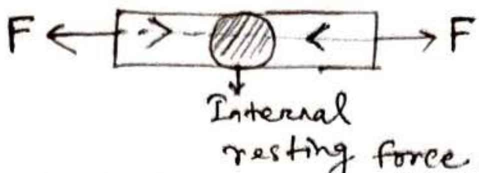
Chapter-1 : Measurement of Stress and Strain

1.1 Define Stress and Strain

Stress

→ stress is defined as the internal property of Material which resisf external loading.



eg: Rubber band stretch, iron Rod etc.

→ The rubber tends to regain it's original position which is stated as stress.

Mathematically →

$$\text{stress } (\sigma) = \frac{\text{Force}}{\text{Unity Area}} \quad , N/mm^2$$

Types of stress

* Tensile stress
* Compressive stress
* shear stress

→ **Tensile Stress**

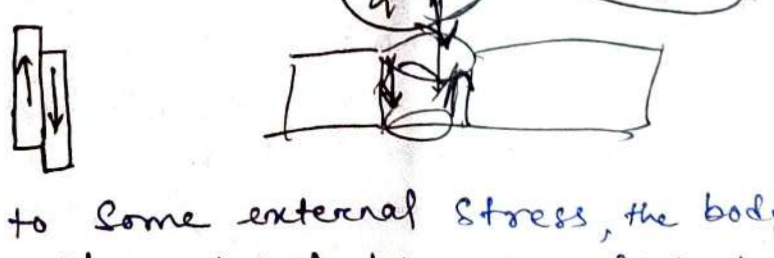
The stress created when two equal and opposite pull is acting on a body is said to be tensile stress.

→ **Compressive stress**

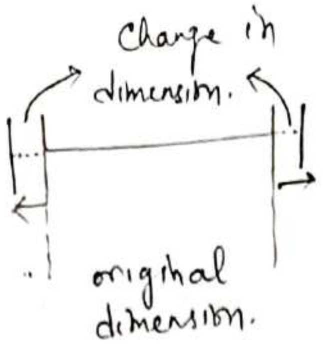
The stress created when two equal & opposite push is acting on a body is said to be compressive stress.

→ **Shear stress**

The stress created when two equal & opposite side is acting on a body is called a shear stress.



* **strain** :- Due to some external stress, the body tends to change it original dimension, which is referred as strain.



$$\text{Strain } (\varepsilon) = \frac{\text{Change in dimension}}{\text{Original dimension}}$$

unit = Unit less $= \frac{\Delta l}{l} = \frac{cm}{cm} =$ unit less.

Types

Tensile strain

~~if the dimension length of the body ch.~~

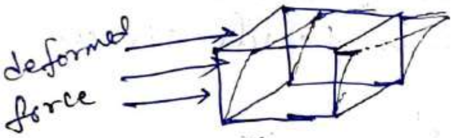
if the dimension of the body increases under the action of the force, the strain caused is referred as tensile strain.

Compressive Strain

if the dimension of the body decreases under the action of the force, the strain caused is referred as ~~to~~ compressive strain.

Shear Strain

if the dimension of the body deformed under the action of the force the strain caused is referred as shear strain



$$\text{Shear Strain} = \frac{\text{lateral displacement}}{\text{it's distance from fixed place}}$$

volumetric strain

if the volume of the body changes under the action of force, the strain caused is referred as volumetric stress.

1.2 Explain different types of Sensor & Transducer to convert Stress and Strain into electrical voltage

Sensor

A sensor is a device that detects and responds to some types of input from the physical environment. The Specific input could be light, heat, motion, moisture pressure, or any one other physical quantities converted electrical quantity.

→ Solar cell Sensor or photo voltaic cell.

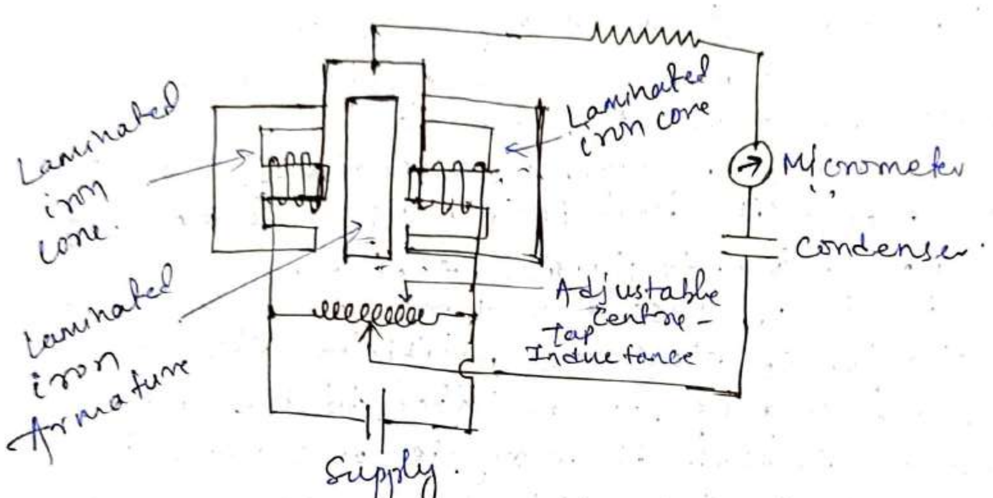
Transducer

Transducer is a device which converts one form of energy to other form of energy.

→ Piezo electric type.
→ Resistance type gauge.
→ Capacitive strain gauge.
→ Inductive strain gauge.

Inductive strain gauge

Inductance gauge have also been developed and uses for various applications. Inductance gauge can take several forms and the one commonly used has two laminated iron cores carried on the frame piece which is mounted to the test specimen at one end.



→ The opposite end of the specimen is fixed with a laminated iron armature situated in betn two cores.
→ When a change in length betn the two end occurs, the air gap betn the armature and one core increases while the gap betn the armature and the other core decreases.
→ Thus due to change in air gap, the inductance of two coils on iron cores changes and a current flows.
→ The change in the current is a direct measure of relative motion betn the gauge attachment points. They have the easy read out and have high output.

Piezoelectric gauge

Piezoelectric gauge for measurement of strain have limited application.

1) No power supply is needed as they as self-generating.
2) They produce appreciable output per unit strain.

* Strain gauges Transducer

→ These find application in the measurement of load, force, thrust, pressure, torque, displacement & flow etc.

→ The effect of the above variable to be measured has first to be converted in to displacement action by bellows, bourdon tube or cantilever beam etc. They are used for both static and dynamic measurements.

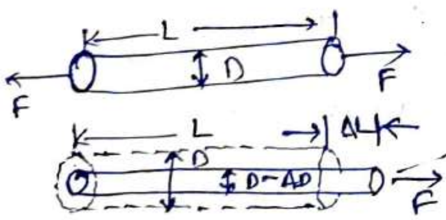
1.4 Explain theory of operation of Resistive strain gauge

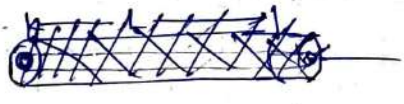
→ Strain gauge is a positive-type resistance transducer which converts a mechanical displacement in to a change of resistance. It is most commonly used transducer for the measurement of displacement.

→ The resistance gauge is essentially a fine wire which changes it's resistance, when mechanically strained, due to physical effects.

→ It's length & cross sectional area vary & a change of electrical resistivity also occurs.

→ The strain gauge is mounted to the measured surface so that it elongates or contracts with that surface. This deformation of the sensing materials causes it to under go a change in resistance.





→ The resistance change ΔR of the strain gauge wire can be calculated by using the expression for the resistance of a conductor or wire of uniform cross-sectional.

$$R = \rho \frac{L}{A}$$

R = resistance of the wire, in Ω

ρ = Specific resistance of wire or conductor material, in Ω-m

L = Length of the wire, in m

A = cross-sectional area of the wire, in m^2 $= \frac{\pi D^2}{4}$

D = diameter of the wire.

the change - in cross - sectional area of the strain gauge wire will be.

$$\Delta A = \pi/4 \, D^2 - \frac{\pi}{4}(D - \Delta D)^2 \quad \text{——— (1)}$$

the poisson's ratio 'μ' which is defined as the ratio of the strain in the lateral direction to strain in the axial direction.

$$\mu = \frac{-\Delta d/d}{\Delta L/L} = -\frac{\text{lateral strain}}{\text{longitudinal strain}}$$

we take +ve side

$$\mu = \frac{\Delta d/d}{\Delta L/L}$$

$$\therefore \varepsilon = \Delta L/L = \text{strain}$$

$$\mu = \frac{\Delta d/d}{\varepsilon}$$

$$\Delta d = \mu . \varepsilon . d$$

Put the value of Δd in eq^n (1)

$$\Delta A = \frac{\pi}{4} d^2 - \frac{\pi}{4}(d - \varepsilon \mu d)^2$$

$$= \frac{\pi}{4} d^2 - \frac{\pi}{4}(d^2 - 2\mu\varepsilon d^2 + \mu^2\varepsilon^2 d^2)$$

$$= \frac{\pi}{4} 2\mu\varepsilon d^2 - \frac{\pi}{4}\mu^2\varepsilon^2 d^2$$

$$= \frac{\pi}{4} d^2 (2\mu\varepsilon - \mu^2\varepsilon^2) \quad \text{——— (2)}$$

Now, the change in resistance due to change in area will be

$$\frac{\Delta R_1}{R_s} = \frac{\Delta A}{A}$$

$$\Rightarrow \Delta R_1 = R_s \frac{\Delta A}{A}$$

$$= \frac{R_s}{A} \frac{\pi}{4} d^2 (2\mu\varepsilon - \mu^2\varepsilon^2) = \frac{R_s}{A} \cdot A (2\mu\varepsilon - \mu^2\varepsilon^2)$$

$$= R_s \varepsilon (2\mu - \mu^2 \varepsilon^2) \quad \text{——— (3)}$$

R_s is resistance of the unstrained wire

The change in resistance due to change in the length will be

$$\Rightarrow \frac{\Delta R_2}{R_s} = \frac{\Delta L}{L}$$

$$\Rightarrow \Delta R_2 = R_s \frac{\Delta L}{L}$$

$$\Delta R_2 = R_s \varepsilon$$

Therefore total change in resistance ΔR_s of wire produced by the strain will be

$$\Delta R_s = \Delta R_1 + \Delta R_2$$
$$= R_s \varepsilon (2\mu + \mu^2 \varepsilon) + R_s \varepsilon$$
$$= R_s \varepsilon (1 + 2\mu + \mu^2 \varepsilon)$$

Since the strain is very small, the term containing μ^2 may be neglected.

$$\Delta R_s = R_s \varepsilon (1 + 2\mu) \quad \text{--- (4)}$$

Gauge factor

The gauge factor of the strain gauge is defined as the unit change in resistance per unit change in length.

$$G = \frac{\Delta R_s / R_s}{\Delta L / L}$$

$$= \frac{\Delta R_s / R_s}{\varepsilon} \qquad \therefore \frac{\Delta R_s}{R_s} = \varepsilon (1 + 2\mu)$$

$$= \frac{\varepsilon (1 + 2\mu)}{\varepsilon}$$

$$\boxed{G = 1 + 2\mu}$$

The gauge factor can be written as

$$\boxed{G = 1 + 2\mu + \frac{\Delta \rho / \rho}{\varepsilon}}$$

- 1: Resistance change due to change in length
- 2μ: Resistance change due to change in area.
- $\frac{\Delta \rho / \rho}{\varepsilon}$: Resistance change due to piezoresistive effect

So, neglect the piezoresistive effect

$$\boxed{G_f = 1 + 2\mu}$$

$\therefore$ poisson's ratio for most metal lies in the range 0.25 to 0.35, & accordingly the gauge factor in the range 1.5 to 1.7.

1.3 - Define Strain & classify Strain Gauge

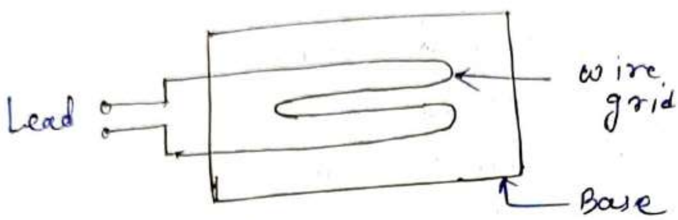
Basically, there are two types of strain gauges:

i) Bonded strain gauge

ii) Unbonded strain gauge.

i) Bonded Strain Gauge

→ The bonded strain gauges, a grid of fine wire is cemented to a thin paper sheet or very thin bakelite sheet & covered with a protective sheet of paper or thin bakelite.



→ When the surface to which the strain gauge is bonded is disturbed because of an applied force or load, the strain gauge is also strained.

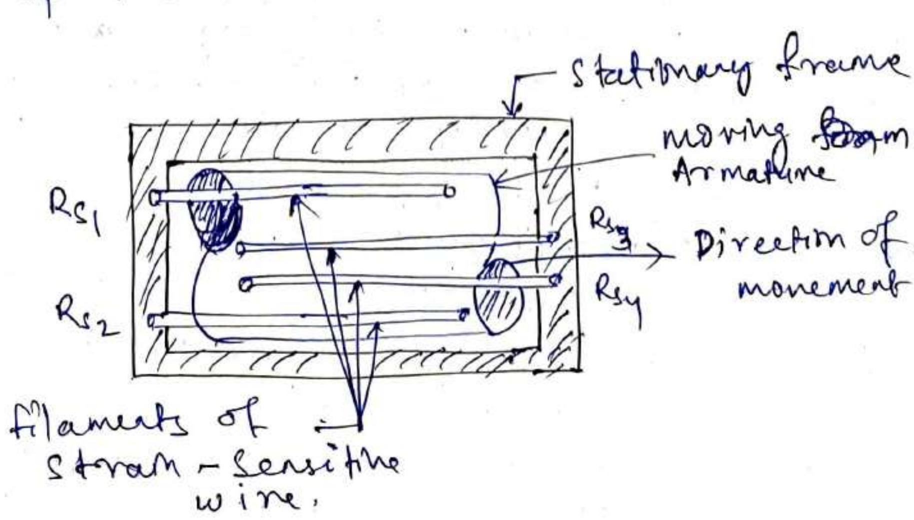
→ The resistance of the wire changes on account of change in length and diameter of the wire.

→ The strain gauge size varies with the application. Small size is 3mm X 3mm square, larger more than 2.5cm long & 1.25 cm wide.

→ The strain gauge is useful only for measuring very small displacements (strains). For larger displacement can be measured by bonding the gauge to a flexible element such as thin cantilever beam & applying the unknown displacement to the end of the beam.

(ii) Unbonded Strain Gauge

→ The unbonded strain gauge consists of a stationary frame and an armature that is supported in the centre of the frame.



→ The armature can move only one direction & it's travel in that direction is limited by four filaments of strain-sensitive wire wound betn rigid insulators that are mounted on the frame & one the armature.

→ When an external force is applied to the strain gauge, the armature moves in the direction indicated.

→ The filaments R_{s1} & R_{s2} increases in length where as R_{s3} & R_{s4} decrease in length.

→ The resistance change of the four filaments is proportional to their change in length & this can be measured with a wheatstone bridge.

→ The unbonded strain gauge transducer can be constructed in a variety of the configurations, depending on the required use. They are mainly used in force & pressure transducer & accelerometers.

1.5 - Explain the concept of multi-axial strain measurement by rosette gauge

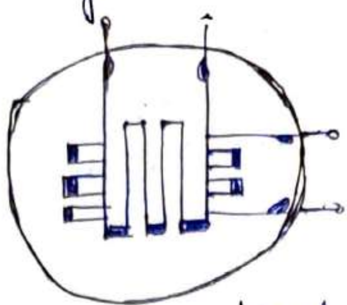
→ The single strain gauges are used to measure only those strains which are parallel to the strain axis. But when the direction of the strain is unknown, it is necessary to use a multiple array of gauges which permit the calculation of the direction as well as magnitude of the two principal strains.

→ Three or four arm rosette gauges are most commonly used. To make the calculation easier gauges are usually set with either 45° or 60° angle betn them.

Two element Rosett gauge

→ These are used for the measurement of stress in biaxial stresses fields, where the directions of principal stress are known.

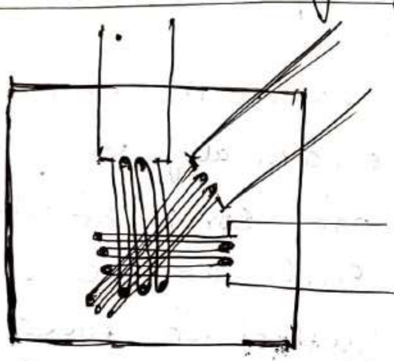
→ The strain gradient along the surface is high and it is important to approach a point as possible, the grids are stacked one on the top of the other, being insulated betn each other.



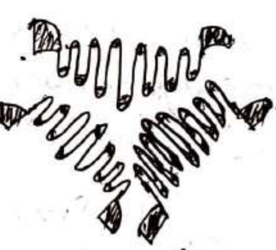
(Two gauges placed upon each other at 90°)

→ A variation of the two element rosette is the stress gauge which utilizes an axial and a transverse element with different resistances.
→ The ratio of resistances is such that the combined output of the two elements is proportional to stress, the output of the axial element is proportional to strain.

Three element rosette gauge



3 element rosette
45° planar (wire)



3-element rosette
60° - planar
(foil)

→ The three element rosette are most widely used to determine the direction & magnitude of principle strain resulting from complex loading of structure.
→ In this type also there exist over lapping type & single plane type of gauges.
→ The 45° & 60° rosette provides greater angular resolution and is normally used when the approximate direction of the principle strain is known.
→ These are used in general biaxial stress field.

Classification of Strain Gauge

Depending upon the principle of operation & their constructional features, strain gauges are classified in to three types.

1) Electrical strain Gauge.
2) Mechanical strain Gauge
3) optical strain Gauge.

1) Electrical strain Gauge :-

→ The electrical strain gauge are most commonley used. the electrical strain gauges measures the changes that occur in resistance, capacitance or inductance due to strain transfered from the Specimen to the basic gauge element.

→ the most commonly used strain gauge is the bonded resistance type of strain gauge. the other two i.e capacitance & inductance type are used in special types of applications.

2) Mechanical strain Gauge :-

→ In these gauges, the change in length, Δl is ~~magnitude~~ magnified mechanically using levers or gears. these gauges are comparatively larger in size & as such can be used in application where sufficient area is available on the Specimen for fixing the gauge. these gauges are employed for the static strain measurement only.

3) optical strain Gauge

→ These gauges are similar to mechanical strain gauges except that the magnification is achieved with multiple reflectors using mirrors or prisms.

→ In one type a plane mirror is rigidly fixed to a movable knife-edge. when stress is applied, the mirror rotates through an angle & the reflected light beam from the mirror subtends an angle twice that of the incident light.

→ ~~These~~ The measurement accuracy is high & independent of temperature variations

Foil strain gauge:

→ In this type of strain gauge, the strain is detected using a metal foil. The metal and alloys used for the foil & wire are nichrome, Nickel, constantan, & platinum.

→ The foil type strain gauges & wire type strain gauges are similar including almost the same gauge factor.

→ The advantage of foil type strain gauge is that they can be fabricated on a large scale and can be made in shape.

→ Due to large surface area foil gauges have a much greater dissipation capacity. Therefore they can be used at a higher operating temperature range.

→ The etched foil strain gauge can be made thinner as comparable wire units & they are more flexible.

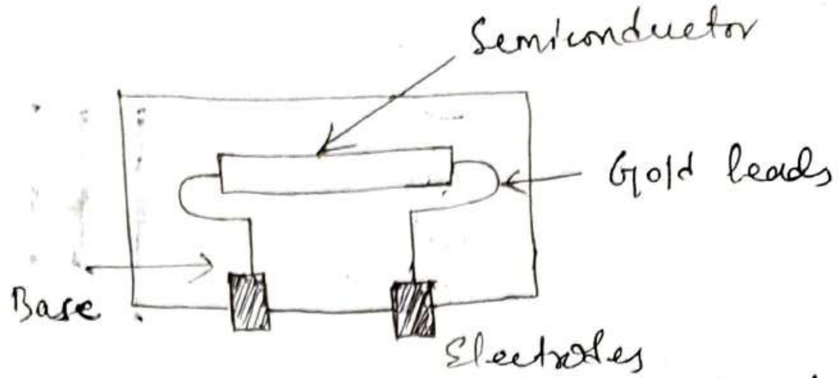
→ ~~Due to all these properties, the etched foil strain gauge can be made thiner as comparable wire units.~~

→ Due to all these properties, the etched foil can be mounted in remote and restricted places & specially on curved surfaces.

→ The resistance film formed is typically 0.2 mm thick. resistance foil gauge is betn 50 & 1000 Ω.

1.7 Semiconductor type strain gauge

→ This type of strain gauges are used when a high value of gauge factor is desired. Their gauge factor is 40-50 times as high as that of wire gauges.



→ The principle of operation of the semiconductor strain gauge is the piezo-resistive effect. i.e the change in the value of resistance due to change in resistivity of the semiconductor because of strain applied.

→ In metallic gauges, the change in resistance is mainly due to change in dimension when strained.

→ Semiconductor material used are germanium & silicon.

→ The semiconductor wafer or filament used has a thickness of 0.05 mm. They are bonded on suitable insulating substrates, such as teflon. Gold leads are used for making contacts.

→ This gauge factor is measured at room temperature the gauge factor of this type of strain gauge is about 130 ± 10% for a unit of 350 Ω.

→ The gauge is stable & can be operated with conventional indicating & recording systems.

Advantage

→ it has a high gauge factor of about 120 which allows measurement of very small strain of the order of 0.01 microstrain.

→ The hysteresis characteristics of semiconductor strain gauge is excellent.

→ it has good frequency response.

→ it is small & compact in size

→ The life of semiconductor strain gauge is long.

Disadvantage

1. The linearity of the gauge is poor.
2. The Semiconductor strain gauge is sensitive to change in temperature.
3. It is more expensive.
4. The gauge factor varies with strain.

1.6 Selection Criteria strain gauge material and Bonding material techniques

→ Strain gauge sensing element material can be divided in to two groups :- 1. Metallic, & 2. Semi conductor.

1. Metallic

a) constantan → A copper - ~~nickel~~ nickel alloy with a low and controllable temperature co-efficient. commonly used for static measurements, transducer applications & for dynamic measurements where alternating strain level donot exceed ± 1500 micro strain. operating temperature limits are -70°c to +250°c.

b) Nichrome

→ A nickel chrome alloy used for high temperature static and dynamic strain measurements. Under ideal conditions of temperature compensation the alloy may be used for dynamic measurement to 950°c & for static measurement to 650°c.

c) Dynaloy

→ This nickel - iron alloy has a high gauge factor.
→ it is recommended for measurement of dynamic strain where the higher temperature sensitivity of the alloy can be tolerated.

d) stabiloy

→ this is the modified nickel-alloy which has a wide compensation range from cryogenic to elevated temperature gauges made of this alloy are generally excellent zero stability to 350°c; minimum drift to +450°c.

e) platinum alloy :-

→ A platinum - tungsten alloy which displays unusual stability and fatigue life at elevated temperatures. Gauges made of this material are recommended for dynamic tests to 800°c & static tests to 650°c.

→ This alloy has a relatively large temperature Co-efficient of resistance & can not be adjusted for self-temperature compensation.

* Semiconductor

→ The material used in the manufacture of Semiconductor strain gauges is a specially processed silicone crystal which is cut in to filaments.

→ These filaments have either a 'P' (positive) - characteristic or 'N' (negative) characteristics.

→ The resistance of strain gauges constructed P-type Silicone increase with an increase in tensile strain.

→ N-type gauges decreases in resistance as tensile strain increases.

→ Gauge factors of Semiconductors types may range to a high value of 150 as compared with a practical high of 4.5 for gauges using metalic sensing elements.

→ Semiconductor strain gauge material find their greatest usage in high output transducer such as load cells and pressure cells when circuit compensation techniques can be used to minimize temperature sensitivity effect.

* Strain gauge Bonding Techniques

i) Duco gauges :-

→ In these gauges, the wire is supported by a thin paper base impregnated with nitrocellulose & bonded with a cellulose cement.

→ these are used when the temperature surrounding the gauge is less the 82°C. The cementing process for these gauges is very simple & drying time is relative less.

(ii) Bakelite gauges

→ In these gauges the wire is moulded in a heat hardening or thermosetting phenol resin & bonded to to the test surface with a phenol-resin cement. These are very suitable in surroundings where temperature is less than 230°c & more than 82°c.

→ Bakelite gauges also find use at end below room temperature for those installations which require long time stability & freedom from creep.

→ These are also used on the permanent installations made of concrete rein-forced rods, where it is expected to take strain readings periodically for many months or even years.

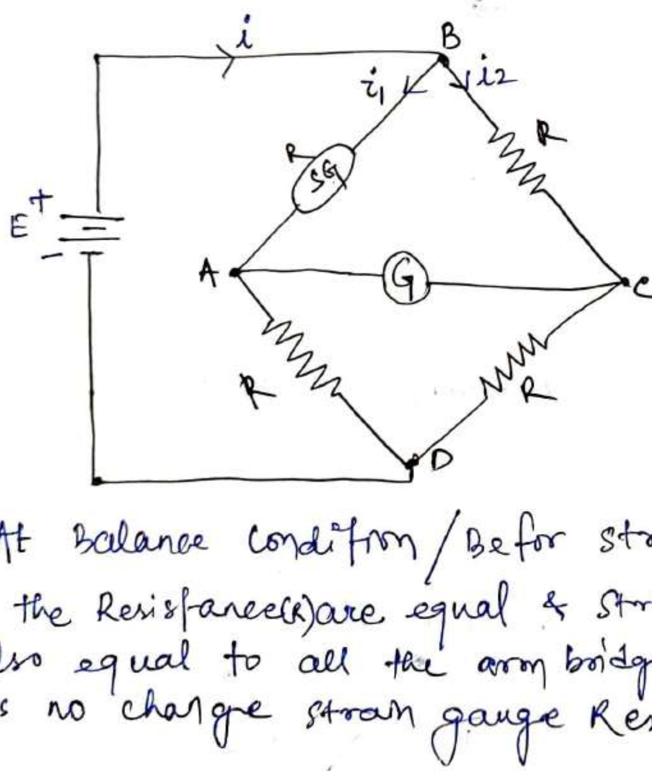
1.8 Strain gauge auxilary circuite (Wheatstone Bridge methode).

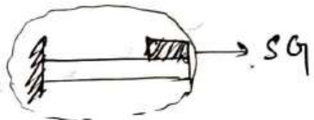
→ it presents one of the most convenient and accurate methods of resistance measurement

Two methode

① Null / Balance Instrument
② Deflection Instrument.

① Null / Balance Instrument





At Balance condition / Befor stress apply or strain apply all the Resistance(R) are equal & Strain gauge Resistance (R) also equal to all the arm bridge resistance, So there is no change strain gauge Resistance (R).

At balance condition galvanometer branch current $i_G = 0$.

As no current is flowing through branch AC,
voltage at A = voltage at C

∴ voltage drop from B to A = voltage drop from B to C

$i_1 R_1 = i_2 R$ ∴ ~~But if all for Resistance unequal~~

$i_1 R_g = i_2 R$

∴ let four bridge resistance are unequal

R_1, R_2, R_3, R_4

Strain gauge $= R_1$

So,

$$i_1 R_1 = i_2 R_2$$

$$i_1 R_4 = i_2 R_3$$

$$\boxed{R_1 = \frac{R_2}{R_3} \times R_4}$$ → Balance Bridge condition.

→ Null mode is more accurate

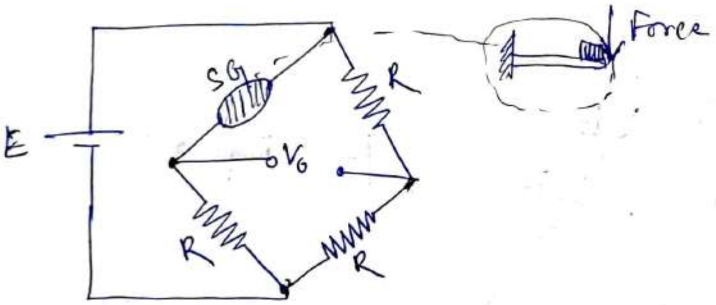
→ it is less used.

→ Time consuming is slow.

→ only for static inputs.

(2) Deflection Instrument

a) Quarter Bridge



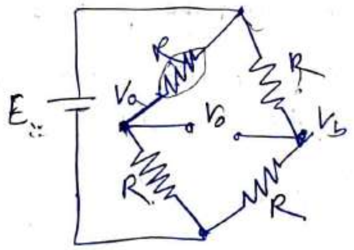
Befor i/p force

Bridge balance & all four resistance equal

So, $V_0 = V_a - V_b$

$$V_0 = E \cdot \frac{R}{R+R} - E \cdot \frac{R}{R+R}$$

$= 0$



After input Force

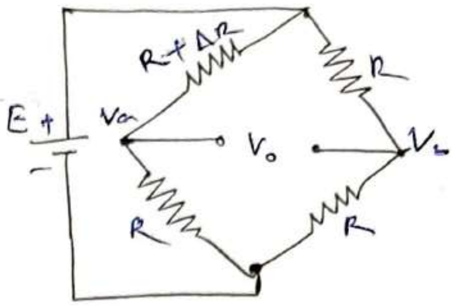
tensile force $= R + \Delta R$

compressive force $= R - \Delta R$

Force $\propto \varepsilon \propto \Delta R$

take tensile force as input

So, After input force Bridge unbalance the current is flow through galvanometer & also we can measure voltage across galvanometer.



$V_o = V_a - V_b$

$V_a = E \cdot \frac{R+\Delta R}{R+\Delta R+R}$, $V_b = E \cdot \frac{R}{R+R}$

$V_o = E \cdot \frac{R+\Delta R}{2R+\Delta R} - E \cdot \frac{R}{2R}$

$= E \cdot \frac{R+\Delta R}{2R+\Delta R} - E \cdot \frac{1}{2}$

$= E\left[\frac{2R+2\Delta R-(2R+\Delta R)}{4R+2\Delta R}\right] = E \cdot \left[\frac{2R+2\Delta R-2R-\Delta R}{4R+2\Delta R}\right]$

$\Rightarrow E \cdot \left[\frac{\Delta R}{4R+\Delta R}\right]$ where $4R \gg 2\Delta R$

$2\Delta R$ = very small so we neglect it

$V_0 \Rightarrow E \cdot \frac{\Delta R}{4R}$ — (1)

As we Gauge factor $(G_f) = \frac{\Delta R/R}{\Delta L/L} = \frac{\Delta R/R}{\varepsilon}$

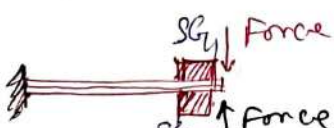
$\Rightarrow \Delta R = G_f \cdot \varepsilon \cdot R$ — (2)

Put the value in eqn (1)

$V_o = E \cdot \frac{G_f \cdot \varepsilon \cdot R}{4R}$ $\Rightarrow$ $\boxed{V_o = \frac{E}{4} \cdot G_f \cdot \varepsilon}$

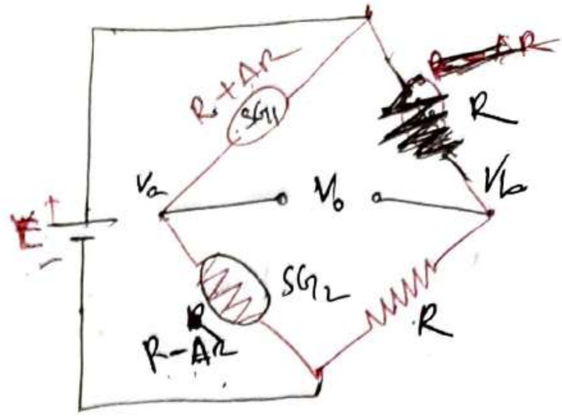
Drawback of Quarter bridge →
→ Sensitivity is low.
→ Ambient temperature Sensitivity (error).

(b) <u>Half Bridge</u>



1. Tensile → R → R+ΔR
2. compression → R → R−ΔR

$V_0 = V_a - V_b$



$$= E \cdot \frac{R+\Delta R}{R+\Delta R+R} - E \cdot \frac{R-\Delta R}{R-\Delta R+R}$$

$$= E\left[\frac{R+\Delta R}{2R+\Delta R} - \frac{R-\Delta R}{\Delta R}\right]$$

$$V_0 = E \cdot \frac{R+\Delta R}{R+\Delta R+R-\Delta R} - E \cdot \frac{R}{R+R}$$

$$= E \cdot \frac{R+\Delta R}{2R} - E \cdot \frac{R}{2R}$$

$$= E\left[\frac{R+\Delta R}{2R} - \frac{1}{2}\right] = E\left[\frac{2R+2\Delta R-2R}{4R}\right]$$

$$= E \cdot \left[\frac{2\Delta R}{4R}\right] = E \cdot \frac{\Delta R}{2R} \quad (2)$$

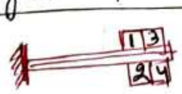
$\therefore$ $\boxed{\Delta R = G_f \cdot \varepsilon \cdot R}$ in previous eqn (2)

Put the value.

$$V_0 = E \cdot \frac{G_f \cdot \varepsilon \cdot R}{2R} \Rightarrow \boxed{V_0 = \frac{E}{2} \cdot G_f \cdot \varepsilon}$$

→ This half Bridge more accurate
→ Sensitivity increase by 2 times of Quarter bridge.
→ Temperature compensation are require.

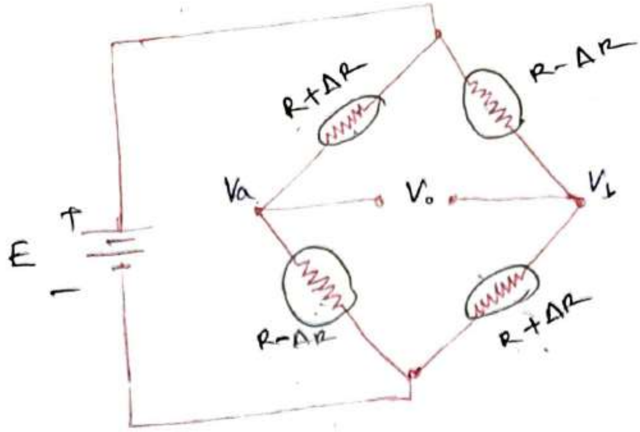
ⓒ Full Bridge strain gauge



Strain gauge 1 & 3 → Tensile strain
→ R → R+ΔR

Strain gauge 2 & 4 → compressive strain →
R → R−ΔR.

→ Proper installation of strain gauge in bridge
the Same strain Strain gauge is instal in opposite arm of bridge, & opposite strain is placed adjacent arm of bridge.



$V_0 = V_a - V_b$

$$V_0 = E \cdot \frac{R+\Delta R}{R+\Delta R+R-\Delta R} - E \cdot \frac{R-\Delta R}{R+\Delta R+R-\Delta R}$$

$$= E \cdot \frac{R+\Delta R}{2R} - E \cdot \frac{R-\Delta R}{2R}$$

$$= E \cdot \left[\frac{R+\Delta R-(R-\Delta R)}{2R} \right] = E \cdot \left[\frac{R+\Delta R-R+\Delta R}{2R} \right]$$

$$= E \cdot \frac{2\Delta R}{2R} = E \cdot \frac{\Delta R}{R} \qquad \because \Delta R = G_f \cdot \varepsilon \, R$$

$$\Rightarrow V_0 = E \cdot \frac{G_f \cdot \varepsilon \cdot R}{R}$$

$$\boxed{V_0 = E \cdot G_f \cdot \varepsilon}$$

Advantage

① High Sensitivity = (Q1 : 2H : 4F)

② Temperature compensation is removed.

Characteristics of Deflection type Bridge

→ less accurate.
→ mostly used
→ Fast in response.
→ it is can be use both static as well as dynamic input.

Q.1 During a test, the strain gauge with resistance of 200 ohm undergoes a change of 0.120 ohm & the strain of the gauge is 1.2×10^{-4}. Then the gauge factor will be :

(Ans) :-

Strain gauge resistance $R = 200\,\Omega$

Change in resistance $\Delta R = 0.120\,\Omega$

Strain $\varepsilon = 1.2 \times 10^{-4}$

$$\text{Gauge factor } (G_f) = \frac{\Delta R / R}{\varepsilon} = \frac{\frac{0.120}{200}}{1.2 \times 10^{-4}} = \frac{\frac{120}{200 \times 1000}}{1.2 \times 10^{-4}}$$

$$\frac{\frac{12}{200 \times 100}}{\frac{12}{10} \times 10^{-4}} = \frac{12}{200 \times 100 \times 12 \times 10^{-5}}$$

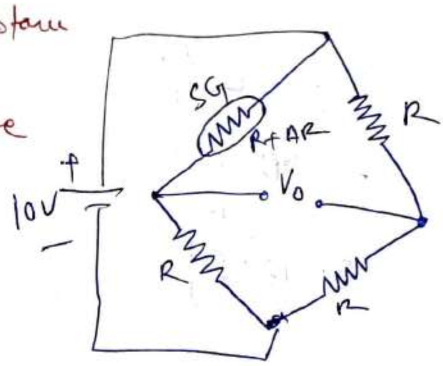
$$= \frac{1}{2 \times 10^{-1}}$$

$$= \frac{10}{2} = 5 \quad \text{(Ans)}$$

Q.2 A strain with nominal resistance $R = 120\,\Omega$ is installed in a branch of a wheatstone bridge having for unstrained strain gauge. $R_1 = R_2 = R_3 = R_4 = R$ and $V_i = 10V$, As a result of bending the beam, on which it is cemented, the strain gauge is subject to a strain. A digital voltmeter with input resistance $R_m = 10M\Omega$ gives reading of $V_0 = 5mV = 5 \times 10^{-3} V$

(Ans) a) Calculate of the resistance $\Delta R = ?$

b) the strain ε for gauge factor $= G = 2$.



Quatenbridge

Ans

$R = 120$

$V_i = 10V$

$V_0 = 5mV$

$$V_0 = \frac{V_i}{4} G_f \cdot \varepsilon = \frac{10}{4} \times 2 \times \varepsilon$$

$$\Rightarrow 5 \times 10^{-3} = \frac{10}{4} \times 2 \times \varepsilon$$

$$\Rightarrow \varepsilon = 10^{-3}$$

$$G_f = \frac{\Delta R / R}{\varepsilon} \Rightarrow 2 = \frac{\Delta R / 120}{10^{-3}}$$

$$\Rightarrow 2 \times 10^{-3} \times 120 = \Delta R$$

$$\Rightarrow \Delta R = 240 \times 10^{-3}$$

$$= 0.24\,\Omega \quad \text{(Ans)}$$

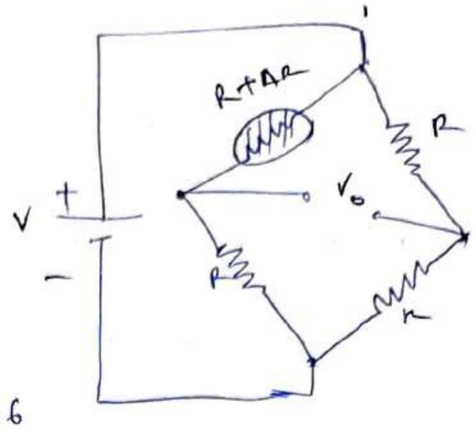
Q.3 A unit ratio quarter bridge strain gauge produces an output of 1 mV for a strain of 500 microstrain when bridge is excited by 4 volts. the gauge factor. The gauge factor of the element is ?

(Ans) A unit ratio quarter bridge means resistance means all the resistance are equal.

$V_0 = 1\,mV$

For strain $\varepsilon = 500\,\mu$ strain

$V = 4V$



$$V_0 = \frac{V}{4} \cdot G_f \cdot \varepsilon$$

$$1 \times 10^{-3} = \frac{4}{4} \times G_f \times 500 \times 10^{-6}$$

$$G_f = \frac{1 \times 10^{-3}}{500 \times 10^{-6}} = \frac{10^3}{500} = 2$$

Q.7 A metal wire strain gauge having an unstrained resistance of 120Ω & a gauge of 2.1 is bonded on to a steel grinder so that it experience a tensile stress of 10^8 pa. of young's modulus for steel is 2×10^{11} Pa. The strained resistance of the gauge is ____ Ω.

(Ans) unstrain resistance $R = 120\,\Omega$

Gauge factor $G_f = 2.1$

tensile stress $\sigma = 10^8$ pa.

$$\text{Young's modulus } E = \frac{\text{Stress}}{\text{Strain}} = \frac{\sigma}{\varepsilon} = 2 \times 10^{11} \text{ pa.}$$

$$\varepsilon = \frac{\sigma}{E} = \frac{10^8}{2 \times 10^{11}} = 0.5 \times 10^{-3}$$

$$G_f = \frac{\Delta R/R}{\varepsilon} \Rightarrow \Delta R = G_f \cdot \varepsilon \cdot R$$

$$= 2.1 \times 0.5 \times 10^{-3} \times 120$$

$$= \frac{21}{10} \times \frac{5}{10} \times 10^{-3} \times 120$$

$$= 126 \times 10^{-3}\,\Omega.$$

$$\text{strain Resistance} = R + \Delta R = 120 + 126 \times 10^{-3}$$

$$= 120 + .126$$

$$= 120.126\,\Omega$$

1.9 Effect of change of Temperature of Strain gauge operation

→ For accurate measurement of static strains, it is absolutely necessary that the adequate temperature compensation be provided in the wheatstone bridge.

There are two methods

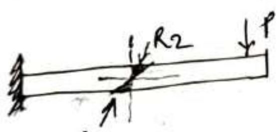
① Dummy gauge arrangement.

② poisson arrangement.

① Dummy strain gauge arrangement.

→ The error due to change of temperature arise of two reasons which are resistance change of the wire in the strain gauge & the other due to the differential expansion existing betn the gauges and the metal to which bonded.

→ If the temperature co-efficient of two are not same. The temperature compensation is accomplished by installing a second strain gauge (commonly known as 'dummy' gauge) on an unstrain



piece of the same metal as that to which the strain gauge is bonded.

→ The dummy gauge is connected in the bridge as R_2. Generally R_1 (resistance of active strain gauge) and (resistance of dummy gauge) R_2 are same and both experience the small resistance change due to an increase in temperature.

→ when change in resistance becomes $R_1 + \Delta R_1$ and $R_2 + \Delta R_2$ of the bridge, at initial condition the bridge eqn is

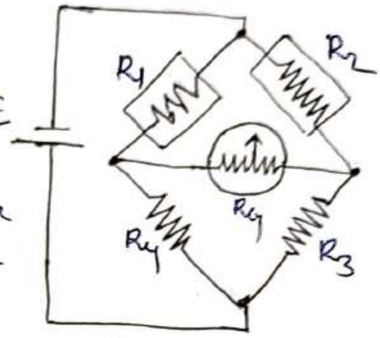
$$\frac{R_1}{R_2} = \frac{R_4}{R_3}$$

due to effect of temperature

it becomes $\dfrac{R_1 + \Delta R_1}{R_2 + \Delta R_2} = \dfrac{R_4}{R_3}$

→ The ratio is undisturbed because the numerator & denominator of the left hand side are both increased in the same proportion.

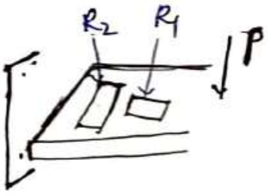
→ it may be noticed that the temperature compensation in the wheatstone bridge can be achieved by connecting the dummy either as R_2 or R_4. if it is connected as R_3 then the effect of thermally caused resistance changes would be doubled instead of being compensated.



→ Dummy gauge is not necessary that connected in the inactive manner only, rather it can measure strain also & give increased output e.g in arrangement gauge R_4 is strain in tension & R_2 in compression. R_4 is connected as active gauge R_2 as the compensating gauge in the bridge, the temperature effects are cancelled

② Poisson - arrangement :-

→ In this arrangement R_2 is in tension & R_1 in compression & both are placed 90° to each other.



→ the ratio of strain varies as the poisson ratio from 0.25 to 0.35 & thus the bridge output is approximately 25% greater than if temperature compensation were obtained by merely cementing R_2 to unstrained piece of metal

→ in Wheatston Bridge connection the output voltage

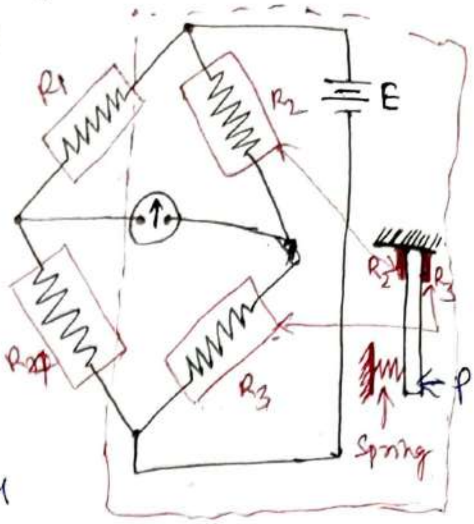
$$V_0 = \frac{E}{4} G_f \cdot \varepsilon (1+\mu)$$

1.10 Explain the operation instrument for static & dynamic strain gauge measurement

a) Instrument for static strain measurement

→ Instrument employing direct current to power the bridge circuit. This instrument is composed of four strain a battery and a galvanometer.

→ In the circuit R_1 is the active gauge, R_4 the dummy or compensating gauge & R_2 & R_3 are bonded to the opposite sides of a thin cantilever beam for the purpose of balancing the bridges.



→ The gauges R_1 & R_4 are bonded to the test surface, R_3 & R_4 along with beam, battery, galvanometer & means for straining the cantilever beam are all built in to the instrument.

→ In order that deflection of beam in either direction may be obtained without any backlash, free end of the beam is spring loaded from one side with a low rate spring.

→ R_1 is strained due to load, the bridge is unbalanced as indicated by the galvanometer & the balance is restored by adjusting beam deflection, the balancing control for which is calibrated directly in micro-mm per mm of strain for particular gauge factor.

Limitation of this simplest instrument are :-

i) The electrical resistance change accompanying typical strain is very small, & in order to detect strain accurately, an extremely sensitive galvanometer needed.

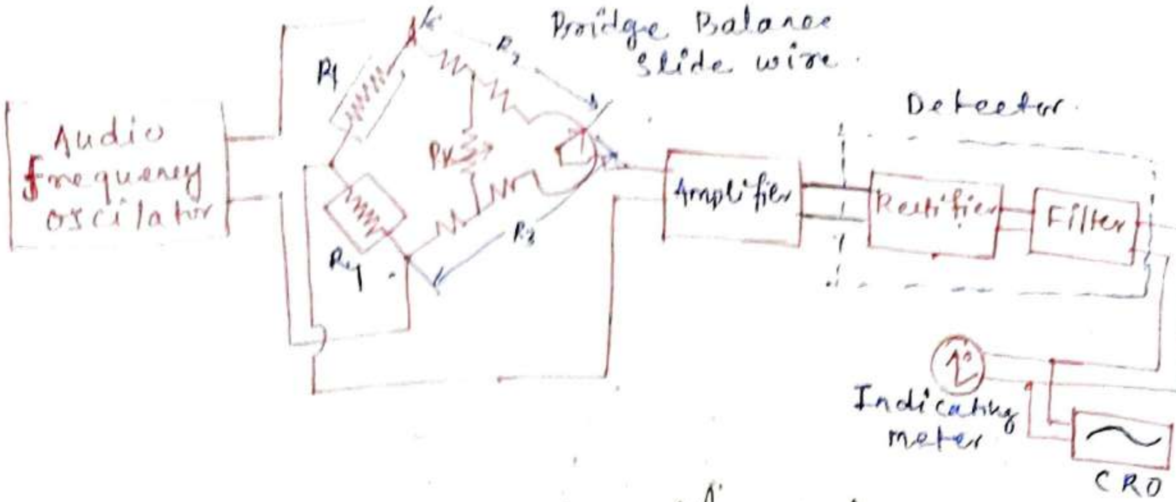
ii) the balancing is tedious & slow operation.

iii) D.C output of the bridge can't be amplified further.

b) → Instrument employing a.c source from oscillator to power the bridge & the audio-frequency amplifier, rectifier & micro-ammeter in the output side.

→ In this instrument the bridge is fed from an audio-frequency oscillator (from 60 to 4000 cps).

→ the output of the bridge is fed to an amplifier X(1000) & then to a detection circuit consisting of a rectifier & filter & finally to the indicator.



→ Variable resistor R_x is employed in order to make adjustments of strain gauges of different gauge factor.

→ The bridge is balanced by varying R_2 and R_3 & for this purpose, balancing slide wire is provided.

→ The coarse adjustment is usually incorporated in a multiple point switch, each step corresponding to a definite amount of strain.

→ The fine adjustment is made by sliding wire arrangement. In order to know about the sign of the strain i.e whether tensile or compressive a phase-sensitive detector is employed in to rectifying circuit which indicates whether the bridge output is in phase with supply voltage or 180° out of phase.

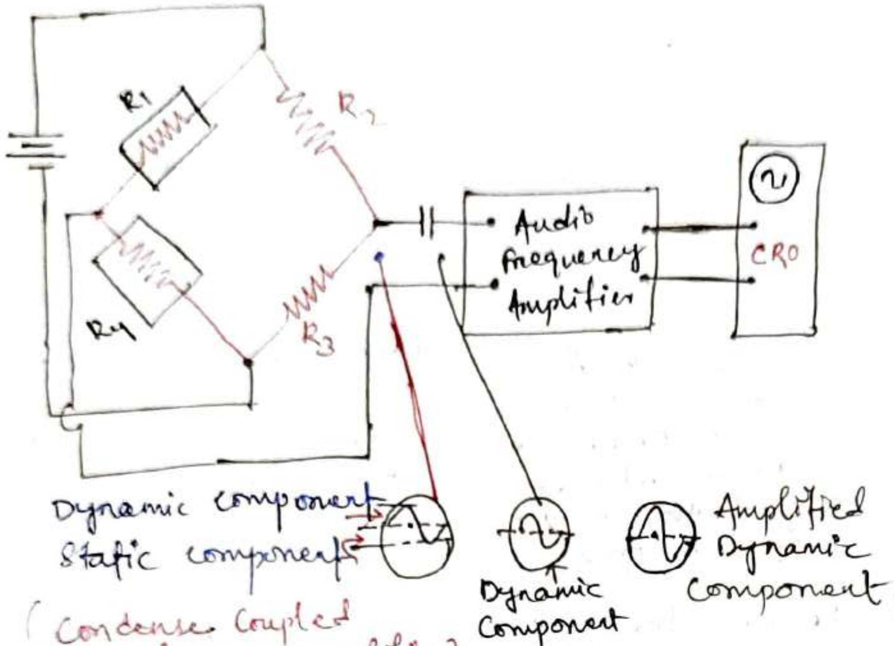
2. Instrument for Dynamic Strain measurement-

→ when strain is any structure is varing at more than several cycles per minute, it would be very difficult to determine the strain by the process of balancing the bridge.

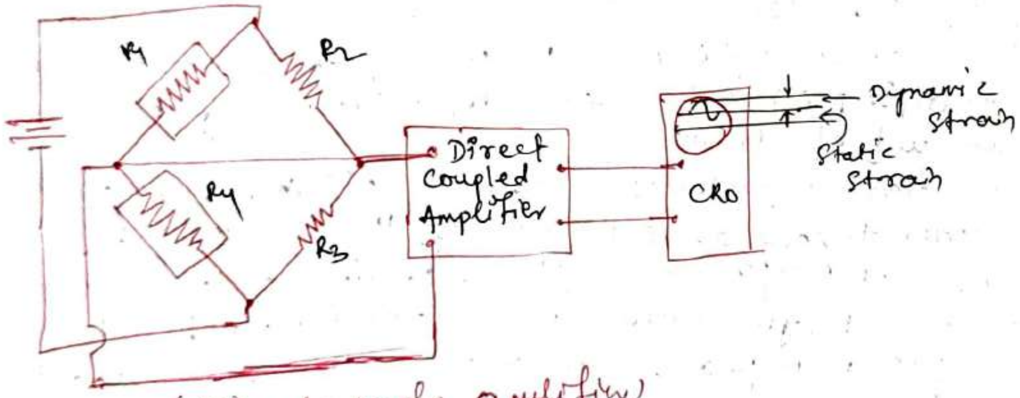
→ For measuring the dynamic strains either wheatstone bridge with output being applied to CRO. or potentiometer circuit are employed.

→ The wheatstone bridge may be powered either by d.c or a.c source. As the output of the bridge circuit is comparatively small, considerable amplification is required in order to drive the commonly used high frequency indicator.

Using d.c Source of Supply & condenser - coupled audio - frequency amplifier & the direct coupled amplifier, the output wave forms for both the cases are shown.



(Condense Coupled audio - frequency amplifier)

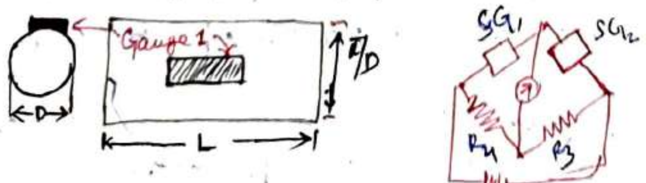


(Direct couple amplifier)

1.11 - Give some application of strain Gauge

1) Axial loading

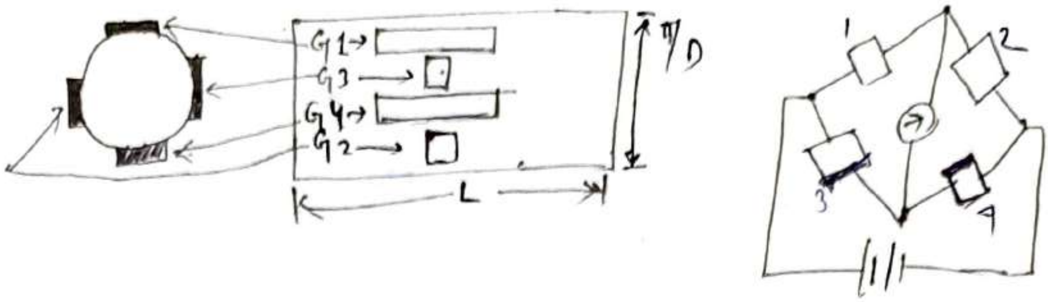
a)



→ Simplest application using a simple measuring gauge with external compensating gauge. Arrangement measures strain at the test point such as bending component due to ecentric loading. Temperature compensation is provided by dummy gauge 2.

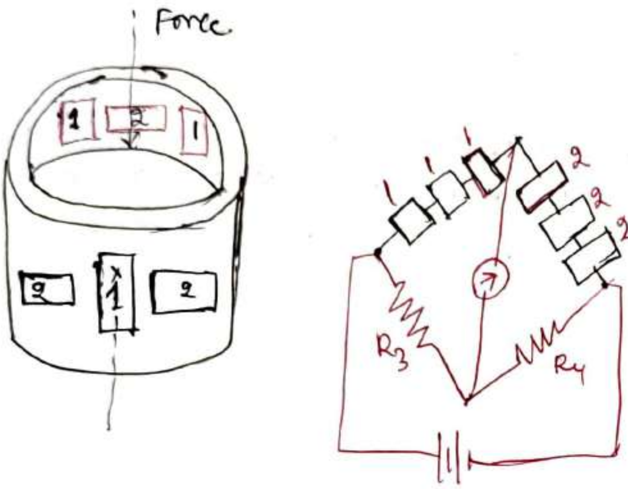
& we can use two bending gauge using same cylinder.

b)



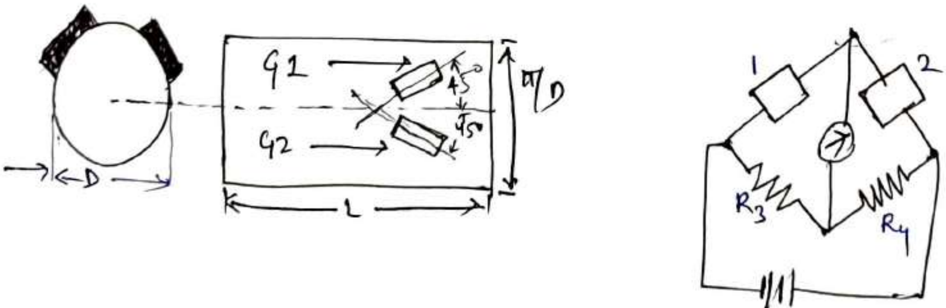
→ Two axial and two circumferential gauge provide complete temperature compensation & bending effects also eliminated.

c)

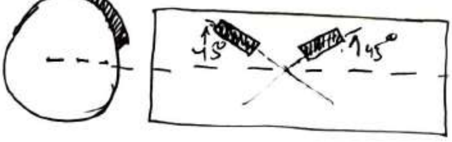


→ load cell employing 3 series connected axial gauges & three series connected poission-ratio gauges. it eliminates effect of eccentric loading & provides temperature compensation

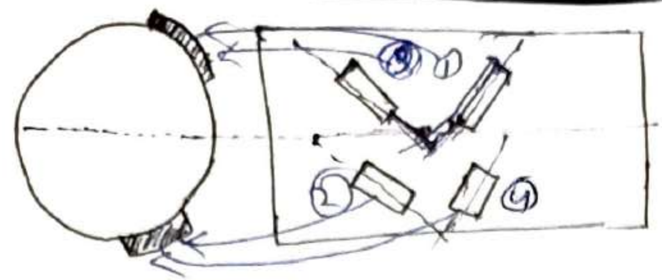
2) Torsion loading



→ Two gauge configuration for measurement torsion & providing temperature compensation. Sensitive to torque and bending but insensitive to axial load.



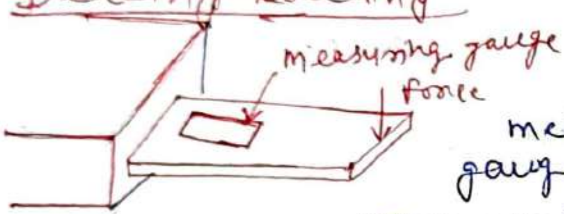
Two gauge configuration sensitive to torque & relatively insensitive to bending. Bending strains, if are cancelled.

→ 

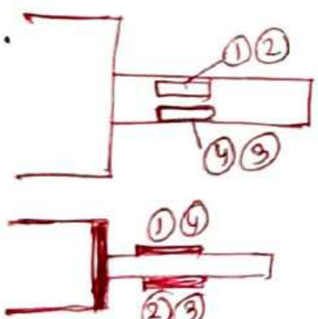
→ Configuration providing maximum sensitivity to torsion & insensitive to temperature, axial load & bending.

→ it is desirable that gauges be placed as closely together axially as possible in order to completely cancel the bending effects

③ Bending loading

→ 

→ Simplest arrangement for measuring bending stress - Dummy gauge is used for temperature compensation, measuring beam also sensitive to any axial load component.

→ 

→ Four-gauge arrangement, temperature compensation is provided and strains from axial loads also eliminated.

CH.-2 MEASUREMENT OF DISTANCE & VELOCITY

2.1 Define velocity & Disitance

Distance

→ Distance is the total movement of an object without any regard to direction. ~~we object without any regard to direction~~. we can define distance as to how much ground an object has covered despite it's starting or ending point.

→ Distance is a Scalar quantity as it only depends upon the magnitude and not the direction.

→ Distance can only have positive values.

Velocity

→ The meaning of velocity of an object can be defind as the rate of change of the object's position with respect to a frame of reference & time.

→ it is a vector quantity, which means we need both magnitude (speed) & direction to define velocity.

$$\vec{V} = \frac{\text{displacement}}{\text{time}}$$

→ SI unit (ms^{-1}).

2.2:- Potentiometric Displacement Transducer performance characteristics

→ A potentiometer is a resistive type transducer. It is generally used to measure linear or angular displacement.

→ The resistive transducer are those in which the resistance change due to a change in some physical phenomenon.

→ The change in the value of resistance with a change in the length of the conductor can be used to measure displacement

$$R = \rho \cdot \frac{l}{a}$$

ρ = Resistivity of conductor (Ωm)

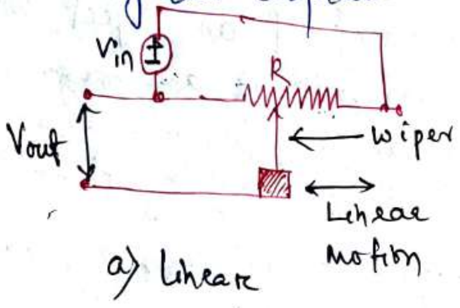
l = length of the conductor (m)

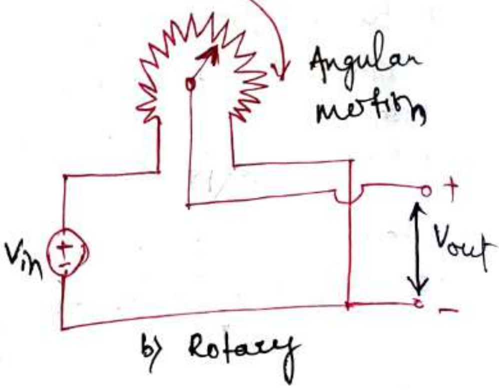
a = Area of cross section of conductor (m^2).

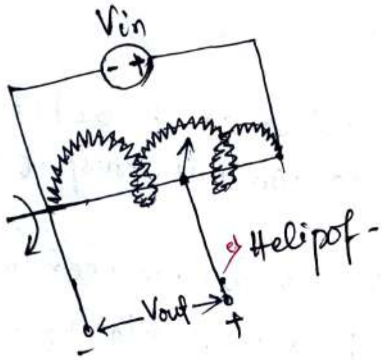
→ The resistive transducer are designed to measure the distance by methods of variantion of any one of the quantities length, area, & resistivity.

Construction & working

→ A potentiometer resistance transducer (or simply potentiometer) is generally used to measure linear or angular displacement.







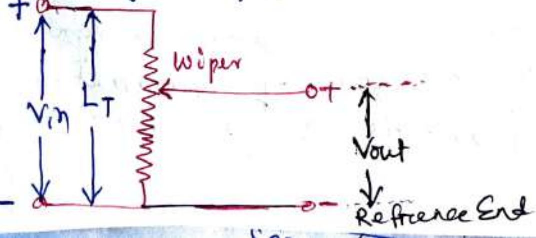
→ A resistance potentiometer consists a wire wound resistive element along with a sliding contact which is called as wiper.

→ A wire is made up of platinum or nickel alloy with diameter as small as 0.01 mm. The resistive element is made up of moulded carbon or carbon film.

→ The wire is wound on an insulating former. The linear and rotary potentiometer are shown above.

→ In helipot potentiometer, the resistive element is in the form of helix so it is known as Helipot.

→ We know that using resistance potentiometer mechanical displacement is converted into an electrical output. The linear or angular displacement is applied to the sliding contact & then the corresponding change in resistance is converted into voltage or current. The combine measurement of linear & angular motion will be done by helipot.



→ A potentiometer is consist of resistive elements provided with a sliding contact. Let us consider a translational potentiometer as shown above.

→ we know that using resistance potentiometer mechanical displacement is converted in to an electrical output.

→ The linear or angular displacement is applied to the sliding contact & then the corresponding change in resistance is converted in to voltage or current.

→ The combine measurement of linear & angular motion will be done by helipot.

→ A potentiometer is consist of resistive elements provided with a sliding contact. let us consider a translational potentiometer as shown.

→ In this transducer, the measurand is converted in to a change in position of wiper which causes the change in ratio of resistance i.e, the ratio betn one fixed end and wiper contact divided by the total resistance of the potentiometer

→ The potentiometer is excited by d.c or ac voltage.

The output of the potentiometer is given by .

$$V_{out} = \left(\frac{l}{L_T}\right) V_{in}.$$

V_{out} = voltage betn wiper contact and fixed reference end.

l = length of wire betn wiper contact & reference end.

L_T = Total length of the potentiometer wire.

V_{in} = Total applied voltage to potentiometer wire.

Types of potentiometer & materials used for potentiometer

On the basis of materials used the potentiometers are classified in to types.

i) wire wound potentiometers

(ii) Non-wire potentiometers.

i) wire-wound potentiometer :-

→ it is used for large currents at high temperature.

→ The materials used for wire wound potentiometer are platinum, nickel-chromium, nickel-copper

→ The resistance temperature co-efficient of such materials is very low & is of the order of $20 \times 10^{-6}/°C$ or even less.

→ The resolution of wire wound potentiometer is about 0.025 mm to 0.05 mm.

2. Non-wire potentiometer

→ The non-wire potentiometer is also called continuous potentiometer. It consists a continuous resistance element without any wire winding as such it resolution is increased compared with wire wound potentiometer, the maximum speed with which shaft can be rotated is about 200 rpm only.

→ It is sensitive to small temperature changes
→ It has very high wiper contact resistance which is variable. Hence it cannot carry large current

a) thin metal film → In such type of potentiometer resistance element is formed by depositing a very thin layer of metal on proper insulating material like glass, ceramic. Such potentiometer is used for a.c & d.c

b) Carbon film

In carbon film potentiometer, a thin film of carbon is deposited on a proper insulating material like glass, ceramic etc. low cost & low temperature co-efficient.

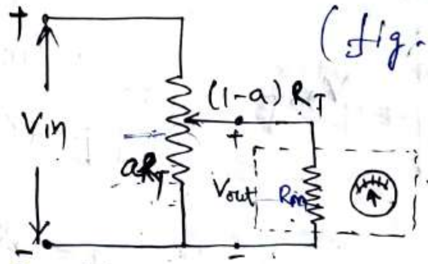
c) Hot moulded carbon :- In such type of potentiometer a resistance element is formed by moulding a mixture of carbon & plastic.

d) Cement : The resistance element is formed by fusing precious metal particles in the ceramic base. The main advantages of such potentiometer is large power rating at high temperatures.

Characteristics of potentiometer

1) Linearity & Sensitivity

→ We know that in order to achieve a good linearity the resistance of potentiometer should be as low as possible.



(fig. a)

→ In order to get a high sensitive, the voltage should be high which in turn requires a high input voltage.

→ Due to limitations of power dissipation, the input voltage is limited by the resistance of the potentiometer.

2) Loading Effect

The output terminals of potentiometer are connected to a meter having internal resistance R_i as shown in fig. a.

R_T = Total resistance of potentiometer.

R_m = Internal resistance of meter.

Let $a = \frac{l}{L}$ is a constant such that $0 < a < 1$ & it varies linearly with the position of wiper.

Then aR_T be the fraction of R_T below wiper. & meter Resistance R_m, the equivalent resistance betn wiper & fixed reference end of potentiometer.

$$R_{eq} = aR_T \parallel R_m = \frac{aR_T R_m}{aR_T + R_m}$$

By the potential divider rule (or voltage divider rule) the output voltage V_{out} is given by

$$V_{out} = \left[\frac{R_{eq}}{R_{eq} + (1-a)R_T}\right] V_{in}$$

put the value $R_{eq} = \frac{aR_T R_m}{aR_T + R_m}$

& simplyfying.

$$V_{out} = \frac{a V_{in}}{1 + a(1-a)\frac{R_T}{R_M}}$$

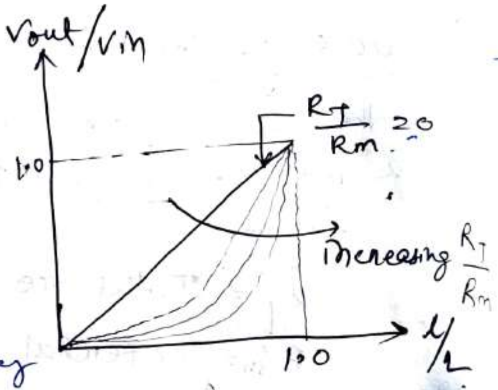
where $a = \frac{l}{L}$.

when $R_M >> R_T$ equation reduces

$V_{out} = a V_{in}$.

$$V_{out} = \left(\frac{l}{L}\right) V_{in}.$$

it's clearly that when ratio of $\frac{R_T}{R_M}$ is very small, the output is almost ideal one. But as the value of ratio $\frac{R_T}{R_m}$ ~~increases the~~ increases the non-linearity also increases. it is shown in the figure.



→ Hence to have linear output for linear displacement the meter impedance should be as large as possible.

3) **Loading Error :**

The error in output voltage due to loading effect is defined as

$$\text{Error} = \begin{bmatrix}\text{output voltage} \\ \text{with full load}\end{bmatrix} - \begin{bmatrix}\text{output voltage} \\ \text{with no-load}\end{bmatrix}$$

Substituting values of output voltage with full load and no load we get

$$\text{Error} = \frac{aV_{in}}{1+a(1-a)\frac{R_T}{R_M}} - aV_{in}$$

after we Simplyfing this then we get

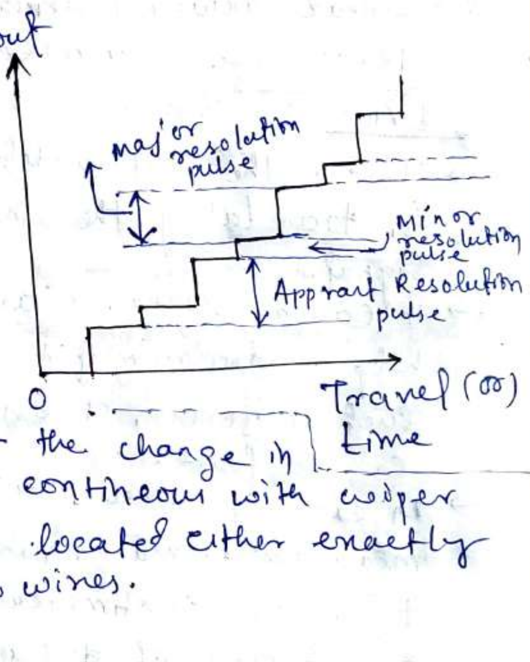
$$\text{Error} = \left[\frac{a^2(1-a)\frac{R_T}{R_M}}{1+a(1-a)\frac{R_T}{R_M}}\right]V_{in}$$

Thus the percentage error in given by

$$\%\ \text{Error} = \left[\frac{a^2(1-a)\frac{R_T}{R_M}}{1+a(1-a)\frac{R_T}{R_M}}\right]V_{in} \times 100$$

4) Resolution

→ Practically, the output voltage of the wire wound potentiometric displacement transducer is not contineous for the given input with wiper movement but varies in step giving a staircase waveform.



→ The main reason for the non-contineous output is that the change in resistance betn winding is not contineous with wiper movment. The wiper may be located either exactly on the wire or across the two wires.

Advantages of potentiometers

1. it is Simple in construction and operation.
2. it is having high electrical efficiency & provides sufficient output for further control operation.
3. it is very useful for displacement measurement of large amplitude.
4. it is best suited for measurement in the system with least requirement.
5. it is not so much expensive.

Disadvantage of potentiometers

1. In linear potentiometer, large force is required to move wiper.
2. It has limited resolution & high electronic noise in output.

3. It is suffers from mechanical wears & misallignment of wiper.
4. the output of potentiometer is insensitive to the variation in displacement of wiper betn the two consecutive turns of wire.

Application

1. it can be used for measurement and control of large displacement about 5mm to 500mm.
2. it can be used as electric sensing elements in pressure measurements, accelerometers, air craft.
3. It can also be used in hydraulic jacks for shaft position control, in pen recorders in servo balance position control.
4. It has signal output hence additional amplifier circuitry is not required to drive indicating or recording devices at output.

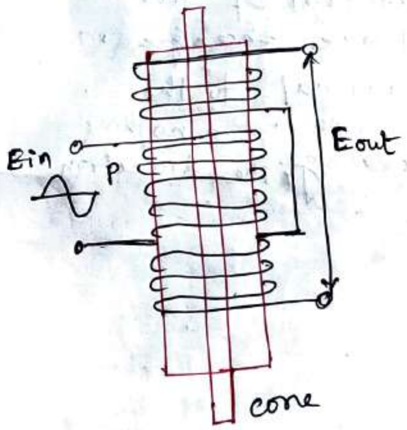
2.3 Linear Variable Differential Transformer (L.V.D.T), Performance characteristics & it's application

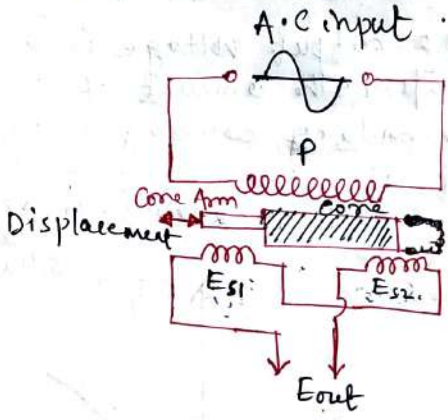
LVDT

→ This is the most widely used inductive transducer for translating the linear motion in to an electrical signal.
→ It can be linear or angular (rotational) motion. with help of displacement transducer, many other quantities such as force, stress, pressure, velocity & acceleration can be found.
→ In case of linear displacement, the magnitude of measurement many range from a few micrometer to a few centimeters.
→ A majority of displacement transducer detect the static or dynamic displacement by means of suitable mechanical links coupled to the point or body whose displacement is to be measured.
→ A simple & more popular type of displacement ~~transducer~~ transducer is the variable inductance type where the inductance is varied according to the displacement.
→ This is achieved either by varying the self inductance & the mutual inductance betn the two coils.

→ The good accuracy, fine resolution & good stability make, LVDT most suitable as a position measuring device. The LVDT forms the basic sensing element in the measurement of pressure, load & acceleration.

Construction of LVDT:-





→ The LVDT consist of a single primary winding P and two secondary winding S_1 and S_2 wound on a hollow cylindrical former.

→ The secondaries have an equal number of turns but they are connected in series opposition so that the emf induced in the coils oppose each other.

→ The primary winding is connected to an ac source, whose frequency may range from 50Hz to 20kHz. A movable soft iron core slides inside the hollow former.

→ The position of the movable core determines the flux linkage betn the a.c excited primary winding & each of the two secondary winding.

→ The displacement to be measured is applied to an arm attached to the cone. with the core in the centre as reference position, the induced emf in the secondaries are equal & since they oppose each other, the output voltage will be zero volt

Working of LVDT

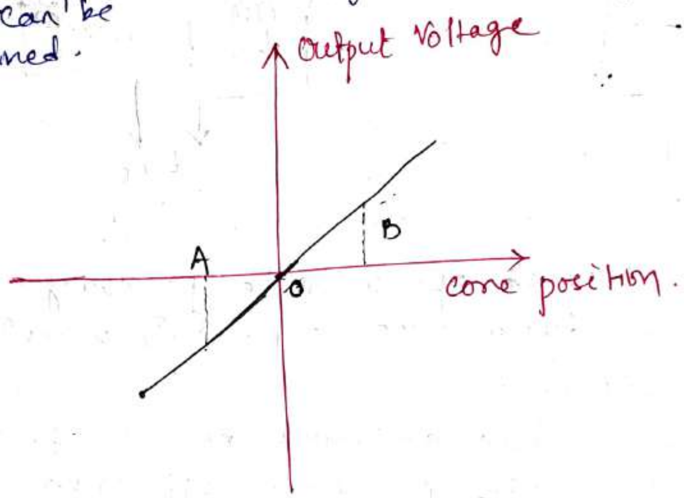
→ when an externally applied force moves the core to the left-hand position, more magnetic flux links the left-hand coil than the right-hand coil.

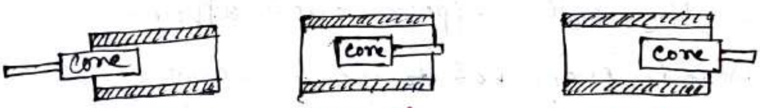
→ The emf induced in the left-hand coils, E_{s1}, is therefore larger than the induced emf of the right-hand coil E_{s2}.

→ The magnitude of the output voltage is then equal to the difference betn the two secondary voltages & is in phase with the voltage of the left hand coil.

→ When the core is forced to move to the right more flux links the right-hand coil than the left-hand coil and the resulting output voltage, which is difference betn E_{S_2} & E_{S_1} is now in phase with the emf of the right hand coil.

→ The LVDT output voltage is a function of the core position. The amount of a voltage change in either Secondary winding is proportional to the amount of movement of the core. By nothing which output is increasing or decreasing, the direction of motion can be determined.





Core at A — Core at O Null position — Core at B

(output voltage of LVDT at different core positions)

→ The output ac voltage ~~change in either Secondary~~ inverts in phase as the core passes through the central null position. As the core moves from the central null position.

→ The core moves from the centre, the greater is the difference in value betn E_{S_1} & E_{S_2} and consequently the greater the output voltage.

→ The amplitude of the output voltage is a function of the distance the core moves while the polarity or phase indicates the direction of the motion.

→ The amount of output voltage of an LVDT is a linear function of core displacement with a limited range of motion.

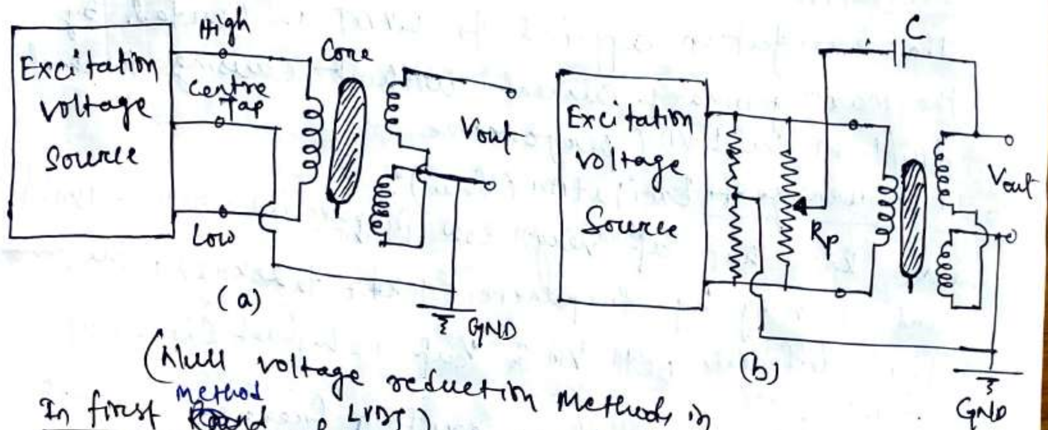
Characteristics of LVDT

1. Null voltage Reduction:-

Ideally the output of LVDT should be zero when core is at null position. Practically there exists a small residual voltage because of harmonics excitation frequency & stray capacitance coupling betn primary & secondary windings. Such a residual voltage is called null voltage.

→ The null voltage can be reduced using two basic methods as explain below.

~~In first method~~



(Null voltage reduction Method in LVDT)

In first method of null voltage reduction as shown in fig. (a) an excitation source with centre tap is used.

→ The centre tap is connected to one end of the secondary terminal & is grounded because of grounding capacitive coupling effects are minimized.

→ In Second Method of null voltage reduction as shown in fig. (b). the potentiometer Rp is adjusted for zero Vout when core is at null position. The values of resistor R and Rp are selected sufficiently low to avoid loading of excitation voltage source. This method is practically useful when centre tapped excitation voltage source is not available.

2. Linearity The standard LVDT usually designed up to 5mm show a good linearity up to 0.1%. The long range LVDTs are designed up to 300mm or more show moderate linearity up to 1 to 2 %.

3. Infinite Resolution

The LVDT has very high resolution, ideally infinite because LVDT is frictionless & induction principle is based on variation of mutual inductance betn core & two coils

is related linearly with displacement of cone.
→ with these two properties LVDT produces output by responding to the most minute core motion.

4. Sensitivity

→ The Sensitivity is the output of LVDT with core positioned at full scale displacement with primary excited at specified nominal input voltage.
→ The output of LVDT is generally specified as Vout/Vin Displacement. The Sensitivity of LVDT is typically 1 to 2mV/V/0.01 mm at specified the excitation frequency of 2 to 5kHz.

5. Excitation

The excitation applied to LVDT is limited by the maxm primary current without causing thermal drift in the LVDT performance.

6. Frequency of Excitation (fex):-

→ We know that at very low frequencies (50Hz to 1kHz), and at very high frequencies (10kHz to 20kHz), the phase difference betn Vin & Vout is highest (i.e about ±90°).
→ For every LVDT, there exists a frequency in betn low & high frequencies at which phase difference is zero. Such frequency is used for better sensitivity & proper detection.

7. Dynamic Response

→ The excitation frequency limits dynamic response of LVDT. The basic requirement for proper measurement is that excitation should be at least 5 to 10 times greater than maximum frequency of measurement. Typically for LVDT, the maximum frequency of measurement is 1kHz.

Advantage of LVDT.

1. Linearity :- The output voltage of LVDT is almost linear for displacement up to 5mm.
2. High output :- The LVDT gives reasonably high output and hence requires less amplification.
3. High Sensitivity :- The LVDT has high sensitivity of about 300mV/mm i.e 1mm displacement of the core produces a output voltage of 300mV.

4. Ruggedness :- The LVDT is mechanically rugged and can with stand mechanical shock & vibrations.

5. Less friction :- Since there are no sliding contact, the friction is very less.

6. Low Hysteresis

The LVDT has a low hysteresis, hence it's repetability is extremely good.

7. Low power consumption

most LVDTs consume less than watt of power.

→ Small, simple & light in weight.

Disadvantages of LVDT

1. comparatively large displacement are necessary for the applicable differential output.
2. They are sensitive to stray magnetic fields. However this interference can be reduced by shielding.
3. the temperature effects transducer.
4. the dynamic response is limited.

Application of LVDT

1. The LVDT can be used in all applications where the displacement ranging from fraction of a few mm to a few cm have to measured.
2. Acting as a secondary transducer LVDT can be used as a device to measure force, weight & pressure etc.

2.4 Capacitive transducer and it's signal conditioning circuit

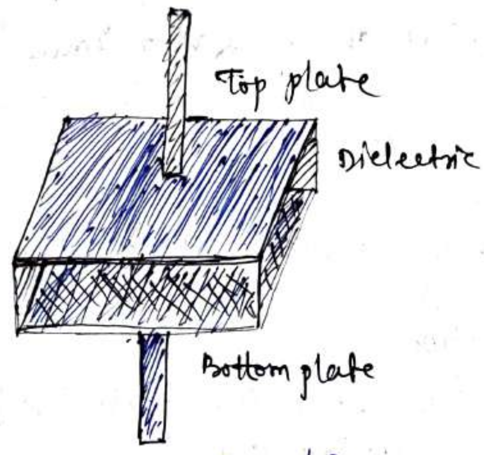
Capacitive Transducer

→ A capacitor of two conductors (plates) that are electrically isolated from one another by a nonconductor (dielectric). When the two conductors are at different potential (voltages) the system is capable of storing an electric charge.

→ The storage capability of a capacitor is measured in farads. The principle of operation of capacitive transducer is based upon the equation for capacitance of a parallel plate capacitor.

$$C = \frac{\varepsilon A}{d}$$

A = overlapping area of plates
d = Distance betn two plates
ε = Permittivity (dielectric constant)



By defination = $i = \frac{dQ}{dt}$

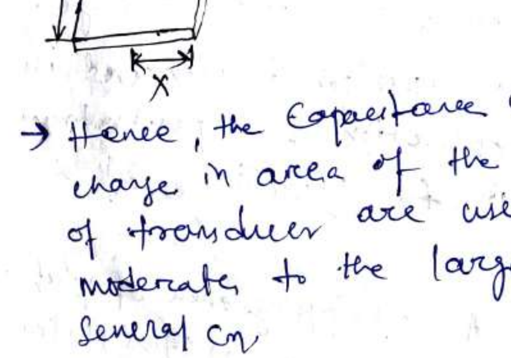
$V = \frac{Q}{C}$ V = voltage betn two plates
Q = Charge
C = Capacitance.

→ the change of the capacitance can be caused by
1. Change in overlapping area (A)
2. change in the distance betn the plates (d)
3. change in the dielectric constant (ε_r).

1. Change in Overlapping area (A)

→ capacitance of a capacitor is directly proportional to the area of the plates (A).

$C \propto A$



Area of the plates forming capacitor = Wx

$C = \frac{A\varepsilon}{d} = \frac{(wx)\varepsilon}{d}$ F

x = length of overlapping part of plates (m).
w = width of overlapping of plates.

→ Hence, the Capacitance change linearly with the change in area of the plates. due to this type of transducer are used for the measurement of moderate to the large displacement i.e 1µm to several cm

→ In the above of we move the left side the ~~capacitance or~~ area is increases with respect to capacitance if we move the right side the moving plate then capacitance decreases

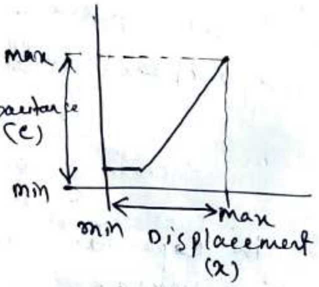
→ the response is almost linear but a small amount of non-linearity is observed due to the edge effects in the capacitor.

$$\text{Sensitivity}(S) = \frac{\partial C}{\partial x} = \frac{\varepsilon \cdot w}{xd} \ F/m.$$

$$\boxed{S = \frac{\varepsilon w}{d} \ F/m}$$

→ This type of capacitive transducer is suitable for measurement of linear displacement ranging 1mm to 10mm.

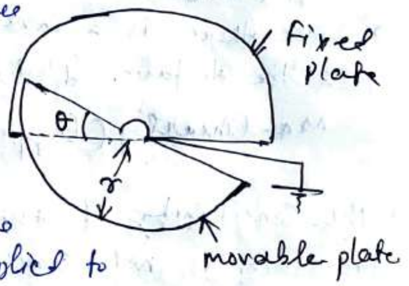
→ The sensitivity is constant & do not depend on displacement (x). the relationship betn capacitance & displacement is linear.



→ Measurement of angular displacement

→ the principle of change of capacitance with change in area can be employed for the measurement of the angular displacement

→ This transducer consists two plates one is fixed and other is movable, the angular displacement to be sensed is applied to the movable plate, the capacitance becomes maximum when $\theta = 180°$ & the two plates completely cover each other.

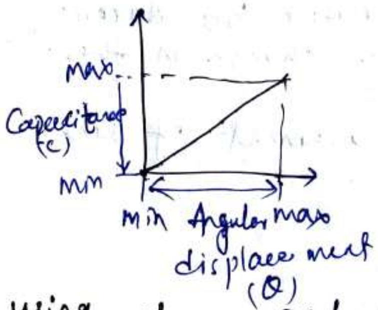


max^m value of capacitance

$$C_{max} = \frac{A\varepsilon}{d} = \frac{\pi \varepsilon r^2}{d}$$ r = radius of the movable plate.

at an angle 'θ', capacitance become

$$C = \frac{\varepsilon \theta r^2}{2d}, \quad \text{Sensitivity } S = \frac{\partial C}{\partial \theta} = \frac{\varepsilon r^2}{2d}$$

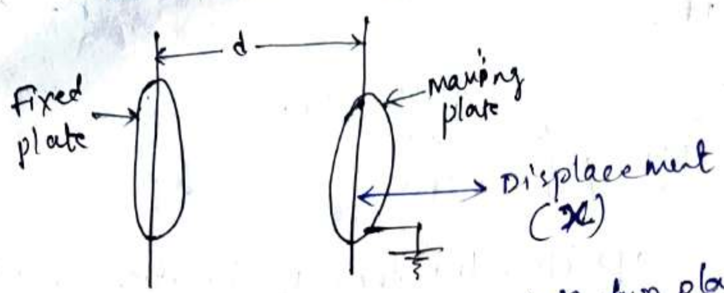


The variation of capacitance with angular displacement is linear.

② Transducer using change Distance betn plates

→ The capacitance can be varied by the change of distance 'd' betn the plates.

→ one of the two plates is kept fixed and the other plate is made movable, the displacement to be sensed is applied to the movable plate.



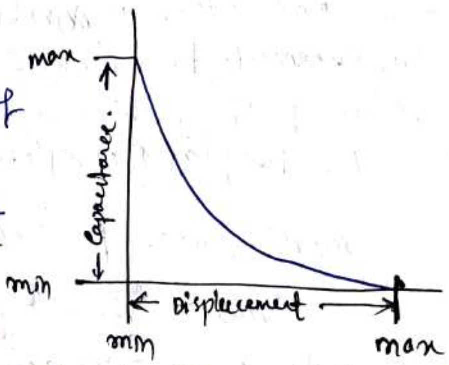
→ If we increase the distance betn two plate then the Capacitance will decrease.
→ If we decrease the distance betn two plate then the capacitance will increase.

$$C = \frac{A\varepsilon}{d}$$

$$C \propto \frac{1}{d}$$

→ So, the capacitance increases as the distance decreases & vice-versa.
→ Since there is a inverse relationship betn the capacitance & the distance 'd' hence the response become completely non-linearly (hyperbolic)

→ The sensitivity of this transducer is not constant but varies over the range of transducer.



Sensitivity, $S = \frac{\partial C}{\partial x} = -\frac{\varepsilon A}{x^2}$

→ Transducer using change in distance betn plates is used only for the measurement of small displacement

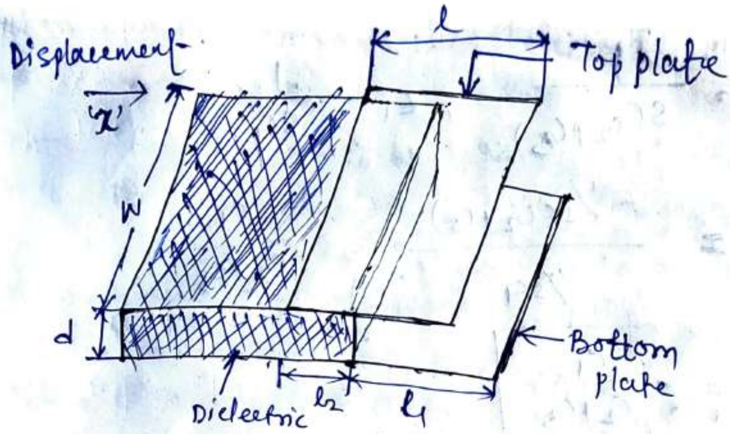
→ Transducer using Dielectric constant betn plates

→ The third principle of capacitive transducers is the variation of capacitance due to the change in the dielectric constant betn the plates.
→ it is used for the measurement of linear displacement

$$C = \frac{A\varepsilon}{d}$$

$$C \propto \varepsilon$$

Hence, capacitance is directly proportional to the dielectric constant of the medium.



dielectric having a refractive permittivity = ε_r
permittivity of free space = ε_0
initial capacitance of the transducer,

$$C = \varepsilon_0 \frac{W l_1}{d} + \varepsilon_0 \varepsilon_r \frac{W l_2}{d}$$

$$= \varepsilon_0 \frac{W}{d} [l_1 + \varepsilon_r l_2] \quad \text{— (1)}$$

let the dielectric be moved by a distance 'x' in the direction as indicated in the fig.
the capacitance change from C to C+ΔC

$$C + \Delta C = \varepsilon_0 \frac{W}{d}(l_1 - x) + \varepsilon_0 \varepsilon_r \frac{W}{d}(l_2 + x)$$

$$= \varepsilon_0 \frac{W}{d} l_1 - \varepsilon_0 \frac{W}{d} x + \varepsilon_0 \varepsilon_r \frac{W}{d} l_2 + \varepsilon_0 \varepsilon_r \frac{W}{d} x$$

$$= \varepsilon_0 \frac{W}{d} l_1 + \varepsilon_0 \varepsilon_r \frac{W}{d} l_2 + \varepsilon_0 \varepsilon_r \frac{Wx}{d} - \varepsilon_0 \frac{W}{d} x$$

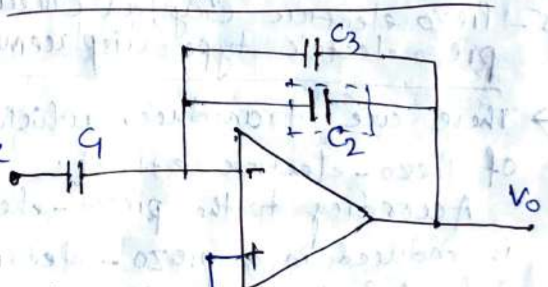
$$= \varepsilon_0 \frac{W}{d}(l_1 + \varepsilon_r l_2) + \varepsilon_0 \frac{Wx}{d}(\varepsilon_r - 1)$$

$$= C + \varepsilon_0 \frac{Wx}{d}(\varepsilon_r - 1)$$

change in capacitance $\Delta C = \varepsilon_0 \frac{Wx}{d}(\varepsilon_r - 1)$.

Hence, it can be seen that change in capacitance is proportional to displacement.

~~Signal conditioning~~ Signal conditioning circuit of capacitive displacement Transducer



→ In Signal conditioning circuit here we use op-amp (operational amplifier) is use.

→ one capacitor C_1 is use in input & C_2 & C_3 are connected in parallel with feed back connection with op-amp.

$$\frac{V_o}{V_i} = -\frac{Z_f}{Z_i}$$

$$Z_f = \frac{1}{S(C_2+C_3)}, \quad Z_i = \frac{1}{SC_1}$$

$$\frac{V_0}{V_i} = \frac{-1/S(C_2+C_3)}{1/SC_1} = \frac{-C_1}{C_2+C_3}$$

$$\boxed{\frac{V_0}{V_i} = -\frac{C_1}{C_2+C_3}}$$

Advantages of capacitive Transducer

→ They have very High Sensitivity.
→ they have good frequency response & hence can be used for dynamic measurement.
→ they require less force to operate them.
→ They have very less loading effect due to high input impedance.
→ They can be used to get the resolution of the order of 2.5×10^{-3} mm.

Disadvantage of capacitive Transducer

→ They are sensitive to the temperature variations.
→ their circuitry is complex.
→ The metallic parts must be insulated from each other, So as reduce the effect of stray capacitance, the frame of the transducer must be earthed.
→ Capacitive transducer may get varied due to the presence of the dust particles.
→ capacitance transducer show non-linear behaviour on account of the edge effect.

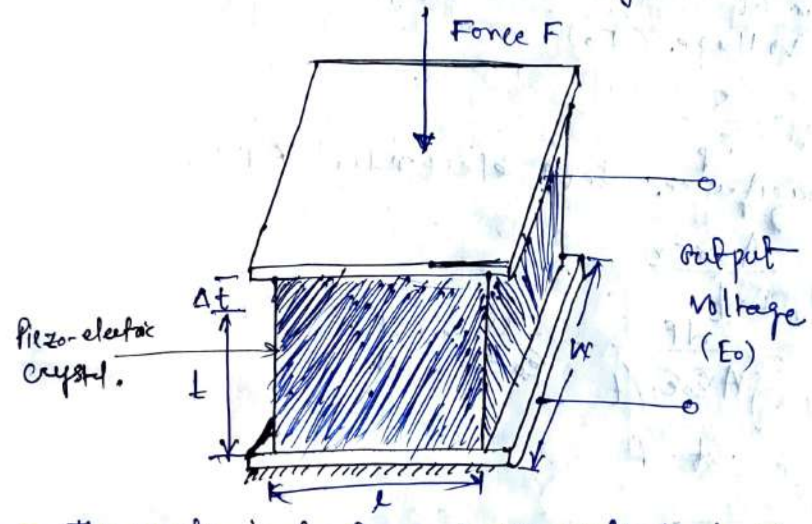
2.5 – Piezo electric Crystal Circuit equivalent Capacitor piezoelectric type displacement Transducer

→ These are transducer which work on the principle of Piezo-electric effect.
According to the piezo-electric effect a voltage is induced in a piezo-electric crystal when it is Subjected to a mechanical stress.
→ The electric field induced is proportional to strain applied. The converse of this is also true i.e the piezo-electric materials gets strained when it is Subjected to a electric field.

piezo-electric materials → Quartz, Rochelle Salt, Barium Titanate ($BaTiO_3$), Lead Zirconate ($PbZrO_3$), Pottassium Dihydrogen phosphate (KDP), Ammonium Dihydrogen phosphate (ADP).

Note:- Quartz & Rochelle Salt are naturally occuring piezo-electric materials & the other are man-made.

→ The piezo-electric transducer are mainly used for the measurement of displacement. They can be used for the measurement of force, pressure & acceleration by converting all these quantities in to equivalent displacement & then to the output voltage.



→ The mechanical force (F) applied to the piezo-electric crystal has to be converted in to the electrical output. The piezo-electric material may be thought as a charge generator & a Capacitor.

→ The mechanical de-formation produced by the force (F) generates a charge & this charge appears as a voltage across the electrodes. The voltage is $E = \frac{Q}{C}$

∴ The piezo-electric effect is direction sensitive, a tensile force produces a voltage of one polarity while a compressive force produce a voltage of opposite polarity

→ The magnitude and polarity of the induced surface charges are proportional to the magnitude & direction of the applied force (F)

$$F \propto Q.$$

Charge, $Q = d \times F$ Coulomb.

d = charge sensitivity of the crystal (C/N).
(it is constant for a given crystal).

F = applied force (N)

Young's Modulus.

$$E = \frac{\text{Stress}}{\text{Strain}} = \frac{(F/A)}{(\Delta t/t)}$$

$$F = \frac{\Delta t}{t} \cdot E \cdot A$$

A = Area of the crystal (m^2)

$= w \times l$

w = width of the crystal (m).

l = length of the crystal (m).

$$Q = d \times \frac{AE(\Delta t)}{t}$$

This charge at the electrodes gives rise to an output voltage (E_0)

$$E_0 = \frac{Q}{C_p}$$

C_p = Capacitance betn electrodes (F).

$$C_p = \frac{A \epsilon_0 \epsilon_r}{t}$$

$$E_0 = \frac{Q}{C_p} = \frac{dF}{A\epsilon_0\epsilon_r/t} = \frac{dt}{\epsilon_0 \epsilon_r} \cdot \frac{F}{A}$$

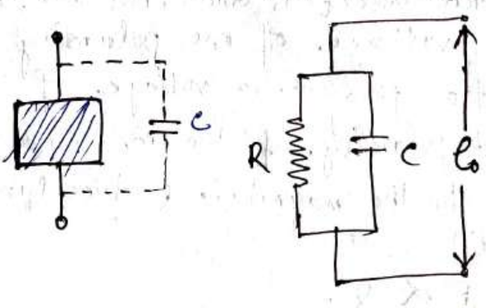
$$E_0 = \frac{d}{\epsilon_0 \epsilon_r} \cdot t \cdot P$$

$$\boxed{E_0 = g \cdot t \cdot P}$$

$g = \frac{d}{\epsilon_0 \epsilon_r}$ } Voltage sensitivity of the crystal (Vm/N)

$$g = \frac{E_0}{P \cdot t} = \frac{E_0/t}{P} = \frac{\text{electric field}}{\text{stress}}$$

* Equivalent circuit of a piezo-electric crystal.



→ At low frequencies then, it is found that voltage is not longer proportional to the deflection. A certain frequency, however, the response curve is essentially flat, until the point is reached where mechanical resonces in the crystal result in peak in the curve.

→ An extension of the frequency range is obtained by increasing the crystal capacitance, although this is accompanied by a reduction in the sensitivity, as is evident.

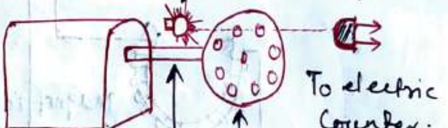
→ To effect such an extension a capacitor is connected in parallel with the crystal.

→ For the same reasons it is necessary to make the resistance R as low as possible. This can be effected by using an electronic tube circuit (cathode follower) with very high input impedance for measurement of the voltage e_o.

2.6 Measurement of velocity

→ ~~Meas~~ photoelectric tachometer

→ This method of speed measurement consist of an opaque disc mounted on the rotating shaft, as shown below.



(Photo-electric tachometer)

→ The disc has a number of equidistant holes on it's periphery. On the one side of the disc there exists a light source & the other side a light sensor is placed.

→ when holes comes in befr the light source & light sensor the sensor turns on.

→ when the opaque portion of the disc come in befr the light source & sensor no output is observed from the light sensor.

→ the frequency at of the output pulse is directly portional to the speed rotation of the shaft. The pulse rate can be measured by an electronic counter. This pulse rate is calibrated in terms of the speed of the shaft.

→ Advantages

→ the output is in the digital from so no A/D conversion is required.

→ Disadvantages

→ The light source has limited life, so it has to be replaced from time to time.

→ we have to count the number of pulses from time to time called the gating period. If gating period is short

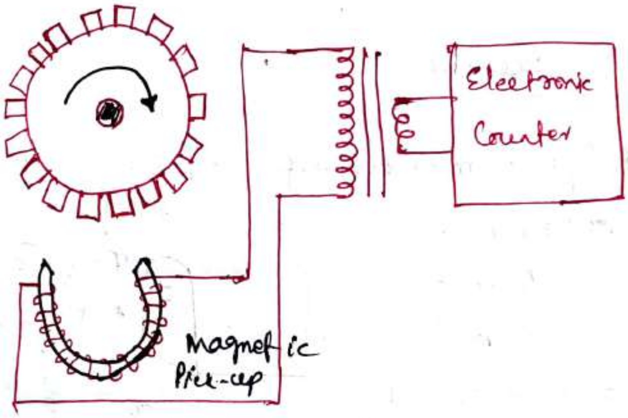
Serious error may occur.

∴ Gating period :- It is the fixed period of time for which the number of pulses produced by the Sensor are recorded.

→ Toothed Rotor Variable Reluctance Tachometer

→ The tachometer generator consists of a metallic toothed rotor mounted on the shaft whose speed is to be measured.

→ A magnetic pick-up is placed near the toothed rotor as is shown in the fig. below.



(Toothed rotor variable reluctance Tachometer)

→ The pick-up consists of the small housings in which the permanent-magnets are placed, whenever the teeth of the rotor cuts the magnetic field produced by the permanent magnet of the pick-up, an emf is developed in it.

→ The output generated ~~& the frequency~~ by the pick-up is in the form of pulses & the frequency of these generated pulses will depend on the no. of teeth of the rotor & speed of the rotation.

$$\text{Speed of the shaft}(n) = \frac{\text{pulses recorded per second}}{\text{No. of teeths on the rotor}} \text{ rps}$$

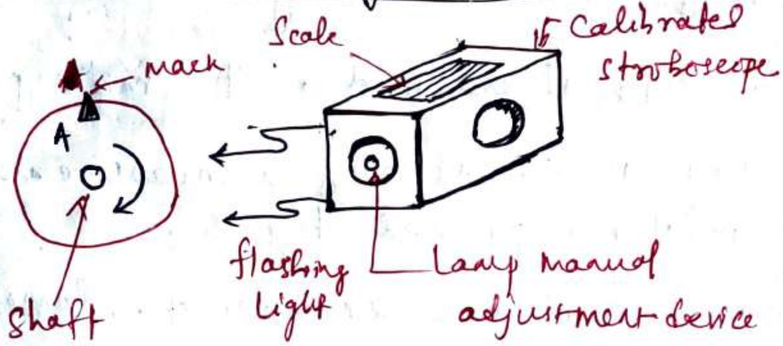
$$= \frac{P}{T} \text{ rps.}$$

$$= \frac{P}{T} \times 60 \text{ rpm}$$

* Stroboscopic Method :-

→ A stroboscopic is a simple and portable device which acts as a source variable frequency flashing brilliant light, the flashing frequency can be sent by the operator.

Shaft Speed Measuring Technique



→ In order to measure the speed of the shaft a distinctive mark is made on the shaft or the disc attached to the shaft.

→ The stroboscopic is made of flash the light ~~direct~~ directly on the mark placed on the shaft. The flashing frequency of the light coming through the stroboscope is adjusted by the manual adjustment available ~~unit~~ until the mark appears to be stationary.

→ The frequency of the flashing light is equal to the speed of the shaft. The scale of the stroboscope its calibrated directly in terms of the speed of the shaft.

→ In case one teeth on the shaft, a stationary image when the frequency ~~which are the multiples~~ of the flashing light (f) is equal to the speed of the shaft (n). i.e stationary image will be formed for n = f.

→ The image will also has ~~been~~ seen as stationary for flashing frequencies which are the multiples of i.e for 2f, 3f, 4f, ... nf this may result in serious errors.

→ The multiple images will be produced for the flashing frequency to be the submultiples of i.e for f/2, f/3, f/4, ... f/n etc.

Chapter-3 Measurement of Density & Viscosity

3.1 - Define Density & Viscosity

* Density

→ The density of material shows the denseness of that material in a specific given area.

→ A material's density is defined as it's mass per unit volume. Density is essentially a measurement of how tightly matter is packed together.

Ex- Iron, platinum & lead are examples of dense material. most likely to 'feel heavy or hard'

→ In general, liquids are less dense than solids and gases are less dense than liquids.

→ This is due to the fact that solids have densely packed particles can slide around one another, & gases have that are free to move all over the place.

$$\text{Density} = \frac{\text{mass}}{\text{volume}} \Rightarrow (\rho) = \frac{m}{V}$$

* Viscosity

→ The viscosity of a fluid is a measure of it's resistance to deformation at a given rate

→ Viscosity is defined as the measure of the resistance of a fluid to gradual deformation by shear or tensile stress. (or)

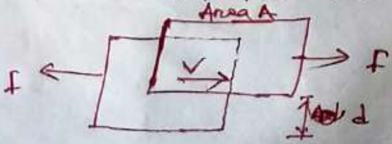
viscosity describes a fluids resistance to flow

Ex- honey has a higher visosity than water

→ Viscosity is measured in terms of a ratio of shearing stress to the velocity gradient

→ The co-efficient of viscosity (η) is the force required per unit area to maintain unit difference of velocity betn two parallel planes in the fluid unit distant apart

$$F = \eta A \frac{V}{d}$$



F = force in dynes
η = co.eff of viscosity of the fluid betn the planes in poises.
A = Area of plane in Sq. cm.
v = velocity in cm/sec
d = distance from fixed plate

3.2 Explain different Units viscosity & density

Units of Density

→ Through SI unit of density is $\frac{kg}{m^3}$
for Solid = g/cm^3
for liquid = g/ml
for gases = g/L

→ Density depends on the temperature and pressure of a Substance. Increasing the temperature of a sample of a Substance generally increase it's volume & therefor decrease it's density.

∴ water density = 1000 kg/m^3.

→ Specific gravity is also known as relative density.

$$SG\text{ (for liquid or Solid)} = \frac{\text{density of liquids (or Solids)}}{\text{density of water}}$$

$$SG\text{ (for gas)} = \frac{\text{density of Gas}}{\text{density of air}}$$

~~Units of Density~~

Units of Viscosity

→ Units Ns/m^2 or $kg/m.s$ = $\frac{1 N.Sec}{m^2}$ = 10 poise

Highly viscous liquid moves slowly
Ex- Glycerin, honey etc.

low viscous liquid moves fast
Ex- water, Kerosine.

→ if viscosity high then it's high friction
→ of viscosity low then it's low friction

Tempr effect

→ if for liquid temperature increase then viscosity decrease
→ if for Gas temperature increase then viscosity increase.

Dynamic viscosity $(\mu) = \tau / \frac{dv}{dy}$

$= \frac{\text{shear stress}}{\text{velocity gradient}}$

→ opposite to the viscosity is called fluidity.

→ Kinetic viscosity $\boxed{\eta = \frac{\mu}{\rho}} = \frac{\text{dynamic viscosity}}{\text{density}}$

CGS Units of kinetic viscosity = Stokes or Centi-Stoke
~~CGS unit of kinetic viscosity~~

→ SI unit of viscosity = pascal · seconds (Pa · s)

CGS unit of viscosity = poise (p)

SI unit kinematic viscosity = square meter per second (m^2/s).

3.3 - Explain different types of density sensor & viscosity sensor

Density sensor

*** photo cell**

→ The top of the float is made opaque so that it serves as a light shutter for a narrow slot in the housing through which light rays are sent. The amount of light passing is measured by a photo cell. Since the immersion of the float. Determine the amount of light passed to the photo cell, the density measurement can converted in to a electrical signal.

*** Differential Transformer**

→ In this method an iron core is provided at the center of the hydrometer chamber & the hydrometer will rise or fall in accordance with the changes in specific gravity of the liquid.

→ The output of the differential transformer changes with the position of the iron core. A potentiometer is used to detect any unbalance in the circuit caused by the output from the differential transformer & to convert the signal in to a specific gravity reading.

Hydrometer

→ This is the most popular device for the measurement of density of liquids in open vessel takes.

→ The hydrometer usually consist of a hollow glass float weighted on one side to make it float up right.
→ The amount of immersion of the glass float depends on the density of the liquid. The glass float is usually calibrated in terms of specific gravity of the liquid under (ratio bet^n the density measurement to that of the water)
→ The specific gravity of the liquid can be easily determined by nothing the amount of immersion from the Scale on the glass float.

→ Viscosity sensor

→ The devices/instruments which are used for the measurement of viscosity are called the viscometers.

1) Falling Sphere Viscometer.

a sphere ball is released in the guide tube in to the liquid of density. The continue to accelerate downward under the force of gravity until it attain the terminal velocity, when the force due to gravity is just balanced by the buoyancy & viscous drag force of the liquid

2) falling piston viscometer

→ In falling piston viscometer, the piston is allowed to fall in the fluid whose viscosity is to be determined

3.4 - Explain the function of hydrometer & hydraulic head type densitometer & chain balance densitometer

Hydrometer

→ Hydrometer is considered the simplest and the fastest method in determination of density & specific gravity of a liquid.
→ The operation of the hydrometer is based on the Archimedes principles that a solid suspended in a fluid will be buoyance up by a force equal to the weight of the fluid displaced.
→ Thus, ligher the liquid (that is, the less it's specific gravity), the deeper the body sinks because a greater

a amount of liquid is required to equal the body's weight.

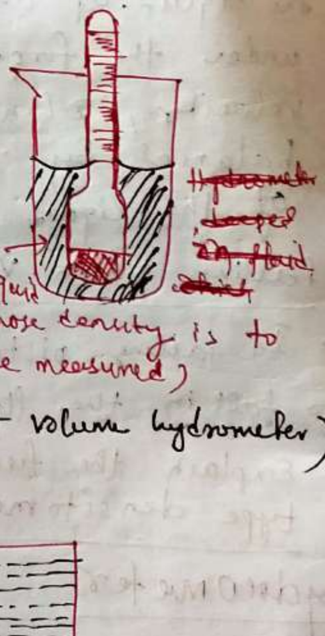
→ The hydrometer usually consists of a hollow glass float weighted on one side to make it float upright

→ A bulb weighted with mercury or lead shot to make it float upright.

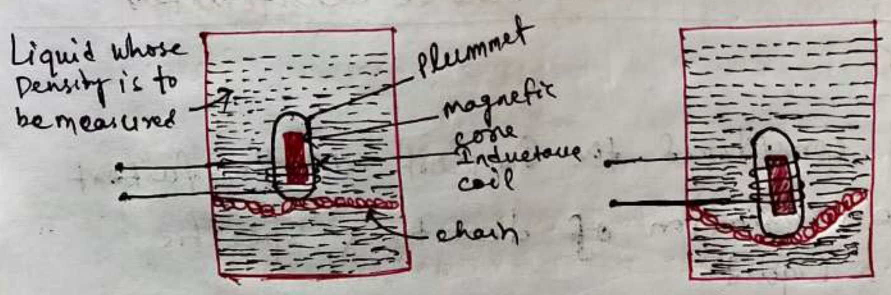
→ The amount of immersion of the glass float depends on the density of the fluid.

→ the glass float is usually calibrated in terms of specific gravity (ratio betn the density of the liquid under measurement to that of water)

→ Thus the specific gravity of the liquid can be easily determined by noting the amount of immersion from the scale on the glass float.



* Chain balance densitometer / (Constant volume hydrometer)



(a) For more dense medium

(b) For less dense medium.

→ In the conventional chain balanced float system a self centering fixed volume submerged plummet is used for density measurement.

→ The plummet is located entirely under the liquid surface. In this method the volume is kept constant and the weight is changed.

→ The plummet made of cylinder having semi spherical. The plummet core is of magnetic material & the plummet moves with in an induction coil.

→ The displaced volume is kept constant by immersing the plummet completely in the liquid.

→ The plummet is fastened by a series of chain kept in a fixed reference point to the plummet.

→ As the plummet rises due to an increase in density; chain weight is transferred from the reference point to the plummet.

→ The plummet will then obtain an equilibrium at a new position where the added weight of chain will equal the added plummet buoyancy caused by the increase in density.

→ The plummet is so weighted that at the middle of it's indicating range it will assume an equilibrium position, where the weight of the calibrating chains is equally supported by the plummet & by the reference point.

→ In case the density of the liquid is more than the mid-range point, the plummet will rise due to increased buoyancy & the chain weight is transferred from the reference point to the plummet.

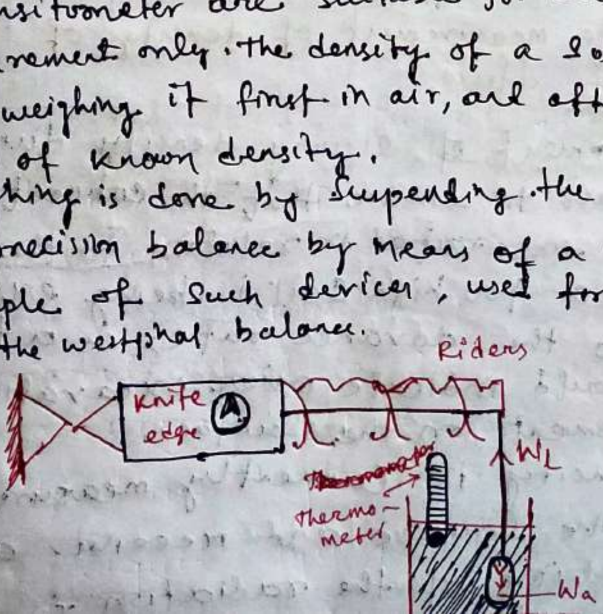
→ The plummet will then obtain an equilibrium at a new position where the added weight of chain will equal the added plummet buoyancy caused by an increase in density. The Reverse is the case for a less dense liquid.

* Hydrostatic Densitometer

→ Hydrostatic densitometer are suitable for solid and liquid density measurement only. The density of a solid is often measured by weighing it first in air, and afterwards in a suitable liquid of known density.

→ The latter weighing is done by suspending the solid under the pan of a precision balance by means of a very thin wire.

→ A typical example of such devices, used for solid density measurement, is the westphal balance.



$$W_L + \rho_L V - W_a = 0$$

W_L = weight of the plummet when suspended in liquid.
W_a = weight of the plummet in air
ρ_L = density of the liquid
V = volume of the plummet

→ From the above eq^n the density ρ_L at temperature t may be calculate. Rider are used for precesion measurements.

→ Accurate temperature measurement is necessary. The inaccuracies of this type of device are mainly limited by the irregularity of meniscus around the wire, particularly in the case of water & aqueous solutions.

<u>advantages</u>

i) Hydrostatic densitometer are rugged
ii) They give accurate results.
iii) They are used for the calibration of the other liquid density transducer.

<u>Disadvantages</u>

i) Hydrostatic densitometers must be installed horizontally on a solid base.
ii) They are not flexible enough to adapt for any proces. thus the proces must be designed for it.

<u>Application</u>

→ Hydrostatic densitometers are suitable for solid & liquid density measurements only.
→ the hydrostatic weighing methods of liquids give continuous reading for two phase liquids such as slurries, sugar solution, powders etc.

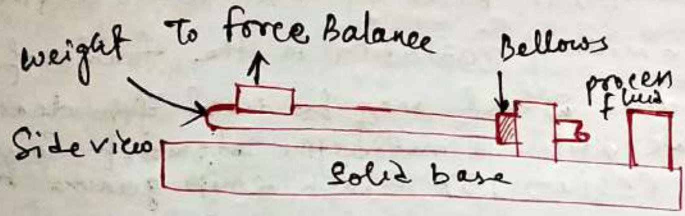
3.5 Explain the measurement of density of slurry types of fluid.

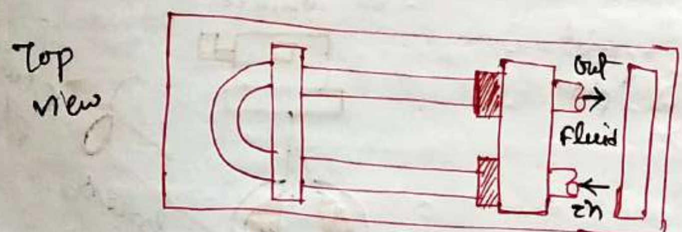
→ The measurement of slurry density during tunneling is important to ensure that the correct amount of soil being excavated in relation to the advance rate, as a too high soil is being excavated in relation to the advance rate, as a too high soil content could indicate over excavation & lead to settlements on the surface.

→ Slurry density is currently measured using a radioactive source and receiver and the level of deflection of the radiation is an indicator of the number of particles betn the two.

→ This method is used in pipe diameters from 300 mm up to 1000 mm plus & is well-proven in dredging & tunnelling but has a no. of disadvantages handling of a radioactive source requires special permit.

3.6 - U-Tube density Gauge





→ This type of density gauge are used for liquid and gas density measurement. They make use of the phenomenon that the natural frequency of oscillation varies with the mass of the oscillating (vibrating) body containing fluid in it or surrounded it.

→ The natural frequency of oscillation is used by the mass varies with density. The natural frequency of the vibrating body is directly proportional to the stiffness & inversely proportional to the combined masses of the body & the fluid.

→ A common device using hydrostatic weighing of liquids consists of a U-tube is pivoted on flexible end coupling, the total weight of the tube changes depending on the density of fluid flowing through the U-tube.

→ The change in the weight needs to be measured accurately and there are a number of methods employed for it.

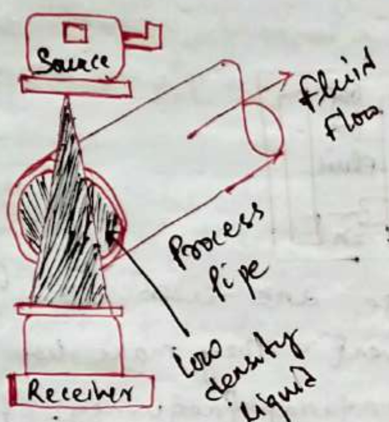
→ The most common commercial meters use a force balance system, the connectors are stainless steel bellows.

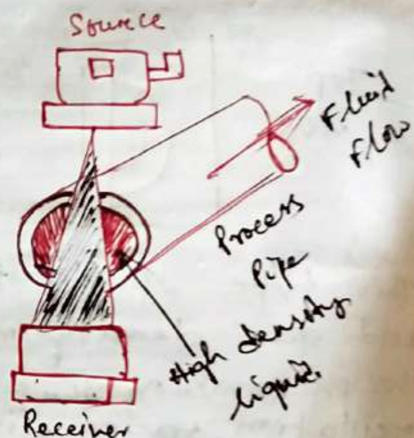
→ ~~Depending~~ Some cases rubber or other materials are used depending on the process fluid characteristics & the accuracy required.

→ The meter must securely be mounted on a horizontal plane for best accuracy.

3.7. Radiation type densitometer

→ Radiation densitometers are suitable for both liquids and solids undergoing dynamic process. The principle of working of radiation densitometer (radioactive density measurements) is based on the radioactive isotopes decay emitting radiation in the form of particles or waves which may be used for density measurements. We utilise a radioactive ~~element~~ source consisting of Cesium 137 which emits gamma rays.





→ A radiation densitometer comprises of a radioactive source beaming through a process pipe and a receiver system to measure the amount of transmitted radiation.

→ When gamma rays pass through a process fluid (sample under test), they are absorbed in proportion to the material density.

→ The gamma rays are absorbed depending on the volume, mass, & density of samples.

→ The rate of arrivals of the rays after the absorption can be measured using ion or scintillation based on detection.

→ The amount of rays entered in to the known volume sample with the rays detected at the end, the value of absorption may be determined accurately.

→ An increase in denser process fluid absorbs more of the gamma rays.

* Advantage

→ The sensor does not touch sample, hence there is no blockage on the path of the liquid

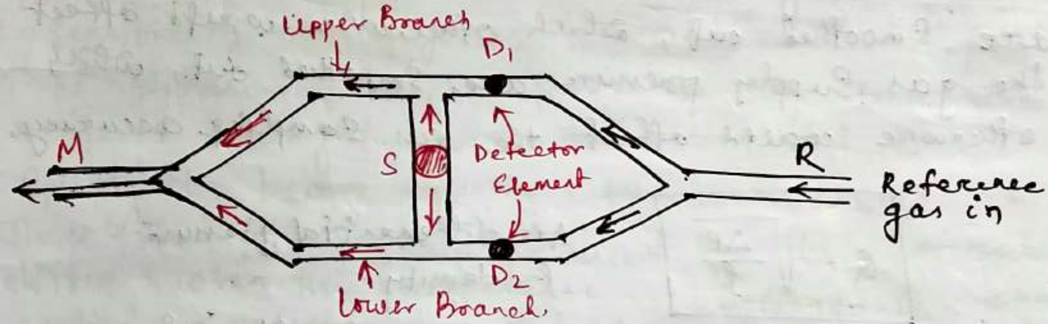
(ii) Multiphase liquids can be measured.
(iii) They come in programmable forms and are easy to interface.

Disadvantages

i) A radio active source is needed, hence, it is difficult to handle.
(ii) For a resonable accuracy, a minm path length is required
(iii) there may be long time constants making them unsuitable in some applications.

Application :- ~~Radiation~~ Radiation densitometers are suitable for solid and liquid density measurements

3.8 Gas Density Detector



→ This method utilises a fluid bridge mounted in the vertical plane. The sample gas whose density is to be determined is made to flow at S and it splits in to two branches after wards.
→ A reference gas enters at R and it splits in to two branches passes around two detector element D_1 & D_2 (thermistor or hot wires), mixes the same gas and the mixture leaves the bridge at M.
→ The detector elements are wired in to an electrical wheatstone bridge. When the flow is balanced, i.e when the density of the sample gas and reference gas are exactly equal, the detector elements are equally cooled and the bridge is balanced.
→ If the density of the sample gas exceeds even slightly the density of the reference gas, there will be a tendency of sinking of the sample gas in to the lower branch of the vertically ~~loo~~ located fluid bridge.
→ The obstructs the flow in path RD_2M causing a rise in temperature of detector element D_2 and

Unbalancing the electrical wheatston bridge:

→ when the sample gas is ligther than the reference gas, the upper branch RD_1M gets obstructed and the unbalance in the bridge occurs in the opposite direction. Thus the unbalance of the electrical wheatstone becomes a measurement of the density of a sample gas.

3.9 Orific type Gas Density meter

→ In this method a contineous sample is drawn from the process by a constant volume blower, through a pressure reducing valve which is set for a constant down stream pressure of about 10cm. of water column.

→ In this way the variations in gas supply pressure are smoothed out, which otherwise would affect the gas supply pressure are smoothed out, which otherwise would affect the gas sampling accuracy.

$$Q = \sqrt{\frac{\Delta P}{\rho}}$$

ΔP = differential pressure

ρ = density

Q = volumetric flow of gas.

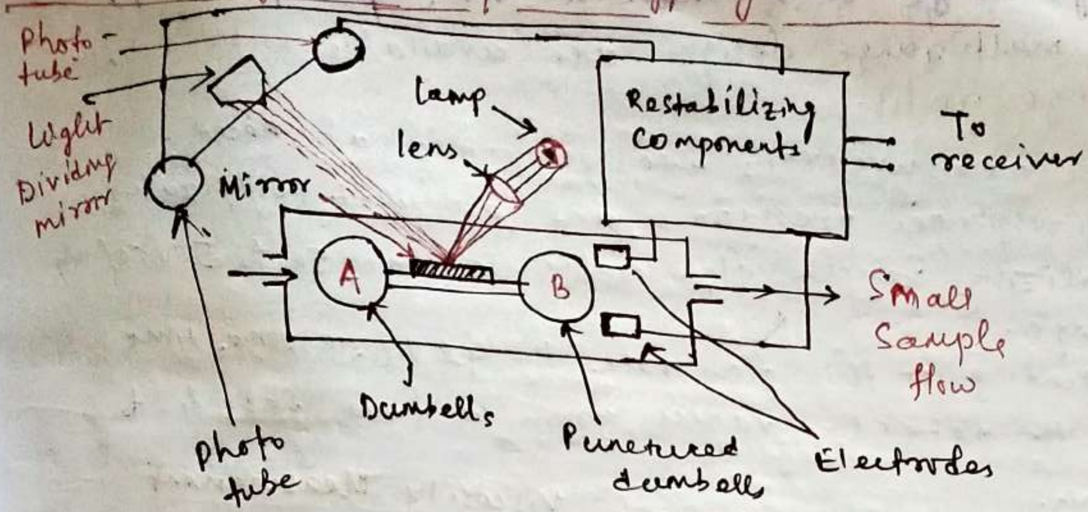
→ ~~The sample gas supply pressure are smoothed out, which otherwise would affect the gas sampling accuracy.~~

→ The sample is then passed through the metering orifice and then through a second orifice to the atmosphere.

→ Beth the two orifice plates the line is tapped by a re-circulating line that connects back to the suction side of the blower.

→ the atmospheric discharge is thus limited to about 30% of blower capacity the differential pressure of the constant volume flow across the metering orifice varies directly with changes in the specific gravity of the gas sample.

3.10 Electromagnetic Suspension type gas densitometer.



→ The main working component of this detector is a small dumbbell supported on a quartz fiber. One of the spheres ~~on the bell supported~~ is sensitize to buoyancy effects (changes in gas density). The other is not.

→ Insensitivity to buoyancy is achieved by puncturing that sphere. A mirror fixed to the dumbell and reflects a light beam to a dividing mirror that splits the beam equally betn two photo cell.

→ There fore the signals produced by the photcells will differ. When this difference is amplified it can be applied to recenter the dumbbell.

→ This is achieved by applying a new electrical potential to the electrodes that generate the electrostatic field around one of the Spheres. The Sphere is made conductive with a coating of rhodium.

→ Measuring the electrical potential required to the stabilize the dumbbell gives a linear indication of the torque created by the differential buoyancies, which in turn is an indication of sample density.

→ If the sample is at ambient conditions, the instrument scale can be calibrated in specific gravity or molecular weight units.

3.11 Measurement of Specific gravity of Gas

→ In contrast with the manual displacement units these detectors are adaptable for continuous measurement and generate output signals for remote readout.

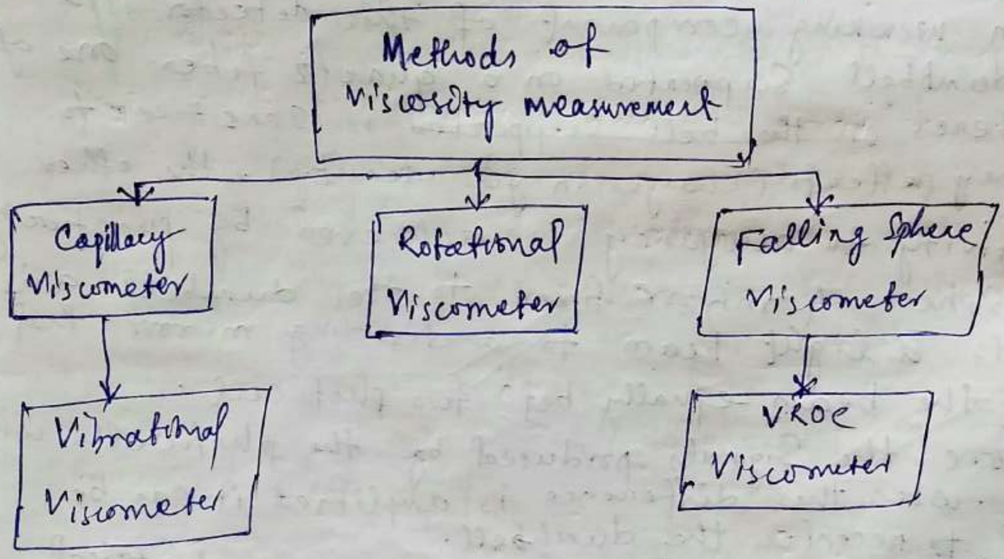
→ They are available with spans of 0.07 to 2.0 SG based on air with ±1% full scale accuracy

→ Single-range units have a total span of 1.0 SG, and multi range designs are available, with a 5:1 range ratio.

→ the measurements are performed at near-atmospheric pressures and ambient temperatures utilizing sample flow rate in the 50 to 500 cc/min range.

→ Depending on this flow rate the 95% response time of the detector varies from a few seconds to 1 min.

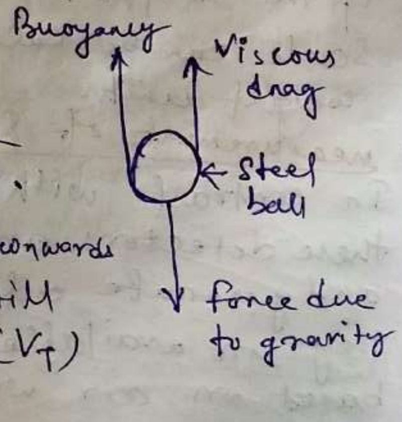
3.12 Explain Various methods of Viscosity Measurement



* Rotational Viscometer

→ The rotational viscometer are probably the most widely use rheometer. the operating principle of rotational type viscometer is based on the that the torque necessary to overcome the viscous resistance to the induced movement (torque) by rotation of a spindle is directly proportional to the viscosity of the fluid.

* Falling Sphere Viscometer



→ In this type of viscometer a a sphere ball of known diameter (d) is released in the guide tube in to the liquid of density (ρ).

→ The ball continue to accelerate downwards under the force of gravity untill it attain the terminal velocity (V_T)

→ When the force due to gravity is just balanced by the buoyancy and viscous drag force of the liquid.

* Vibrational Viscometer

→ Vibrational viscometer date back to the class that operates by measuring the damping of an oscillating electromechanical resonator immersed in a fluid whose viscosity is to be determined.

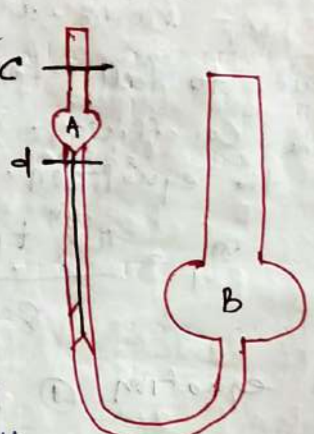
→ The resonator generally oscillates in torsion or transversly. The higher the viscosity the larger the damping imposed on the resonator.

→ Measuring the power input necessary to keep the oscillator vibrating at a constant amplitude. The higher the viscosity the more power is ~~not~~ needed to maintain the amplitude of oscillation.

→ Measuring the decay time of the oscillation once the excitation is switched off. The higher the viscosity, the faster the signal decays.

→ Measuring the frequency of the resonator as a function of phase angle betn excitation & response waveform. The higher the viscosity the larger the frequency change for a given phase change.

3.13 - Explain the function of Ostwald apparatus / capillary viscometer



→ By this method relative viscosity of a liquid with respect to say water is determined. As the the co-efficient of viscosity of water is known, the co-efficient of viscosity of the liquid is found out.

→ This method is of interest only in laboratories and not suited for the continuous measurement in production processes.

→ It consists of a fine capillary tube 10 cm. long & having 0.25 to 0.5 mm diameter. This tube is connected at the upper end to a bulb A and the lower end to bulb U-tube B.

→ The size of the ~~bulb~~ bulb A is such that the total time required to pass the contents of this bulb through the capillary is less than 90 seconds.

→ There are two marks c and d on the tube above and below the bulb A. A known volume of the liquid under examination is taken in bulb B.

→ Then by suction the liquid is taken in bulb A so that the upper level of the liquid is at c. Then with a stop watch the time required for the liquid to fall from c to d is noted.

→ The force which causes water to flow through the capillary is equal to $\rho \cdot g \cdot h$, where 'h' is the difference in levels of the liquid in levels of the liquid in the two limbs of the Ostwald apparatus, ρ is the density of the liquid & g is the acceleration due to gravity.

So the co-efficient of viscosity of the liquid given by the equation is

$$\eta = \frac{\pi R^4 t \cdot h g \cdot \rho}{8 V l} \quad \text{——} \ (1)$$

→ Then a standard liquid, say water, whose co-efficient of viscosity is known, is passed through the capillary tube as in the case of the first liquid and the time required by the liquid to fall from c to d is noted.

The co-efficient of viscosity η_1 is given by the equation,

$$\eta_1 = \frac{\pi R^4 t_1 h \rho_1 g}{8 V l} \quad \text{——} \ (2)$$

from equation (1) & (2)

$$\frac{\eta}{\eta_1} = \frac{\rho t}{\rho_1 t_1}$$

The absolute viscosity of water at 25°C is 8.95×10^{-3} and is equal to

$$\boxed{\eta_1 = \frac{\rho t}{\rho_1 t_1} \times 8.95 \times 10^{-3}}$$

3.14 - Define co-efficient of viscosity & explain different types viscosity co-efficient & Stokes law

Stokes law

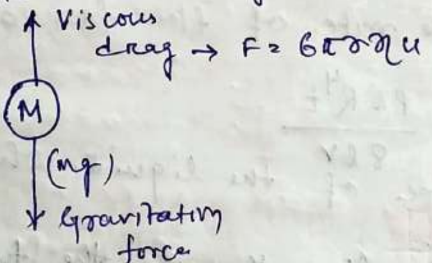
→ If a solid body is passed through a liquid, a thin layer of the liquid in immediate contact with the solid body is at rest & due to the viscosity of the liquid, a viscous drag is exerted on the moving body.

→ In order to keep the body moving inside the liquid with a uniform velocity, a steady force should be applied to the body over come the effect of the viscosity of the liquid.

→ According to Stokes law, if a ball of radius 'r' passes through the liquid with a velocity 'u', the viscosity of the liquid being 'η', the force F applied to the ball which just balances the effect of drag due to viscosity is given by equation.

$$F = 6\pi r \eta u$$

* If the Sphere is falling under the influence



of gravity, the down ward force is given

$$\frac{4}{3}\pi r^3(\rho - \rho')g$$

ρ = density of the Sphere

ρ' = density of the medium through which it fall's.

* At a stage constant speed is attained when the force due to viscosity is equal to the gravitional pull.

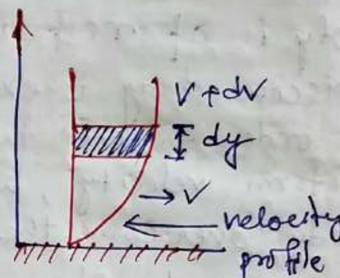
$$\frac{4}{3}\pi r^3(\rho - \rho')g = 6\pi r \eta u$$

$$u = \frac{2g r^2(\rho - \rho')}{9\eta}$$

* Example

If you pour honey through a hole Styrofoam cup, it will flow very slowly, where as water will flow a lot faster because of low viscosity.

Dynamic Viscosity = $\frac{\text{Shear stress}}{\text{velocity gradient}}$



* Viscosity depends on

1. Nature of liquid.
2. Dissolves solid or dissolves objects
3. it's temperature variation

* kinetic viscosity - $\eta = \frac{\mu}{\rho}$, $\frac{\text{dynamic Viscosity}}{\text{density}}$

8.15 - Distinguish betn Newtonian & Non-newtonian fluid

→ The relationship betn the coefficient of viscosity of a liquid and the rate of flow from a capillary tube :-

$$\eta = \frac{P\pi R^4 t}{8 l V}$$

where V = volume of the liquid which flow the tube.
t = Liquid flows through the tube.
l = length of tube
R = Radius of tube.
P = pressure causing flow.

* Newton's law of Viscosity

→ Newton's law of viscosity states that ~~"Stress~~ "Shear stress is directly proportional to velocity gradient" The shear stress betn two adjacent layer of fluid is directly proportional to the negative..

Mathematically the law can be stated as

$$\tau_y = -\mu \frac{dv}{dy}$$

Where μ is the constant of proportionally known as dynamic.

* Newtonian fluids

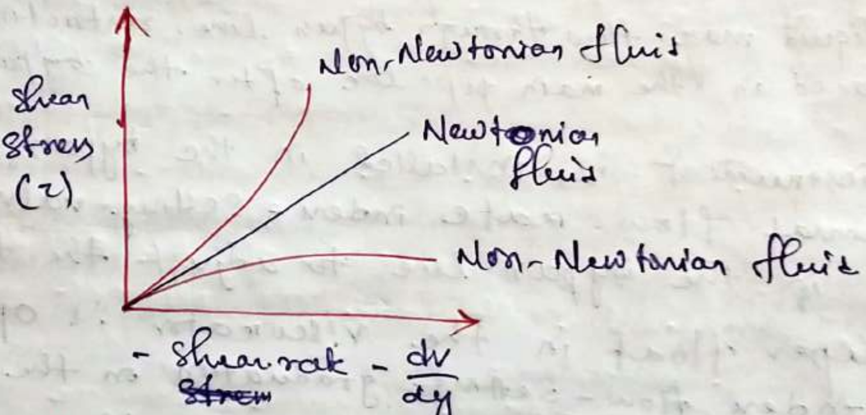
→ The fluids that obey the newton's law of viscosity are known as Newtonian fluids.

Ex- most of the petroleum products like lub oils are Newtonian, all gases and most liquids having simpler molecular formula & low molecular weight as water, benzene, ethylalcohol, CCl_4, hexane.

* Non - Newtonian fluids

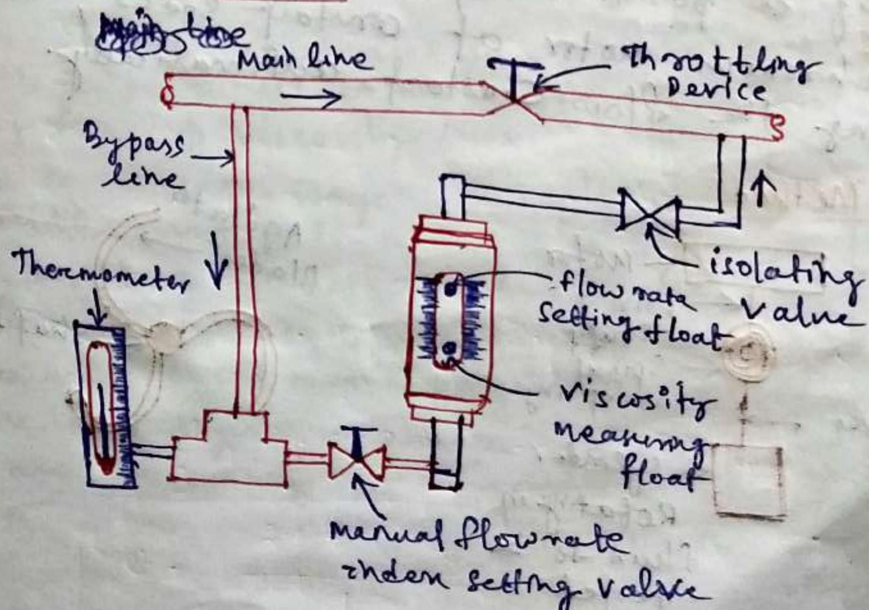
→ Fluids which do not obey the newton's law of viscosity are called non - newtonian fluids.

Ex- complex mixtures like - slurries, soap, toothpaste, paper pulp, chocolate paste, polymer solution etc.



3.16 Explain function of two float viscorator ; Torque viscosity & Saybolt viscosity

* Two float Viscorator



→ This method utilise the fact that the rotameter floats are not only sensitive to flow but also to viscosity.

→ Thus if two floats be developed of such shapes that one is sensitive to flow only and the other to both flow & viscosity.

→ It is possible to use these two floats and note the difference betn their responses to determine viscosity. A ~~mod~~ modification to this method is possible by keeping the flow rate constant & using only one float.

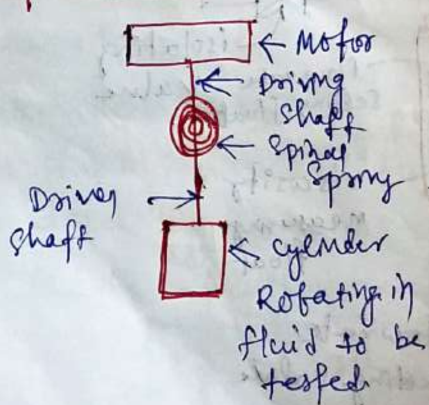
→ The schematic arrangement of two float viscorator is shown above. A bypass connection is taken from the main line and in order to that resonable amount of liquid may flow through bypass line, restriction (orifice) is placed in the main pipe line after the bypass is taken off.

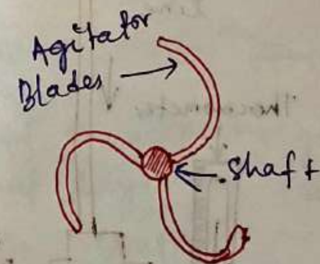
→ The instrument is installed in the bypass line. A manual flow rate index - setting valve is used in the bypass line to adjust the flow till the uper float in the viscorator is opposite the index flow - setting graduation on the capacity scale.

→ Viscosity is then read by nothing the position of the lower float power part of scale.

i) using a positive displacement pump driven by a synchronous motor of constant speed, thus keeping the flow constant automatically.

* Torque Method





→ The working of the viscosity instruments of this type is based on the principle that different torques are required to rotate an agitator at constant speed in fluids of different viscosities.

→ The instrument consist of an agitator wheel which is rotated at constant speed by an electric motor. The drive from motor shaft to the agitator wheel is transmitted through a spiral spring.

→ Due to viscous drag of the fluid under measurement the motor shaft winds up the spiral spring by an amount proportional to the viscosity of the fluid in which agitator rotates.

→ It is thus obvious that both the motor and cylinder rotate at constant speed but cylinder is lagging constantly by some definite amount from the motor shaft, depending upon the viscosity of fluid.

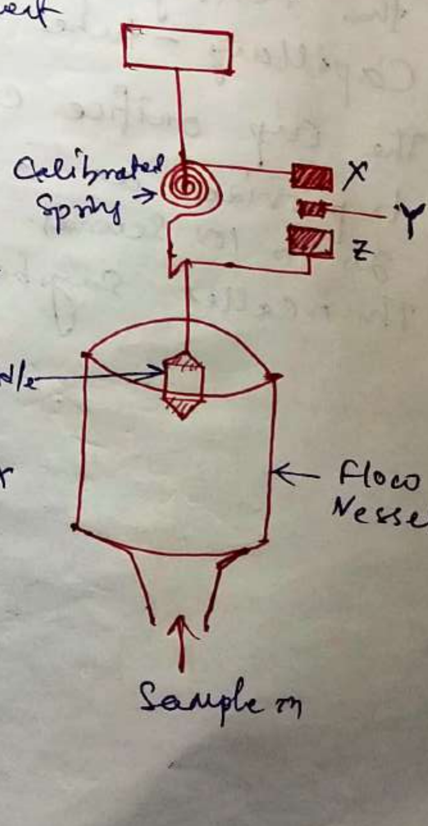
→ The angular relationship i.e lag betn motor shaft and cylinder shaft or the winding up of the spiral spring is converted on to an electrical signal by using either variable capacitance transducer or variable resistance transducer.

→ Torque to rotate, a torque element in a liquid. A synchronous motor drives vertical spindle with disc, paddle or cylinder submerged in test liquid.

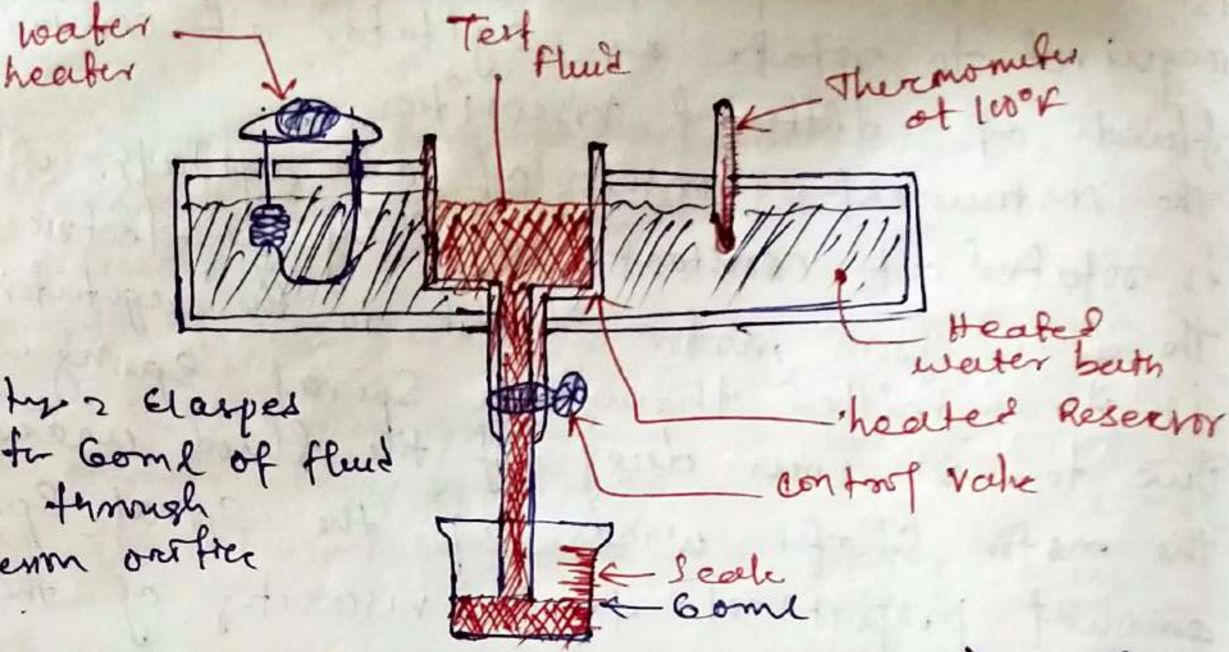
→ Drive is through calibrated spring. Angular lag of spindle behind motor is proportional to viscosity & is measured in various ways.

→ one possible method is to measure lag of rotating contact Z behind X by stationary contact Y.

→ Other recorder based on the principle measure lag angle by change in resistance or capacitance



Saybolt Viscosity



viscosity = elapsed time for 60ml of fluid to pass through precision orifice

→ A device used to measure the viscosity of a fluid. The Saybolt viscometer controls the heat of the fluid & the viscosity is the time is taken the fluid to fill a container

→ Efflux-cup viscometer are most common used for field work to measure the viscosity of oils, syrups, varnish, paints and Bitumen emulsion.

→ The Saybolt viscometer, one of the efflux cup viscometer is the standard instrument for the testing petroleum products.

→ the testing procedure is quite similar to the Capillary-tube viscometer.

→ The cup orifice combination should be selected to provide an efflux time with range of 20 to 100 seconds.

→ This is called Saybolt universal seconds.