Introduction

- Force represents mechanical quantity which changes or tends to change the relative motion or shape of the body on which it acts.
- Force is a vector quantity.

Force ɣ rate of change of (mass x velocity)

ɣ mass x rate of change of velocity

ɣ mass x acceleration

Thus , F ɣ ma ; $F = \frac{ma}{g_c}$

Force measurement

- A measure of the unknown force may be accomplished by the method incorporating the following principle:

i) Balancing the force against a known gravitational force on a standard mass (scales and balances)

ii) Translating the force to a fluid pressure and then measuring the resulting pressure (hydraulic and pneumatic load cells)

iii) Applying the force to some elastic member and then measuring the resulting deflection (proving ring)

iv) Applying the force to known mass and then measuring the resulting acceleration

v) Balancing the force against a magnetic force developed by interaction of a magnet and current carrying coil.

1. Scales and balances

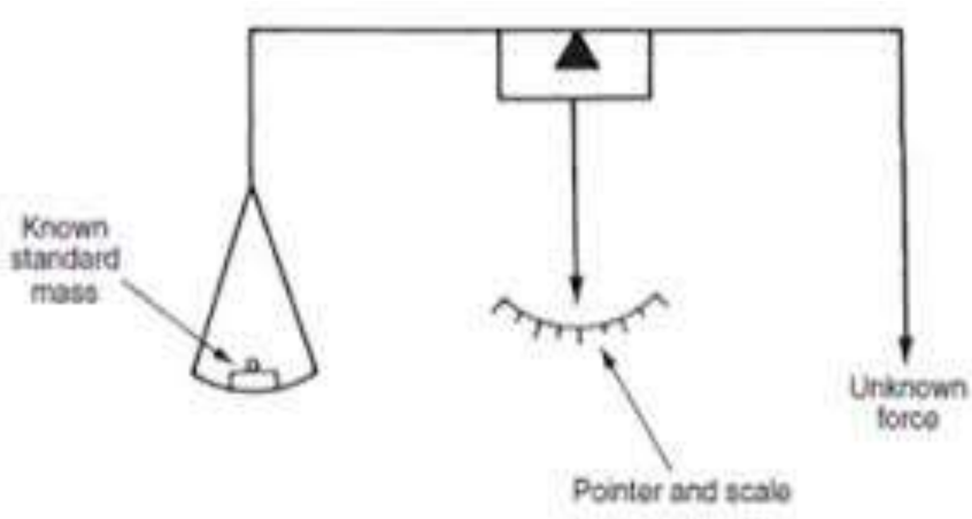
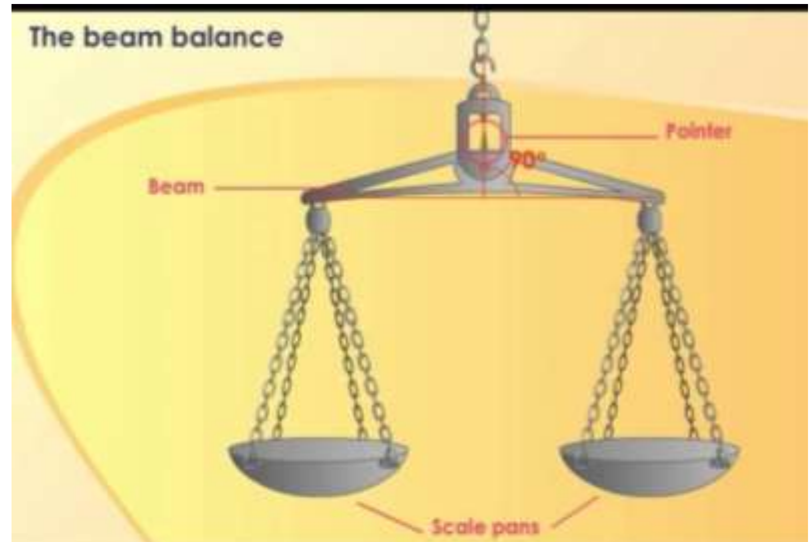


Fig 5.1 Equal Arm Balance



$$m_1 l_1 = m_2 l_2$$

$$W_1 = W_2$$

Unequal arm balance:

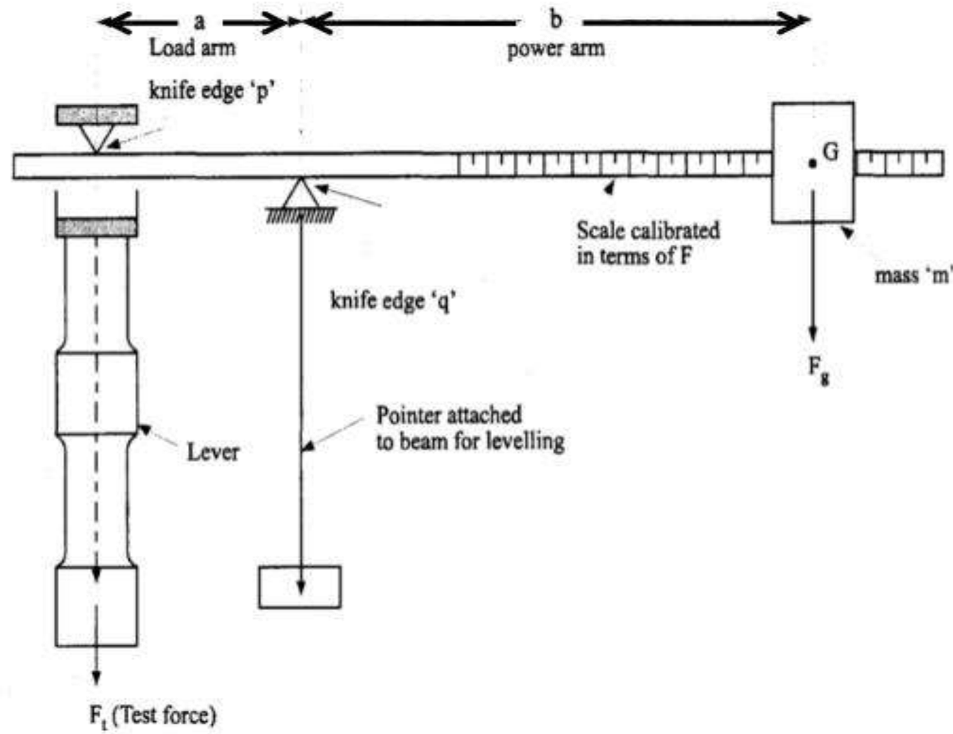
- For balance of moments,

$$F_t * a = F_g * b$$

or test force,

$$F_t = F_g * (b / a)$$

Therefore, the test force is proportional to the distance ‘b’ of the mass from the pivot.



- Balance may be specified in two ways:

1) Mechanical advantage that represents the ratio of load to power ,or
2) Multiple *M* defined as

$$M = \frac{power\ arm}{load\ arm}$$

$$= \frac{distance\ between\ the\ fulcrum\ and\ the\ power\ point}{distance\ between\ the\ fulcrum\ and\ the\ load\ point}$$

- From balance of moments:

$$F_t \times a = F \times b$$

$$F_t = F \times b/a$$

$$= mg \times b/a$$

$$= Constant \times b \quad ....(1)$$

Multi lever platform scale

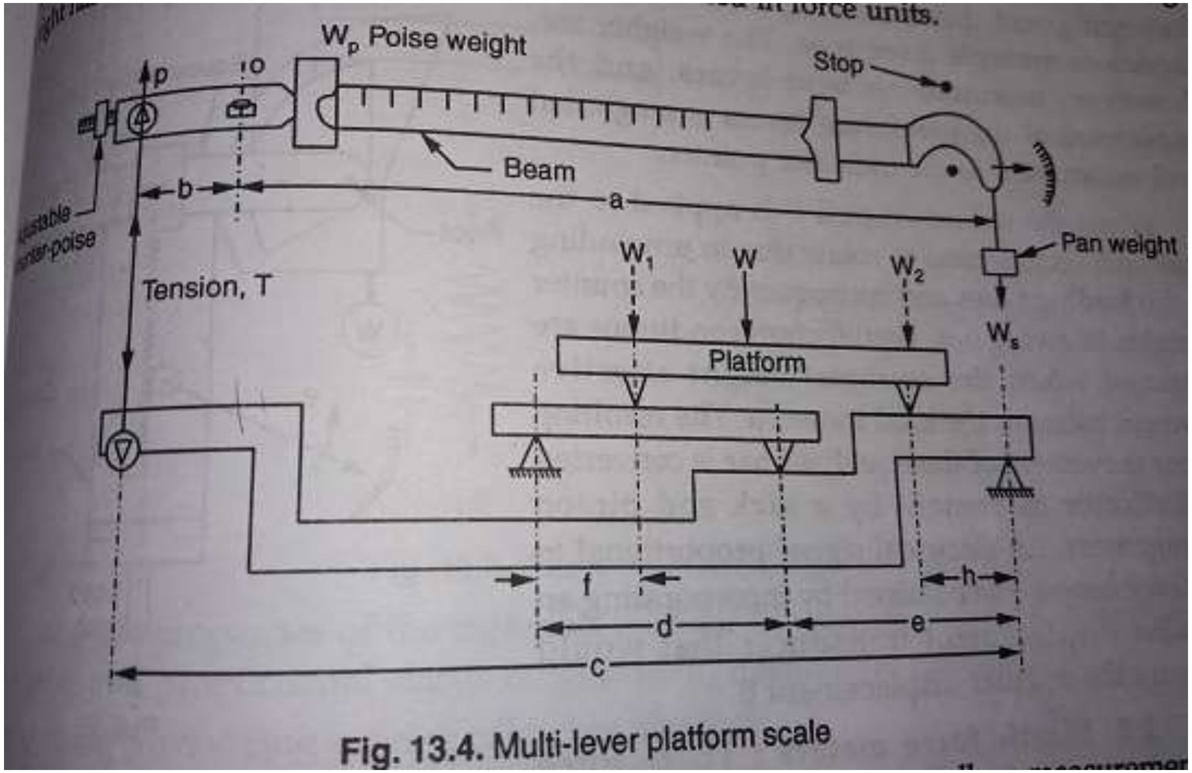


Fig. 13.4. Multi-lever platform scale

- The moment equation are then written as:

$T \times b = W_s \times a$ ....(2)

And **$T \times c = W_s \times f/a \times e + W_2 \times h$** ....(3)

- Genearlly the **lever system is so proportioned that $h/e = f/d$**.

Then we have:

$T \times c = h\,(W1 \times W2) \Rightarrow hW$ ....(4)

•Eliminating T from equation (2) and (3);

Ws x a/b = W x h/c ……………………….(5)

Or **W= (a/b) x(c/h) Ws => R Ws** …………………………….(6)

Where constant **R = ac / bh** is called **Multiplication ratio** of the scale.

WORKING

• Pendulum scale (in Fig) is a self balancing and direct reading force measuring device of multiple lever type.

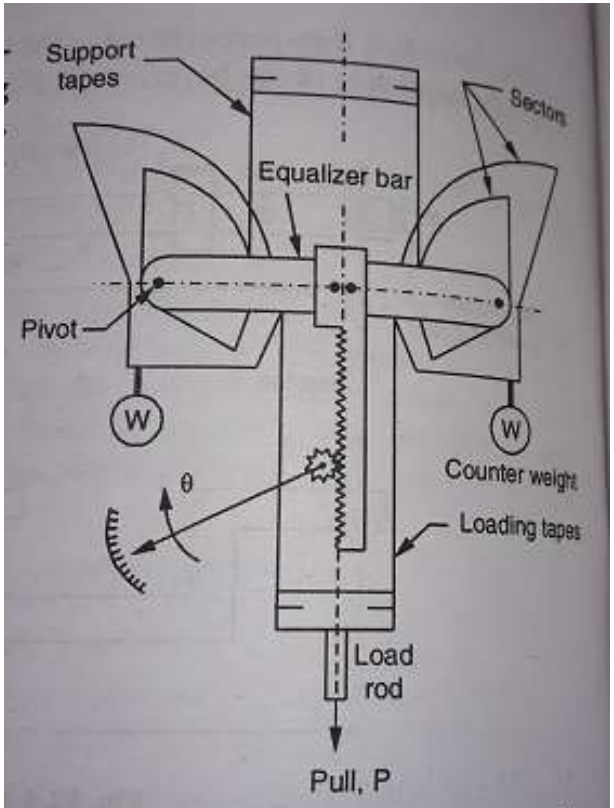


Fig. 13.5. Essentials of a pendulum scale

•When the unknown pull P is applied to the load rod, sectors tend to rotate due to unwinding of the loading tapes and consequently the counetr weights W swing out.

•Equilibrium conditions are attained when the counter weight effective moment balances the load moment.

•The resulting linear movement of the equalizer bar is converted to indicator movement by a rack and pinion arrangement.

•An electrical signal proportional to the force can also be obtained by incorporating an angular displacement transducer hat would measure the angular displacement θ.

2. Elastic force meters

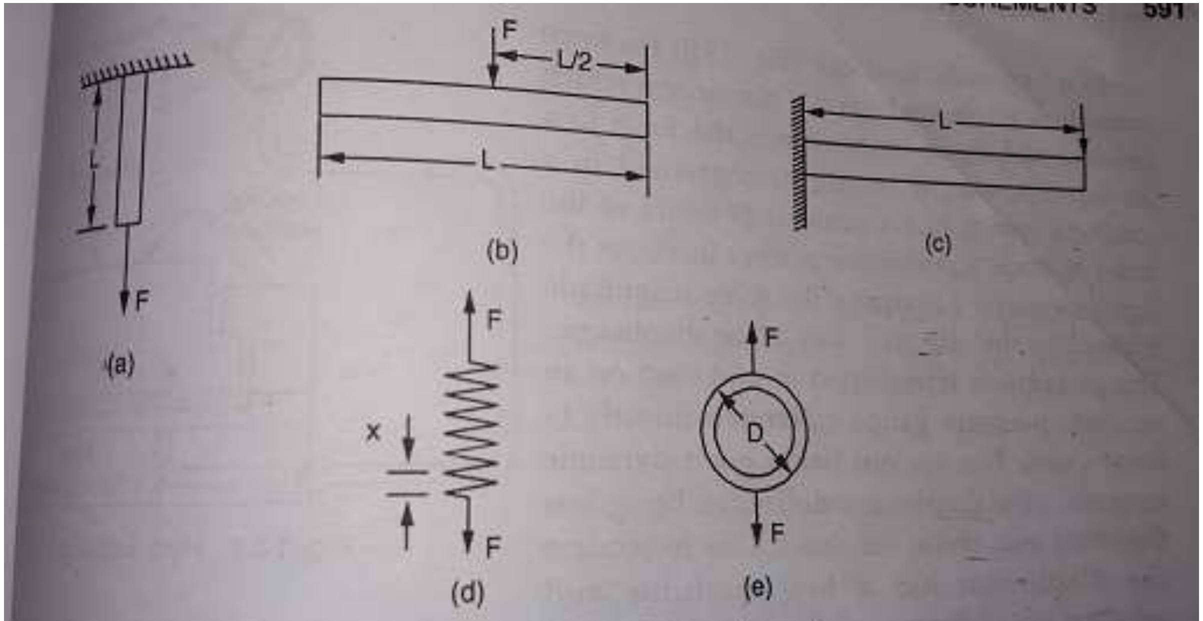


Fig. 13.6. Elastic deflection elements

— *simple bars :*

$$x = \frac{FL}{AE} \quad ; \quad K = \frac{AE}{L}$$

— *Simply sup ported beams :*

$$x = \frac{1}{48}\frac{FL^3}{EI} \quad ; \quad K = \frac{3EI}{L^3}$$

— *spring :*

$$x = \frac{8FD_m^3 N}{C\ D_w^4} \quad ; \quad K = \frac{C\ D_w^4}{8\ D_m^3\ N}$$

- **Proving Ring**

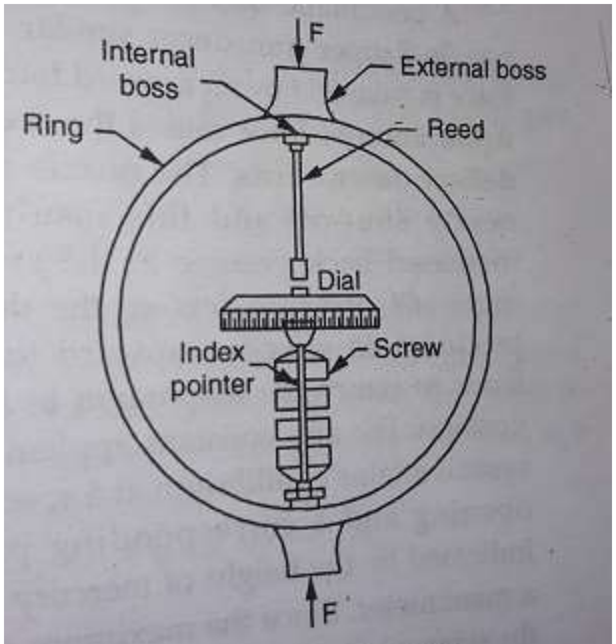


Fig. 13.7. Proving ring

Proving ring

- The proving ring is a device used to measure force. It consists of an elastic ring of known diameter with a measuring device located in the center of the ring.
- They are made of a steel alloy.
- manufactured according to design specifications established in 1946 by the National Bureau of Standards (NBS).
- Proving rings can be designed to measure either compression or tension forces.

Proving ring

- Standard for calibrating material testing machine.
- Capacity 1000 N to 1000 kN.
- Deflection is used as the measure of applied load.
- This deflection is measured by a precision micrometer.
- Micrometer is set with a help of vibrating reed.

$$M = \frac{PR}{2}\left(\cos\phi - \frac{2}{\pi}\right)$$

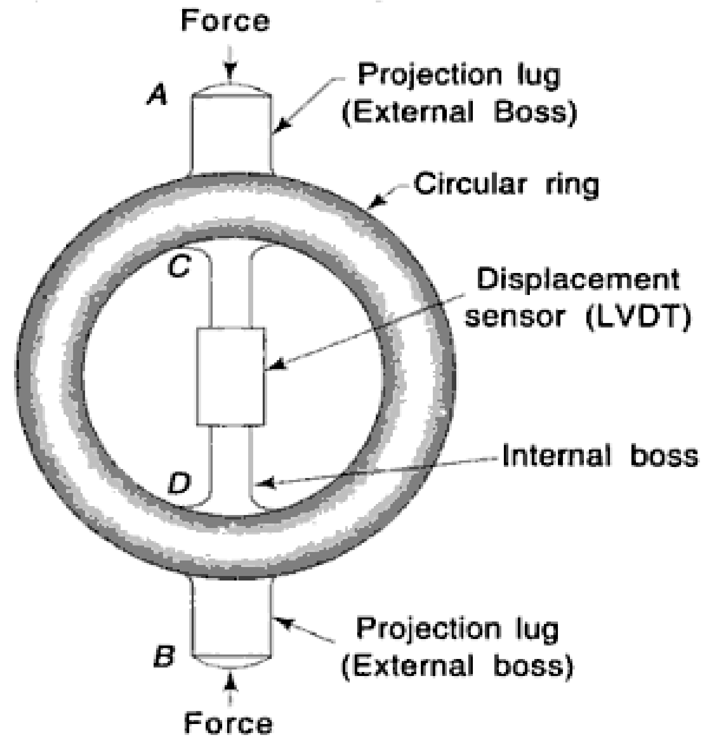
P = force or load
M = Bending moment
R = Radius of proving ring

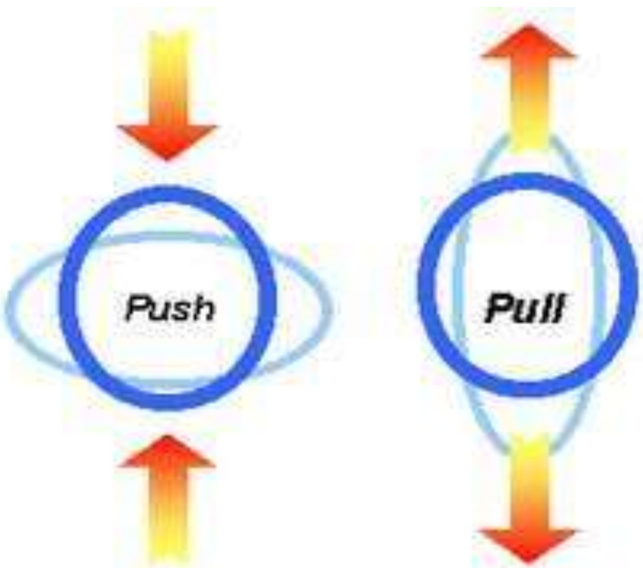
Proving Ring:

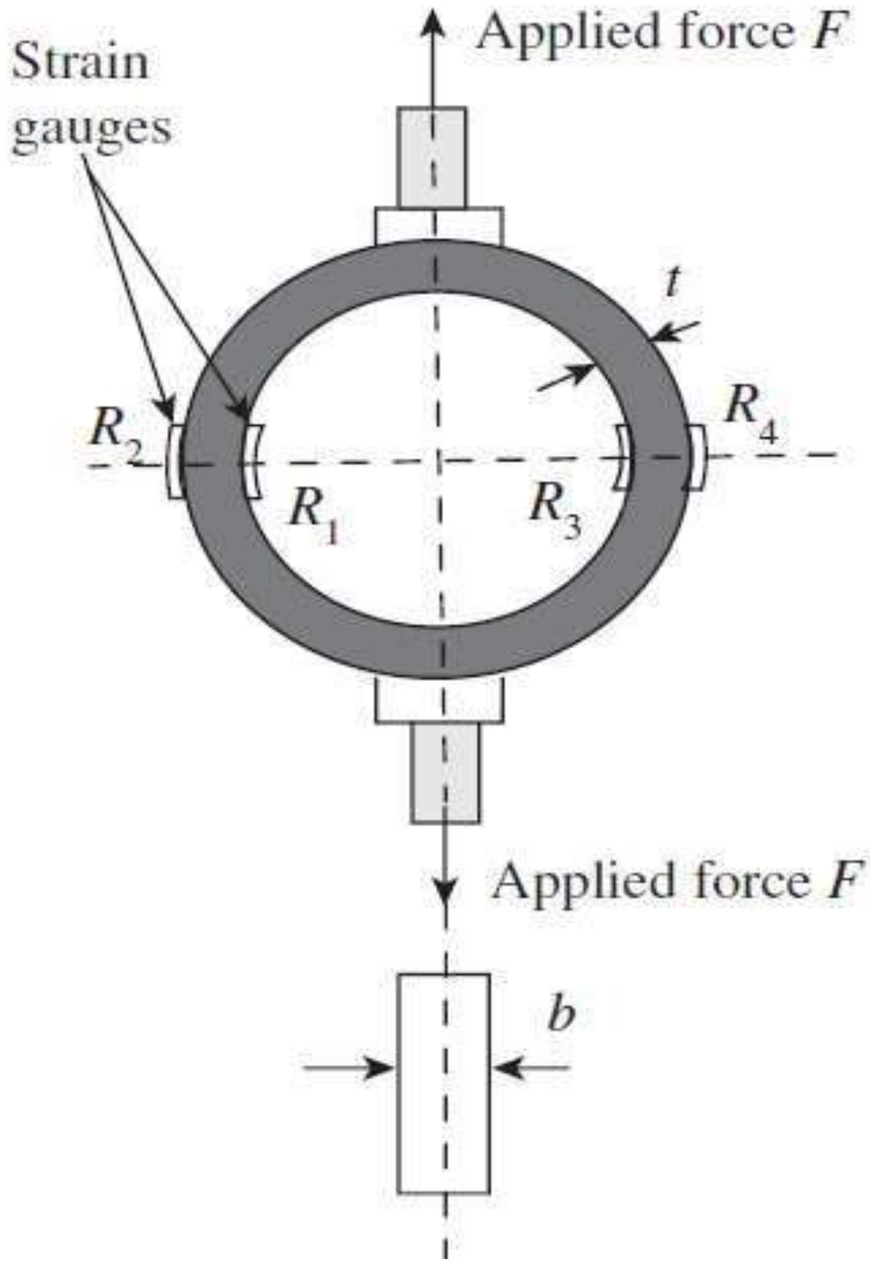
- A ring used for calibrating tensile testing machines. It works on the principle of LVDT which senses the displacement caused by the force resulting in a proportional voltage.

- It is provided with the projection lugs for loading. An LVDT is attached with the integral internal bosses C and D for sensing the displacement caused by application of force.

- When the forces are applied through the integral external bosses A and B, the diameter of ring changes depending upon the application which is known as ring deflection.




Push
Pull


Applied force F
Strain gauges
t
R_2
R_4
R_1
R_3
Applied force F
b

3.Mechanical Load Cell

- Hydraulic Load cell

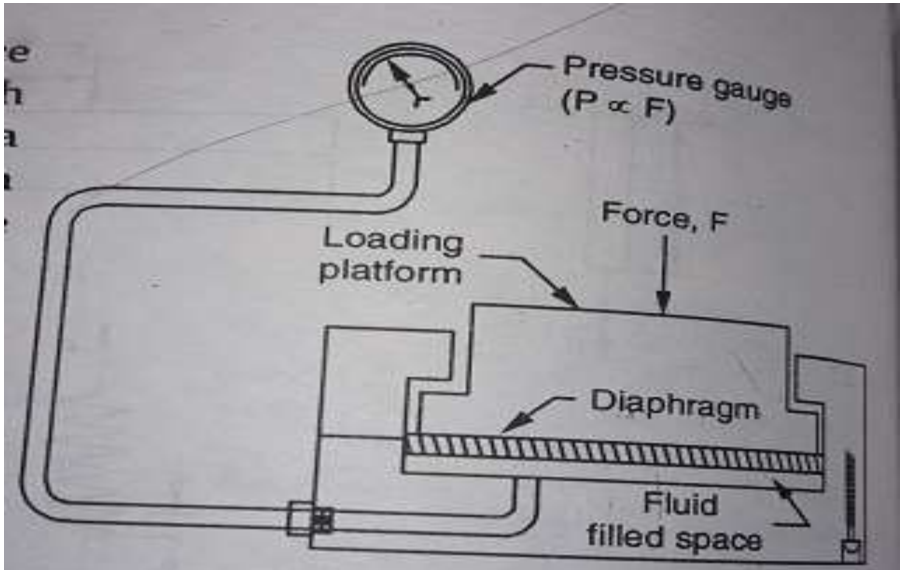


Fig. 13.8. Hydraulic load cell

- **Pneumatic load cell**

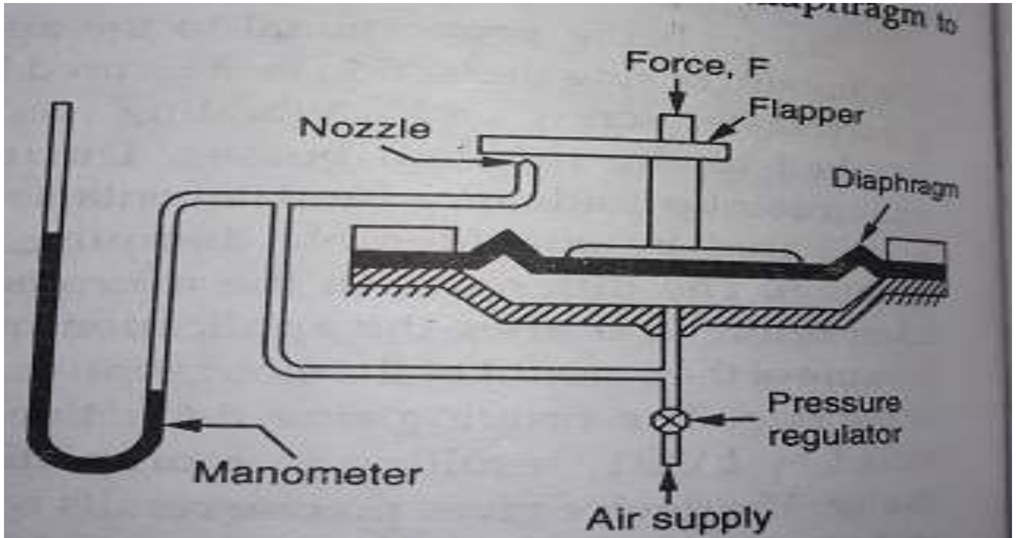
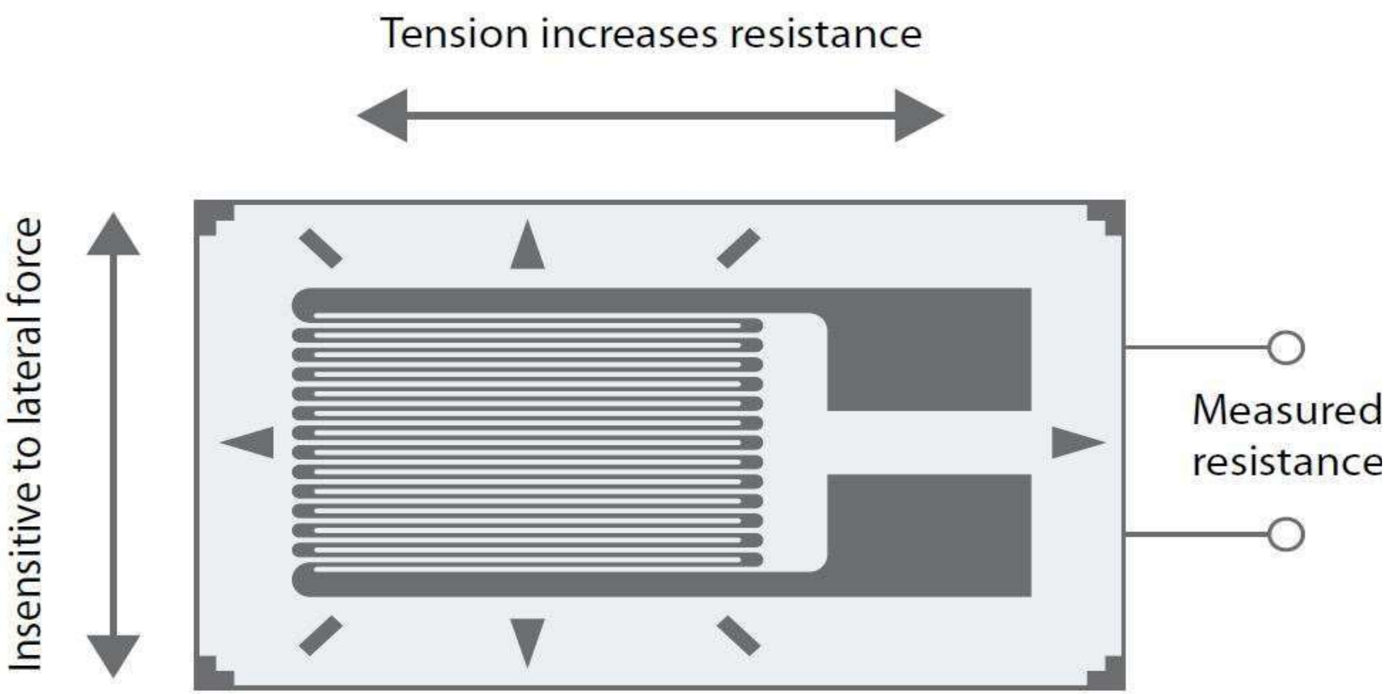
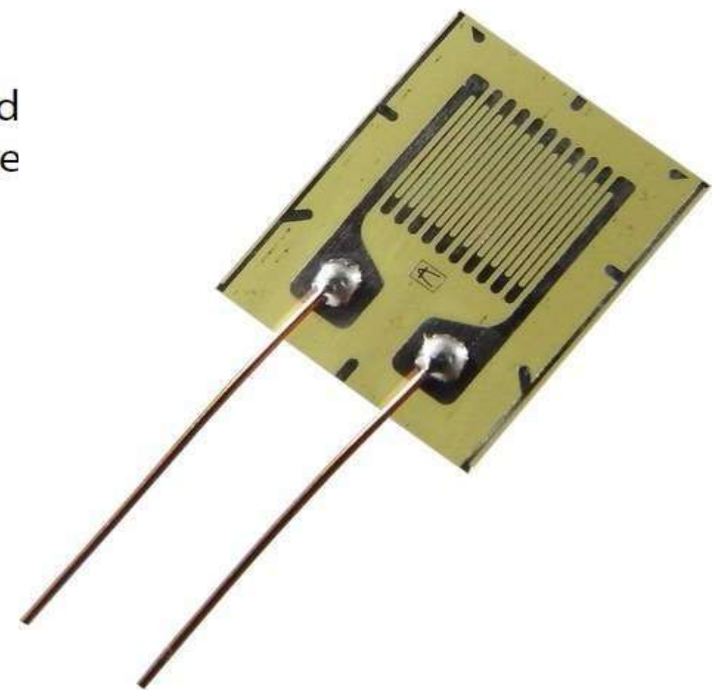


Fig. 13.9. Pneumatic load cell

Strain gauge load cell





• Strain gauge load cell

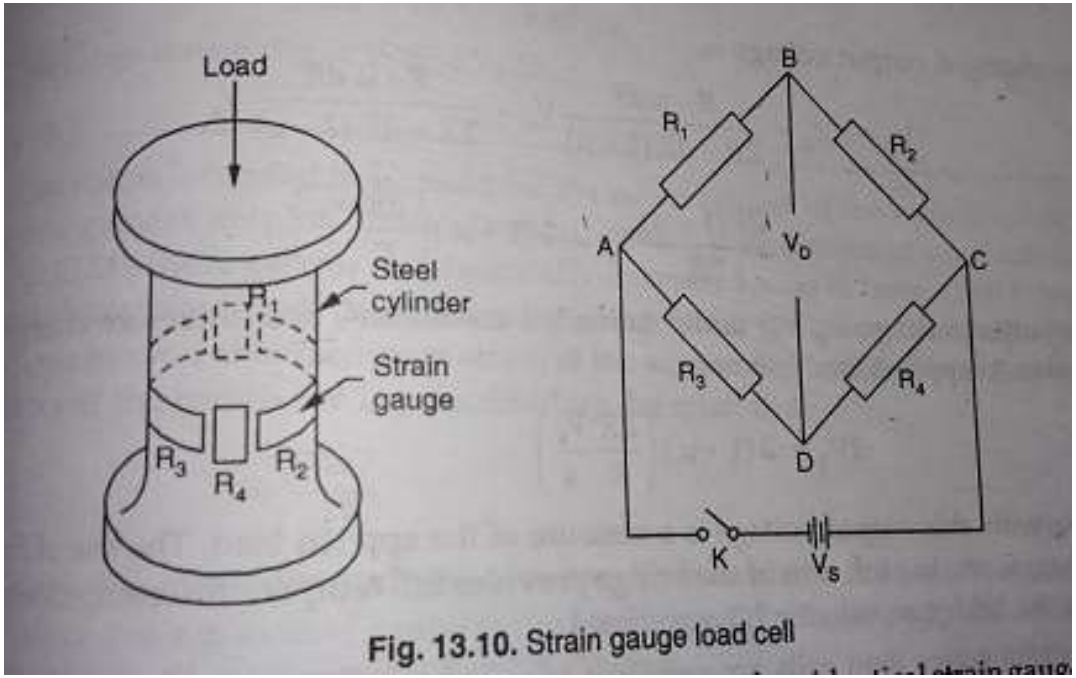
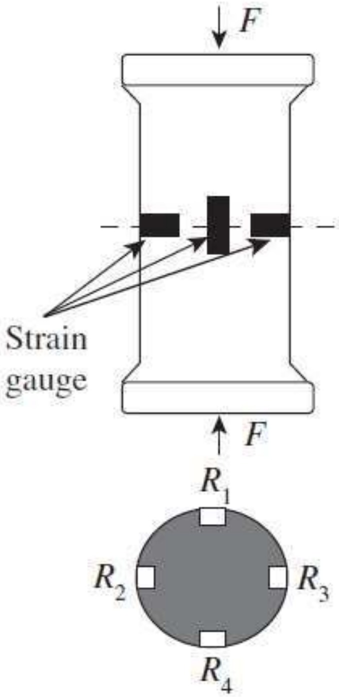
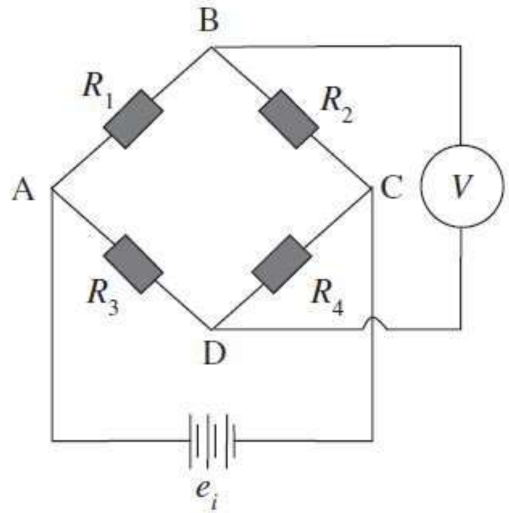


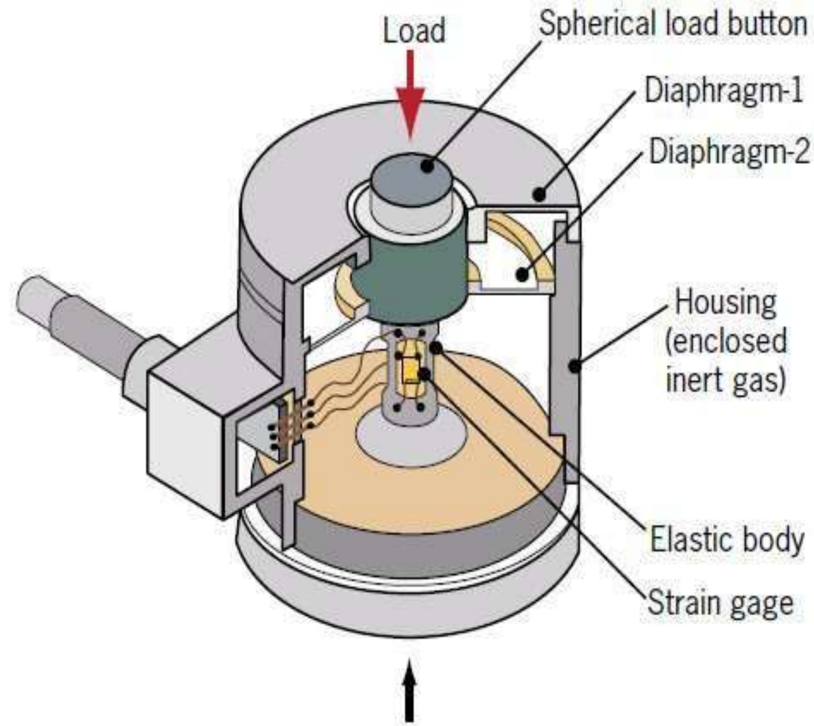
Fig. 13.10. Strain gauge load cell

• It converts weight or force into electrical output which are provided by the strain gauges.

•These output can be connected to various measuring instruments for indicating, recording and controlling the weight or force.


F
Strain gauge
F
R1
R2
R3
R4


B
R1
R2
A
C
V
R3
R4
D
e_i


Load
Spherical load button
Diaphragm-1
Diaphragm-2
Housing (enclosed inert gas)
Elastic body
Strain gage

- A simple load cell consist of a steel cylinder which has a four identical strain gauge mounted.
- Gauge R1 and R4 are along the direction of applied load and the gauge R2 and R3 are attached circumferentially at right angles to gauges R1 and R4.
- These four gauges are connected electrically to the four limbs of a Wheatstone bridge ckt.
- **When there is no load on cell**, all the four gauges have the same resistance. The terminals B and D are at the same potential, the bridge is balanced and the output voltage is zero.

$$V_{ab} = V_{ad} = \frac{V_s}{2} \quad ; \qquad V_o = V_{ab} - V_{ad} = 0$$

- When **compressive load is applied** to the unit, the vertical gauge (R1 and R4) undergo compression and so decrease in resistance.
- Simultaneously the circumferential gauges R2 and R3 undergo tension and so increase in resistance.
- In poissons arrangement, the positive and negative strains (and so changes in resistance) are related to each other by the poissons ratio.
- When strained, the resistance of the various gauges are:
- R1 and R4 = R-dR (compressive) and R2 and R3 = R+μdR (Tension)

- Potential at terminal B is,

$$V_{ab} = \frac{R_1}{R_1 + R_2} V_s$$

$$= \frac{R - dR}{(R - \delta P) + (R + \mu dR)} V_s$$

$$= \frac{R - \mu dR}{2R - dR(1 - \mu)} V_s$$

- Potential at terminal D is,

$$V_{ad} = \frac{R_3}{R_3 + R_4} V_s$$

$$= \frac{R + \mu dR}{(R + \mu dR) + (R - dR)} V_s$$

$$= \frac{R + \mu dR}{(R + \mu dR) + (R - dR)} V_s$$

$$= \frac{R + \mu dR}{2R - dR(1 - \mu)} V_s$$

- The changed output voltage is;

$$V_o + dV_o = \frac{R - \mu dR}{2R - dR\left(1-\mu\right)} V_s - \frac{R + \mu dR}{2R - dR\left(1-\mu\right)} V_s$$

$$= \frac{dR\left(1+\mu\right)}{2R} V_s$$

$$= 2\left(1+\mu\right)\left(\frac{dR}{R}\frac{V_s}{4}\right)$$

- The output voltage Vo = 0 under unloaded condition, and therefore change in output voltage due to applied load becomes,

$$dV_0 = 2\left(1+\mu\right)\left(\frac{dR}{R}\frac{V_s}{4}\right)$$