Pressure Measurement

Introduction

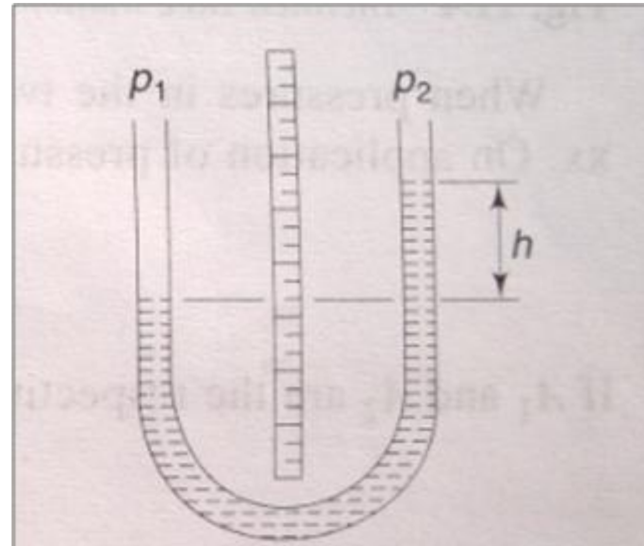
- Pressure means force per unit area exerted by a fluid on the surface of the container.
- Absolute pressure means the fluid pressure above the reference value of a perfect vacuum or the absolute zero pressure.
- Atmospheric pressure, at sea level, is nearly 14.7 lb/in^2 (psi) or 1.013×10^5 N/m^2 (Pa) or 760 mm of Hg.
- Pressures higher than 1000 atmospheric pressure are regarded as very high pressure.
- Pressures of the order of 1 mm of Hg or below are regarded as very low pressure.

Moderate Pressure Measurement

- Manometers : Used for measuring static pressures
- Others using Elastic Members : Used for measuring static and dynamic pressures

Manometers

- Simplest device for measuring static pressure.
- Uses water, mercury or any other fluid.
- One of the pressures (p_2) applied to limb 2 is atmospheric pressure.
- The difference in levels h is an indication of pressure difference.
- ρ is the mass density of liquid used in manometer.
- Fluid should be non-corrosive & not have any chemical reaction with fluid whose pressure is being measured.
- Should have low viscosity.
- Should have negligible surface tension and capillary effects.



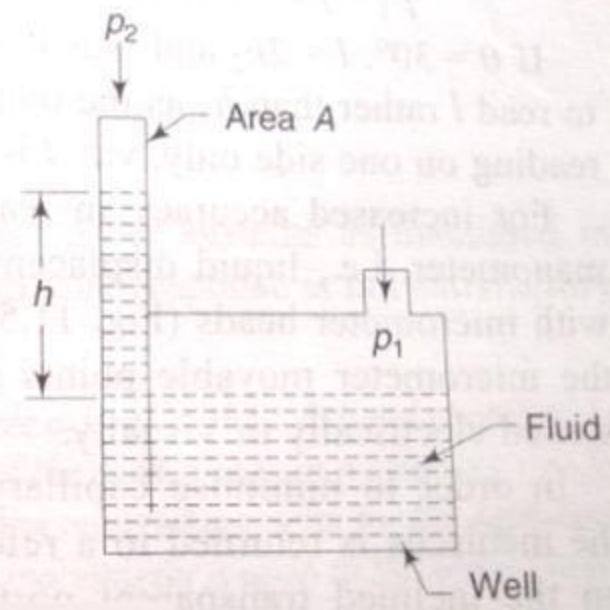
U-tube manometer

$$\frac{p_1 - p_2}{\rho g} = h$$

Cistern or well type manometer-

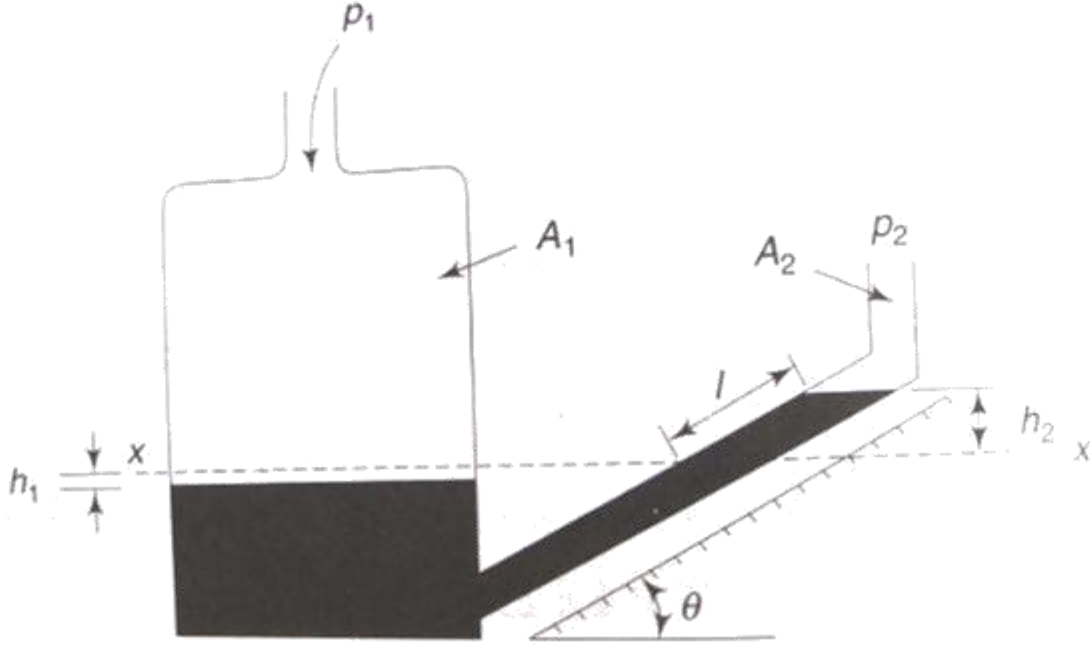
- Easy to use with high sensitivity.
- The well area is large compared to that of the tube.
- Thus only a single leg reading may be noted & change in level in the well may be ignored.
- Force equilibrium gives:

$$p_1A - p_2A = Ah\rho g$$



Cistern or well type manometer

$$\frac{p_1 - p_2}{\rho g} = h$$



Inclined tube manometer

$$h_1 + h_2 = \frac{p_1 - p_2}{\rho g}$$

If A_1 and A_2 are the respective areas of the two limbs,

$$A_1 h_1 = A_2 l$$

$$h_2 = l \sin\theta$$

From Eqs. (11.2)–(11.4), we get

$$p_1 - p_2 = \rho g l \left(\frac{A_2}{A_1} + \sin\theta \right)$$

If $A_1 \gg A_2$ or A_2/A_1 is negligible,

$$p_1 - p_2 = \rho g l \sin\theta = \rho g h_2$$

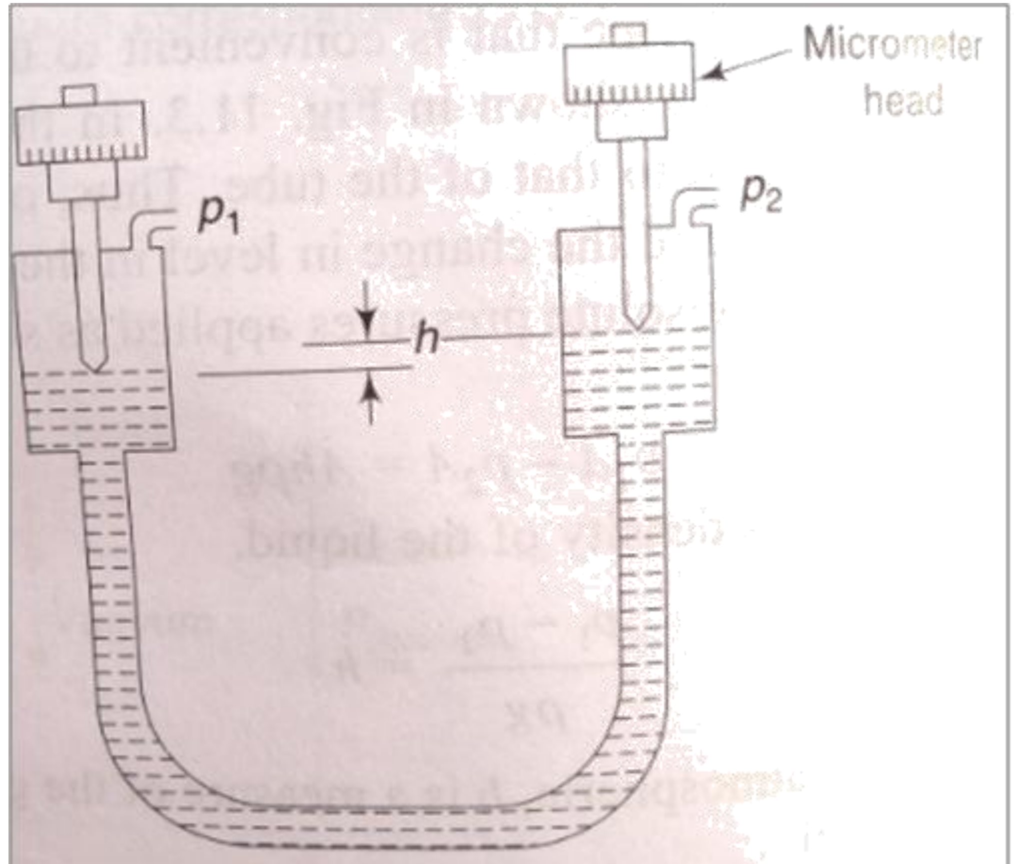
Inclined Tube Manometer:

- The length l along the inclined tube is read as a measure of the pressure difference

  ($p_1 – p_2$)

Micrometer Type Manometer:

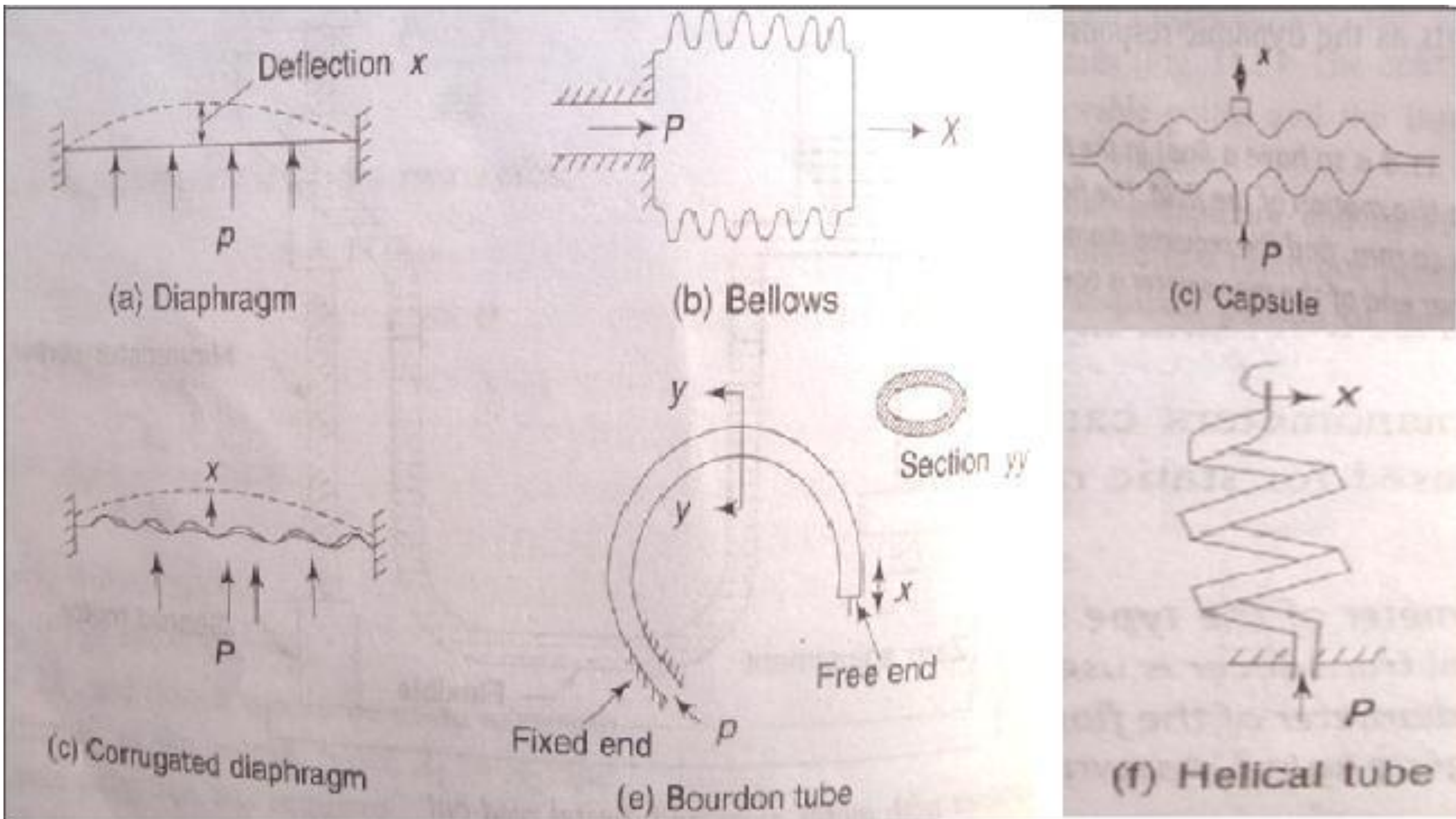
- For increased accuracy in reading the output of manometer i.e. liquid displacements, can be measured with micrometer heads.
- The contact between micrometer movable points and the liquid may be sensed electrically or visually.

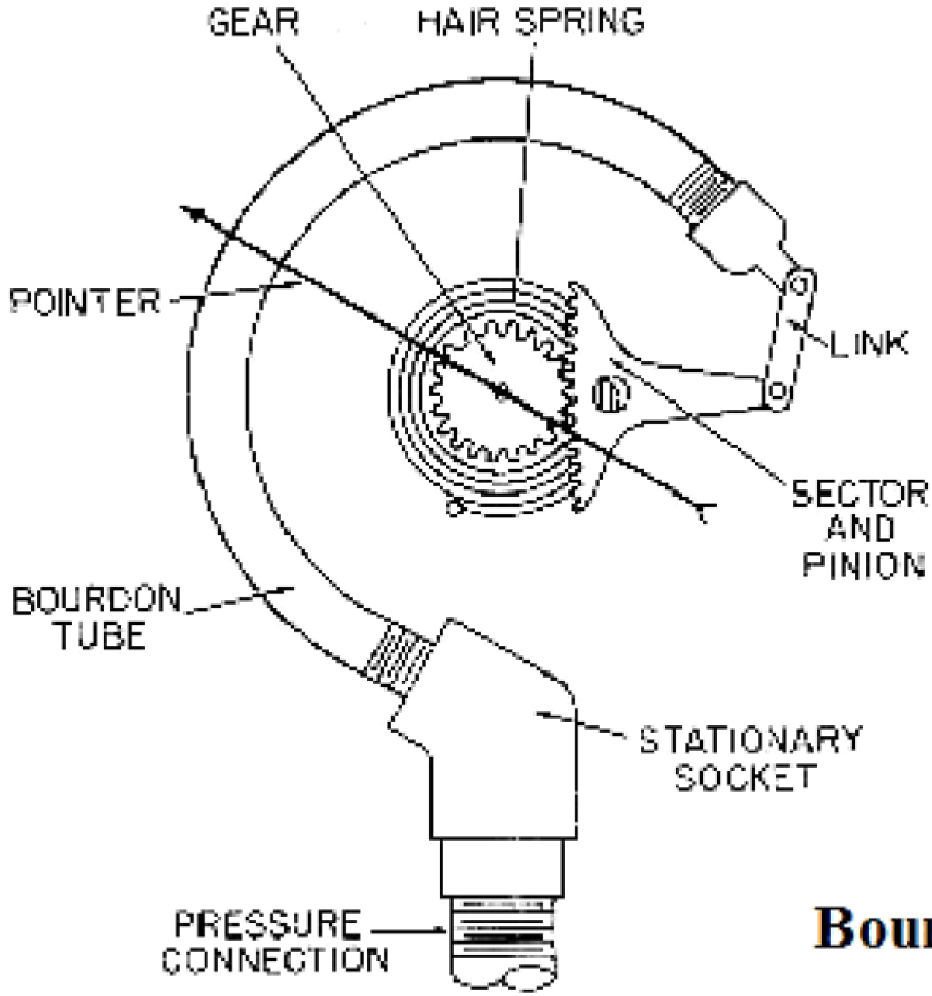


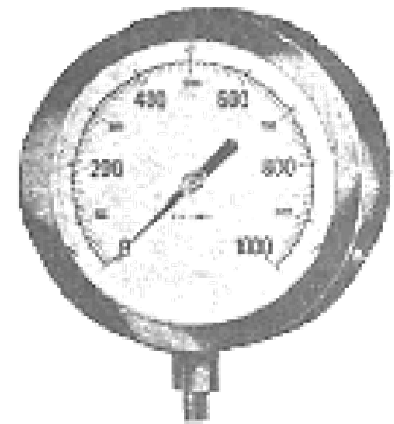
Micrometer type manometer

Elastic transducers

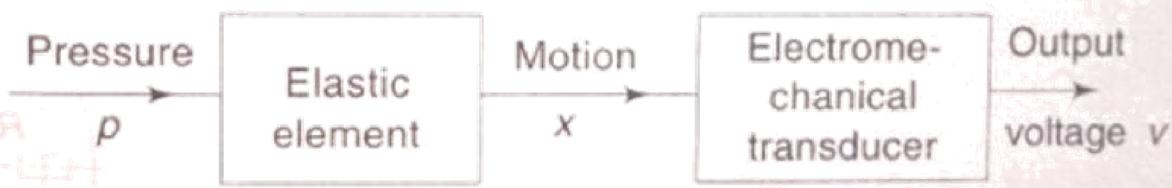
- Elastic elements when subjected to pressure, get deformed. The deformation may be measured by mechanical or electrical methods.
- The elastic elements may be in the form of diaphragms, capsules, bellows, C or helical tubes.







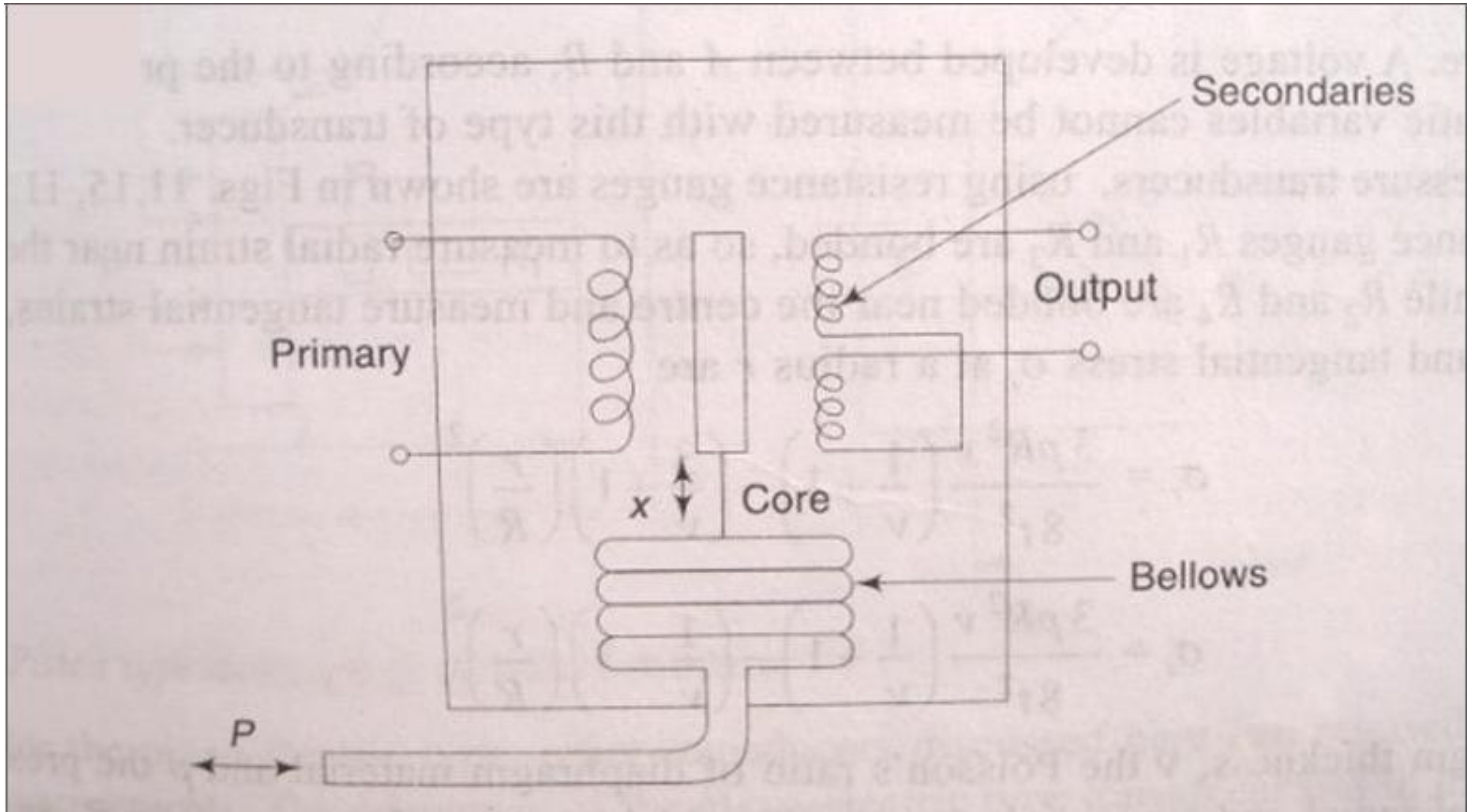
Bourdon Pressure Gauge



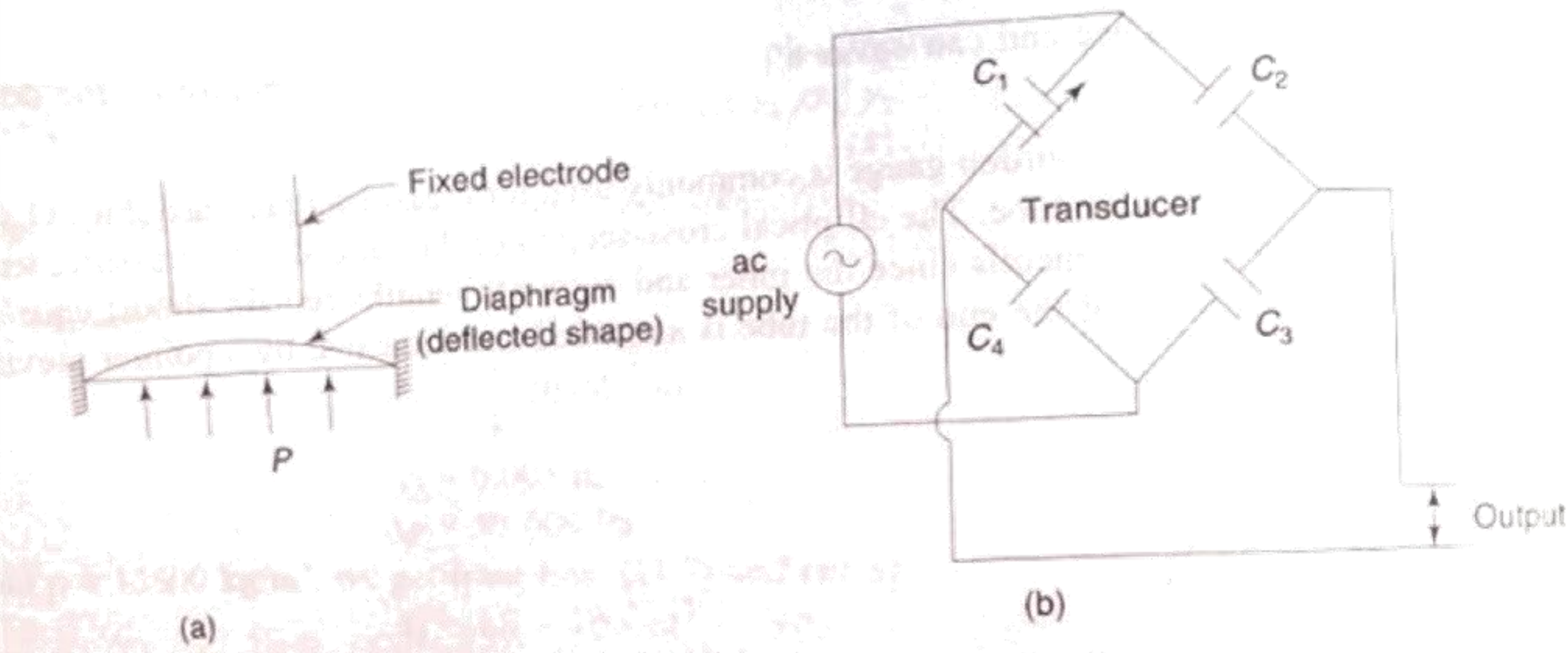
Pressure measurement using an elastic element and an electromechanical transducer

LVDT- type pressure transducer:

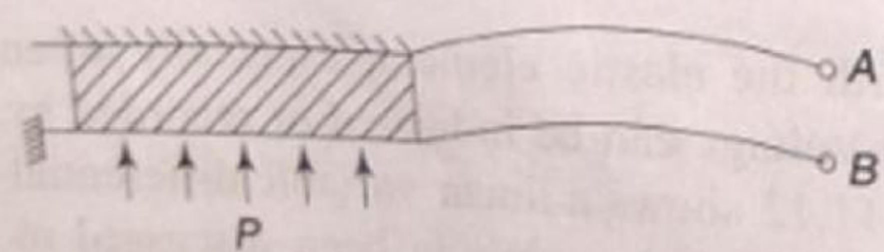
- The motion of the bellows is communicated to the core, whose motion gives an output voltage proportional to it.
- Bellow motion is proportional to pressure p, so output voltage is also proportional to p.



LVDT-type pressure transducer

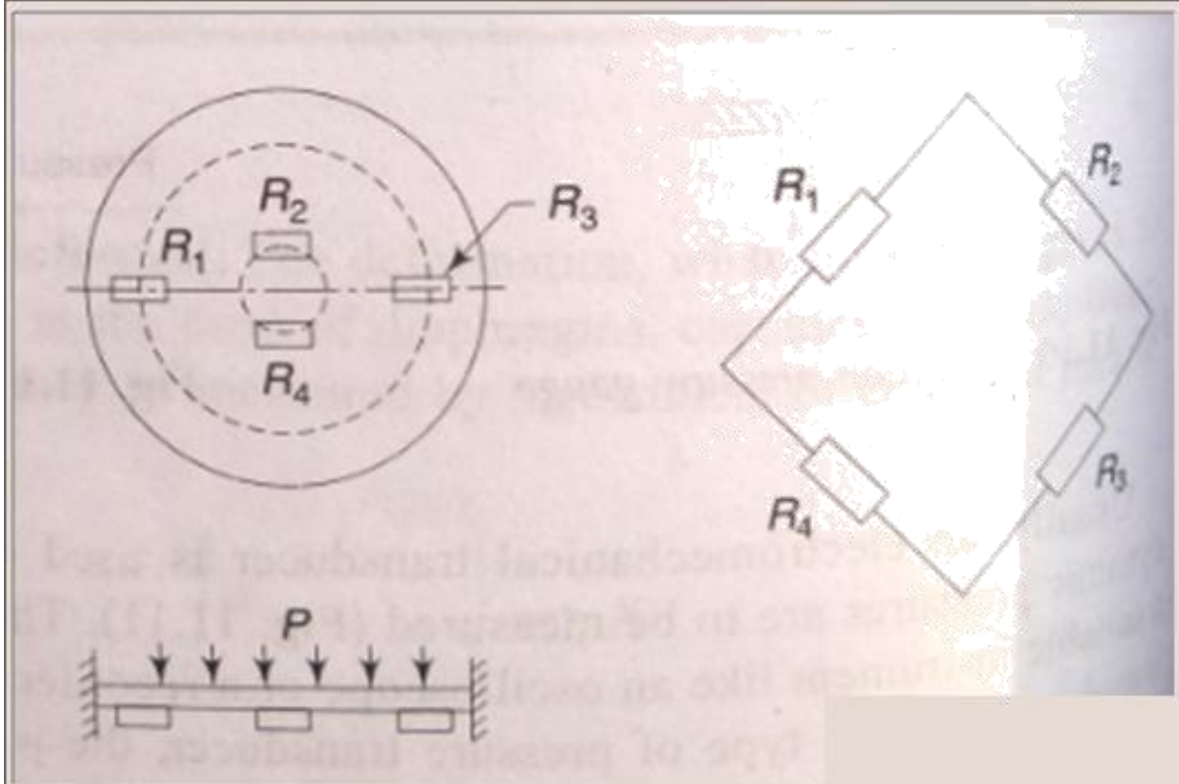


Capacitance-type pressure transducer



Piezeo-electric type pressure transducer

- Resistance gauges R_1 & R_3 are bonded , so as to measure radial strain near outer radius of the diaphragm while R_2 & R_4 are bonded near the centre and measure tangential strains.



Diaphragm type strain gauge pressure transducer

σ_r = Radial stress

σ_t = Tangential stress

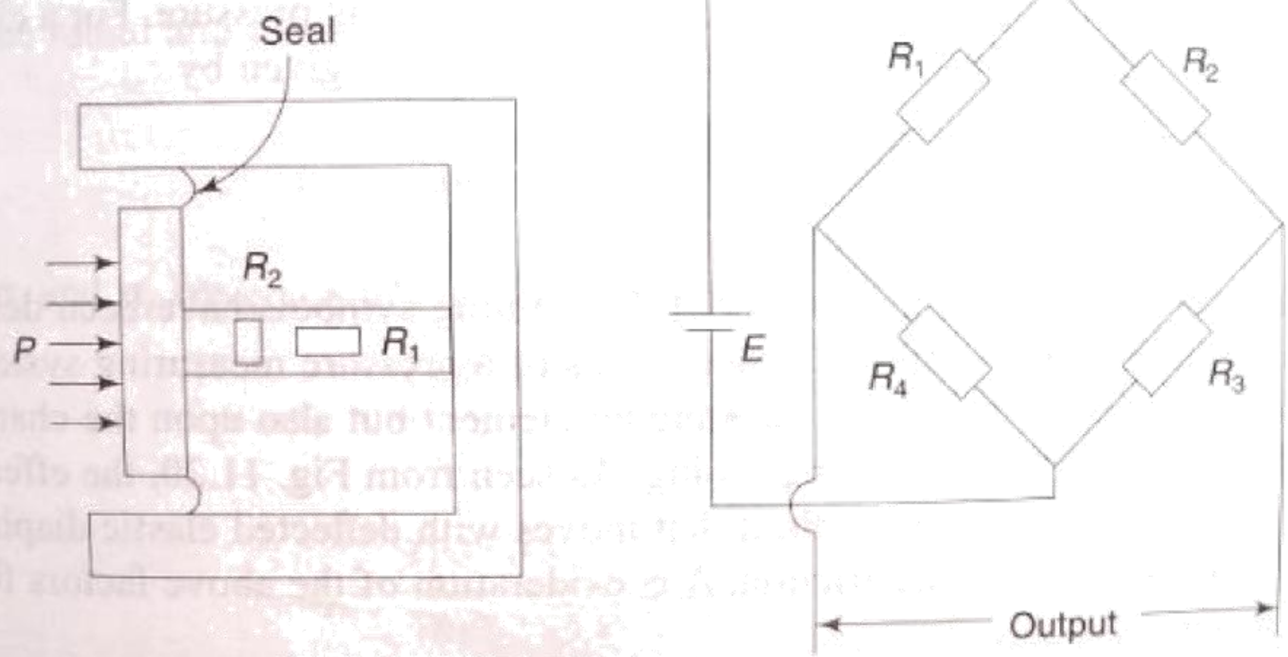
t = diaphragm thickness

V = Poisson's ratio of diaphragm material

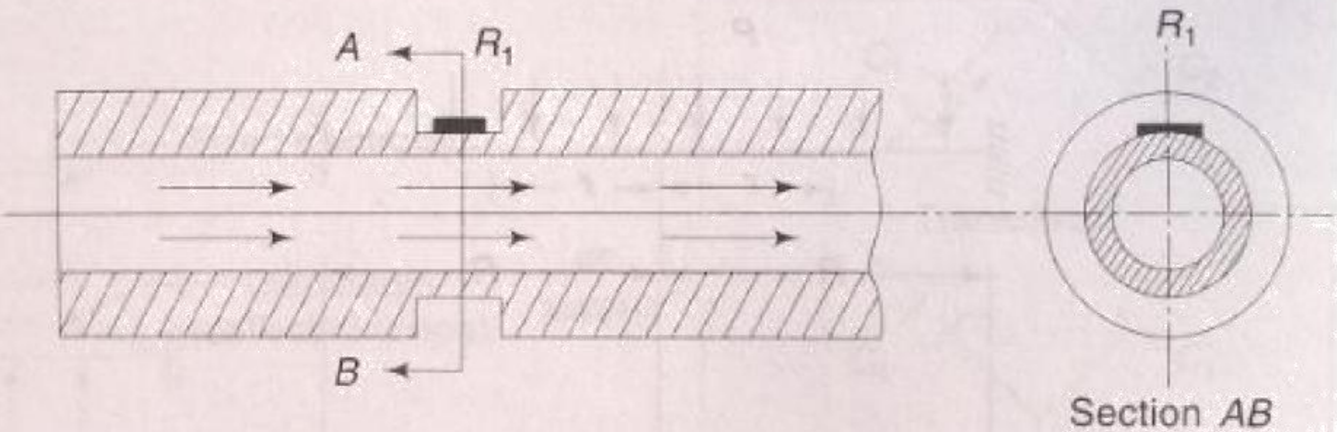
p = pressure on the diaphragm.

$$\sigma_r = \frac{3pR^2 v}{8t^2}\left(\frac{1}{v}+1\right)-\left(\frac{3}{v}+1\right)\left(\frac{r}{R}\right)^2$$

$$\sigma_t = \frac{3pR^2 v}{8t^2}\left(\frac{1}{v}+1\right)-\left(\frac{1}{v}+3\right)\left(\frac{r}{R}\right)^2$$



Piston type strain gauge pressure transducer

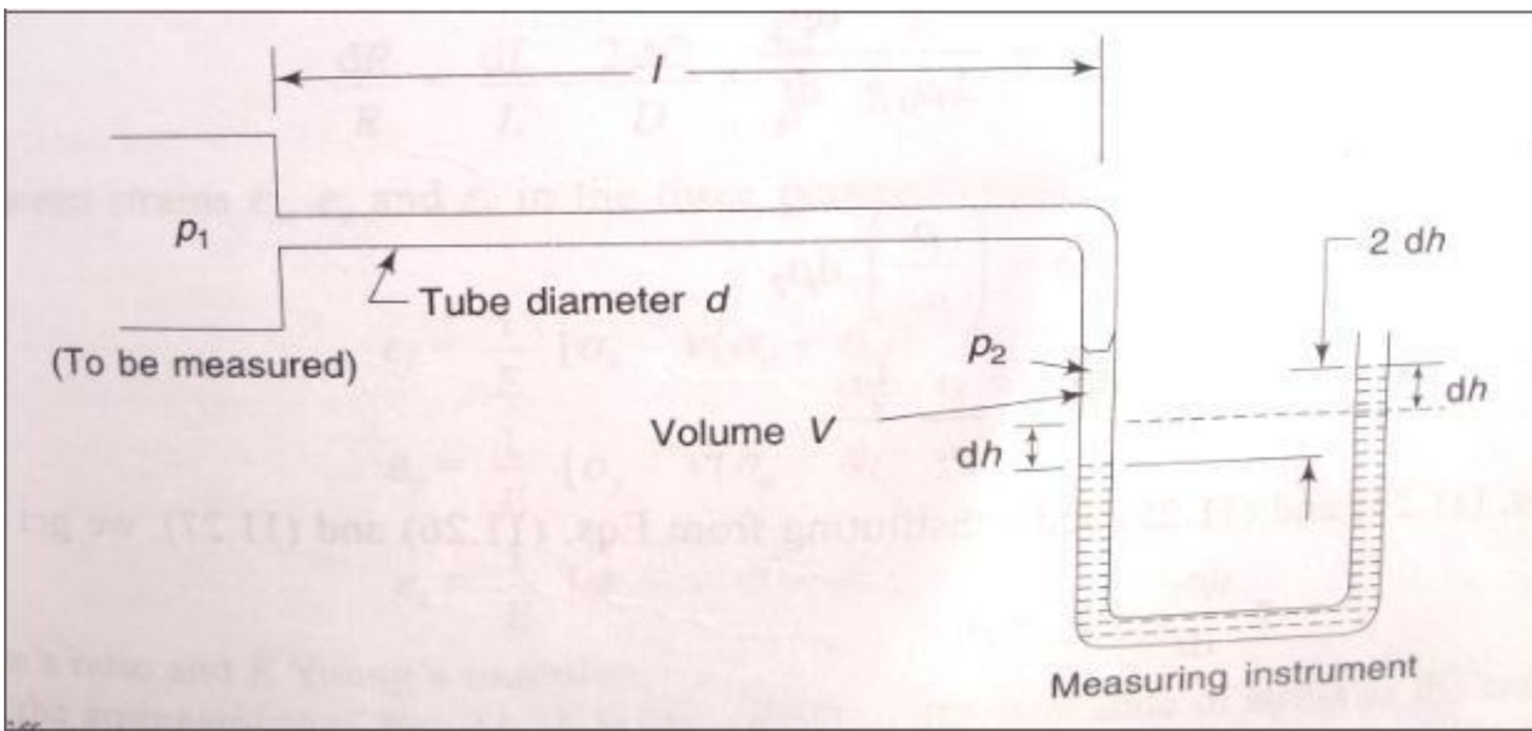


Strain gauge pressure transducer for measuring fluid pressure in a pipe

Dynamic effect of connecting tubing

- Tubing causes a lag under dynamic conditions.
- Mass flow rate of fluid flow in the tubing would be affected due to-

1) change of fluid density due to pressure change.
2) change of volume of fluid as a result of change of liquid level of the manometer.



- Pressure loss in the tubing is

$$p_1 - p_2 = \frac{128\,\mu l Q}{\pi d^4}$$

- Mass flow rate of fluid through the tubing,

  μ is viscosity of fluid,
  Q is volume flow rate.
  ρ is mass density of fluid mass.

$$\rho Q = \frac{\rho \pi d^4 (p_1 - p_2)}{128\,\mu l}$$

- Flow rate is also equal to d/dt (ρV) where V is volume of space Flow rate

$$\frac{\rho \mathrm{d}V}{\mathrm{d}t} + \frac{V \mathrm{d}\rho}{\mathrm{d}t}$$

- A is area of cross-section of manometer tube and dh is the liquid motion in manometer.

$$\mathrm{d}V = A\,\mathrm{d}h$$

Also,

$$2dh = \frac{dp_2}{\rho_0 g}$$

ρ_0 being mass density of liquid in manometer. Thus,

$$dV = \frac{A}{2\rho_0 g} dp_2$$

or

$$\frac{dV}{dt} = \frac{A}{2\rho_0 g} \frac{dp_2}{dt}$$

Further, due to pressure change dp_2,

$$d\rho = \left(\frac{\rho}{p_2}\right) dp_2$$

or

$$\frac{d\rho}{dt} = \frac{\rho}{p_2} \frac{dp_2}{dt}$$

$$\tau \frac{dp_2}{dt} + p_2 = p_1$$

where $\tau = \frac{128 \mu l}{\pi d^4} \left[\frac{A}{2\rho_0 g} + \frac{V}{p_2} \right]$

τ is the time constant of the first order relation representing the lag of system.
In order to reduce τ, the l, A and V should be small and d should be large.