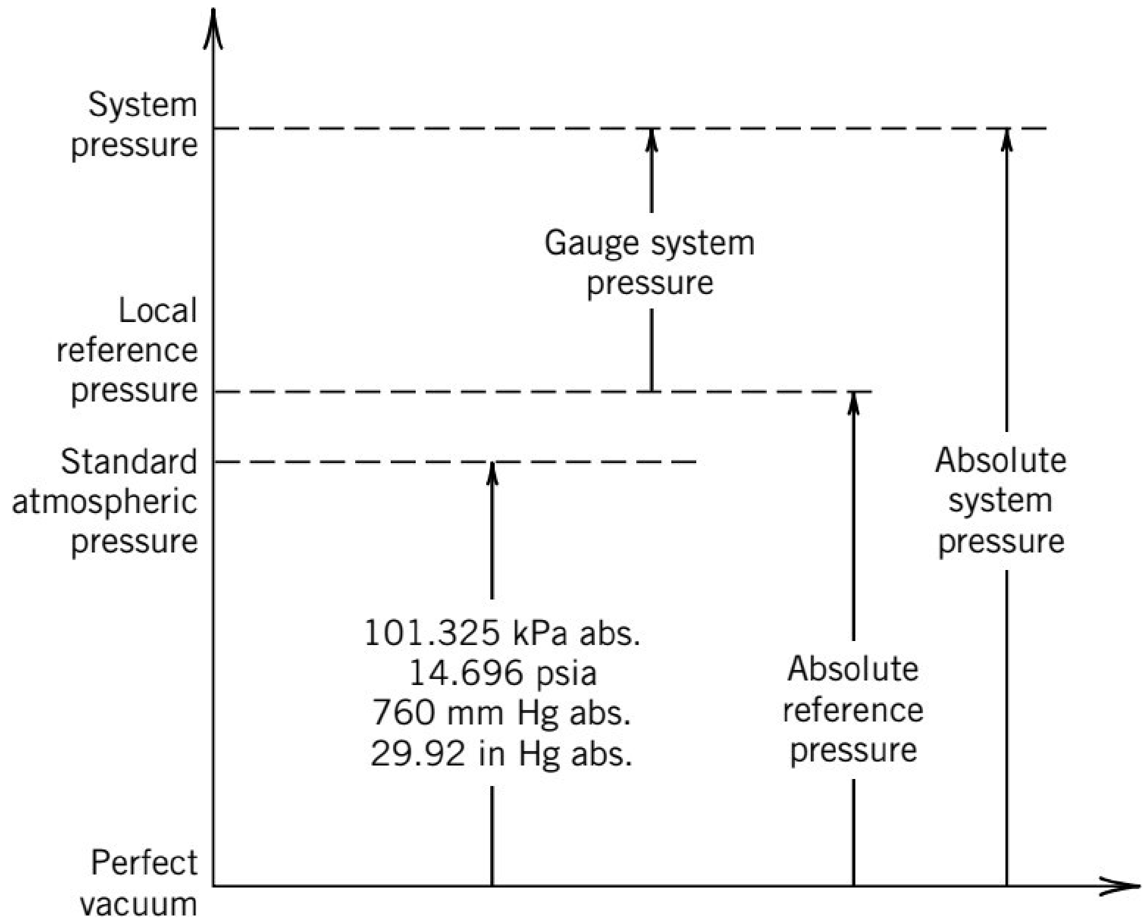
Measurement of Pressure

Applications:

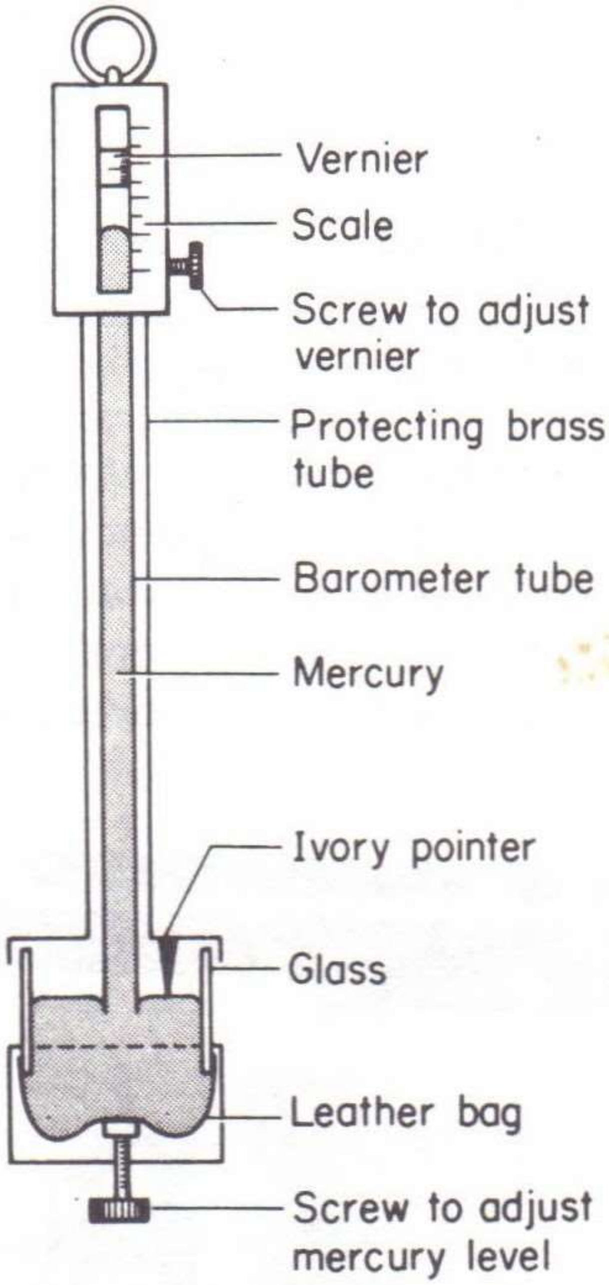
- Barometer (weather)
- MAP sensor (manifold absolute vacuum in ICE)
- Pitot tube (aircraft velocity)
- Altimeter (cabin pressure)
- Sphygmomanometer (blood pressure)



Relative pressure scales

Fortin Barometer

- In the Fortin barometer, the level of mercury in the glass at the bottom of the barometer cistern is adjusted to a scale zero, known as the zeroing (Ivory pointer) point, each time a reading is to be taken.
- The level of mercury in the column is then read against the scale, using a vernier adjustment for extra accuracy.
- Air is evacuated from the top of the tube of mercury and the lower end is fixed in the cistern containing the reservoir of mercury.
- The Fortin barometer is simple to use as it has a clear easy-to-read linear scale.
- These barometers can be mounted on a wall or suitable pillar.

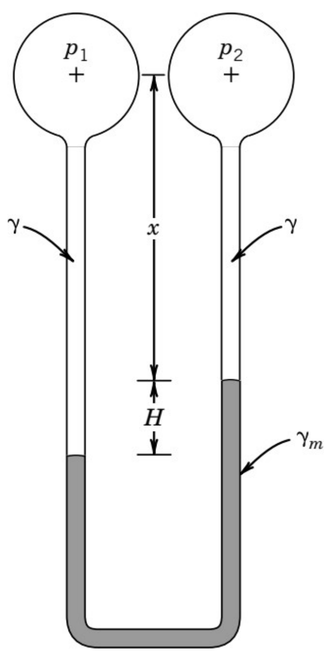


Fortin Barometer

Fortin barometer measures atmospheric pressure by using a mercury reservoir and a glass tube to detect changes in the level of mercury.

Working principle: Due to the change in atmospheric pressure, the height of the mercury column in the barometer changes. As a result, the mercury level in the cistern also changes. The first step in measuring atmospheric pressure using Fortin's barometer is to set the mercury level in the cistern. Using the adjustment screw, set the level of the mercury in the cistern such that the ivory pointer just touches the mercury. The reading of the top of the mercury column is then measured using both the main scale and the vernier scale.

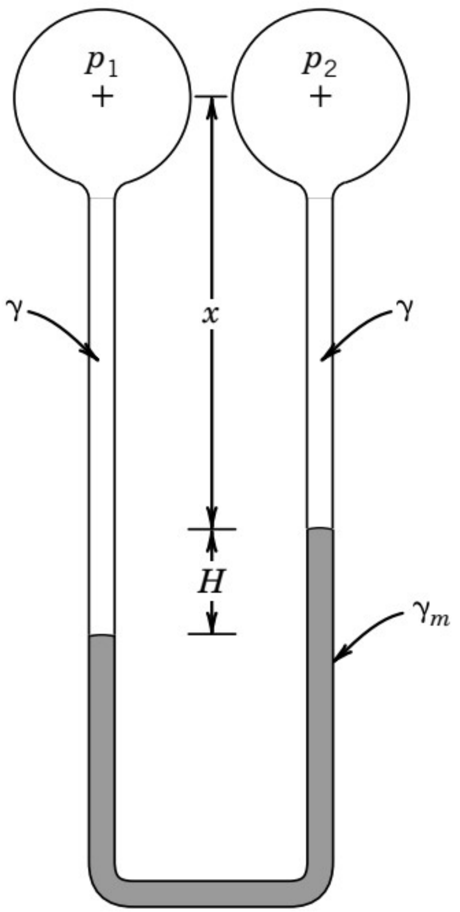
Manometer



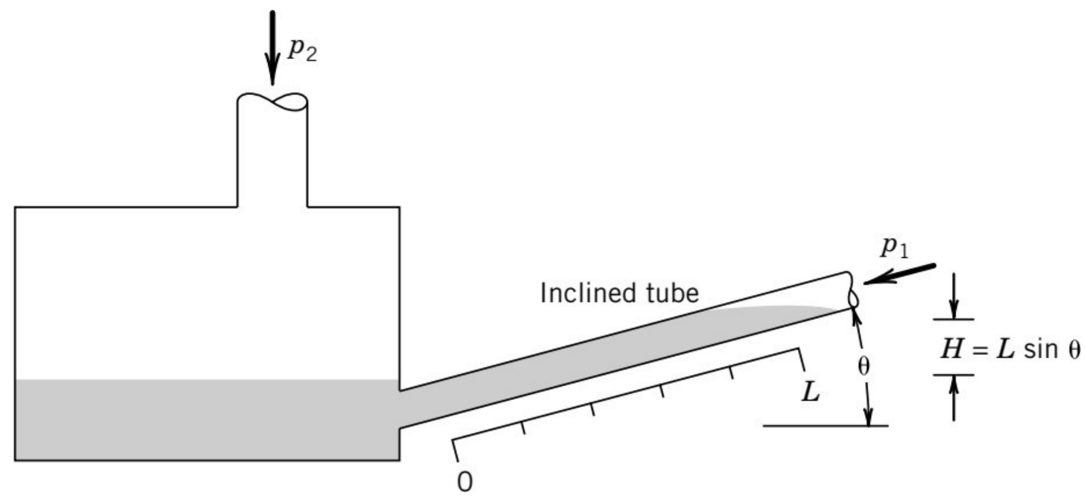
- Manometer is the simplest device for measuring static (differential) pressure.
- It contains water/mercury or other suitable fluid(s) inside the tube.
- When a pressure line is connected to one column of manometer, the fluid in the column is forced down and the fluid in the other column rises.
- By measuring the difference in height of the fluid in the two columns, the pressure of the inlet can be expressed in some height of the manometric fluid.

$$P_1 - P_2 = (\gamma_m - \gamma)H = (\rho_m - \rho)gH$$

Manometer



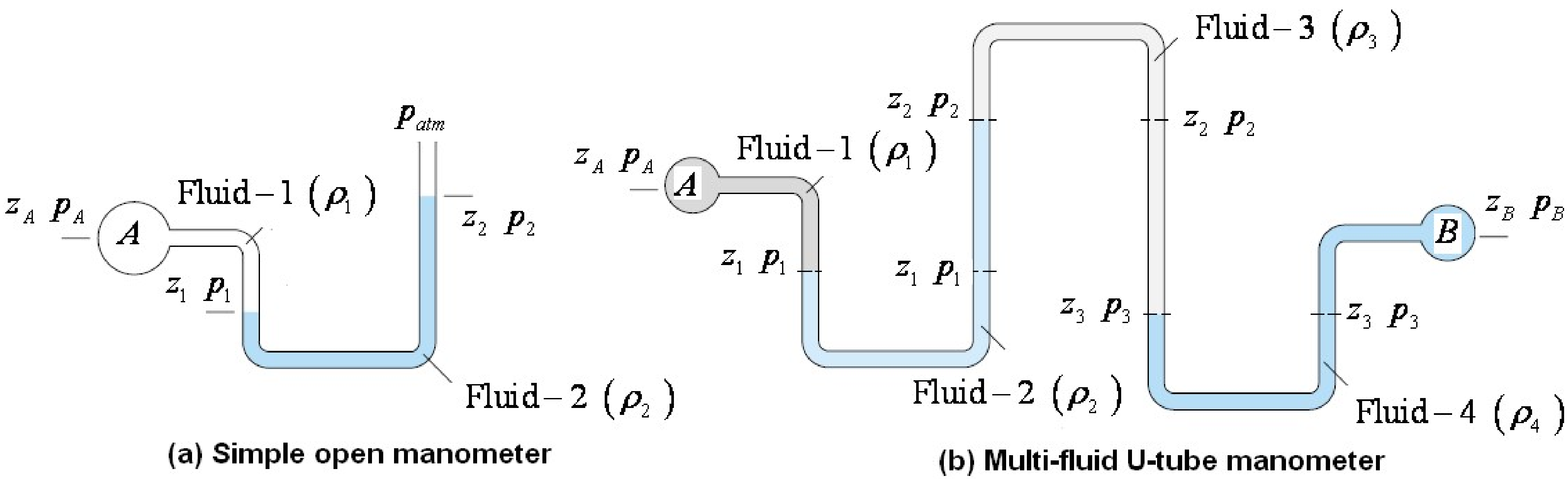
U-tube manometer



Inclined tube manometer

$$P_1 - P_2 = (\gamma_m - \gamma)H = (\rho_m - \rho)gH$$

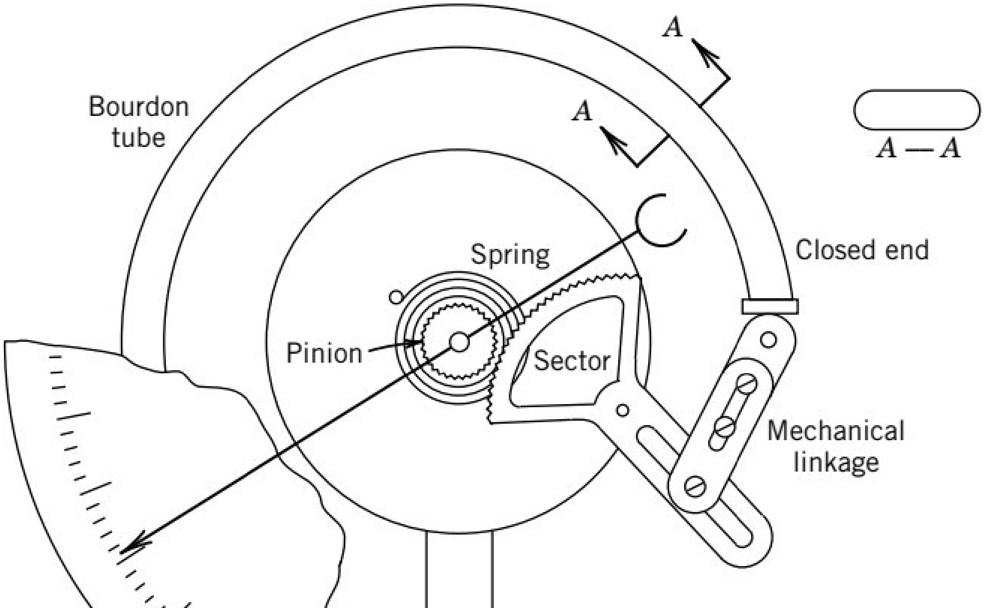
Manometer



- If a manometer contains multiple fluids, then the pressure is determined by equating pressures at the same vertical height of continuous columns of each fluid.

Bourdon Tube Pressure Gauge

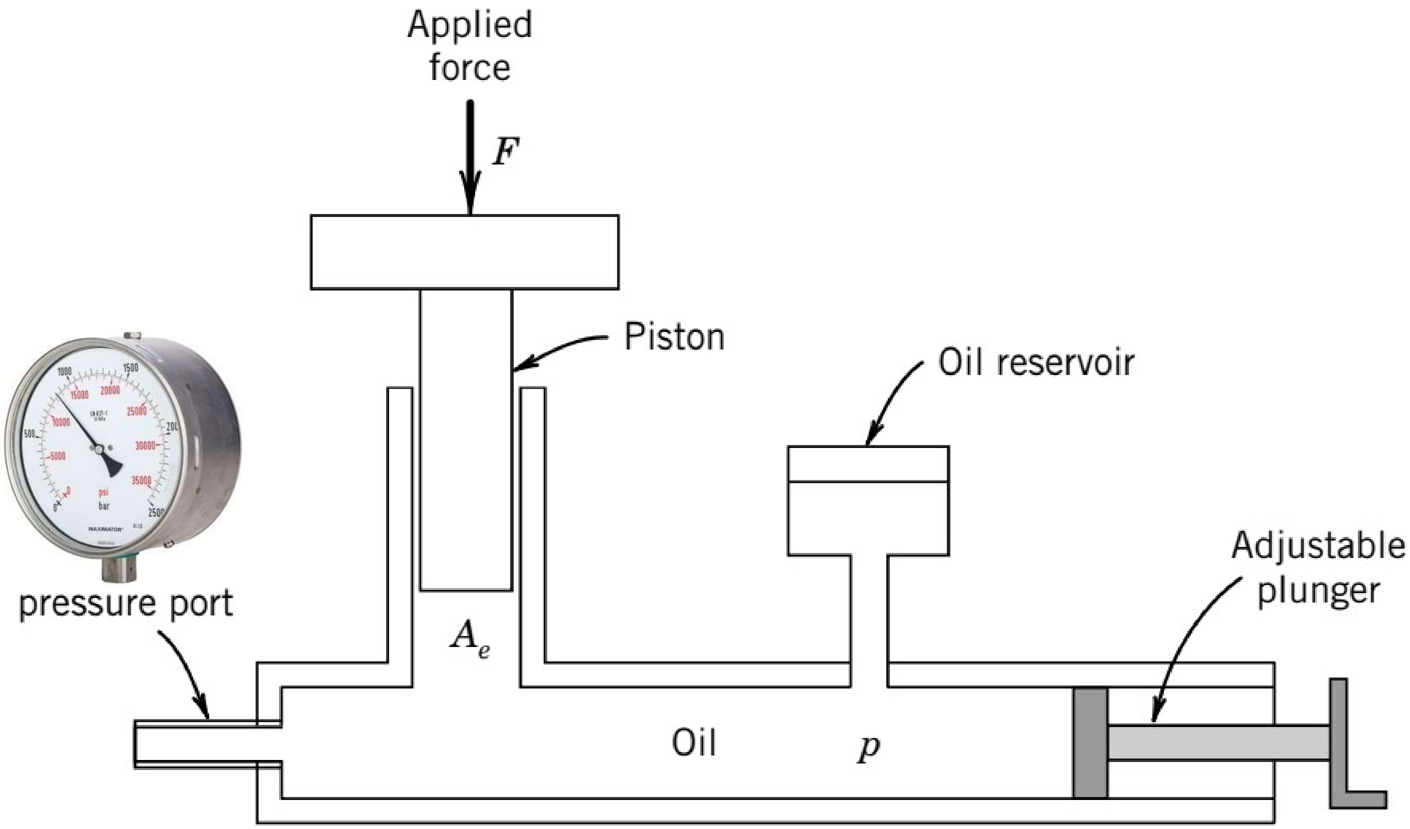
It consists of a C-molded hollow tube whose one point is fixed and connected to the pressure-applying point and the other end is left free. The cross sectional part of the tube is elliptical. At the point when pressure is applied the elliptical tube attempts to obtain a circular cross segment. Thus stress is created and the tube tries to straighten up.



Bourdon Tube Pressure Gauge

Subsequently, the free end of the tube moves in an upward direction, depending upon the magnitude of the pressure. The applied pressure is in a proportional relation with the displacement of the free closed end of the tube. A deflecting and indicating mechanism is connected to the free end that rotates the pointer and indicates the pressure reading.

Deadweight pressure tester



Used for static calibration

1MNN1

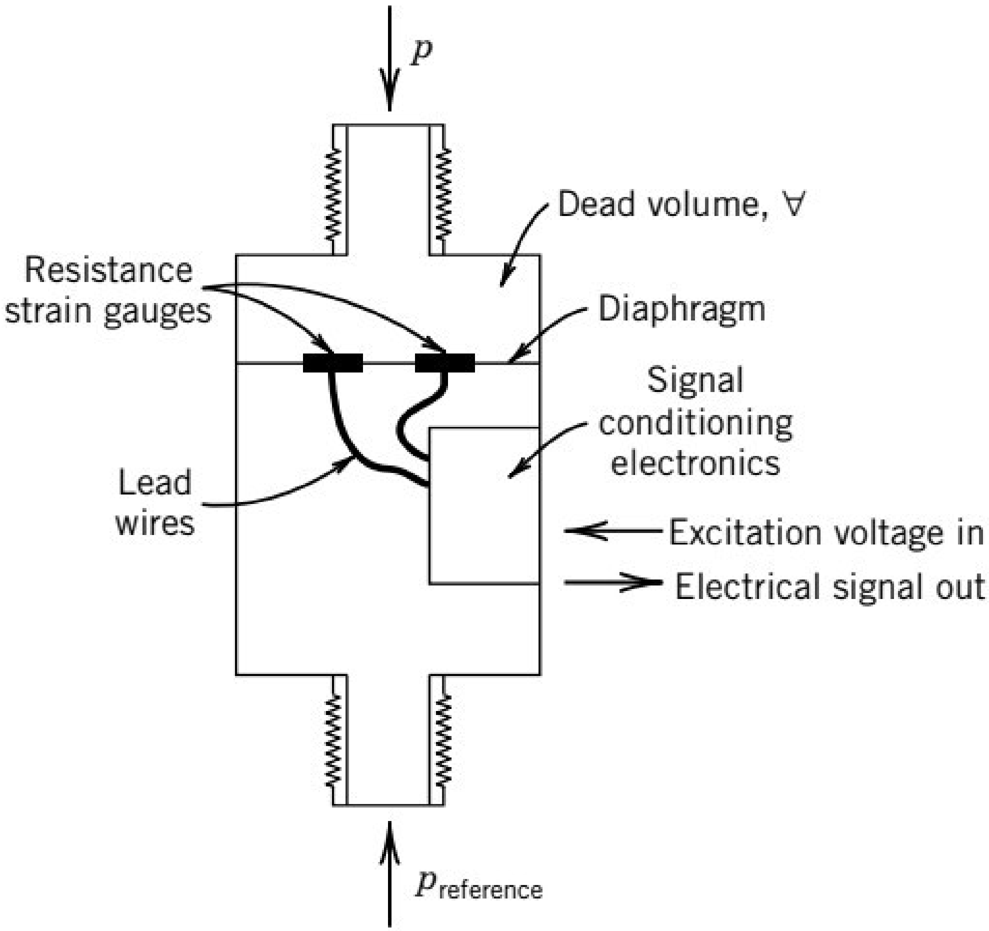
Deadweight pressure tester

A deadweight tester is used to calibrate pressure-measuring instruments. It works by balancing a known mass against the force of an unknown pressure on a piston.

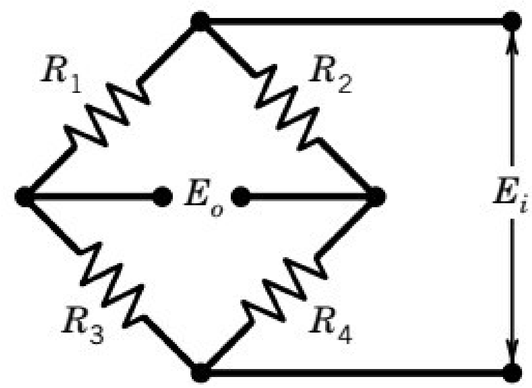
1. A mass is placed on a piston in a cylinder.
2. Fluid is pressurized beneath the piston.
3. The pressure in the fluid is equal to the force exerted by the mass on the piston's cross-sectional area.
4. When the force exerted by the mass equals the pressure applied the system is in equilibrium.
5. The formula for calculating the unknown pressure is P=M/A
   P is the pressure, M is the mass of the weight and A is the area of the piston.

1MNN1 1710105 - Most. Naznin Nahar, 16-Dec-24

Diaphragm Pressure Transducer with Strain Gauge



(a) Sensing scheme

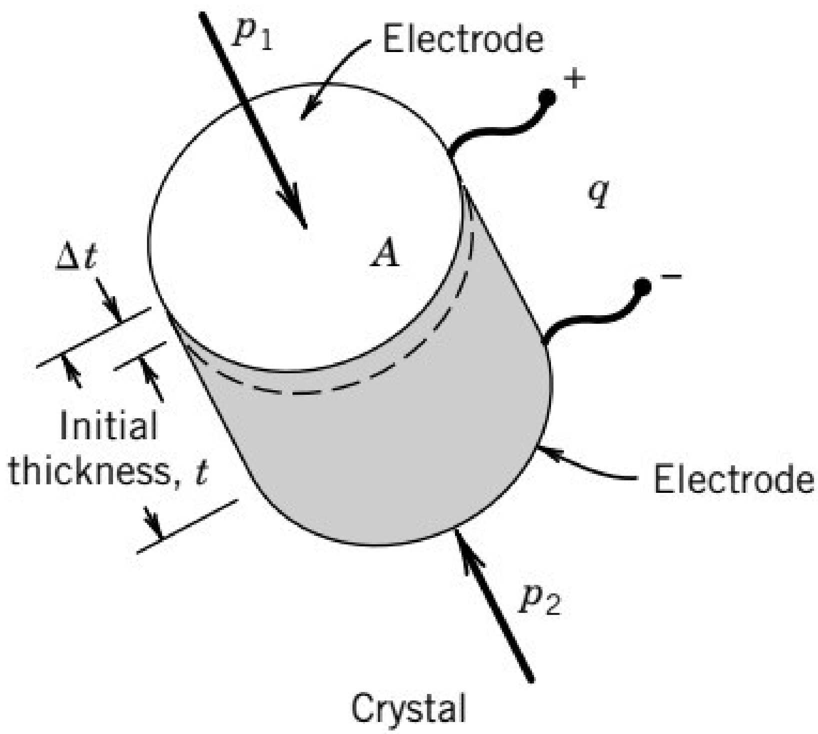


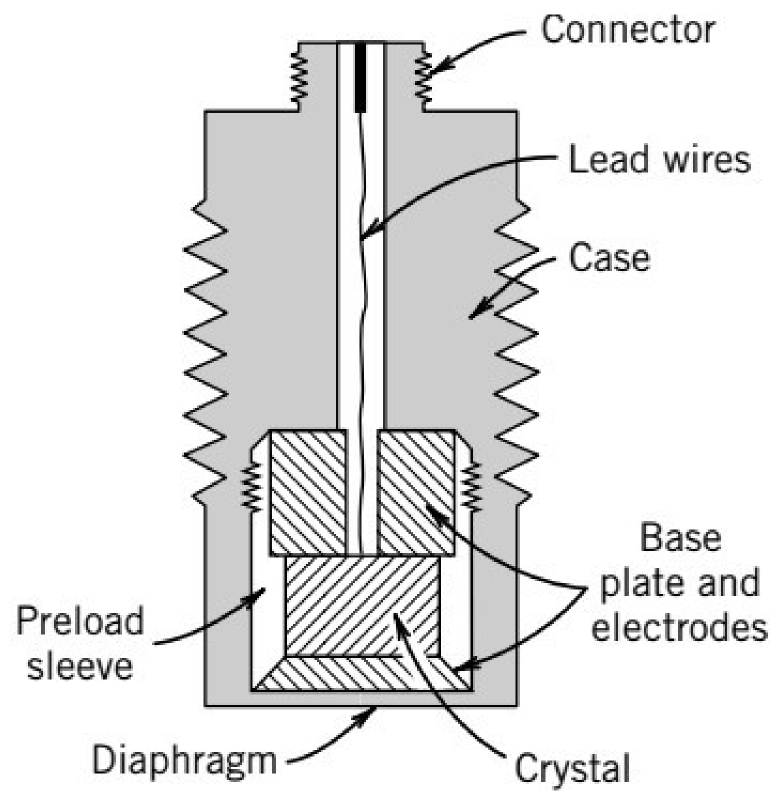
(b) Bridge–strain gauge circuit for pressure diaphragms.

Diaphragm Pressure Transducer with Strain Gauge

A diaphragm pressure transducer with a strain gauge is a mechanical device that converts pressure changes into an electrical signal. It works by bonding strain gauges to a flexible diaphragm, which deforms when pressure changes. The deformation changes the resistance of the strain gauges, which are usually arranged in a Wheatstone bridge. This converts the pressure measurement into an electrical signal that can be used.

Piezoelectric Pressure Transducer





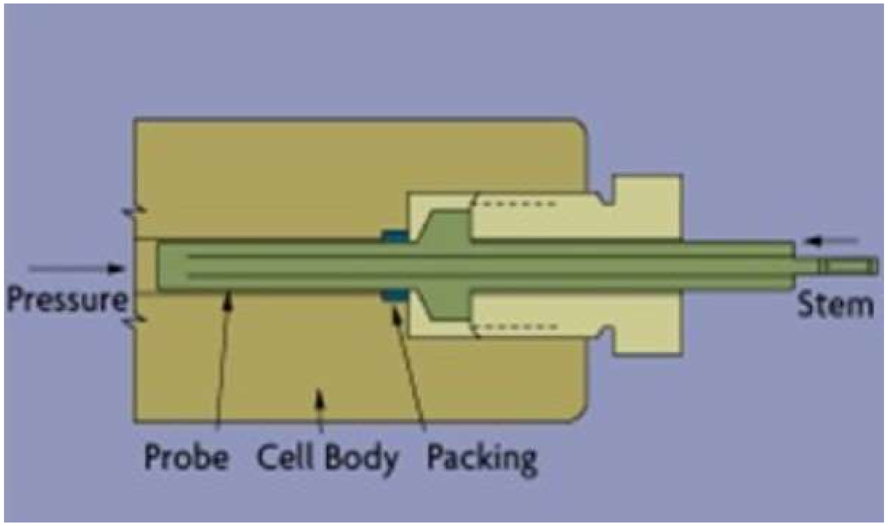
Piezoelectric Pressure Transducer

A piezoelectric pressure transducer is a sensor that converts mechanical pressure into an electrical charge or voltage. It produces charge/ voltage when stress is applied to the piezoelectric material.

Working Principle

1. **Piezoelectric effect**: When mechanical stress is applied to a piezoelectric material, like quartz, the material's internal atomic structure distorts, separating positive and negative charges on the electrodes.
2. **Charge generation**: The generated charge is proportional to the applied mechanical stress. The polarity of the charge depends on the direction of the applied force.
3. **Voltage measurement**: The charge is measured as a voltage proportional to the pressure. A charge amplifier converts the charge into a 0-10V signal that can be easily measured.

Electric Resistance Pressure Gauge (Coil)



- The sensing element consists of a loosely wound coil of relatively fine wire which compresses when subjected to a high pressure.
- The change in length and cross-section of the wire affect its electrical resistance when pressure applied at a rate determined by the bulk modulus of the material.

Electric Resistance Pressure Gauge (Coil)

An electric resistance pressure gauge also known as a strain gauge pressure transducer, operates based on the principle that when a conductor is stretched or compressed, its electrical resistance changes proportionally to the applied strain, allowing for pressure measurement by detecting these resistance variations in a specially designed coil of wire attached to a sensing diaphragm that flexes under pressure.

Working Principle:

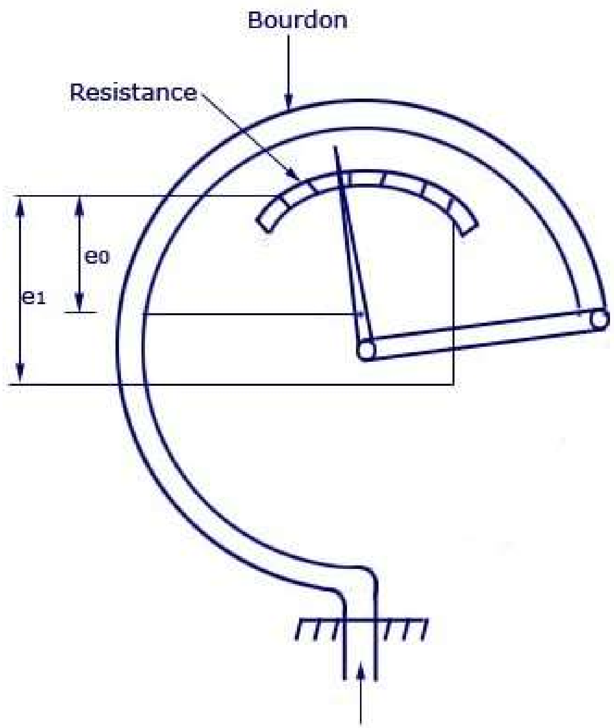
1. The core component is a thin, coiled wire made from a material with a high gauge factor, meaning its resistance changes significantly with strain.
2. The flexible diaphragm is attached to the coil and deforms when pressure is applied, causing the coil to stretch or compress.
3. As the coil deforms due to pressure, its electrical resistance changes, which can be measured using a Wheatstone bridge circuit.

Electric Resistance Pressure Gauge (Coil)

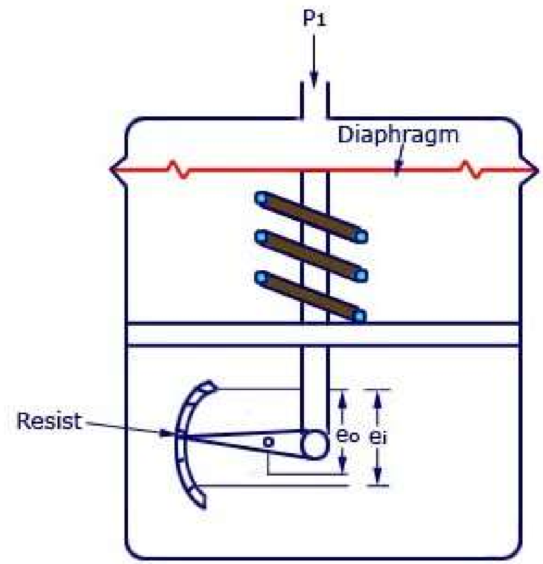
4. The electrical circuit allows for precise measurement of small resistance changes by comparing the resistance of the strained coil to a reference resistor.

5. The change in resistance is converted into a proportional electrical signal which can be read as a pressure value on a display or used in control systems.

Electric Resistance Pressure Gauge (Others)

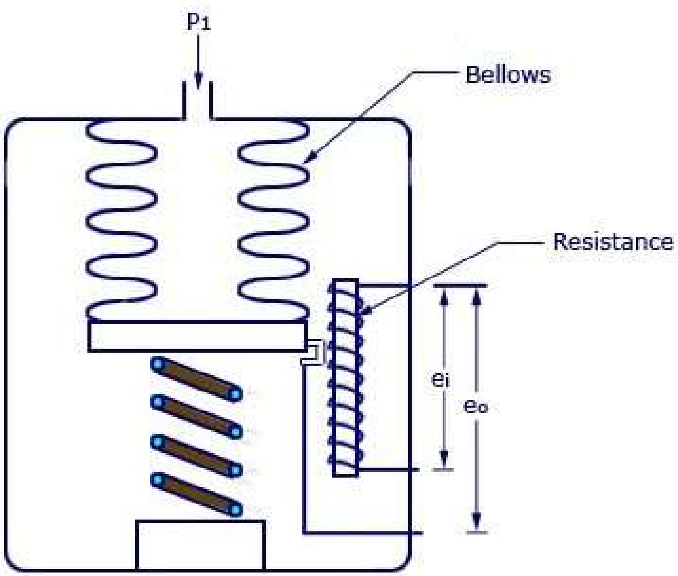


Bourdon Tube Electrical Pressure Transducer

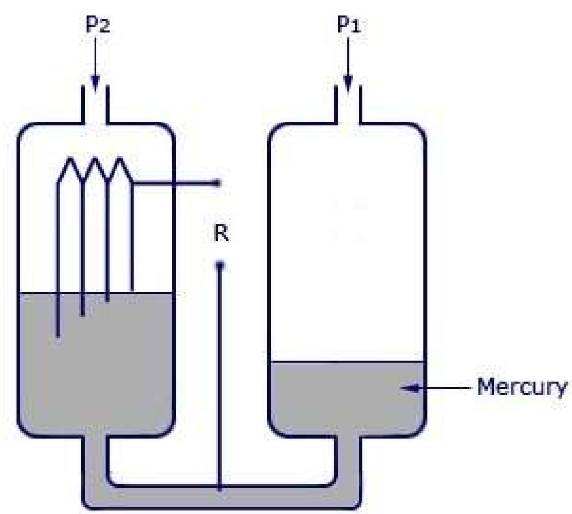


Diaphragm Type Electrical Pressure Transducer

Electric Resistance Pressure Gauge (Others)

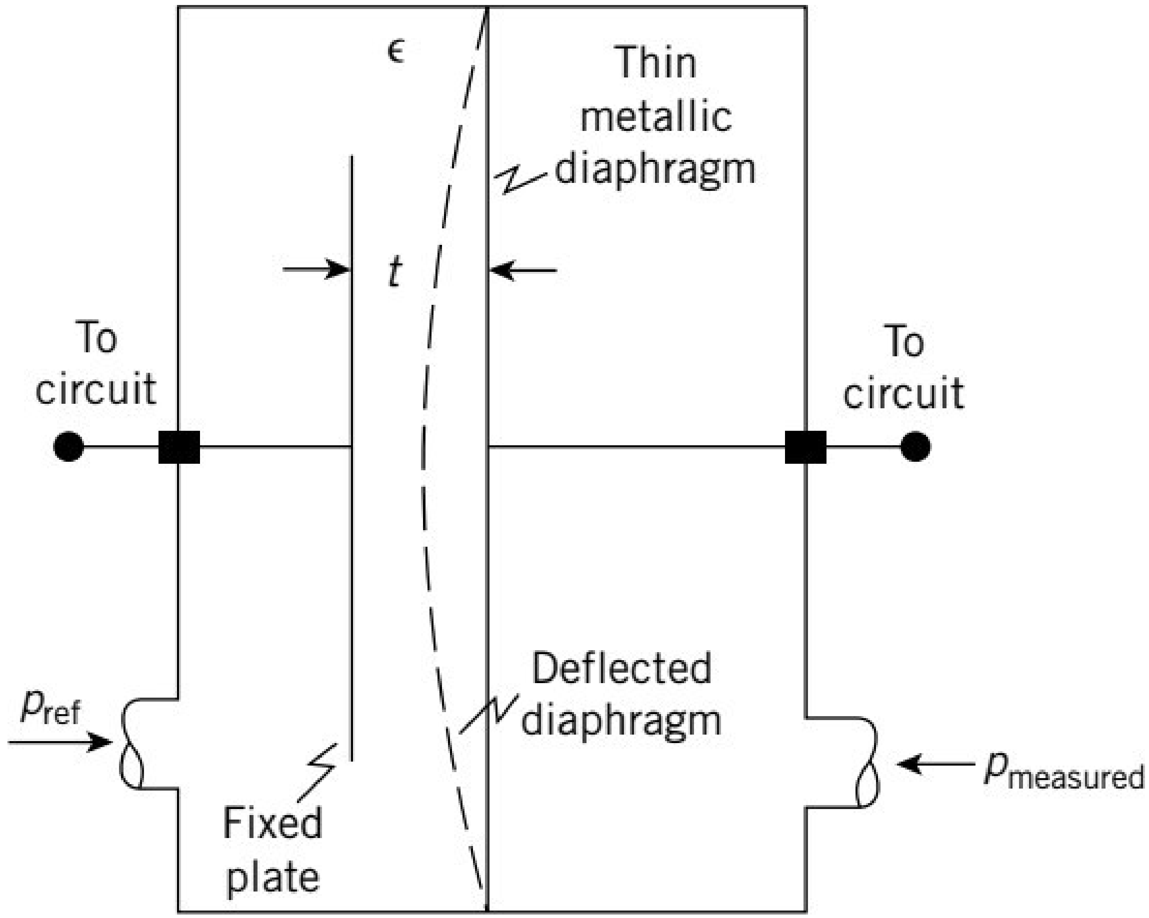


Bellows Type Electrical Pressure Transducer



Liquid Contact Type Resistance Pressure Gauge

Capacitance Pressure Transducer



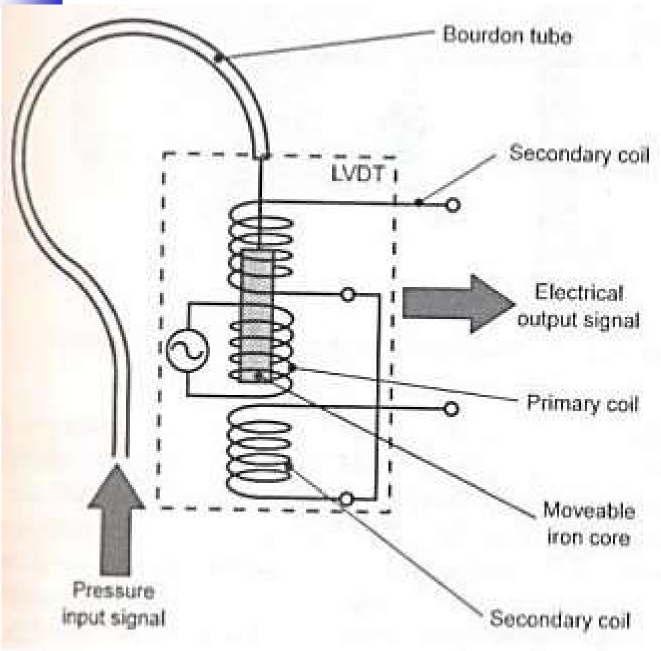
Capacitance Pressure Transducer

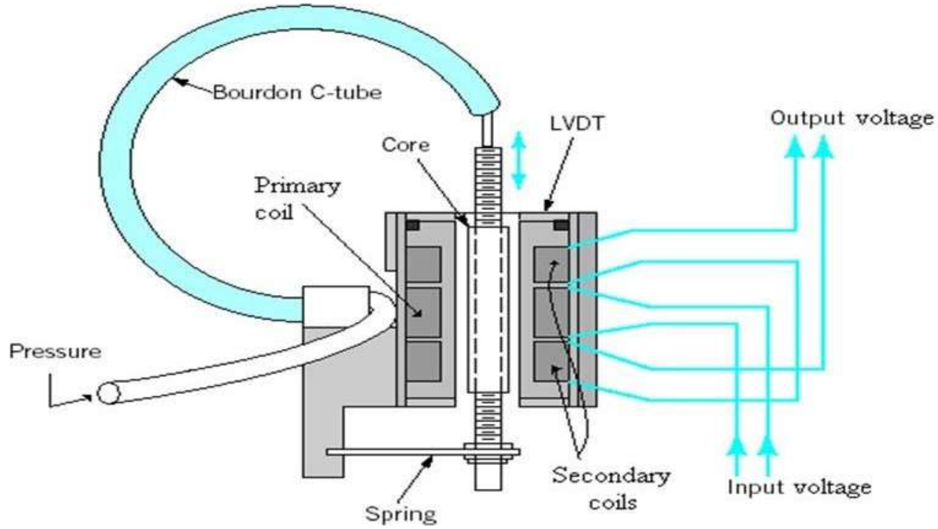
A capacitance pressure transducer measures pressure by converting changes in capacitance into an electrical signal.

Working principle:

1. When pressure is applied to the diaphragm, it deflects and changes the distance between the sensing and reference elements.
2. This change in distance alters the capacitance between the plates.
3. The change in capacitance is converted into an electrical signal.
4. The electrical signal is sent to a data acquisition system for processing and analysis.

LVDT Pressure Transducer (With Bourdon Tube)





- LVDT can be combined with a Bourdon tube
- LVDT converts displacements into an electrical signal
- The signal can be displayed on an electrical device calibrated in terms of pressure

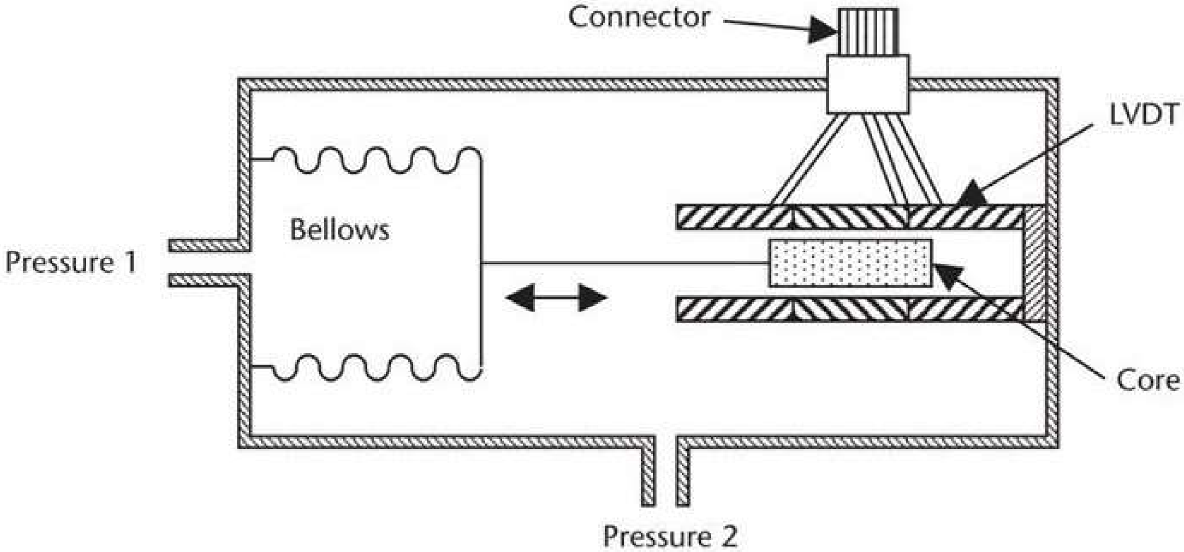
LVDT Pressure Transducer (With Bourdon Tube)

Working Principle of LVDT(Linear Variable Differential Transformer):

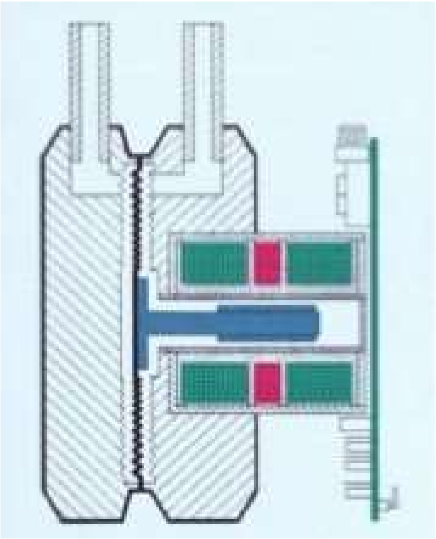
A pressure transducer using an LVDT with a Bourdon tube works by converting applied pressure into a displacement through the deformation of the Bourdon tube and then the displacement is converted into an electrical signal by the LVDT. Bourdon tube acts as a primary sensing element and the LVDT acts as a secondary sensing element.

1. When pressure is applied to the closed end of the C-shaped Bourdon tube, its cross section changes, causing the free end to move slightly.
2. The moving end of the Bourdon tube is connected to the core of the LVDT. As the Bourdon tube deflects due to pressure, the LVDT core moves proportionally within its coil assembly.
3. The LVDT generates an electrical signal based on the change in magnetic flux caused by the core movement, providing a voltage output that is directly proportional to the applied pressure.

LVDT Pressure Transducer (Others)



LVDT with bellows



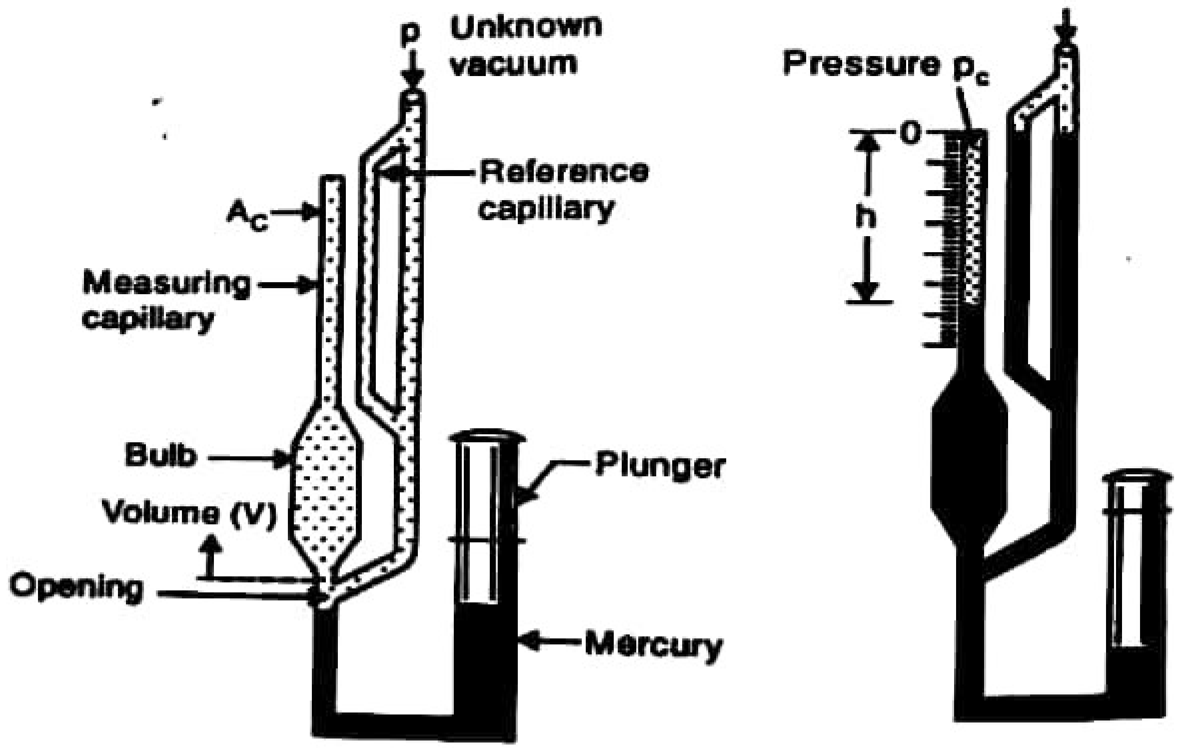
LVDT with diapharms

- LVDT can be combined with bellows
- LVDT can also be used with diaphragms

McLeod Gauge
(10^{-4} to 10^{-6} torr, i.e., 10 mPa to 0.1 mPa)

Construction: The McLeod gauge consists of a reservoir containing mercury. A plunger is attached on top of the reservoir which is used to raise or lower the level of mercury into the reference column and bulb. Above the reservoir, there is a bulb and reference column. The point of connection of the bulb and reference column is the opening or cut-off point. The other end of the reference column is open to vacuum pressure and it has a reference capillary. The reference capillary has a zero reference point up to which the mercury is raised. The mercury rises in the capillary as much as it rises in the column but only the volume differs. The reference column is attached to a measuring capillary which is a sealed chamber from which the final volume of gas is read.

McLeod Gauge
(10^{-4} to 10^{-6} torr, i.e., 10 mPa to 0.1 mPa)



Working Principle: The McLeod gauge works by compressing a known volume of low-pressure gas into a smaller volume to measure the pressure of the gas. It uses Boyle's law i.e. PV=constant.

1. The unknown vacuum pressure source is connected to the reference column and the pressure is applied. The level of mercury is adjusted so that it is at the opening or cut-off point. Now the unknown pressure fills the bulb and capillary. The volume of unknown pressure is the volume of the bulb and capillary.
2. The mercury is forced into the bulb and capillary by operating the plunger. Once the level of mercury crosses the cutoff point or opening, it stops the entry of applied pressure into the bulb and measuring capillary. The level of mercury is raised until it reaches the zero reference point. The pressure and volume of gas trapped in the measuring capillary are read and the unknown vacuum pressure is calculated.

Selection of Pressure Measuring Instrument

For moderate pressure

- Manometers
- Elastic elements (diaphragm, bellows, capsules, tubes, spiral helix, etc.)

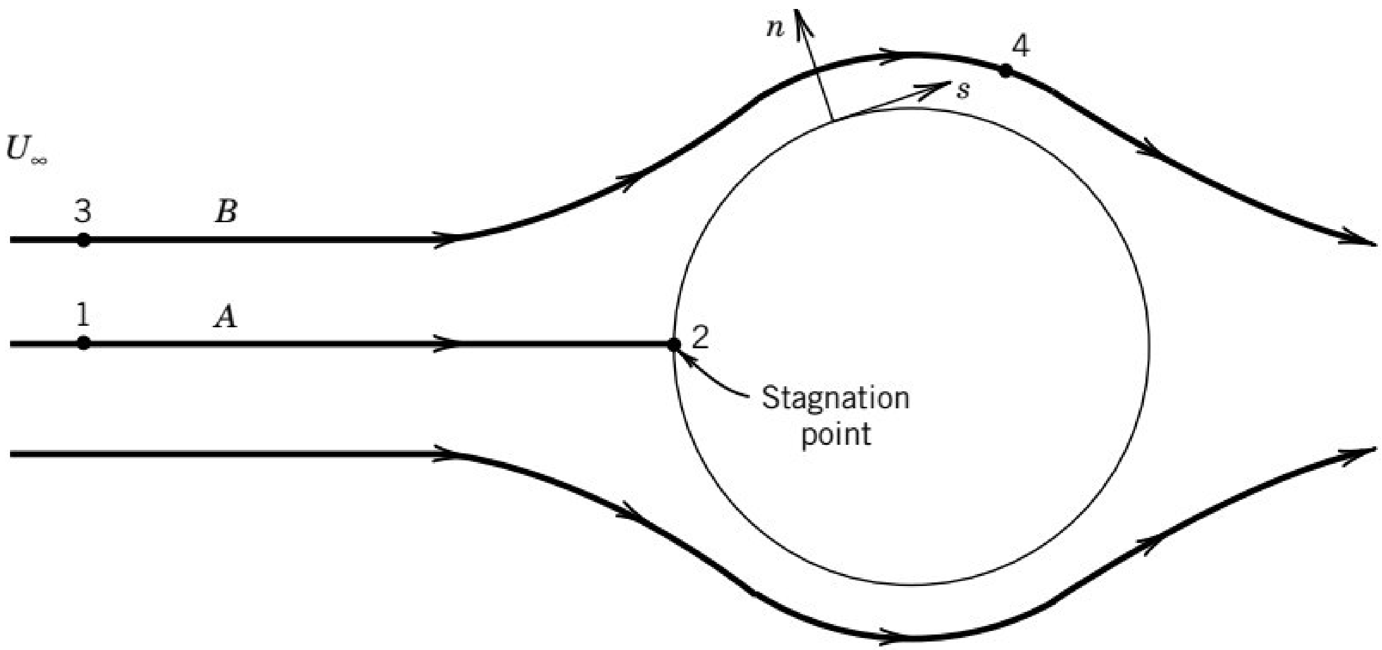
For high pressure (>1000 atm)

- Electrical resistance/capacitance/inductive (LVDT)/magnetic pressure transducers
- Piezoelectric/optical/resonant pressure transducer

For very low pressure (< 0.001 atm i.e., 1/760 atm which is 1 torr)

- McLeod gauge
- Pirani gauge
- Ionisation gauge

Pressure in a Moving Fluid

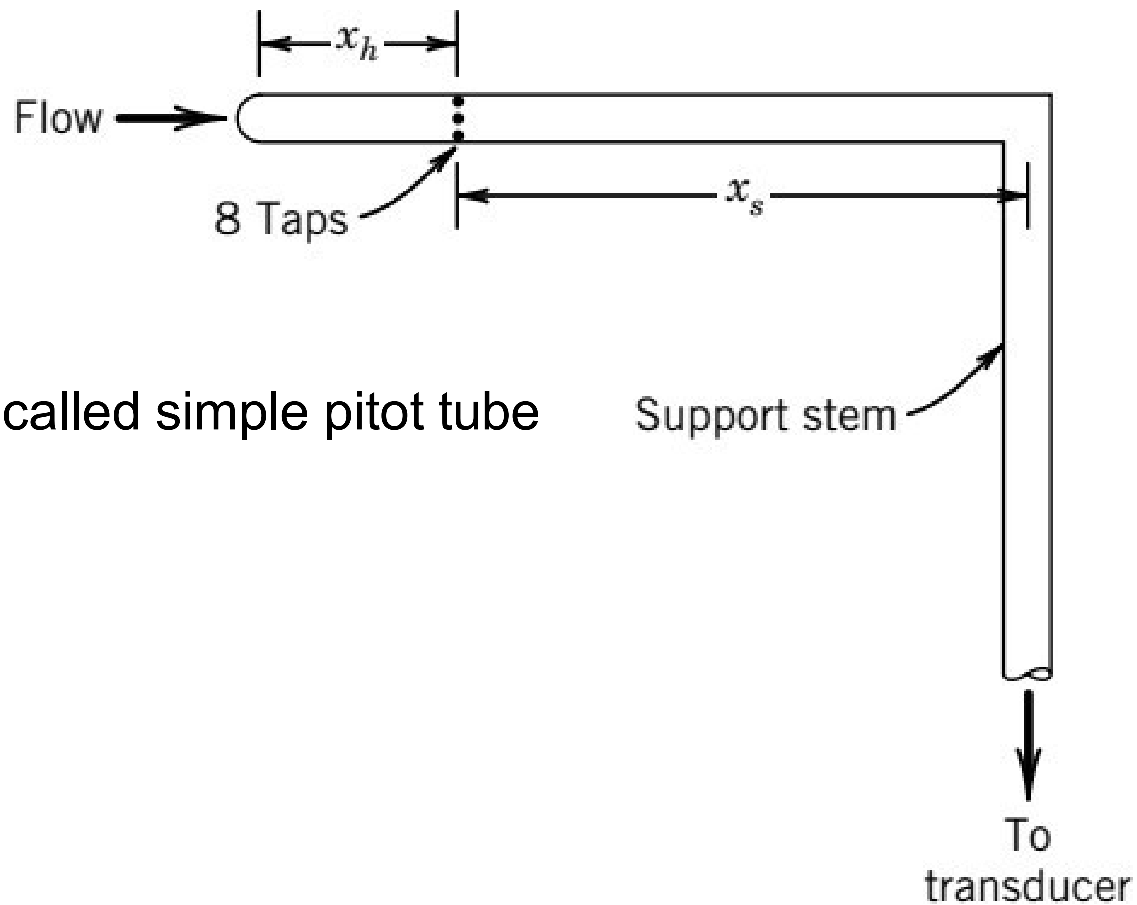


Streamline flow over a bluff body

$$p_1 + \rho U_1^2/2 = p_2 + \rho U_2^2$$

$$p_3 + \rho U_3^2/2 = p_4 + \rho U_4^2$$

Pitot Tube Used for Static Pressure



this is called simple pitot tube

Fluid Pressure and Velocity Measurement

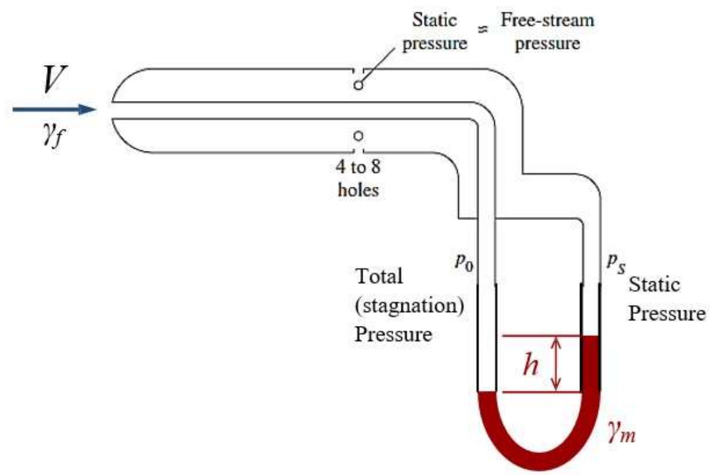
For local velocity measurement inside duct, wind tunnel etc.

Apply Bernoulli equation between stagnation point and static point:

$$\frac{p_0}{\gamma_f} + \frac{V_0^2}{2g} + z_0 = \frac{p_s}{\gamma_f} + \frac{V^2}{2g} + z_s$$

$$\Rightarrow \frac{p_0}{\gamma_f} = \frac{p_s}{\gamma_f} + \frac{V^2}{2g}$$

$$\boxed{\Rightarrow V = \sqrt{\frac{2(p_0 - p_s)}{\rho_f}}}$$



Pitot tube (pitot-static tube)

Now from principle of manometry

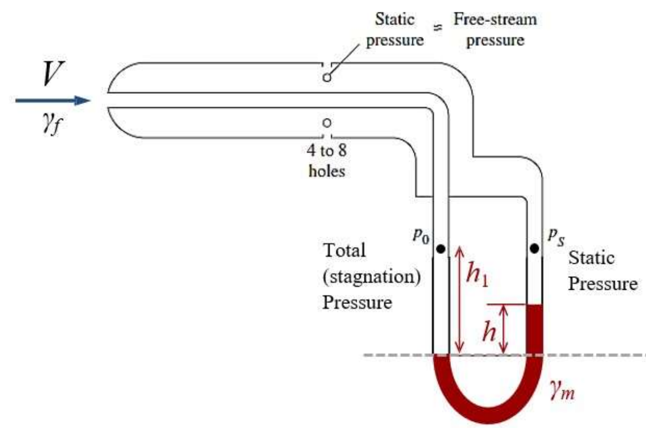
$$p_0 + \gamma_f h_1 = p_s + \gamma_f (h_1 - h) + \gamma_m h$$

$$\Rightarrow p_0 = p_s - \gamma_f h + \gamma_m h$$

$$\Rightarrow p_0 - p_s = h(\gamma_m - \gamma_f)$$

$$\Rightarrow p_0 - p_s = \gamma_f h \left(\frac{\gamma_m}{\gamma_f} - 1 \right)$$

$$\boxed{\Rightarrow p_0 - p_s = \gamma_f h \left(\frac{S_m}{S_f} - 1 \right)}$$



Pitot tube (pitot-static tube)

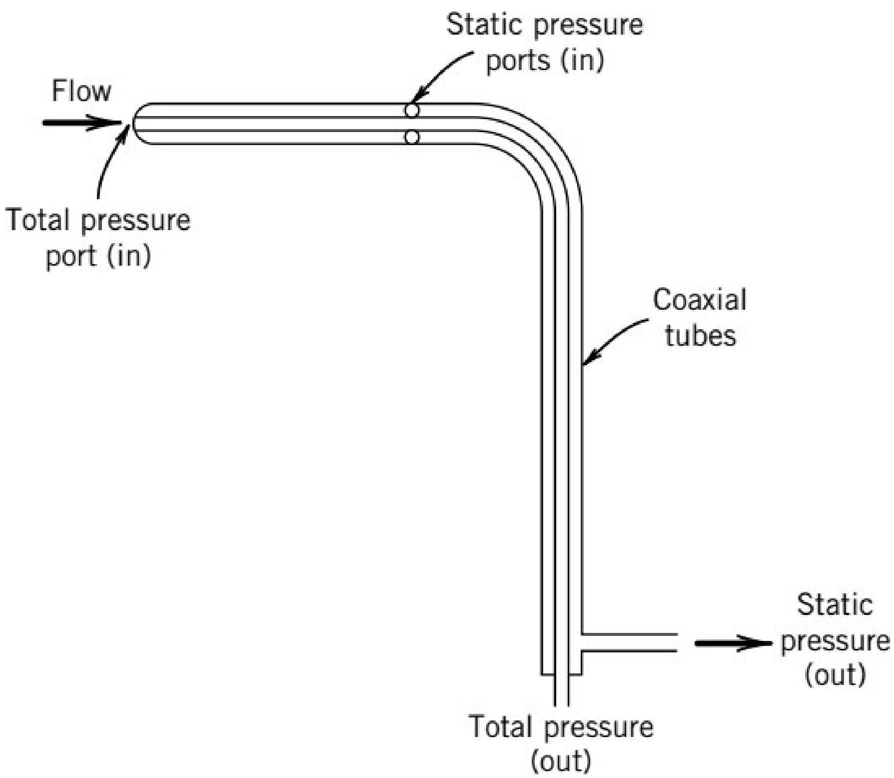
So, the velocity can be measured as follows:

$$\Rightarrow V = \sqrt{\frac{2(p_0 - p_s)}{\rho_f}}$$

$$\boxed{\Rightarrow V = \sqrt{2g \left(\frac{S_m}{S_f} - 1 \right) h}}$$

m: manometric fluid
f: flowing fluid

Fluid Pressure and Velocity Measurement



Total pressure:

$$p_t = p_x + \frac{1}{2}\rho U_x^2$$

Dynamic pressure:

$$p_v = p_t - p_x = \frac{1}{2}\rho U_x^2$$

Velocity of fluid:

$$U_x = \sqrt{\frac{2p_v}{\rho}} = \sqrt{\frac{2(p_t - p_x)}{\rho}}$$

Note that ρ in the equation is the density of the flowing fluid, not the manometric fluid. [Manometric fluid is used to calculate the differential pressure in the manometer]

Fluid Pressure and Velocity Measurement

The manometer connected to the Pitot tube of an aircraft records the stagnation pressure as 0.77 m of mercury. At the given altitude, the air density is measured as 1.13 kg/m^3 and the static pressure is measured as 90 kPa. What is the aircraft velocity in km/h?

$$V_\infty = \sqrt{\frac{2g(p_t - p_x)}{\gamma}}$$

$$= \sqrt{\frac{2(p_t - p_x)}{\rho}} = \sqrt{\frac{2(0.77 \times 13.6 \times 9810 - 90000\ )}{1.13}}$$

$$= 150\ m/s$$

$$= 540\ km/h$$

Velocity of fluid:

$$U_x = \sqrt{\frac{2p_v}{\rho}} = \sqrt{\frac{2(p_t - p_x)}{\rho}}$$

Note that in case of closed channel (e.g., pipe) flow, the volumetric flow-rate can also be measured using the pitot-tube if the cross-section of the channel is known.