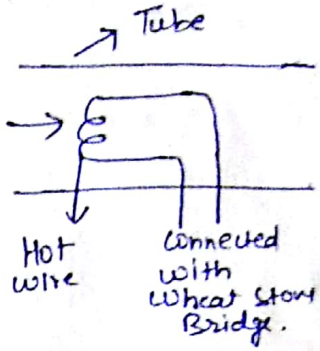
ρ = Density of fluid.

$$\boxed{V = \sqrt{\frac{2(P-P_0)}{\rho}}}$$

→ Pitot tube is widely used in the aircrafts by which aircraft's speed can be determined.

(ii) Hot Wire Anemometer :-

→ In this flow measurement of fluid is done by the help of hot wire. When fluid passes through the hot wire, then hot wire gives the heat to the fluid. Due to which some changes in temp. take place in hot wire.

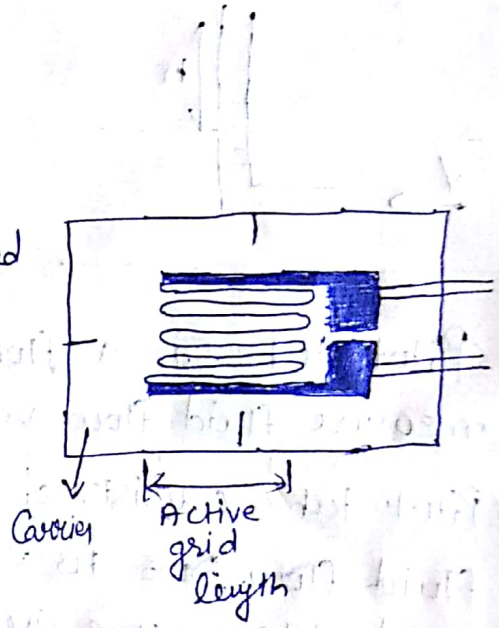


Due to change in temperature of wire resistance also changes. By the change in resistance of wire flow velocity can be measured.

Strain Measurement

Strain Gauge :-

→ It is based on principle that if a metal conductor is stretched or compressed, its resistance changes because of its
(i) length change
(ii) Diameter change
(iii) Resistivity change.



i.e; $R = \rho \frac{L}{A}$

where, R = Resistance
ρ = Resistivity of material
L = length of Material.
A = Cross sectional area of material.

→ The metallic strain gauge consists of very fine wire and arranged in a grid pattern.

→ The strain experienced by test specimen is transferred directly to the strain gauge which respond with a change in electric resistance.

→ It is very important that strain gauge be properly mounted on the test specimen so that the strain is accurately transferred from the test specimen.

→ Strain can be determine by following equation :-

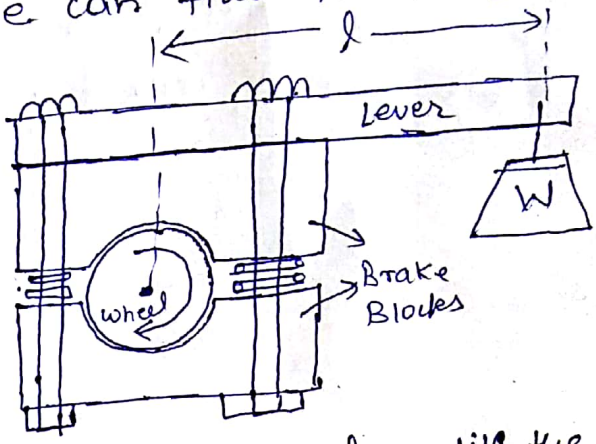
$$G.F = \frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{\varepsilon}$$

where, G.F = Metallic strain gauge.

Torque Measurement :-

(i) Prony Break Dynamometer

→ Dynamometer is a brake but in addition it has a device to measure the frictional resistance. By knowing the frictional resistance, we can find the torque transmitted.



→ Prony Brake develops mechanical friction on the periphery of ~~moving~~ rotating wheel by the means of brake blocks.

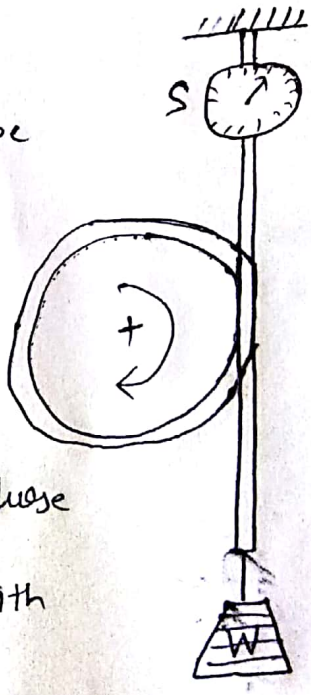
→ Break blocks squeezed against the wheel until the friction torque F.R balance the torque W.L.

$$\text{Torque} = F \times R = W \times L$$

(ii) Rope Brake Dynamometer :-

$$T = (W - S)\left(\frac{D+d}{2}\right)$$

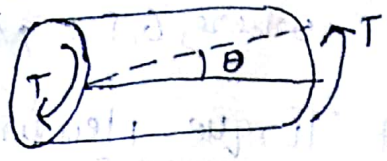
where, W = Weight at the end of rope
S = Stiffness of spring
D = Diameter of pulley
d = Diameter of rope.



Rope brake dynamometer consist of rope coound round the pulley fixed to the shaft of the engine whose torque is to be measured. The upper end of rope is attached with the spring and lower end of the rope is attached with the weight.

(iii) Torque Measurement by pointer & Scale :-

Suppose the angle of twist on the shaft due to application of torque T is θ, which can be directly read by pointer & Scale. The value of torque applied is directly related to angle of twist as



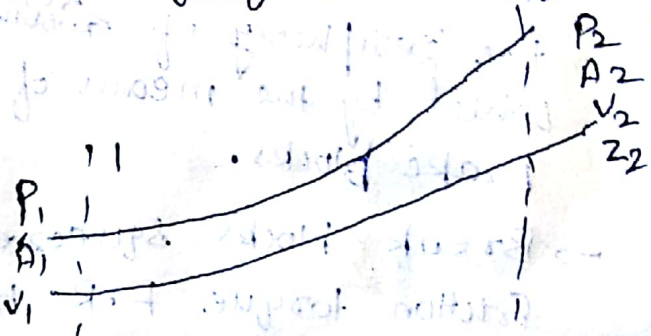
$$\frac{T}{J} = \frac{\tau}{R} = \frac{G\theta}{l}$$

$$\Rightarrow \frac{T}{J} = \frac{G\theta}{l} \Rightarrow \boxed{\theta = \frac{Tl}{GJ}}$$

For shaft $J = \frac{\pi d^4}{32}$

Flow Measurement :-

(i) Flow Measurement through Velocity of fluid Over Known Area :-



Let us consider the fluid flow through a closed channel of variable cross-section. Let the pressure, velocity, cross-sectional area and height above the datum as P_1, V_1, A_1 & Z_1 for section 1 and corresponding values for section 2 be P_2, A_2, V_2, Z_2 respectively. We can find the final velocity V_2 by help of Bernoulli's equation

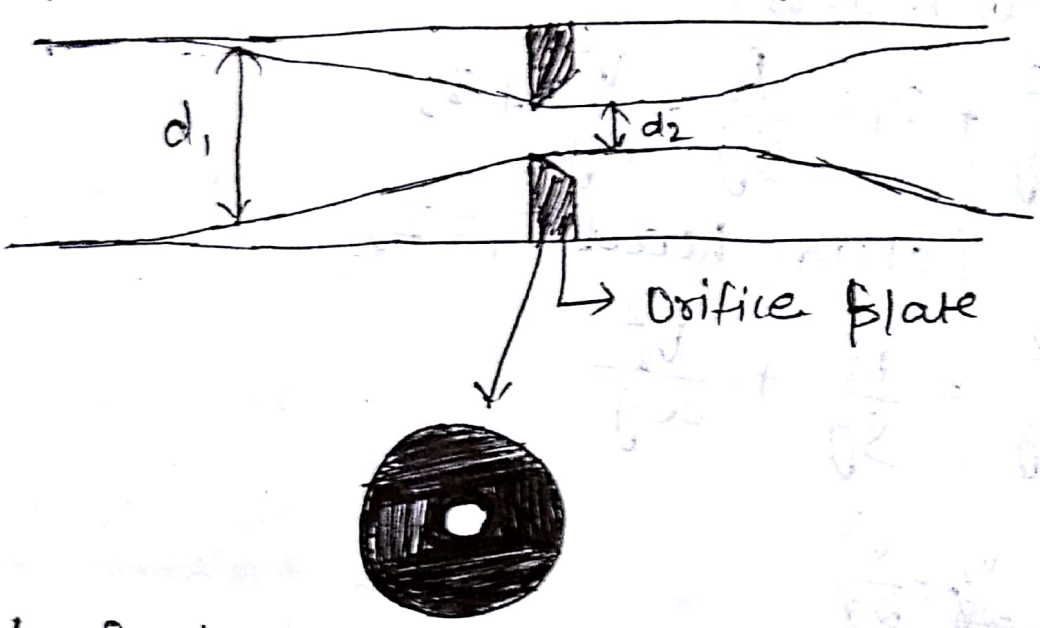
$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2$$

After finding the value of V_2, we can find ~~the value of~~ flow of fluid through passage.

$$\boxed{Q = A_2 V_2}$$

(ii) Orificemeter

In orificemeter, an orifice plate is placed in the pipe line as shown in figure.



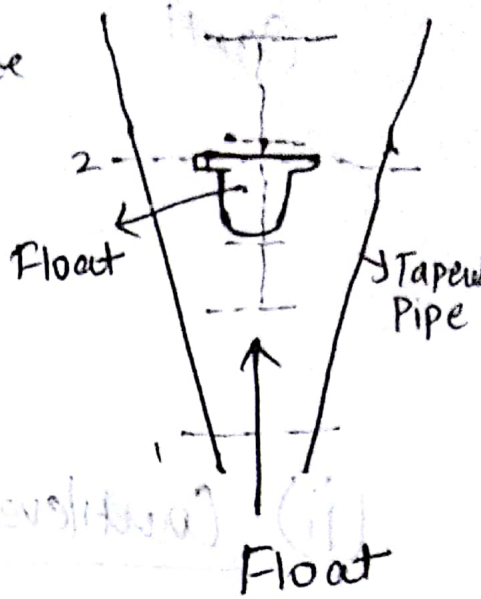
If d_1 & d_2 are the diameters of the pipe line and the orifice opening. Then we have find V_2 by Bernolli's equation:-

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + z_2$$

After finding the value of V_2 we can find Flow by $\boxed{Q = A_2 V_2}$

(iii) Rotameter

→ Rotameter is only used for vertical pipeline. It is less accurate than that of other flow meter. On this the vertical pipe is tapered. Flow of fluid is from bottom to the top. There is a cylindrical type metallic float inside the tube. When fluid goes upward with high velocity then float move upward. If velocity of fluid is low then float comes downward. On this case first we find velocity at section 2 by Bernolli's eqn.



$$\frac{P_1}{\rho g} + \frac{v_1^2}{2g} + z_1 = \frac{P_2}{\rho g} + \frac{v_2^2}{2g} + z_2$$

After that we find discharge by equation.

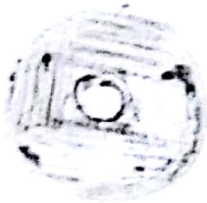
$$\boxed{Q = A_2 V_2}$$

We have to desire this equation for all flowmeters :-

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} + Z_1 = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + Z_2$$

For same Datum head $Z_1 = Z_2$

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} = \frac{P_2}{\rho g} + \frac{V_2^2}{2g}$$



$$\frac{P_1}{\rho g} - \frac{P_2}{\rho g} = \frac{V_2^2}{2g} - \frac{V_1^2}{2g}$$

$$\frac{2(P_1 - P_2)}{\rho} = V_2^2 - V_1^2$$

$$\Rightarrow \frac{2(P_1 - P_2)}{\rho} = Q^2\left[\frac{1}{A_2^2} - \frac{1}{A_1^2}\right]$$

$$\Rightarrow Q^2 = \frac{2(P_1 - P_2)}{\rho} \cdot \frac{A_1^2 A_2^2}{A_1^2 - A_2^2}$$

$$\Rightarrow Q = \sqrt{\frac{2(P_1 - P_2)}{\rho}} \times \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}}$$

For orificimeter & Rotameter

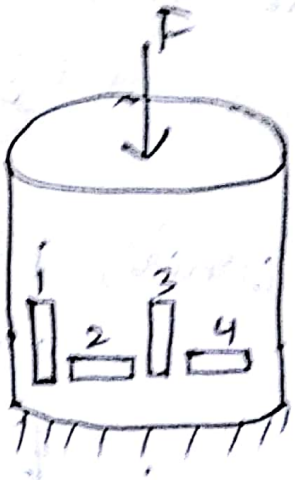
$$\Rightarrow Q = C_d \sqrt{\frac{2(P_1 - P_2)}{\rho}} \times \frac{A_1 A_2}{\sqrt{A_1^2 - A_2^2}}$$

where C_d = Coefficient of discharge.

Force Measurement :-

(1) Load Cell :-

Force can be measured easily from a load cell. Here two strain gauges are fixed to measure longitudinal strain, while other two measuring the transverse strain. Strain gauge 2 and 4 measure the longitudinal strain.



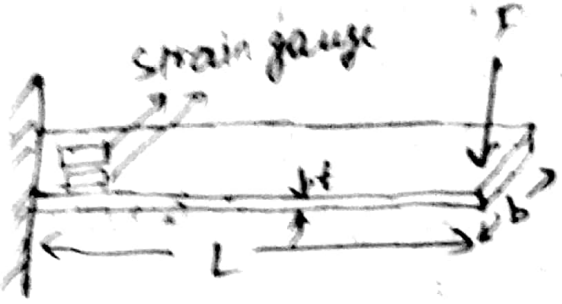
$$\varepsilon_1 = \frac{-F}{AE}$$

Strain gauge 1 and 3 measure the transverse strain.

$$\varepsilon_2 = +\frac{\nu F}{AE}$$

where ν = Poisson's ratio
F = Force applied
A = C/S Area
E = Modulus of Elasticity of material.

(ii) Cantilever Beam:



→ Cantilever Beam can be used for measurement upto 10 kg of weight. One end of cantilever beam is fixed and other is free as shown in figure. Strain gauge are used to measure the strain. By the help of strain we can find force applied on the cantilever.

$$\varepsilon = \frac{6FL}{Ebt^2}$$

where, F = Force applied on cantilever beam
L = Length of Cantilever beam
E = Modulus of Elasticity of material
b = width of cantilever beam
t = thickness of cantilever beam.