UNIT - IV

MEASUREMENT OF PRESSURE & TEMPERATURE.

PRESSURE:

-> UNITS OF PRESSURE

-> MANOMETERS (5 types)

-> ELASTIC TYPE PRESSURE GAUGES
  - BOURDON TUBES.
  - BELLOWS
  - DIAPHRAGMS.

-> ELECTRICAL METHODS - Elastic elements with LVDT & Strain Gauges.

-> MEASUREMENT OF VACUUM - Types
  - McLeod Gauge, Ionisation Gauge, Pirani Gauge

-> TESTING & CALIBRATION OF PRESSURE GAUGES
  - Dead Weight Tester.

TEMPERATURE:

-> THERMODYNAMIC TEMPERATURE SCALE + IPTS

-> BIMETALLIC THERMOMETERS

-> ELECTRICAL METHODS OF TEMPERATURE MEASUREMENT
  - RESISTANCE THERMOMETERS / RTDs
  - THERMISTORS
  - THERMOCOUPLES

-> PYROMETERS
  - OPTICAL PYROMETERS
  - TWO COLOUR RADIATION PYROMETERS.

MEASUREMENT OF PRESSURE:

UNITS OF PRESSURE:

→ $\text{Pressure} = \frac{\text{Force}}{\text{Area}}$.

→ Has the unit similar to stress

→ Consider pressure as force per unit area exerted by a fluid on a containing wall.

ie pressure in fluid systems.

Absolute Pressure : Value of force per unit area on the containing wall by a fluid.

Gauge Pressure : Represents the difference between the absolute pressure & the local atmospheric pressure.

Vacuum : Represents the amount by which the atmospheric pressure exceeds the absolute pressure.

$$P_a = P_g + P_s$$
$$P_v = P_s - P_a.$$

$$P_g = P_a - P_s$$
$$P_v = P_s - P_a$$

where P_a → Absolute Pressure | P_s → atmospheric pressure
P_g → Gauge pressure | P_v → vacuum pressure.

Thus Absolute Pressure → +ve gauge pressure.
Vacuum Pressure → −ve gauge pressure.

Some of the commonly used with units of pressure are.

Psi (pounds per square inch)

1 inch of water $= 249.1\ N/m^2$
$= 249.1$ Pa (Pascal)

1 mm of mercury = 1 torr = $133 \, N/m^2$ = 133 Pa

1 lbf / inch^2 = $6.895 \, kN/m^2$ = 6.895 kPa

1 Kgf / cm^2 = $98.1 \, kN/m^2$ = 98.1 KPa

The atmospheric pressure at sea level } = $101.3 \, KN/m^2$ (or) 760 mm of Hg.

TYPES OF PRESSURE MEASURING DEVICES:

① MECHANICAL INSTRUMENTS:

Two Types

* ① Balancing the unknown force produced by P with a known force.

  Eg: Manometers, Ring & bell type gauges.

* ② Balancing the unknown force through a force produced due to stress in elastic medium (in known Area)

  Eg: Bourdon tubes, bellows & diaphragms.

② ELECTROMECHANICAL INSTRUMENTS:

-> Use mechanical means to detect pressure.

-> Electrical means to indicate or record pressure.

③ ELECTRONIC INSTRUMENTS:

-> depend on some physical change that can be detected and indicated or recorded through electronic means.

MANONETERS:

Principle: Measure the unknown pressures by balancing against the gravitational force of liquid heads.

-> used as primary standards for pressure measurements from low vacuum range to about $0.1\ MN/m^2$.

Advantages:

-> simple construction
-> High accuracy
-> good repeatability
-> wide range of filling fluids
-> used as meas. devices/ primary standards.

Disadvantages

-> lack of portability
-> Need of leveling
-> Hazardous condn → when Hg is used
-> Errors due to meniscus in small diameter tubes.

Material Used:

Manometer bodies : Brass, stainless steel, Al, steel.

Tubes : Pyrex

Scales : Read pressure in terms of mm of water (or) in mm of Hg (or) kN/m^2 (KPa).

(i) the absolute pressure if $P_2 = 0$

(ii) Gauge Pressure if $P_2 = P_S$ = atmospheric pressure

(iii) Differential Pressure, if P_2 is the second pressure to be compared with P_1

Range : upto 40 KN/m^2 & Max operating upto 3 MN/m^2 pressures

Desirable Properities of Manometric fluid :

① low viscosity to give quick response.

② low coefficient of thermal expansion in order to avoid changes in density

③ low vapour pressure.

④ Negligible surface tension & capillary effects.

⑤ Non sticky nature.

⑥ Non corrosive

⑦ Non - poisonous

⑧ long term stability

⑨ → The type of liquid dep on pressure & nature of fluid whose pressure is being measured.

⑩ → To obtain increase sensitivity (ie) large change in level liquids having low density should be used

→ cheap liquid : water — Disadv

It evaporates

∴ Needs frequent topping off

TYPES:

① U-TUBE MANOMETER:

→ For measurement of liquid or gas pressures.

→ It is filled with manometric fluid whose specific gravity is known.

Specific gravity = $\frac{\text{density of a sub.}}{\text{density of ref sub}}$

→ Diff b/w P on two limbs $\propto h$

h - diff b/w levels of fluid in 2 limbs.

→ The P balance equation is

$$\boxed{P_1 + g h \rho_f = P_2 + g \cdot h \cdot \rho_m}$$

∴ Differential Pressure:

$$\boxed{P = P_1 - P_2 = gh(\rho_m - \rho_f)}$$

where g is gravitational constant ($9.81\ m/s^2$)

ρ_m - specific gravity of Manometric fluid

ρ_f - specific gravity of transmitting fluid - kg/m^3

h - Read using a scale → ||el to g ↓

$P = P_1 - P_2$ is measured @ dashed line location

If P due to txing fluid is neglected,

then $\boxed{P = P_1 - P_2 = g \cdot h \cdot \rho_m}$

If P_1 is the pressure being measured, the U tube manometer may be used for measurement of:

Disadv:

Transparent → Readability difficult use dye to make it coloured.

→ Mercury: Most commonly used.

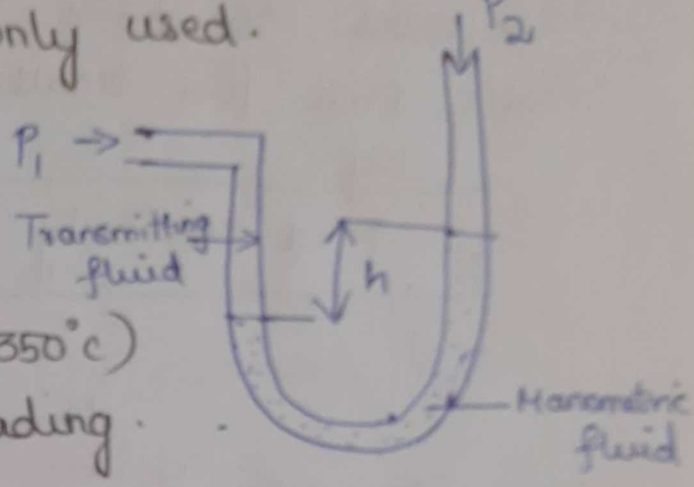
Adv:

→ low vapour pressure

→ Non sticky

→ wide Temp range (−20° to 350°c)

→ sharp meniscus - easy reading.



U-Tube Manometer

Disadv:

→ High density → poor sensitivity

→ Expensive.

→ Mobility & density affected by contamination

→ If exposed - Hazardous.

Other Manometric fluids:

→ Transformer oil (suitable for Ammonia gas flow meters & measurements of small P. differences)

→ Aniline (for low P air/gas flow except Ammonia, Cl)

→ Dibutyl-phthalate (for ammonia gas)

→ Carbon Tetrachloride (for Cl gas)

→ Tetrabromomethane (ammonia gas)

→ Bromoform.

② WELL TYPE MANOMETER

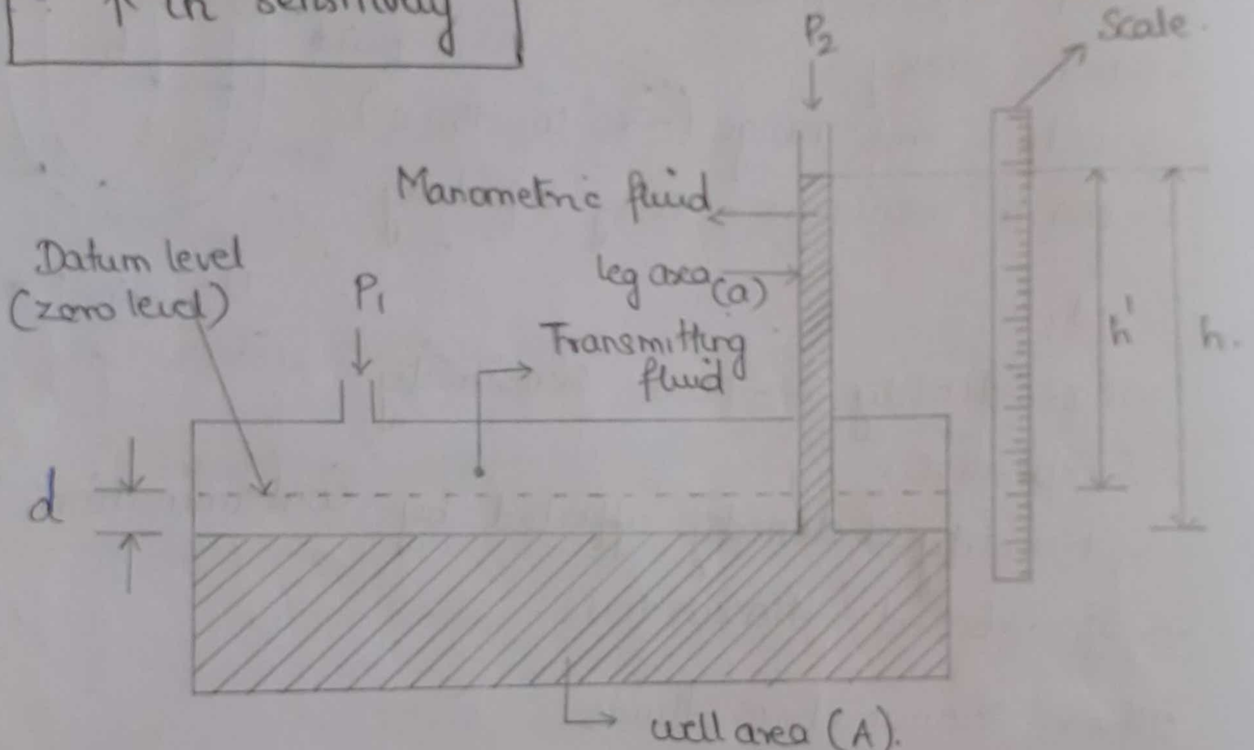
→ Unlike U-tube manometer, 2 legs do not have same area.

→ One of the tubes is substituted by large well / reservoir.

→ cross sec. area of well >> area of other leg

→ ∴ Even for small displ in well → large displ. in leg.

$\boxed{\therefore \uparrow \text{ in sensitivity}}$



→ $P = P_1 - P_2 = gh(\rho_m - \rho_f)$

→ 'h' is not the displacement measured.

→ The displ ht from zero level is measured → h

$$d = h - h'$$

d → displacement of liq level in well on account of differential pressure, m^2

A, a → Area of cross section of well & tube respectively (m)

∴ Vol. of liquid displaced in well = d.A

Vol. of liquid displaced in tube = $h'.a$

Equating both $\Rightarrow dA = h' \cdot a$

W.K.T $\rightarrow d = h - h' \Rightarrow (h-h')A = h'a$ $\quad hA - h'A = h'a$

$$h = h'\left(1+\frac{a}{A}\right)$$

$hA = h'(a+A)$

$h = h'\left(\frac{a+A}{A}\right)$

$h = h'\left(1+\frac{a}{A}\right)$

$$\therefore P = P_1 - P_2 = gh'\left(1+\frac{a}{A}\right)(\rho_m - \rho_f)$$

$$= gh(\rho_m - \rho_f)$$

→ We measure only → (h') ∴ To know h we need ratio $\frac{a}{A}$ → Area correction factor.

For an area ratio $\frac{a}{A} = 0.02$ → A reading of 100 mm for h' would be indicated as $h = 100(1+0.02) = 102$ mm as a result of the special graduations made on the tube with smaller area.

RAISED WELL MANOMETERS:

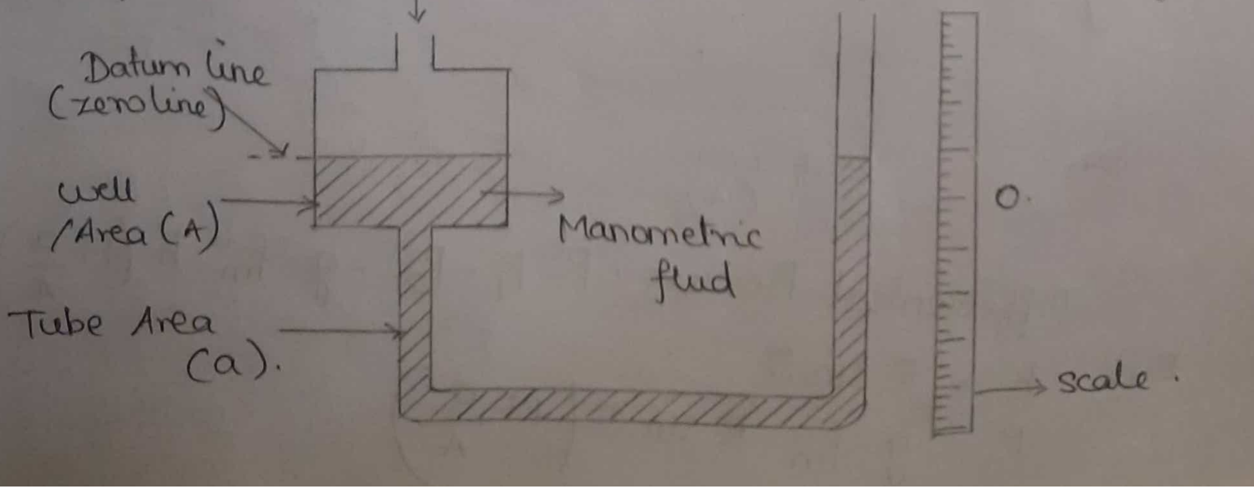
→ Well is located in a raised position

→ Zero level located anywhere along the column

∴ Vacuum & P measurement possible.

→ The location of zero level is lower than mid point of the scale.

→ Movable - Manual or Power wells adjusted



(3) INCLINED TUBE MANOMETER:

-> The vertical leg is placed in a almost horizontal position so that -> small ΔP in well -> large change in liq level in inclined leg.

$\therefore$ ↑sed sensitivity

-> If slope is 1:20 to the horizontal, A rise of 'h' mm in liq would mean that the displacement of liq along the tube is 20.h mm

let A -> area of well (m^2)

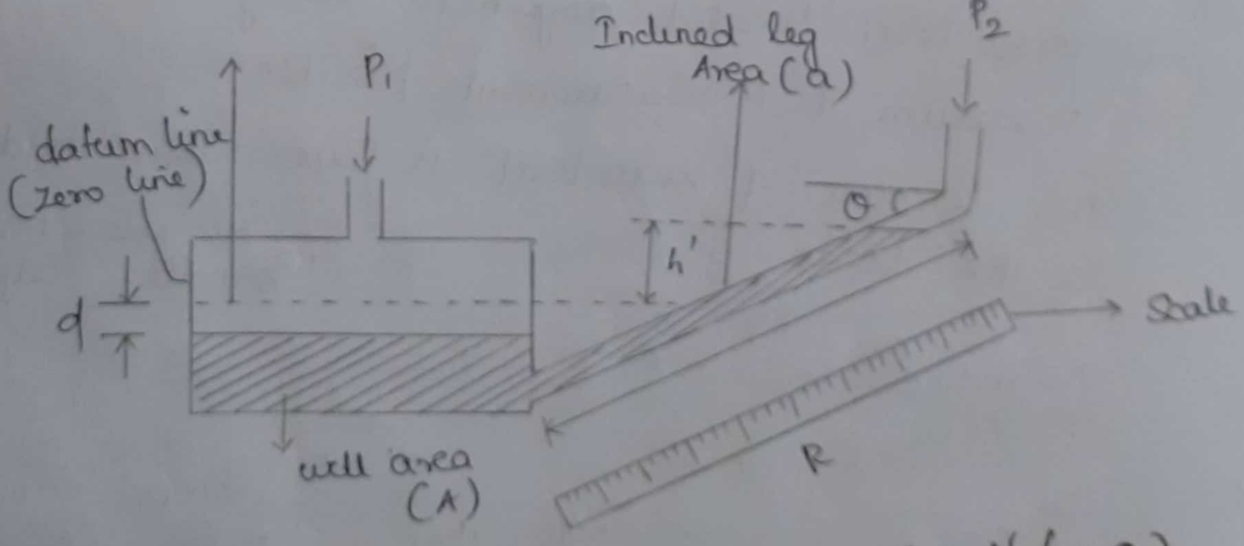
a -> area of inclined tube (m^2)

d -> displacement of liq column in inclined tube (m)

ρ_m -> density of manometric fluid (kg/m^3)

R -> scale reading (m)

θ -> angle of inclination of leg.



$\therefore$ Differential Pressure, $P = P_1 - P_2 = g \cdot \rho_m \cdot h' \left(1 + \frac{a}{A}\right)$

But $h' = R \sin\theta$

$P = g \cdot \rho_m \cdot R \sin\theta \left(1 + \frac{a}{A}\right)$

when the area of well >> area of inclined leg

(ie) $A >> a$, then

$$P = g \cdot \rho_m \cdot R \sin \theta$$

$\therefore$ If θ is known : diff $P \propto R$

Thus we can get P by reading R value from scale calibration in terms of pressure.

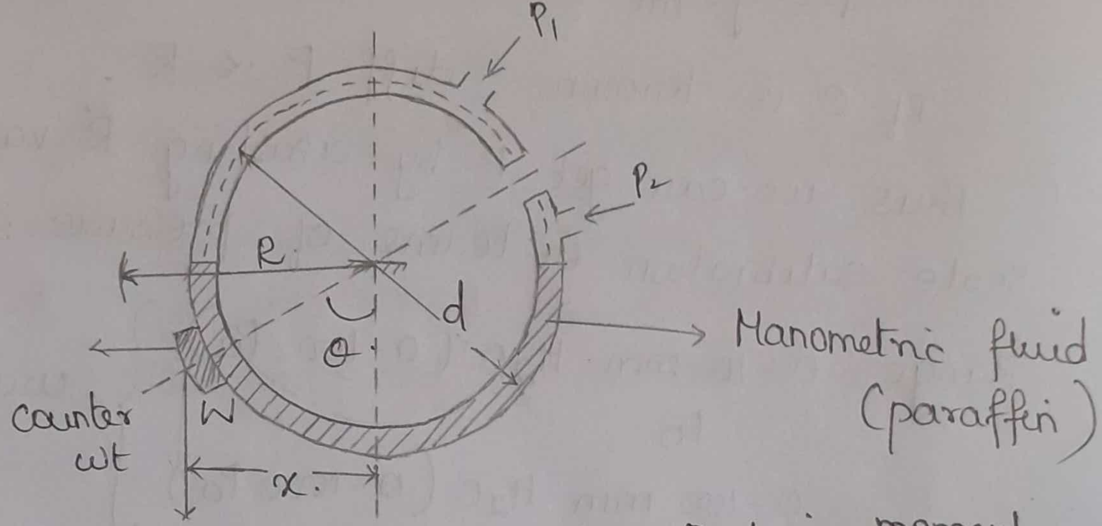
Range: 0 - 10 mm H_2O (0 - 100 Pa)
to
0 - 100 mm H_2O (0 - 1000 Pa) } using H_2O

0 - 1250 mm of Hg (0 - 12.5 KPa) using Hg.

(4) RING BALANCE MANOMETER:

- → consists of tube made of polythene or any other light & transparent material.
- → bent in the form of ring
- → supported at centre using Pivot.
- → The tubular chamber is divided into 2 parts by splitting and sealing.
- → filled with light liquid like kerosene or paraffin oil.
- → counter wt 'W' is attached to the ring.
- → P_1 & P_2 are the i/p P → act on the walls
- → As P_1 ↑es, it lowers the level of liquid on its side of the ring → so the ring turns about its centre.

→ As it becomes out of balance → the counter weight W exerts a restoring moment to bring back the balance.



At equilibrium: Moment due to diff. pressure = Restoring moment of counter weight

$$\therefore (P_1 - P_2) \cdot A \cdot d/2 = W \cdot g \cdot x$$

$$(P_1 - P_2) \cdot A \cdot d/2 = W \cdot g \cdot R \sin\theta$$

$\therefore$ Differential pressure : $P = P_1 - P_2 = \dfrac{2 W g R \sin\theta}{Ad}$

where W → mass of counter weight (kg)

R → Radius on which counter wt moves (m)

A → Area of cross section of ring

d → Mean diameter of ring

θ → angle of tilt of counter weight from the vertical axis

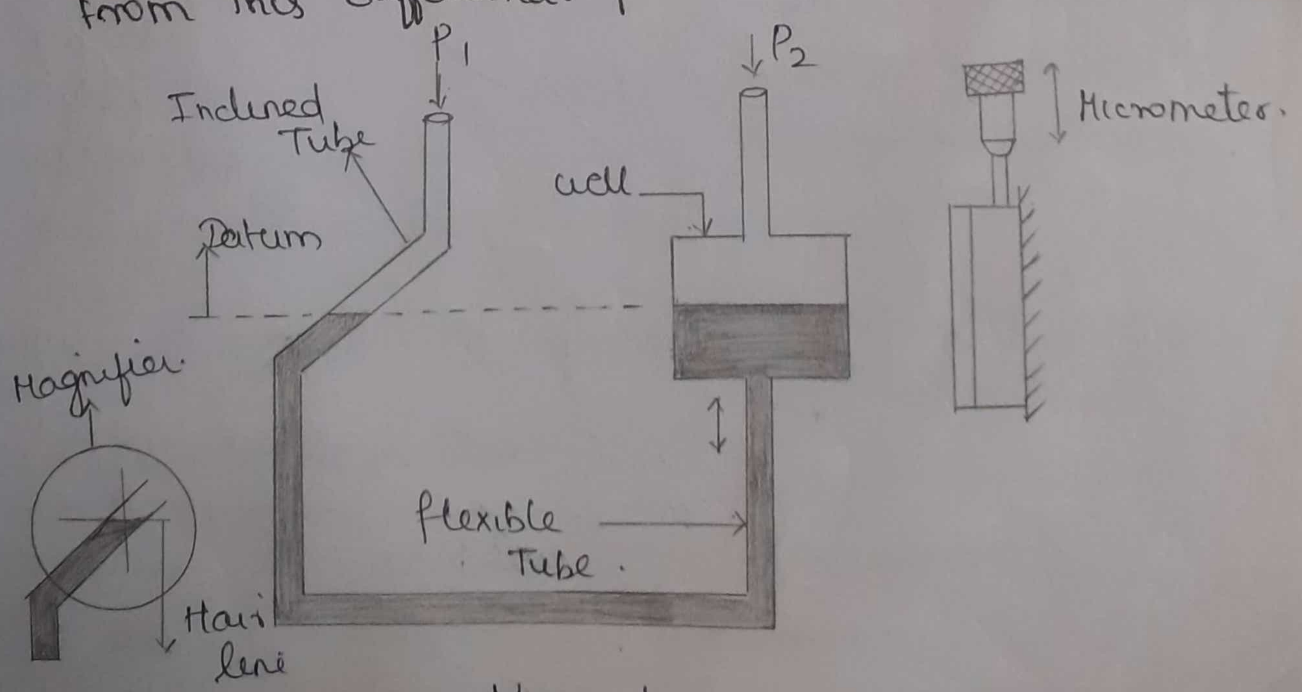
$\therefore$ The angle θ is a moment of diff. pressure

→ The angle of tilt, θ, is usually small & is about 30° on each side of y axis, Therefore the scale is nearly linear.

MICROMANOMETER:

- → To measure extremely small differential pressures
- → Variation of inclined tube manometer
- → Initially adjusted so that $P_1 = P_2$ → Meniscus in inclined tube is located at reference point.
- → The reading of the micrometer that is used to adjust the well height is noted.
- → level of hair line / ref pt → zero differential pressure.
- → When unknown pressure diff is applied → Meniscus moves.
- → Meniscus restored to initial position by lowering or raising the well (The micrometer reading is noted now)
- → The diff b/w final & initial readings of micrometer ⇒ height 'h' of the liq. column

From this differential pressure can be formed.



Micrometer

UNIT - IV

MEASUREMENT OF PRESSURE

ELASTIC TYPE MEASUREMENT GAUGES:

- For measurement of very high pressures upto 700 MN/m^2
- Three types of pressure elements:
  ① Bourdon Tube ② Bellows ③ Diaphragms.
- These depend on the displacement caused by pressure
- This displacement — causes deflection of a pointer
  — produce an electrical signal with help of secondary transducer.

① BOURDON TUBES:

Advantages:

- simple
- versatile
- low cost
- high P range
- good accuracy
- easily adaptable for elec. o/p

Disadvantages

- low spring gradient
  - limits precision measurement
- susceptible to shock & vibration & hysteresis.

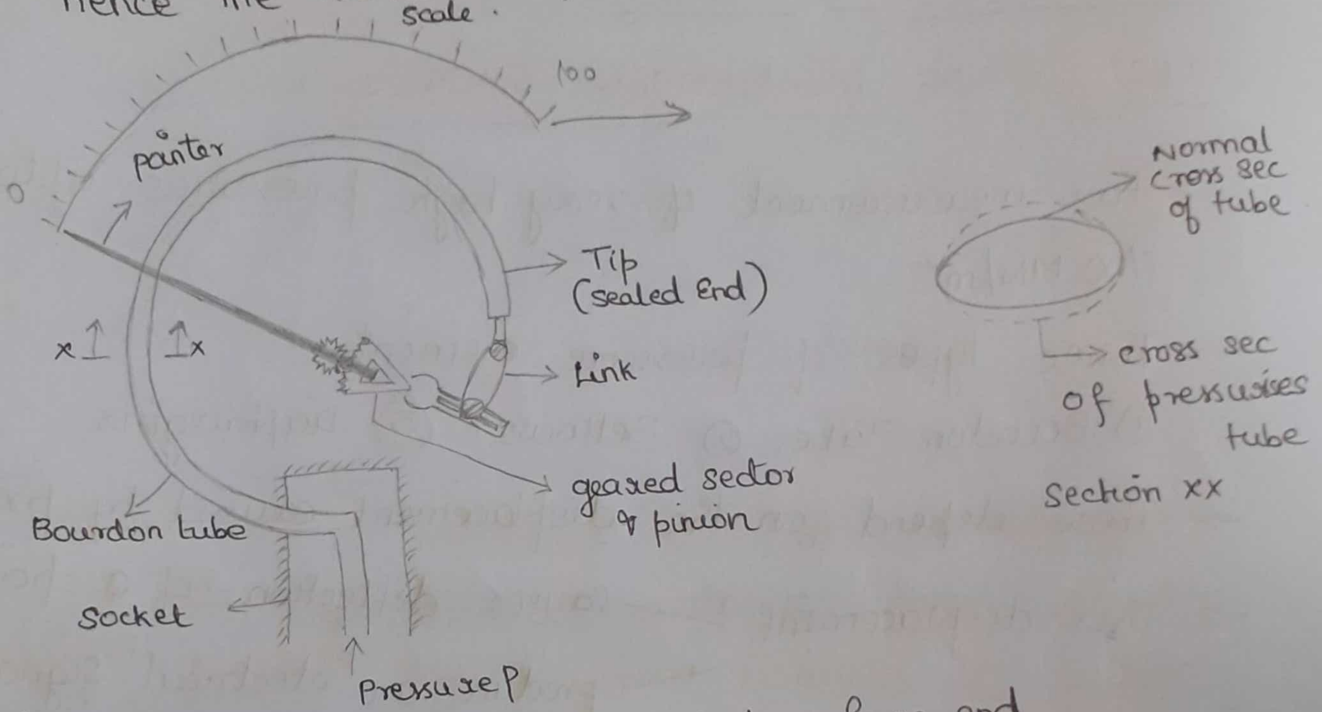
TYPES: ① C Type ② Spiral Type ③ Helical Type.

(i) C-Type Bourdon Tube:

- used for local indication & also for pressure Transmission and control applications.

→ The oval tube is made into an arc of 250° and hence the name C for the configuration.

3M



→ One end of tube – tip – sealed – free end.

→ attached by a link work to mechanism that operates a pointer.

→ other end of the tube is fixed to a socket where the P is applied.

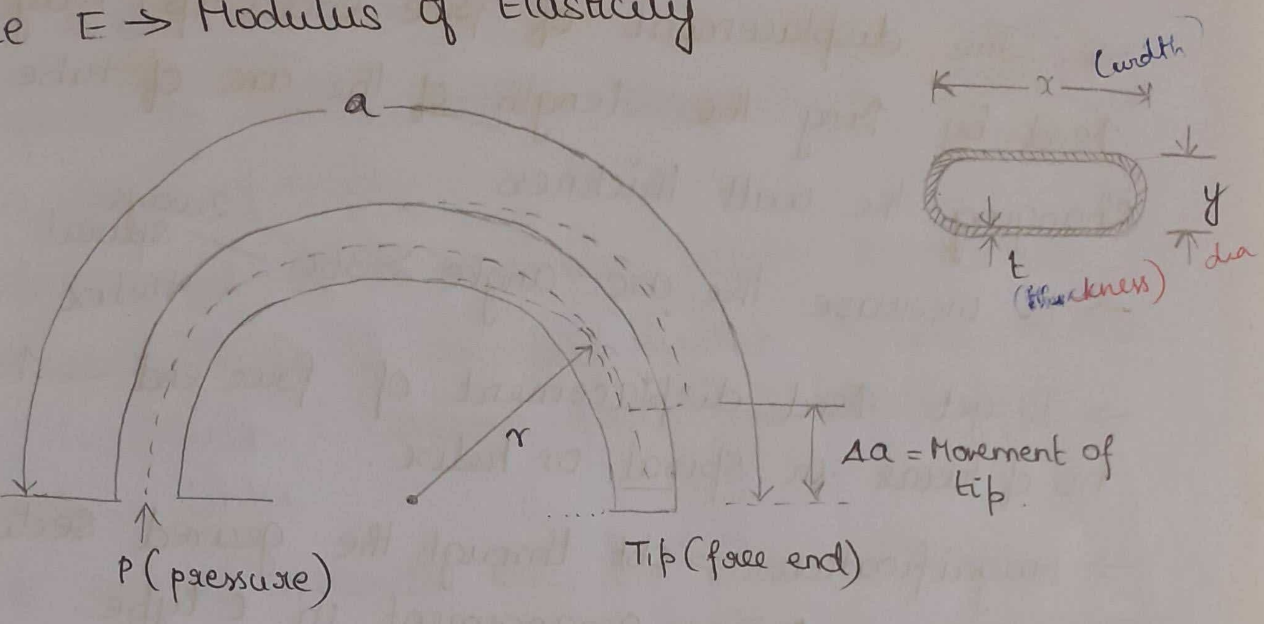
→ Internal P → changes the cross section of the tube from oval to circular.

→ tip – spring loaded link work – geared sector and pinion arrangement which amplifies the displacement of tip and converts into the deflection of pointer.

→ The displacement of tip is

$$\Delta a = 0.05 \frac{aP}{E} \left(\frac{r}{t}\right)^{0.2} \left(\frac{x}{y}\right)^{0.33} \left(\frac{x}{t}\right)^{3} \quad \text{— (I)}$$

where E → Modulus of Elasticity



→ The relation b/w displ of tip & P is non-linear.

→ But a linear relation b/w defl. of pointer & P applied is obtained using geared sector & pinion movement.

→ accuracy : ±0.5 to ±2% or poorer
Normal accuracy is about ±1%.

Measure
$P_r \to 700$ MPa

(ii) SPIRAL TYPE:

→ From the eqn (I) : the disp of tip is inversely proportional to the wall thickness & dep on cross section of tube.

→ P is directly proportional to the arc length 'a'
a → dep on angle subtended by the arc.

→ In a tube having arc of 180°, the displacement of the tube will be twice that of a similar tube having an arc of 90°

→ ∴ The displacement of free end (tip) may be ↑sed by ↑ing the length of the arc of tube w/o changing the wall thickness.

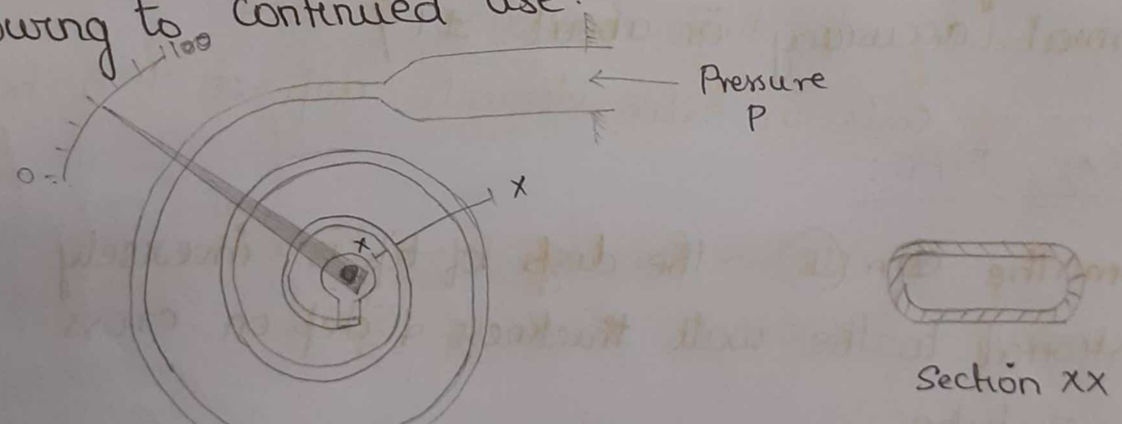
→ To increase the arc angle > 360° < 2 ways: Spiral, Helix.

→ To get ↑sed displacement of free end → ↑se the no. of turns in spiral or helix.

→ Magnification → obt through the geared sector and pinion arrangement in c type.

→ But in spiral & helix → No need of further mag.

→ ∴ The absence of geared sector and pinion arrangement eliminates the backlash which tends to occur when the arrangement becomes worn out owing to continued use.



→ Spiral tubes are made by winding several turns of the tube with its flattened cross section in the form of spiral

→ P applied → spiral tends to uncoil → produces a longer movement of the tip → pointer → indicator

→ accuracy of spiral type > c type.
Typical value : ±0.5%.

(iii) HELICAL TYPE

→ Similar to spiral element except it is wound in the form of helix.

→ Displacement of tip in helical tube > spiral tube

→ A central shaft is installed within helical element and the pointer is driven from this shaft by connecting links.

→ The system transmits only the circular motion of the tip to the pointer which is directly proportional to ΔP.

Advantages:

→ High over-range capabilities abt 10 : 1

→ Stability in fluctuating P applications.

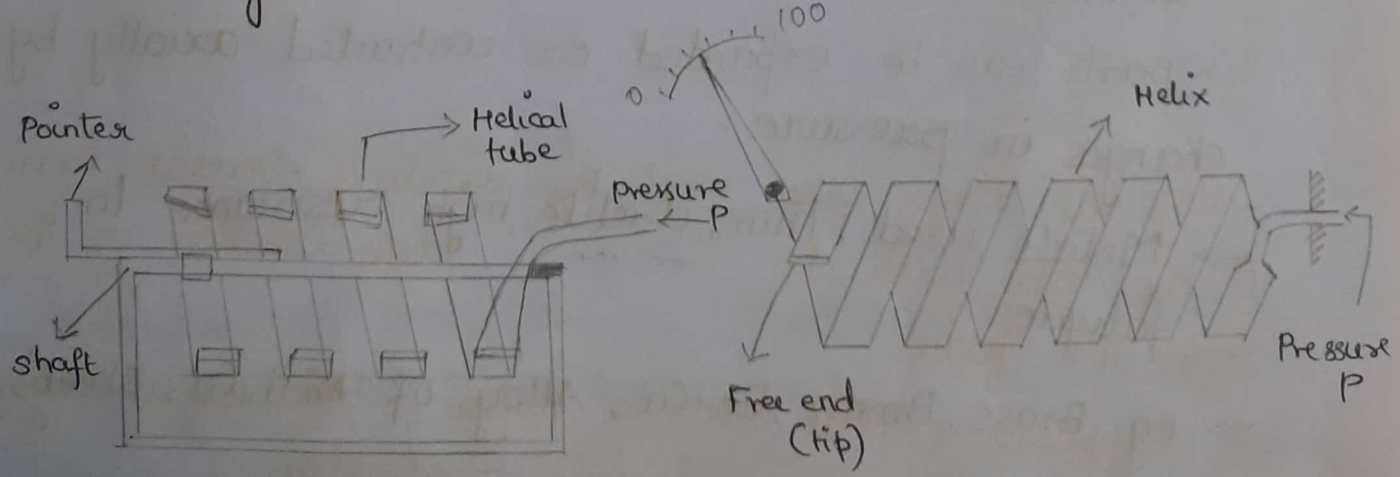
→ Adaptability for high pressure service.

→ The no. of coils in helix elements dep. on P to be measured

Measure

→ generally 3 coils → for high P → 16 coils. 15 MPa to 550 MPa

→ Accuracy : ±0.5% to ±1% of span.



Helical type Bourdon tube

MATERIALS FOR BOURDON TUBES:

Brass, Alloy steel, stainless steel, Bronze, phosphor Bronze, Beryllium copper, K Monel, Ni-span C.

→ choice of material depends on.

1. elastic nature suitable for P range.
2. Process Medium.
3. Temperature
4. Corrosive resistance of the media.

For non-corrosive environment: Phosphor Bronze.

For corrosive & high P envi : stainless steel or Monel.

→ P range : 70 KPa to 700 MPa

C type : Vacc to 700 MPa & higher

Spiral : Vac to 30 MPa

Helical : 1.5 MPa to 550 MPa.

② BELLOWS:

→ series of circular parts resembling folds in accordian.

→ parts can be expanded or contracted axially by changes in pressure.

→ Metals used: thin, ductile, high resistance to fatigue.

→ Eg. Brass, Bronze, Be-Cu, Alloys of Ni & Cu, steel, Monel.

→ Most of bellows → seamless → Made from drawn tubing by hydraulic or Rapid forming.

→ Other Methods → Soldering, welding, Rolling, Spinning, Turning.

The displacement of bellows element is given by

$$d = \frac{0.453\, P b n D^2 \sqrt{1-\nu^2}}{E t^3}$$

Applications
① load cell - around strain gauge
② vacuum interpoler - transformer

where $P \rightarrow$ pressure (N/m^2)

$b \rightarrow$ Radius of each corrugation (m)

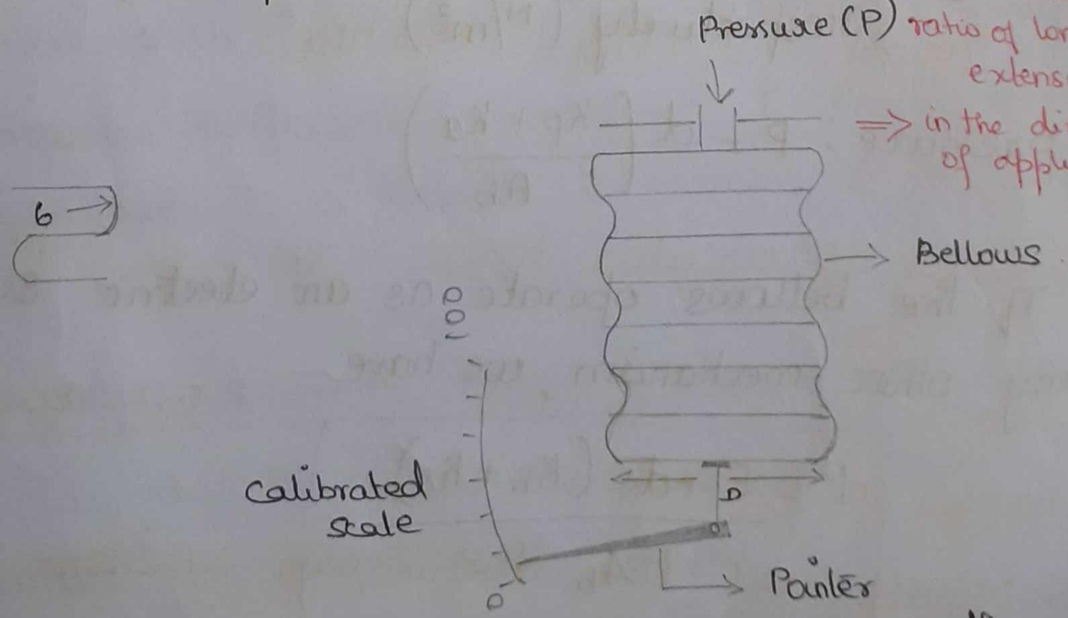
$n \rightarrow$ no. of semi-circular "

$t \rightarrow$ thickness of wall (m)

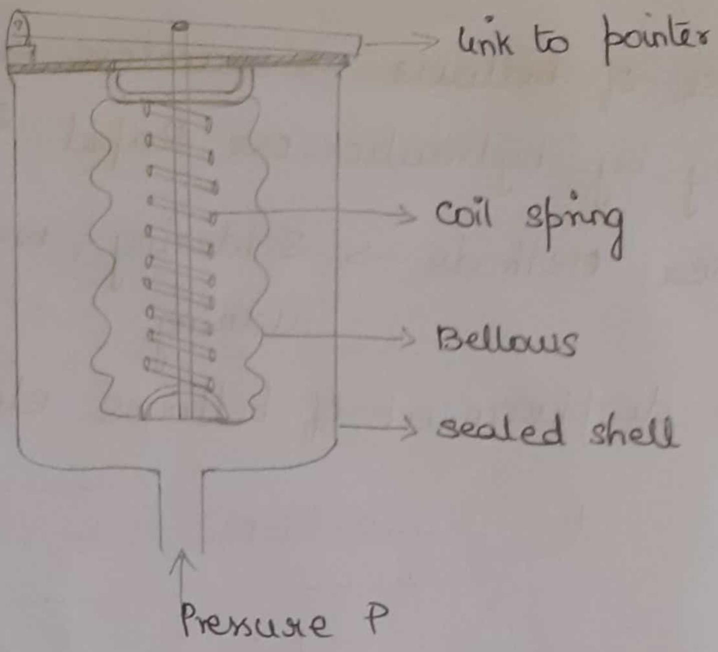
$D \rightarrow$ Mean diameter (m)

$E \rightarrow$ Modulus of Elasticity (N/m^2)

$\nu \rightarrow$ poisson's ratio. - ratio of transverse contraction strain / ratio of longitudinal extension strain ⇒ in the direction of applied force



→ Bellows can move over a greater distance than req & ∴ to give max life & ↑ accuracy, its movement is opposed by a calibrated spring so that only a part of max. stroke is used. It is called Spring loaded Bellows.



Spring loaded Bellows

Deflection of bellows when opposed by spring is

$$\boxed{d = P \frac{A_b}{K_b + K_s}}$$

$A_b \rightarrow$ effective area of bellows (m^2)

$K_b, K_s \rightarrow$ Stiffness constant of bellows & springs respectively (N/m^2)

pressure ; $P = d\left(\frac{K_p + K_s}{A_b}\right)$

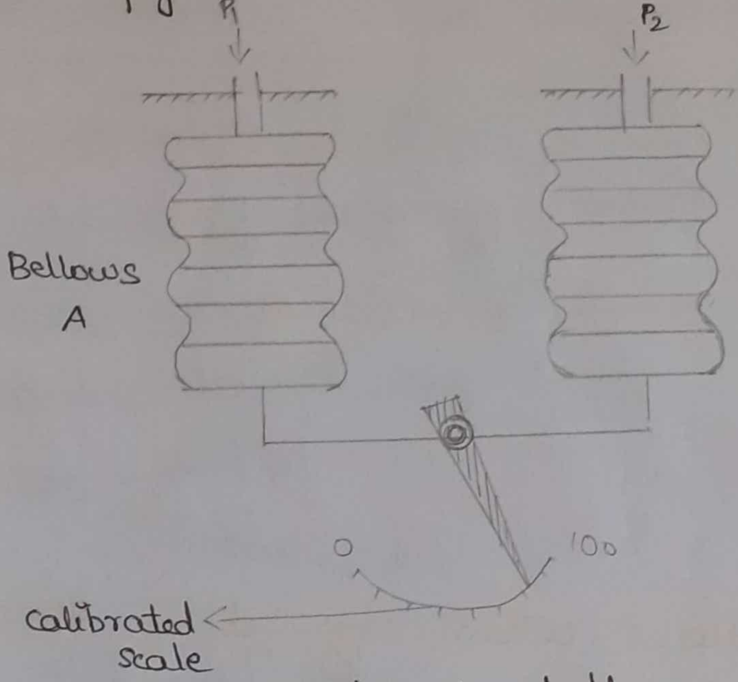
If the bellows operate as an electric switch or any other mechanism, we have

$$\boxed{P = \frac{F + d_s (K_b + K_s)}{A_b}}$$

where $F \rightarrow$ force req to oper switch or mech (N)

$d_s \rightarrow$ deflection req to operate switch or mechanism (m)

3 configuration to measure : Absolute P
Gauge P
Differential P.



→ pressure applied to bellows A → P_1
" " " B → P_2

→ To measure Absolute pressure, bellows B is evacuated and resultant pressure 'P_1' → Abs. P

atmo - atm

→ To measure gauge pressure : Open bellows B to atmosphere with P_2 = Atm P and reading = gauge P

$P_g = P_a - P_s$

→ To measure differential pressure : $P = P_1 - P_2$ is done when pressure P_1 is applied to bellows A & P_2 is applied to bellows B.

DOUBLE BELLOWS DIFFERENTIAL PRESSURE GAUGE :

→ For low diff P measurement of high static P
→ 2 bellows are filled with liquid.
→ High P compresses the high P bellows.
→ The liquid is transmitted through low P passage.
→ This causes the bellows on low pressure side to expand.

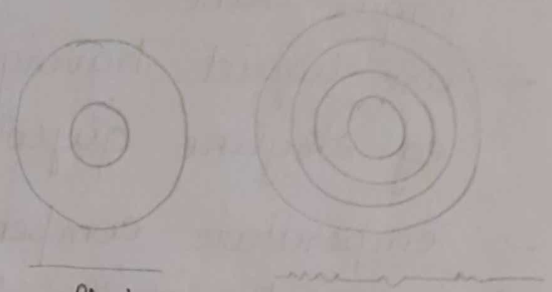
③ DIAPHRAGMS : (Thin membrane flexible disc)

→ P applied → diaphragm deflects. def $\propto$ P.

→ Movement of diaphragm dep on thickness & diameter

→ Since movement is small → the diaphragm elements do not req. springs.

Types < flat, corrugated.



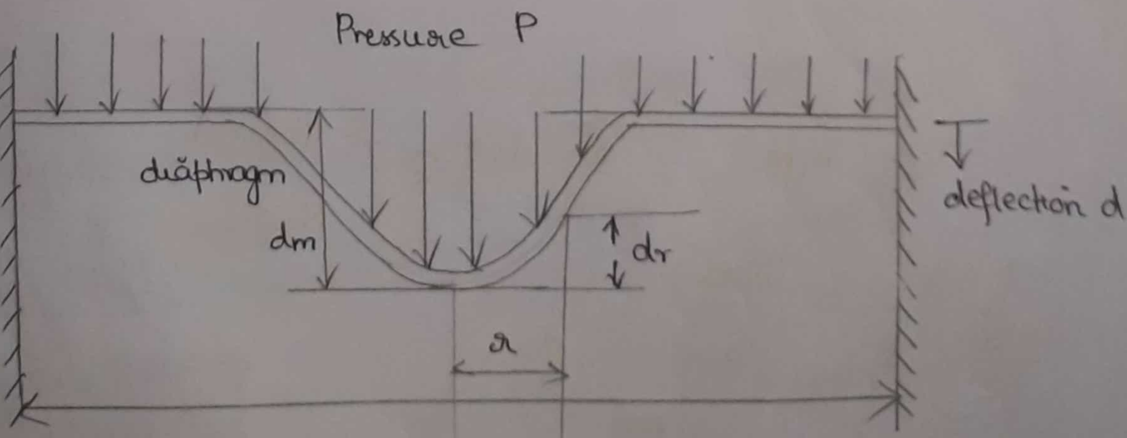
For flat diaphragm :

The maximum deflection :

$$\boxed{d_m = \frac{3P}{16Et^3} R^4 (1-\nu^2)}$$

The deflection @ any radius :

$$\boxed{d_r = \frac{3P(1-\nu^2)}{16Et^3} (R^2 - r^2)^2}$$



These relationship are valid for uniform pressure loading on entire surface of disc & also when the deflection smaller than half the thickness of disc whon $d \leq 0.5$

→ This continues until force on span spring equals difference b/w the forces acting on 2 bellows.

→ pulsation dampner: To ctrl rate of flow.

→ Span spring: To ctrl span of the element.

→ o/p movement is txed through a pressure tight torque tube.

→ use liquid having low co-eff of thermal expansion eg. ethylene glycol, water.

→ Temperature compensating Bellows: To adjust the capacity of the bellows on ↑P side to change of volume that occurs due to ↑se in Temp.

Advantages: Simple, rugged, moderate price, To measure low P, Med P, high P

→ To meas Abs, gauge & diff. P, ↓se in drift & hysteresis

→ well adapted to vacuum meas.

Disadvantages: Not suitable for dynamic meas coz of ↑ mass & longer relative movement.

→ req Temp. compensating device

→ The response is linear when $d \leq 0.5t$

→ To have linear relation for deflection $d > 0.5t$, we go for the "corrugated diaphragm".

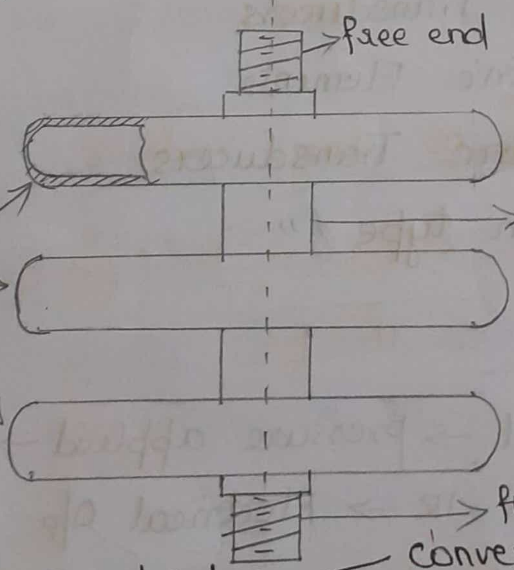
↳ greater O/p

↳ high magnification.

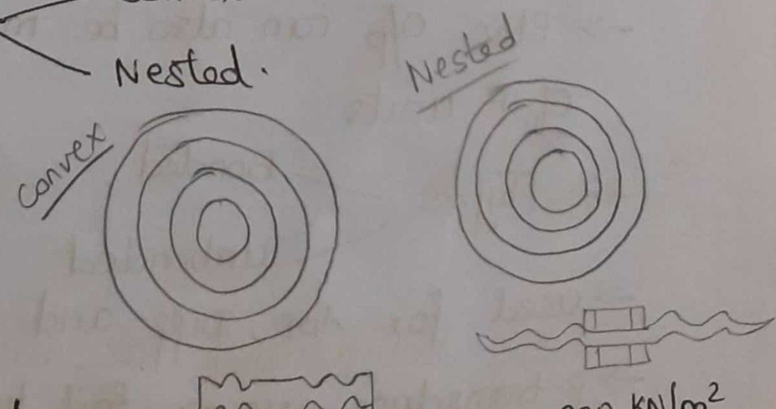
→ In some cases 2 diaphragms are bonded together at circumference by soldering or pressure welding to form a CAPSULE

→ A diaphragm element may contain 2 or more capsules connected together.

→ Total deflection = Σ of deflection of indiv capsules.



Two types of capsules — convex / Nested.



Materials Used:

Metals → phosphor, Bronze, SS

Be-Cu, Ni-span C,

Monel, Inconel, Ni.

Non-metals → Buna N Rubber

– Nylon

P. Range = 0-50 N/m^2 to 0-200 KN/m^2

Accuracy = ±0.5 % to ±1.25 %

ELECTRICAL METHODS

ELECTROMECHANICAL PRESSURE TRANSDUCERS:

The applied pressure is converted b/into displacement using elastic elements. This displacement is transduced into electrical form using secondary transducers.

The secondary transducers are.

1. Potentiometer
2. Strain gauges.
3. Inductive Transducers.
4. LVDTs
5. Capacitive Transducers.
6. Piezoelectric Elements
7. Photoelectric Transducers
8. Oscillation type "

STRAIN GAUGES:

→ Elastic element → pressure applied → deflection → strain gauge → ΔR → Electrical O/p signal.

→ Elec O/p can also be measured directly in terms of P units

→ Types — Bonded / unbonded

→ used for Abs, Diff and gauge pressure.

→ P. transducer using foil type metal S.Gs have

29 ans

(5) MEASUREMENT OF VIBRATION:

(=> If the displacement time variation is generally in continuous form with some degree of repetitive nature, it is called vibration.)

→ when this occurs as a single event → with the motion generally decaying or damping out before further action takes place → "SHOCK".

→ Measured using Accelerometers or velocity Transducers

→ o/p of transducer → pulsating → Measure frequency using Digital freq. meter.

(6) MEASUREMENT OF FORCE (Ref: Rajput pg. 626)

FORCE: It is any cause that produces, stops or changes the motion of a body or tends to produce these effects.

30 ans

(Methods:

(1) Scales & Balances & springs : Balancing the force against a known gravitational force on a standard mass.

(2) Proving Ring : Applying the force to some elastic member & then measuring resulting deflection.

(3) Load cell : Translating the force to a fluid pressure & then measuring resulting pressure.

(4) Balancing the force against magnetic force

(5) Applying force to known mass & then measuring acceleration.)

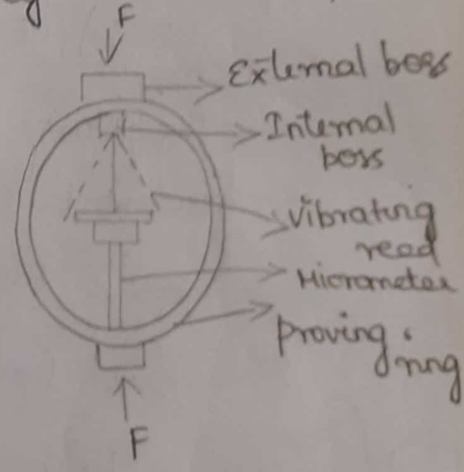
1) SCALES & BALANCES & SPRINGS :

→ Weighing machine (scales) – measure force – by comparing weights
↳ based on the principle of equilibrium
2 forces acting at equal / diff dist from fulcrum
→ creates 2 Torques.

⇒ BEAM SCALE : For spring – testing devices
wide range, High accuracy.

⇒ PENDULUM SCALES : Requires force should be steady for 2 to 3 seconds for the scale to come to rest.

⇒ SPRINGS : Few grams to 20000 kg
spring alloys or ordinary springs
↓ high accuracy at T = 0 to 50°C
↓ accuracy = 0.5 to 1.0 %.



② PROVING RINGS :

(→ used as force standards
3 / ans → To calibrate " Material Testing Machines " where Dead weight stds cannot be used.
→ To measure Heavy forces.
→ It is a ring of known phy dimension & mech. properities.)
→ Compressive or Tensile load to external bosses → change in diameter

$$\Delta d \propto F .$$

→ Δd is measured by micrometer screw & a vibrating reed attached to internal bosses.

micrometer reading after ~ Mm reading before ⇒ Amt of compression or elongation of ring.

→ Δd → Also measured using LVDT
core is attached to the ring.

- Max deflection : 1% of outside dia of ring
- Force range : 2 KN to 2 MN
- Rings : very stable & accurate to ± 0.1 %
but Non-linearity. So actual force is found using calibration curve.

③ LOAD CELLS:

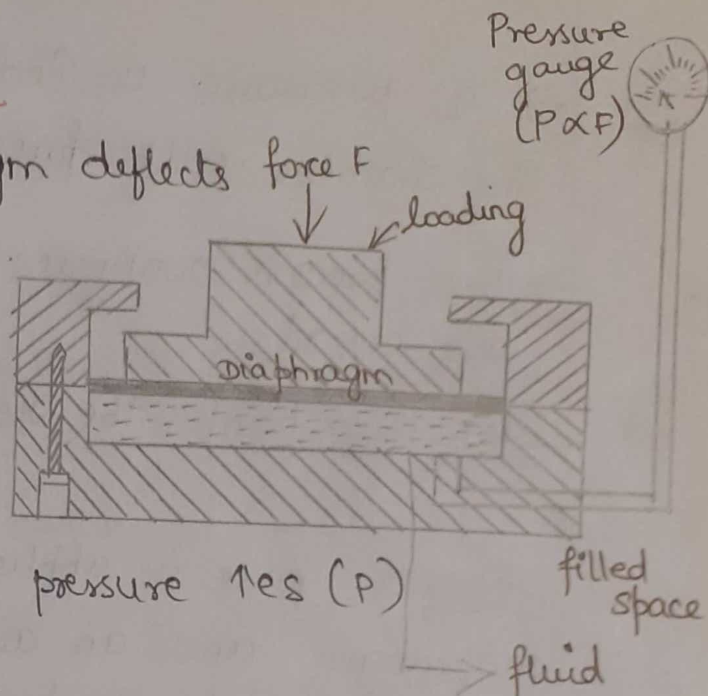
→ They are used to measure force through indirect methods (ie) secondary transducers.

→ Uses : Elastic Member + Strain gauges
Elastic Member ↓ (primary transducer)
Strain gauges ↓ (secondary Transducer)

Factors to be Considered:

(i) Stiffness of the Elastic element
(ii) Optimum positioning of gauges on the element
(iii) Provision for compensation of the temperature.

(i) HYDRAULIC LOAD CELL:



-> force applied -> diaphragm deflects
-> transmits force to liquid.
-> preload pressure of liquid medium = 2 bar filled in confined space.
-> when F applied -> liquid pressure ↑es (P)

$$\text{pressure 'P'} = \frac{\text{force}}{\text{area of diaphragm}}$$

-> pressure is Txed to pressure gauge
(calibrated in force units)

-> Useful range : upto 25 MN
accuracy : 1% of FSR
Resolution : 0.02%.

(ii) PNEUMATIC LOAD CELL: (based on force-balance principle)

-> force applied on one side of the piston _ This is balanced by pneumatic pressure on the other side.

-> The pressure thus obtained = The force applied
-> It is measured using a bourdon tube.

Construction & Working:

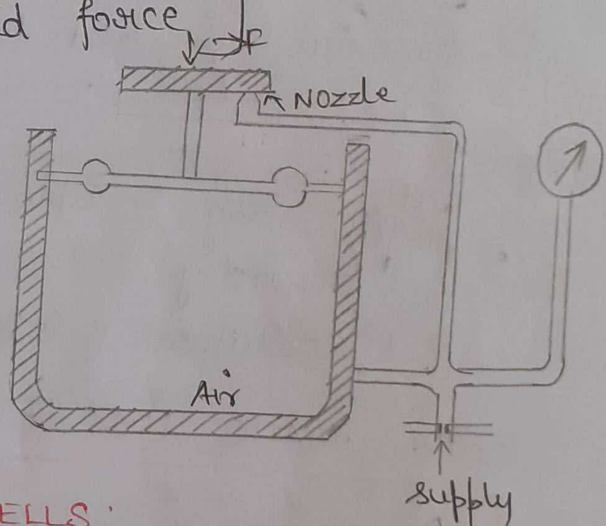
-> It has a inside chamber which is closed with a cap.
-> Air pressure built up inside the chamber until its value equals the force on the cap.

→ If pressure is ↑ed further, the air inside the chamber will forcefully open the cap

→ The process continues until both the pressures are equal.

→ At this point, the reading of the pressure = Input force.

[If a force is applied to one side of a diaphragm and an air pressure is applied to other side, some particular value of pressure will be necessary to exactly balance the force. This pressure ∝ applied force]



→ can measure upto 25KN

→ accuracy : 0.5% of full scale.

③ STRAIN GAUGE LOAD CELLS:

→ converts force into electrical o/p provided by strain gauge.

→ Then using various instruments, for indicating, recording & controlling the force

→ strain gauge directly applied to force developing device. Device is calibrated against strain-gauge o/p.

→ To measure Transient & Non-steady forces.

Construction & Working:

→ steel cylinder on which 4 identical strain gauges are mounted.

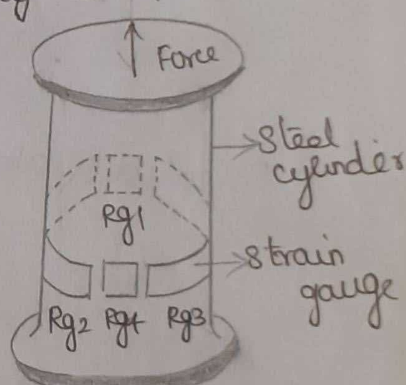
Gauges

R_{g1} & R_{g4} → along direction of applied load

R_{g2} & R_{g3} → attached circumferentially to R_{g1} & R_{g4}

→ All the 4 gauges are connected electrically to the four limbs of a wheatstone bridge.

→ All 4 gauges are connected electrically to 4 limbs of a wheatstonebridge ckt.



No load condition : No force :

→ All 4 gauges have same resistance.

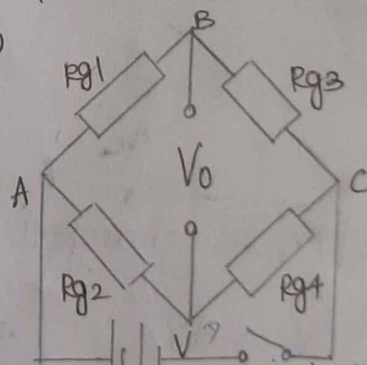
$$R_{g1} = R_{g2} = R_{g3} = R_{g4}$$

→ ∴ Terminals B & D are at same potential

Bridge is balanced : o/p $V = 0$

ie $$V_{AB} = V_{AD} = \frac{V}{2}$$

$$V_0 = V_{AB} - V_{AD} = 0$$



On application of Compressive load:

Vertical gauges : R_{g1} & R_{g4} undergo compression key (-ve strain)

∴ ↓ in resistance.

circumf. gauges : R_{g2} & R_{g3} undergo tension (+ve strain)

∴ ↑ in resistance.

The 2 strains are not equal. related with each other by Poisson's ratio 'μ'.

$$\therefore \quad R_{g1} = R_{g4} = R - dR$$

poisson's ratio

$$R_{g2} = R_{g3} = R + \mu dR$$

Potential at terminal B : $V_{AB} = \left[\dfrac{R_{g1}}{R_{g1}+R_{g3}}\right] V$

$$= \left[\frac{R-dR}{(R-dR)+(R+\mu dR)}\right] V$$

$$= \left[\frac{R-dR}{2R-dR(1-\mu)}\right] V$$

Potential at terminal D : $V_{AD} = \left[\dfrac{R_{g2}}{R_{g2}+R_{g4}}\right] V$

$$= \left[\frac{R+\mu dR}{(R+\mu dR)+(R-dR)}\right] V$$

$$= \left[\frac{R+\mu \cdot dR}{2R-dR(1-\mu)}\right] V$$

The changed o/p voltage.

$$V_0 + dV_0 = \left[\frac{R-dR}{2R-dR(1-\mu)}\right] V - \left[\frac{R+\mu dR}{2R-dR(1-\mu)}\right] V$$

$$= -\left[\frac{dR(1+\mu)}{2R-dR(1-\mu)}\right] V$$

$$= \left[\frac{dR(1+\mu)}{dR(1-\mu)-2R}\right] V$$

$$V_0 + dV_0 = \frac{dR(1+\mu)}{2R} V$$

$$= 2(1+\mu)\left(\frac{dR}{R} \cdot \frac{V}{4}\right)$$

at unbalanced condition : o/p $V = 0$

∴ change in o/p V due to applied load becomes

$$dV_0 = 2(1+\mu)\left(\frac{dR}{R} \cdot \frac{V}{4}\right)$$

∴ voltage is a measure of applied load.

→ 4 arm bridge ckt provides full temp compensation & also increases the sensitivity of bridge $2(1+\mu)$ times.

Applications:

↳ road vehicle weighing devices.

↳ Draw bar & tool force dynamometers

↳ crane load monitoring.

(4) MEASUREMENT OF TORQUE

32 ans(**TORQUE**: It is the tendency of a force to rotate an object about an axis, fulcrum or pivot.

→ It is the twisting moment given to an object.

$$\text{Torque} = \text{force} \times \text{distance}$$

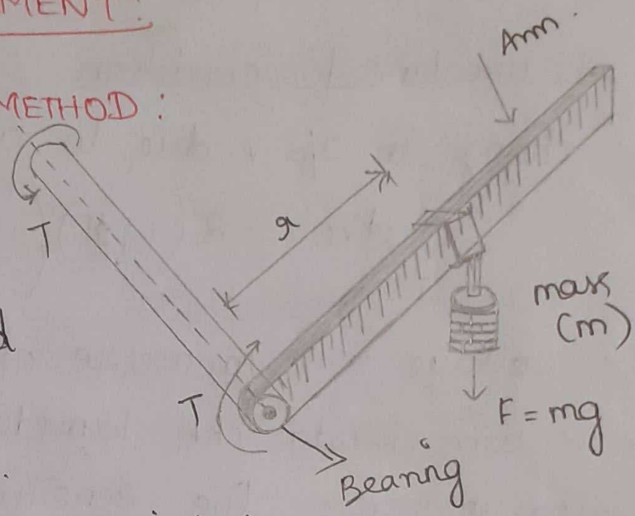
$$T = F \times r$$

Eg: In a shaft, if the force is applied, tangentially and in the plane of transverse cross-section the torque or twisting moment $= F \times d$.

→ If two opp. turning moments → pure torsion - tendency of shearing off.

METHODS OF MEASUREMENT:

① GRAVITY BALANCE METHOD:



$T = F \times r$

$= m \times g \times r$

→ 'm' can be varied

(or)

'r' can be varied.

→ Arm, must be kept horizontal

Arm distance ⊥r to line of action of force.

→ friction torque at bearing → causes error.

→ This error may be eliminated by arranging to apply equal & opposite force.

② MECHANICAL TORSION METER:

For the angular deflection of a shaft subject to Torque.

$$\frac{T}{I_p} = \frac{\tau}{r} = \frac{C\theta}{l}$$

where T → Torque transmitted by the shaft

I_p → polar moment of inertia of the shaft section.

τ → Max. shear stress induced at the outside surface.

r → Radius at which max. shear stress occurs.

C → Modulus of rigidity of the shaft material

θ → angular twist

l → length of the shaft over which the twist is measured.

The above relation gives.

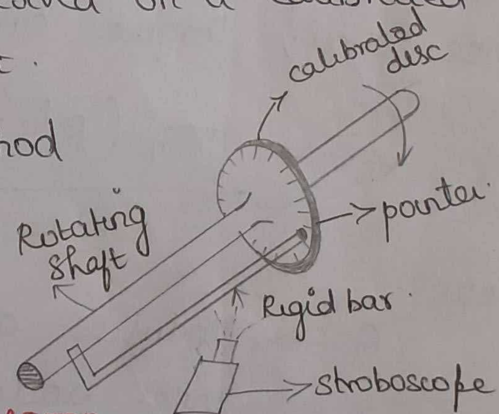
$$T = \left(\frac{I_p}{r}\right) \times \tau \quad \text{or} \quad T = \text{constant} \times \tau.$$

and $$T = \left(\frac{I_p C}{l}\right) \times \theta \quad \text{or} \quad T = \text{constant} \times \theta.$$

→ In that type, the angular def. of a parallel length of shaft is used to measure Torque.

→ Angular twist is observed on a calibrated disc attached to rotating shaft.

↳ using stroboscopic method (intermittent viewing & persistence of vision)

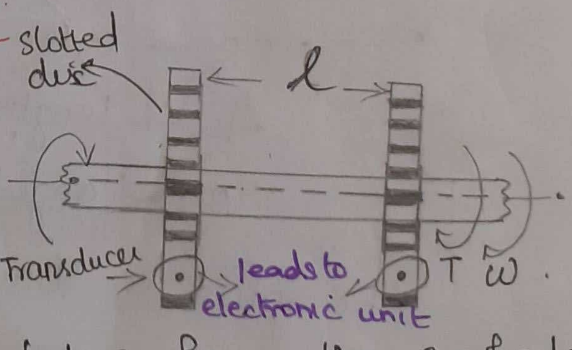


③ ELECTRICAL TORSION METER

Two sets of measurement.

(i) Count of the impulses from the 2 slotted disc

↳ gives freq (or) shaft speed



(ii) A measure of the time b/w pulses from the 2 wheels this signal is proportional to the twist θ & hence the torque (T)

using T & ω → power being txed by the shaft can be calculated.

(4) STRAIN GAUGE TORSION METER:

→ widely used method for torque meas from a rotating shaft.

→ 4 wire - bonded strain gauges are mounted on a 45° helix with the axis of rotation &

→ placed diametrically opposite

→ when shaft is under torsion: gauges 1 & 4 will elongate due to tensile component along 1 diagonal axis.

↳ gauges 2 & 3 will contract due to compressive comp.

→ Measure the tensile & compressive strains & hence shaft torque can be calculated.

$$T = \frac{\pi G (R^4 - r^4)}{2L} \theta \quad Nm.$$

where:

G → Modulus of rigidity

r → inner radius of shaft

R → outer radius of shaft.

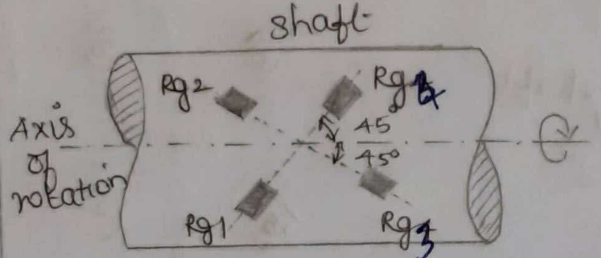
L → length of shaft

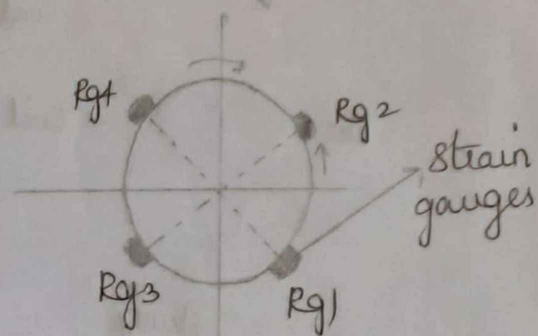
θ → angular deflection of shaft.

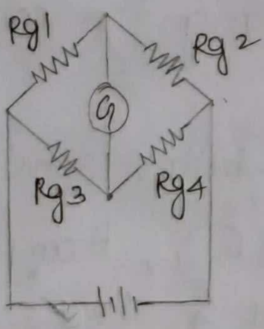
The value of strain in the gauges will be

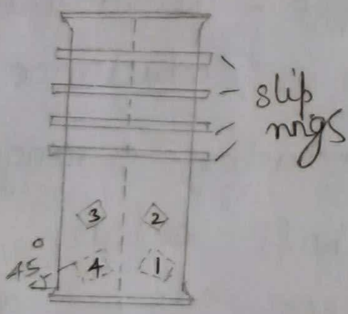
$$\epsilon_{45^\circ} = \pm \frac{TR}{\pi G (R^4 - r^4)}$$

→ The gauges are kept in bridge arrangement so that → deformation due to axial & transverse loads is cancelled out in the final readout.









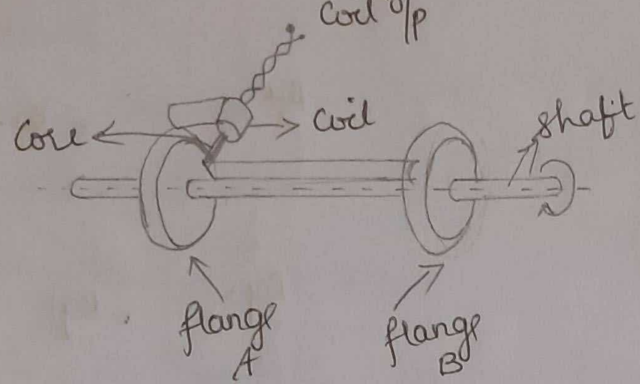
Advantages:

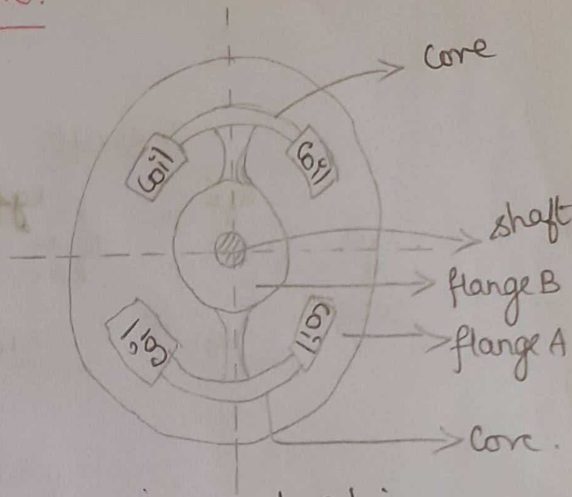
-> Temperature compensation
-> gives max. sensitivity for a given torque
-> Automatic compensation for bending & axial loads.

Difficulties:

-> connection of bridge to its power source & display arrangement ∴ use SLIP RINGS (one for each bridge terminal)
-> rubbing contacts are made b/w rings & stationary brushes which are connected to the i/p & o/p equipment.

(5) INDUCTIVE TORQUE TRANSDUCER:





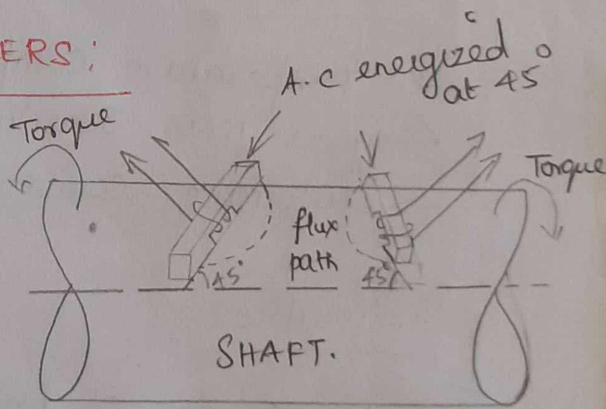
-> Torque - displacement -> change in core position - change in Inductance.

-> 4 inductors arrangement -> better sensitivity (4 times)

-> If shaft rotates clockwise ↻, than inductance of coil 2 & 3 ↑es, L of coil 1 & 4 ↓es.

(6) MAGNETOSTRICTIVE TRANSDUCERS:

based on change in permeability of magnetic materials when they are subjected to strain



-> μ ↑es with -ve strain
μ ↓es with +ve strain

-> 2 AC energized coils from 2 arms of A.C bridge wound on iron core are positioned such that their flux path co-incide with dir of max strain.

-> No torque -> bridge balanced -> No o/p

-> Torque applied -> ↓ in μ in one coil ∴ L ↓es
↑ in μ in another coil ∴ L ↑es

-> voltage o/p of A.C bridge is indication of torque loading on the exciting circuit provides a measure of viscosity.

(11) MEASUREMENT OF FLOW:

→ General method:

→ There is a obstruction created in path of fluid

→ so there is a change in pressure → This depends on the flow rate.

→ we must measure the pressure before and after obstruction.

→ These are mech means of measuring liquid flow

eg: orifice plate
venturi tube
Rotameter
} Indirect methods.

(Direct Methods:

38 ans
① Turbine Meters
② Electromagnetic flow meter
③ Hot wire anemometers.
④ flow meter using thermistors.
⑤ ultrasonic flow transducer.)

① TURBINE METERS:

→ volumetric flow meters.

→ o/p is in form of digital elec. signal.

① pulse freq $\propto$ flow rate

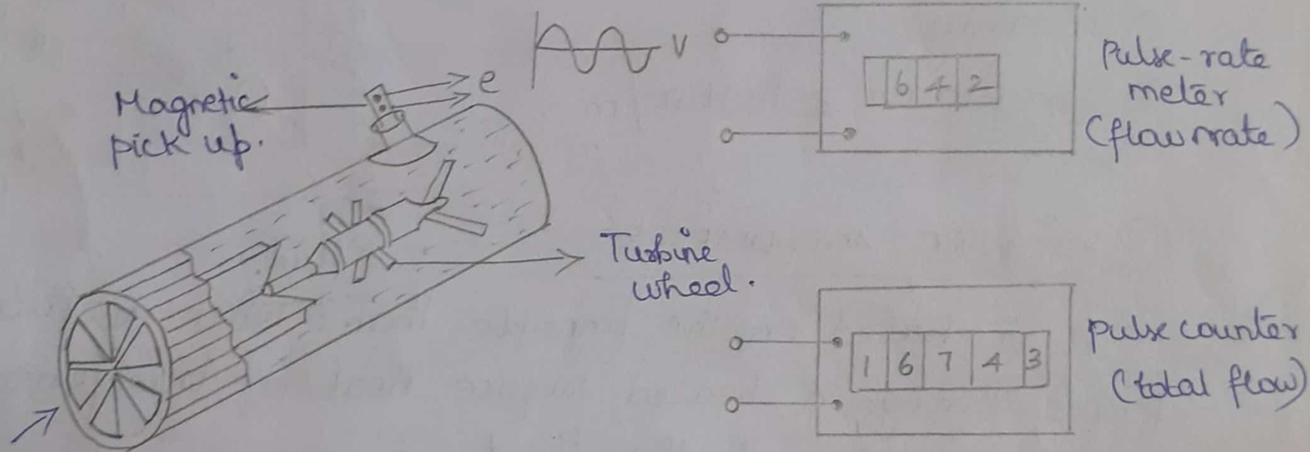
② Total count of pulses $\propto$ Total quantity when each pulse rep. discrete volume

→ Magnetic pickup type

→ Hydraulically supported turbine motor

→ A permanent magnet is kept at 90° to axis of rotation

→ when rotor rotates → magnet rotated → A rotating magnetic field is produced → A.C voltage in the coil → the freq of a.c voltage $\propto$ flow rate.



② ~~ELECT~~

② ELECTROMAGNETIC FLOW METERS :

→ to measure flow rates of fluids like slurries, sludge and conducting liquids.

→ pair of electrodes on opposite side of pipe through which conducting fluid flows.

→ pipe → non conducting & non magnetic

→ surrounded by electromagnet

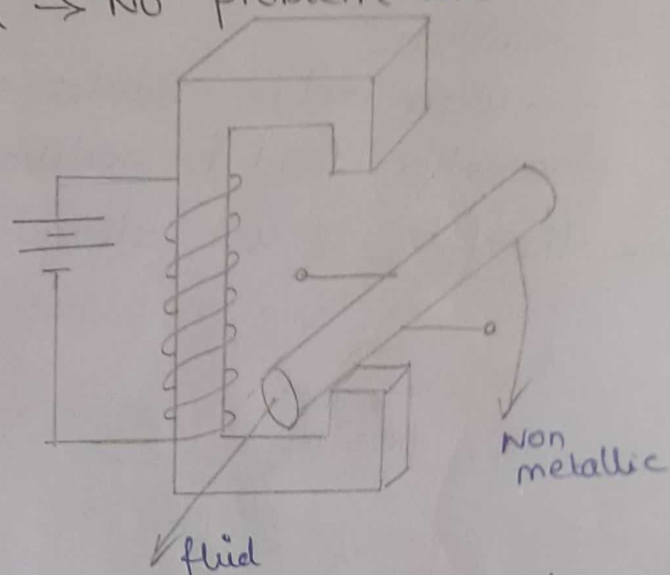
→ when conducting fluid flows → emf induced

$$E = Blv.$$

$B \rightarrow$ flux , $l \rightarrow$ length of cond ; $v \rightarrow$ velocity
$B \downarrow$ constant, $l \downarrow$ constant

Non-conducting pipe $\rightarrow$ To avoid short circuit

If heavy conducting liquid $\rightarrow$ No problem.



Advantages:

1. No obstruction to flow
2. Linearity
3. Conductance $\geq 10 \mu\Omega/m$.

3) HOT WIRE ANENOMETER:

→ It is based on the principle that "when a fluid flows through a heated surface, heat is transferred from the surface to the fluid.

→ The heat loss measured $\propto$ flow rate.

Procedure:

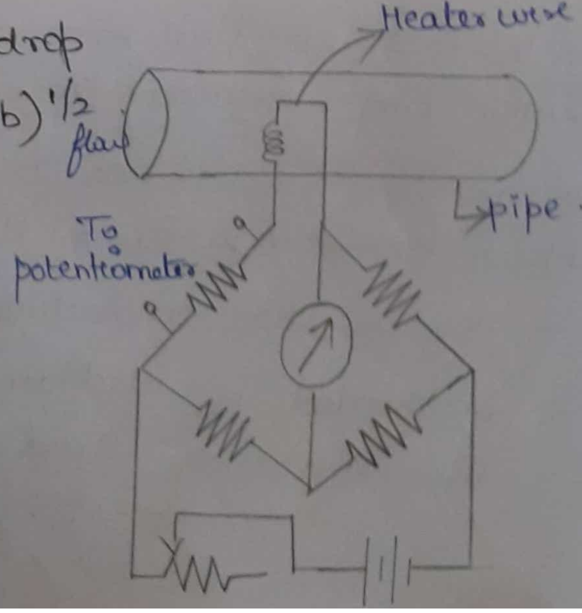
→ Adjust the current through wire → so temp is constant

→ Read the heating I

→ Bridge unbalanced

→ I is measured from V drop

Heat loss $= a(v\rho + b)^{1/2}$



Heat generated = Heat lost

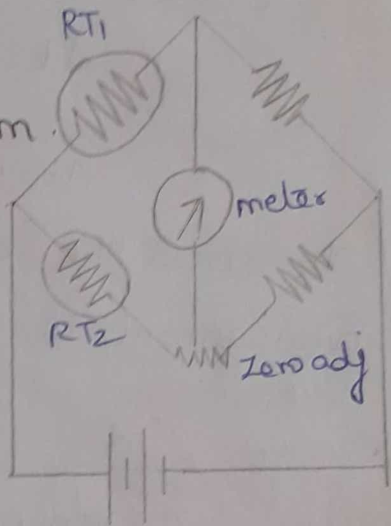
$$I^2 R = a(v\rho + b)^{1/2}$$

flow rate : $v = \dfrac{\left(\dfrac{I^4 R^2}{a^2} - b\right)}{\rho}$

→ R & T constant → flow rate $\propto$ I

→ for Transient condition : CRO

→ Pt, Tungsten wire → 0.0025 mm.



④ USING THERMISTOR

RT_1 → sealed

RT_2 → to pipe

when air / fluid flows → RT_2 cooled

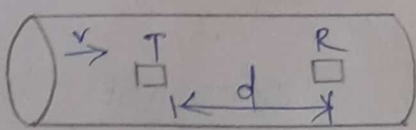
→ R ↓es → Bridge unbalanced

→ current through meter → calibrated to read flow rate.

⑤ ULTRASONIC FLOW METER:

→ 2 piezo crystal in liq/gas separated by a distance

Transmitter receiver.



→ The Tx is activated. It generates ultrasonic waves. The time taken for the waves to reach R is noted 'Δt'

$$\Delta t_1 = \frac{d}{c+v}$$

$$\Delta t_2 = \frac{d}{c-v}$$

c → velocity of sound

v → linear velocity of flow.

sig is opposite to current flow.

phase shift : $\Delta\phi_1 = \dfrac{2\pi f d}{c+v}$ rad opp. dir phase shift $\Delta\phi_2 = \frac{2\pi f d}{c-v}$ rad

The fn. of T & R are reversed.

$$\Delta t = \Delta t_2 - \Delta t_1 = \frac{2dv}{c^2-v^2}$$

$c >> v$

$$\Delta t = \frac{2dv}{c^2}$$

$\frac{d}{c-v} - \frac{d}{c+v}$ $\frac{cd+vd-dc+vd}{c^2-v^2}$ $\Delta t \propto \frac{2vd}{c^2-v^2}$

$\therefore \Delta t \propto v$

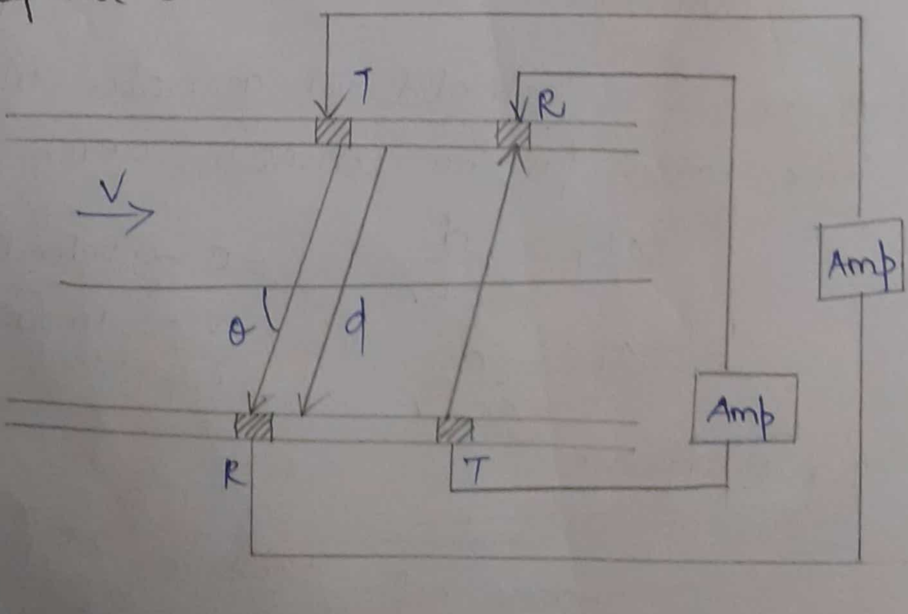
To avoid the dependence on 'c' (velocity of light) the following arrangement is adopted.

$$\Delta t_1 = \frac{d}{c+v\cos\theta} \quad \text{or} \quad f_1 = \frac{c+v\cos\theta}{d}$$

$$\Delta t_2 = \frac{d}{c-v\cos\theta} \quad \text{or} \quad f_2 = \frac{c-v\cos\theta}{d}$$

$$\Delta f = f_1 - f_2 = \frac{2v\cos\theta}{d}$$

Does not depend on 'c'.



(8) MEASUREMENT OF POWER: (Ref. Rajput. pg. 636)

33 ans (→ **Dynamometer**: (Used to measure the torque being exerted along a rotating shaft so as to determine the shaft power i/p or o/p of power generating, transmitting & absorbing machinery.

Absorption, Transmission, Driving } Types

The dynamometers are classified as follows.)

(i) **ABSORPTION DYNAMOMETERS**: Power measured is converted into heat by friction or by other means. It is lost as heat or dissipated to surrounding → No useful purpose.

Eg: → Mechanical brakes
- prony brakes
- Rope brakes.

→ Hydraulic or fluid friction brakes
→ Eddy current dynamometer.

(ii) **TRANSMISSION DYNAMOMETER**: Power being transmitted either to or from the dynamometer is not absorbed or dissipated. After measurement, energy is conveyed to the surroundings in a useful mechanical or electrical form.

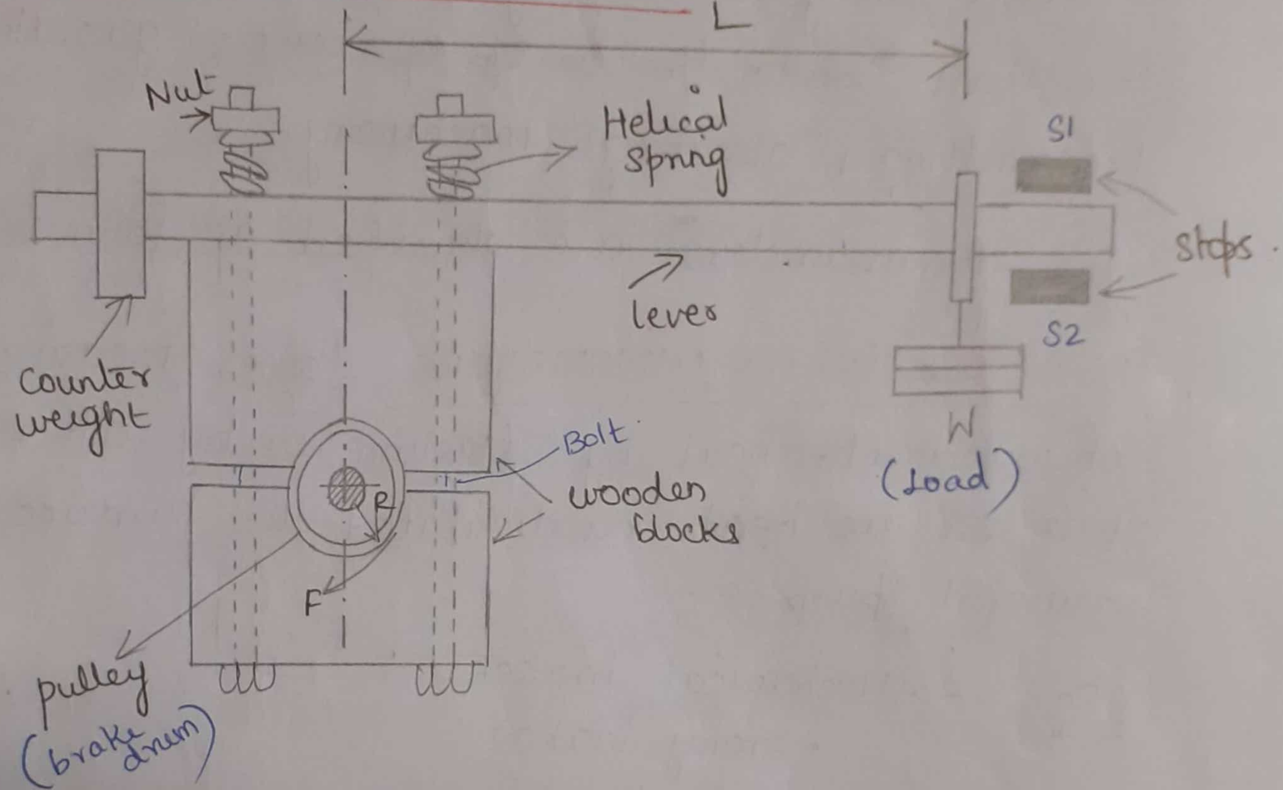
Eg: → Torsion & belt dynamometer
→ Epicyclic train dynamometer
→ strain Gauge dynamometer.

(iii) **DRIVING DYNAMOMETER**: Measure power & also supply energy to operate the tested devices.

Eg: → Electric Cradled Dynamometer.

ABSORPTION DYNAMOMETER:

PRONY BRAKE DYNAMOMETER:



CONSTRUCTION:

→ 2 wooden blocks placed around a pulley fixed to the shaft.

→ Blocks are clamped by means of 2 bolts & nuts

→ Helical spring b/w nut & upper block.

↳ To adjust pressure on the pulley to control its speed.

→ A long lever attached to upper block → carries weight W at its outer end.

→ To balance the brake when unloaded → A counter weight at other end.

→ 2 stops : To limit the motion of lever.

WORKING :

When brake is to be operated → load suitable wts W & nuts are tightened until the engine shaft runs at a constant speed & the lever is in horizontal position. Under these conditions, moment due to wt W must balance the moment of frictional resistance b/w the blocks & the pulley.

let

W = weight at the outer end of the lever, N (newtons)

L = Horizontal distance of the weight W from the centre of the pulley (m)

F = frictional resistance b/w the block & pulley (N)

R = Radius of the pulley (m)

N = speed of the shaft (r.p.m)

The moment of the frictional resistance or torque of the shaft.

$$T = W \times L = F \times R \text{ (Nm)}$$

work done in one revolution $= T \times \theta$ (angle turned)

$= T \times 2\pi$ Nm

∴ Work done per minute $= T \times 2\pi \times N$ Nm.

∴ Brake power of engine :

$$B.P = \frac{T \times 2\pi N}{60} = \frac{(W \times L) \times 2\pi N}{60} \text{ watts}$$

⇒ when the driving torque on the shaft is not uniform, the dynamometer is subjected to severe oscillations.

ROPE BRAKE DYNAMOMETER :

→ Most commonly used.

→ Construction : One, two or more ropes wound around flywheel (or) rim of a pulley fixed to the shaft.

→ upper end of ropes → to spring balance.

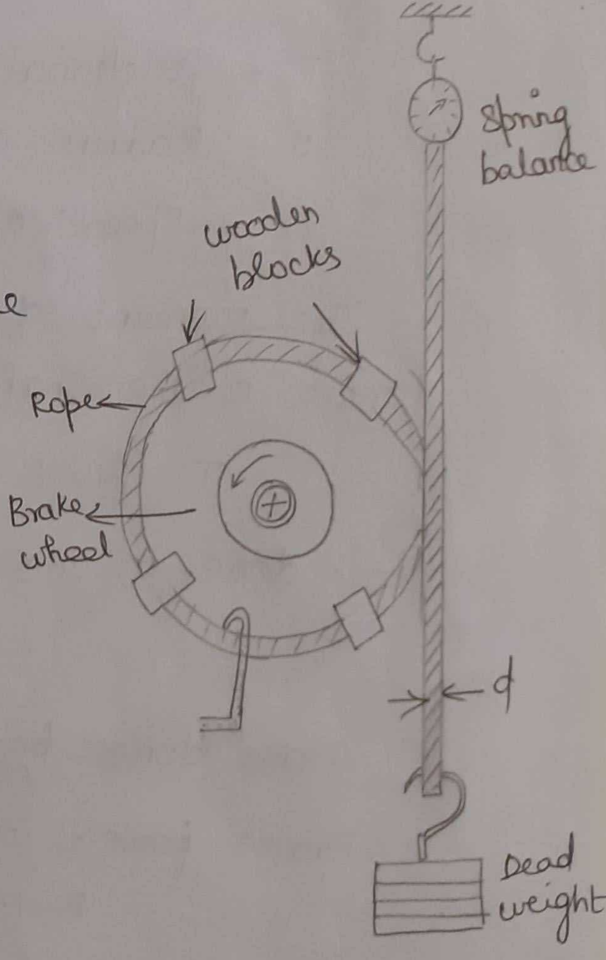
→ lower end of ropes → kept in position using dead weight

→ wooden blocks → To prevent slipping of rope.

Working :

To operate the brake → engine run at constant speed.

Frictional Torque must due to rope be = Torque txed by the engine



Let

W = weight at end of rope (N)

S = spring balance reading (N)

N = engine speed (r.p.m)

D = Diameter of the brake wheel (m)

d = Diameter of the rope (m)

(D+d) = effective diameter of the brake wheel.

Then Work / Revolution = Torque x angle turned per revolution.

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

$$= (W-S) \times (D+d) \times \pi$$

work done / min $= (W-S)\pi(D+d) \times N$

work done / sec $= \dfrac{(W-S)\pi(D+d) \times N}{60}$

B.P $= \dfrac{(W-S)\pi(D+d)N}{60 \times 1000}$ KW (N in rpm → N in rps is divided by 60)

$= \dfrac{(W-S)\pi DN}{60 \times 1000}$ KW (if d is neglected)

$= \dfrac{T \times 2\pi N}{60 \times 1000}$ KW

→ Keep the brake cool with soapy water → To avoid loss of engine energy due to frictional resistance that is converted to heat.

Adv:

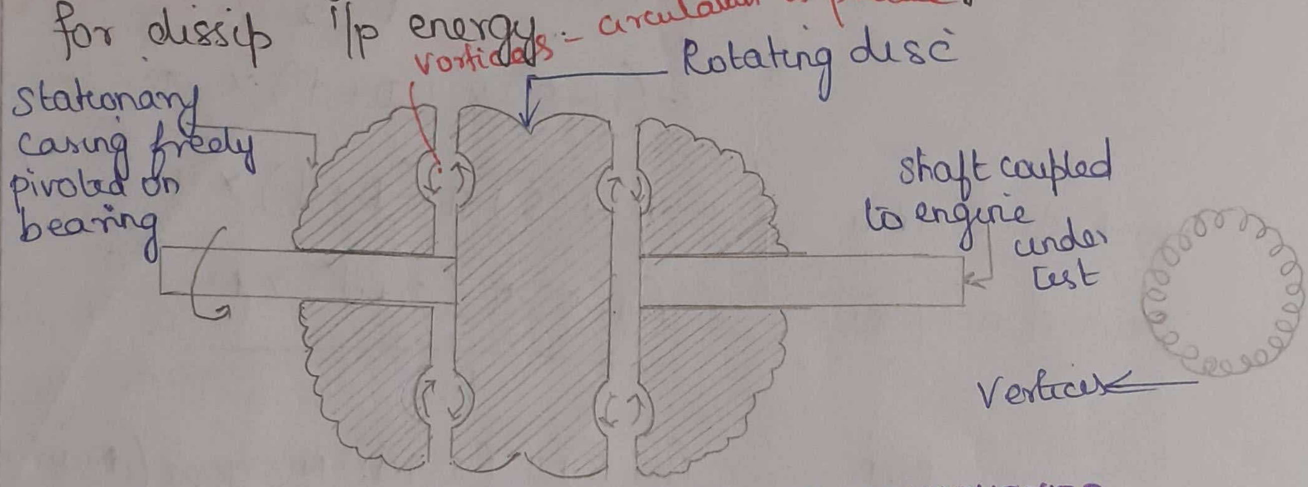
cheap + easy construction.

Disadv:

Not very accurate due to change in friction coefficient due to T.

FLUID FRICTION (HYDRAULIC) DYNAMOMETER:

→ Uses fluid friction rather than dry friction for dissip i/p energy.



WATER VORTEX DYNAMOMETER.

Construction:

→ Rotating disc (R.D) & Stationary casing (S.C) - 2 halves on either side of R.D
↓ connected to driving shaft; it revolved insided S.C.

→ S.C is mounted on antifriction bearing & has a brake arm & balance system attached to it.

→ semi-elliptical recesses in S.C match with grooves in R.D to form chambers through which water flows.

Working:

→ when the brake is operating → water flows in a helical path in the chamber.

→ consequently the vertices and eddy currents are set-up in the water and these tend to turn the dynamometer casing in the direction of the shaft.

This tendency is opposed by the brake arm & balance system due to which the torque is measured.

control of braking action.

(1) By varying qty of water.

(2) By varying pressure of water

(3) By varying distance b/w R.D & S.C

- Power absorption (P) : $P \propto N^3 (d)^{1/5}$ approx

where N → rotational speed ; d → rotor diameter

- speed limit = 10,000 rpm (approx) Usual power limit 25000 H.P

Advantages:

High abs capacity in ↓ cost, ↓ space.

water → cooling effect.

EDDY CURRENT DYNANOMETER:

Principle: when an isolated conductor cuts across magnetic flux, voltage is induced and local currents (called eddy currents) flow in a short circular path. These eddy currents get dissipated within the conductor in the form of heat.

Construction:

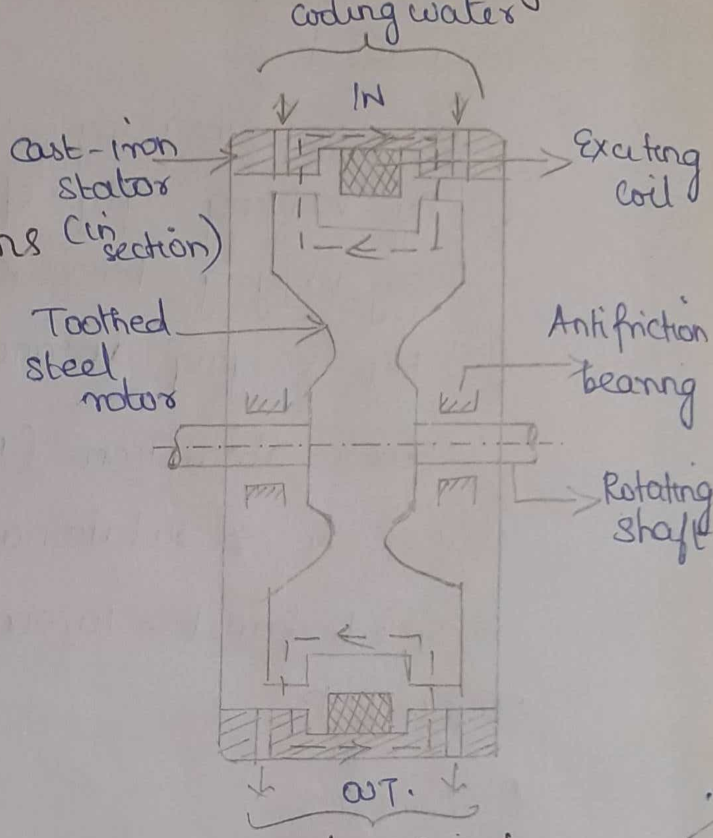
→ Toothed steel rotor → mounted on a shaft

→ Smooth bared cast iron stator

→ clearance b/w stator & rotor is very small.

→ exciting coil in stator → gets D.C supply

→ The stator is cradled on antifriction bearings & is provided with a brake arm to which a spring balance is attached.



Working :

→ On operation, the rotor turns change in flux density on stator.

→ eddy currents introduced which oppose rotation of rotor.

→ The moment of resistance is measured by brake arm & then torque & shaft power may be calculated.

→ power is conv to heat carried off partly by air & water.

power limit : 300 H.P ; speed limit : 6000 rpm

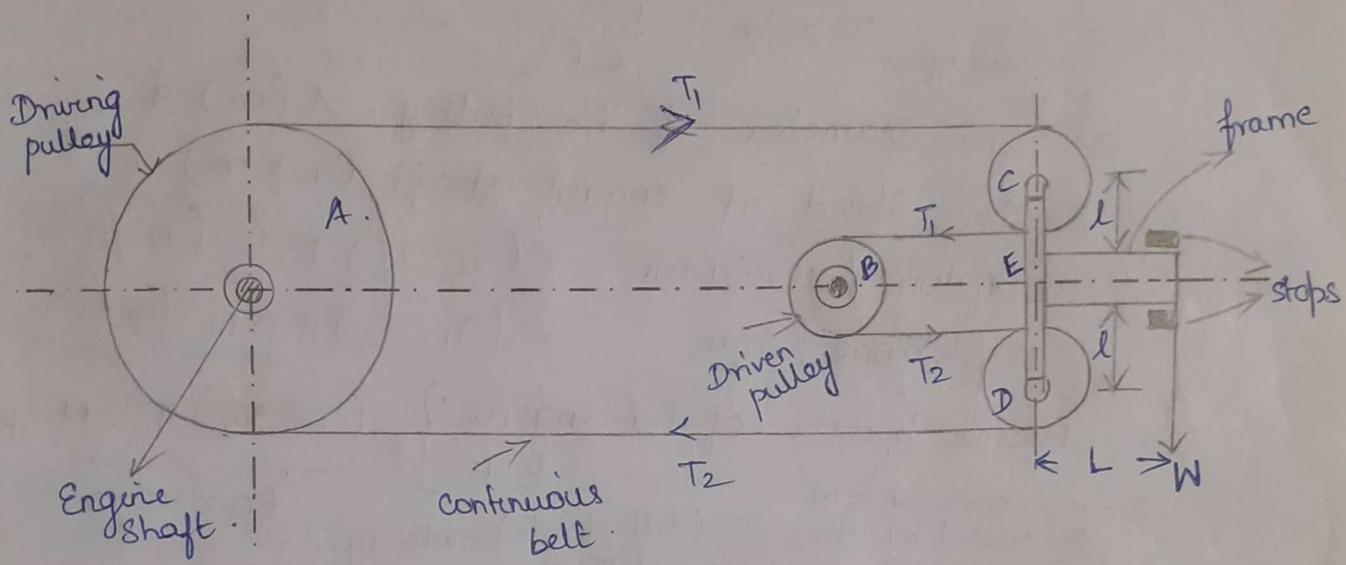
Advantages :

① Good control at low speed
② Small size for given capacity
③ Suitable for high speed range also.

BELT TRANSMISSION DYNAMOMETER : (Transmission type)

Principle : When power being txed by the belt from one pulley to another, the tangential effort on the driven pulley is equal to the difference between the tensions in the tight and slack sides of the belt.

→ A belt dynamometer is used to measure directly the difference b/w the tensions of the belt, while it is running.



→ Has a pulley A (driving pulley) → rigidly fixed to shaft

→ pulley B (driven pulley) → mounted to another shaft to which the power is txed.

→ A & B are connected by means of a continuous belt passing round 2 pulleys C & D mounted on T-shaped frame.

→ The frame is pivoted at E & its movement is controlled by 2 stops.

→ ∵ Tension in tight side of belt (T_1) > Tension in slack side of belt (T_2)

The total force acting on pulley C (ie $2T$) > force (ie $2T_2$) on D

→ This causes movement abt E in anticlockwise direction

→ Inorder to balance it, a weight W is app at a distance L from E.

Taking moments about the pivot 'E', neglecting friction,

$$2T_1 \times l = 2T_2 \times l + W \times L$$

$$2l(T_1 - T_2) = W \times L$$

N = in rpm. So divided by 60 so rps.

$$T_1 - T_2 = \frac{WL}{2l}$$

Let D = Diameter of the pulley, A (m) &

N = Speed of engine shaft (r.p.m)

circumference of pulley

Work done / revolution $= (T_1 - T_2)\,\pi D$ (N·m) per rev

Work done / min $= (T_1 - T_2)\,\pi D N$ (Nm)

given speed velocity

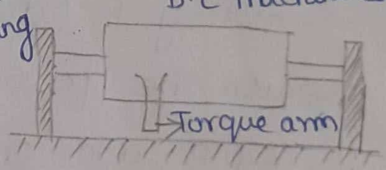
∴ Brake power of the engine B.P $= \dfrac{(T_1 - T_2)\,\pi D N}{60 \times 1000}$ KW

D = mm converted to m so divided by 1000. P = (diff of belt tension) x velocity

D.C DYNAMOMETERS:

→ Most versatile & accurate

It is a cradled Dynamometer & used for power & Torque measurement in



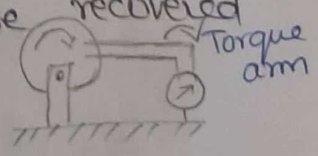
→ Internal Combustion engines

→ small steam turbines

→ pumps & other mech equipment.

→ D.C machine → acts as both motor & generator.

__Generator:__ When it is coupled to a power gen. machine. The power gen in the generator is dissipated in resistance grids or may be recovered as useful power.



__Motor:__ It may act as driving dynamometer. It may drive a test machine which is power abs. device like pump. The O/p power of pump may be smoothly

→ The piston + weight combo floats freely under these conditions

At equilibrium: fluid force = gravitational of wts force + friction drag

$$M*g$$

$$P \cdot A = Mg + F$$

$F = m \times a$.

$$\boxed{\therefore \text{pressure} = P = \frac{Mg + F}{A}}$$

The accuracy of dead weight tester is affected by three factors.

(i) Friction Force between Piston & Cylinder:

→ Friction force ↓sed by good surface finish & fit b/w cylinder & piston.

→ rotate piston so that kinetic friction is applied rather than static friction with probability of stick slip conditions.

(ii) Uncertainity of Value of effective Area 'A':

→ Area upon which the weight force acts is neither the area of piston nor area of cylinder.

→ The effective area depends on the clearance spacing and viscosity of oil.

→ If clearance is small → eff area ≃ area of piston

→ At high P → elastic deformation of cylinder → ↑ses clearance spacing → ↑ error.

(iii) Uncertainity of value of gravitational const 'g'

→ Tester calibrated by manufacture for specific 'g' value. usually the standard is 9.80665 m/s^2

→ local 'g' value differs → for better accuracy corrections must be applied.

Both manometers & DWT are suitable for static calibration only.

MEASUREMENT OF TEMPERATURE:

TEMPERATURE: It is a thermal state of a body which distinguishes a hot body from a cold body.

→ T is proportional to the stored molecular energy (ie) molecular K.E of the molecules in a system.

→ It is also defined as the degree of hotness or coldness of a body or an environment measured on a definite scale.

THERMODYNAMIC TEMPERATURE SCALE:

This was first introduced in 1927 inorder to develop a standard for temperature. measurement.

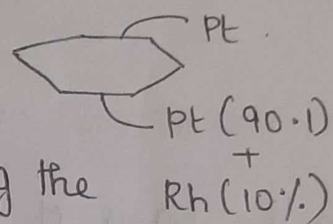
→ In 1927 during the conference of weights of and Measures → produce a practical scale of temp which gives thermodynamic temperatures.

IPTS - 68 is based on the use of 3 thermometric systems

THERMOMETRIC SYSTEMS:

① 14 to 904 K - Pt Resistance Thermometer

② 904 to 1338 K - Thermocouple



③ >1338 K - Optical pyrometer using the plank radiation formula with meas of intensity of radiation.

→ Temperature is the key factor to control industrial processes (esp) chemical operation.

→ There are different methods used to measure temperature.

→ Operating limitations in terms of

↳ Time of response

↳ Temperature range

↳ distance of operation

↳ Compatability with other control elements.

Applications: Many : Eg : temp of oven, distant planet, a red hot blume of iron being rolled, parts of human body, windings of elec. machines, etc.

→ Temp is not measured by direct means like disp, P,

→ It is measured through indirect means.

ΔT → causes various effects → physical, chemical, optical, electrical.

→ These effects are used for measurement of T. using proper temp. sensing devices.

→ Eg. of effects, P, V, R, expansion co-eff, colour of radiation, etc.

CLASSIFICATION OF TEMPERATURE MEASURING DEVICES:

On the basis of:

1. Nature of change produced in temp. sensing element.
2. Electrical and non-electrical operating principles.
3. Temperature range of the instrument.

① Based on Nature of change produced:

(i) Glass Thermometer → expansion of liquids

(ii) pressure Gauge Thermometer → ΔP

(iii) Differential Expansion Thermometers → exp. of 2 dissimilar metals

(iv) Electrical Resistance Thermometers → ΔR

(v) Thermocouples → emf produced

(vi) Optical Pyrometers → visible radiation

(vii) Radiation " → amt of radiation emitted & absorbed.

(viii) Fusion " → graduated fusion materials

(ix) Calorimetric "

(x) Colour Temperature charts.

→ revised in 1948 → then in 1968 — ..... then 1990

→ 1990 scale reduced the lower limit of scale from 13.8 K to 0.65 K and values of defining fixed points of new scale were adjusted to confirm as closely as possible to thermodynamic temperatures.

INTERNATIONAL PRACTICAL TEMPERATURE SCALE: (IPTS)

→ Formulated in 1927 - 7^{th} General conf. on wts & Measures.

→ Revised in 1968 - 13^{th} general conference.

→ It consists of reproducible reference temperature or primary fixed points defined by a no. of pure substances with assigned values of temperatures determined with precision on ideal or perfect gas temperature scale.

→ 12 fixed points in 1968.
Highest being → Normal freezing point of Gold (Gold point) → 1064.43 °C

Lowest → Triple point of hydrogen → −259.34 °C

It is stated that:

⇒ The triple point represents an equilibrium state between solid, liquid & vapour phases of a substance.

⇒ Normal boiling point is the temperature at which the substance boils at standard atmospheric pressure of 760 mm Hg.

⇒ Normal freezing point is the solidification or the melting point temperature of the substance at standard atmospheric pressure.

UNITS OF TEMPERATURE

Unit of the fundamental physical quantity to measure degree of hotness / coldness (ie) thermodynamic Temperature (T) is the kelvin (K)

kelvin: is defined as the fraction $\frac{1}{273.16}$ of the thermodynamic temperature of the triple pt of water

$$t \text{ (in °C)} = T \text{ (in K)} - 273.15$$

$$T_{triple\ pt} - T_{ice\ pt} = 0.0100 \pm 0.0001 \text{ K}$$

(or)

$$t_{triple\ pt} - t_{ice\ pt} = 0.0100 \pm 0.0001 \text{ °C}$$

It can be written as.

$$T_{triple\ pt} = 273.16 \text{ (exactly) K}$$

$$T_{ice\ pt} = 273.1500 \pm 0.0001 \text{ K}$$

$$t_{triple\ pt} = 0.01 \text{ (exactly) °C}$$

$$t_{ice\ pt} = 0.0000 \pm 0.0001 \text{ °C}.$$

BIMETALLIC THERMOMETERS:

→ used for local temperature measurements

→ use two fundamental principles:

① ↳ all metals expand or contract with change in temperature.

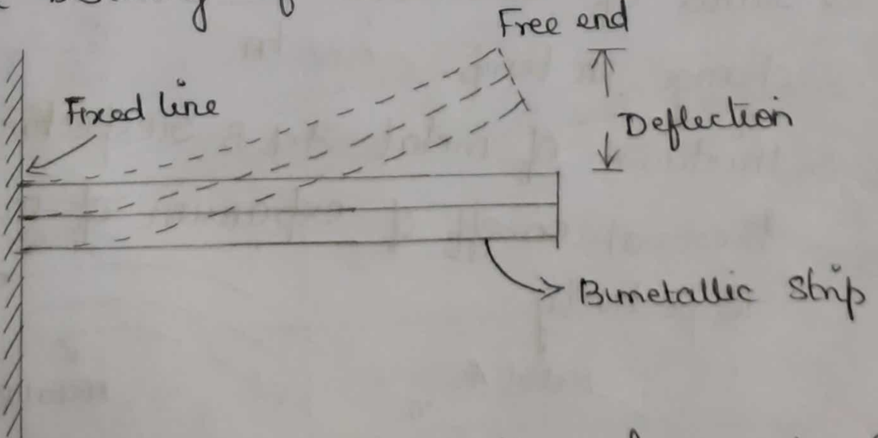
② → The temperature co-eff of expansion is not the same for all metals and therefore their rates of expansion or contraction are different.

③ This diff in rates is used to produce deflections prop to ΔT.

CONSTRUCTION:

→ Consists of a bimetallic strip which is constructed by bonding together two thin strips of different metals such that they cannot move relative to each other.

→ The differential change of expansion of 2 metals result in bending of the bimetallic strip with ΔT.



→ If bimetallic strip is in the form of cantilever beam with on end fixed, then ΔT causes the free end to deflect.

→ Depending on the metals used the temp range of linear rel b/w T & deflection varies.

→ $d_{\text{free end}} \propto \dfrac{\Delta T \cdot l^2}{t}$

→ consider bimetallic strip made of 2 metals A & B with different thermal expansion co-eff.

→ They are bonded together at Temp T_1

→ A change in Temp $(T_2 - T_1)$ → causes diff. expansion

→ strip deflects into a uniform. circular arc.

Radius of the arc is given by.

$$r = \frac{t\left[3(1+m)^2 + (1+mn)\left(m^2 + \frac{1}{mn}\right)\right]}{6(\alpha_A - \alpha_B)(T_2 - T_1)(1+m)^2}$$

$$\frac{1(3(4)+(2)(2))}{6(4)}$$

where

t → total thickness of strip

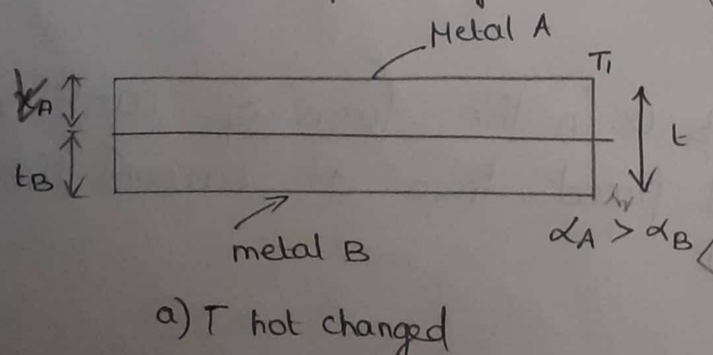
m → ratio of moduli of elasticity $= \dfrac{E_B}{E_A}$.

n → ratio of thickness $= \dfrac{t_B}{t_A}$.

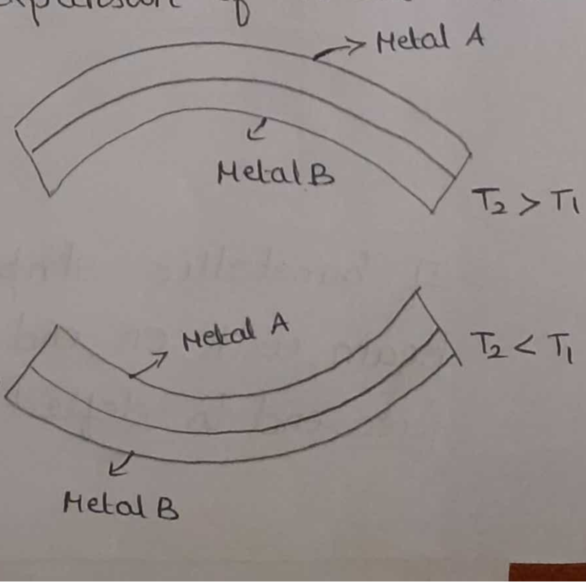
$T_2 - T_1$ → change in temp.

t_A, t_B → thickness of metal A & B respectively.

α_A, α_B → thermal co-eff of expansion of metals A & B respectively.



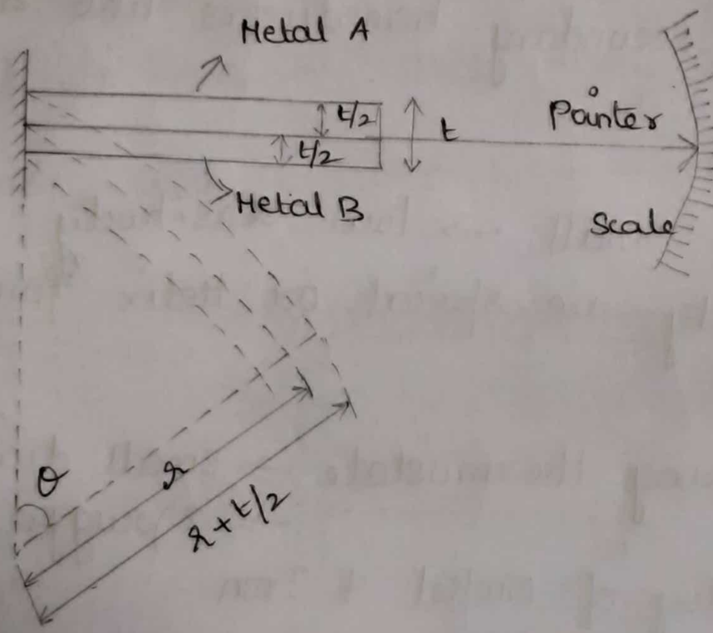
a) T not changed



→ The strip bends towards the side whose metal has a lower thermal expansion coefficient when T ↑es and reverse happens when T ↓es.

In most practical cases $m = n = 1$.

$$\therefore \ r = \frac{2t}{3(\alpha_A - \alpha_B)(T_2 - T_1)}$$



→ A strip of length L is assumed to bend through a circular arc when ΔT

$$\frac{r + t/2}{r} = \frac{\text{Expanded length of strip A}}{\text{Expanded length of strip B}}$$

$$= \frac{L\left[1 + \alpha_A (T_2 - T_1)\right]}{L\left[1 + \alpha_B (T_2 - T_1)\right]}$$

$$r = \frac{t}{2}\left[\frac{1 + \alpha_B (T_2 - T_1)}{(\alpha_A - \alpha_B)(T_2 - T_1)}\right]$$

If any one metal has very low thermal exp. coefficient say B → then $\alpha_B \simeq 0$

$$\therefore r = \frac{t}{2\alpha_A(T_2 - T_1)}$$

∴ The deflection at free end is direct indication of the temperature of the strip

→ can also use secondary transducers like ΔR, ΔL & ΔC

Disadvantages

↳ deflection is small → low sensitivity

→ To ↑ sensitivity use spiral or Helix form

Application:

Air conditioning thermostate → small dia
→ ↑ rugged.

→ Invar → Alloy of Nickel & Iron

Advantages:

→ Simple, robust, Inexpensive

→ Accuracy : ±0.5% to ±2%.

⇒ Not used for T > 400°C or +550°C

Other Applications:

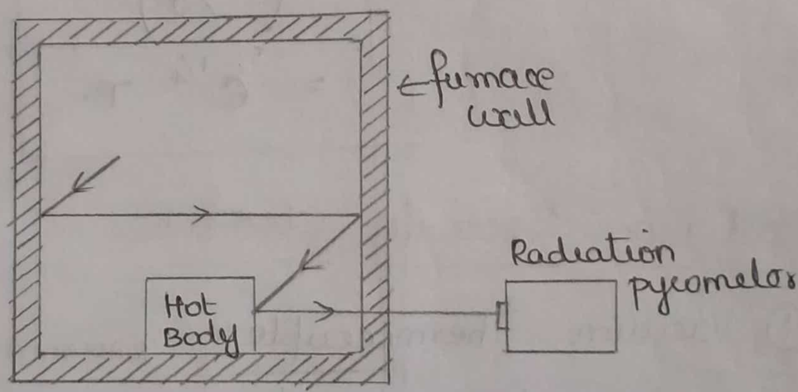
→ Refineries, oil burners, fire vulcanizers, hot solder tanks, hot wire heaters.

Black Body Conditions:

→ Not difficult to get good black body conditions

→ Hot body enclosed by walls at the same temp, then both walls & body radiate and absorb heat at the same rate. If a small hole is made in the container/ this area behaves as perfect black body; since the rays leaving the enclosure would have been reflected many a times.

→ Furnace with a small hole → at o/p → pyrometer.



Heated Body inside a furnace.

⇒ wall T = Heated body T

$$\alpha + \rho + \tau = 1$$

absorption, reflection, Transmission factors.

τ for most solids $= 0$

$\therefore \alpha + \rho = 1$

$\rho = 0$, $\tau = 0$, $\alpha = 1$

By Kirchoff's Identity: $\epsilon = \alpha$

From outside → reflected radiant energy is seen.

for B.B radiation : $\epsilon = \alpha$

heated obj must radiate the amt of energy it absorbs.

→ Even when we view the obj in box → rod is seen

∴ Heated body is considered to be black body.

To measure T of a body ⇒ use value of 'q'

$$\boxed{q = \epsilon \sigma T^4 \Rightarrow \therefore T = \left(\frac{q}{\epsilon \sigma}\right)^{1/4}}$$

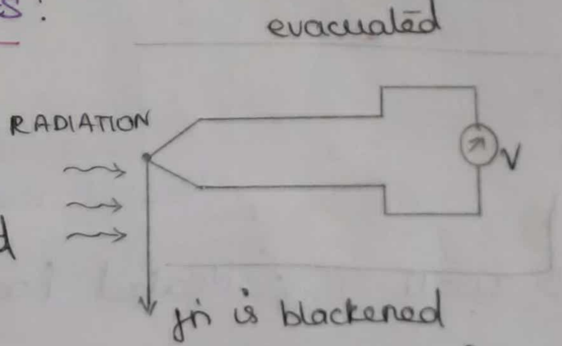
For apparent black body : $\epsilon = 1$

$$\therefore \boxed{\begin{aligned} T_a &= \left(q/\sigma\right)^{1/4} \\ &= \epsilon^{1/4} T. \end{aligned}}$$

Radiation Receiving Elements:

① Vacuum Thermocouple:

heat loss due to convection & conduction is ↓ed due to envelope.



→ Thermocouple → low mass → evacuated → ∴ fast response.

② Thermopile:

→ jn is blackened → absorbs all heat.

→ The ref jn is kept in a shielded position away from the region of direct radiation.

→ To compensate variable ambient T → Nickel resistance spool.

→ Typical response Time : 2s.

PYROMETERS:

PYRO - Fire, METER - Measuring Instrument

→ used for measuring high Temperature & when physical contact is not possible.

→ In corrosive environments

→ For rapidly moving objects.

Radiation Pyrometry:

↳ Measure the radiant heat emitted or reflected by a hot object.

↳ Thermal radiation is electromagnetic radiation emitted as a result of temperature.

↳ wavelength of thermal radiation : 0.1 to 100 μm

→ operating principle based on Black Body concepts

Total thermal radiation emitted by Black Body $\boxed{q_b = \sigma T^4 \ W/m^2}$

where σ → Stefan Boltzmann Constant = 57.2×10^{-9} $(W/m^2 K^4)$

T → Absolute Temp (K)

→ practically transfer of energy takes place at $T > 0K$.

Prevost's Theory of Exchange:

For two black bodies in sight, each will radiate energy to the other, and hence the net energy transfer:

$$q_b = \sigma (T_1^4 - T_2^4) \ W/m^2 \quad T_1 > T_2$$

If $T_1 >> T_2 \Rightarrow q_b \propto T_1^4$

Eg: hot body Temp $T_1 = 600°c$
Room Temp $T_2 = 30°c$ → can be neglected

⇒ A rough black surface radiates more heat than a smooth bright surface. This effect is called emissivity & it is expressed as.

$$\boxed{\epsilon = q/q_b.}$$

where q → heat radiated by gray body (W/m^2)

$$\boxed{q = \epsilon . \sigma T^4} \quad W/m^2$$

The value of emissivity is from 0 to 1.

⇒ The energy is radiated over a wide range of frequencies of the e.m. spectrum.

Based on Plank's Radiation law:

The distribution for any particular wavelength (λ) is

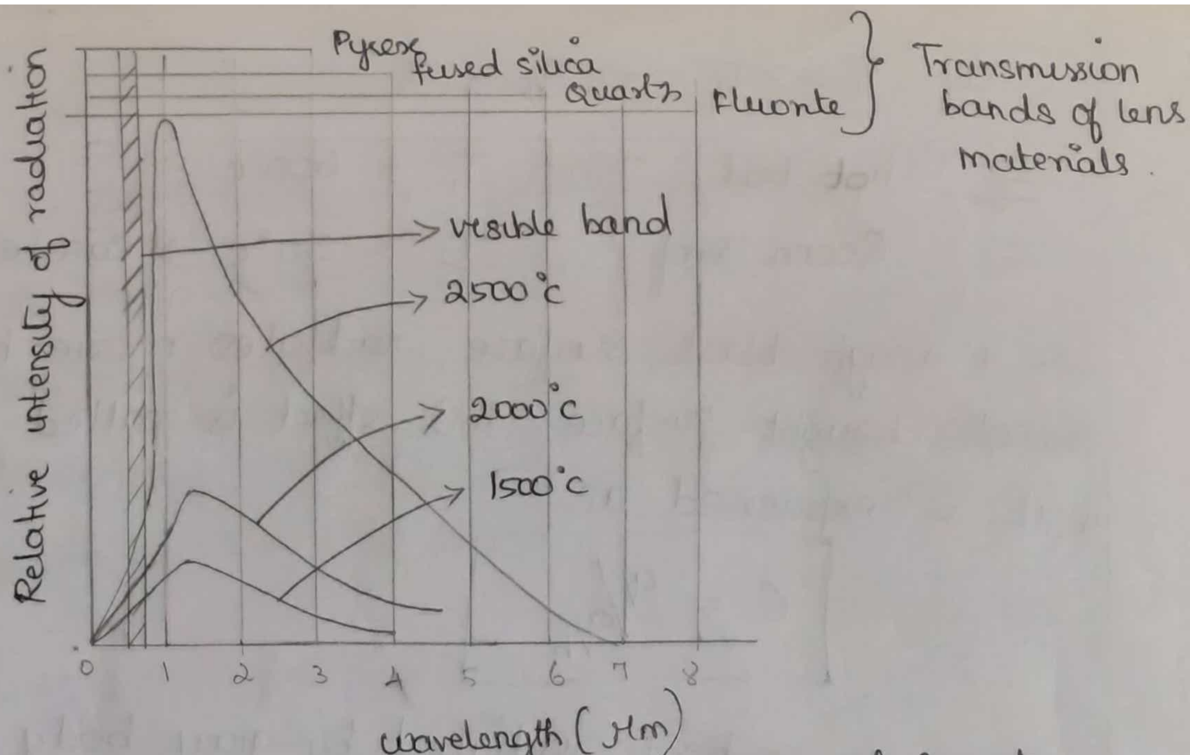
$$\boxed{q_{b\lambda} = \frac{C_1 \lambda^{-5}}{(e^{C_2/\lambda T} - 1)}}$$

$q_{b\lambda}$ = monochromatic emissive power W/m^2
λ = wavelength in m
where $C_1 = 0.374 \times 10^{-5}\ wm^2$
$C_2 = 14.4 \times 10^{-3}$ mk.
C_1 & C_2 → constants

→ From the graph → the intensity at each f for a particular Temp is found.

→ For band of 'λ' or freq → Area under curve → Energy radiated.

→ A gray body → has constant emissivity at all λ.



→ As T ↑es → Point of Max intensity shifts to shorter wavelength.

By Wien's Displacement law:

Max. Radiant Intensity : $\boxed{\lambda_m \cdot T = 2900}$.

where λ_m → wavelength at which maximum intensity occurs (μm)

→ This is a common phenomenon observed in the change of colour of a body being heated. A metal gradually heated changes its colour from red, which has a long wavelength to yellow and white as the intensity of radiation ↑es at the shorter wavelengths of visible spectrum.

Principles of Radiation Temperature Measuring Devices.

① Total radiation pyrometry : Measure Total energy from a heated object.

② Selective/ partial radiation pyrometry : Measure energy at a specific λ. Eg : Optical pyrometer.

(3) BOLOMETER :

$\Delta T \rightarrow \Delta R$ (change in resistance)

→ made of thin ribbon of Pt or Ni

→ ΔR meas using Wheatstone's Bridge.

→ Thermal energy exposed → R ↑ → Bridge unbalance.

→ fast response but expensive.

(4) PHOTOELECTRIC TRANSDUCER :

→ Sensitive to given portions of spectrum.

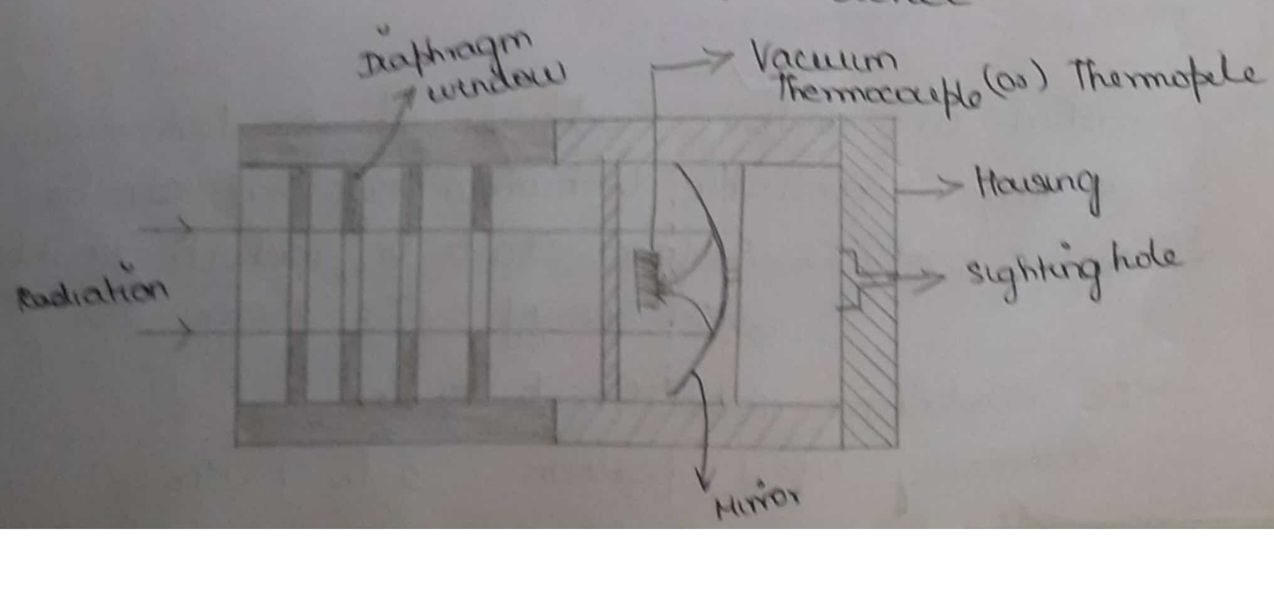
→ used with partial radiation / optical radiation pyrometer.

TOTAL RADIATION PYROMETERS :

→ Receives all the radiation from a particular area of hot body & focuses it to a temperature sensitive transducer like thermocouple, thermopile, Bolometer, etc.

→ Total radiation → visible (light) + Invisible Radiations (IR)

→ consists of radiation receiving element } + Temp. indicating device.



-> Mirror type radiation receiver.

-> Diaphragm unit + Mirror to focus radiation on thermopile.

-> Mirror to Transducer distance is adjusted for proper focus.

-> Since NO lens is present -> Abs + reflection effects are absent.

-> The temperature meas are independent of the distance of the target.

-> If any absorbing media is present -> o/p is less
smoke, dirt, gases.

-> If any heat sources like hot gases, flame, high T particles -> o/p is high.

-> poor sensitivity at lower temperature.

-> not suitable for $T < 600°c$

-> useful range : 1200°c to 3500°c

-> o/p from total rad. pyro is taken to PMMC instrument or self balancing potentiometer | digital displays.

-> recorded for control purposes.

INFRARED PYROMETERS:

-> partial or selective radiation pyrometers.

-> IR rays -> invisible to human eye but can be felt

-> At $T > 550°c$ -> Surface starts to radiate visible light energy ∴ IR energy ↑es.

-> IR Spectrum : 0.22 μm to 17 μm
commonly used portion : 2 to 7 μm.

→ photoelectric Transducers are most commonly used for IR pyrometers.

→ Eg: photovoltaic cell.

↳ It responds to wavelengths in IR region.

↳ can measure T down upto 400°c.

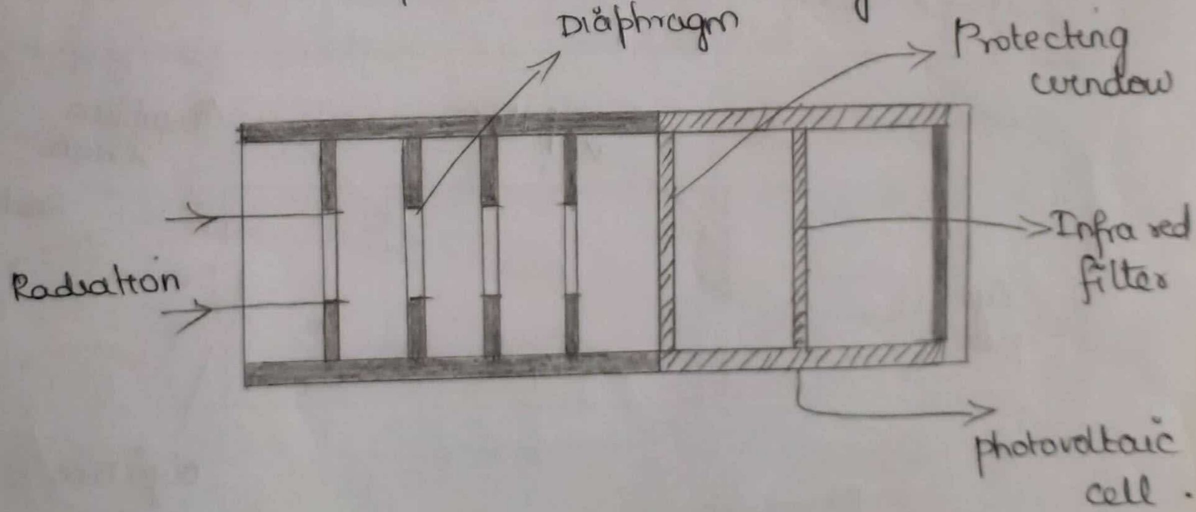
→ High speed of response.

→ Ensure cell does not get overheated when focussing IR rays.

→ Area of first diaphragm decides cone of radiation

→ protective window → To protect cell from physical damage.

→ filter is used in the range of 1000°c to 1200°c to ↓ IR radiation & prevent over heating.



→ Depends on Txn of IR energy being emitted by a heated body to a detector

→ No direct contact → only focussing of sensor head on hot object.

OPTICAL PYROMETERS :

PRINCIPLE :

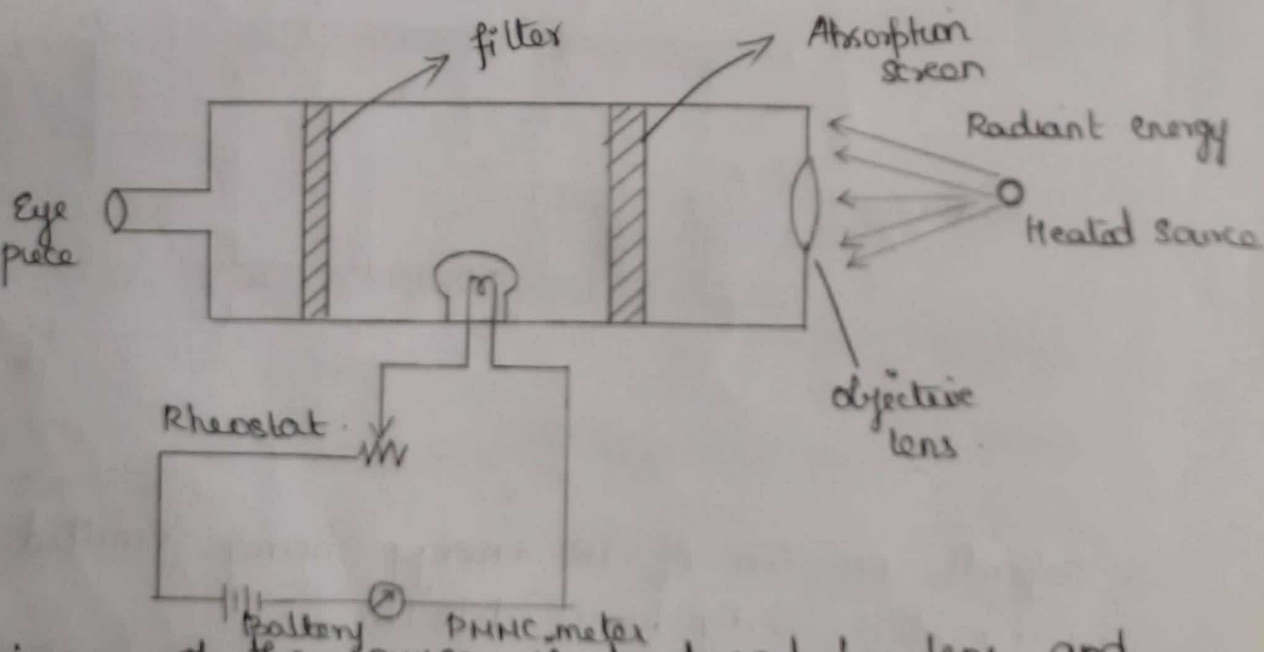
→ Heat an object at high T → radiation falls under visible range.

→ In visible range a given wavelength has fixed colour & energy of radiation is found as Intensity or Brightness

→ Amount of Brightness → Indication of Temperature

→ In an optical pyrometer, w.l of radiation accepted is restricted by means of colour filter and brightness is measured by comparison with standard lamp.

Disappearing filament Optical pyrometer :



→ image of the source is produced by lens and made to co-incide with filament of electric lamp.

→ current through filament 'I' is varies to control lamp brightness

→ The filament is viewed through an eye piece of a filter.

→ The current through the filament is adjusted until the filament and image are of equal brightness.

3 CASES:

① If Brightness of image produced by source = Brightness produced by filament.

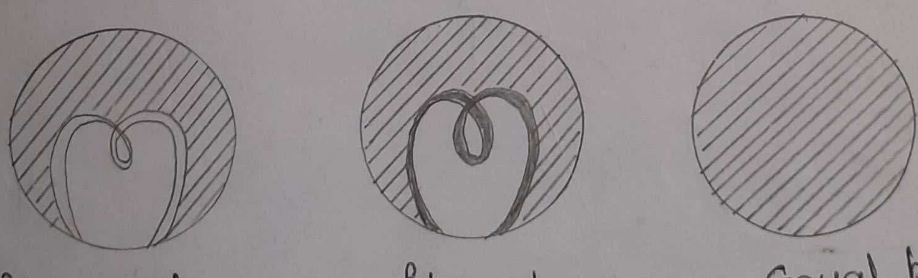
→ outline of filament disappears.

② If Temp of filament is higher than required for equality of brightness.

→ filament becomes too bright.

③ If temp of filament is lower.

→ filament becomes dark.



filament too bright   filament too dark   Equal brightness

⇒ Intensity of any wavelength dep. upon the temp of radiating body.

⇒ Temp of filament dep. upon the current flowing through the lamp, the instrument may be directly calibrated in terms of filament current

Int. of radiation $\propto$ Temp & Temp of filament $\propto$ I

-> Max allowable temp of lamp : 1400 °c. This limits range of measurement.

-> Range can be extended using absorption type screen near objective lens. extended to 3000°c

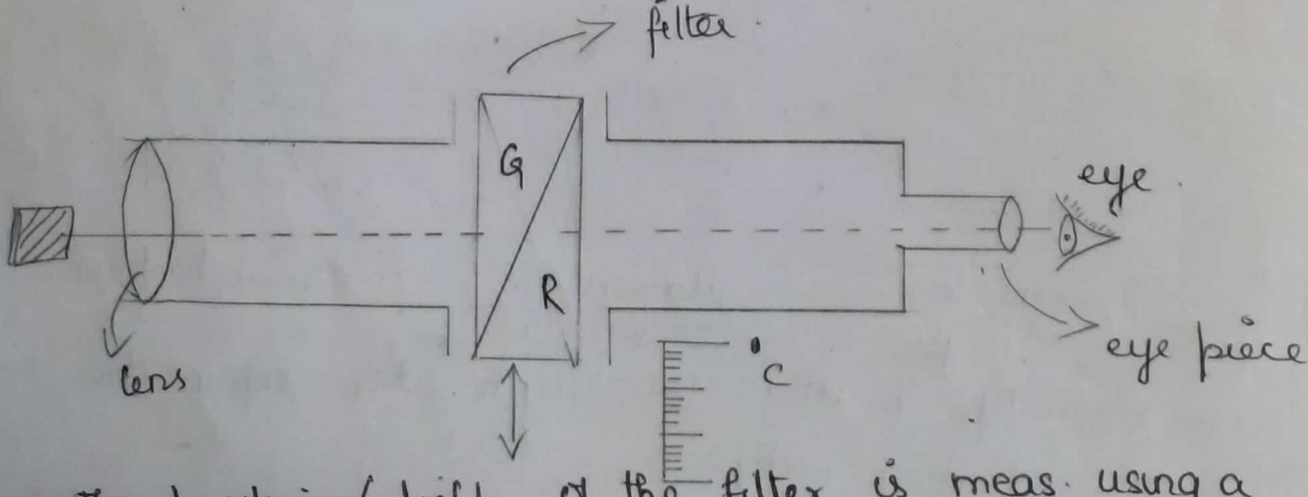
TWO COLOUR RADIATION PYROMETER:

-> also called Ratio pyrometer.

-> The ratio of spectral radiances at 2 w.l is estimated by human eye. The observer adjusts the filter position so that target appears grey.

-> If Target Temp ↑es -> % of green ↑
% of red ↓

-> ratio of spectral radiant intensity is function of temp If Target Temp ↑es -> ratio of $\frac{W_{\lambda 1}}{W_{\lambda 2}}$ ↑es.



-> The position / disple. of the filter is meas. using a scale which is calibrated in terms of Temp (°c)

-> range : 1200 to 2000 °c
Error : ± 20 to 30 °c.