Introduction To Instrumentation

UNIT – II

Pressure measurements: units of pressure - Manometers - Different types, - Elastic type pressure gauges - Bourdon tube - Bellows - Diaphragm - Elastic elements with LVDT & Strain gauge - Capacitive type pressure gauge - Measurement of Vacuum - Mcleod gauge - Thermal Conductivity gauge - Ionisation gauge.

2.0 Instrumentation refers to the art and science of collection of several instruments and auxillary equipment & their utilization for conducting successfully a test or an experiment on a system process (or) plant.

There are different kinds of Instruments such as electrical, electronic & mechanical. There are many types of Instrumentation such as electrical, Industrial, electronics & mechanical.

2.1 Pressure is one of the most important parameters to be controlled in many applications. Pressure is defined as the force exerted by a fluid on unit area.

Units of pressure:

S.I units : Newton/meter^2 (N/m^2) (or) pascal

Pressure is also expressed in terms of height of column of a fluid, bar, torr etc.

1 pascal = $1\ N/m^2$

1 bar = $10^5\ N/m^2$

1 atm = 1.013×10^5 pa

= 1.013 bars.

= 760 mm of mercury

= 10.3 m of water

1 torr = 1 mm of Hg (1 mm of mercury).

Other terms related to pressure are —

Atmospheric Pressure: pressure due to the air surrounding the Earth's surface is called atmospheric pressure.

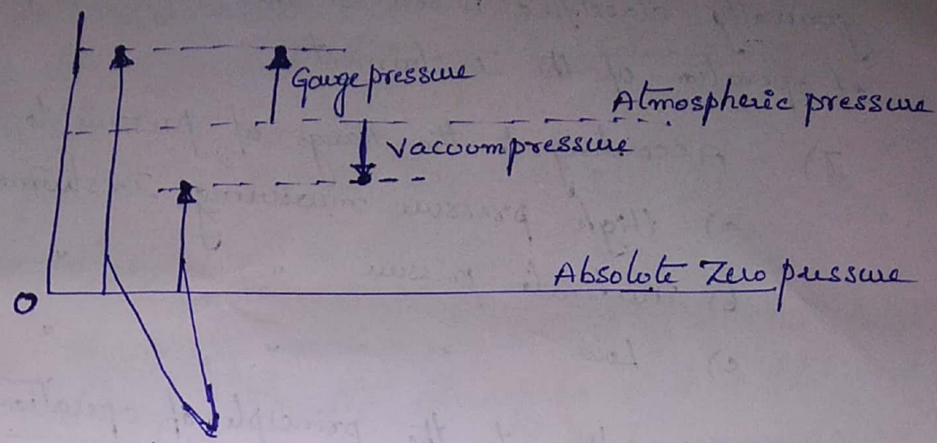
Absolute pressure: It refers to the pressure measured with reference to absolute zero pressure (or) perfect vacuum.

Gauge pressure: It represents the difference between the absolute pressure and the atmospheric pressure.

In other words it is the pressure measured with reference to the atmospheric pressure.

Vacuum pressure: It represents the amount of ~~which~~ pressure by which the atmospheric pressure exceeds the absolute pressure.

The relation among different types of pressure is



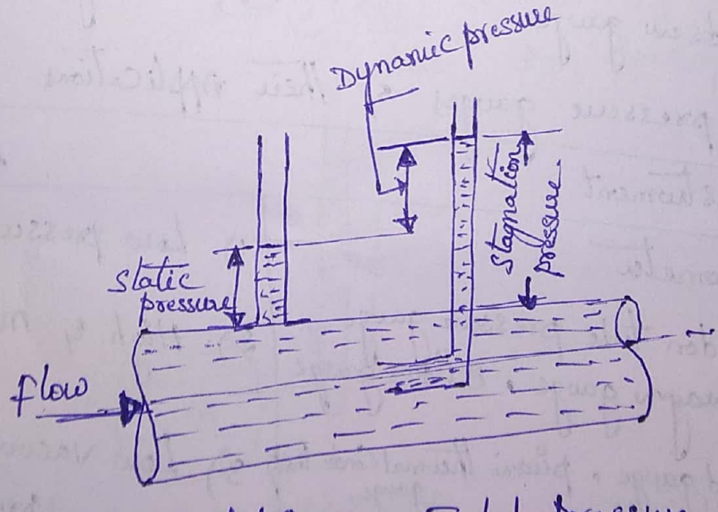
(1) fig: Relation between different pressures.

Absolute pressure = Atmospheric pressure + Gauge pressure

Vacoom pressure = Atmospheric pressure - Absolute pressure.

Static pressure: It is defined as the pressure acting on the wall by a fluid at rest or flowing parallel to the wall in a pipe (fig 2)

Stagnation or Total pressure: It is defined as the pressure that would be obtained if the fluid stream were brought to rest isentropically (fig: 2)



fig(2): static & Total pressure

2.2 Classification of Pressure Measuring devices : These are generally classified based on the range of pressure & the principle of operation of the Instrument.

I) According to the Range of pressure to be Measured

a) High pressure measuring Instruments (Above 700 atm)

b) Moderate pressure " " .

c) Low " " " [1mm of Hg (or) below]

II) According to the principle of operation

1) Balancing the pressure by a column of liquid (or) dead weight

(a) Manometers (b) Dead weight tester (c) McLeod gauge.

(2) By measuring Elastic deformation caused by the pressure

(a) Bourdon tube pressure gauge (b) Diaphragm pressure gauge

(c) Bellows pressure gauge

(3) Special methods (By measuring change in electrical quantities that vary with pressure)

(a) Pirani thermal conductivity gauge (b) Ionization gauge

(c) Knudsen gauge (d) Bridgman gauge.

→ Different pressure gauges & their Applications

Instrument	Application
1) Manometer	1) Low pressure
2) • Bourdon tube pressure gauge • Diaphragm gauge • Bellows gauge	2) High & medium pressures
3) • McLeod gauge • Pirani thermal Conductivity gauge • Ionisation gauge • Knudsen gauge	3) Low vacuum & ultra high vacuum pressures.
4) • Bourdon tube pressure gauge • Diaphragm gauge • Bulk modulus (or) Bridgman gauge	4) Very High pressures.

2.3 Manometers

Manometers are defined as the devices used for measuring pressure at a point or difference of pressure between two points in a fluid by balancing the column of fluid by the same or another column of the fluid.

Manometers are classified into two categories

1) Simple Manometers (2) Differential manometers

2.3.1 Simple Manometers

A simple manometer consist of a glass tube having one of its ends open to the atmosphere and other end is connected to a point where the pressure is to be measured.

Simple manometer include

1) piezometer 2) U-Tube manometer 3) Single column manometer

1) Piezometer: It is the simplest form of a manometer used to measure the gauge pressure at a point in the fluid. One end of the manometer is connected to the point where the pressure is to be measured and the other end is open to the atmosphere as shown in fig 2.3. If "h" is the rise in liquid level in the piezometer tube with respect to point "A" then pressure at A is given by

$P = wh$ → (1) eqn where, w = specific weight of liquid $= \rho g$

where ρ = density of liquid

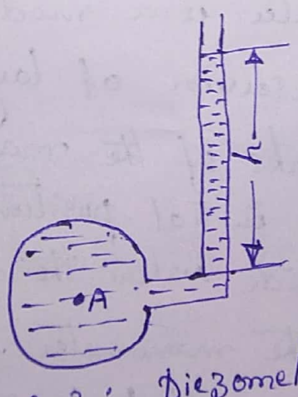


fig 2.3 : piezometer.

2) U-Tube manometer:

It Consists of a glass tube bent into U-shape. one End of the U-tube is open to the atmosphere & other End is Connected to the point where the pressure is to be measured as shown in fig 2.4.

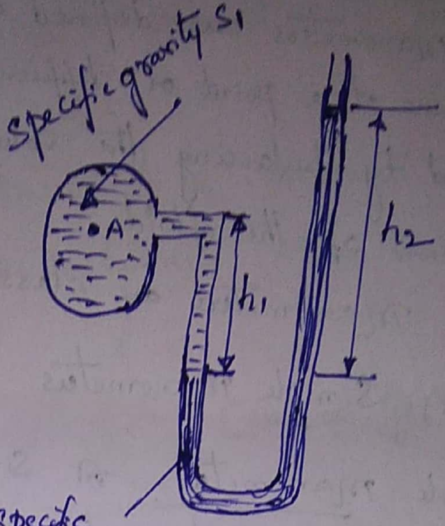


fig 2.4: U-Tube manometer

The U-tube is generally filled with mercury or any other liquid whose specific gravity is greater than the specific gravity of the liquid whose pressure is being measured.

from fig 2.4 the pressure head at 'A' is given by

$$h = h_2 s_2 - h_1 s_1 \longrightarrow (2)$$

where h_1 = ht. of light liquid in the U-tube above datum

h_2 = " " heavy " " " " " " "

S_1 = specific gravity of light liquid

S_2 = " " " heavy liquid.

3) Single Column Manometer:

Single Column manometer is a modified form of U-tube manometer in which a reservior of large Cross sectional area is Connected to one of the limbs of the manometer as shown in fig 2.5. X-X represents the initial position with which the liquid level in both the limbs coincide when the manometer is not connected to pressure point p. when the manometer is Connected to the pressure point, liquid in the right limb is raised to a height 'h_2'

Let 'Δh' be the fall in liquid level in the Reservior

Rise of heavy liquid in right limb is Equal to the fall of heavy liquid in the reservior $a \times h_2 = \Delta h \Rightarrow \Delta h = \frac{a h_2}{A} \rightarrow (3)$

where a = Area of cross-section of the right limb

A = Area of " " of the reservior

writing the pressure gauge eq. to fig 5. we get

$$h = \Delta h\,[S_2 - S_1] + h_2 S_2 - h_1 S_1 \longrightarrow (4)$$

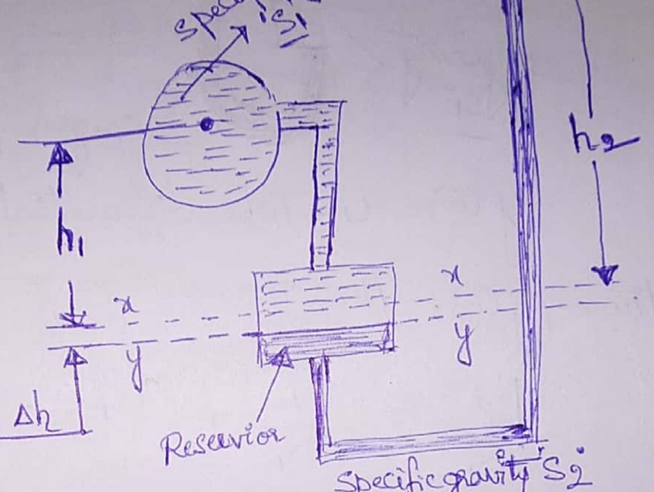


fig 5: Single column vertical manometer.

where

h = pressure head at A $\cdot \left(\frac{P_A}{w}\right)$

S_1 = sp. gravity of light liquid

S_2 = sp. gravity of heavy liquid

Combining eq's (3) and (4) & neglecting $\frac{a}{A}$

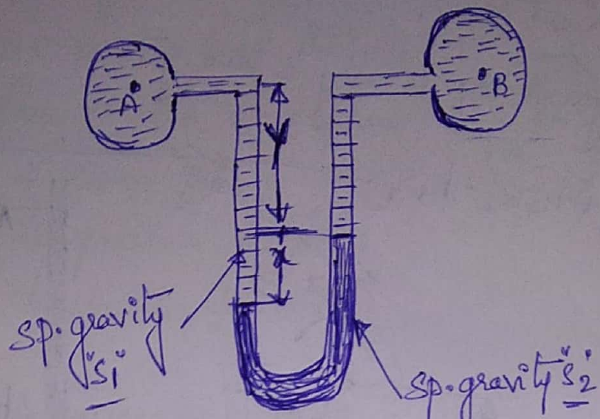
we get $h = h_2 S_2 - h_1 S_1 \longrightarrow (5)$

To increase the sensitivity, generally the right limb of the single column manometer is kept inclined and the manometer is called inclined single column manometer.

2.3.2 Differential manometer:

Differential manometers are the devices used for measuring the difference of pressure between two points in a fluid.

U-Tube Differential manometer: A simple U-Tube differential manometer is shown in fig (6). It consists of a U-Tube, two ends of which are connected to two points whose pressure difference is to be measured. The U-tube ~~consists of~~ contains heavy manometric liquid.



fig(6): U-Tube differential manometer.

from the fig(6); the pressure gauge equation is

$$\frac{P_B}{w s_1} = \frac{P_A}{w s_1} + (y+x) - x \cdot \frac{S_2}{S_1} - y \longrightarrow (6)$$

$$\Longrightarrow \frac{P_A}{w} - \frac{P_B}{w} = x(S_2 - S_1) \longrightarrow (7)$$

where

$\frac{P_A}{w}$ = pressure head at A in terms of water head

$\frac{P_B}{w}$ = " " " B " " " ".

S_1 = sp. gravity of liquid whose pressure is to be measured.

S_2 = " " " heavy manometric liquid

x = difference in heights of manometric liquid in two liquids.

Micromanometer: Micromanometer is used to measure small pressure differences with high precision. Simple micromanometer is shown in fig(7). It consists of two transparent basins which are connected on one side to a U-tube and other side of the basins are connected to the pressure points A and B. It contains two different immiscible manometric liquids of specific gravities S_1 & S_2.

[immiscible = Not forming a homogeneous mixture when mixed]

[illegible]

C-C' and D-D' represents intial positions of the manometric liquids in the reservoirs & U-tube respectively.

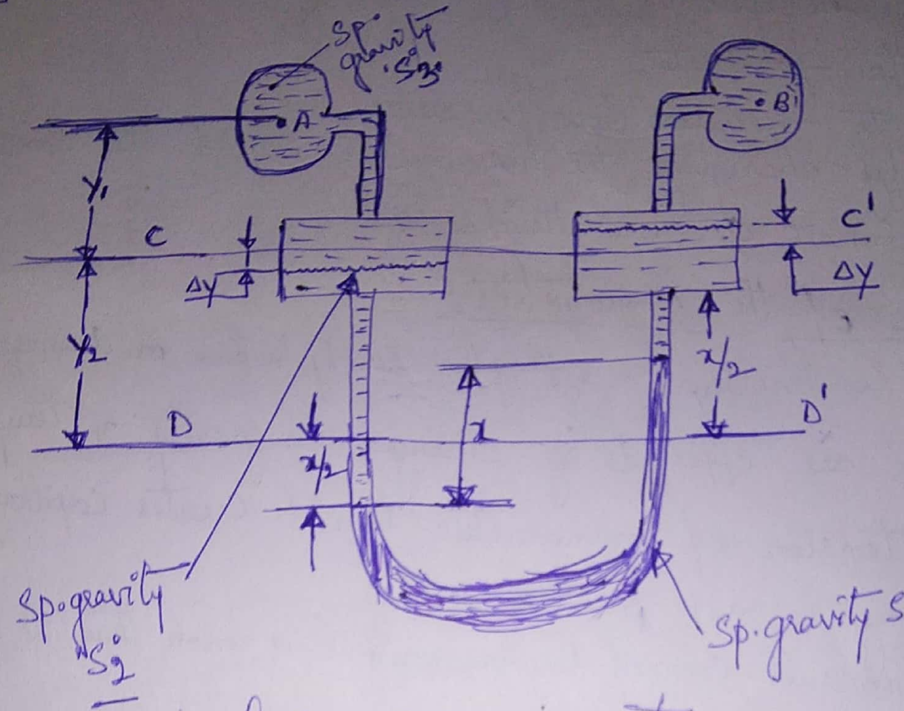


fig (7): Micromanometer.

writing the pressure gauge eq. for fig (7)

$$\frac{p_A}{w} - \frac{p_B}{w} = (y_1+\Delta y)S_3 + \left(y_2-\Delta y+\frac{x}{2}\right)S_2 - xS_1 - \left(y_2+\Delta y-\frac{x}{2}\right)S_2 - (y_1-\Delta y)S_3 \rightarrow (8)$$

But $\Delta y \times A = a\left(\frac{x}{2}\right)$

Substituting the value of Δy in eq (8)

we get

$$\frac{p_A}{w} - \frac{p_B}{w} = x\left[S_1 - S_2\left(1-\frac{a}{A}\right) - S_3\left(\frac{a}{A}\right)\right] \rightarrow (9)$$

If a/A is small then $S_2 \cdot a/A$ and $S_3 \cdot a/A$ can be neglected.

Then eq (9) becomes.

$$\boxed{\frac{p_A}{w} - \frac{p_B}{w} = x(S_1 - S_2)} \rightarrow (10)$$

Advantages of the Manometers:

1) High accuracy and good Sensitivity
2) Relatively inexpensive.
3) Easy to fabricate.
4) Suitable to measure low pressures.
5) Simply by changing the manometric liquid the Sensitivity of the Instrument can be altered.

→ ## Limitations of the Manometers:

1) Fragile Construction (fragile = Easily broken or damaged)
2) Readings are effected by changes in gravity & temperature.
3) Surface tension of manometric liquid creates capillary affects
4) Recording is not possible
5) High pressures cannot be measured (i.e more than 2 atms)

2.4 **Elastic Transducers:** Elastic elements get deformed when Subjected to pressure. There are wide variety of metallic Elastic Elements that might be used as pressure transducers. The deflection/ deformation of the Elastic Element is measured by a Convenient method. Different types of pressure measuring Elastic transducers are—

1) Bourdon Tube pressure gauge
2) Diaphragm pressure gauge.
3) Bellows pressure gauge.

2.4.1 **Bourdon Tube pressure gauge:** The actuating mechanism of a bourdon tube pressure gauge is shown in below fig (8). It Consists of an Elastic tube of steel (or) bronze which is of Elliptical shape and is bent into a circular arc. This tube is called bourdon tube which acts as a pressure Sensing element. One End of the tube is closed & other End is open to allow the fluid into the tube whose pressure is to be measured. A System of gears are provided to magnify the deflection of the tube & to rotate the pointer on a graduated scale.

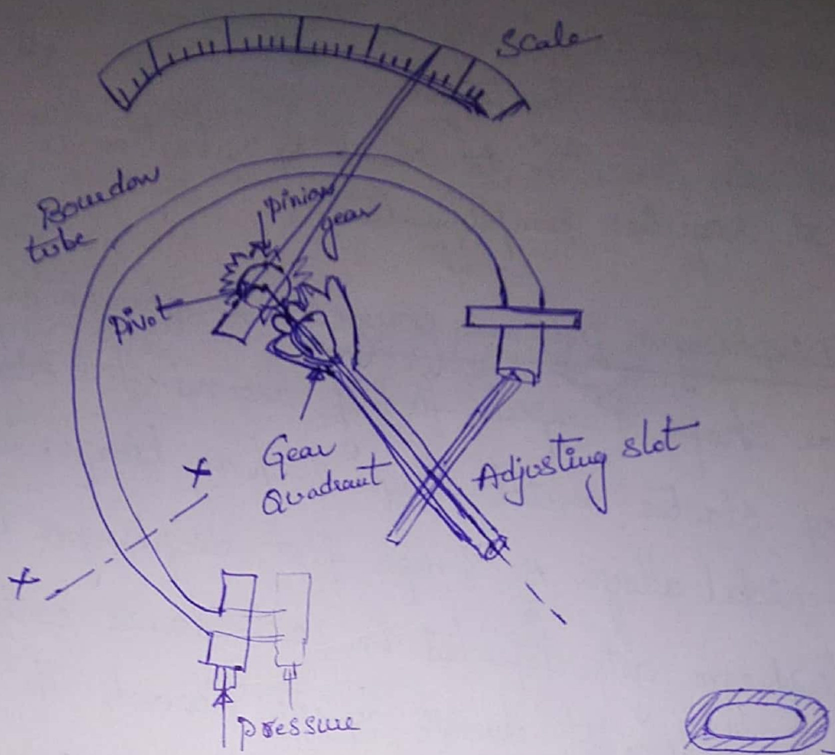


fig: (8). Bourdon tube with Mechanical Amplification

In operation, when the open ~~and the~~ end of the bourdon tube is connected to the pressure point, fluid under pressure enters the tube and the elliptical shape of the tube gradually changes to circular shape. This change in shape causes the tube to straighten out slightly. The change in curvature of the tube is transmitted through a system of gears to the pointer which rotates on the graduated dial.

Bourdon tube pressure gauge can also be used to measure negative pressures. When the negative pressure enters the tube, the tube tends to close thereby moving the pointer in the reverse direction.

Advantages.

1) Low cost and simple construction
2) High accuracy
3) Rugged construction
4) wide range of measurement are possible
5) portable size
6) Direct reading is obtained.

Disadvantages:

1) It responds slowly to the pressure changes.
2) It exhibits hysteresis.
3) It is sensitive to shock & vibration
4) It requires amplification.

2.4.2 Diaphragm pressure gauges: Diaphragm is a thin plate of circular shape clamped firmly around its edges. Diaphragms are made of elastic metal alloys such as bronze, stainless steel and ferrous-nickel alloys. A simple flat diaphragm is shown in fig (9-a). The diaphragm gets deflected in accordance with the pressure differentials across the sides. It always deflects towards the low pressure side. The deflection is then sensed by an appropriate displacement transducer.

The deflection of a diaphragm gauge is given by (fig 9-b)

$$Y = \frac{3p(1-v^2)(R^2-r^2)^2}{16Et^3} \longrightarrow (12)$$

$$Y_{max} = \frac{3p}{16Et^3}(1-v^2)R^4 \quad \text{at } r=0 \longrightarrow (13)$$

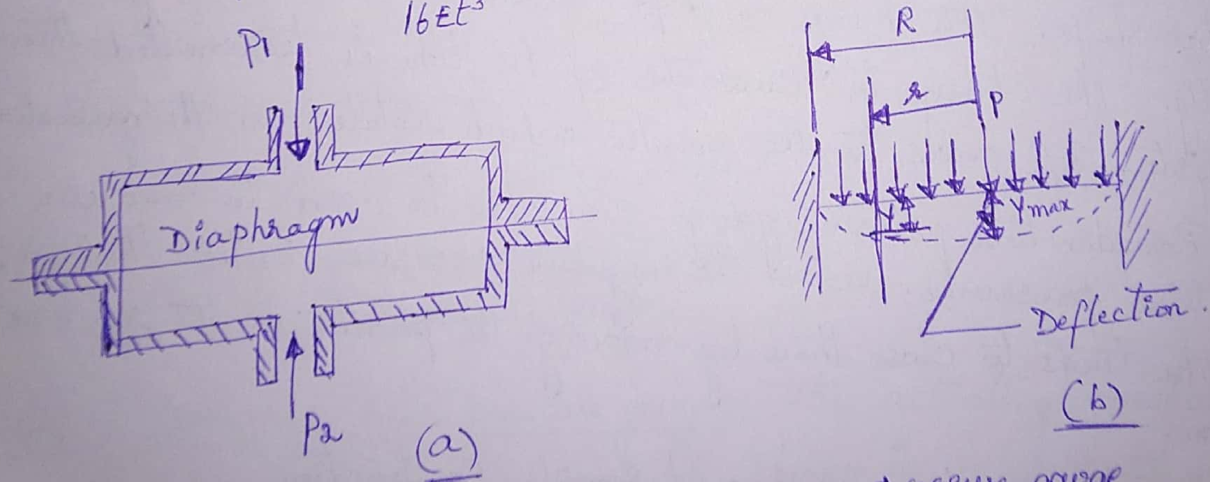


Fig (9): A Diaphragm pressure gauge

An electrical-resistance strain gauge may also be installed on the diaphragm to sense the deflection. Other diaphragm deflection measuring transducers are capacitive and inductive transducers.

— graduated scale.

Amplification of deflection of the diaphragm can also be done by means of mechanical linkages.

Diaphragms can be in the flat, corrugated, dish and capsule shapes as shown in fig (10):

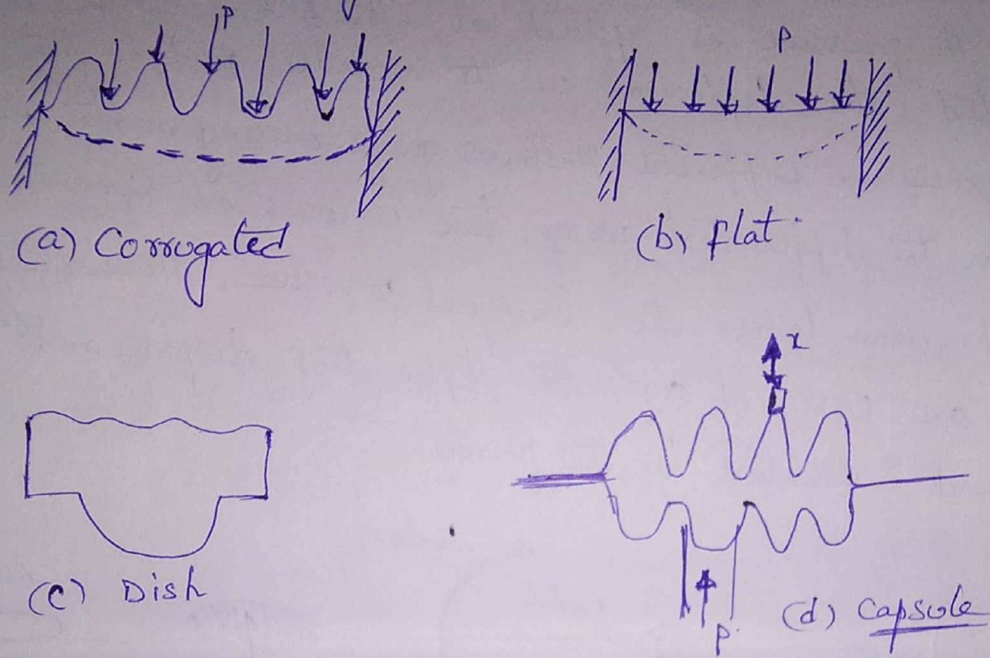


fig (10): Different types of Diaphragms.

Advantages: (1) They are available in small sizes and at low cost

(2) They exhibit linearity over wide range

(3) They can withstand over pressures.

(4) Absolute and differential pressures can be measured

(5) Minimum hysteresis and no permanent zero shift.

Limitations: (1) They need protection from vibration & shock

(2) They cannot be used to measure high pressures.

(3) Difficult to repair these gauges.

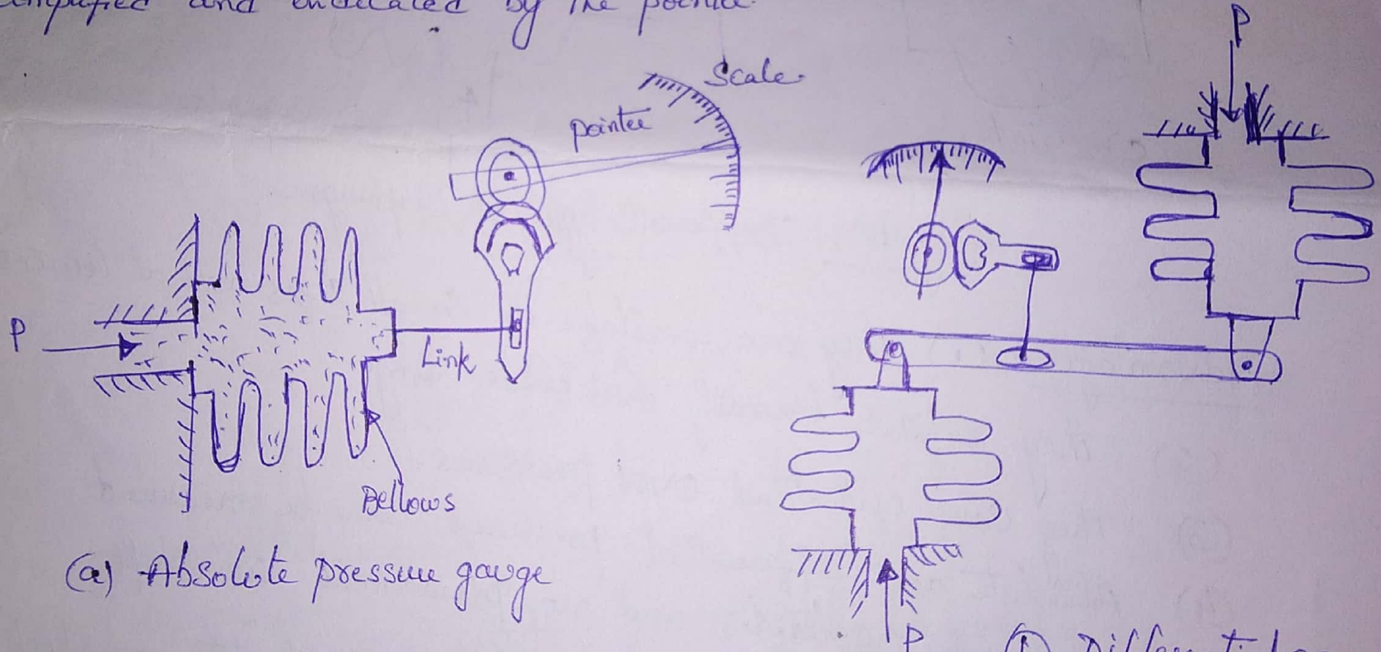
Applications: (1) They are used as low pressure absolute gauges

(2) Used as draft gauges.

2.4.3 Bellows pressure gauges:

Bellows gauge is made of a thin metallic tube having deep circumferential corrugations. Common bellows materials are trumpet brass, stainless steel, phosphor bronze & beryllium, Copper.

when the pressure is applied at fixed end of the bellows, it gets elongated. The deflection of the movable end is the measure of applied pressure. Different Bellows gauge arrangements are shown in fig 5.11. In the differential gauge, two bellows are connected to the ends of an arm lever. for unequal pressures, the deflections in the bellows are unequal and the differential displacement is amplified and indicated by the pointer.



(a) Absolute pressure gauge

(b) Differential gauge.

Fig 5(11): Bellows pressure gauge arrangements.

Advantages:

1) Simple and rugged Construction
(2) They can be used for the measurement of both gauge & differential pressures.
(3) They can be used for low & moderate pressures
(4) Moderate Cost.

Limitations:

1) problems of hysteresis & zero shift
2) Not suitable for dynamic measurements due to their large mass.
3) Temperature compensation is required
4) Cannot be used for high pressure measurement.

① Elastic Element with LVDT & strain Gauge - ② Capacitive Type pr. gauge
③ Meas. of vaccum Mcleod, Thermal conductivity, Ionisation

Low pressure Measurement:

Pressure below atmosphere may be called as low pressure or vaccum.
Common units of low pressure are torr and micrometer.

$$1 \text{ torr} = 1 \text{ mm of Hg}$$

$$1 \text{ micrometer} = 0.001 \text{ mm of Hg. } (10^{-3} \text{ torr})$$

Very low pressure may be defined as any pressure below 1mm of mercury, and an ultra low pressure is defined as any pressure less than a nanometer (10^{-3} μm).

Low pressure measuring instruments are classified into two categories.

1) Direct measurement: Direct method involves measurement of displacement caused by the action of force. Spiral bourdon tube, flat & corrugated diaphragms, capsules, and various forms of manometers ~~which~~ ~~were~~ are the examples of direct measurement.

2) Indirect (or) Inferential methods: Indirect methods involves the measurement of certain pressure controlled properties such as volume, thermal conductivity, current etc. Mcleod gauge, Pirani thermal conductivity gauge, Ionisation gauge are examples of this type.

Mcleod Gauge:

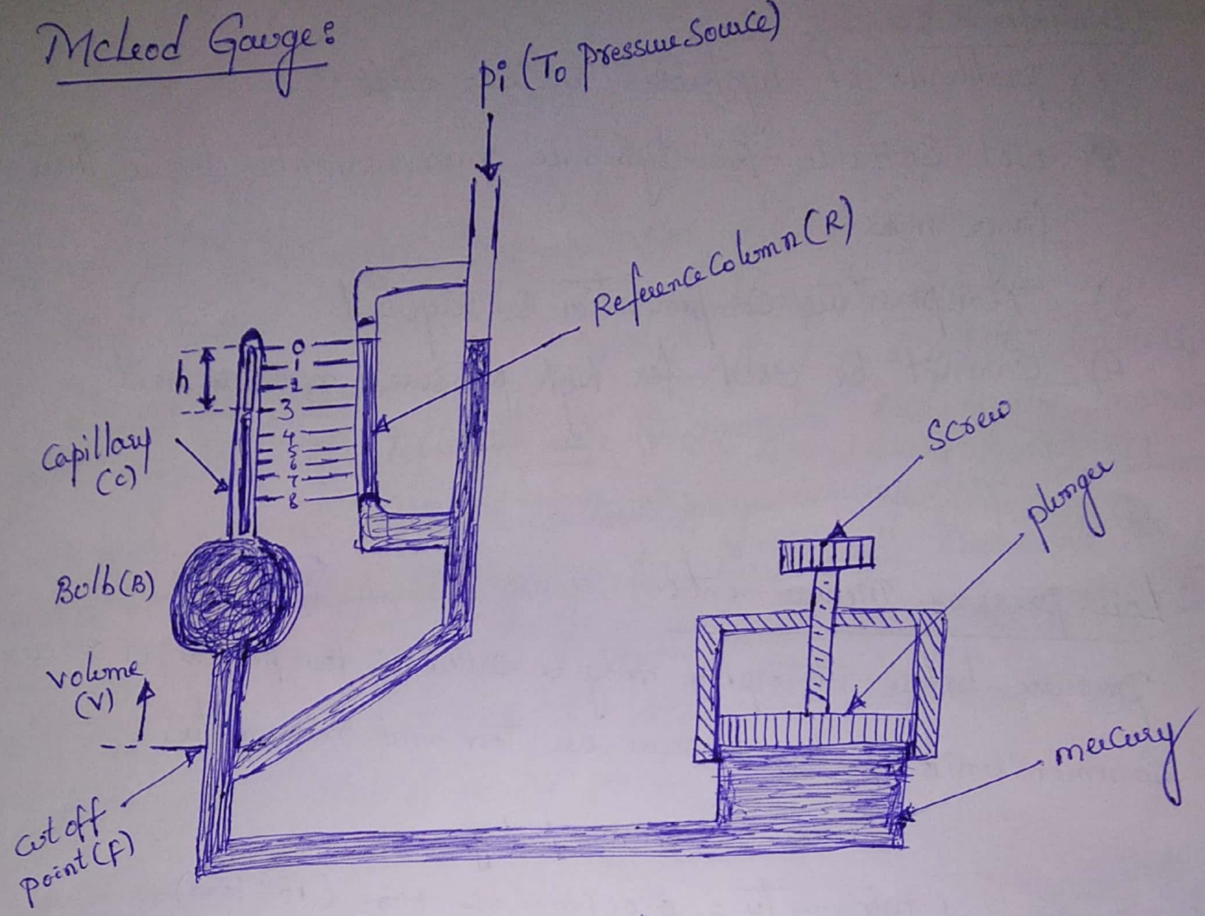


Fig: Mcleod Gauge.

Mcleod gauge is used to measure the pressure ranging from 0.01 microns to 50mm of Hg. It works on the principle of Compressing a Sample of known Volume of low pressure gas to a known Volume & to a sufficiently high pressure which can be read with a Simple manometer. The unknown low pressure is then calculated by using Boyle's Law.

Construction & working:

The Mcleod gauge is shown in the above fig. The unknown pressure Source (p_i) is Connected to the point A of the gauge. The plunger is then withdrawn inorder to lower the level of mercury in the Capillary (C), bulb (B) and Reference Column (R) thus allowing unknown low pressure gas into the bulb (B) and the Capillary (C) of the gauge. Mercury is then forced out of the reservior D by pushing the plunger down. when the level of mercury reaches the cut off point F, a known volume of gas is trapped in the bulb & the capillary. further movement of the plunger causes the compression of the trapped gas. The downward movement of the plunger is continued until the mercury level reaches zero reference point in the reference column (R). The pressure (p) of the gas trapped in the capillary 'c' is equal to the difference in height 'h'.

Applying Boyles Law:

$$p_i V = p(Ah) \longrightarrow (1)$$

But $$p = p_i + wh \longrightarrow (2)$$

Combining the eq's (1) & (2)

we get $$p_i V = (p_i + wh)(Ah) \longrightarrow (3)$$

$$p_i = \frac{wAh^2}{V - Ah} \longrightarrow (4)$$

In terms of mercury head eq (4) can be written as

$$\frac{p_i}{w} = \frac{Ah^2}{V - Ah} \longrightarrow (5)$$

Assuming $V >> Ah$, eq (5) can be written as

$$\frac{p_i}{w} = \frac{Ah^2}{V} \longrightarrow (6)$$

where

Pi = unknown pressure
A = Area of the Capillary tube
P = Pressure of gas in Capillary after Compression
V = Volume of the bulb & Capillary till point F.
w = Specific weight of the mercury

Advantages:

1) It may be used as reference standard to Calibrate other low pressure measuring devices.
2) Good operating range.
3) Its operation is independent of the gas Composition.

Limitations:

1) Continuous measurement is not possible.
2) It gives Error readings of the gas whose pressure is being measured Contains any vapour
3) fragile Construction.

Pirani Thermal - Conductivity Gauge:

At low pressures, the thermal Conductivity of gas changes with pressure. The Pirani gauge is an Instrument that measures the pressure through the change in thermal Conductivity of the gas.

Construction:

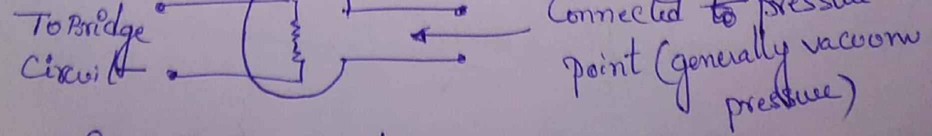


fig: Pirani thermal Conductivity gauge

It Consists of an electrically heated filament made of tungsten (or) platinum which is placed inside the vacuum space as shown in fig. The heat loss from the filament mainly depends on the thermal conductivity of the gas & the temperature of the filament. The lower the pressure, the lower the thermal conductivity & Consequently higher the filament temperature for a given heat input.

The pressure of the gas may be measured in two ways —

1) Measuring the temperature of the filament by a thermocouple circuit (or)
2) Measuring the change in resistance of the filament.

The pirani gauge uses the later principle to measure the pressure. The change in resistance may be measured with an appropriate bridge circuit.

As the heat loss from the filament is also a function of ambient temperature, a second gauge is connected in series with the first gauge as shown in below fig to Compensate variations in the ambient conditions.

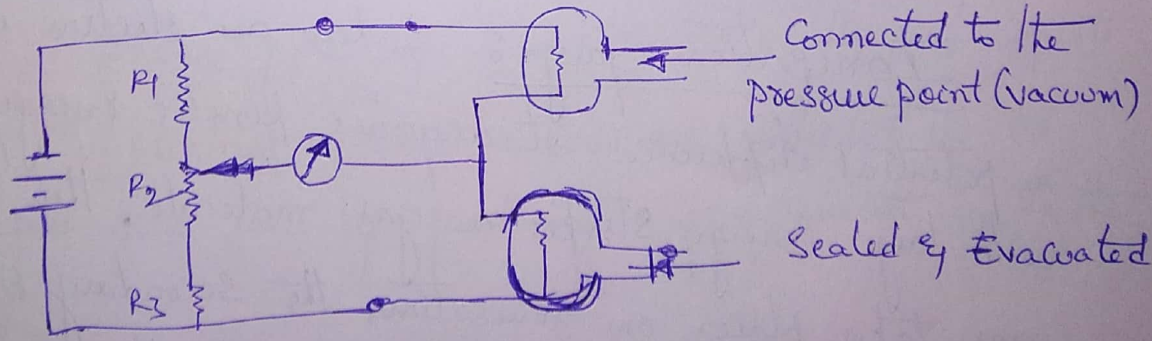


fig: pirani gauge with a temp. Compensation.

In this, first the measurement gauge is evacuated & then both the gauges are exposed to the same environmental conditions. The bridge circuit is then adjusted to null position with the help of resistance R_2. Now the measurement gauge is exposed to the fluid whose pressure is to be measured. The deflection of the bridge from the null position will be compensated for changes in the environment temperature.

Advantages:

1. They can measure the pressures in the range of 10^{-4} to 1 torr.
2. Rugged & inexpensive construction.
3. Continuous reading is possible
4. Exhibits linearity in the range 0.02 to 1mm Hg
5. Remote reading is possible.

Limitations:

1. Narrow range.
2. Frequent calibration is needed.
3. It requires external power source.

Ionization Gauge: When an electron is passed through a potential difference, it acquires kinetic energy. If the electron with large energy strikes a gas molecule, then ionisation of the gas takes place. On ionisation, the secondary electrons are knocked out leaving the molecules as positive ions. The number of positive ions are proportional to the number of gas molecules present in the gas, in turn the number of gas molecules are proportional to the pressure of the gas which is to be measured. Therefore the number of positive ions are proportional to the pressure of gas. An instrument which uses the ion concept to measure the pressure is called Ionisation gauge. An ionization gauge is shown in below fig. It consists of a heated cathode which emits the electrons, a positively charged grid & a negatively charged plate. These are enclosed in a glass envelope, which is connected to the pressure source whose pressure is to be measured.

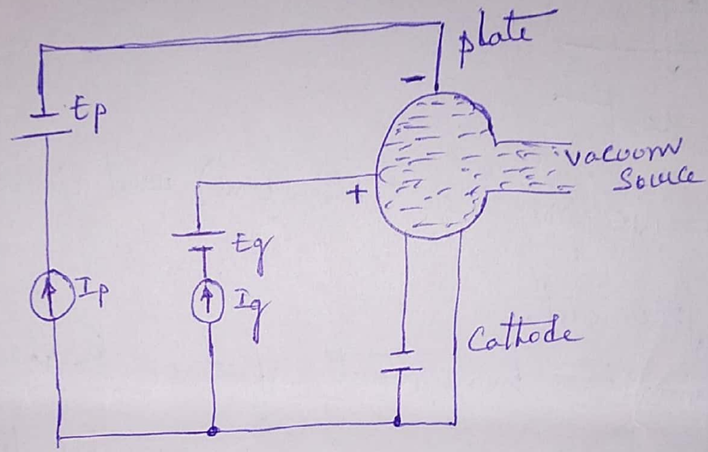


fig: Schematic of Ionization gauge

In operation, electrons emitted from the heated cathode are accelerated by the positively charged grid. As electrons move towards the grid, they collide with the gas molecules thereby ionizing the gas. The +ve ions are collected by the plate which is maintained at a -ve potential, which causes a flow of a plate current I_p. The electrons & the -ve ions are collected by the positively charged grid thereby producing a grid current i_g in the grid circuit.

The pressure of the gas is given by

$$P = \frac{1}{k} \cdot \frac{i_p}{i_g}$$

where k = Sensitivity of the gauge.

Advantages :

1. wide range of measurement is possible (i.e 10^{-2} torr to 10^{-10} torr)
2. It shows constant sensitivity for a given gas over a wide range of pressure
3. Remote indication & process control is possible
4. It exhibits quick response to pressure changes.

Dis-Advantages :

1. High cost
2. Excessive pressure (1 to 2 μm) will cause rapid oxidation of the filament.
3. filament burns out, if it is exposed to air.
4. Decomposition of some gases occur by the hot filament.