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Syllabus

Chapter-1

Measurement of temperature:

- 1.1 Classify methods of temperature measurements.
- 1.2 Explain measurement of temperature by non-electrical methods.
 - A. Liquid expansion type.
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 - C. Gas & vapour expansion type.
- 1.3 Explain measurement of temperature by electrical methods of measurement.
 - A. Resistance thermometer.
 - i) State advantage of resistance thermometers over other types.
 - ii) Describe the methods of measurement of change in the resistance by null balance bridge method.
 - iii) Compensation of lead resistance by 3-wire & 4-wire method.
 - B. Thermocouples.
 - i) Explain principle of thermoelectricity (Seebeck, Peltier & Thomson effects).
 - ii) Classify thermocouple materials.
 - iii) Describe the function of thermocouple extension wires.
 - iv) Describe the methods of measurement of output of the thermocouples. Also state the types of thermocouples insulating materials & their function.
 - v) State the advantages & disadvantages of thermocouple type thermometer.
 - vi) Explain the cold junction compensation of thermocouple.
 - C. Thermistors.
 - i) Explain the basic principle & characteristics of thermistors.
 - ii) State the method of temperature measurement by thermistor & their uses.
 - D. Pyrometers.
 - i) Explain the principle & operation of radiation & optical pyrometer with suitable diagram & sketch.
 - E. Describe the function & use of temperature switch.

Chapter-2

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- 2.2 Explain the working principle & use of mechanical methods of measurement of pressure by:
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 - ii) Capacitive pressure transducer.

- iii) Reluctance pressure transducer
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- i) Thermal conductivity Gauge.
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- 5.2 General telemetry system.
- 5.3 Types of telemetry system.
- 5.4 problems in telemetry system.
- 5.5 pressure to current converter.
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Chapter-6 Aquatic measurement

- 6.1 Define Aquatic pressure.
- 6.2 Explain characteristic of sound pressure level & power level.
- 6.3 Explain the function of typical sound system such as microphone.

Text books

1. Industrial Instrumentation by S.K. Singh of McGraw Hill education.
2. Electrical Instrumentation & process control by Dr. J.P. Navari, E.R. Sonal Sapre. of S. char.
3. Mechanical measurement & control - by R.K. Khedker

MEASUREMENT OF TEMPERATURE

1.1 → Classify methods of Temperature →

* The temperature of a substance is a measure of the hotness, or coldness of that substance. If two bodies are placed in contact then heat tends to flow from a body at a higher temperature to a body at a lower temperature.

* Temperature Scales

i) The lower fixed point, or ice-point.

ii) The upper fixed point, or steam point.

→ The lower fixed point or ice-point is the temperature of ice, prepared from distilled water melting under a pressure of 760 mm of mercury.

→ The upper fixed point, or steam-point is the temperature of steam from pure distilled water boiling under a pressure of 760 mm of mercury.

→ The temperature interval betⁿ the ice-point & steam point is known as the fundamental interval.

* Fahrenheit and Centigrade Scales →

$$\frac{^{\circ}\text{C}}{100} = \frac{^{\circ}\text{F} - 32}{180}$$

* Kelvin and Centigrade Celsius →

$$^{\circ}\text{K} = ^{\circ}\text{C} + 273.15$$

* Basic fixed points → all corresponding to the normal atmospheric pressure of 760 mm of mercury, and are used to standardise thermometers.

i) Boiling point → The boiling point is the temperature at which the substance changes physical state & becomes a gas.

ii) Freezing point → The freezing point is the temperature at which the substance changes physical state & becomes a solid.

(iii) Triple point:- A particular temperature and pressure (02) at which three different phases of one substance can exist in equilibrium is known as triple point.

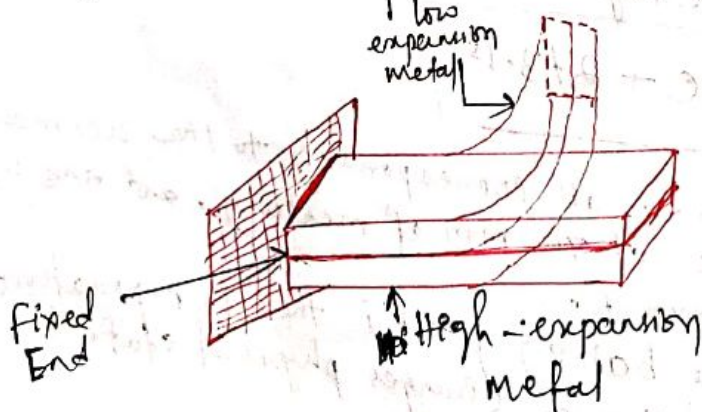
- * 1) Expansion thermometers
- 2) Filled system thermometers
- 3) Electrical temperature instruments
- 4) Pyrometer.

1.2 Explain measurement of temperature by non-electrical methods.

a) Expansion of Solids

→ Bimetallic thermometers

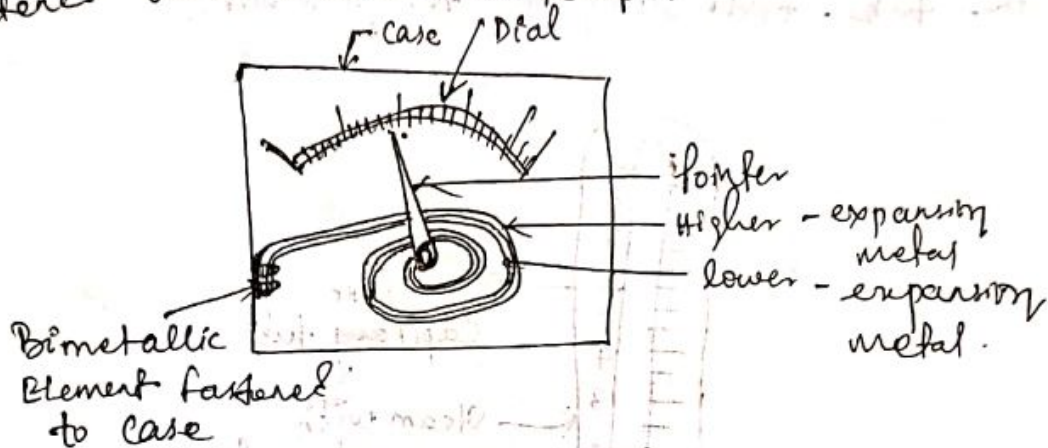
- * The expansion of Solids is employed mainly in bimetallic elements by utilizing the differential expansion of bonded strips of two metals
- * It consists of two metal strips of metal such as invar and brass welded together, each strip made from a metal having a different co-efficient of thermal expansion.
- * Whenever the welded strip is heated, the two metals change length in accordance with their individual rates of thermal expansion.
- * The two metals expand to different lengths as the temperature rises. This forces the bimetallic strip to bend towards the side with low co-efficient of thermal expansion.



- * If one end of the bimetallic strip is fixed so that it cannot move, the distance the other end bends is directly proportional to the square of the length of

the metal strip, as well as to the total change in the temperature, and is inversely proportional to the thickness of the metal. (83)

- The movement of the bimetallic strip utilized to deflect a pointer over a calibrated scale.
- A longer strip can be contained in a relatively small space if the strip length is wound in a spiral, helix or multihelix form.
- If the bimetallic element is wound in a spiral coil is tightened with increase in temp.



- Bimetallic thermometers are inexpensive, relatively rugged, and easy to read. They are also reasonably accurate if handled carefully. They are available for the temperature range from -103 to 100°C (-75 to 540°C).

Advantage

- i) their cost is low
- ii) they are tough & can't easily be broken.
- iii) they are easily installed & maintained.
- iv) they have good accuracy relative to cost.
- v) they have fairly wide temp. range.

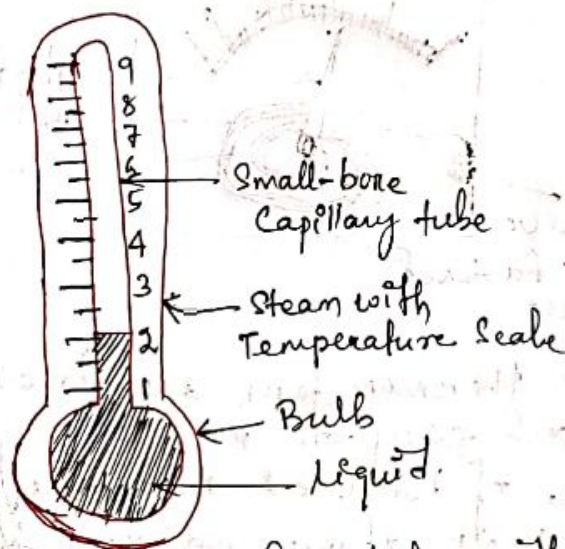
Disadvantage

- i) they are limited to local mounting.
- ii) only indicating type is available.

b) Expansion of liquids

c) Liquid-in-glass thermometers →

- the liquid-in-glass thermometer is one of the simplest temperature measuring device widely used in both laboratory & industry.
- Its operation is based on the fact that liquid expands as the temperature rises. In this type of thermometer, the expansion causes the liquid to rise in the tube indicating the temperature.

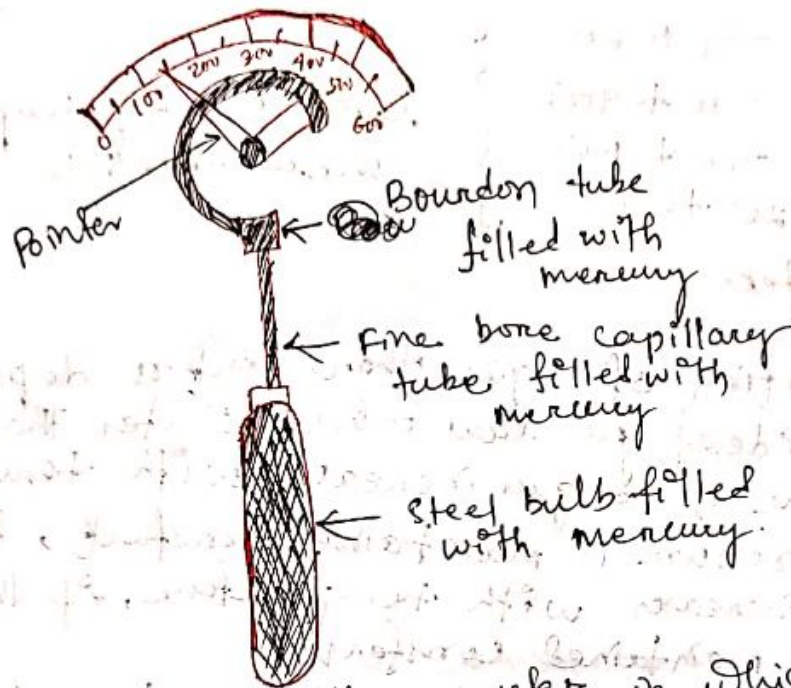


- It consists of a small bore glass tube with a thin-walled glass bulb at its lower end. The liquid that fills the bulb ~~at its lower end~~ and part of the tube is usually mercury.
- As heat is transferred through the well and metal stem and into the mercury, the mercury expands, pushing the column of mercury higher in the capillary, above which indicates the temperature.
- The liquid-in-glass thermometer is commonly used for the temperature range of -18.4 to 608°F (-120 to 320°C).
- Where mercury is used as liquid, it freezes at (-39°C) . For measuring very low temperature, alcohol is used as liquid.
- They are fragile and not easily adapted to automatic recording or transmission of temperature data.

→ The industrial mercury-in-glass thermometer is used in applications such as open tanks containing liquids, cooking kettles, certain nonmetal baths, steam lines, pipe lines for fluid flow & air ducts.

Ques) Liquid-in-metal Thermometer

→ The liquid-in-glass thermometers are overcome in liquid-in-metal thermometers. ~~A liquid-in-metal~~



→ A liquid-in-metal thermometer in which mercury has been used as liquid and the metal is steel. This mercury-in-steel thermometer works on exactly the same principle as the liquid-in-glass thermometer.

→ The glass bulb is replaced by a steel bulb & the glass capillary tube by one of stainless steel. Mercury ~~is used as liquid in the system~~ is used as liquid in the system. As mercury in the system is not visible, a Bourdon tube is used to measure the change in its volume.

→ The Bourdon tube, the bulb and the capillary tube are completely filled with mercury, usually at a higher pressure.

→ When the temperature to be measured rises, the mercury in the bulb expands more than the bulb so that some mercury is driven through the capillary tube into the Bourdon tube.

→ As the temperature continues to rise, increasing amounts of mercury will be driven in to the Bourdon tube, causing it to bend.

→ One end of the Bourdon tube is fixed, while the motion of the other end is communicated to the pointer which moves on a calibrated temperature scale.

* mercury → -39 to 650°C
xylene → -40 to 400°C
Alcohol → -46 to 150°C
Ether → 20 to 90°C

} liquid use for temp measurement

(iii) Gas thermometers

→ The operation of gas thermometers depend upon the ideal gas law which states that the volume of a gas increases with temperature if the pressure is maintained constant, & the pressure increases with temperature, if the volume is maintained constant.

→ If a certain volume of inert gas is enclosed in a bulb, capillary & Bourdon tube and most of the gas in the bulb, then the pressure indicated by the Bourdon tube may be calibrated in terms of the temperature of the bulb.

→ Nitrogen is the favorite fill for a gas-filled thermometer because it is almost inert & inexpensive. It does react somewhat with the steel bulb material at temperature exceeding 427°C .

→ Extremely low temperatures use gas helium should be used.

(iv) Vapor - pressure thermometers

(07)

- The vapour - pressure thermometer is also a filled system thermometer. In this system the bulb is the partially filled with liquid, while the capillary & Bourdon tube are filled with vapour.
- In this system some of the liquid vaporizes during operation.



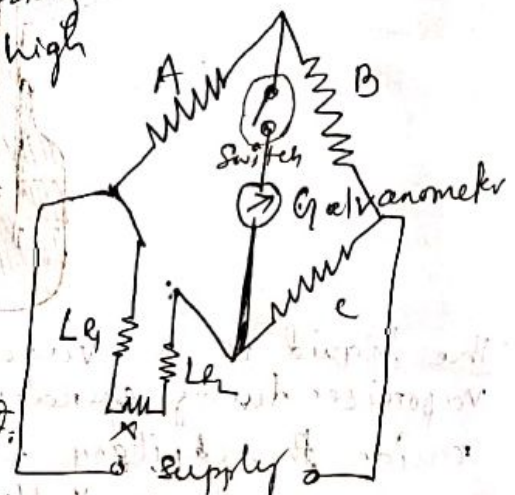
Temperature range is
-200°C to 400°C

- The liquid in a vapour pressure system boils and vaporizes during operation which creates a gas or vapor inside the capillary & Bourdon tube.
- The liquid inside the bulb continues to boil until the pressure in the system equals the vapour pressure of the boiling liquid. At this point the liquid stops boiling unless its temperature increases.
- When the temperature of the substance surrounding the bulb drops, the liquid and vapour inside the bulb also cool. This causes some of the vapour to condense.
- The vapour condenses, the pressure inside the system decreases. This action continues until the pressure drops to the vapour pressure of the boiling liquid.
- Due to this change in pressure, the Bourdon tube uncoils as pressure increases and coils tightly as it decreases. This movement of Bourdon tube may be connected to a pointer or to a pen on a strip chart recorder to indicate temperature.

1.3 Explain measurement of temperature by electrical methods of measurement.

A. Resistance thermometer / Resistance temperature Detector (RTD)

- The resistance of certain metals changes with temperature change. Resistance thermometer utilizes this characteristics.
- With the increase of temperature the electrical resistance of certain metals increases in direct proportion to the rise of temperature.
- The electrical resistance of a wire of known and calibrated material is measured, the temperature of the wire can be determined. Platinum, Copper & Nickel are generally used in resistance thermometers.
- Change in resistance by null balance bridge method. The bridge consists of a sensing element resistance X having high temperature Co-efficient & Resistance A, B & C whose ohmic values do not alter with change of temperature.
- L_1 & L_2 are the lead wire resistance of the sensing element.
- The principle of wheat stone bridge states that in balanced condition (When no current flows through galvanometer).

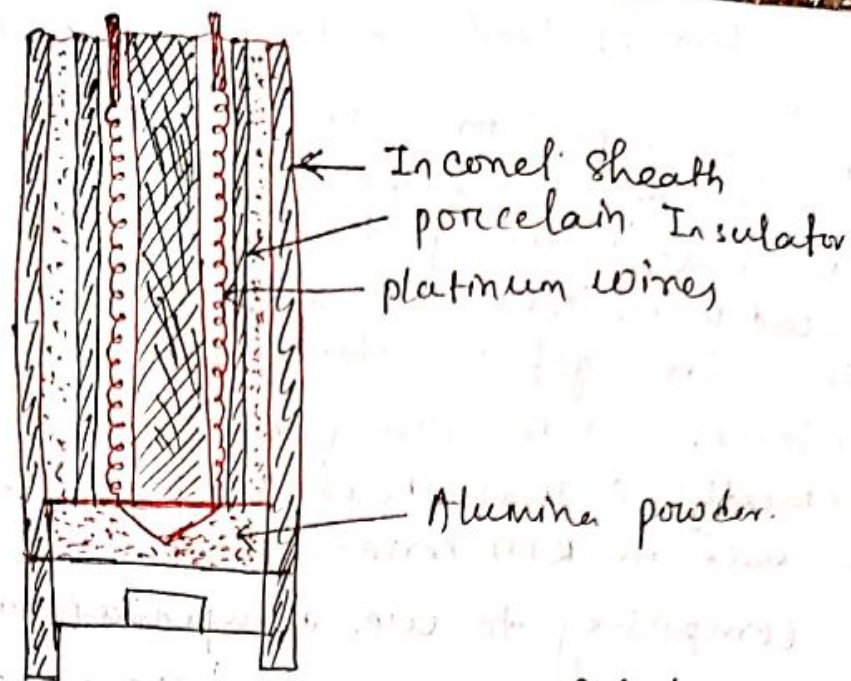


$$\frac{A}{B} = \frac{(X + L_1 + L_2)}{C}$$

- Now when resistance X changes the wheat-stone bridge becomes unbalanced & thus galvanometer will give deflection which can be calibrated to give the suitable temperature scale.
- Resistance wire are generally long spring like enclosed in a metal sheath.

$$R_T = R_0 (1 + \alpha \Delta T)$$

R_0 = Resistance at temperature (0°C)
 ΔT = change in temp^r
 R_T = Resistance at temp^r $(T^\circ\text{C})$



- The resistance element is surrounded by a porcelain insulator which prevents short circuit betⁿ wire & the metal sheath.
- Two leads are attached to each side of the platinum wire when this instrument is placed in a liquid or a gas medium whose temperature is to be measured, the sheath quickly reaches the temperature of the medium.
- This change in temperature causes the platinum wire inside the sheath to heat or cool, resulting in a proportional change in the wire's resistance.
- platinum is also available as a deposited film sensor and nickel and Balco are available in foil type sensor.

Advantages

- They possess high accuracy of measurement.
- They have a wide temperature range from -200 to 650°C .
- They are small in size.
- They are fast in response.
- They have good reproducibility.
- They have shown accurate performance.
- Temperature compensation not required.

Disadvantages

- Their cost is high.
- They need a bridge circuit, power supply.
- They produce mechanical abuse of vibration.
- They have larger bulb size than thermocouples.

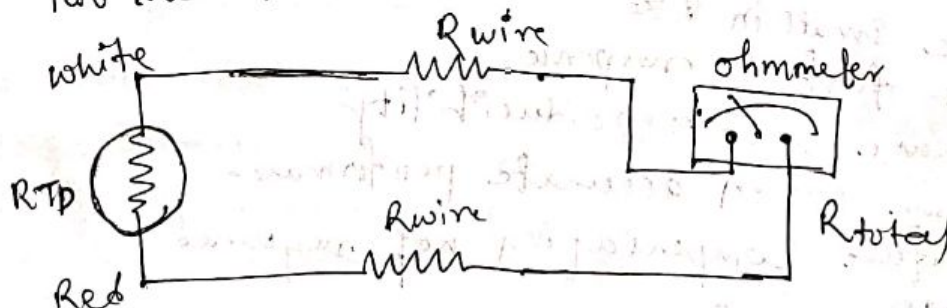
(iii) compensation of lead resistance by 3-wire & 4-wire method.

- As RTD is a resistor, the ohm meter or the resistance measuring devices are connected parallel to the lead wires of the RTD.
- The lead wire resistance adds to the RTD resistance as the wires got resistance and this combined resistance will be shown as the RTD resistance incorrectly. So that lead compensation techniques are used in RTD connections.
- it is compulsory to use compensation technique in the industrial sector, because of the wide range of temperature measurement is needed.
- The non linearity of RTD becomes a significant problem as range got wider, so we must a way to use low-resistance RTDs & deal with the (less) problem of wire resistance.

* There are three connection circuits for RTD wire circuit:

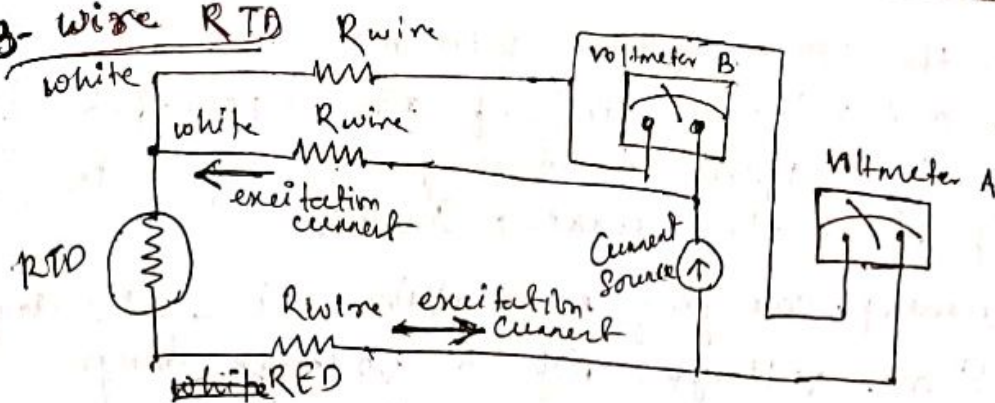
- * Two-wire circuit
- * Three-wire circuit
- * Four-wire circuit

→ Two-wire circuit



A two-wire RTD connection which shows the wire resistance as R_{wire} . The resistance of the lead wire will be added to the total resistance R_{total} .

3-wire RTD



- Voltmeter A measures the voltage dropped across the RTD plus the voltage dropped across the bottom current-carrying wire.
- Voltmeter B measures just the voltage dropped across the top current-carrying wire. The both current-carrying wire should have the same resistance so that subtracting the voltage across A from the voltage across Voltmeter B give the

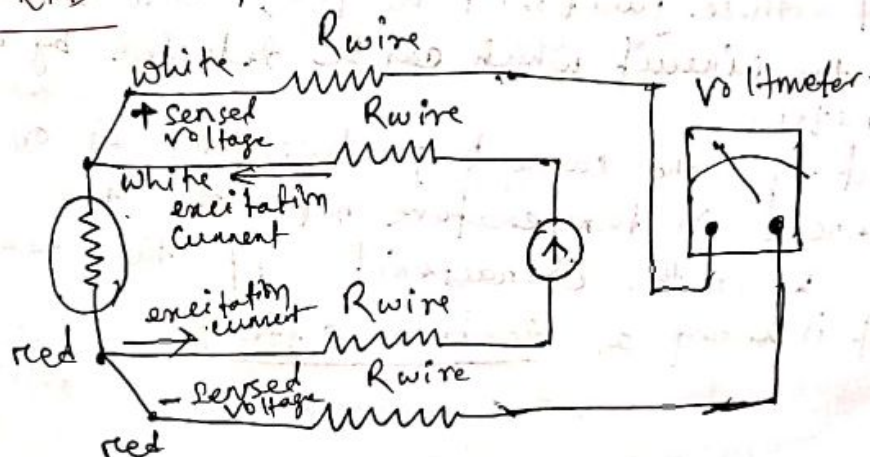
$$V_{RTD} = V_{meter(A)} - V_{meter(B)}$$

If the resistance of the two current carrying wires is precisely same then the calculated voltage will be same as the actual RTD voltage.

Disadvantages of three-wire RTD:

- * Susceptibility to self heating error
- * Susceptibility to signal noise.
- * Need for lead resistance compensation.
- * Need for power supply.

4-wire RTD



- Here in the four wire RTD circuit, the current and voltage circuit are separated. Current is supplied to through a separate circuit from the current source.
- This current carrying excitation wire will drop ~~drop~~ some voltage. Which voltage drop will not read in the voltmeter.
- The two sense wire connects betn voltmeter & the RTD, it poses resistance & drops voltage in the sensing wire.
- Only a little current is drawn through the sensing wire which makes the voltage drop ~~no~~ negligible.
- The resistance of the current carrying wires are of no. effect because the voltmeter never senses their voltage drops, and the resistance of the voltmeter's sensing wires are of no. effect because they carry practically zero current.

B. Thermocouple :-

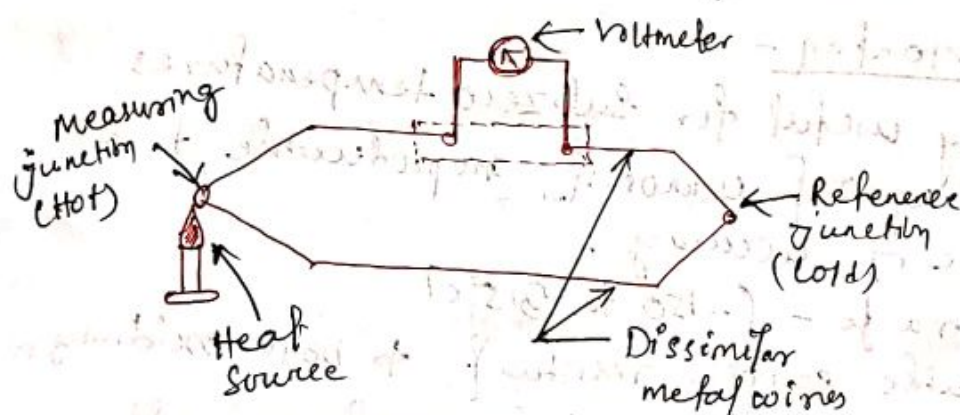
- The working principle of a thermocouple depends on the thermoelectric effect. If two dissimilar metal are joined together so as to form a closed circuit, there will be two junction where they meet each other.
- If one of these junctions is heated, then a current flows in the circuit which can be detected by a galvanometer.
- The amount of the current produced depends on the difference in temperature betn the two junctions & on the characteristics of the two metal. It is known as Seebeck effect.

Peltier effect

⊛ Peltier effect: this governs the emf resulting solely from contact of two different metals & magnitude varying with temperature of this contact.

Thomson effect

→ This is the emf. resulting from the temperature gradient along the single wire & is less predominant. The instruments are negligible & thus, the instruments measures the Peltier emf only & in this case of the temperature of one junction kept is kept constant or its emf generation is compensated for the effective emf.



- The thermocouple made from two different kinds of metals. The wires are joined at the ends which form two junctions, a measuring junction and a reference junction.
- Heating the measuring junction produces a voltage greater than the voltage across the reference junction. The difference between two voltages is measured and voltmeter reading is converted to its corresponding temperatures.
- materials are copper-constantan, iron-constantan, chromel-alumel, platinum-rhodium & chromel-constantan.

(ii) Thermocouple materials

→ Two metal conductor combination for thermocouples should possess the following

- i) Reasonably linear temp emf relationship
- ii) Sufficient thermoe.m.f per degree of temperature change to facilitate detection & measurement

- (iii) Should be physically able to withstand sustained high temperatures, rapid temperature change & the effects of corrosive atmosphere
- iv) The thermocouple should follow when temperature rise or falls.

→ Thermocouple lead wire sizes vary from gauge 14 to 26. In many instances the size is determined by the strength required to withstand the tensile force of pulling wire through the protecting conduit.

→ when thermocouple is used in conjunction with millivoltmeter-read out devices.

a) Copper - constantan -

- it is very useful for subzero temperatures stands well against corrosion, reproducible to a high degree of accuracy.
- Preferable range - $(-150 \text{ to } 315^\circ\text{C})$.
- it is stable couple resistant to both oxidising and reducing atmosphere but needs protection from acidic vapour.

b) Iron - constantan

- it is useful in low oxygen atmospheres, used for temperatures above 540°C .
- Oxidation is appreciable and higher size of wire is suggested. If enamelled iron wire is used the couples are stable in air.
- Iron wire undergoes crystalline change of kept at high temperature for long time.

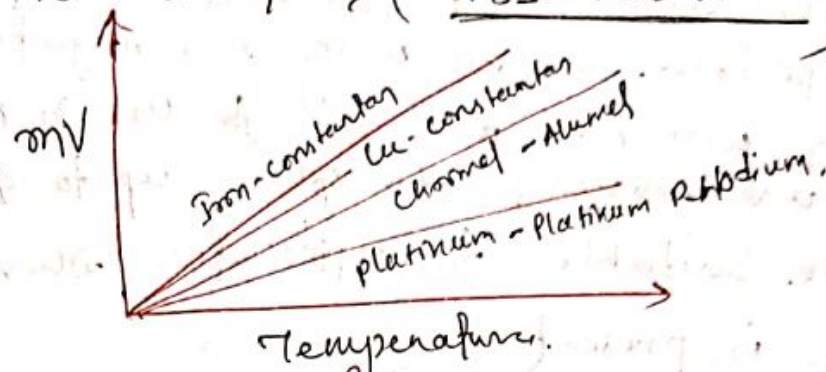
c) chromel / alumel

- Suitable in oxidising atmosphere, more service life than iron constantan at higher temperature.
- Susceptible to chalcogenides in atmosphere free from free oxygen. Suitable up to 1150°C .
- Both wires are prone to damage by sulphurous gases.

(15)
d) Platinum-Rodium platinum →

Suitable for higher temperature ranges, affected by reducing gases and shall be protected with Sillimanite tubes. Use above 548°C .

* Tungsten-rhenium → $(-185^{\circ} + 02100^{\circ}\text{C})$



* Types of thermocouple

i) Iron-constantan (J-type)

→ The iron-constantan "J" curve thermocouple with a positive iron wire and a negative constantan wire is recommended for reducing atmospheres.

→ The operating range for this alloy combination is 870°C for the largest wire sizes.

→ J (Iron-constantan) (+) white & Red (-)

(ii) Chromel-constantan (E)

→ The chromel-constantan thermocouple may be used for the temperatures up to 870°C in a vacuum or inert, mildly oxidizing or reducing atmosphere.

→ As ~~red~~ sub-zero temperatures, the thermocouple is not subject to corrosion. This thermocouple has the highest emf output of any standard metallic thermocouple.

→ E (chromel-constantan) (+) purple & (-) Red.

→ Temp range: -252 to 870°C .

(iii) Chromel-Alumel (K)

→ The chromel-Alumel (K) curve thermocouple with a positive chromel wire and a negative alumel wire is recommended for use in clean oxidizing atmosphere.

→ The operating range for this alloy is 1260°C .

③ K chromel - constantan
(+) Yellow, (-) Red.
Range: (-252 to 1200°C)

iv) Copper - constantan (T-type)

→ The copper-constantan 'J' type thermocouple with a positive copper wire & a negative constantan wire is recommended for use in mildly oxidizing and reducing atmosphere up to 400°C
→ They are suitable for application where moisture is present.

→ T (chromel - constantan)
(+) Blue & Red (-)

Range (-250 to 380°C).

v) Platinum Rhodium Alloys (S, R & B)

→ Three types of 'noble-metal' thermocouples are in common use they are (a) a positive wire of 90% platinum & 10% rhodium used with a negative wire of pure platinum, (b) a positive wire of 87% platinum & 13% rhodium used with a negative wire of pure platinum, &

(c) a positive wire of 70% platinum & 30% rhodium used with a negative wire of 94% platinum & 6% rhodium.

→ They have a high resistance to oxidation & corrosion temperature as high as 1800°C.

(iii) Describe the function of thermocouple extension wires

→ It is extremely uneconomical to extend the thermocouple elements to the instruments. Specially for noble-metal thermocouples, therefore, lead wires of cheap materials (possessing the similar thermo-electric characteristics as the thermocouple elements) must be used.

There are also known as compensating leads. (17)

- Extension wires must be placed in conduits and conduit grounded to prevent leakage from power installations or lighting circuits. It is very important that the extension wire be connected to the thermocouple wire and -ve to the -ve and not vice-versa.
- The wire must be kept at least a 0.3 metre away from any a.c line, otherwise induced alternating current may affect the pyrometer reading.

<u>Thermocouple</u>	<u>Extension wires</u>	<u>Range</u>
① Platinum Rhodium Platinum	Copper, Copper Nickel alloy	20-220°C
② Chromel Alumel	chromel Alumel	-15-100°C
③	Copper constantan	20-220°C
	Iron, Copper, Nickel alloy	-15-220°C
③ Iron constantan	Iron constantan	-15-220°C
④ Copper constantan	Copper-constant	-15-100°C

iv) Describe the methods of measurement of output of thermocouples state the types of thermocouple insulation materials & their function.

- In order to protect the thermocouple wire against the corrosion & erosion effect of working medium & strength to withstand high pressures, the thermocouple are entirely covered by a sheath made of a material which can withstand the highest temperature as well as atmosphere to which the thermometer is to be subjected.
- The sheath is made up of two portions, ~~remaining at low temperature may be made of iron~~, one of which is in the hot medium (material for it being as specified below) & other portion remaining at low temperature may be made of iron.

iv) The sheath is securely attached to the head which contains the connector for attaching the leads of the thermocouple ends.

1. Wrought iron metal tube

SL No.	material composition	temp. limit °C
1.	wrought iron	700°C
2.	Stainless Steel	1000°C
3.	Nickel	1158°C
4.	Inconel	1260°C

Ceramic protecting tubes

1.	Sillimanite	1650°C
2.	fused Silica	1300°C
3.	fire brick	1450°C
4.	SiC	1650°C
5.	Silica	1600°C
7.	Mullite	1660°C
8.	Vycor	1000°C

iv) Thermocouple Advantage & Disadvantage

Advantage

- i) They have rugged construction.
- ii) They are inexpensive.
- iii) They are simpler to use than resistance thermometers.
- iv) There is no need of a bridge circuit.
- v) They have extremely wide temperature ranges from -270° to 2800°C .
- vi) They have wide variety of designs to both standard & special applications.
- vii) Their electrical output is adaptable to a variety of readout and/or control devices.
- viii) They have high response speed compared to filled system thermometers.

(ix) They possess good accuracy.

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x) calibration checking is easily made

xi) They possess long transmission distance.

xii) They have good reproducibility.

Disadvantages

i) They have limited use in temperature span of less than about 33°C because of the relatively small change in junction voltages with the temperature.

ii) Extension leads must be housed in metal conduit, as low junction voltage can cause the device to pick up stray electrical signals.

iii) They need to hold reference junction temperature constant or compensation for any deviation.

iv) Their temperature-voltage relationship is non-linear.

v) They hold chances of stray voltage pickups.

vi) Temperature span are not as narrow as filled system or resistance thermometers.

vii) They require much of an amplifier for many applications.

viii) They need expensive accessories for control applications.

(VI) Explain the cold junction compensation of thermocouple.

→ For correct temperature indication, reference junction shall be kept at constant temperature, but in practice it is seldom possible to maintain a constant temperature.

→ One method is to use a temperature sensitive compensating resistor in the measurement circuit. This resistor is located close to the reference junction, so that both are equally affected by changes in ambient temperature.

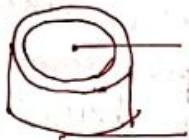
→ When emf output of the thermocouple drops, because of rise of reference junction temperature, the resistance of the compensating resistor rises.

→ The circuit is arranged such that the increase value of the resistor compensates for decreased thermocouple output.

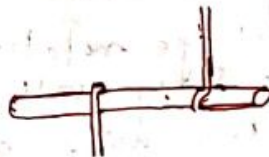
① Thermistor

- A thermistor is a non-metallic resistor (Semiconductor of ceramic material) having a negative temperature co-efficient of resistance and this co-efficient at room temperature is about ten times higher than that of copper or platinum.
- These are much more sensitive than conventional elements of metal wire.
- Thermistors are made by mixtures of metallic oxides such as manganese, nickel, cobalt, copper, iron & uranium.
- These are suitable for use only up to about 300°C .

Thermistor
IC - MCP9700A



Disc type with lead



Rod type.



Washer type

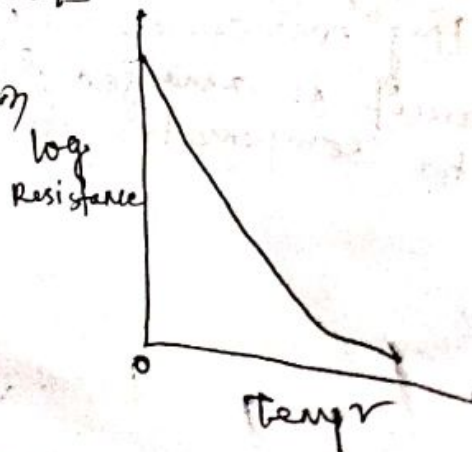


Bead type.

- To measure temperature with a thermistor, it is placed in the environment whose temperature is to be measured. As the temperature of the substance or environment increases, the resistance of the thermistor decreases.

Characteristics of thermistors

- The curve which represents the relationship of resistance - temperature is usually plotted in terms of the logarithm of resistance & temperature.



(i) Resistance characteristics

(21)

$$R = a e^{b/T}$$

where a & b are constants

R = resistance of thermistor at absolute temperature T .

$$\frac{R_0(T_1)}{R_0(T_2)} = e^{B \left(\frac{1}{T_1} - \frac{1}{T_2} \right)}$$

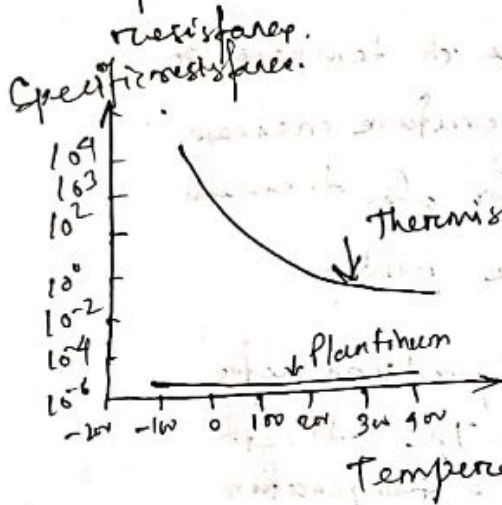
$R_0(T_1)$ & $R_0(T_2)$ = resistance of thermistor in ohms at absolute temperature T_1 & T_2

T_1 & T_2 = absolute temperatures in $^{\circ}K$

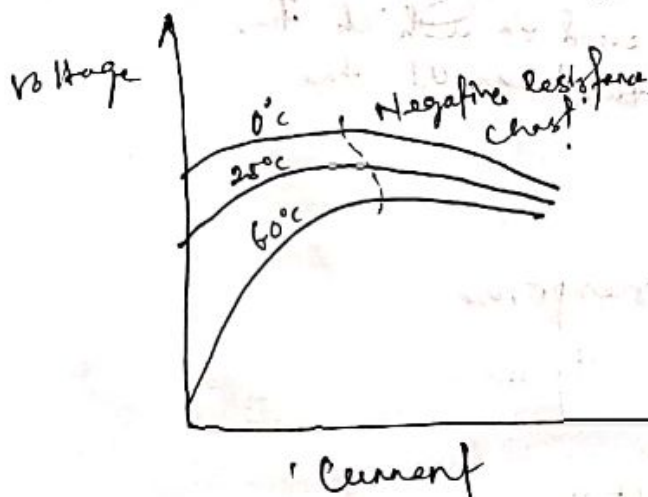
$$e = 2.718$$

B is constant over small ranges of T and it depends on the material used to make thermistor.

→ electrical power being dissipated within a thermistor will heat it above its ambient temperature & thereby reduce its resistance.



(ii) Voltage Current characteristics

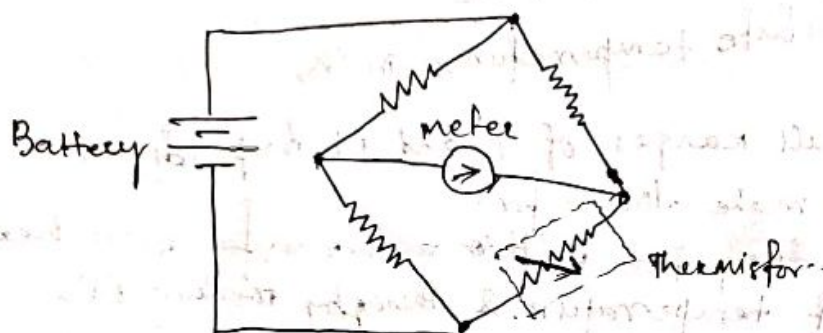


→ The voltage applied to a thermistor is small enough not to cause any rise in heat, it follows ohm's law.

→ If voltage is gradually decreased, the current will increase & the heat generated in the thermistor will finally begin to raise temperature above that surrounding.

Q.1 State the methods of temperature measurement by thermistor & their uses

- There are two main types of thermistor:
- 1. positive temperature co-efficient (PTC) &
 - 2. negative temperature co-efficient (NTC),
- & the characteristic of a thermistor is non-linear & cannot be characterized by a single co-efficient



- At balanced conditions, when there is no change in temperature the galvanometer indicates zero. As the temperature increases or decreases the resistance of the thermistor also decreases or increases due to which the Wheatstone bridge circuit becomes unbalanced.
- The electric current flows through the galvanometer which indicates on the calibrated scale. The deflection of the galvanometer can be calibrated as a temperature scale.
- For very accurate temperature measurement a differential bridge circuit is used in which two thermistors are connected as two legs of the Wheatstone bridge.

Advantages

- They have small sizes & fast response.
- They are suitable for narrow spans.
- Their cost is low.
- They exhibit a greater sensitivity.

Disadvantage

(28)

- i) Temperature versus resistance curve is very non-linear.
- ii) they are unsuitable for wide temperature spans.
- iii) Stability is doubtful at higher temperature over 316°C .
- iv) they are limited for process applications.

D. Pyrometer

- All the temperature - measuring methods discussed are physical contact of thermometer with the body whose temperature is to be measured.
- At high temperature above 1400°C the thermometer may melt due to direct physical contact.
- Pyrometer is a technique for measuring temperature without physical contact. It depends upon the relationship between the temperature of a hot body & the electromagnetic radiation emitted by the body.
- A body is heated, it emits thermal energy known as heat radiation. A black matt surface (or a black body) is a very good absorber of heat radiation & also a very good emitter of such radiation when heated.

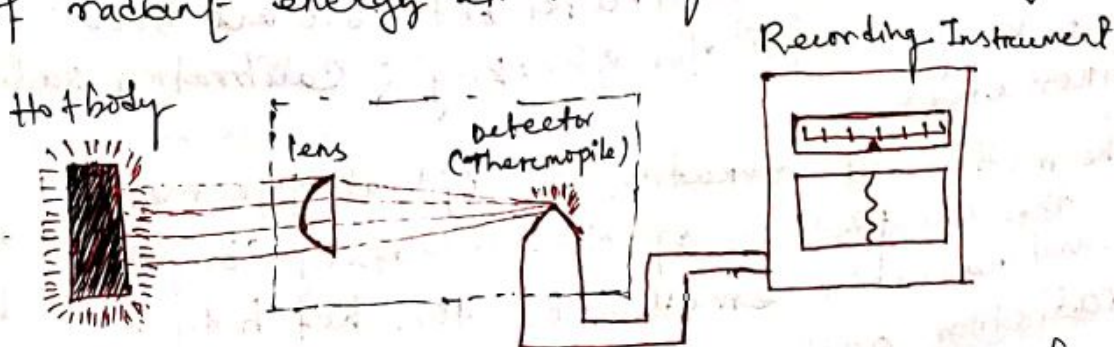
There are two types of pyrometer

① Radiation Pyrometer

② Optical Pyrometer

Radiation Pyrometer

- Operation of radiation pyrometer is based upon the measurement of radiant energy emitted by the hot body.



- The above diagram of a radiation pyrometer, it consists of a lens to focus radiated energy

from the body, whose temperature is required on to a detector or receiving element.

→ This element-receiving element may have a variety of forms such as resistance thermometer, or a thermocouple or thermopile.

→ A thermopile consists of several thermocouples connected in series. A temperature indicator, recorder or controller is attached with the receiving element to indicate the temperature.

→ When the total energy radiated by a hot body whose temperature is to be measured, enters the pyrometer, it is focussed by the lens on to the detector.

→ The detector is a thermopile whose measuring junctions are attached to a blackened disk. The disk absorbs energy when the pyrometer is focussed on a hot body and its temperature rises.

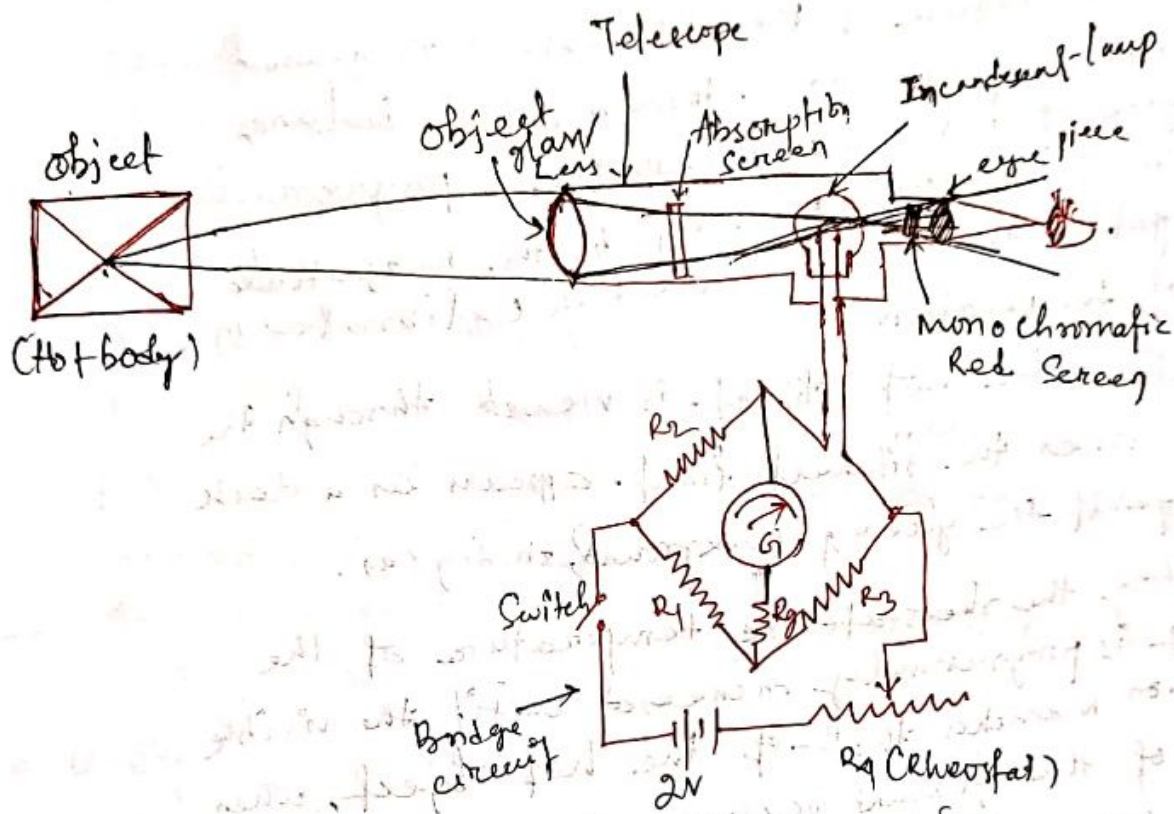
→ The reference junction of the thermopile is attached to the pyrometer case. The difference in temperature between the measuring junction attached to the disk & the reference junction - attached to the case generates a voltage that is directly related to the temperature of the blackened disk.

Optical Pyrometer

→ Optical Pyrometer provides an accurate method of measuring temperatures between 600 and 3000°C & are very useful for checking & calibrating radiation pyrometer.

→ The method of operation of optical pyrometer is based on the comparison of the intensity (brightness) of the visual radiation emitted by the hot body with the radiation emitted by the ~~hot body~~ source of known intensity.

→ The brightness (or intensity) of radiation emitted by the ⁽²⁵⁾ hot body whose temperature is to be measured is matched with the brightness of a calibrated reference (lamp) whose temperature is known. for the temperature range from 700 to 3000°C.



(a) Filament colder than background

(b) Filament invisible against background

(c) Filament hotter than background

→ An optical pyrometer consists of an incandescent lamp filament which is used as the reference source of radiation. This is arranged in the field of vision of a telescope through which both of (the filament) & the hot body, are viewed simultaneously.

→ the filament is heated by a 2 volt battery in series with a rheostat by which the temperature of the filament is adjusted. This filament is connected in one arm of a wheat-stone bridge

- Circuit across which is connected a moving coil galvanometer.
- the electrical resistance of the lamp filament varies in accordance with its temperature, while the resistance in other arms of the bridge are of a material, the ohmic value of which doesn't alter with change of temperature.
 - As the temperature of the filament is increased the bridge is progressively thrown out of balance. ~~The degree of is increased the bridge is progressively~~ the degree of unbalance is shown by the magnitude of the galvanometer deflection which is calibrated in terms of temperature.
 - In operation, the hot object is viewed through the telescope when the filament first appears as a dark line against the glowing background, as in fig (a).
 - On rotating the rheostat the temperature of the filament is progressively increased until the visible radiation matches that of the hot object, when the tip of the filament becomes invisible against the background, as shown in fig (b).
 - The temperature may be read off from the galvanometer provided that the rheostat is not moved after the temperature match is obtained. An absorption screen is used betw the object & the filament that reduces the intensity of the radiation from the object reaching the filament so that the filament may be matched to a hot man which is considerably higher temperature.
 - A monochromatic red screen is fitted to the eye piece so that it may be brought in to the field of vision at will.

E. Describe the function & use of temperature switch

(27)

- Temperature switches are the mechanisms used to measure temperature. The working of a temperature switch is based upon the temperature variations taking place in an enclosed space, or in an open area adjoining the temperature switch. & a pressure switch is almost same. Since both the devices get triggered by the variation in pressure.
- In many of the temperature switch designs, the temperature sensing element is positioned in such a way that the rise or drop in temperature results in the increase and decrease of internal pressure of liquid or gas such as in liquid filled temperature switches.
- This variation in pressure can then be used to actuate a switching mechanism.

Use of temperature switch

- Oil exploration.
- Radiator overheating.
- Battery chargers
- Hot Air Ballons

Question

1. What is the principle of thermometer? Which liquid is commonly used in the thermometer? What advantages does liquid have over other thermometer liquids?
2. What is a thermocouple? Name any two types of thermocouples.
3. Describe with the help of a diagram, the construction & working of a thermocouple type of pyrometer?

CHAPTER - 2

MEASUREMENT OF PRESSURE?

2.1 Classify methods of pressure measurement

Pressure

- Pressure is defined as the amount of force applied to a surface or distributed over it & is measured as force per unit area.
- The force used to calculate the pressure must act at a right-angle to the surface.
- If force acts at a slant, then only that part of it which acts at right angles is used to calculate the pressure.
- The part of the force which acts parallel to the surface does not contribute to pressure.

Unit of pressure

- pressure expressed in terms of pounds per square inch (PSI).

- the atmospheric pressure is approximately 14.696 psi (or 1 kg/cm²)

a) High pressure

1 newton per square metre (1 N/m²) = one

1 atmospheric pressure (1 atm) = 14.696 psi = 101.325 kPa

b) low pressure

1 milibar = 100 dyne/cm² = 14.5 × 10³ psi

1 micron = 10⁻⁶ mmHg = 19.34 × 10⁶ psi

1 torr = 1 mmHg = 1000 microns = 19.34 × 10³ psi

Different types of pressure

- a) Gauge pressure :- most liquid pressure gauge use atmospheric pressure (14.7 psi) as a zero point. i.e. they indicate a pressure of

Zero psi at the surface of a liquid even though the pressure is actually 14.7 psi.

→ A gauge that indicates zero at atmospheric pressure measures the difference betⁿ actual & atmospheric pressure. This difference is called gauge pressure.

b) Absolute pressure

→ Absolute pressure is actual total pressure (including atmospheric pressure) acting on a surface. It is act as psia.

c) Vacuum or Differential pressure

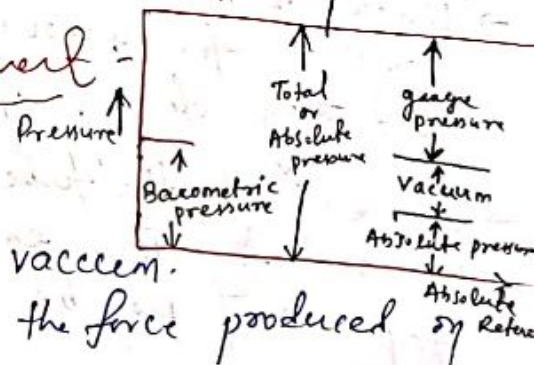
→ Gauges that indicate gauge pressure may be designed to indicate pressure below zero. Such a gauge is called a vacuum gauge. Gauges that indicate absolute pressure cannot indicate pressure below zero because zero is a perfect vacuum.

d) Static pressure and velocity pressure

When the fluid is in equilibrium, the pressure at the particular point is identical in all direction and independent of orientation. This called static pressure.

velocity pressure = Total pressure - static pressure.

* Methods of pressure measurement :-



- Manometer method.
- Elastic pressure transducer
- pressure measurement by measuring vacuum.
- pressure measurement by balancing the force produced on a known area by a measured force.
- Electrical pressure transducer.

2.2 Explain the working principle & use of mechanical methods of measurement by :-

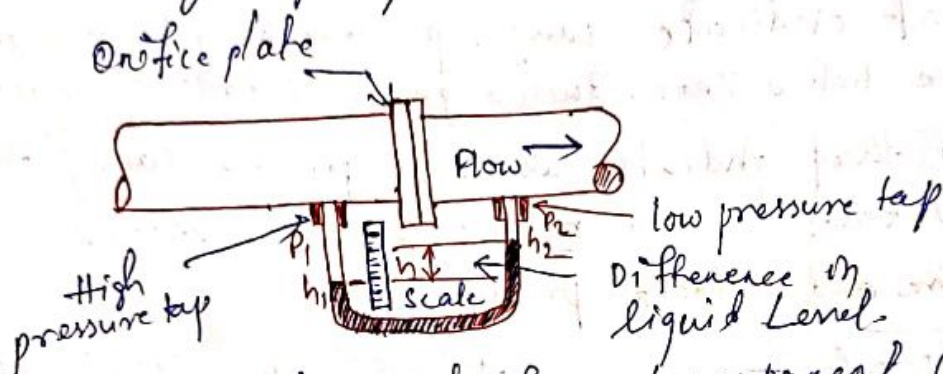
i) Manometer

→ The manometer is the simplest measuring instrument used for gauge pressure (low-range pressure) measurements, by balancing the pressure against the weight of a column

of liquid. The action of all manometers depends on the effect of pressure exerted by a fluid at a depth.

a) V-Tube Manometer

→ The V-tube is the simplest form of the manometer and is used for experimental work in laboratories. By suitable choice of liquids a wide range of pressure can be recorded.



→ Construction: It consists of a transparent (glass) tube constructed in the form of an elongated U and is partially filled with a liquid; most commonly water or mercury.

→ Water & mercury are used because their specific weights for various temperatures are known exactly and they do not stick to the tube.

→ One end of the tube is connected to one pressure tap and the other end is connected to the other pressure tap, or it may be left open to the atmosphere.

→ Working:

When there is a pressure difference betⁿ the two ends of the tube, the liquid level goes down on one side of the tube & up on the other side. The difference in liquid levels from one side to the other indicates the difference in pressure.

$$(P_1 - P_2) = (\rho - \rho_1) (h_1 - h_2) g$$

$$\boxed{P = (\rho - \rho_1) g h}$$

ρ = density of fluid in U-tube

ρ_1 = Density of fluid whose pressure is being measured.

$h = (h_1 - h_2)$, difference in fluid levels

g = acceleration due to gravity.

→ When a manometer is used to measure low pressure then water is used as the liquid & when it is used to measure high pressure then mercury is used as the liquid.

→ Mercury is almost 14 times as heavy as water. Therefore the difference in levels in a mercury-filled manometer is about $1/14$ of what it would be if water were in the tube.

Limitations

In the U-tube manometer, the application of pressure causes the liquid in one leg to go down while that in the other leg goes up, so there is no fixed reference.

Seen

by

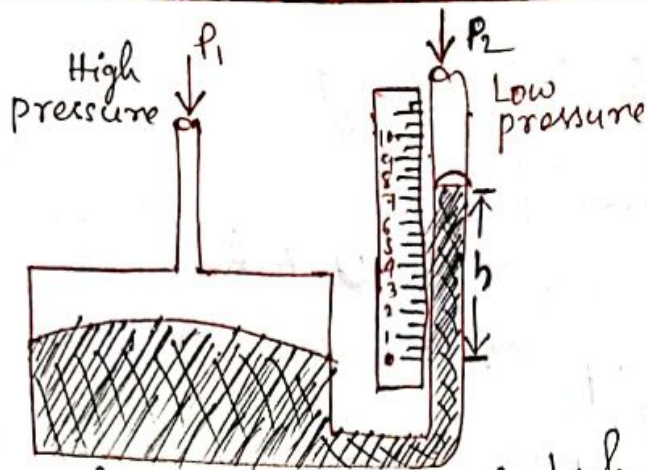
SHW

b) Well-type manometer :-

* The well-type manometer is widely used because of convenience. The reading of only a single is required in it. It consists of a very large-diameter vessel (well) connected on one side to a very small sized tube.

* Thus the zero level moves very little when pressure is applied. Even this small error is compensated by suitable distortion of the length of scale.

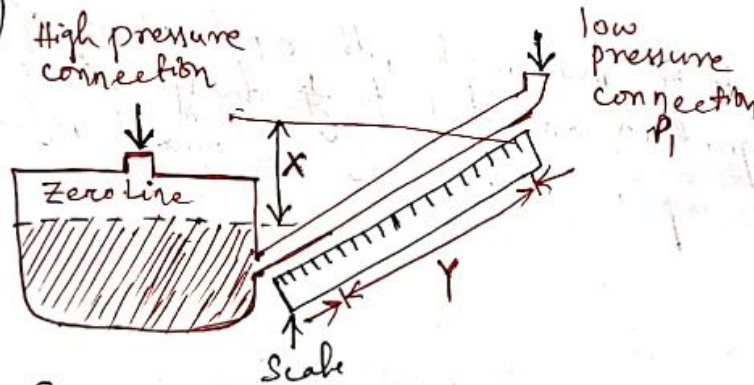
→ This arrangement is sensitive to non-uniformity of the tube cross-sectional area and is thus considered somewhat less accurate.



→ In a single-leg instrument, high accuracy is achieved by setting the zero level of the well at the zero level of the scale before each reading is taken.

c) Inclined manometer

- The inclined tube manometer or staff manometer is an enlarged leg manometer with its measuring leg inclined to the vertical axis by some angle.
- The angle of inclination is of the order of 10° . The inclination is done to expand the scale and thereby to increase the sensitivity.



- The inclined manometer is used to measure very small pressure differences (in hundredths of an inch of water). The manometer is tipped so that the liquid moves a larger distance through the tube as it rises.
- The distance y that the liquid moves through the tube is greater than the distance x that the liquid rises.

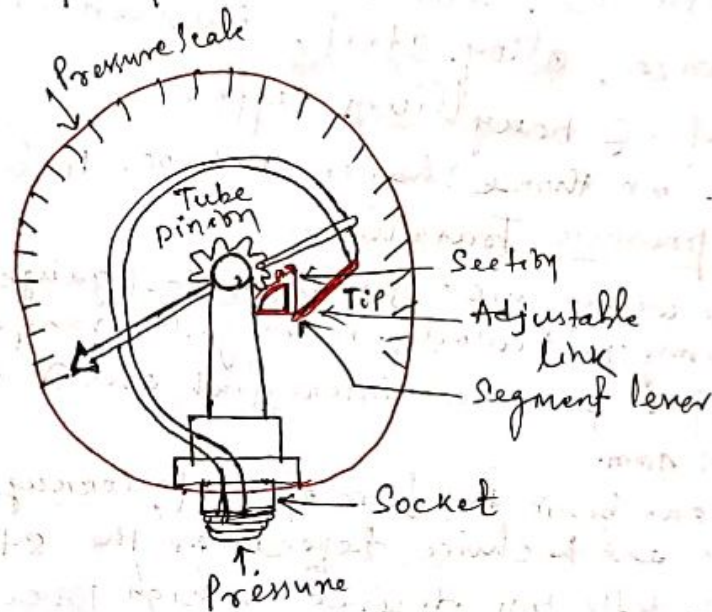
(i) Elastic pressure Transducer

a) The C-type Bourdon Tube pressure Gauge

→ The Bourdon tube is the most frequently used pressure gauge because of its simplicity and rugged construction. It covers range from 0-15 psig to 0-100,000 psig, as well as vacuum from 0 to 30 inches of mercury.

Construction and working:

→ A C-type Bourdon tube consists of a long thin-walled cylinder of non-circular cross-section, sealed at one end, made from materials such as phosphor bronze, steel and beryllium copper, and attached by a light-line work to the mechanism which operates the pointer.



→ The other end of the tube is fixed and is open for the application of the pressure which is to be measured. The tube is soldered or welded to a socket at the base through which pressure connection is made.

→ As the fluid under pressure enters the Bourdon tube, it tries to change the section of the tube from oval to circular and this tends to straighten out the tube.

→ The resulting movement of the free end of the tube causes the pointer to move over the scale. The tip of the Bourdon tube is connected to a segmental lever through an adjustable length link.

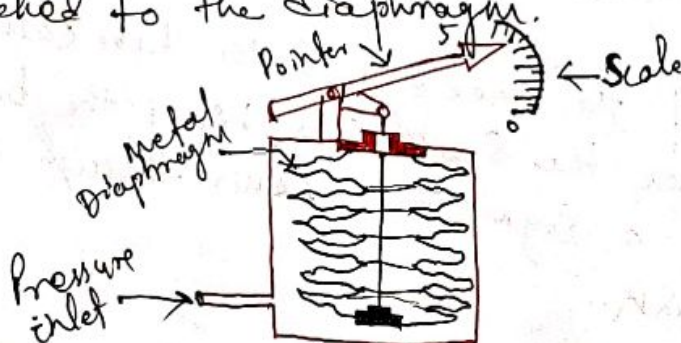
- The lever length also may be adjustable. The segmental lever end on the segment side is provided with a rack which meshes to a suitable pinion mounted on a spindle.
- The Segmental lever is suitably pivoted and the spindle holds the pointer. A hair spring is sometimes used to fasten the spindle to the frame of the instrument to provide the necessary tension for proper meshing of the gear teeth, thereby freeing the system from backlash.
- Bourdon tubes are made of a number of materials depending upon the fluid & pressure such as phosphor bronze, alloy steel, stainless steel, monel metal & beryllium copper.
- also we make in three shapes C-type, Helical & spiral

⑥ Diaphragm pressure Transducer

- Diaphragm are widely used for pressure (gauge pressure) and draft measuring; particularly in very low ranges. They can detect a pressure differential even in the range of 0 to 4 mm.
- The diaphragms can be in the form of flat, corrugated or dished plates and the choice depends on the strength and amount of deflection desired. In high precision instruments the diaphragms are generally used in a pair, back-to-back to form an elastic capsule.
- Diaphragm elements can be made to cause change in electrical circuits thus converting pressure ~~meas.~~ movement to electrical signal.

④ Metallic Diaphragm Gauge

- It consists of a thin flexible diaphragm made of the materials such as brass or bronze. A pointer is attached to the diaphragm.

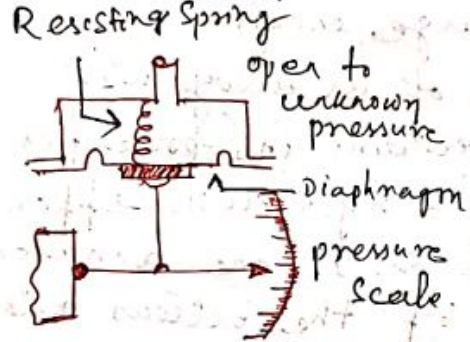


→ The force of pressure against the effective area of the diaphragm causes a deflection of the diaphragm. In some case the diaphragm of the diaphragm is opposed by the spring qualities of the diaphragm itself and in other cases a spring is added to limit the deflection.

→ The motion of the diaphragm operates an indicating or a recording type of instrument. It is used for installation in moving equipments such as aircrafts.

(2) Slack Diaphragm Gauge :-

→ It is more difficult to measure pressure below the atmospheric pressure because the changes are small. The full range from the atmospheric pressure to a perfect vacuum is only 14.7 psi (1 kg/cm²)



→ pressure in this range can be measured with a slight modification of the diaphragm. A diaphragm with a large area produces a large change in force from a small change in pressure.

→ Making the diaphragm slack rather than tight allows it to move a large distance in response to a small pressure change.

→ A slack diaphragm can be made of rubber or other flexible materials.

Advantage

- Their cost is moderate.
- They possess high over-range characteristics.
- They are adaptable to absolute and differential pressure measurement.
- They have good linearity.
- They are available in several materials for good corrosion resistance.

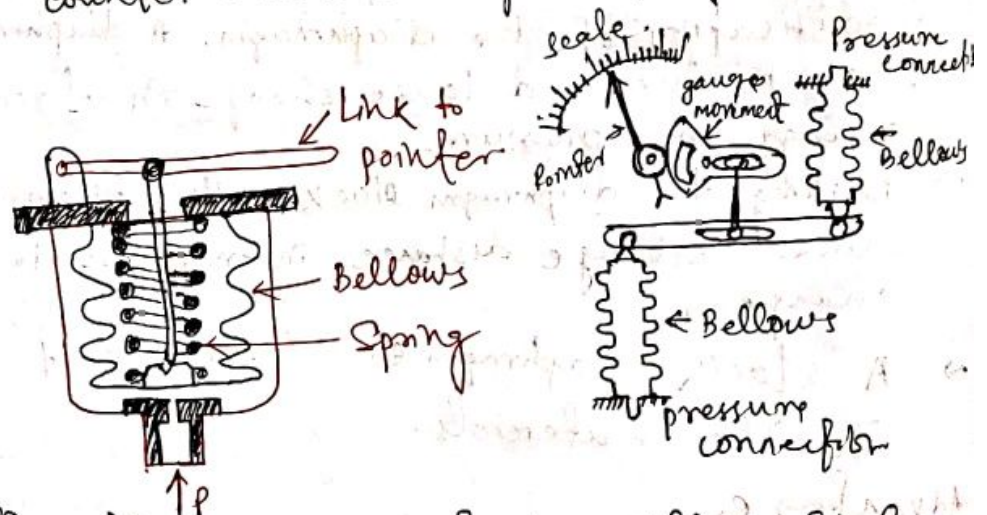
- They are small in size.
- They are adaptable to Shunt Services.

Disadvantages

- They lack good vibrating & shock resistance.
- They are difficult to repair.
- They are limited to relatively low pressures.

C. Bellows

- The bellows-type gauges are used for the measurement of absolute pressure (normal as well as low pressure). It is some what more sensitive than Bourdon-tube gauge.
- It is generally used for the range down to 155.14g (3psi). It may be used for even lower pressures up to 40 mm Hg by making the bellows large enough.
- The bellows are made of an alloy which is ductile, has high strength and retains its properties over long use i.e. has very little hysteresis effect.
- They are used in two forms. In one arrangement, pressure is applied to one side of the bellows and the resulting deflection is counter-balanced by a spring.



- In another differential arrangement the differential pressure is also indicated. In this device one pressure is also indicated. In this device, one pressure is applied to the inside of one sealed bellows while the another pressure is applied to the inside of another sealed bellows.

→ Spring - opposed bellows elements are very sensitive & are quite useful in working signalling and tripping devices because of the considerable amount of movement for a given change in pressure.

→ For larger static pressures (up to 2000 psi) & large differentials pressure up to 50 psi).

Advantage

- its cost is moderate.
- it is able to deliver high force.
- it is adaptable for absolute & differential pressure.
- it is good in the low - to moderate pressure range.

Disadvantage

- it is unsuitable for high pressures.
- the availability of metals and work-hardening of some of them is limited.

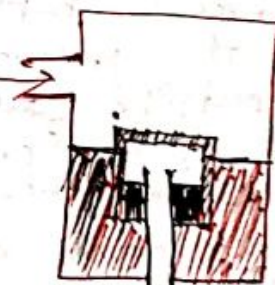
(iii) Bell type of pressure Gauge

→ In the bell type of pressure gauge, the force produced by the difference of pressure on the inside and outside of a bell is balanced against a weight or against the force produced by the compression of the spring.

* There are two types of bell gauges:

a) Thick wall Bell gauge :-

→ It consists of a bell suspended with the open end downwards. low ch a sealed chamber, usually pressure made of cast iron, containing 12 psi a liquid such as oil or mercury.



↑ High pressure P_1 psi.

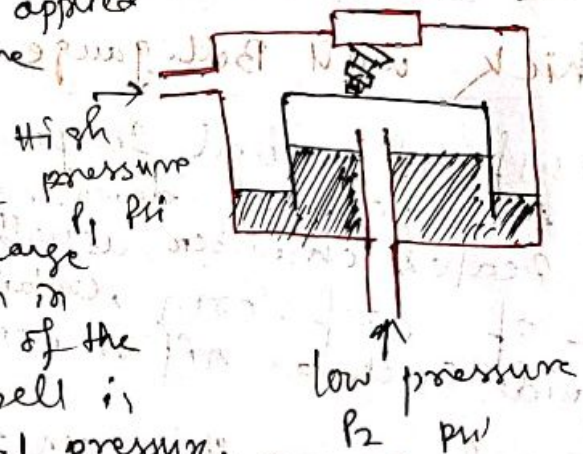
→ The liquid covers the open end of the bell and acts as a seal, forming two chambers. In this type of instrument, gravity provides the controlling force.

→ The higher pressure is led in to the inside and the lower pressure acts on the outside of the bell. The resulting forces cause the bell to rise until equilibrium is reached between the upward force and the apparent weight of the bell.

- As the bell rises, a small portion of it is immersed in the sealing liquid so that the upward thrust on it due to buoyancy is reduced.
- its apparent weight will therefore increase. Now, since the pressure within the bell is greater than that outside it will cause the level of the liquid on the outside of the bell to be ~~greater~~ greater than the level on the inside, as well as causing the bell to rise.
- Now, travel of the bell is proportional to the differential pressure to be measured. The thickness and density of the material of which the bell is made its cross-sectional area and the density of the sealing liquid are determined by the range of pressure for which the instrument is meant to be used.

b) Thin wall Bell Gauge

- In this type of instrument, the bell is made of thin material and the controlling force is obtained by means of a spring.
- the high pressure is usually applied to the outside of the bell & the low pressure to the inside.
- The difference betn the force due to the pressure acting on the outside causes the change in length of the spring, which in turn changes the position of the bell. The travel of the bell is proportional to the differential pressure.
- In this type of instrument the range is determined by the modulus of elasticity of the spring and the density of the sealing liquid.



23. Explain the working principles & use of electrical method of measurement of pressure by:-

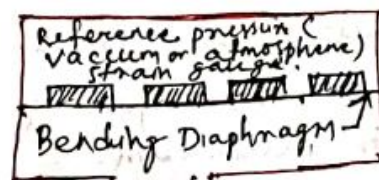
- In general a transducer is a device which convert one form of energy into another form of energy. However in the field of electrical instrumentation a transducer is defined as a device which convert a physical quantity, a physical condition, or mechanical output into an electrical signal.
- Most of the methods of converting mechanical output into an electrical signal work equally well for the bellows, the diaphragm and the Bourdon tube.
- mechanical motion is first converted into a change in electrical resistance & then the change in resistance is converted into a change in electrical current or voltage.
 - i) pressure sensing element such as a bellows, a diaphragm, or a Bourdon tube.
 - ii) primary conversion element e.g. resistance or voltage.
 - iii) secondary conversion element.

a) Strain gauge pressure transducer

→ strain gauge is a passive type resistance pressure transducer whose electrical resistance changes when it is stretched or compressed. It can be attached to a pressure sensing diaphragm.

* Basic principle

- The strain gauge is a fine wire which changes its resistance when mechanically strained, due to physical effects. A strain gauge may be attached to the diaphragm so that when the diaphragm flexes due to the process pressure applied on it.
- The strain gauge stretches or compresses. This deformation of the strain gauge causes the variation in its length and cross-sectional area due to which its resistance also changes.



→ The resistance change of a strain gauge is usually converted into voltage by connecting one, two or four similar gauges as of a Wheatstone bridge known as strain gauge bridge and applying excitation to the bridge. The bridge output voltage is then a measure of the pressure sensed by the strain gauges.

Construction & working

- A bridge circuit with four strain gauges R_{g1} , R_{g2} , R_{g3} & R_{g4} . Two strain gauges R_{g1} & R_{g4} are mounted so that increasing pressure increases their resistance.
- strain gauges R_{g2} & R_{g3} are mounted so that increasing pressure decreases their resistance. A change in temperature affects all the four strain gauges in the same way, resulting in no change in the pressure indication.
- At balance, when there is no pressure, no current flows through the galvanometer G , and hence there will be no deflection in the galvanometer.
- The pressure is applied the strain gauge stretches & compresses accordingly and the bridge circuit is unbalanced due to the change in resistance of the strain gauge.
- A current flows in the galvanometer, which is measured by the deflection of the galvanometer. These changes affect the output of the bridge circuit which indicates a change in measured pressure. This change in output voltage may be calibrated for the pressure change.

Advantages

- i) they are small & easy to install.
- ii) They have good accuracy.
- iii) they are available for wide range of measurements (from vacuum to 200,000 psi).
- (iv) they possess good stability.
- v) They have high output signal strength.
- vi) they have high overrange capacity.
- vii) They are simple to maintain.
- viii) they contain no moving parts.
- ix) they possess good shock & vibration characteristics.

- x) they are readily adaptable to electronic systems.
- xi) they possess fast speed of response.

Disadvantages

- i) Their cost. is moderate to high (could be offset by reduced installation cost).
- ii) Electrical read out is necessary in these transducers.
- iii) they require constant voltage supply.

B) Capacitive pressure transducers

* Basic principle

The principle of operation of capacitive pressure transducer is based upon the familiar capacitance equation of the parallel plate capacitor.

$$C = \frac{\epsilon_0 \epsilon_r A}{d}$$

C = the capacitance of a capacitor in farad.

A = area of each plate in m^2 .

d = distance betⁿ the two plates in m

$\epsilon_0 = 8.854 \times 10^{-12}$ Farad/m

ϵ_r = dielectric constant (relative permittivity)

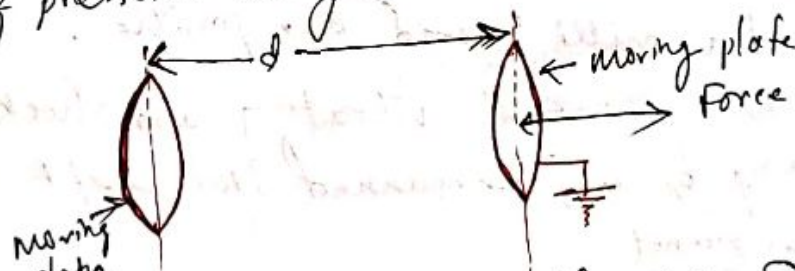
Thus, capacitance of a capacitor varies

- i) the area A of the plate is changed.
- ii) the distance d betⁿ the two plates is changed.
- iii) The dielectric constant ϵ_r is changed.

→ The capacitance of a parallel plate capacitor is inversely proportional to the spacing betⁿ the plates. This.

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

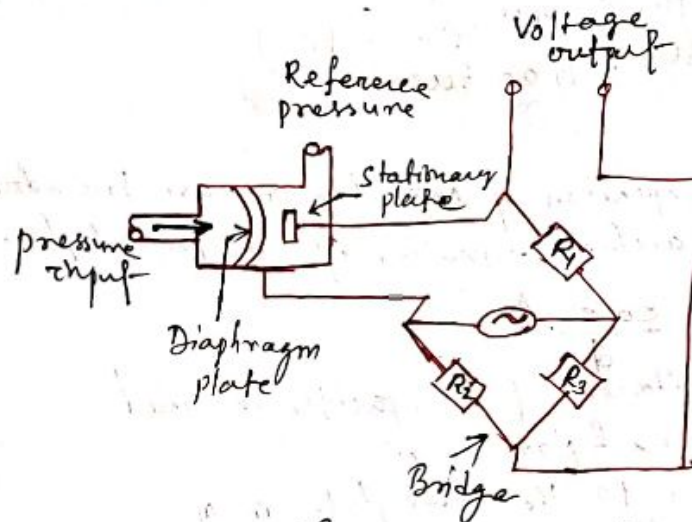
→ This is used in the capacitive pressure transducer for detecting pressure changes.



* construction and working:

→ It consists of a fixed plate & a movable plate which is free to move as the pressure applied changes. According to the change in pressure the movable plate also changes its position, due to which the distance d is changed.

- With an increase in pressure (as $C \propto 1/d$). With an increase in pressure, the distance d becomes less, due to which the capacitance C is increased (as $C \propto 1/d$).
- With a decrease in pressure, the distance d increases & thus capacitance C is decreased. This change in capacitance can be calibrated to measure the change in pressure.



- In place of a movable plate a diaphragm may be used which expands and contracts due to change in pressure. The diaphragm plate acts as a movable plate of a capacitor.
- A fixed plate is placed near the diaphragm. These plates form a parallel plate capacitor which is connected as one of the arms of a bridge.
- Any change in pressure causes a change in distance between the diaphragm and fixed plate, which unbalances the bridge. The voltage output of the bridge corresponds to the pressure applied to the diaphragm plate.

Advantages

- i) It gives rapid response to change in pressure. Response time as short as ten milli seconds are possible.
- ii) It can withstand a lot of vibration and shock, as in a hard landing by an unmanned spacecraft on the surface of a planet.
- iii) It is extremely sensitive.
- iv) It has good frequency response.

Disadvantages

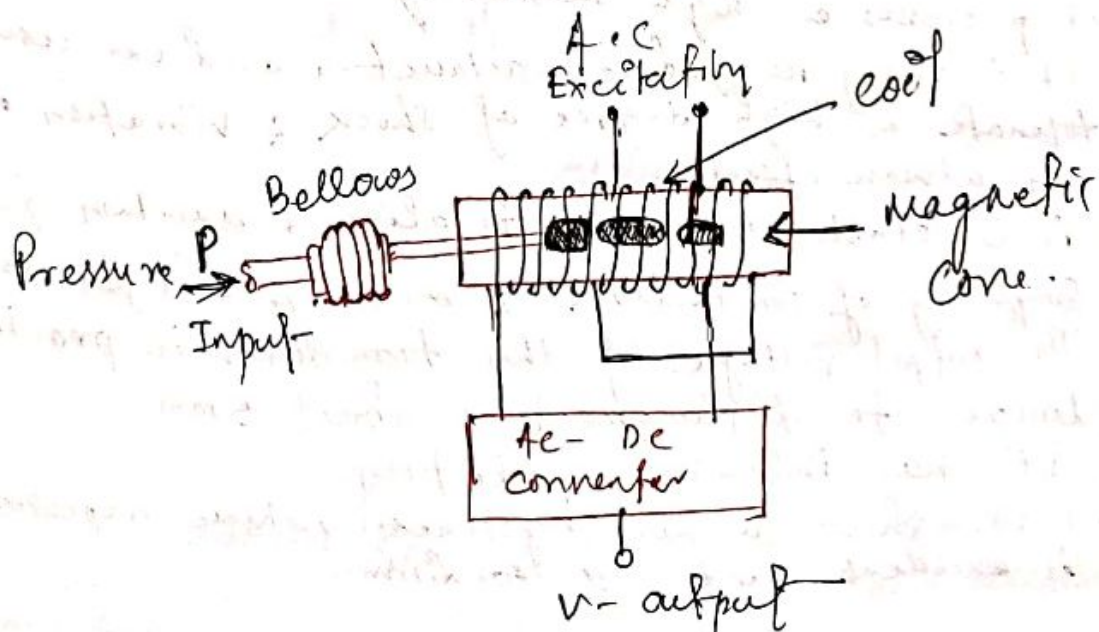
- i) The metallic parts of the capacitor must be insulated from each other.
- ii) The performance of a capacitive transducer is severely affected by dirt & other contaminants.
- iii) The sensitivity of a capacitance transducer is adversely affected by change in temp.

c) Reluctance pressure Transducer

- Reluctance in a magnetic circuit is equivalent to resistance in an electrical circuit. The spacing (or coupling) betⁿ two magnetic devices (or coils) changes, the reluctance betⁿ them also changes.
- Thus a pressure sensor can be used to change the spacing betⁿ two coils by moving one part of the magnetic circuit.
- This motion changes the reluctance betⁿ the coils, which in turn changes the voltage induced by one coil in the other. The change in the induced voltage can be interpreted as a change in pressure.

a) Linear Variable Differential Transformer (LVDT)

- It is the most widely used inductive transducer to translate linear motion into an electrical signal.



Construction and Working

- It consists of a primary winding (or coil) and two secondary windings (or coils). The windings are arranged concentrically next to each other.
- They are wound over a hollow bobbin which is usually of a non-magnetic & insulating material. A ferromagnetic core (armature) is attached to the transducer sensing shaft (such as bellows).
- The core is ~~generally~~ generally of a high permeability ferromagnetic alloy & has the shape of a rod or cylinder.
- An AC excitation is applied across the primary and the movable core varies the coupling betⁿ it and the two secondary windings. When the core is in the centre position, the coupling to one secondary and hence its output voltage increases while the coupling and the output voltage of the other secondary decreases.
- Any change in pressure makes the bellows expand or contract. This motion moves the magnetic core inside the hollow portion of the bobbin. It causes the voltage of one secondary winding to increase, while ~~simultaneously~~ ^{simultaneously} reducing the voltage in the other secondary winding.
- The difference of two voltages appears across the output terminals of the transducer and gives a measure of the physical position of the core and hence the pressure.

Advantage

- i) it possesses a high sensitivity.
- ii) it is very rugged in construction and can usually tolerate a high degree of shock & vibration without any adverse effects.
- iii) it is stable and easy to align & maintain due to simplicity of construction; small size & light body.
- iv) The output voltage of this transducer is practically linear for displacements of about 5mm.
- v) It has infinite resolution.
- vi) It shows a low hysteresis, hence repeatability is excellent under all conditions.

Dis advantages

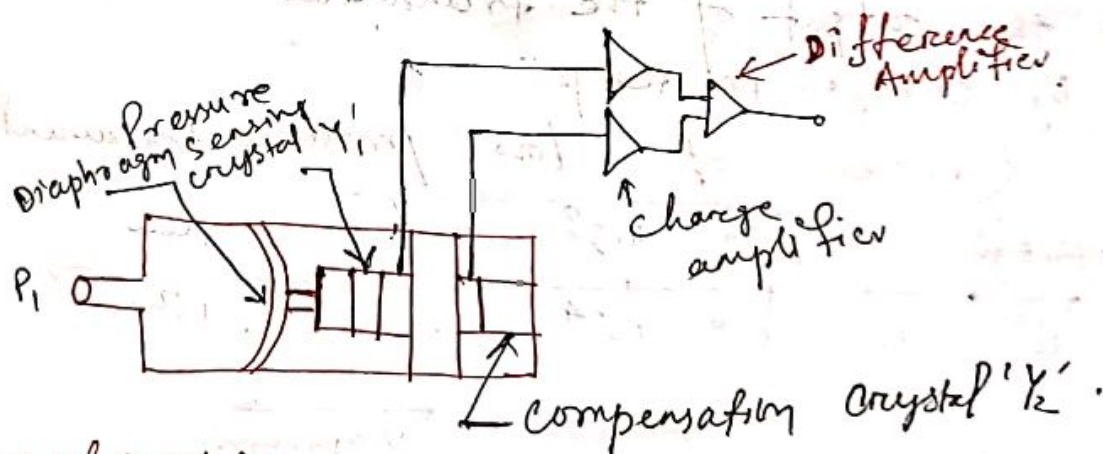
- Relative large core are required for appreciable amount of differential output.
- They are sensitive to stray magnetic fields but shielding possible
- Temperature affects the performance of the transducer

Q1) Piezoelectric pressure transducer

- These devices utilize the piezoelectric characteristics of certain crystalline and ceramic materials (such as quartz) to generate an electrical signal.

Basic principle

- Such transducer depend upon the principle that when pressure is applied on piezoelectric crystal (such as quartz) an electrical charge is generated.
- There are about 40 crystal-line materials that, when subjected to a squeeze, generate an electrical charge. Some of the piezoelectric materials are barium titanate sintered powder, crystal of quartz, tourmaline, & Rochelle.



Construction and working

- It consists of a diaphragm by which pressure is transmitted to the piezoelectric crystal Y_1 . This crystal generates an electrical signal which is amplified by a charge amplifier.
- A second piezoelectric crystal Y_2 is included to compensate for any acceleration of the device during use. This compensation is needed because rapid acceleration of the transducer creates additional pressure on

the piezoelectric crystal. vibration is of high, rapidly changing acceleration.

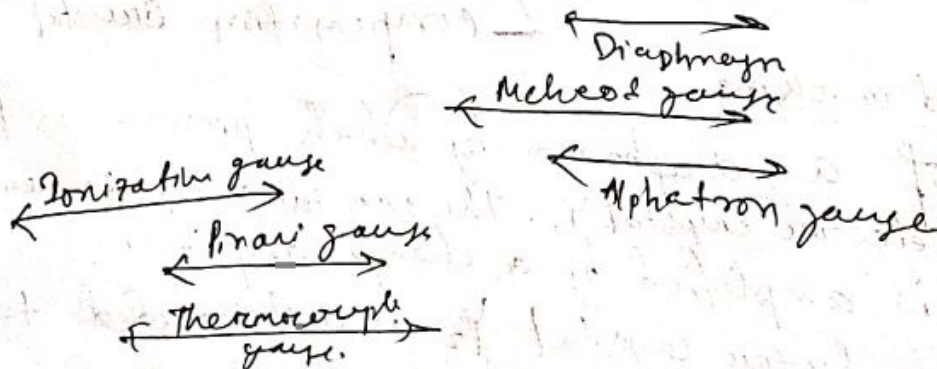
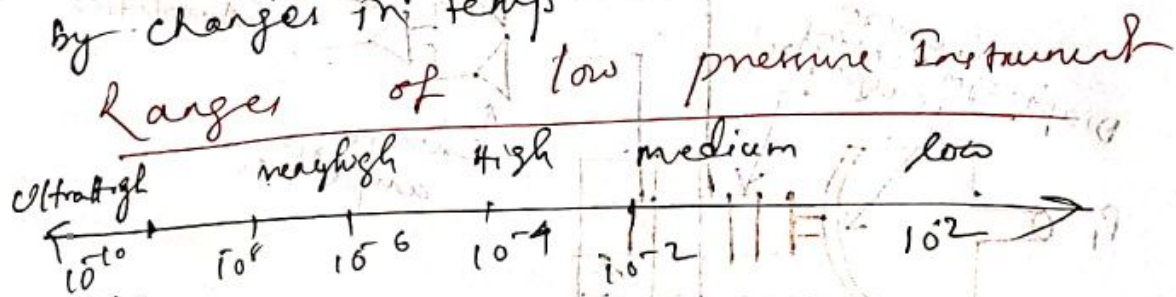
- Signals from the compensating crystal, are amplified by a second charge amplifier. A different amplifier is used which subtracts pressure along all effects of acceleration are removed.
- Piezoelectric pressure transducer are used to measure very high pressures that change very rapidly.
- Ranges up to 0-50000 psi

Advantages

- the transducer needs no external power and is therefore self-generating (active type)
- it has a very good high-frequency response.

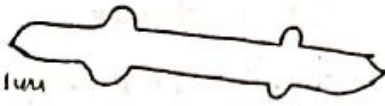
Disadvantages

- this type of transducer cannot measure static pressures.
- the output of the transducer is affected by changes in temp.



2.4 Describe the operation & Explain the working principle of vacuum gauge.

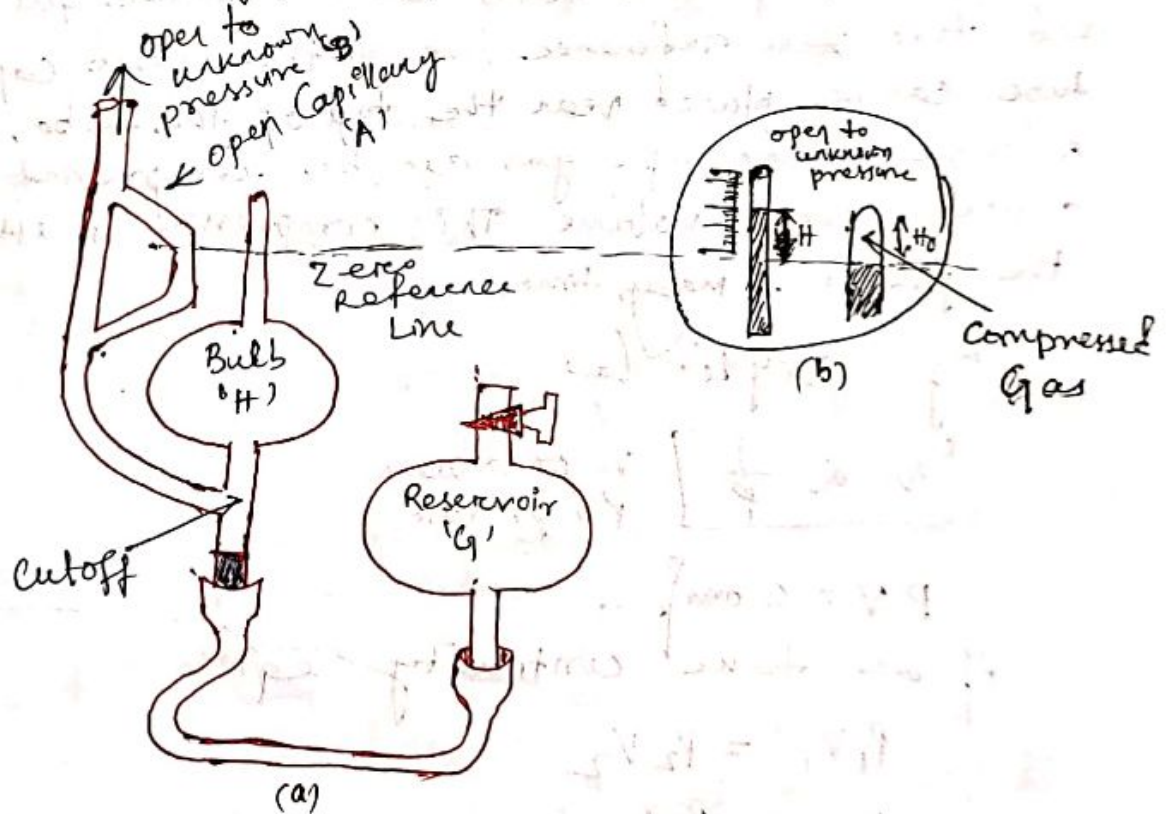
→ Capsule is used for vacuum pressure measurement.



→ It is possible to obtain pressure from 100 mbar down to 10 mbar.

McLeod Gauge

→ The McLeod gauge is used for measuring very low pressures down to one hundred-thousandth of an inch of mercury (or 10 mbar down to 10^{-3} mbar). The McLeod gauge amplifies pressure by compressing a gas into a small volume. The pressure of the compressed gas is then measured with a mercury manometer.



Construction & working

- A McLeod gauge is connected to the unknown gas whose pressure measurement is required. The gas enters the gauge through B and fills the tubes down to the level of the mercury reservoir.
- The pressure is equal throughout the tubes and the bulb mercury is pumped up from the reservoir G. At the mercury rise above the cutoff, it traps gas inside the bulb.

- The mercury is then pumped higher in the gauge ~~and~~ until all the gas in the bulb is compressed into the closed capillary tube.
- The operator allows the mercury to rise until it reaches a zero reference line on the closed capillary tube. the mercury rises faster in the open capillary tube.
- The compressibility of gas in the closed capillary tube makes the pressure of the trapped gas higher than the measured pressure.
- ~~The compression of gas in the~~ This pressure difference cause a difference in the mercury levels in the two tubes. The difference in height is used to calculate the pressure.
- The volume of the bulb can be made quite large and the zero reference line on the closed capillary tube can be placed near the top of the tube. Thus a large volume of gas can be compressed into a very small volume. This compression multiplies the pressure many times.

By Boyle's law

$$V \propto \frac{1}{P}$$

V_2 volume
 P_2 pressure

$$PV = \text{const.}$$

if we take continuity eqn

$$P_1 V_1 = P_2 V_2$$

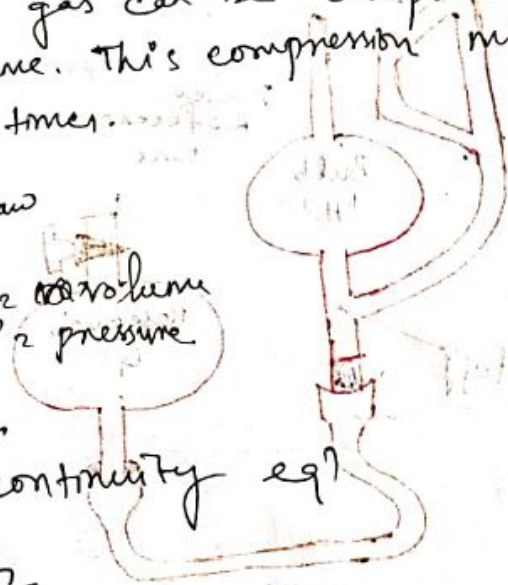
$$PV = P_c V_c$$

$$V_c = a_c \times h_c$$

$$P_c = h_c \rho_m + P$$

$$\begin{aligned} P V &= (h_c \rho_m + P) a_c h_c \\ &= \cancel{P a_c h_c} + a_c h_c^2 \rho_m \end{aligned}$$

$$\Rightarrow P [V - a_c h_c] = a_c h_c^2 \rho_m$$



$$P = \frac{a_c h^2 \rho_m}{V - a_c h}$$

P = measured pressure

V = volume of air is known

V_c = capillary air volume

a_c = area of capillary

h = height of capillary or equal mercury height.

ρ_m = Density of mercury.

→ The McLeod gauge is a very accurate pressure-measuring device and often serves as a standard for calibrating other low pressure gauge.

(B) Thermal-Conductivity Gauge

→ Thermal conductivity gauge measure pressure by measuring the changes in the ability of a gas to conduct heat. The ability of a material to carry heat by conduction is called 'thermal conductivity'.

→ The conductivity of a gas does not change when the pressure changes until the pressure drops below about one torr. As the pressure continues to drop, the conductivity of gas decreases and the gas loses its ability to conduct heat.

→ ~~the relationship between changes in conductivity~~

→ At low pressure the conductivity of a gas has a direct relationship to its pressure. Working range of pressure 10^{-4} torr up to about 10^{-2} torr.

Basic operating principles

→ A pressure gauge based on changes in thermal conductivity is made by enclosing a wire filament in a chamber connected to the pressure source.

→ When voltage is applied to the filament electricity flows making it hot. The rising temperature increases the resistance of the filament. The filament then reaches an 'equilibrium temperature' the temperature at which heat is produced in the filament as fast as it is removed. Heat is removed by both radiation & conduction. connection is so tight that it can be ignored.

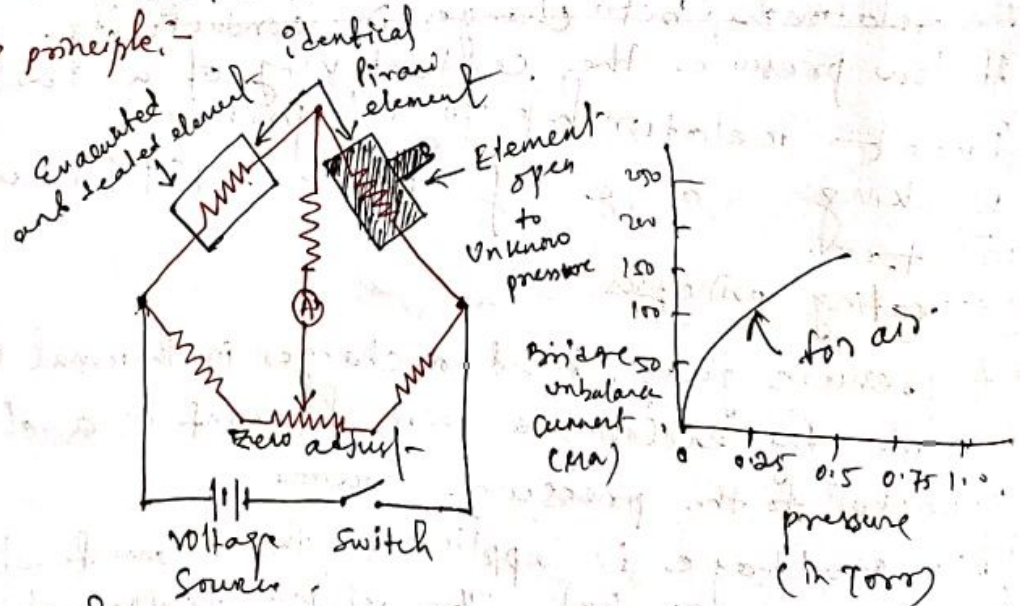
- The voltage applied to the filament is held constant and any change in pressure cause a change in conductivity of the gas surrounding the filament.
- The change in conductivity changes in the resistance equilibrium temperature of the filament, which in turn causes the change in the resistance. Therefore, the change in resistance is used to indicate the pressure change.
- An increase in conductivity due to an increase in pressure increases the flow of heat away from the filament decreasing the temperature of the filament. A decrease in conductivity (due to decrease in pressure) increases the filament temp.

Two types →

a) Pirani Gauge

- It consists of two wire filaments. one filament serves as a reference and is sealed in an evacuated glass. While the other filament is kept in a container connected to the source of pressure. These two filaments are connected in a bridge circuit.

operating principle:-



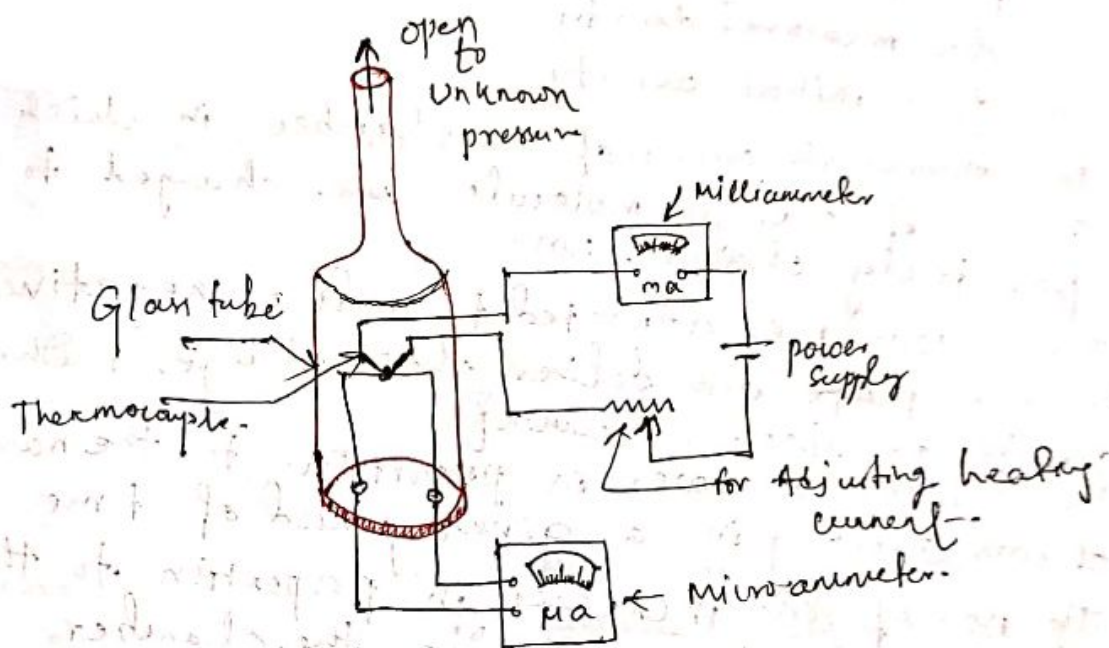
- If the resistance of the two pirani elements are equal no current flows through the ammeter. But if the flow through the ammeter changes current will
- This current flow indicates a change in pressure of the gas being measured. A curve kept the bridge unbalance

current (ma) & the pressure (torr). Pirani gauge are used for the pressure range about 10^5 to 1 torr.

→ ~~gases~~ Because gases differ in heat conductivity, the gauge must be calibrated for the gas being measured.

(b) Thermocouple Gauge

→ The thermocouple gauge works on the same basic principle as the pirani gauge. The only difference is that the filament temperature is measured by a thermocouple.



→ It requires careful calibration, but once calibrated it is as accurate as the pirani gauge. A curve betw. thermocouple current (ma) & pressure (torr): Thermocouple gauge are used for the pressure range from about 10^4 to 1 torr.

Disadvantage

→ Both the pirani gauge & thermocouple gauge are easily damaged by organic vapours. The filaments can become coated with a deposit of decomposed vapours which alters the way the filament transfers heat.

C) Ionization Gauges

- An ionization gauge measures the density of a gas. The operating principle of the ionization gauge follows Boyle's law, i.e. at constant temperature the ratio of pressure of two gases is equal to the ratio of their ~~two~~ two densities.

$$\frac{P}{P_1} = \frac{\rho}{\rho_1}$$

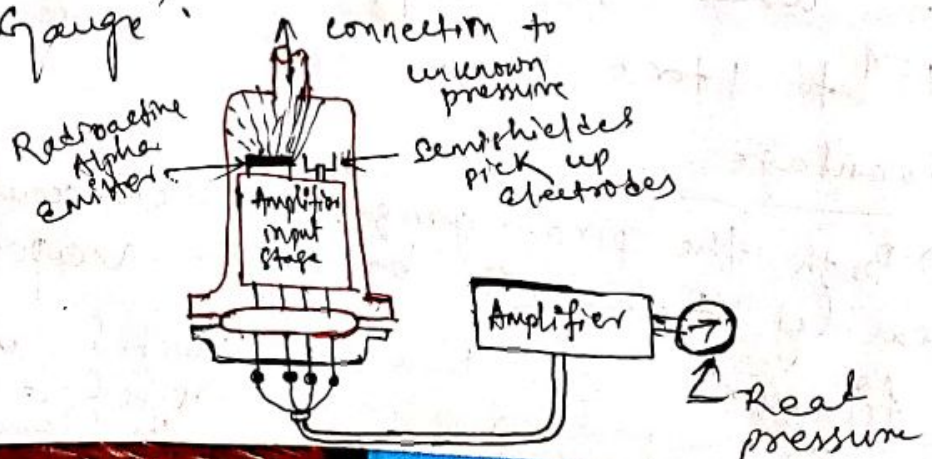
P = measured pressure

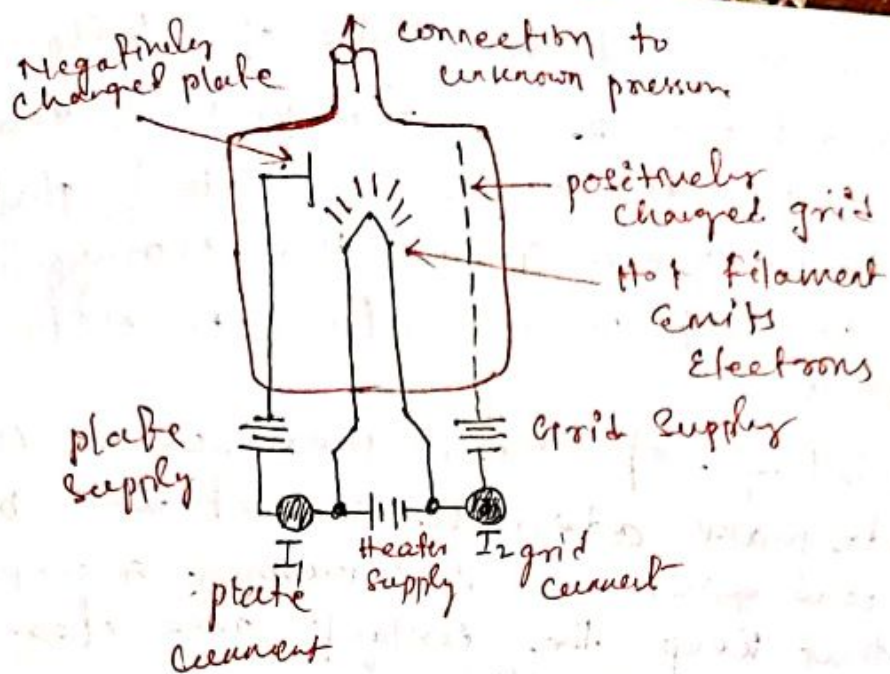
P_1 = initial pressure

ρ = measured density

ρ_1 = initial density

- This instrument consists of a chamber in which some of the gas molecules are charged to positively charged ions.
- These ions are attracted towards a negatively charged plate and deliver their charge, which creates an electric current.
- The current increases in proportion to the number of ions arriving in a given period of time. The no. of ions increases in proportion to the density of the gas inside the chamber.
- Thus the pressure is measured proportional to the relative density. There are two methods used to produce gas ions. In the first method, a stream of alpha (α) particles are produced from a radioactive source. An ionization gauge using alpha radiation is known as "Alphatron Gauge".





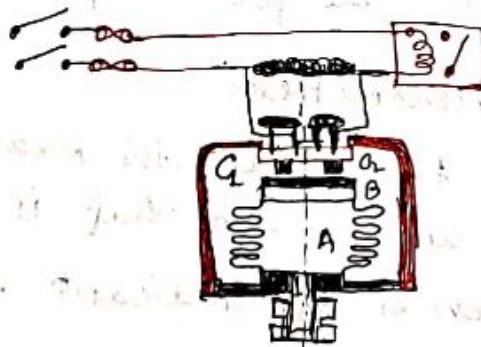
$$P = \frac{1}{S} \frac{I_1}{I_2}$$

S is sensitivity

→ In the second method, a stream of electrons, produced from a red hot filament are attracted towards a positively charged grid of wire. Any positively charged ions produced due to collision of electrons with gas molecules are attracted towards the negatively charged plate. A hot filament ionization gauge such works on this principle.

2.5 Pressure Switch

→ A pressure switch turns an electric circuit 'ON' or 'OFF' at a preset pressure. This pressure is called the set point of the switch. A pressure switch is used in some form of control eg to operate a solenoid valve at a given pressure or ~~start~~ start up a pump.



→ The pressure switch is usually a micro switch or a mercury switch. A Bourdon tube, a diaphragm or a bellows can be used to actuate the switch. Simplest form of a pressure switch used to actuate a pump.

→ The pressure is fed to the inside of a bellows which carries a contact plate B. When the pressure reaches a sufficient (or preset) value the contact plate touches contact point C & D thus closing an electrical circuit to an alarm or motor control gear.

→ The flexibility of the bellows ensure that the plate makes adequate contact with both points and gives a slight rubbing or wiping action that keeps the contact area clean.

uses of pressure switches

→ One of the most important use of the pressure switch is in limiting pressure e.g. in steam power plants. The pressure of the steam entering a turbine must not exceed an upper limit. The pressure switch is used to operate a safety valve which vents steam when the pressure exceeds the upper limit.

→ In another important use of the pressure switch is in the computer panel. In the computer panel, blowers are used for cooling purposes. Whenever the blower fails due to any reason, a pressure switch is actuated which cuts off the power supply of the panel.

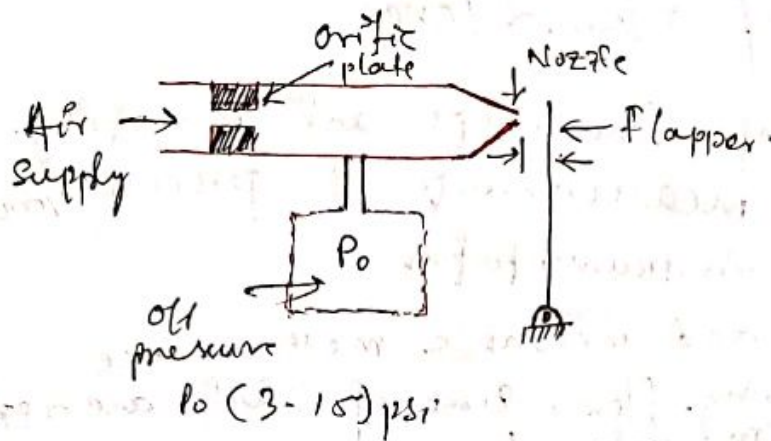
* Pneumatic pressure Transmitters

→ A pneumatic transmitter translates the measured value (from sensors) into an air pressure that is transmitted to various receiver devices for indication, recording, alarm & control.

Flapper nozzle

→ A pneumatic control system operates with air. The signal is transmitted in the form of variable air pressure (often in the range of 0.2 to 0.1 bar)

(3-15) psi that initiates the control action.



- Constant air pressure is supplied to one end of the pipeline. There is an orifice at this end. At the other end of the pipe, there is a nozzle and a flapper. The gap between the flapper & the nozzle is set by the input signal.
- As the flapper moves closer to the nozzle there will be less air flow through the nozzle & the air pressure inside the pipe will increase. On the other hand, if the flapper moves further away from the nozzle the air pressure decreases.
- At the extreme of the nozzle is open (flapper is far off) the oil pressure is equal to atmospheric pressure of the nozzle is blocked. The output pressure will be equal to the supply pressure.

Chapter - 3

3 Measurement of Flow & Level

→ measurement of flow rate and quantity is the oldest of all measurements of process variables in the field of instrumentation.

→ Many accurate and reliable methods are available for measuring flow, some of which are applicable only to liquids, some only to vapours and gases & some others to both. Fluids to be measured may be clear or opaque, clean or dirty, wet or dry, erosive or corrosive.

3.1 classify flow meter and explain the principle of operation with diagram?

i) Inferential type flowmeter

- a) variable head or differential meters
- b) variable area meters
- c) Magnetic meters
- d) Turbine meters
- e) Target meters
- f) Thermal flowmeters
- g) Vortex flowmeters
- h) Ultrasonic flowmeters.

~~ii) positive displacement meters~~

ii) Quantity flowmeters

- a) positive displacement meters
- b) metering pumps

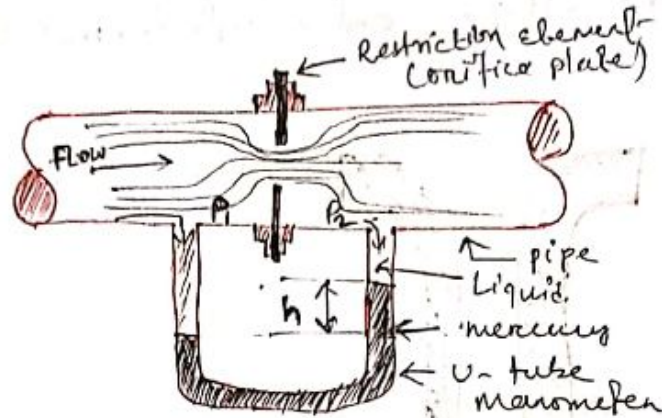
(iii) Mass flowmeter.

3.2 Variable head type Flowmeter:

→ This is one of the oldest and most widely used methods of industrial flow measurement. It measures volume rather than mass flow rates, but mass rate can be calculated or computed easily by knowing or sensing temperature & pressures.

Basic operation

- Variable head flowmeters operate on the principle that a restriction (or obstruction) in the line (or pipe) of a flowing fluid, introduced by the orifice plate or venturi tube or elbow, produces a differential pressure across the restricting element which is proportional to the flow rate.



- The proportionality is not a linear one but has a square root relationship in that the flow rate is proportional to the square root of the differential pressure.
- This relationship was derived from Bernoulli's theorem which states that in a flowing stream, the sum of the pressure head,
- The velocity head and elevation head at one point is equal to their sum at another point removed in the direction of flow from the first point plus the loss due to friction betw the two points.
- velocity head is defined as the vertical distance through which a liquid would fall to attain a given velocity.
- pressure head is the vertical distance through which a column of the flowing liquid would rise in an open-end tube as a result of the static pressure.

$$V = K \sqrt{\frac{2gh}{f}}$$
$$Q = KA \sqrt{\frac{2gh}{f}}$$

$$W = KA \sqrt{\frac{2gh}{f}}$$

v = velocity of flowing fluid.

Q = volume flow rate.

W = mass flow rate.

A = cross-sectional area of pipe through which fluid is flowing.

h = differential head (pressure) across the restriction element.

g = acceleration due to gravity.

f = density of the flowing liquid.

Reynolds Number

→ Reynolds number is a very important reference number in the accurate determination of flow. It is used to determine the point at which the flow goes from the viscous to the turbulent stage.

→ As the flow changes from viscous to turbulent all vice versa, there is a very marked change in the value of the flow coefficient, but there is very little change with further increase in speed.

→ If very high degrees of accuracies are desired, other head meters are employed.

$$R_D = \frac{VD\rho}{\mu}$$

R_D = Reynolds number

V = average velocity

D = inside pipe diameter

ρ = density of flowing fluid.

μ = absolute viscosity.

Advantages

→ It is relatively low especially for large lines.

iii) it offers the widest application coverage of any type of meter.

(iii) it is accurate ($\pm 1\%$ to $\pm 2\%$) & reliable

iv) it can be easily removed without shutting down the process

v) it is adaptable to any pipe size & flow rate.

Disadvantages

→ There is relatively high permanent pressure loss in it

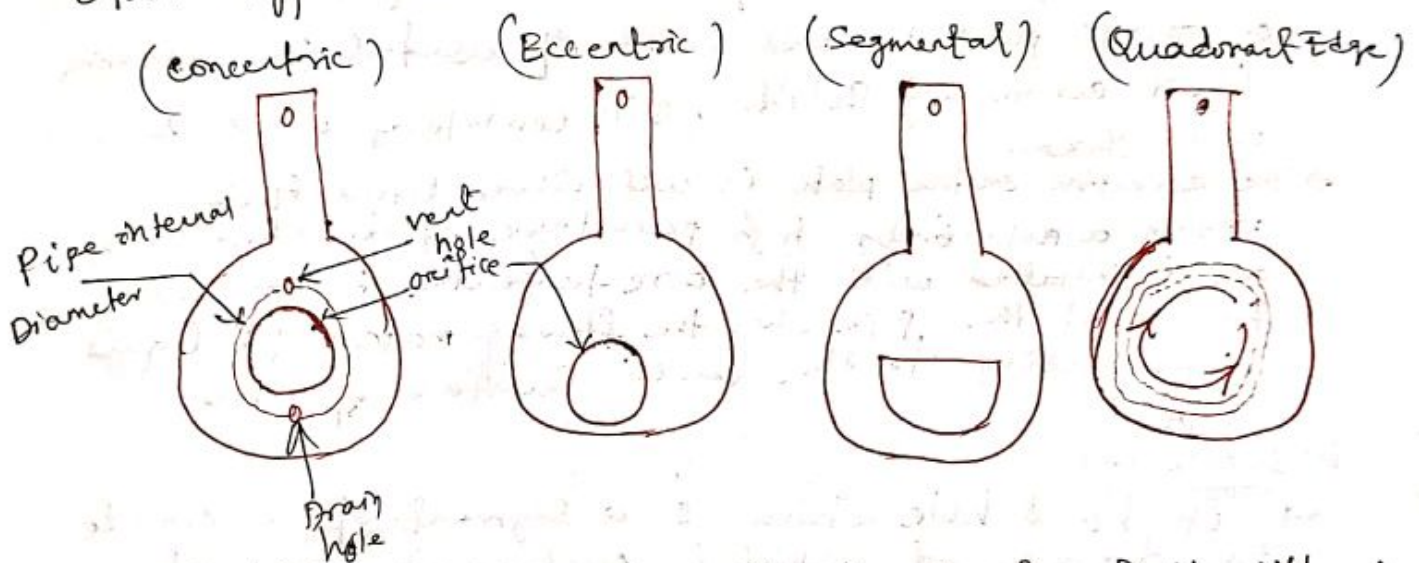
→ it is difficult to use for slurry services.

→ it exhibits square root relationship bet head & flow rate.

→ it is difficult to measure pulsating flow with this type of meter.

i) Orifice plates

→ Orifice are the simplest and cheapest form of primary elements and are used more frequently than all other types.



→ An orifice plate is inserted in the line & the differential pressure across it is measured. There are types of orifice plates which are:

- a) concentric orifice plate.
- b) Eccentric "
- c) Segmental "
- d) Quarter edge "

- i) concentric orifice plate
- it is most widely used. it is usually made of stainless steel and its thickness varies from 3.175 to 12.7 mm ($\frac{1}{8}$ to $\frac{1}{2}$ in). depending on pipe line size and flow velocity.
 - it has a circular hole in the middle of it. If it is installed in the pipeline with the hole concentric to the pipe, it is also made from other materials such as nickel, monel, phosphor bronze etc.
 - to withstand the corrosive effects of the fluid. The plate thickness at the orifice edge should not exceed.

ii) Eccentric orifice plate

- it is similar to the concentric plate except for the offset hole which is bored tangential to a circle, concentric with the pipe and of a diameter equal to 98% of that of the pipe.
- Location of the bore prevents clogging of solid material or foreign particles and makes it useful for measuring fluids containing solids, oil containing water & wet steam.
- The eccentric orifice plate is used where liquid fluid contain a relatively high percentage of dissolved gas, and is installed with the bore tangential to the upper surface of the pipe when the flowing material is liquid & tangential to the lower surface of the pipe.

iii) segmental

- It has a hole which is a segment of a circle the diameter of which is customarily 98% of the pipe diameter.
- It is installed with the diam horizontal & with the curved section of the opening coincident with the lower surface of the pipe.

iv) Quadrant Edge

- This type of orifice plates is used for flows such as heavy crudes, slurries & slurries & viscous flows. It is constructed in such a way that the edge is rounded to form a quarter-circle.
- The plate has a concentric opening with a rounded to upstream edge rather than the sharp square edge normally used.

→ it may be used when the line Reynolds number ranges from 100,000 or above down to 3,000 to 5,000.

Advantages

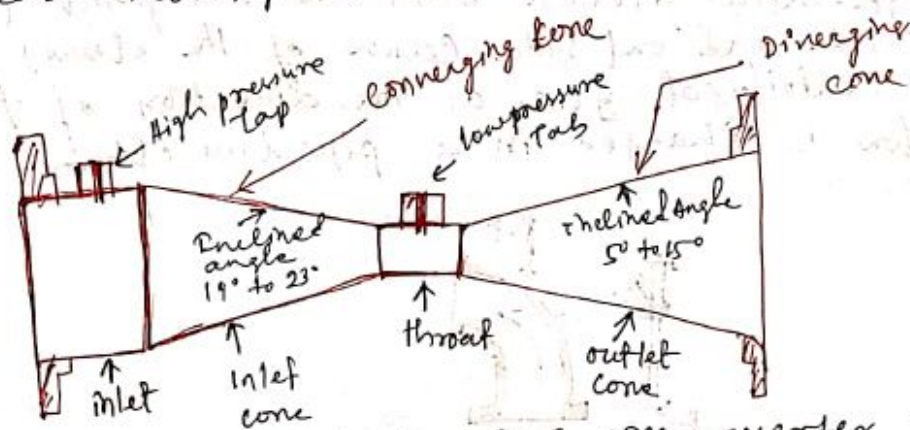
- its cost is low
- They can be used in a wide range of pipe sizes.
- They can be used with differential pressure devices.
- They are well-known and have predictable characteristics.
- They are available in many materials.

Disadvantages

- They cause relatively high permanent pressure loss.
- They tend to clog, thus reducing use in slurry services.
- They have square root characteristics.
- Their accuracy is dependent on care during installation.
- They have choking characteristic because of erosion, corrosion & sealing.

b) Venturi tube

- A venturi tube is used where permanent pressure loss is of prime importance, and where maximum accuracy is desired in the measurements of high viscous fluids.
- it consists of a straight inlet section of the same diameter as the pipe in which the high pressure tap location of the decreased pressure in an area where flow velocity is neither increasing nor decreasing.
- A diverging recovery cone in which velocity decreases & the decrease velocity head is recovered as pressure head.



- The pressure taps are located one-quarter to one-half pipe diameter up stream of the inlet cone and at the middle of the throat section.
- The venturi tube can be used to handle a fluid which is handled by an orifice plate and fluids that contain some solids, if contains no sharp corner & don't projectible into the fluid stream, it can be also used to handle

slurries and dirty liquids that build up around other primary elements, if the pressure taps are protected from plugging.

→ These are usually made of cast iron or steel. Venturi co-efficient less affected by a decreasing Reynolds number.

Advantages

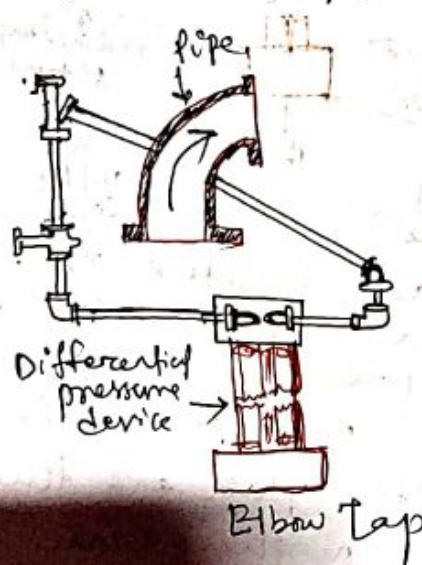
- It causes low permanent pressure loss
- It is widely used for high flow rates
- It is available in very large pipe sizes.
- It has well-known characteristics.
- It is more accurate over wide flow ranges than orifice plates or nozzles.
- It can be used at low & high beta ratios.

Disadvantages

- It cost is high.
- It is generally not used below 76.2 mm pipe size.
- It has the limitation of a lower Reynolds number of 150,000.

E) Elbow Taps

→ The flow measurement using elbow taps as a primary element, depends on the measurement of the differential pressure betn. the two points (the inside and out-side corners of the elbow) developed by centrifugal force as the direction of fluid flow is changed in a pipeline elbow.



- The taps are located at opposite ends of diameter in the plan of the elbow, and the diameter which passes through the taps is at either 45° or 22.5° from the elbow face.
- Elbow taps are rarely used. if accuracy is poor, varying from ± 5 to $\pm 10\%$

Advantages

- i) The elbow taps are easy to add to existing installation where elbow exist.
- ii) its cost is comparatively low.
- iii) it allows no additional pressure loss.
- iv) with the elbow taps there are no obstruction in the line.
- v) it has good repeatability.

Disadvantages

- its accuracy is poor.
- Differential pressure developed is relatively small.

Weirs

- weirs are used to measure flow rate primarily on open channels such as water works including irrigation, waste and sewage systems, and in pipes and conduits that are generally not completely filled with liquid.
- it is an obstruction in a flowing stream over which the liquid is made to pass. with the use of weir, flow rates can be measured from a few gallons per minute to millions of gallons per day.
- there are three types of weirs such as rectangular, v-notch & Cippolletti or trapezoidal.



Rectangular



v-notch



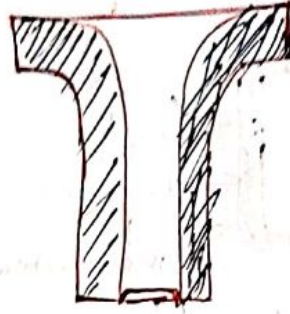
Cippolletti

Advantages

- i) its cost is low
- ii) it can be constructed on location when being used
- iii) it is not easily damaged.

C) Flow nozzles

- The flow nozzles are used for flow measurements at high fluid velocities and are more rugged and more resistant to erosion than the types of flow nozzles, the long-radius flow nozzles.
- A flow nozzle consists of a convergent inlet whose shape is a quarter ellipse, and a cylindrical throat,



- Differential pressure measurement taps are normally located one pipe diameter upstream and one-half diameter downstream from the inlet faces of the nozzle.
- For a given diameter and a given differential pressure, it allows measurement of flow rates almost 65% more than that of the orifice plate.
- Flow nozzles are manufactured commonly from stainless steel, chrome-nickel steel. Flow nozzles should not be used at Reynolds number down to 6000.

Advantages

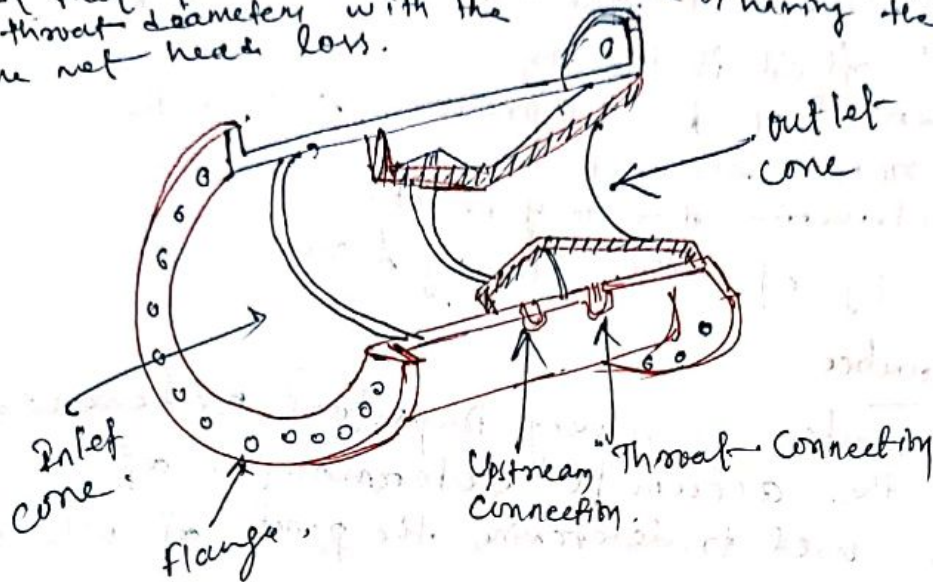
- i) Its permanent pressure loss is lower than that for an orifice plate.
- ii) It is available in numerous materials.
- iii) It is useful for fluids containing solids that settle.
- iv) It is widely accepted for high-pressure & temperature steam flow.

Disadvantage

- Its $C_{d,f}$ is higher than orifice plate.
- It is limited to moderate pipe sizes.
- It requires more maintenance.

Dall tubes

- The dall tube is a modified form of venturi tube, a cross-section of.
- it consists of two truncated cones each with a relatively large cone angle. the throat is formed by a circumferential slot located betⁿ the two smaller diameters of the truncated cone.
- the differential pressure produced by a dall tube is much higher than that of venturi tube or nozzle, having the same upstream & throat diameters with the same net head loss.



- The dall tube can be used in circumstances where the velocity of flow through the pipe is such that, with a specified head loss, it is not possible to design a venturi tube to generate a sufficiently large differential head to operate a recovery instrument.

Advantage

- The dall tube has a low head loss.
- it has a short length.
- Dall tube is available in numerous materials of construction.
- The dall tube has no upper line-size limit.

Disadvantage

- its pressure difference is sensitive to up-stream disturbances.
- more straight pipe requires in the approach pipe length.
- it is not considered for measuring flow of hot fluid.

- The taps are located at opposite ends of diameter on the plan of the elbow, and the diameter which passes through the taps is at either 45° or 22.5° from the inlet face.
- Elbow taps are rarely used. if accuracy is poor varies from ± 5 to $\pm 10\%$.

Advantages

- i) The elbow taps are easy to add to existing installation where elbow exist.
- ii) its cost is comparatively low.
- iii) it allows no additional pressure loss.
- iv) with the elbow taps there are no obstructions in the line.
- v) it has good repeatability.

Disadvantages

- its accuracy is poor.
- Differential pressure developed is relatively small.

Weirs

- weirs are used to measure flow rate primarily in open channels such as water works including irrigation, waste and sewage systems, and in pipes and conduits that are generally not completely filled with liquid.
- it is an obstruction in a flowing stream over which the liquid is made to pass. with the use of weir, flow rates can be measured from a few gallons per minute to millions of gallons per day.
- there are three types of weirs, such as rectangular, v-notch & cippolletti or trapezoidal.



Rectangular



v-notch



Cippolletti

Advantages

- i) its cost is low.
- ii) it can be constructed on location when being used.
- iii) it is not easily damaged.

Disadvantages

- i) It is applicable only to open-channel measurements
- ii) It's field calibration is required
- iii) It's accuracy is poor (generally not over 2 to 3%).

Flumes

- The flume (known as parshall flumes) is a special type venturi-flume developed by the Colorado agricultural experiment station, and is used essentially for the same purpose as the weirs.
- It is considered more practical than weirs because it's loss of head is about one-fourth that of a weir.

Advantages

- i) It handles greater flow than weir.
- ii) It can be constructed on location
- iii) It is easy to construct as all its sections are plane surfaces.
- iv) Its dimensions are not easily altered to cause incorrect measurements.

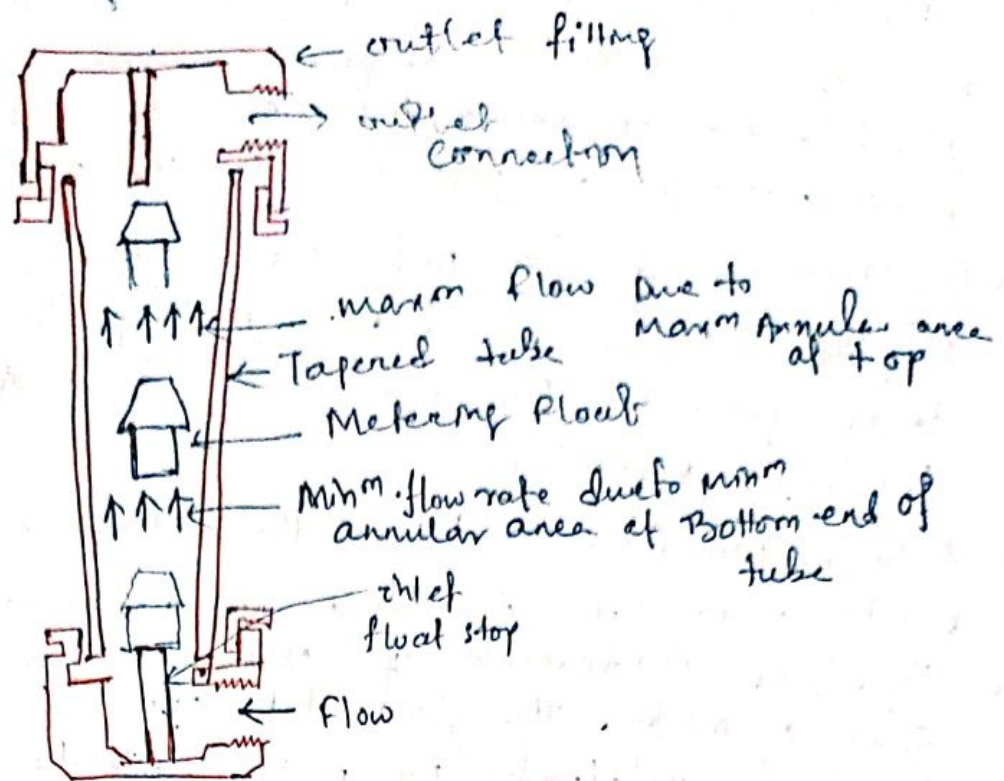
Disadvantages

- i) It is more expensive than weir.
- ii) It requires calibration.

3.3 Variable area flowmeters.

Rotameters

- The rotameter is the most extensively used form of the variable area flowmeter. It consists of a vertical tapered tube.
- The tube made tapered so that there is a linear relationship betn the flow rate & position in the float within the tube.
- The free area betn float and inside wall of the tube forms an annular orifice. The tube is mounted vertically with the small end at the bottom.



- The fluid to be measured enters the tube from the bottom and passes upward around the float, and exits at the top.
- When there is no flow through the rotameter, the float rests at the bottom of the metering tube where the max diameter of the float is approximately the same as the bore of the tube.
- When fluid enters the metering tube, the float moves up, and the flow area of the annular orifice increases. The pressure differential across the annular orifice is proportional to the square of its flow area and to the square of the flow rate.
- The float is pushed upward until the lifting force produced by the pressure differential across its upper & lower surface is equal to the weight of the float.
- If the flow rate rises, the pressure differential and hence the lifting force increases temporarily and the float then rises, widening the annular orifice until the force caused by the differential is again equal to the weight of the float.

- The pressure differential remain constant and the area of the annular orifice (i.e. the area betw float and inside wall of tube) to which the float moves, changes in proportion to the flow rate.
- Any decrease in flow rate causes the float to drop to a lower position. Every float position corresponds to one particular flow rate for a fluid of a given density & viscosity.
- A calibration scale printed on the tube or near it, provides a direct indication of flow rate.
- The tube materials of rotameters may be glass or metal. The glass tube are commonly used for relatively low pressure and temperature service of non-hazardous fluids such as water and air.
- For high pressure the glass is not used because the glass can be broken easily. Metal tubes are used. For indication, such as magnetic or electronic indication which is the linear motion of the float is converted into a rotary motion by movement of a point on a scale.
- The majority of application of rotameters are for low viscosity fluid, corrections must be provided for the changes in fluid density & specific weight.
- Rotameters can smoothly measure flows as high as 4000 gpm (920 ltr/hr).

Advantage

- its cost is relatively low.
- Rotameters have good rangeability.
- it is good for metering small flows.
- it is easily equipped with alarm switches & transmitting devices.

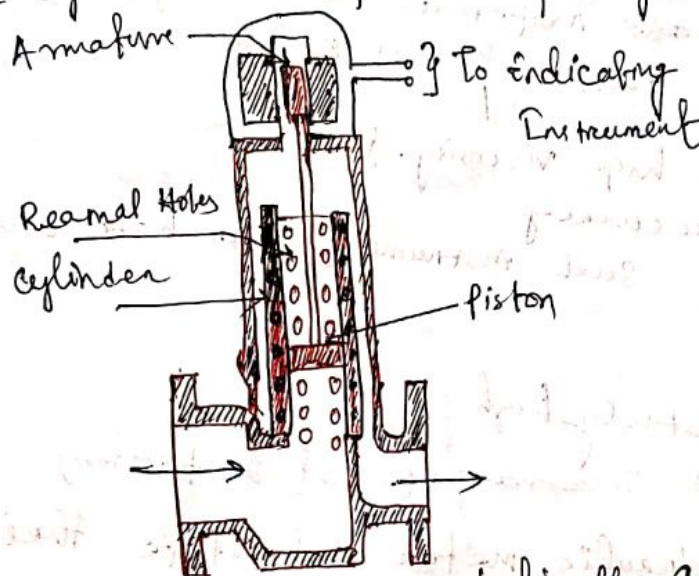
- it handles wide variety of corrosives.
- it can be used in some light slurry services.
- viscosity - immune floats are available in rotameters.
- it has low pressure drop requirement.

Disadvantages

- the glass tube type is easily subject to breakage.
- it must be mounted vertically.
- it is not good in pulsating services.
- Rotameter are generally limited to small pipe sizes.
- Rotameter are limited to low temp.
- the accuracy about $\pm 1/2$ to $\pm 10\%$.

Cylinder and piston Type Flowmeters

- The cylinder and piston type variable area flowmeter is most oftenly used for measuring flow of fuel oils, tar, chemical liquors, and other such high viscosity fluids.
- it consists of a cylinder and a piston fitted into it. A series of reamed holes are provided in the walls of the cylinder to provide passage for fluid flow.



- These holes are spaced helically around the cylinder in rows, to provide a continuous variation in area for various heights of the piston.
- By spacing the holes properly in the cylinder, the calibration of the instrument is made linear to the weight of the piston is constant the pressure difference is constant.

- The flow reading of the meter is transmitted using a reluctance-type transducer. When fluid enters the cylinder, the piston exerts a constant downward force & the difference in pressures
- between the two sides of the piston places the piston in a particular position.
- The down stream flow is increased, the pressure on the load side of the piston reduced. The increased differential pressure then forces the piston up,
- Thereby increasing the area of the opening through which the fluid can flow until the pressure differential is again balanced.
- The linear movement of the piston in the cylinder is sensed by a linear variable differential transformer (LVDT) which converts this linear motion into voltage signal which is proportional to the flow rate.
- These types of meter are used for high viscosity fluids materials which are corrosive or might clog lines, and materials whose flow coefficients are not well known.

Advantages

- i) It is good for high viscosity fluids.
- ii) It has good accuracy.
- iii) The range of such instrument can have wide variations.

Disadvantages

- i) Its cost is relatively high.
- ii) It has limited size range (about 25 to 100 mm).

3.4 Explain Non-hydraulic meter and state their industrial uses.

a) Magnetic Flowmeters

- Magnetic flowmeters are traditionally the first type of flow meters to be considered for high corrosive application & for application involving measurement of erosive slurries.

→ These meters utilize the principle of Faraday's law of Electromagnetic Induction for measurement.

→ it states that whenever a conductor moves through a magnetic field of given field strength, a voltage is induced in the conductor which is proportional to relative velocity betⁿ the conductor & the magnetic field.

→ this concept is used in electric generator. In case of magnetic flowmeter, electrically conductive flowing liquids work as the conductor. The induced voltage is given by the equation

$$E = BVL$$

$$V = \frac{E}{CBL}$$

E = induced voltage in volts

C = dimensional constant

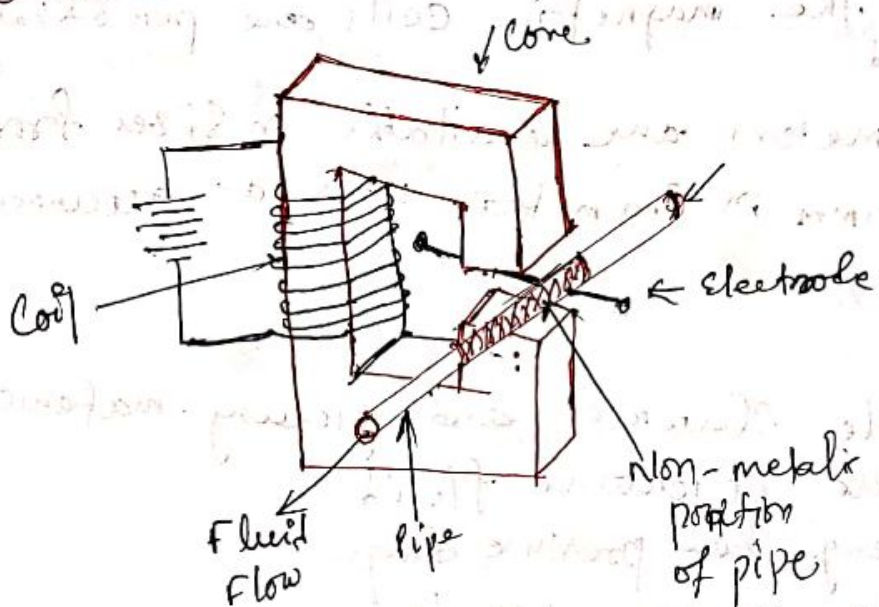
B = magnetic field in weber/m²

L = length of conductor (fluid) m

V = velocity of the conductor (fluid) in m/s

The induced voltage is directly proportional and linear with volumetric flow rate.

Construction and working



- The magnetic flowmeter consists of an electrically insulated or non-conducting pipe such as fiber glass, with a pair of electrodes mounted opposite to each other and flush with the inside walls of the pipe & with magnetic coil mounted around the pipe so that a magnetic field is generated in a plane of ~~the pipe~~ manually perpendicular to the axis of the flowmeter body and to the plane of electrode.
- principle of a magnetic flowmeter in which the flowing liquid acts as the conductor, the length L of which is the distance betn the electrodes & equal the pipe diameter.
- The liquid passes through the pipe section, it also passes through the magnetic field set up by the magnet coils, thus ~~induces~~ inducing the voltage in the liquid which is detected by the pair of electrodes mounted in the pipe walls.
- The amplitude of the induced voltage is proportional to the velocity of the flowing liquid. The magnetic coils may be energized either by AC or DC voltage, but the recent development is the pulsed DC-type in which the magnetic coils are periodically energized.
- magnetic meters are available in sizes from 2.54 to 2540mm in diameter, with an accuracy $\pm 1/2$ to $\pm 2\%$.

Advantages

- i) it can handle slurries and greasy materials.
- ii) it can handle corrosive fluid.
- iii) it has very low pressure drop.
- iv) it is totally obstruction less.
- v) it is available in several construction materials.

- vi) it is available in large pipe size and capacities.
 - vii) it can be used as bidirectional meter.
 - viii) measurements are unaffected by viscosity, density, temperature and pressure.
- Disadvantage & Limitation:

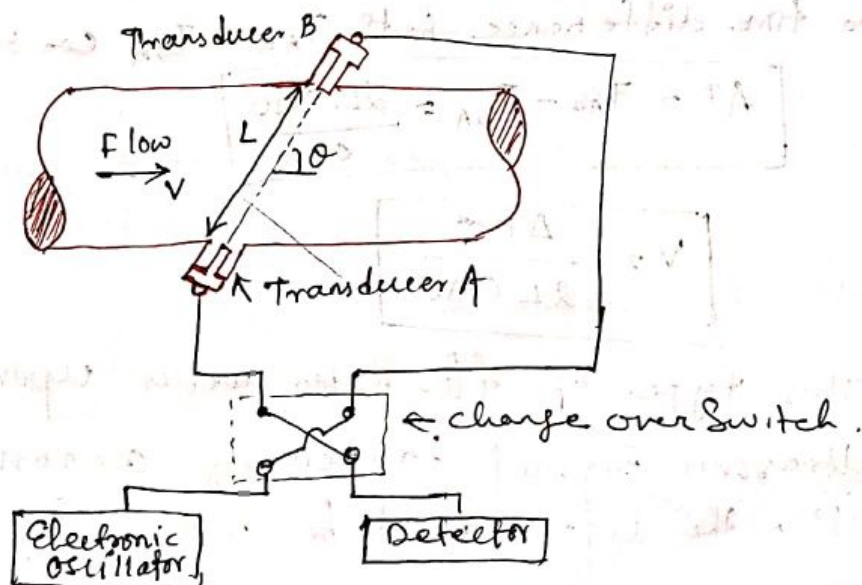
- i) it is relatively expensive.
- ii) it works only with fluids which are adequate electrical conductors.
- (iii) It is relatively heavy, especially in larger sizes.
- iv) It must be full at all times.
- v) it must be explosion proof when installed in hazardous electrical areas.

B) Ultrasonic Flowmeters

- In ultrasonic flowmeter, the measurement of flow rate is determined by the variation in parameter of ultrasonic oscillation. There are two types of ultrasonic flowmeters currently in use.

i) Time Difference Type

- These devices measure flow by measuring the time taken for ultrasonic wave to transverse a pipe section, both with and against the flow of ~~liquid~~ liquid within the pipe.
- it consists of two transducer A & B inserted into a pipe and working both as transmitter and receiver.



- The ultrasonic waves are transmitted from Transducer A to transducer B and vice versa. An electronic oscillator is connected to supply of Ultrasonic wave alternately to A or B which is working as transmitter through a change over switch, when the detector is connected simultaneously to B or A which is working as receiver.
- The detector measures the transit time from upstream to downstream transducer and vice-versa
- The time T_{AB} for ultrasonic waves to travel from transducer A to transducer B is given by expression.

$$T_{AB} = \frac{L}{c + v \cos \theta}$$

and Time to travel B to A

$$T_{BA} = \frac{L}{c - v \cos \theta}$$

where L = the acoustic path length betⁿ A & B
 c = velocity of sound in the fluid.
 θ = angle of path with respect to the pipe axis.
 v = velocity of fluid in pipe.

The time difference betⁿ T_{AB} & T_{BA} can be calculated

$$\Delta T = T_{AB} - T_{BA} = \frac{2Lv \cos \theta}{c}$$

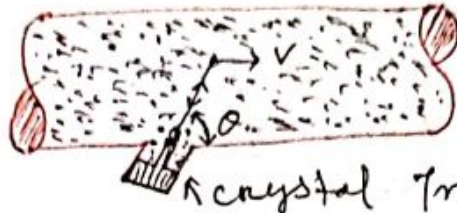
$$v = \frac{\Delta T c}{2L \cos \theta}$$

- This type of flow meter relies upon an ultrasonic signal traversing across the pipe, the liquid must be relatively

Free of Solids and air bubbles.

Doppler Flowmeters

→ In doppler flowmeter an ultrasonic wave is projected at an angle through the pipe wall into the liquid by a transmitting crystal in a transducer mounted outside the pipe.



crystal Transducer.

→ part of the ultrasonic wave is reflected by bubbles or particles in the liquid and is returned through the pipe wall to a receiving crystal. Since the reflectors (bubbles) are travelling at the fluid's velocity, the frequency of the reflected wave is shifted according to the Doppler principle. The velocity of the fluid is given by the eqn

$$V = \frac{\Delta f C_t}{2 f_0 \cos \theta} = \Delta f K$$

Δf = difference betⁿ transmitted and received frequency.

C_t = velocity of sound in the transducer.

f_0 = frequency of transmission.

θ = angle of transmitter & receiver crystal with respect to the pipe axis.

K = constant.

Advantages

i) it does not impose additional resistance to the flow or disturb the flow pattern as the transducer are inserted in the wall of pipe.

ii) its velocity/output relationship is linear.

iii) it has no moving parts.
iv) its precision is in order of 0.01%.

3.5 Thermal Flowmeters

→ Thermal flowmeters are very popular for the measurement of unsteady flow of gases and can be used to measure flow rate in terms of mass, which is a very desirable feature, especially on gas service.

There are two types

i) Heat Transfer Flowmeters

→ Thermal flowmeters are very popular for the measurement of unsteady flow of gases, and can be used to measure flow rate in terms of mass, which is a very desirable feature, especially on gas service.

→ This type of flowmeter measures the rise in the temperature of the fluid after a known amount of heat has been added to it. Its theory is based upon the specific heat equation which is given as

$$Q = W C_p (T_2 - T_1)$$

$$W = \frac{Q}{C_p (T_2 - T_1)}$$

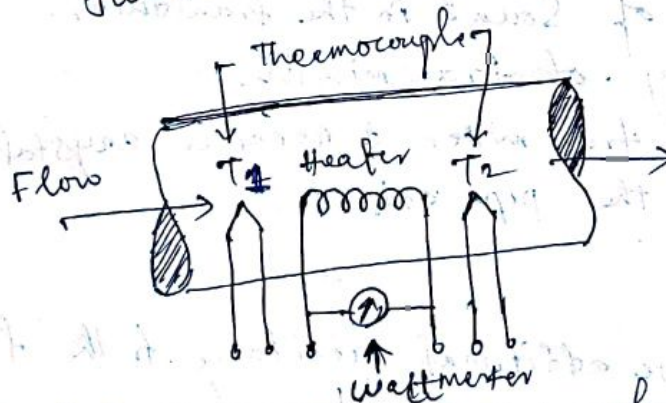
Q = heat transfer

W = mass flow rate of fluid.

C_p = specific heat of fluid.

T_1 = initial temperature of the fluid before heat has been transferred.

T_2 = final temperature after heating the fluid.

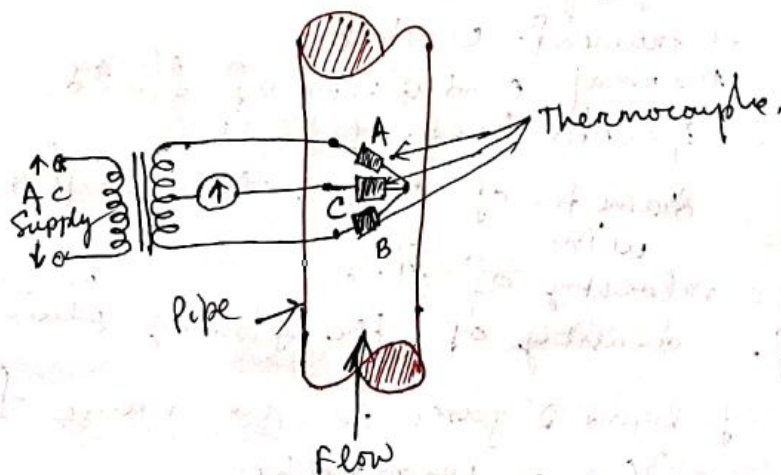


→ A schematic diagram of a heat transfer flowmeter which consists of an electric immersion heater for the heating of flowing fluid.

- Two thermocouple (or resistance thermometer) T_1 & T_2 are placed at each side of the heater. The thermocouple T_1 measures the temperature of fluid before it is heated, while the thermocouple T_2 measures the temperature Δt after.
- the power supply to the heater equals the heat transferred to the fluid i.e Q and is measured by a wattmeter. Thus by measuring the value of Q , T_1 & T_2 the flow rate W of liquid is determined from the eq.
- This type of flowmeter has disadvantages in that the temperature sensor and the heater are directly placed in to the fluid stream, and thus, they easily damaged by corrosion and erosion.
- for large input power is required to measures high flow rates.
- These disadvantages are overcome by mounting the heater & upstream & down stream temperature sensor (T_1 & T_2) on the outside of the piping. But it results in a non-linear response.

(B) Hot-wire Flowmeters

- This type of flowmeter measures the effect of the flowing fluid on a hot body. A hot-wire flowmeter consists of two thermocouples A & B , connected in series to form a thermopile. A third thermocouple C is placed in the output circuit of the thermopile.



- The thermopile is heated by passing an alternating current to it. The alternating current doesn't pass through the third thermocouple and it is therefore not electrically heated.
- The whole assembly is placed into the fluid (usually gas) stream whose flow rate is to be determined.
- The fluid (gas) cools the heated thermopile by the convection, and since the input power to the thermopile is held constant.
- ~~Specific heat and thermal conductivity~~ The thermopile attains an equilibrium temperature and produces an emf that is a function of the temperature of the gas, velocity of the gas, and its density, specific heat and thermal conductivity.
- The third thermocouple (unheated) attains the ambient temperature of the gas, generating an emf that is proportional to the gas temperature which cancels the effect of the ambient gas temperature on the output signal of the heated thermopile.

The output voltage signal of this type of instrument is given by the eqⁿ

$$E = \frac{C}{2(\pi K c_p \rho d v)^{1/2} + K}$$

E = voltage generated.

C = instrument constant.

K = thermal conductivity of fluid.

c_p = specific heat of fluid.

d = diameter of heated thermocouple wire.

v = velocity of fluid.

ρ = density of the flowing fluid.

- Flow of liquid & gases in the range from $0.5 \text{ cm}^3/\text{min}$ to $18,000 \text{ m}^3/\text{hr}$.

3.6 Quantity flow meter

→ Quantity flowmeters are used for the measurement of small percentage of industrial flow rate. These meters operate by passing the fluid to be measured through the meter in separate and distinct measurements of alternately filling and emptying containers of known fixed capacity.

Two types

- ① positive displacement meters
- ② metering pumps.

① Positive Displacement Meters

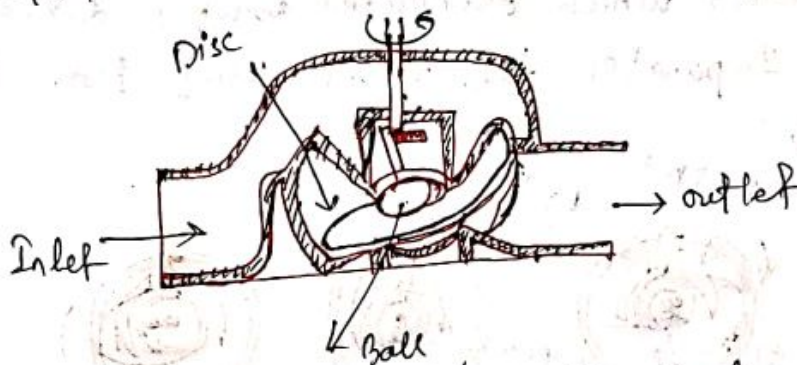
→ positive displacement meters are essentially flow quantity meters. They are most widely used for the applications where the highest degree of accuracy and good repeatability are required.

→ These devices work on the principle that as the liquid flows through the meter, it separates the flow of liquid into separate known volumetric increments which are counted and totalled.

- i) Nutating disc type.
- ii) Oscillating ~~rod~~ piston type.
- iii) Rotating vane type
- iv) Reciprocating piston type
- v) lobed impeller type.

i) Nutating disc type

→ Nutating disc meter is used extensively for residential water service measurement, but can be used in many industrial applications.



→ it consists of a radially allotted disc mounted on a ball bearing. An axial pin is attached with the ball which moves in a circular motion and drives a cam that

is connected to a gear train and a totalizing register. The disc is fitted in to the metering chamber which divides it into four volumes, two above the disc on the inlet side & two below the disc on the outlet side.

→ As the liquid flows through the meter, pressure drops from inlet to outlet causes a wobbling or rotating motion to the disc, and for each rotation of the disc a specific volume of liquid equal to the metering chamber minus the volume of the disc assembly passes through the meter.

→ max^m capacity 150 gpm.

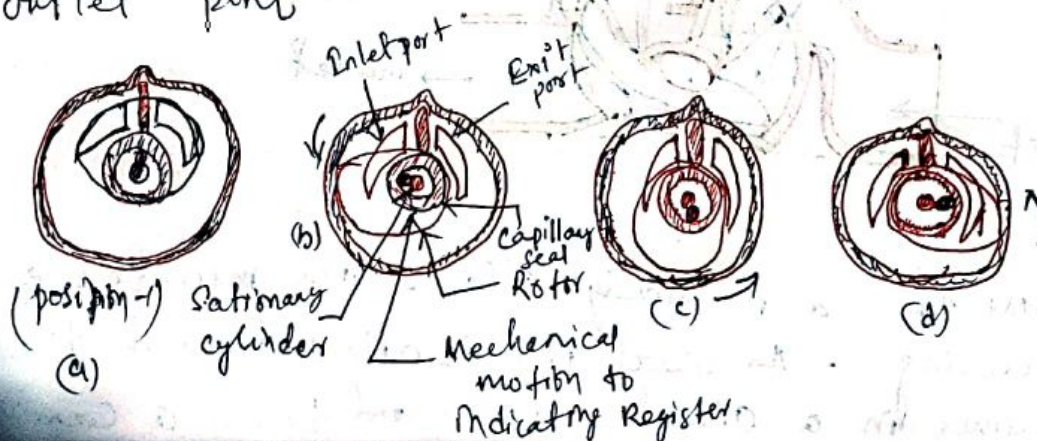
Advantages

- i) its cost is relatively low.
- ii) it is applicable to automatic liquid batching system.
- (iii) it can make use of moderate pressure loss.

Disadvantages

- i) it is limited as to pipe size and capacity.
- ii) it has a fair accuracy.
- (iii) clean fluids only should be measured.
- (iv) Oscillating piston meters

→ The oscillating piston meter is similar to the rotating disc meter except that the measurement device is a split ring which oscillates in one plane only. It consists of a slotted cylinder which oscillates about a dividing bridge that separates the inlet port from the outlet port.



- The measuring sequence starts with the position 1 where the piston is in the neutral position. fluid enters through the inlet port into the chamber and forces the piston to the left end causing it to roll downward (counter-clockwise) as in position 2.
- This movement of the piston forces the liquid in the left side of the piston to be discharged through the outlet port.
- At position 2, most of the piston surface is under the influence of incoming fluid and is driven vertically downward as shown in position 3. & liquid enters the space betn the inner chamber and the inside wall of the piston to give a continuous smooth motion to the piston.
- The rotation of the piston is transmitted through a diaphragm to the gear train & register.
- This type of meter in addition to the residential water purposes, has the capacity of handling clean viscous and corrosive liquid.

Advantage

- It's accuracy is good especially at low flow rates.
- It can be easily applied to automatic liquid batching system.
- good repeatability.
- easy install & maintain.
- its cost is moderate.

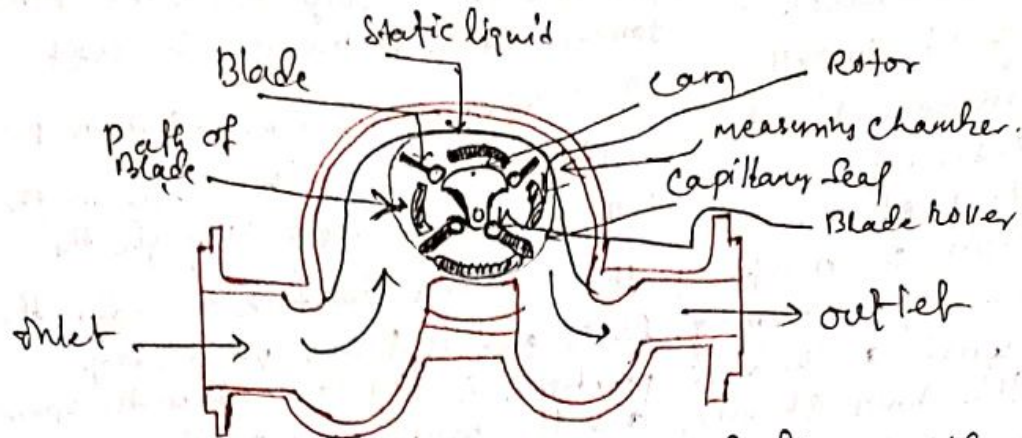
Limitation

- it is available only in small sizes.
- It has limited power for driving mechanical accessories.
- clean fluid must be used.

(iii) Rotating Vane meters

- The rotating vane meter is most widely used in the petroleum industry and is used for such services as gasoline and crude oil metering.
- It consists of a cylindrical rotor that revolves on ball bearing around a central shaft and stationary cam.
- As liquid flow against an extended blade the resulting rotation of the rotor and the action of the cam causes the blades to act as cam followers, creating

measuring chamber that accurately measure fluids through - pat.



→ Capillary action of the metered fluid effectively seals the blades to form the measuring cavities.

Advantage

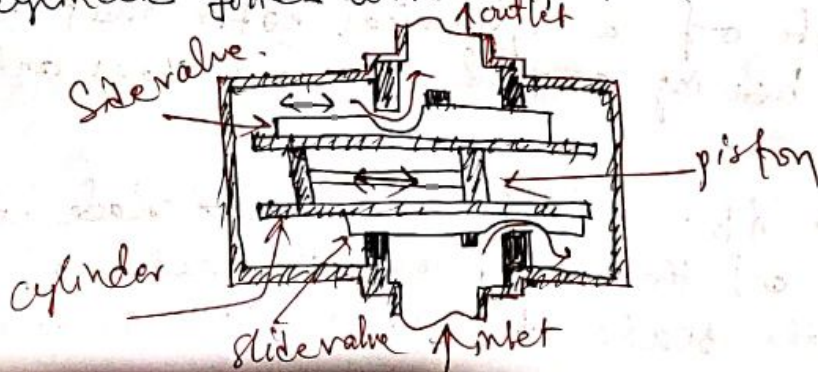
- it allows low pressure loss
- It is applicable to a wide variety of gas & liquid fluids including viscous materials.
- it has relatively high temperature & pressure ratings
- it is available in numerous construction materials
- it has a good accuracy.

Limitation

- it tends to be bulky & heavy in larger sizes
- its cost is relatively high
- its accuracy decreases at low flow rates.

Reciprocating Piston meters

- The reciprocating piston meter is the oldest of the positive displacement meters. It is widely used in petroleum industry
- It is very similar in construction to a reciprocating steam engine piston and cylinder. It consists of a cast iron cylinder fitted with a piston.



- Two slide valves are attached at the inlet and outlet points. The fluid to be measured enters through the inlet forcing the piston to the left until the cylinder is full and piston is in its extreme left position.
- At this point an external leakage causes both slide valves to move and thus the liquid enters the left cylinder forcing the piston to its extreme right position.
- When the right cylinder becomes full, the slide valves again move and the cycle is repeated. The external arm of the slide valve drives a counter which provides a total of the fluid quantity that has passed through the meter.

Advantages

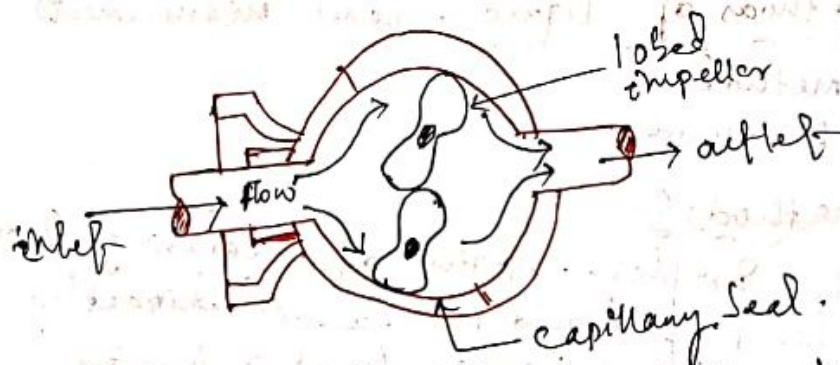
- (i) Its accuracy is high.
- (ii) Construction materials are not limited in reciprocating piston meters.

Limitations

- Their cost is relatively high.
- They are subject to leakage.
- Problems are created by dirty fluids.
- It requires high maintenance cost.
- It is restricted to moderate flow rates.

5) Lobed Impeller Meters

- The lobed impeller meter is widely used in measuring & controlling of petroleum crudes and finished products. It consists of two lobed impellers which are geared to the maintain a fixed relative position. These impellers rotate in opposite direction within the housing.



- A register is attached to one of the impellers through a gear train mechanism. The fluid to be measured is trapped in the space between the lobes and is passed from inlet to outlet.

→ A recent addition to this general type of meter is one using ovalgeared rotors in place of the lobed rotors. These meters may be used for either liquids or gases, and are normally built for service.

Advantages

- i) it is increasingly accurate at higher flows where leakage & slip is decreased.
- (ii) it can be used for corrosive service
- (iii) it has a good capacity range

Limitation

- i) its cost is relatively high.
 - (ii) it requires frequent maintenance of rotating parts.
- (iii) Reciprocating piston pumps

→ The reciprocating piston pump is mainly used in the heavy chemical & manufacturing industry. It employs a piston or plunger with the inlet and outlet check valves & the piston moves with a reciprocating motion within a chamber.

3.7 Level Measurement

→ level measurement is one of the oldest measurement

The measurement of Industrial process level parameters

is of great importance in the industrial field.

i) classify methods of liquid - level measurement

a) Direct methods

b) Indirect methods

a) Direct methods

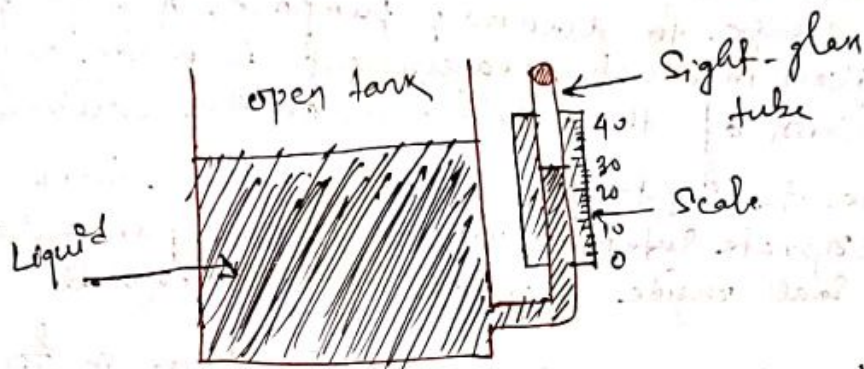
→ This is the simplest method of measuring liquid level. The level of liquid is measured directly by means of the following level indicators.

- i) Hook - type level Indicator
- ii) Sight Glass
- iii) Float type

Sight Glass

→ A sight glass (also called a gauge glass) is another method of liquid level measurement. It is used for the continuous indication of liquid level within a tank or vessel.

→ A sight glass instrument consists of a graduated tube of toughened glass which is connected to the bottom of the tank at the bottom in which the water level is required.

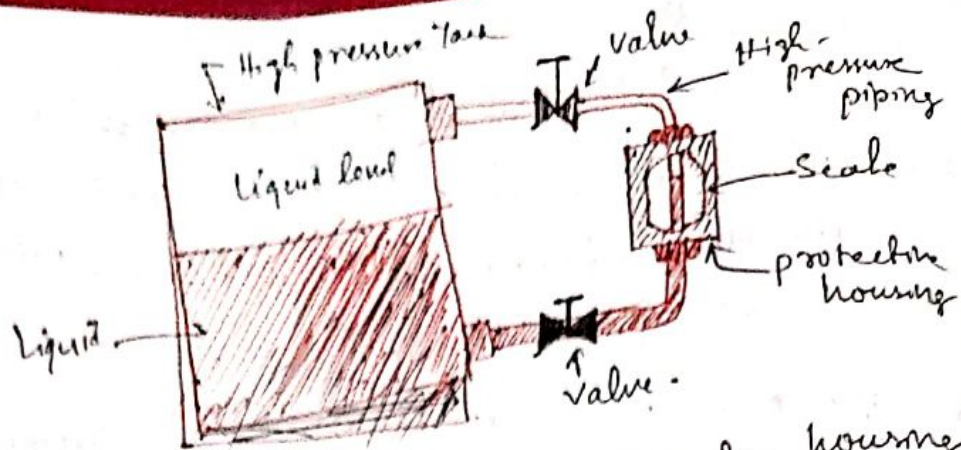


→ A simple sight glass for an open tank in which the liquid level in the sight glass matches the level of liquids in the tank. As the level of liquid in the tank rises and falls, the level in the sight glass also rises and falls accordingly.

→ Thus by measuring the level in the sight glass, the level of liquid in the tank is measured. In sight glass, it is not necessary to use the same liquid as in the tank.

→ When it is decided to measure a liquid level with the liquid under pressure or vacuum, the sight glass must be connected to the tank at the top as well as at the bottom, otherwise the pressure difference between the tank and the sight glass would cause false readings.

→ In this case, for ~~between~~ the ~~glass tube is enclosed sight glass~~ would cause false readings. The smaller value.



- The glass tube is enclosed in a protective housing and two valves are provided for isolating the gauge from the tank in case of breakage of the sight glass.
- The smaller valve at the bottom is provided for blowing out the gauge for cleaning purpose. A high pressure sight glass in which measurement is made by reading the position of the liquid level on the calibrated.
- This type of sight glass in high-pressure tanks is used with appropriate safety precautions. The glass tube must have a small outside diameter and a thick wall.

Advantages

- The standard practice is not to go in for a glass tube of more than 900mm length. In case the height of the tank is more than 900mm two or more sight glass level gauges are provided at different levels.

Disadvantages

- i) Direct reading is possible.
- ii) Special designs are available for use up to 316°C and 10,000 psi.
- iii) Glass designs are available in numerous materials for corrosion resistance.

Disadvantages

- i) It is read only where the tank is located which is not always convenient.
- ii) Sight glasses are located on the outside of the tank. The liquid in the sight glass may freeze in cold weather even though the liquid inside the tank does not & thus it may cause error in the reading.

- (iii) Heavy, viscous liquid or liquids containing material which fall out of solution and clog the tube measured satisfactorily by a sight glass.
- (iv) overlapping gauges are needed for long level spans
- (v) Accuracy and readability depend on the cleanliness of glass and fluid.

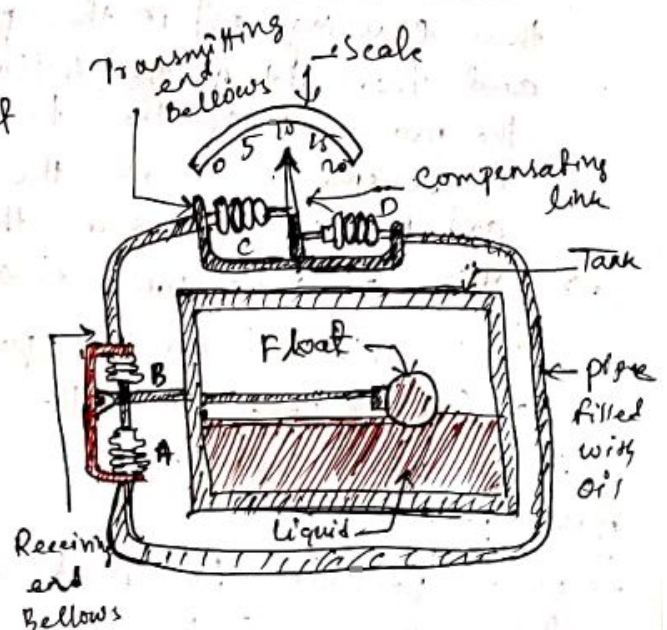
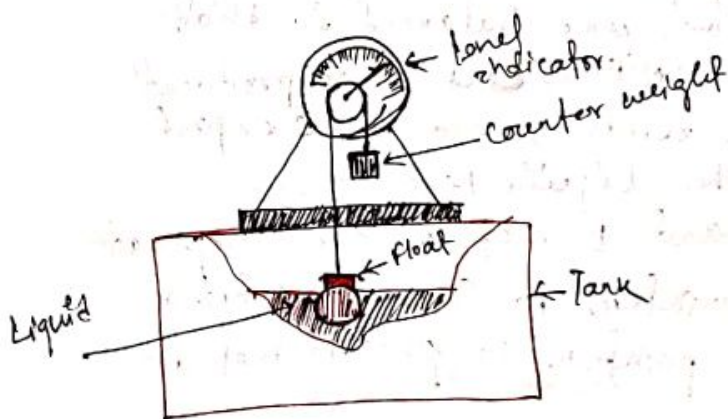
Float - Type level Indicator

→ Float operated level indicator is used to measure liquid levels in a tank in which a float rests on the surface of liquid & follow the changing level of liquid.

→ The movement of the float is transmitted to a pointer through a suitable mechanism which indicates the level on a calibrated scale.

→ Various types of floats are used such as hollow metal spheres, cylindrical-shaped float & disc-shaped floats.

Construction & working



- The simplest form of float operated mechanism for the continuous liquid level measurement. In this case, the movement of the float is transmitted to the pointer by stainless steel or phosphor-bronze flexible cable wound around a pulley, & the pointer indicates liquid level in the tank.
- The float is made of corrosion resisting material such as stainless steel and rests on liquid level surface betn two grids, to avoid error due to turbulence.
- with float operated type of mechanism, the liquid level can be transmitted to a distant place using a hydraulic transmission system.
- it consists of four bellows elements, two in the transmitter side (C & D) & two in the receiver side (A & B) that are fixed at the outer ends.
- bellows B, C & A, D are hydraulically connected. through pipes filled with an oil. when the float moves up, or down according to change in level it's position is transmitted by a lever arm to the bellows assembly A-B.
- when the level rises, B is compressed and A thus causing oil in the pipe to flow from B to C and from D to A. the bellows are balanced so that the movement at the transmitter end is reproduced in reverse mode at the receiving end, i.e. C expand and D is compressed as the liquid level rises.
- The two bellows C and D act on the compensating link pivoted on the pointer, in same directions and will rotate the pointer in proportional on to the level value.

Advantage

- It is possible to read the liquid levels in a tank from the ground level even if the tank below the ground level,

- (ii) its cost is low and has reliable designs
- (iii) it operates over a large temperature range.
- iv) there is a choice of common - resistant materials to make these.

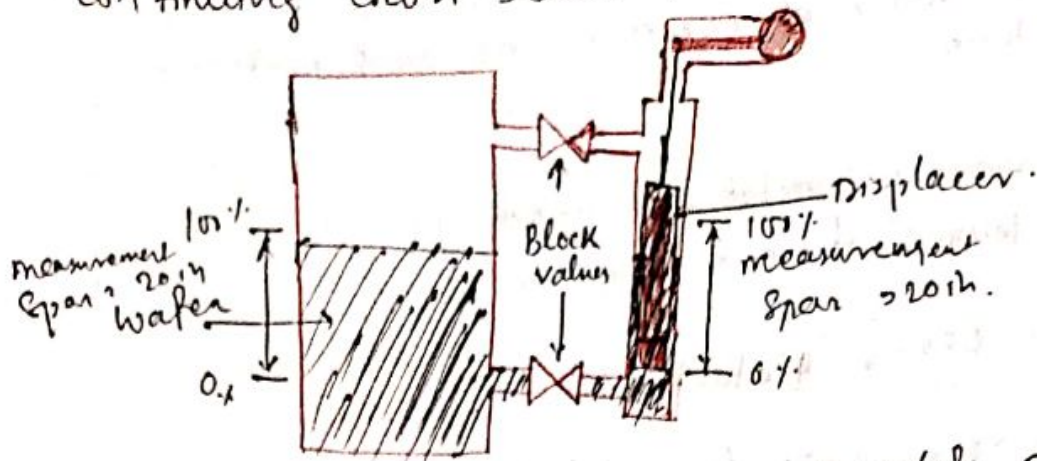
Disadvantages

- i) they are normally limited to moderate pressures.
- ii) they are tailored to tank geometries.

Displacer Level Detector

- The displacer - type level detectors work on the Archimedes principle which states that a body, wholly or partially immersed in fluid, is buoyed up by a force which is equal to the weight of the fluid displaced.
- The cross-sectional area of the displacer & the density of the liquid are constant, then a unit change in level will result in a reproducible unit change in the displacer weight. By detecting the apparent weight of the immersed displacer the level of the fluid is measured.
- The simplest level measuring device of this type consists of a displacer that is heavier than the process liquid and is suspended from a spring scale.
- when the liquid level is below the displacer, the scale shows the full weight of the displacer. As the level rises the apparent weight of the displacer decreases, thereby yielding a linear and proportional relationship betn the spring tension & level.
- There are various types of displacer level detector
 - i) magnetically - coupled switch type.
 - ii) Torque tube type.
 - (iii) Diaphragm & force bar type.
 - iv) Spring balanced type.
 - v) Flexible disc type.
 - vi) Flexible shaft type.
- All of the above types operate on Archimedes principle.

→ The displacer is cylindrical in form with a continuous cross sectional area & created long



on short as need. Normally heights range from fourteen inches to one hundred twenty inches.

→ As liquid level can increase, the displacer rod experiences a bigger buoyant force, creating it appear lighter to the sensing instrument, that interprets the loss of weight as a rise in level and transmits a proportional output signal.

→ As liquid level decreases, the buoyant force on the displacer rod decreases with a corresponding weight increase that is understood as decrease level by the level detector that then provides a corresponding signal output.

Applications

The displacer level sensor is employed in level measuring application like knock-out pots, condensate drums, separators, flash vessels, storage vessels and receiver tanks.

Advantages

- i) They have high accuracy
- ii) They are reliable in clear liquid
- (iii) They can be mounted internally or externally
- (iv) They are adaptable to liquid interface measurement

Disadvantages

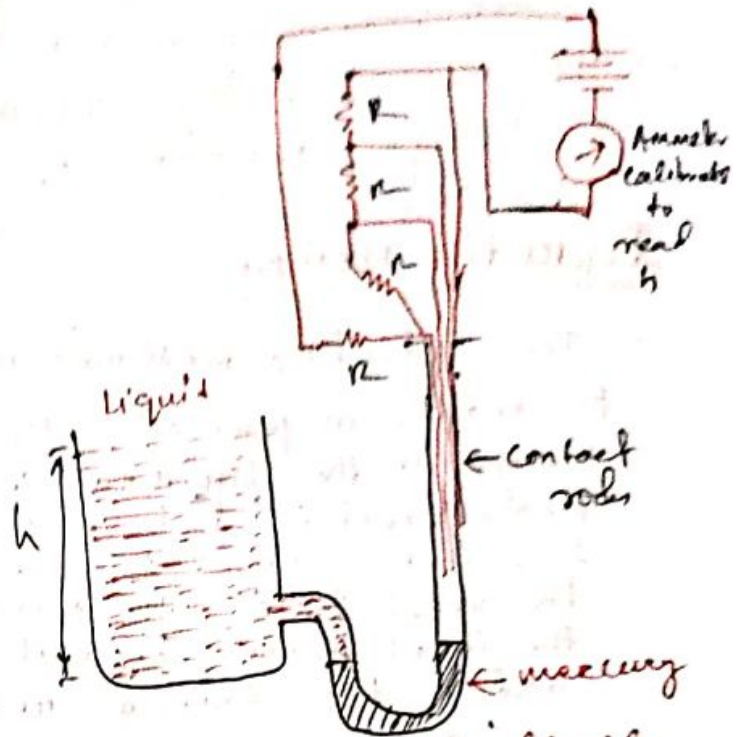
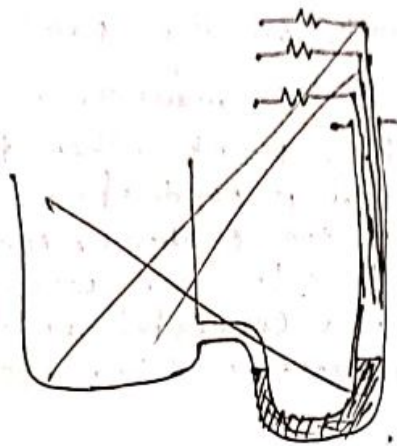
- i) These instruments have limited range service exceeding 1.2 m in length are bulky and difficult to handle

- (iii) External unit may require heating to avoid freezing.
- (iv) Internal unit may require stilling chambers.

B) Indirect Methods

- i) Hydrostatic pressure type
- ii) Electrical methods

(ii) Resistive Level gauge



(Measurement of liquid level by resistive method)

- In this method the mercury is used as a conductor, a number of contact rods are present at various liquid level with resistance R in their arms.
- When the level of the liquid rises the electrode connected to the tube wall and the highest of the immersed rods gets short and the output current is then recorded in the ammeter.
- The output current recorded by the ammeter gives an indication of the liquid level h in the tank.

Advantages

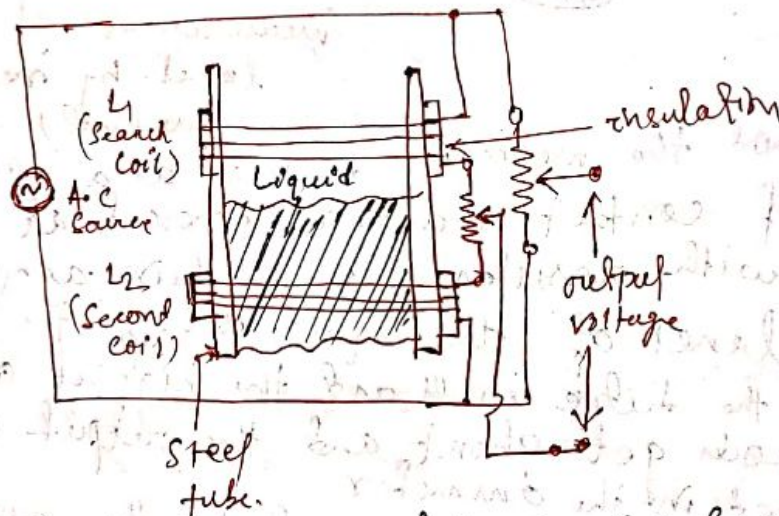
- It can be used for the dynamic level measurement.
- It uses low voltage for operation and hence the danger of shock to the operator gets eliminated.
- The signal obtained is electrical in nature & hence can be used for telemetry purposes.

Disadvantage

- Arching may occur at the resistance contacts hence it is not safe to use such method where the atmosphere is explosive.
- The contact rods may get corroded by the corrosive liquids.
- To increase the accuracy of measurement a large number of electrodes have to be inserted.

Inductive Method

- The inductive methods work on the principle of the change in permeability of the inductor with the change in the liquid level. They work when the liquid whose level is to be measured is conductive. The liquid is allowed to rise in the container containing the steel tubes. The coils L_1 & L_2 are wound around the steel tubes. The coils are connected in series and in between them a resistance is connected.



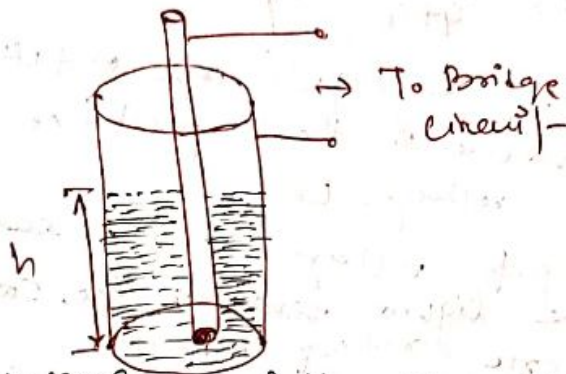
- The coils are energized by an a.c. source. Initially the inductance of the two coils is constant. One of the coils (L_1) acts as a search coil, which search for the rise or fall of the liquid level.
- The inductance of the search coil changes as the liquid rise or fall in between it. This change in inductance leads to the change in the output voltage.
- This output voltage can be calibrated in terms of the liquid level.

(iii) Capacitive Methods

→ The capacitive method of level measurement, depend on the principle of change in the capacitance with the change in the capacitance with the change in the liquid level. The various capacitive methods for level measurement are given as under.

* Variable Area Method

→ This type of method is used for the measurement of the level of both solids and liquids.



→ In this method one of the connection is taken from the outer container and other from the cylindrical rod completely dipped inside the container.

→ The dipped metal rod is completely covered by the insulating material inside the container. The liquid acts as dielectric and capacitance is varied with the height of the liquid as is given below in the expression for the capacitance

$$C = \frac{2\pi\epsilon h}{\log_e\left(\frac{d_2}{d_1}\right)} \quad F$$

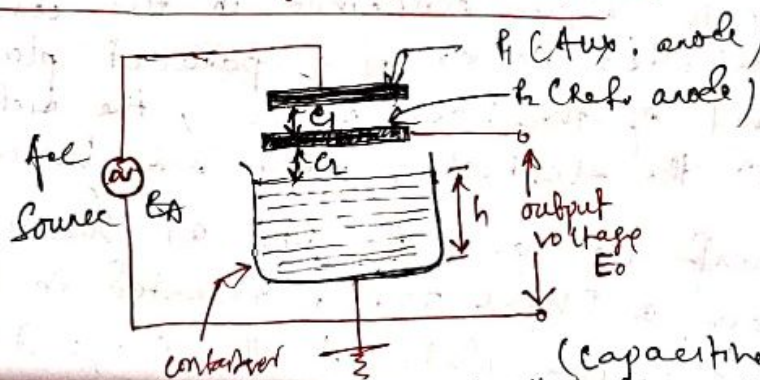
ϵ = permittivity of the insulator.

h = height of the material.

d_1 = diameter of the metal rod (m).

d_2 = external diameter of the insulator (m).

* Capacitive voltage divider method



(Capacitive voltage divider method for measurement of level of high conductivity liquid)

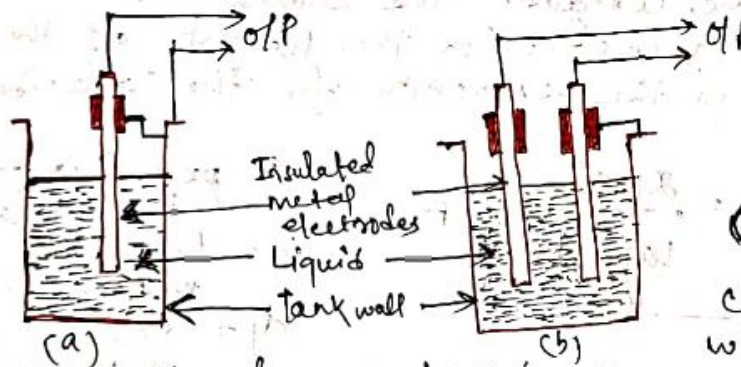
- For the case of a highly conductive liquid, the surface of the liquid can be taken as one of the plates of a parallel plate capacitor.
- So here two capacitors are formed one betⁿ the plates P_1 & P_2 & the other betⁿ the plates P_2 & the liquid surface, thus two capacitances are formed as C_1 & C_2 respectively.
- An a.c voltage E_A is applied betⁿ the plates P_1 & the container and the output (E_o) is taken betⁿ the plates P_2 and the container.

$$E_o = \frac{C_1}{C_1 + C_2} E_A$$

- As the level of the liquid rise or fall in the container the value of the capacitance C_2 varies thus the output voltage E_o .
- Hence the output voltage E_o can easily be calibrated in terms of the liquid level in the container.

* variable Dielectric constant Method.

- It is used for the level measurement of non-conducting liquids. The non-conducting liquids behave as the dielectric materials.



(Measurement of liquid level using capacitive transducer with variable dielectric constant)

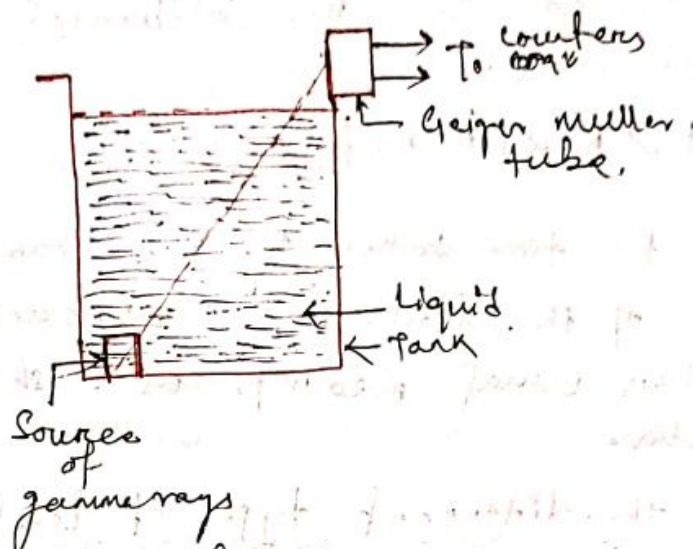
- The arrangement can be seen in the figure above. In the fig. (b) two separate electrodes are placed in the liquid contained in the container, the two electrodes serve as a parallel plate capacitor.
- When the level of the liquid varies, the dielectric constant betⁿ the electrodes varies and hence their capacitance.
- The arrangement can also be done as shown in the fig. (a) where a single rod is inserted in the container, the one plate to the capacitor is

formed by the rod inserted and the other by the wall of the tank itself. The variation of the capacitance is a measure of the level of the liquid.

B) Radiation Type liquid level measurement

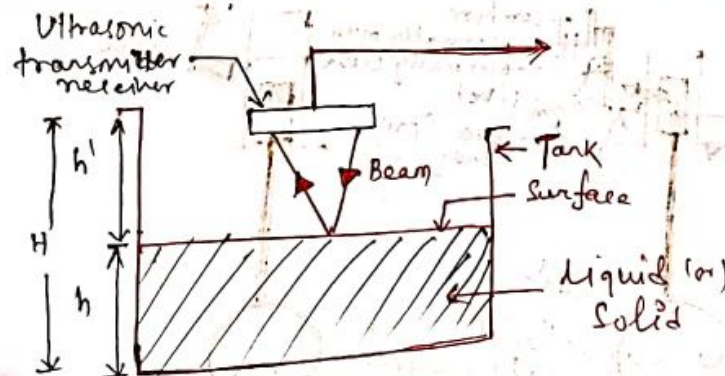
* By using Gamma rays:-

- In this method a source of gamma rays is placed at the bottom of the tank, and a Geiger Muller tube is used to sense the gamma rays.
- The maximum intensity of gamma rays is obtained when the tank is empty.



- As the level of the liquid increases in the tank, the intensity of the gamma rays reaching the counter decreases as some of the rays are absorbed in the liquid.
- The output of the Geiger-Muller counter is in the form of pulses, the pulses thus obtained are sent to the counter.
- The reading on the counter is calibrated in terms of the height of the liquid in the counter.

* Ultrasonic method



→ In this method an ultrasonic transmitter & receiver is mounted on the top of the tank. When the tank is empty the time (t) taken by the pulse to transmit and receive back at the ultrasonic transmitter and receiver is maximum, as the level of the liquid increases in the tank the surface of the liquid come up, now the beam has to travel lesser distance to go and strike the surface & to come back to the receiver.

→ Hence, the time (t) taken by the pulse gets reduced. The time (t) can then be calibrated in terms of the liquid level.

$$t \propto h' \propto (H - h)$$

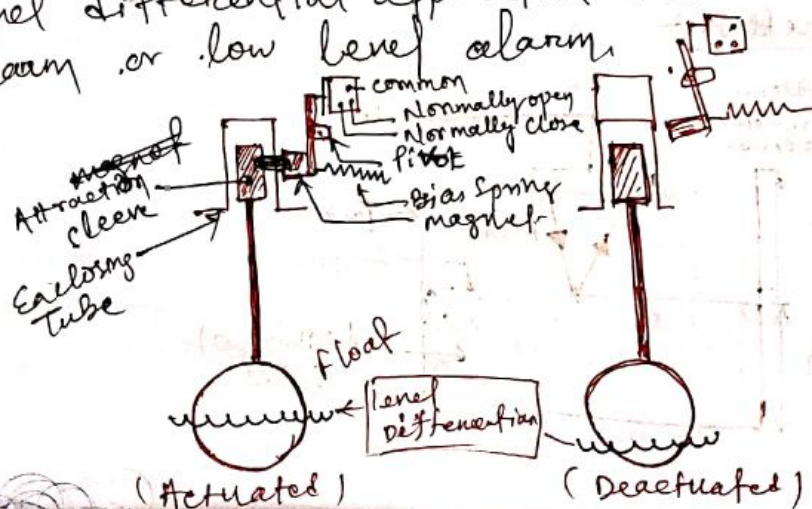
Then, t = time taken by the beam to strike the surface of the liquid and come back & h' , H , h have their usual meanings as shown in the fig. above.

V) States the different types of level switches.

→ All float operated liquid level controls operate on the basic buoyancy principle which states "the buoyancy force action on an object is equal to the mass of liquid displaced by the object".

→ As a result, float ride on the liquid surface partially submerged and move the same distance the liquid level moves.

→ Because of this, they are normally used for remote level differential application such as high level alarm or low level alarm.



- The float rides on the process liquid surface, precisely tracking liquid surface motion. Rising liquid level lifts the float, sliding the attraction sleeve up, inside the enclosing tube & into the magnetic field to actuate the electrical or pneumatic switch (signaling liquid presence).
- Subsequently, falling liquid level lowers the float drawing the attraction sleeve out of the magnetic field to deactivate the electrical or pneumatic switch (signaling liquid absence).
- Float-type level switches are generally able to handle high-temperature applications, & sometimes prove useful for close interface detection.
- Floats can operate up to three switching elements. Independent switching level may be obtained with tandem floats switching arrangements.
- All these are optional & depends on our application.

Applications

Level alarm and controls in power plants, petrochemical plants & refineries, chemical plants, paper mills, Sugar mills, ships etc.

Chapter - 4

Measurements of Force, Torque & Shaft power

4.1 Define Force, Torque & Shaft power

Force

→ Force is any physical quantity which when applied over any body can lead to a change in velocity or the change in the direction of motion or may lead to a change in the shape of the body.

Force is defined as,

$$F = m \times a \text{ Newton (N)}$$

m = mass in (kg)

a = acceleration in (m/s^2)

Torque

→ Torque is the tendency of a force to rotate an object around an axis of a circle or a cylinder. Just like force which is a push or pull, the torque can be considered as a twist.

→ Torque is obtained by measuring force at a known distance.

It is given as

$$T = F \cdot r \text{ in (Nm)}$$

F = Force in (N)

r = distance perpendicular to the force where force is to be measured in (m).

Shaft power

shaft power is that power which you provide or get from machine shaft (in case of generator or motor).

$$P = \frac{2\pi N}{60} \times T$$

T = Rotational force (Torque)

N = Revolution per min.

4.2 Explain Basic methods of measurement of Force

→ Balancing the unknown force against known gravitational force due to standard mass. Scales & balances work on this principle.

- Applying unknown force to an elastic member and measuring the deflection on calibrated force scale or the deflection may be measured by using a secondary transducer i.e. Spring scale, cantilever beam, piezoelectric, strain gauge load cell.
- Translating the force to a fluid pressure and then measuring the resultant pressure and then measuring the resultant pressure. Hydraulic & pneumatic load cell works on the principle.
- Apply force to known mass & then measuring the resultant acceleration.
- Balancing a force against a magnetic force which is developed by interaction of magnet & current in coil.

① Direct methods

It involves a direct comparison with a known gravitational force on a standard mass, say by a balance.

② Indirect methods

It involves the measurement of effect of force on a body, such as acceleration of a body of known mass subjected to force.

* Scales & Balances type

- Equal Arm balance
- Unequal Arm balance
- pendulum scale

* Elastic force meter

- piezoelectric
- cantilever beam
- Spring

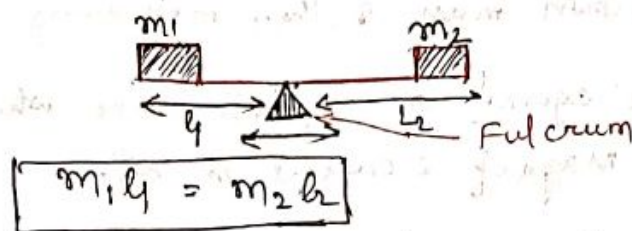
* Load cells

- Strain gauge load cell
- Hydraulic load cell
- Pneumatic load cell

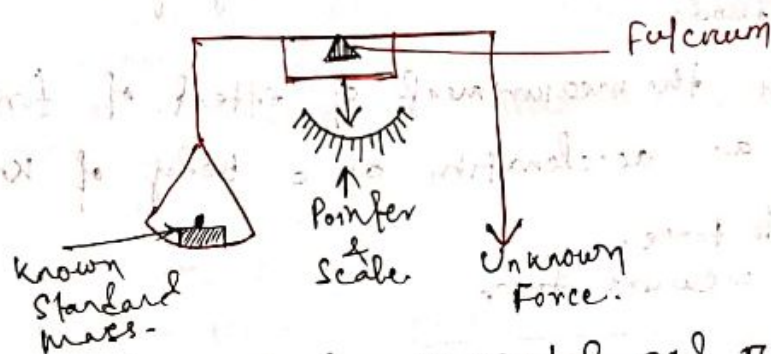
1.3 State and explain Equal and unequal arm balance

Equal Arm Balance

→ An equal arm balance works on the principle of moment comparison. The beam of the equal arm balance is in equilibrium position when clockwise rotating moment equal to anticlockwise moment.



→ That is the unknown force is balanced against the known gravitational force.



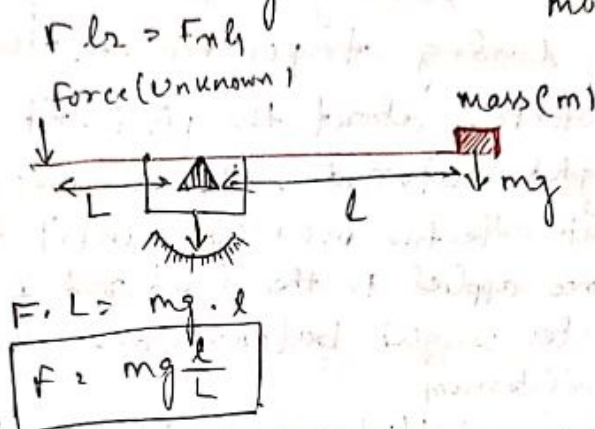
- A beam whose centre is pivoted and rest on the fulcrum of a knife edge. Either side of the beam is equal in length, with respect to the fulcrum.
- A pointer is attached to the center of the beam. This pointer will point vertically downwards when the beam is in equilibrium.
- A provision to place masses at either end of the beam.
- operation
- A known standard mass (m_1) is placed to one end of the beam & an unknown mass (m_2) is placed at its other end.
- Equilibrium condition exist when clockwise rotating moment = anticlockwise rotating moment.

- more over at a given location the ear mass (m_1 & m_2) and hence at equilibrium condition.
- $w_1 = w_2$ that is the unknown force will be equal to the known force.

* Unequal Arm balance

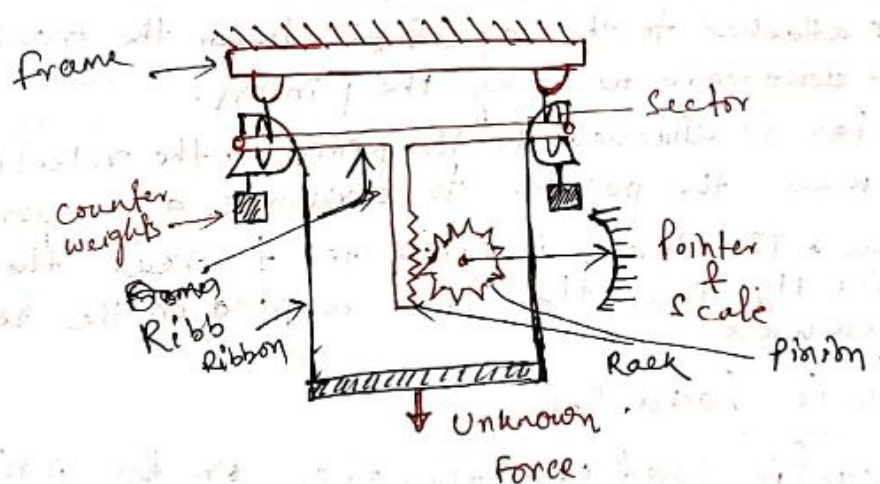
→ An equal arm balance works on the principle of moment comparison. The beam of the unequal arm balance is in equilibrium position when,

clock wise rotating moment = Anti-clockwise rotating moment.



* 1.4 multiple level system of Force measurement

→ It is a moment comparison device. The unknown force is converted to torque which is then balanced by the torque of a fixed standard mass arranged as pendulum.



- The scale's frames carry support ribb these support ribbor are attached to the sectors.
- The loading ribbons are attached to the sector and the load rod a shown. the load rod is in turn attached to the weighing platform.

→ The two Sectors are connected on either side of an equalizer beam. The Sectors carry counter weights. To the center of the equalizer beam is attached a rack & pinion arrangement.

→ A pointer is attached to the pinion which sweeps over a weight (force) calibrated scale

Operations

→ The unknown force is applied to the load rod. Due to this force, the loading tapes are pulled downwards, hence loading tapes rotate the Sector.

→ As the Sectors rotate about the pivot, it moves the counter weight outwards, this movement increases the counter weight effective moment until the torque produced by the force applied to the load rod & the moment produced by the counter weight balance each other, thereby establishing an equilibrium.

→ During the process of establishing equilibrium the equalizer beam would be displaced downward. as the rack is attached to the equalizer beam, the rack also is displaced downward rotating the pinion.

→ During the process of establishing equilibrium the equalizer beam would be displaced downward as the rack is attached to the equalizer beam the rack also is displaced downward rotating the pinion.

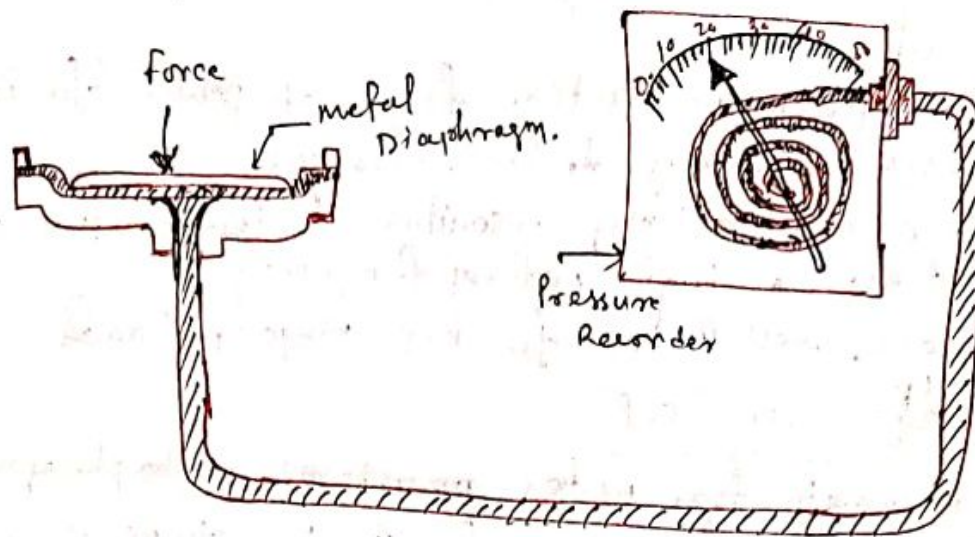
→ As the pointer is attached to the pinion, the rotation of the pinion make the pointer to assume a new position on the Scale. The Scale is calibrated to read the weight directly. Thus the force applied on the load rod is measured.

4.5a) Hydraulic load cell

→ The hydraulic load cell operates on the principle of a force counterbalance. it involves the application of force to a definite area of fluid surface.

→ Thus producing hydrostatic pressure in the fluid, which can be measured by a Burdon-tube manometer or any other type of pressure gauge.

→ The transmitting element betⁿ force and pressure may be piston, bellows or diaphragm.



construction & working

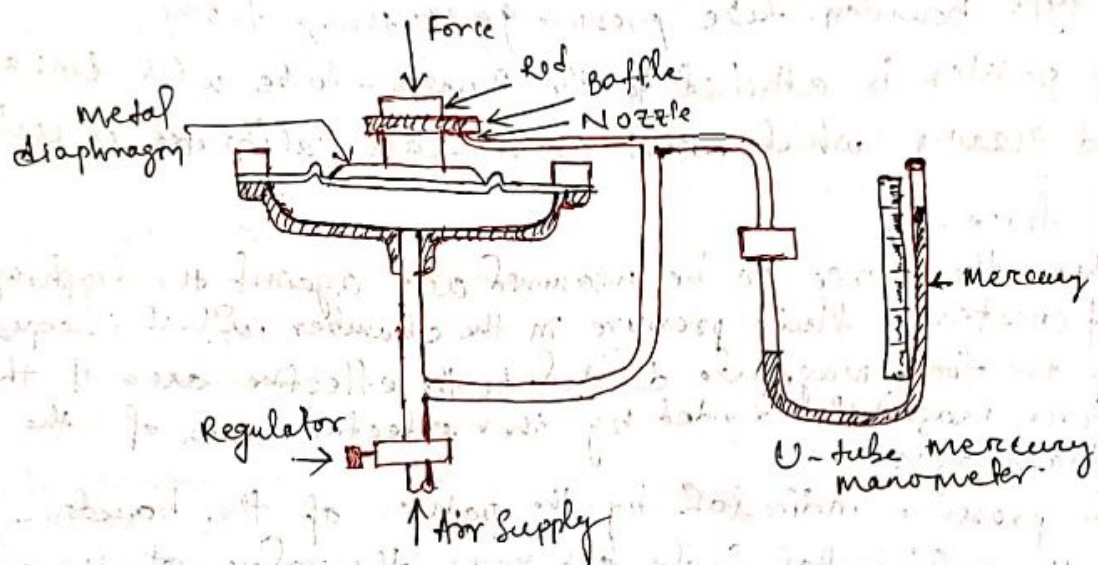
- A hydraulic force meter consists of a metal diaphragm on which the force to be measured is applied. The metal diaphragm is attached to a fluid chamber which is connected to a spiral - type Bourdon - tube pressure gauge through tubing.
- A pointer is attached to the Bourdon - tube with linkage and gearing which moves on a scale calibrated in units of force.
- When the force to be measured acts against the diaphragm, it creates a fluid pressure in the chamber, which is equal to the force magnitude divided by the effective area of the diaphragm.
- This pressure indicated by the pointer of the Bourdon - tube on the calibrated scale and gives the value of the applied force.
- The hydraulic force meter may be used for measurement of force in the range 0 to 30,000 Newton.
- Their accuracy is of order of 0.1% of full scale.
- Resolution is about 0.02%.
- They are self contained and require no outside power for operation.
- They are inherently explosion - proof & are available both for tension & compression force measurement.

Advantages

- They are relatively trouble-free over extended period of use.
- They require no outside force or power for indication.
- They respond quickly to load changes.
- They are relatively insensitive to temperature change.
- They have a high natural frequency.
- They are well suited for high impact loads.

b) Pneumatic load cell

- The pneumatic force meter consists of a diaphragm, operates on the force balance principle. In this type of meter, the variable downward force to be measured is balanced by the upward force of air pressure against the effective area of the diaphragm.



Construction & working

- A pneumatic force meter consists of a diaphragm to which a rod & baffle are attached. Just near the baffle, a nozzle is placed which is connected to the air supply & a pressure measure device such as manometer, Bourdon tube.
- When force to be measured acts on the diaphragm, it moves downward and the baffle covers the nozzle, which in turn causes an increase in the nozzle back pressure. Since the nozzle, which is more nearly shut off.

- The increase in the nozzle back pressure acting on the diaphragm produces an effective upward force which tends to return the diaphragm to its former position.
- An equilibrium position or a balanced position is achieved for a particular constant downward force at a specific nozzle opening & corresponding nozzle back pressure. The force magnitude is indicated by the height of the mercury column.
- Range is (0 to 35 Newton) to (0 to 1250 Newton)
- Accuracy of about 0.5% of full scale.

Advantages

- Suitable for use in hazardous or explosive area.
- They require no special transmitting system.
- They can't cause product contamination due to leakage or hydraulic fluid.
- They are relatively free from temperature errors.

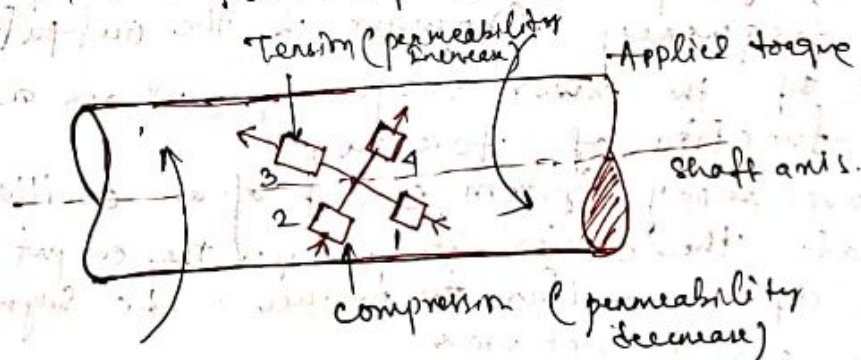
Disadvantages

- They response slowly to sudden load change & therefore are not generally used for fast work.

4.6 Measurement of Torque using Strain Sensor

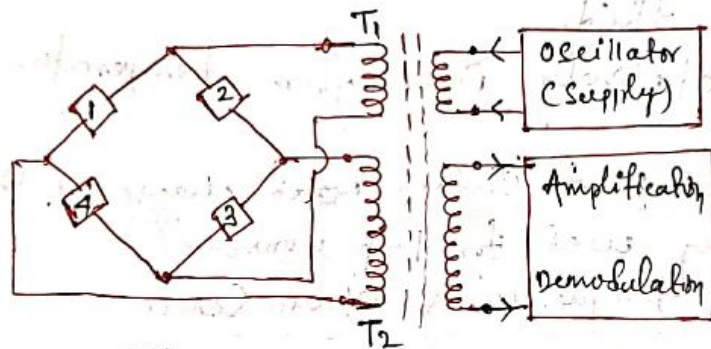
- Measurement of torque using strain sensor is called in-line rotating torque sensor. The in-line rotating torque sensor is used for the torque measurement of rotating equipment construction & working.

- The in-line rotating torque sensor consists of a metal shaft with bonded strain gauge electrically connected in the form of a Wheatstone bridge.



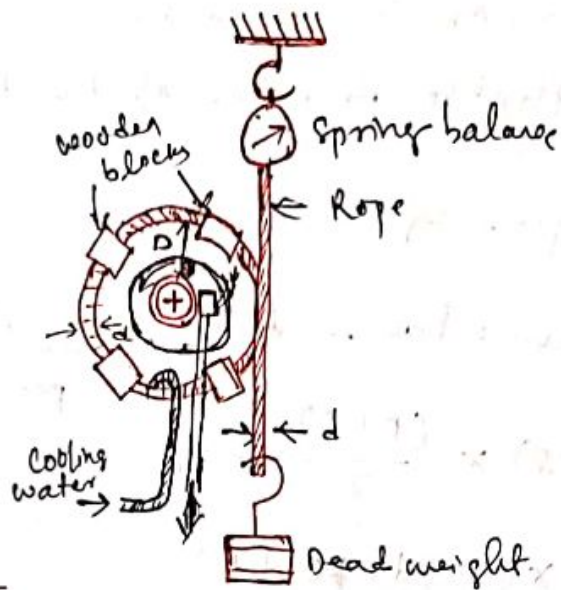
- The stresses acting on a rotating shaft subject to torsion. The strain gauge are kept on the shaft at precisely 45° to the shaft axis to sense compressive & tensile

- deformation due to torsion.
- The strain gauges 1 & 3 must diametrically opposite as must 2 & 4.
 - In one direction at 45° angle to the axis pure tensile stress exist; where 45° in the other direction pure compressing stress is applied.
 - The rotor shaft is elastic & will deflect minutely under the imposed stresses. The output of the Wheatstone bridge is in proportional to torsion & hence to the applied torque on the shaft.
 - Bridge power & output voltage may be connected to the sensor through slip rings and brushes, but this type of pick off is limited to rotational speed in the order of 3000/s at the brush surface.



- A sensor with non-contacting power supply & signal pick off - the slipping are avoided. The bridge power & output signals are transmitted betn rotating & stationary members through transformer T_1 & T_2 .
- The bridge power is a constant amplitude, high frequency sine wave & the output is a sine wave of the power frequency whose amplitude is a function of torque.
- The power supply system consist of an oscillator to generate the carrier frequency. The output circuit consist of a rectifier to produce a dc signal proportional to the output sine wave.

4.7(a) Measurement of shaft power using Rope Breaker



Construction:-

- It consists of one, two or more ropes wound around the fly wheel or rim of a pulley fixed rigidly to the shaft of the engine.
- The upper end is kept in position while the lower end of the rope is kept in position by applying a dead weight.
- In order to prevent the slipping of the rope over the fly wheel, wooden blocks are placed at intervals around the circumference of the fly wheel.

Working

- For the operation of the brake, the engine is made to run at a constant speed.
- The frictional torque due to rope must be equal to the torque being transmitted by the engine.
- If the power is high, so will be the heat produced due to friction between rope & wheel and a cooling arrangement necessary for this. A channel of the flywheel ~~is~~ usually has a flange turned inside in which water is supplied. An outlet pipe at with a flattened end takes the water out.

Let W = weight at the end of the rope (N)
 S = Spring balance reading (N)
 N = engine speed (rpm)

D = Diameter of the brake wheel (m)
 d = diameter of the rope (m)
 $(D+d)$ = effective diameter of the brake wheel

then torque eqⁿ

work/revolution = torque $\times$ angle turned per revolution

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

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

$$\text{Work done/Sec} = \frac{(W-S) \pi (D+d) N}{60}$$

$$\text{Brake power} = \frac{(W-S) \pi D N}{60 \times 1000} \text{ (kW)}$$

$$= \frac{2\pi N}{60 \times 1000} \times T \text{ kW}$$

4 Disadvantages

cheap & easy construction.

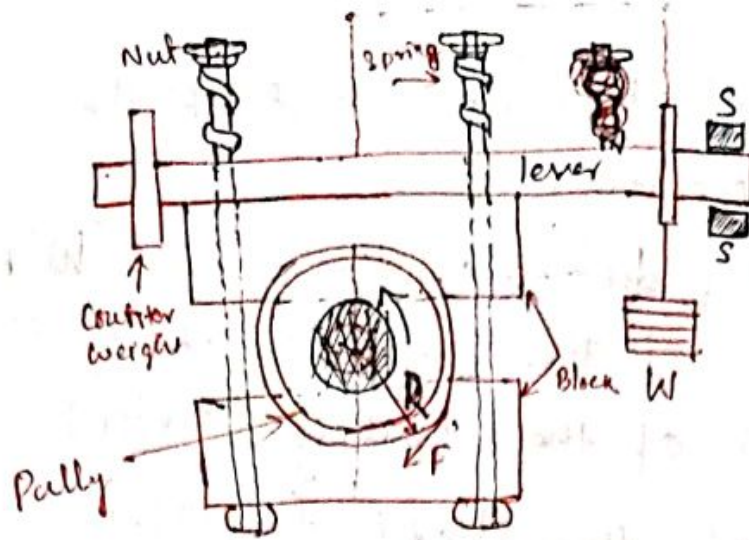
Limitations

it is not accurate because of change in friction coefficient of the rope with temperature.

Applications

This type of absorption dynamometer is most commonly used.

B) Using Poony Brake



- The power measured is converted into heat by friction or by other. It consists of two wooden blocks placed around a pulley fixed to the shaft of an engine whose power is required to be measured.
- Blocks are clamped by means of bolts and nuts. A helical spring is provided between the nut and the upper block to adjust the pressure on the pulley to control its speed.
- The upper block has a long lever attached to it and carries a weight W at its outer end. A counterweight is placed at the other end of the lever which balances the brake when unloaded.
- In order to limit the motion of the lever two stops are provided.

Working

- When the brake is to be operated, the long end of lever is loaded with suitable weights W & nuts are tightened until the engine shaft runs at a constant speed and the lever is in horizontal position.
- Under these conditions, the moment due to the weight W must balance the moment of frictional resistance between the blocks & the pulley.

Let

W = weight of the outer end of the lever (Newton).

L = horizontal distance of the weight (W) from the center of the pulley (meter)

R = radius of the pulley (meter)

N = Speed of the shaft (rpm).

→ Now the moment of the frictional resistance or torque of the shaft,

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

$$\text{Brake power} = \frac{T \times 2\pi N}{60} = \frac{(W \times L) 2\pi N}{60} \text{ (watts)}$$

Limitations

→ When the driving torque on the shaft is not uniform, this dynamometer is subjected to severe oscillation.

Application

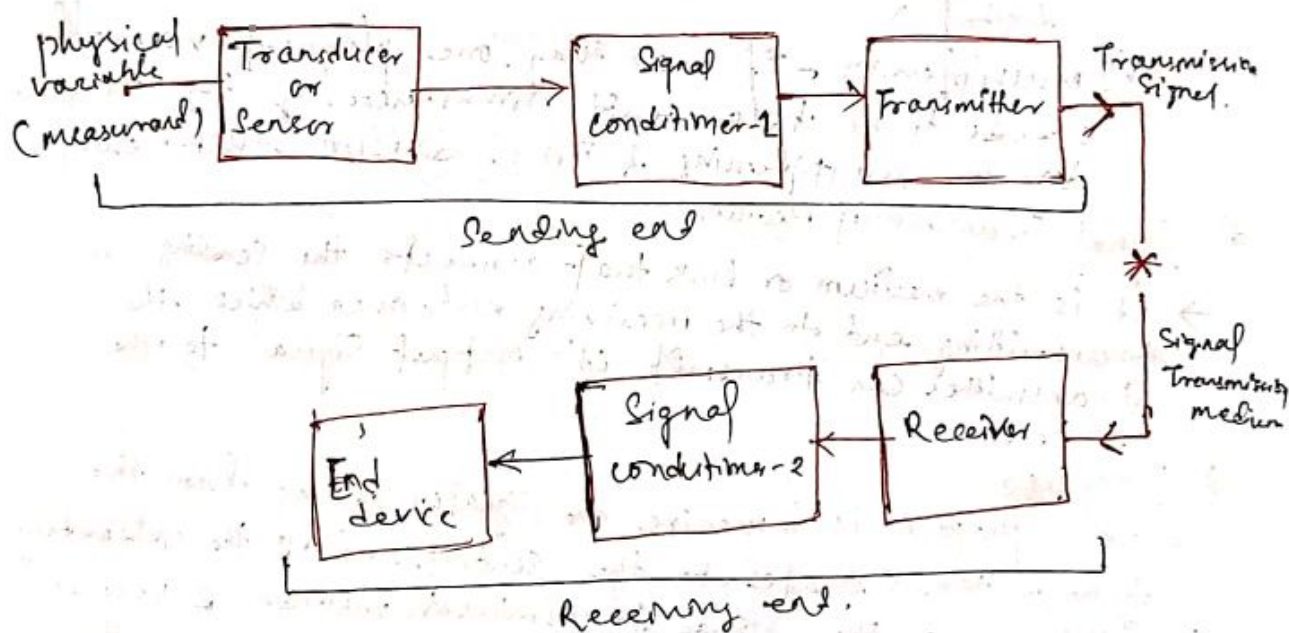
→ measuring power or torque developed by power source such as engines or electric motors.

CHAPTER-5 Telemetry & Various Converters

5.1 Define Telemetry

- Telemetry is the process by which the measured physical quantities, such as pressure, flow, temperature, level displacement, velocity, acceleration etc. are transmitted to a convenient remote location or to multiple location, in a form suitable for displaying, recording, actuating a process etc.
- The use of telemetry system makes it possible to group several instruments in a centralized control room to enable the operator to have a complete picture of the conditions in a plant, without using long connecting pipe from flow meters, liquid level indicators & pressure gauges.
- Measurements made in hazardous & remote location may be transmitted to the control room where the operator can safely control the process.

5.2 General Telemetry System



a) Transducer or Sensor

- converts the physical variable to be telemetered (that is the measurand) into an electrical quantity. This quantity in most cases is either an electrical parameter (variable resistance, inductance or capacitance) or an electrical signal (voltage or current).

b) Signal conditioner - 1

→ converts the electrical output (which may or may not be a signal, as explained above) of the transducer (or sensor) into an electrical signal compatible with the next element is the transmitter. (voltage vs current)
• analog vs digital

c) Transmitter

→ its purpose is to transmit the information signal (a signal containing information, i.e. a signal which is a function of the value of the measured) coming from the signal conditioner - 1 using a suitable carrier signal to the receiving end.

- i) modulation of the carrier signal.
- ii) Amplification for the purpose of transmission.
- iii) Signal conversion - required for the purpose of transmission (convert voltage to current / analog to digital)

(vi) Multiplexing - if more than one physical variable needs to be telemetered, simultaneously by frequency division multiplexing & time division multiplexing.

d) Signal Transmission Medium

→ It is the medium or link that connects the sending or transmitting end to the receiving end, over which the transmitter can transmit its output signal to the receiver.

e) Receiver

→ its purpose is to receive the signals coming from the transmitter (located at the sending end of the telemetry system) via the signal transmission medium & recover the information from the transmitter (located at the sending end) same.

- i) Amplification - amplify the received signal.
- ii) Demodulation - Demodulate the received signal to recover information signal.
- iii) Signal Conversion - this conversion is generally the complementary process of conversion performed by transmitter.

iv) Demultiplexing

if refers to the process separating various information signals. So that they can be delivered to their respective end device.

f) Signal conditioning

process the receiver output necessary to make it suitable to drive the given end devices.

(g) End Device:

The element is so called because it appears at the end of the system. Depending on the purpose of the telemetry in the given situation.

5.3 Types of Telemetry System :-

* According to energy medium.

→ Pneumatic Telemetry.

→ Hydraulic Telemetry.

* According to Electrical

→ Current Telemetry

→ Voltage Telemetry

→ pulse Telemetry.

* According to signal type

→ Analog Telemetry.

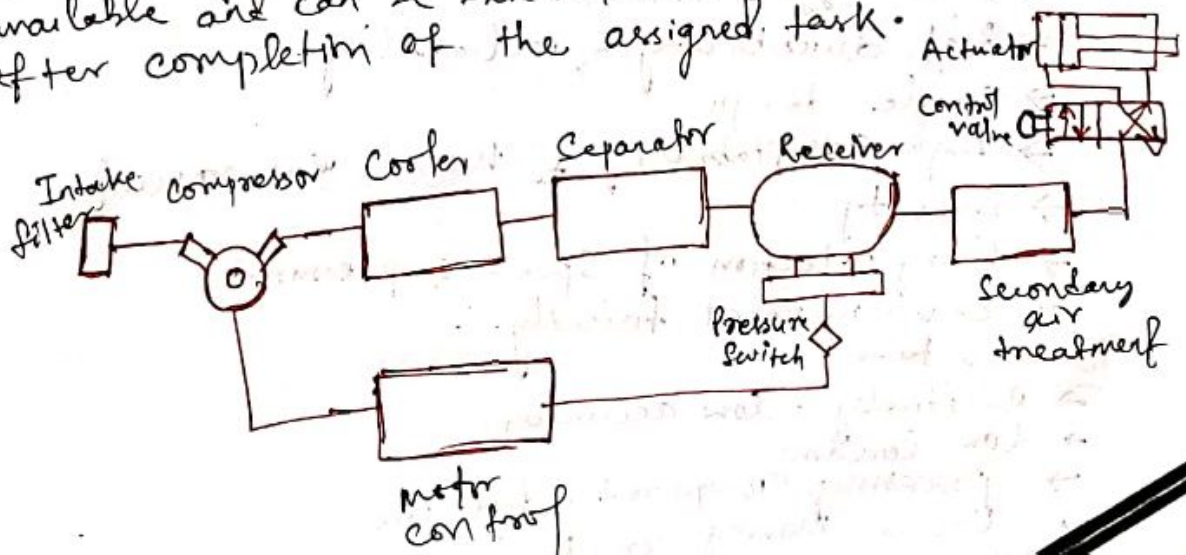
→ Digital Telemetry.

Landline Telemetry system.

Pneumatic Telemetry

→ Pneumatic technology with the study of behavior and application of compressed air in our daily life in general & manufacturing automation in particular.

→ Pneumatic system use air as the medium which is abundantly available and can be exhausted into the atmosphere after completion of the assigned task.



* Air filter:- These are used to filter out the contaminants from the air.

* Compressor:- compressed air is generated by using air compressor. Air compressors are either diesel or electrically operated. Based on the requirement of compressed air, suitable capacity compressor may be used.

* Air cooler:-

During compression operation, air temperature increases. Therefore coolers are used to reduce the temperature of the compressed air.

* Dryer

The water vapor or moisture in the air is separated from the air by using a dryer.

* Control valves

Control valves are used to regulate, control & monitor for control of direction flow, pressure etc.

* Air actuator

Air cylinder and motors are used to obtain the required movements of mechanical elements of Pneumatic System.

* Electric motor

Transforms electrical energy into mechanical energy. It is used to drive the compressor.

* Receiver Tank

The compressed air coming from the compressor is stored in the air receiver.

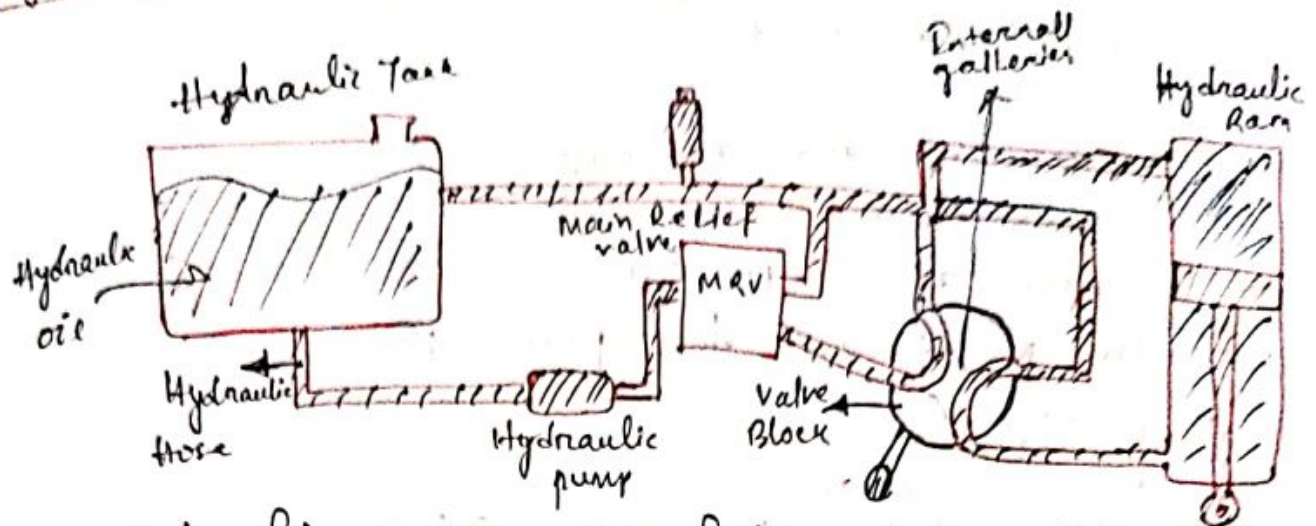
Advantages

- High effectiveness
- High durability & reliability
- Simple design
- High adaptability to harsh environment
- Safety
- Easy selection of speed & pressure
- Environmentally friendly.

Disadvantage

- Relatively low accuracy.
- Low loading
- processing required before use
- Greater moving speed & noise

Hydraulic Telemetry System



- A hydraulic system circulates the same fluid repeatedly from a fixed reservoir that is of the prime mover.
- The fluid is almost non compressible liquid, so the actuators it drives can be controlled to very accurate position speeds or forces.
- Most hydraulic systems use mineral oil for the operating medium. Other fluids such as water, ethylene glycol, or synthetic types are not uncommon. Hydraulic systems usually have a dedicated power unit for each machine.
- Hydraulic Tank → stores liquid/fluid.
- Hydraulic pumps → A hydraulic pump is a mechanical source of power that converts mechanical power into hydraulic energy (hydraulic energy = flow, pressure). It generates flow with enough power to overcome pressure induced by the load at the pump outlet.
- Main relief valve → A hydraulic valve properly directs the flow of a liquid medium usually oil through your hydraulic system. The direction of the oil flow is determined by the position of a spool.
- Filter → Remove dust particles before liquids enter into tank.

Advantages

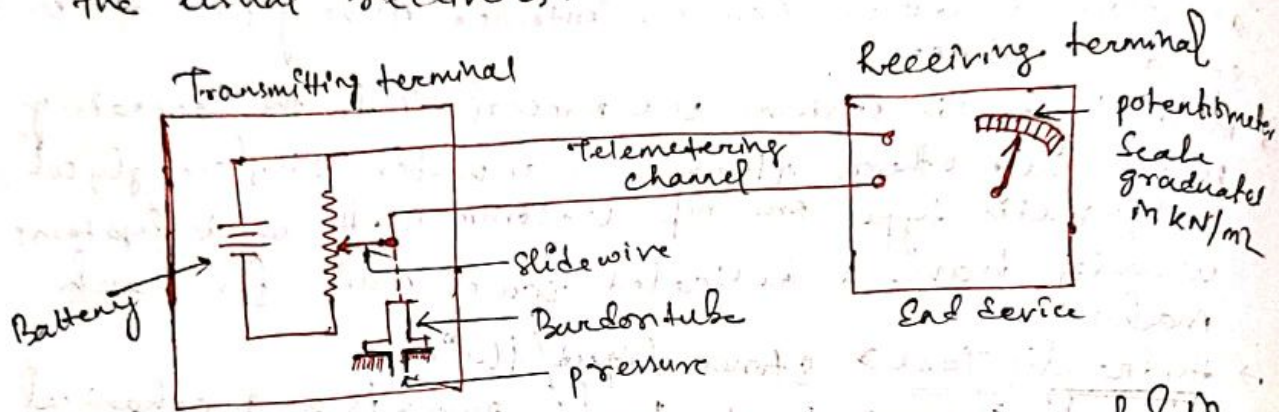
- it gives more power than pneumatic system.
- it's reliable to operate.

Disadvantages

- slower motion than pneumatic.
- complex construction.
- leakage of oil problem.
- more maintenance than pneumatic.

③ Voltage Telemetry

- In these systems the measurement is converted to ac or Dc voltage.
- For such systems, the self-balancing potentiometer are the usual receivers.



Construction

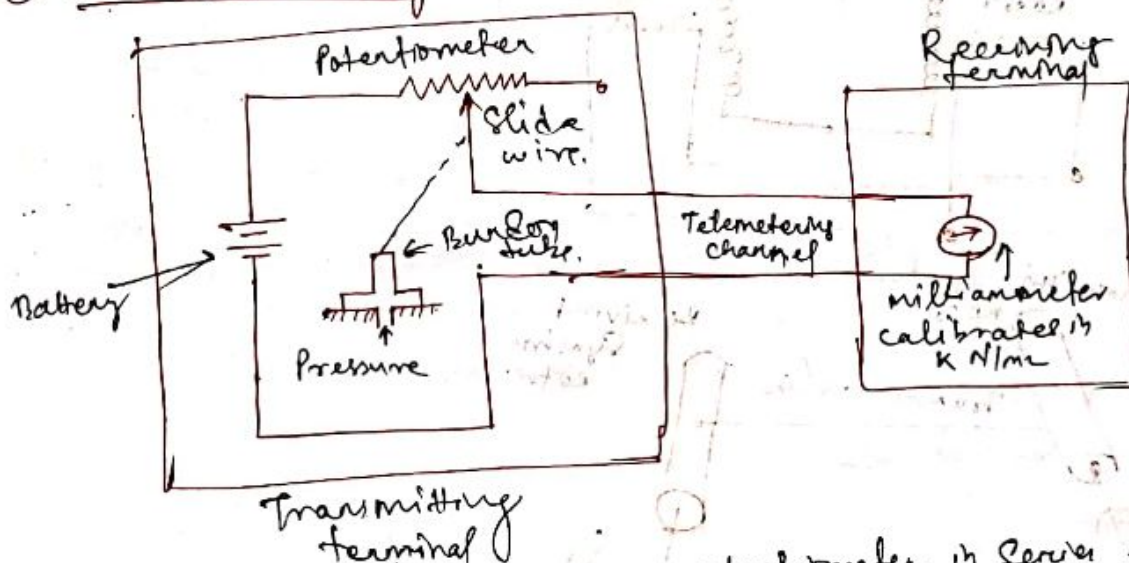
- it consists of a slide-wire potentiometer connected in series with a battery at the transmitting terminal. The sliding contact is connected to the Bourdon tube used for pressure measurement.
- At the receiving terminal a null balance D.C. potentiometer or a recorder is used for pressure measurement.
- ~~→ At the receiving terminal a null balance D.C. potentiometer or a~~
- In betⁿ the ~~terminal~~ transmitting terminal & receiving terminal a pair of wire form a telemeter channel.

- With the change of pressure on the system, the Bourdon tube actuates the slider of the potentiometer, consequently the voltage changes at the transmitting end.
- This voltage is carried by the telemetry channel to the receiving terminal, where it is measured with the help of null balanced D.C. potentiometer indicator calibrated in terms of pressure scale (KN/m^2) or recorded if required.
- ~~if required~~ Some systems make use of the deflection type indicators to measure voltage. These indicators are calibrated for the respective pressure. Basically a null balance D.C. potentiometer reduces the current carried by telemetry channel with negligible pressure.
- Such systems use primary sensing elements, such as microphones, tachometers, Bourdon tube or differential transformer, all produce voltage signal.

Disadvantages

- voltage telemetry system is limited for transmission up to 300 meter distance.
- A voltage telemetry system is very much suitable for adding several input voltage in series provided the measurement is linear, this system needs a relatively more expensive terminal.

④ Current telemetry



- it consists of a slide-wire potentiometer in series with a battery.
- The slider is connected to the Bourdon tube which measures pressure.
- At the receiving terminal, a multimeter is connected in series.

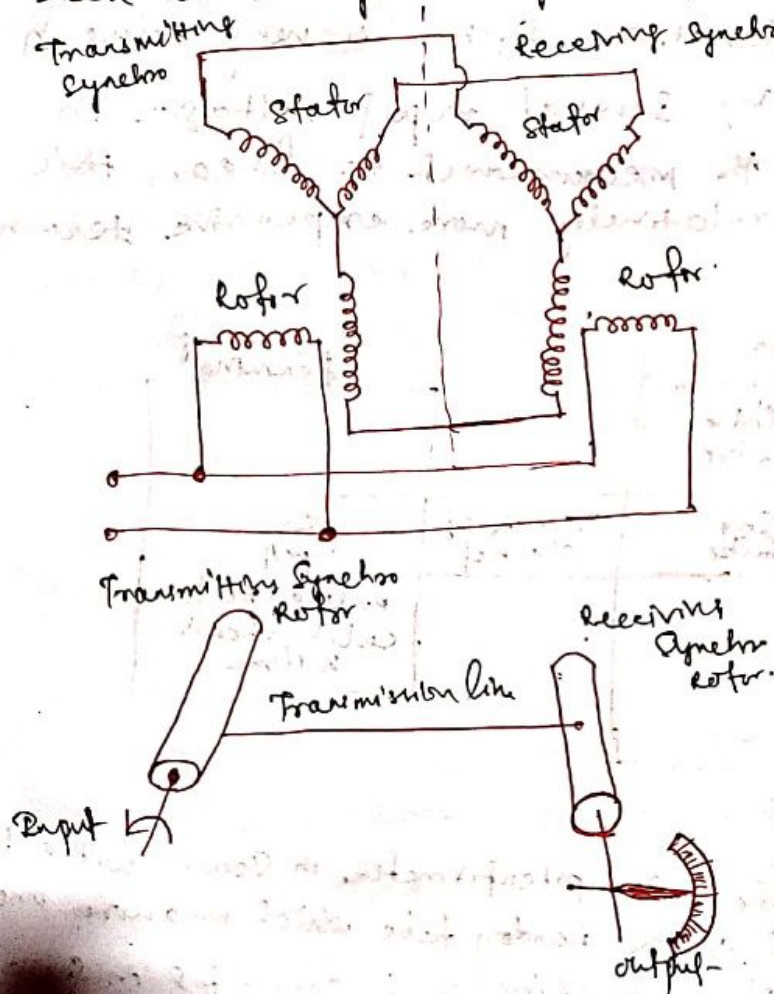
- which is calibrated in terms of pressure scale.
- When the pressure in the system changes, the Bourdon tube moves the sliding contact thereby changing the ~~receiving terminal~~ through the pair the current at the transmitting terminal.
 - This current passes to the receiving terminal through the pairs of wires (telemetry) channel and at the receiving terminal is measured by the milliammeter.

Advantages

- The current system can develop higher voltage than most voltage system.
- Simple D.C milliammeters can be used with special calibration for line resistance.
- Several receivers can be operated simultaneously.
- Several receivers can be operated simultaneously.
- The received signals can be added or subtracted directly.

⑤ Position or Ratio Telemetry

- This type of system, the relative magnitude of two or more quantities is varied in accordance with measured variable. Typical examples are resistance slide wire bridge, inductance bridge, & a.c. self-synchronous generator such as Selsyn or Synchro-generator telemetry system.



- The Selsyn generator converts an angular input displacement of rotor into the relative magnitude of an a.c. voltage or a set of voltages.
- It is similar to three phase induction motor having three-phase stator windings, but two pole fields carrying a single phase excitation winding.
- This system consists of two sets of similar three phase stator windings and single-phase rotor windings & both sets are electrically connected.
- One set works as a transmitter while the other as a receiver. When the rotor of the transmitting Selsyn is in the same position as the rotor in the receiving Selsyn, the emf induced in each is of opposite polarity but equal magnitude. Hence no current flows betn the two stators along the transmission line.
- If the rotor of the rotor of the transmitting Selsyn is turned so it is no longer in the same position as the rotor of the receiving Selsyn, the induced emf in the two stator windings will differ and hence a current will flow betn the two stators.
- The current will flow in a direction which produces torque that causes the rotor of the receiving Selsyn, ~~the induced~~ to move into the same position as the transmitting Selsyn rotor.

Advantage

- This system are usually inexpensive & required only low power the primary element.
- maintenance is low

⑥ Pulse Telemetry

- pulse telemetry is another type of modulation method being widely used today. The information (i.e. the measurand) may be conveyed through radio frequency links to the remote control room.

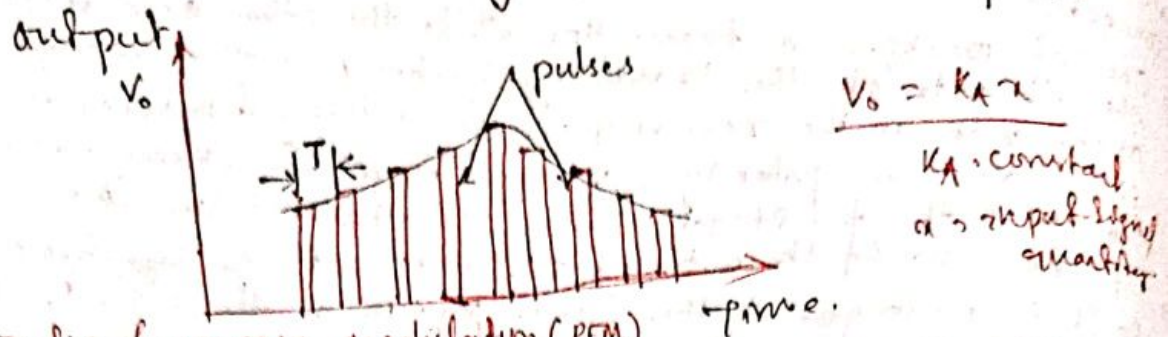
- ① Analog pulse Telemetry.
- ② Digital pulse Telemetry.

Analog pulse Telemetry

- In this type of telemetry the signal (measurand) to be transmitted to remote location is converted into the number of pulses (normally called pulse train) which are d.c or a.c voltage of constant amplitude & small width.
- These pulses are used to modulate a carrier in many ways such as pulse amplitude modulation, pulse frequency modulation, pulse duration modulation, and pulse position modulation.
- ① pulse amplitude modulation
In this the carrier is modulated with pulses whose heights carry the information. the carrier is in the form of a pulse train of constant frequency.

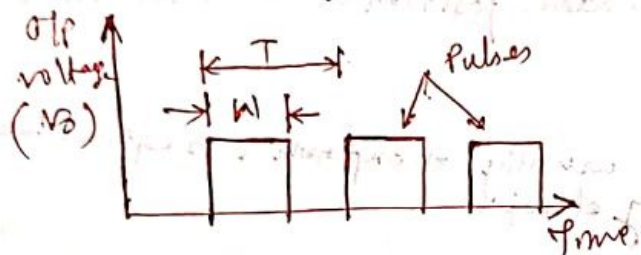
→ The pulse train is produced by pulse generator. In PAM the height of pulse train is varied in accordance with the signal to be transmitted.

$$\text{Frequency } f = \frac{1}{T} \text{ Hz} \quad T = \text{pulse period}$$



(b) pulse frequency modulation (PFM)

→ In it, the sum of pulses is a measure of the time integral of the quantity being measured. The sum of pulses is given as



$$N = \int f dt = \int K_f x dt = K_f \int x dt$$

where, frequency of pulse train f is proportional to the signal x , K_f - constant.

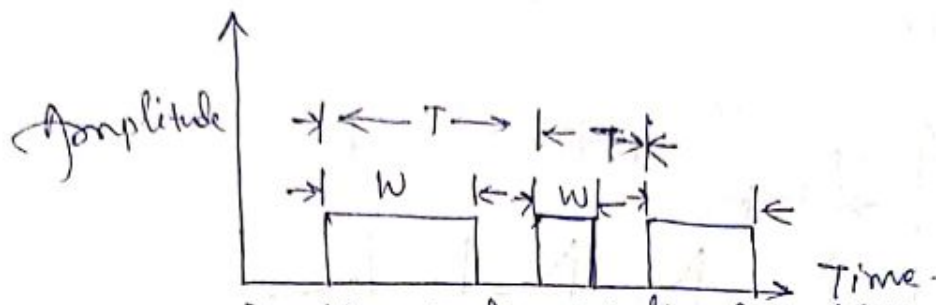
& the time period $T = \frac{1}{f}$ & hence T is inversely proportional to the signal x .

→ pulses are generated using voltage of the frequency technique. The a.c. signal generated by transducer may be directly converted in frequency with the help of Schmitt trigger circuit.

→ In many measurement system the transducer output is directly in the form of pulses. Such transducers include rotating armatures, turbine meter for liquid & gases which are provided with electromagnetic or photoelectric pickups to provide pulses output for the telemetry system.

(i) pulse duration modulation (PDM)

- In pulse duration modulation the magnitude of all pulses remain constant but the duration of the pulses varies.



- one edge of the pulse is fixed in time sequence and the other edge varies in proportion to the value of the information. This type of modulation is also called the pulse width modulation (PWM).
- the width (duration) of the pulse is a measure of the information signal (measurand x) at the beginning of that period. If x is the magnitude of the signal the width of the pulse is given as

~~the pulse~~ $\frac{W}{T} = kx$

- At the end of the fundamental period T (or beginning of next period), the pulse is again repeated with a possible new width (duration), in case the magnitude x of the signal to be transmitted has changed in value.
- The fundamental time T is greater than the maximum possible pulse duration (width) W . The quantity x is retrieved at the receiving end by forming the ratio $\frac{W}{T}$.

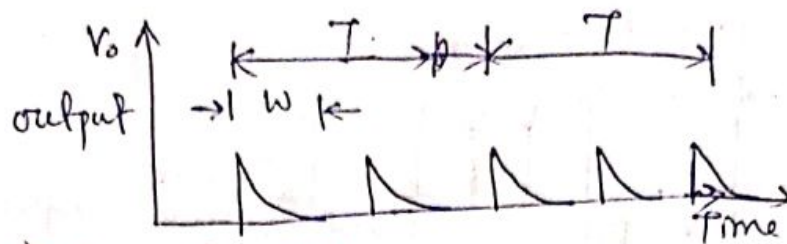
- Duration T system may consist of electromechanical or electronic devices. The output may be a mechanical displacement or an electric analog signal like voltage or current.

Pulse position modulation

- In this signal (or measurand data) x is converted into a time interval, W is the time interval (width) between two successive pulses of short duration.

- A rectangular pulse produced by a Schmitt trigger. Two pulses of short duration are generated from the

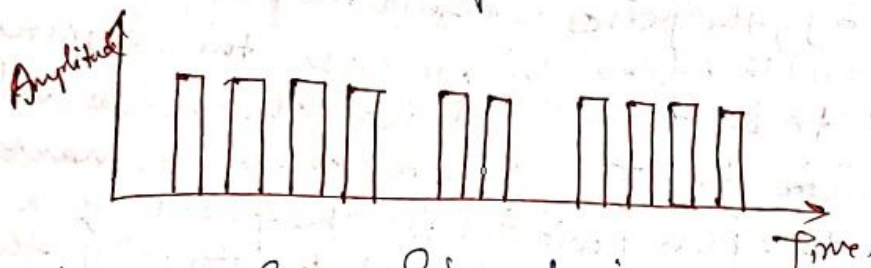
receiving terminal, the pulse is converted into a pulse of duration w using a bistable multivibrator.
 → pulse of short duration can be more easily transmitted over large distance.



Digital pulse Telemetry

→ The data to be measured (measurand) is quantized and transmitted serially as data words in pulse code.

→ Due to this reason the process is also called pulse code modulation (PCM). This system consists of sending information by transmitting series of binary digits.



→ The analog signal is sampled at regular intervals, if then each sample value is converted into coded form.

→ The conversion of analog signal into digital signal coding or encoding. The process of coding introduces what is termed as quantization noise.

→ The noise can be reduced by using higher bit encoder. The bandwidth of the PCM signal depends upon the bandwidth of the original signal & the

the number of bits used to represent the analog signal. it is rather necessary for the receiver to distinguish betn 1 & 0 levels.

Problem in Telemetry System

→ One of the major concerns in the telemetry system is accuracy. We can judge the quality of the system by how accurate it is for the different input signals.

→ Noise & interchannel interference are problems to contribute to poor accuracies. it is possible to improve characteristic of a communication link by higher transmitted power.

→ the Am transmission is most susceptible to atmospheric noise because atmospheric noise is introduced into an electromagnetic wave via amplitude modulation.

→ Interchannel interference may be present due to two major causes

a) if the interchannel spacing (frequency gap betn sub carrier) is too small then one channel may be introduced error into an adjacent channel.

b) Due to the presence of intermodulation.

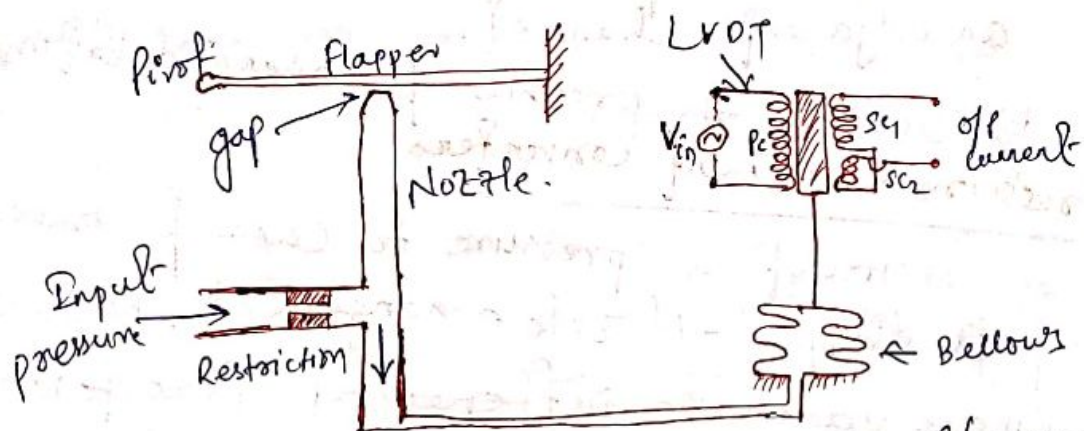
55) Pressure to Current Converters

→ we can construct a pressure to current converter using a flapper - Nozzle arrangement, Bellows & linear variable Differential Transformer (LVDT) circuit.

→ Input pressure is given to flapper - Nozzle arrangement and the output current will come

through the LVDT.

- Flapper Nozzle arrangement: it is type of pressure controlling device. it controls the input pressure by the moving the flapper away or towards the nozzle, if we need high pressure.
- Then nozzle will be closed by the flapper and if we need less pressure, then nozzle will be opened by moving flapper away.
- Bellows:- Bellows are one type of pressure measuring device. they are the elements which will expand or per the ~~app~~ applied pressure. Based on the displacement we can measure the pressure.
- Linear variable Differential Transformer - It works on the principle of mutual inductance. In the LVDT three coils will be present. Primary coil is connected to a power source and Secondary coils are connected in series opposition method.
- At initial position, the voltage induced will be zero. if the core displaces, then due to inductance, voltage will be induced in to the coils, resulting in the current.



- first input pressure is supplied to the flapper - nozzle arrangement - then it will be supplied through a pipe & that pressure is given as input to the bellows. These bellows are connected to the core of LVDT.

- When pressure is applied to bellows, they will expand thus core displaced and the voltage is induced on the Secondary coils of LVDT.
- As voltage is induced, current will flow through the coil. That current is proportional to the input pressure applied. Thus pressure is converted into equivalent current.
- When compared with standard values, we convert 3-15 psi of pressure can be converted to 4-20 mA of current.

Application

- pressure monitor.
- signal conversion for PLC, SCADA & data loggers.
- weather station.
- monitoring refrigeration system.

5.6 Pressure To voltage Converters

We know that piezoelectric transducer which convert pressure to voltage.

Basically (3-15 psi or 0-20 psi) pressure to convert the voltage [(0-5V) or (0-10)V].

Chapter - 6

Acoustic Measurements

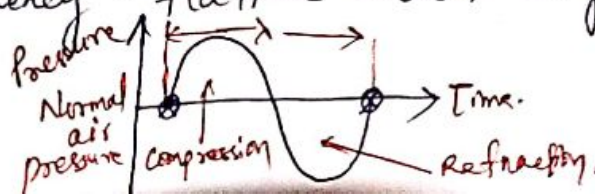
- Acoustic pressure → Sound / acoustic pressure is the local pressure deviation from the ambient atmosphere pressure caused by a sound wave.
- Sound pressure can be measured using microphone & inside water by a hydro phone.
- SI unit : pascal (Pa)
- Acoustic pressure is the difference betⁿ pressure produced by sound wave & barometric (ambient) pressure at the same point in space.
- It's also the RMS of the instantaneous sound pressures over a specified period of time.
- if also known, an effective sound pressure.
 $1 \text{ Pa} = 1 \text{ N/m}^2 = 1 \text{ kg/m.s}^2$
- Normal breathing = 10 dB.
- Washing machine = 50 dB.
- Gradader = 180 dB.
- Lower acoustic pressure of human is capable of hearing is 20 Pa = 0 dB.
- 120 or 130 dB is the pain threshold.

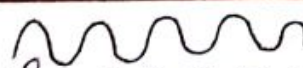
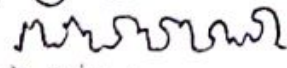
Sound power level

- Total sound energy emitted by a source per unit time (or) rate at which energy is emitted / reflected / transmitted / received per unit time.
- unit (SI) = watt (W).
- 0 dB doesn't mean "no sound". It means a sound level where the sound pressure = reference level.

Characteristics of sound

- Sound travels in longitudinal waves.
- The amplitude determines its volume (loudness).
- Pitch is the frequency of sound (high frequency - shriller sound, shorter wave length).
Low frequency - flatter sound, longer wave length.



- Musical sound is periodic 
- But noise sound is not periodic 
- Sound wave travels at 330 m/s in air.
- The intensity of sound decreases with distance from the source as the inverse square of distance.

$$\frac{I}{I_0} = \left(\frac{r_0}{r}\right)^2$$

Acoustic pressure level

- It's measured in logarithmic scale & decibel sound pressure level (SPL). logarithmic measure of the RMS value of sound pressure of a sound relative to reference value, the threshold of hearing (lowest intensity sound that can be heard).

$$SPL \text{ or } L_p = 20 \log_{10} \left(\frac{p}{p_0} \right) \text{ dB}$$

p measures sound pressure level of a given sound.
 p_0 reference value of 20 μPa .

Acoustic impedance

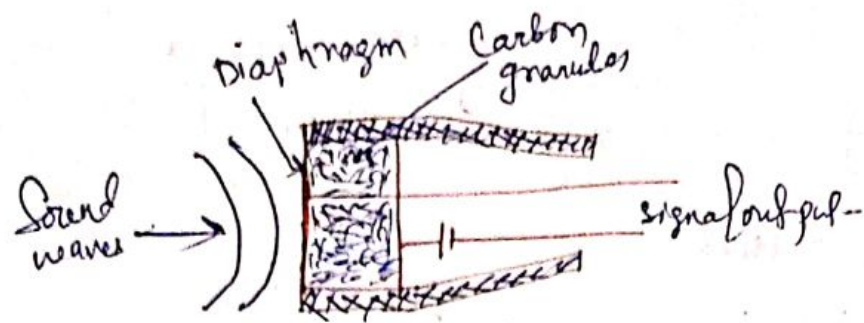
$$Z = \frac{p}{u} \quad \begin{matrix} p = \text{Sound pressure} \\ u = \text{velocity of particle (of wave)} \end{matrix}$$

Microphones

- Special type of pressure transducer converting acoustic energy into pressure wave into electrical energy for the measurement.
- Sensing element used is a diaphragm.
- The range of pressure to be measured is normally small compared to atmospheric pressure.
- The desirable characteristics includes linearity over a wide range of amplitudes & frequency.
- Sensitivity (dB) = $20 \log_{10} (\text{voltage O/P}) + 74 \text{ dB (applied sound pressure mda)}$
- Ex: Sensitivity of -20 dB means that a voltage of 0.1 V will be developed by a sound of pressure level of 74 dB which is the reference condition of sensitivity.

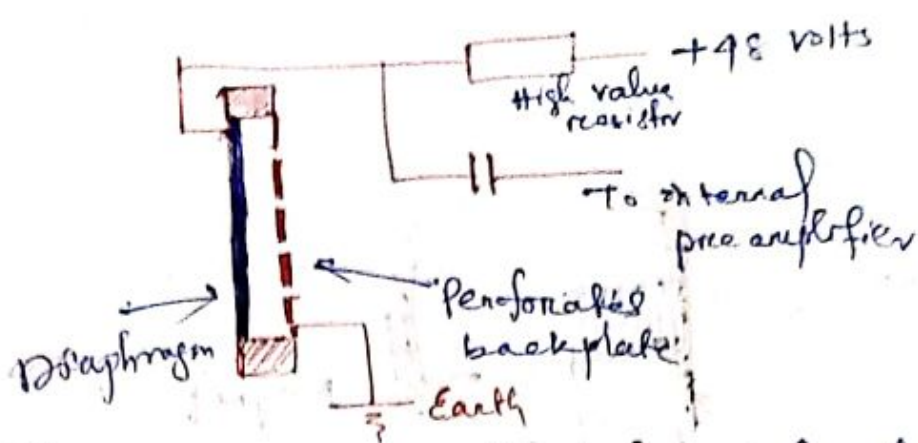
Types of Microphone

Carbon Microphone



- The basic concept behind the carbon microphone is the fact that when carbon granules are compressed their resistance decreases.
- This occurs because the granules come into better contact with each other when they are pushed together by the higher pressure.
- Carbon granules is covered with a thin metal diaphragm. A battery is also required to cause a current to flow through the microphone.
- When sound waves strike the carbon microphone diaphragm it vibrates, exerting a varying pressure on the carbon.
- These varying pressure levels are transferred into varying levels of resistance, which in turn vary the current passing through the microphone.
- It is mostly used in telephones.
- main frequency range = 5 kHz.
- Sensitivity is high (good).
- Capacitive microphone (condenser)

The diaphragm of the microphone forms one of the plates of a capacitor. The other plate is the backplate, which is close to and parallel to the diaphragm.



→ $V = Q/C$, a capacitor with a low value of capacitance will measure a greater voltage across the plates than a capacitor with a high capacitance, for the same value of charge.

→ The diaphragm & backplate of the microphone are charged up to a voltage of 48V. This is done through a high value resistor so the audio signal is not affected.

→ One of the plates of the capacitor in the capacitor microphone is the diaphragm, which moves in response to sound, then as the separation between the plates changes in response to the sound, the capacitance changes & so does the voltage across the plates.

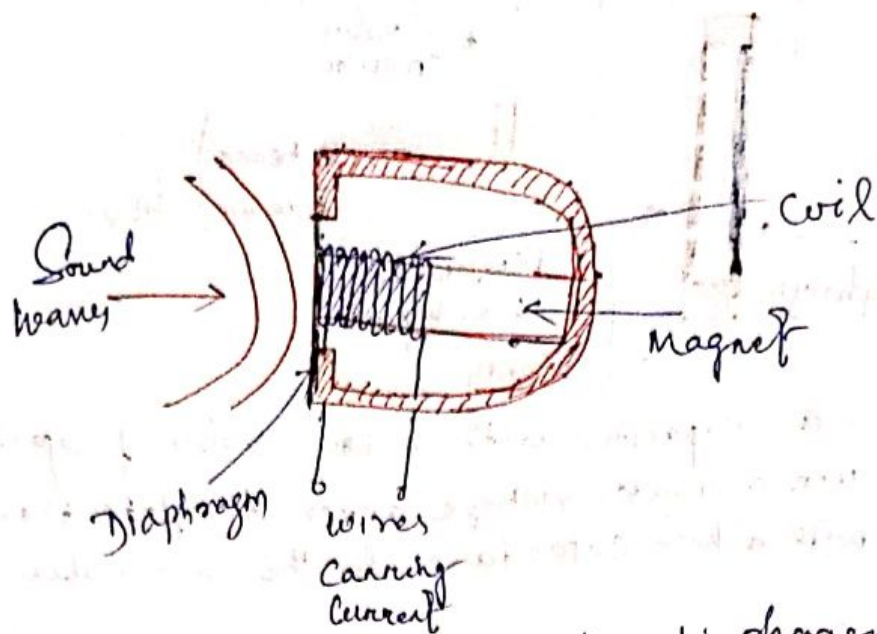
→ expensive & accurate.

→ Sensitivity ≥ -50 dB

Dynamic Microphone

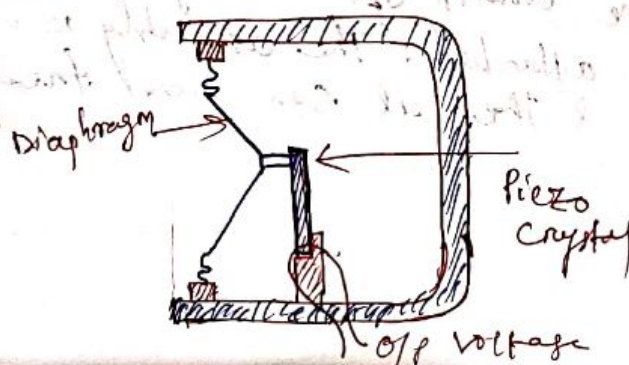
→ The dynamic or moving coil microphone relies on the fact that if a wire held within a magnetic field is moved then an electric current is induced. This is the same effect as seen in an electric generator and many other items.

→ The dynamic microphone consists of a magnet & a diaphragm to which a coil is attached. The assembly is held in place by an outer casing & the coil can move freely over the magnet.



- As sound waves hit the diaphragm, this causes the coil to move backwards & forwards within the magnetic field and as a result an electric current is induced in line with incoming sound vibration.
- Self-generating in nature & low sensitivity of 80 dB. Response peak around 2.5 kHz.
- ④ Inductive Microphones:
 - The diaphragm causes changes of the magnetic properties of certain materials.
 - In turn, these changes appear as changes in dimensions, which are sensed by the dimensions which are sensed by displacement transducer.
 - They have low output impedance, low sensitivity (-100 dB) & operate in the ultrasonic region.
 - if it is used in under water transducer.

⑤ Piezo-electric Microphones



- Crystals which demonstrate the piezoelectric effect produce voltages when they are deformed.
 - The crystal microphone uses a thin strip of piezoelectric material attached to a diaphragm.
 - The two sides of the crystal acquire opposite charges when the crystal is deflected by the diaphragm.
 - The charges are proportional to the amount of deformation and disappear when the stress on the crystal disappears.
 - Early crystal microphones used Rochelle Salt because of its high output, but it was sensitive to moisture & somewhat fragile.
 - Later microphones used ceramic materials such as barium titanate & lead zirconate. The electric output of crystal microphones is comparatively large, but the frequency response is not comparable to a good dynamic microphone.
 - Its frequency response extends to the ultrasonic region above 100 kHz.
 - Low sensitivity ≈ -50 to -100 dB.
 - very linear over a wide range.
 - used in sound measurement system.
-