RESISTANCE TRANSDUCER

$$R = \rho L/A$$

Where, R =Resistance,Ω

ρ = Resistivity of conductor, Ω-
m L = Length of conductor, m

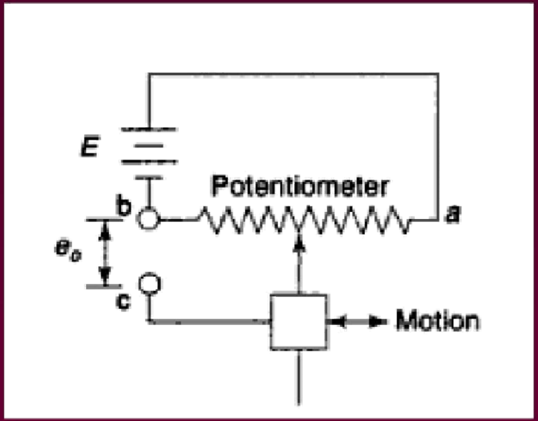
A = Cross-sectional area of conductor, m^2

Classification of resistance transducer:

1. Mechanically varied resistance	- Potentiometer
2. Thermal resistance change	- Resistance thermometer
3. Resistivity change	- Resistance strain gauge

Linear or Angular Motion Potentiometers

- Convert linear motion or angular motion of a rotating shaft into change in resistance.
- Used to measure pressure, force, acceleration, liquid level.



- Advantages:

1. High output
2. Less expensive
3. Available in different sizes, shapes, ranges.
4. High electrical efficiency
5. Insensitive towards vibration and temperature

- Disadvantages:

1. Limited life due to early wear of sliding arm.
2. Noisy & erratic output in high speed operation
3. Resolution is limited in wire wound potentiometer.

Wire wound potentiometer:

- Materials used are platinum, nickel chromium, nickel copper, etc.
- Carry large currents at high tempratures.
- Low temp. coefficient of resistance.
- Resolution is limited. 0.025 – 0.05 mm.
- Limited response to about 5 Hz.

Non wire wound potentiometer:

- Materials used are cermet, Hot moulded carbon, carbon film, thin metal film.
- Improved resolution and life
- May be turned at a speed of 2000 rpm
- More sensitive to temp. changes
- Can carry only moderate currents.

Thermisters & Resistance Thermometers

- These are thermally sensitive variable resistors made of certain conducting and ceramic-like semiconducting materials.
- High negative temperature coefficient of resistance.
- Precision temp.(-60^{0}C to + 15^{0}C) measurements, control and compensation.
- Resistance ranges from 0.5 Ω to 0.75 MΩ.
- Compact, rugged and inexpensive.
- Good stability
- Response time varies from a fraction of second to minutes depending on the size of detecting mass and thermal capacity of thermisters.

- Temperature limit is usually 400^0C or less.
- Measuring current should be maintained to as low as possible to avoid self heating of thermisters.

Applications:

- Measurement of temperature
- Temp. compensation in complex electronic equipment, magnetic amplifiers and instrumentation equipment.
- Measurement of power at high frequencies
- Vaccum measurement
- Measurement of level, flow and pressure of liquids
- Measurement of thermal conductivity.

Strain Gauges

- These types of transducers are based on the principle that if a conductor is streched or compressed, its resistance will change, because of change in its length,area & resistivity.
- Also called piezo-resistive gauges.
- Types of strain gauges:

1. Wire wound strain gauges
2. Foil type strain gauges
3. Semiconductor strain gauges
4. Capacitive strain gauges

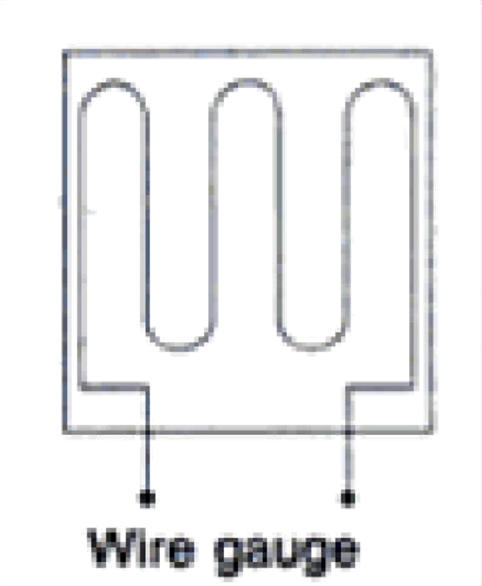
Strain gauges are of two types.

1. Bonded Strain Gauge
2. Unbonded Strain Gauges

Wire Strain Gauges

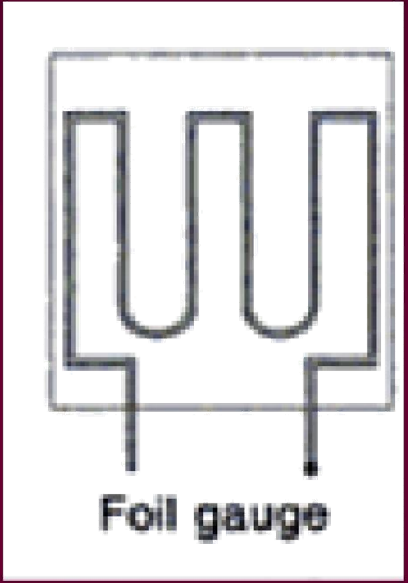
Requirements:

- Should have high value of gauge factor
- Resistance should be as high as possible
- Low resistance temperature coefficient
- Should not have hysteresis effect
- Should have linear characteristics
- Frequency response should be good.



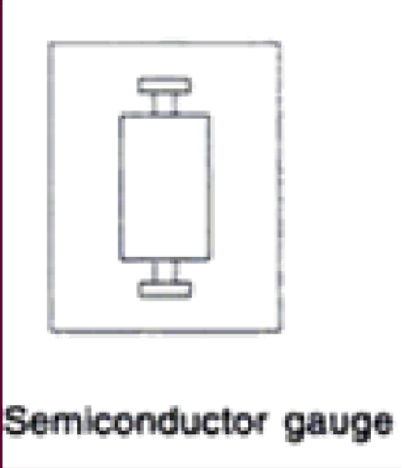
Foil Strain Gauge

- Strain is measured with the help of metal foil.
- Much greater dissipation capacity as compared with wire wound gauges on account of their greater surface area for same volume.
- High operating temperature ranges.
- Available range is 50 to 1000Ω.
- Fabricated economically on a mass scale.



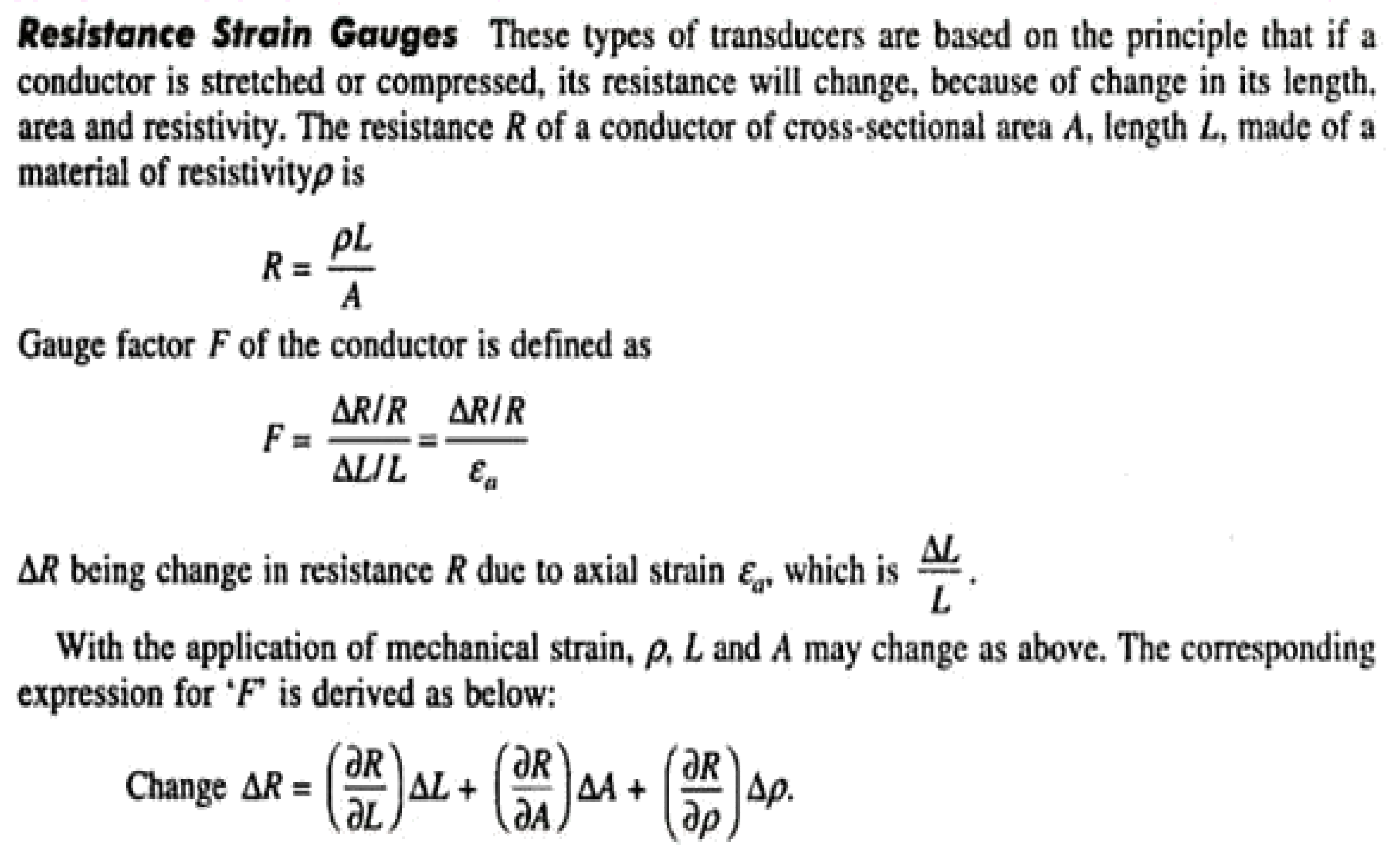
Semiconductor strain gauges

- Change in resistance due to change in resistivity.
- Very high gauge factor and small envelope.
- Silicon and germanium
- Excellent hysteresis characteristics
- Fatigue life is in range of 10^6 operations
- Frequency response upto 10^{12} Hz
- Length from 0.7 to 7 mm.
- Very sensitive to change in temperature.
- Poor linearity.



Capacitive Strain Gauges

- Uses principle of variation of capacitance with variation of distance between electrodes.
- Electrodes are flexible metal strips of about 0.1 mm thickness.
- Strain-capacitance relationship is not linear.
- Strain gauges has a capacitance of about 0.5 pF.
- Its overall size is 5mm x 17mm x 1mm.
- It uses a polyamide film of insulating material.
- Can be used upto a temperature of 300^{0}C.



Resistance Strain Gauges These types of transducers are based on the principle that if a conductor is stretched or compressed, its resistance will change, because of change in its length, area and resistivity. The resistance R of a conductor of cross-sectional area A, length L, made of a material of resistivity ρ is

$$R = \frac{\rho L}{A}$$

Gauge factor F of the conductor is defined as

$$F = \frac{\Delta R / R}{\Delta L / L} = \frac{\Delta R / R}{\varepsilon_a}$$

ΔR being change in resistance R due to axial strain ε_a, which is $\frac{\Delta L}{L}$.

With the application of mechanical strain, ρ, L and A may change as above. The corresponding expression for 'F' is derived as below:

$$\text{Change } \Delta R = \left(\frac{\partial R}{\partial L}\right)\Delta L + \left(\frac{\partial R}{\partial A}\right)\Delta A + \left(\frac{\partial R}{\partial \rho}\right)\Delta \rho.$$

Substituting the expressions for derivatives

$$\Delta R = \left(\frac{\rho}{A}\right) \Delta L - \left(\frac{\rho L}{A^2}\right) \Delta A + \left(\frac{\rho}{A}\right) \Delta \rho$$

Dividing by expression for R from Eq. (4.20),

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} - \frac{\Delta A}{A} + \frac{\Delta \rho}{\rho}$$

Area $A = CB^2$, where B is geometrical dimension of the strain gauge cross-section, an
C is a constant whose value depends on the section, equal to $\pi/4$ for circula
section of diameter 'B' and 1 for square section of sides 'B' each.

$$\Delta A = 2CB\Delta B$$

or

$$\frac{\Delta A}{A} = \frac{2CB\Delta B}{CB^2} = \frac{2\Delta B}{B}$$

Thus,

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} - 2\frac{\Delta B}{B} + \frac{\Delta \rho}{\rho}$$

$$= \varepsilon_a - 2\varepsilon_t + \frac{\Delta \rho}{\rho},$$

ε_a being axial strain $= \dfrac{\Delta L}{L}$

ε_t being transverse strain $= -\nu\varepsilon_a$,

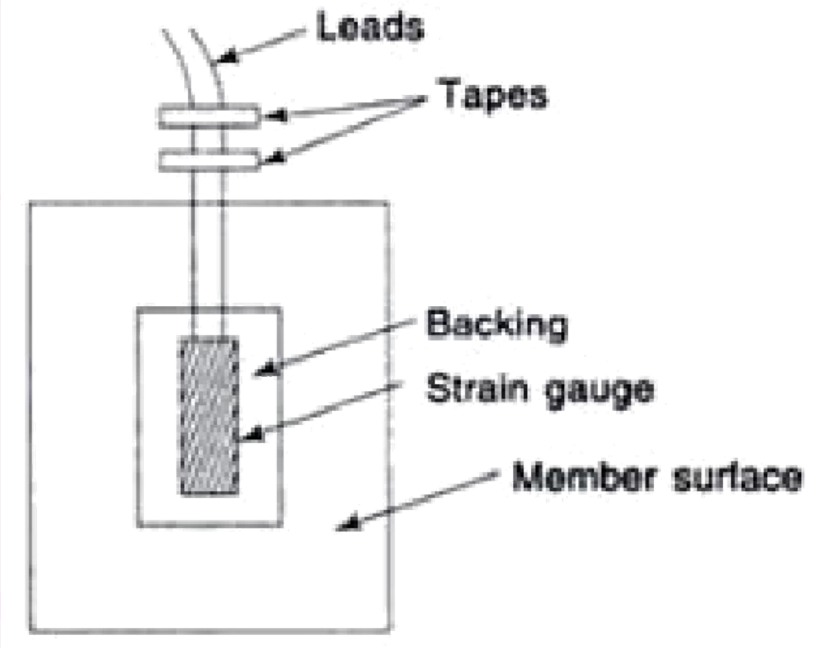
γ is Poisson's ratio.

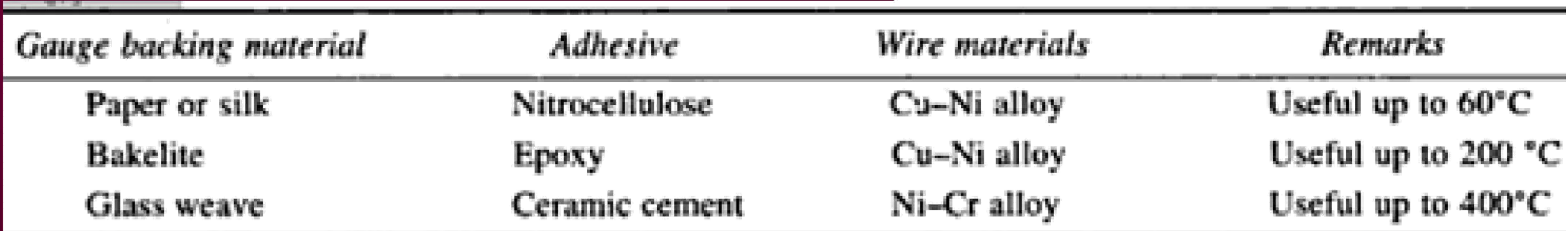
Finally,

$$F = \frac{\frac{\Delta R}{R}}{\varepsilon_a} = 1 + 2\gamma + \frac{\frac{\Delta \rho}{\rho}}{\varepsilon_a}$$

Bonded Resistance Strain Gauges

- Used for measurement of variable like strain, force, torque, pressure, vibration, etc.
- Metallic or semiconductor materials.
- Very sensitive and used in electronic equipment.
- Strains as low as 10^{-7} can be measured.
- Gauge current is limited to 10 – 30 mA

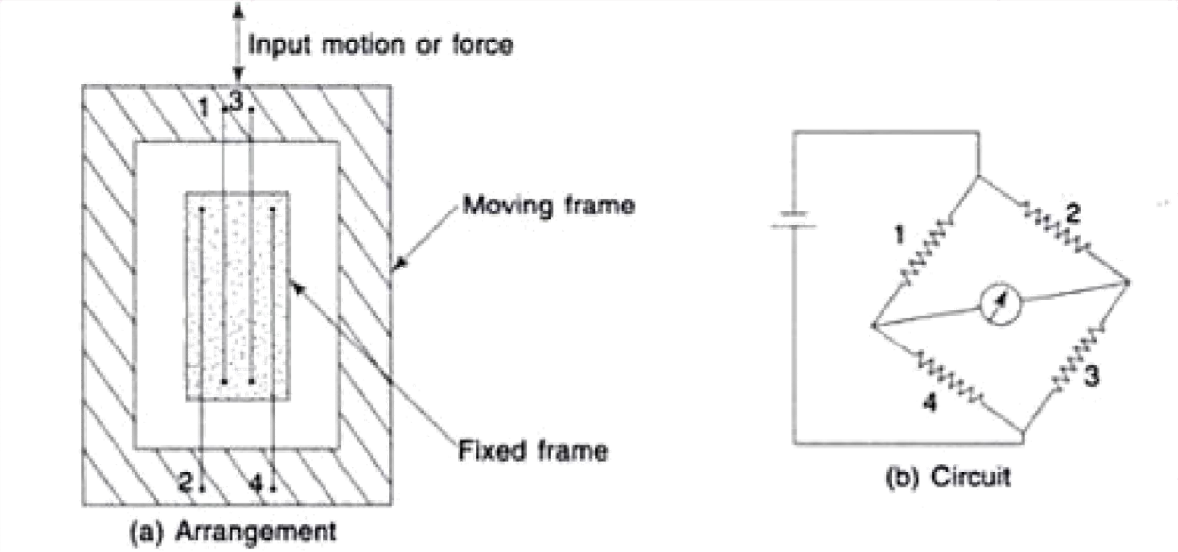




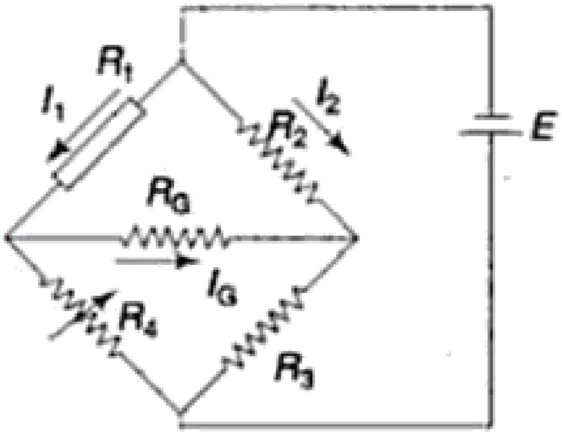
Gauge backing material	*Adhesive*	*Wire materials*	*Remarks*
Paper or silk	Nitrocellulose	Cu–Ni alloy	Useful up to 60°C
Bakelite	Epoxy	Cu–Ni alloy	Useful up to 200 °C
Glass weave	Ceramic cement	Ni–Cr alloy	Useful up to 400°C

Un-bonded Resistance Strain Gauges

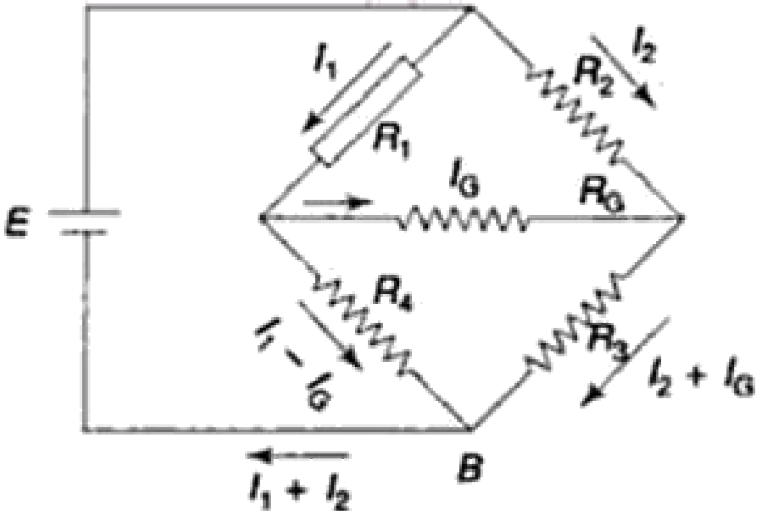
- Resistance wire is stretched between two frames, one moving and other is fixed.
- Typical dimensions of wire are 25 mm in length and 25 µm in diameter.
- Can measure very small motions of the order of 50µm and very small forces.
- Used to measure force, pressure, acceleration, etc.



Balancing of Strain Gauge Bridge Circuit



Balanced strain gauge



Unbalanced strain gauge bridge

The condition for balance is

$$\frac{R_1}{R_4} = \frac{R_2}{R_3}$$

$$I_1R_1 + R_4(I_1 - I_G) = E$$

$$I_1R_1 + I_GR_G - I_2R_2 = 0$$

$$I_GR_G + (I_2 + I_G)R_3 - (R_1 - I_G)\ R_4 = 0$$

$$I_G = \frac{E(R_2R_4 - R_1R_3)}{R_2(R_1 + R_4)(R_G + R_3 + R_4) + R_1R_3R_4 - R_2R_4^2 + R_GR_3(R_1 + R_4)}$$

Taking a special case when $R_1 = R_2 = R_3 = R_4$ and if R_1 changes to $R_1 + \Delta R_1$,

$$I_G = \frac{-E\Delta R_1}{4R_1(R_1 + R_G)}$$

$$= \frac{-EF\varepsilon_1}{4(R_1 + R_G)}$$

where ε_1 is the strain which causes ΔR_1, and

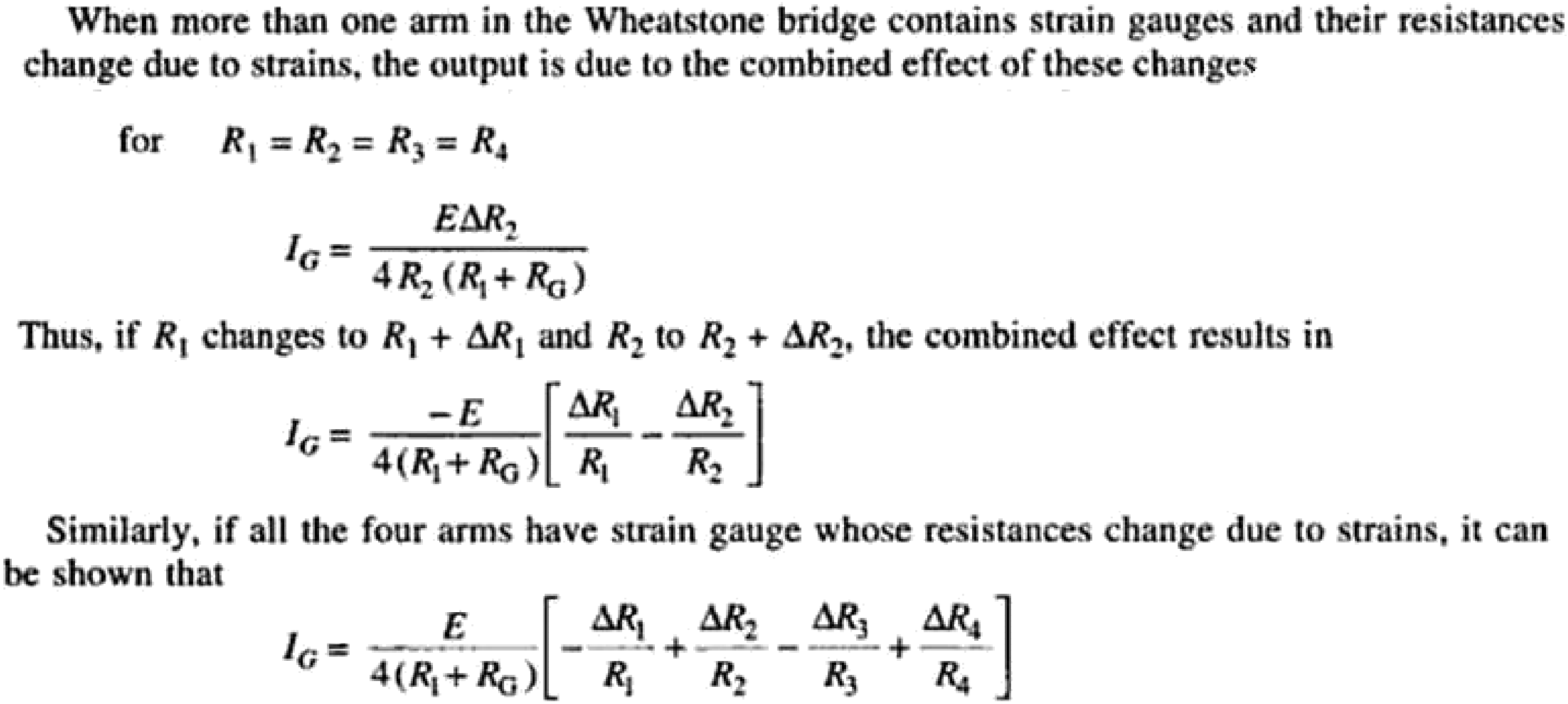
$$\varepsilon_1 = \frac{\Delta R_1}{R_1 F}$$

F being the gauge factor of the strain gauge. Voltage output across $R_G = E_o = I_G R_G$

$$= \frac{-E\varepsilon_1 R_G F}{4(R_1 + R_G)}$$

Open circuit voltage output = $E_o' = \dfrac{-EF\varepsilon_1}{4}$

This is obtained by letting $R_G \rightarrow \infty$



When more than one arm in the Wheatstone bridge contains strain gauges and their resistances change due to strains, the output is due to the combined effect of these changes

for $R_1 = R_2 = R_3 = R_4$

$$I_G = \frac{E\Delta R_2}{4R_2(R_1 + R_{\mathrm{G}})}$$

Thus, if R_1 changes to $R_1 + \Delta R_1$ and R_2 to $R_2 + \Delta R_2$, the combined effect results in

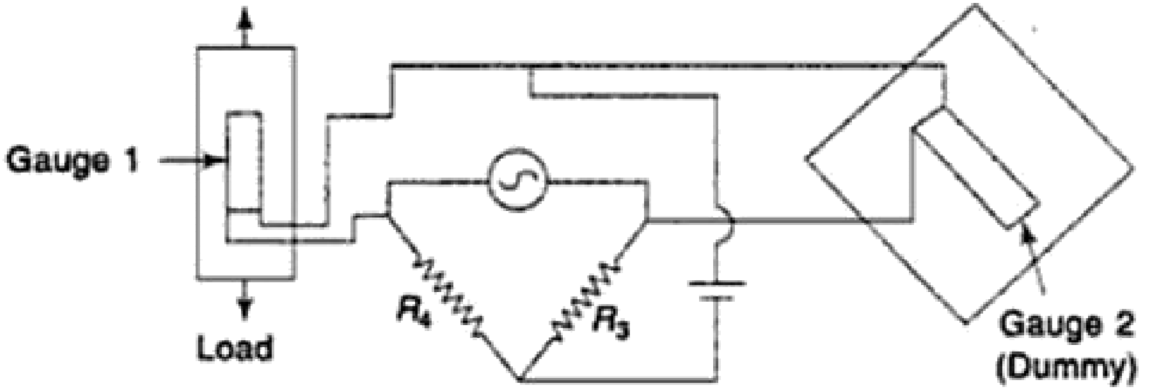
$$I_G = \frac{-E}{4(R_1 + R_{\mathrm{G}})}\left[\frac{\Delta R_1}{R_1} - \frac{\Delta R_2}{R_2}\right]$$

Similarly, if all the four arms have strain gauge whose resistances change due to strains, it can be shown that

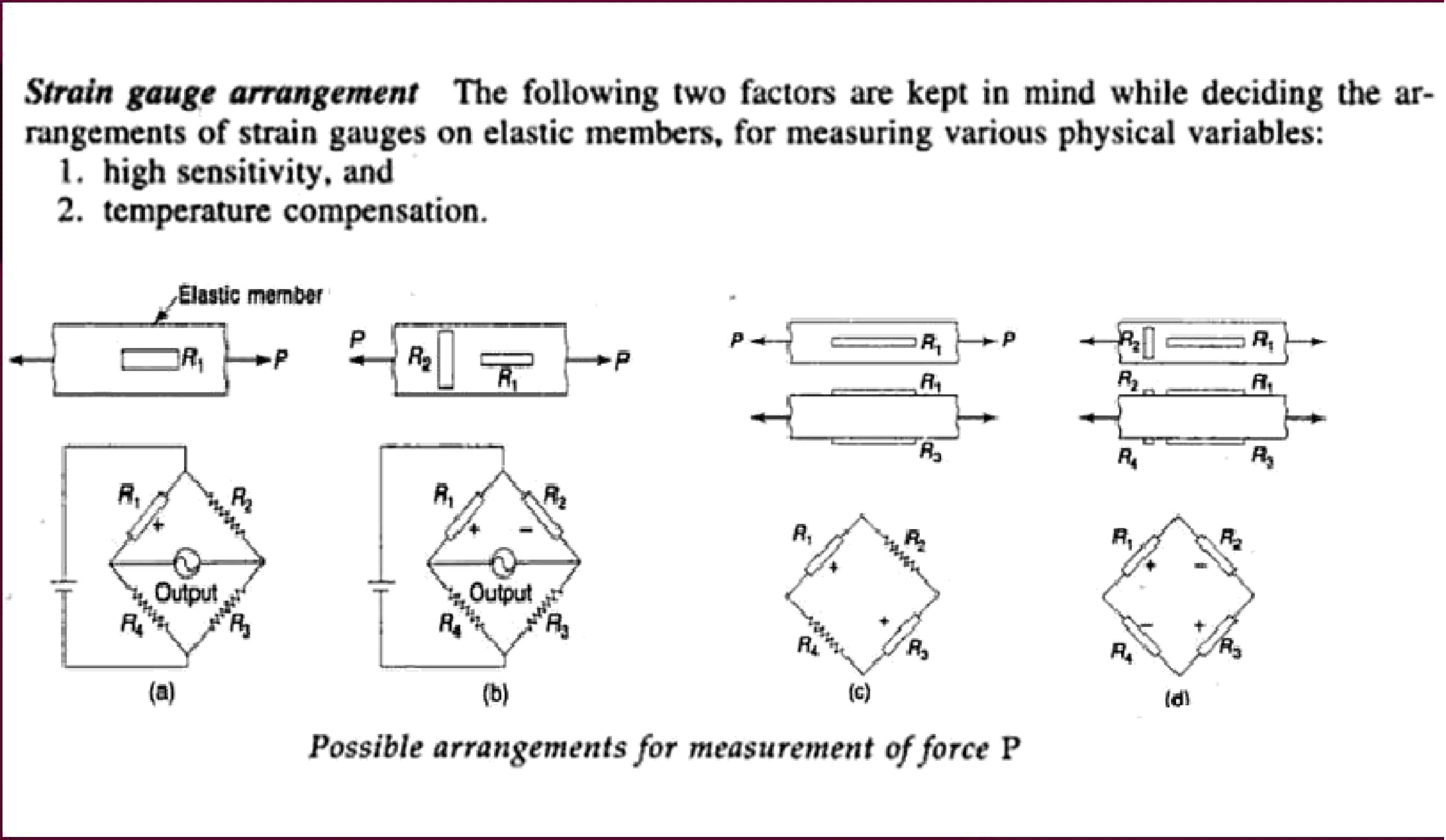
$$I_G = \frac{E}{4(R_1 + R_{\mathrm{G}})}\left[-\frac{\Delta R_1}{R_1} + \frac{\Delta R_2}{R_2} - \frac{\Delta R_3}{R_3} + \frac{\Delta R_4}{R_4}\right]$$

Temperature compensation In addition to strain, temperature change would also change the resistance of a resistance strain gauge. Since it is inconvenient to calculate and apply temperature correction, temperature compensation is made in the experimental set-up itself. This is done by (a) using a dummy gauge or by (b) using more than one active gauge, with proper arrangement of the gauges.

Temperature compensation is necessary when static strains are to be measured. Since a change of temperature causes only a drift in the output signals as such changes are normally slow, for measurement of dynamic strains, temperature compensation is not necessary.



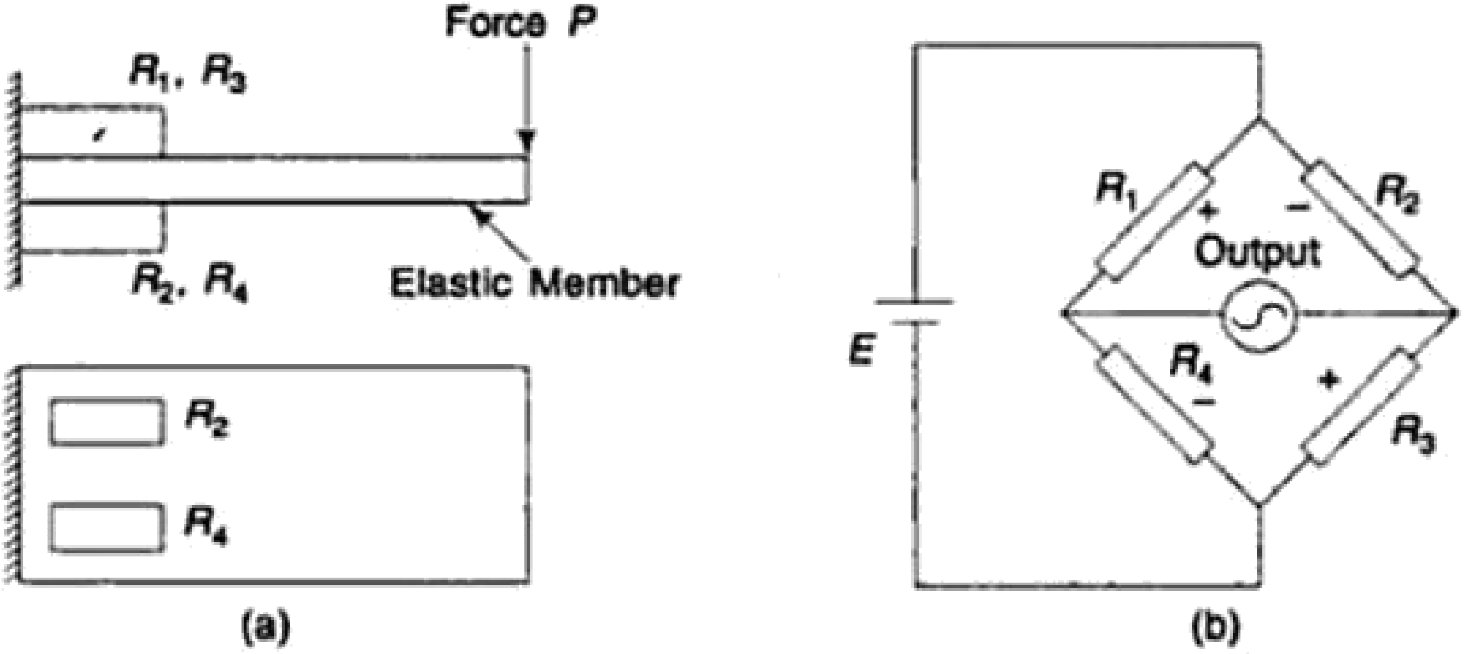
Temperature compensation with a dummy gauge



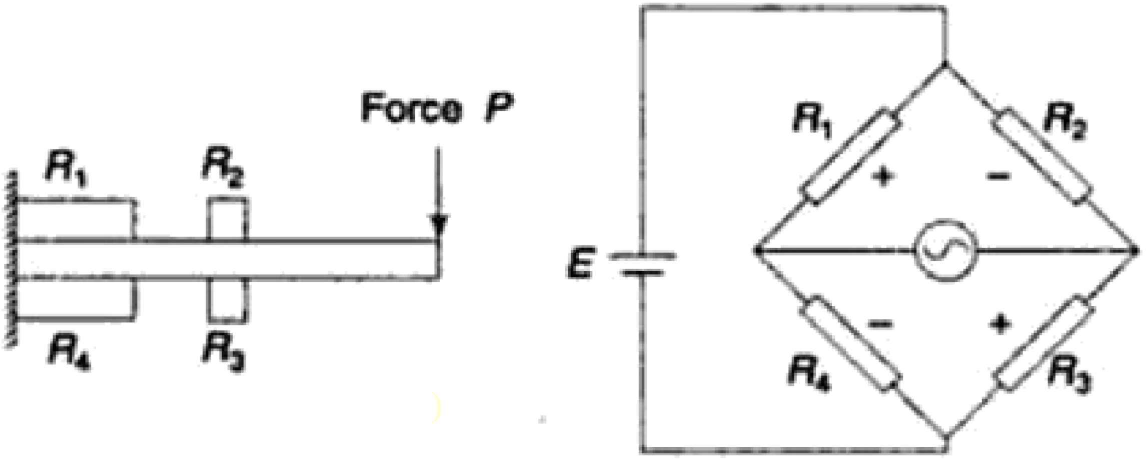
Strain gauge arrangement The following two factors are kept in mind while deciding the arrangements of strain gauges on elastic members, for measuring various physical variables:

1. high sensitivity, and
2. temperature compensation.

Possible arrangements for measurement of force P



Strain gauge arrangement for measuring force P



Alternative arrangement