ELECTRONIC MEASUREMENT & INSTRUMENTATION
(BEC-29)

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UNIT- 2

Lecture-3

Transducers

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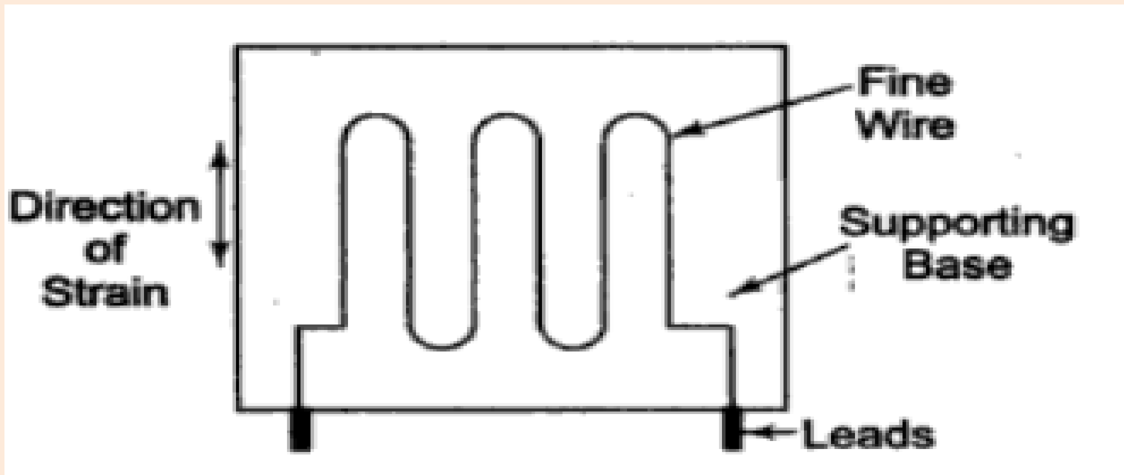
Strain Gauges

- A fine wire element is bounded back and forth, which is usually cemented on the member undergoing stress. The grid of fine wire is cemented on a carrier which may be a thin sheet of paper, bakelite or teflon.



- A tensile stress tends to elongate on the wire and thereby increase its length and decrease its cross-sectional area. The combined effect is increase in resistance.

$$R = \frac{\rho \times l}{A}$$

where ρ = the specific resistance of the material in Ωm

l = the length of the conductor in m

A = the area of the conductor in m^2

Contd..

As a result of strain, two physical parameters are of particular interest.

1. The change in gauge resistance.
2. The change in length.

The measurement of the sensitivity of a material to strain is called the gauge factor (GF). It is the ratio of the change in resistance $\Delta R/R$ to the change in the length $\Delta l/l$

i.e. $$\text{GF}(K) = \frac{\Delta R/R}{\Delta l/l} \tag{13.1}$$

where K = gauge factor

ΔR = the change in the initial resistance in Ω's

R = the initial resistance in Ω (without strain)

Δl = the change in the length in m

l = the initial length in m (without strain)

Contd..

Since strain is defined as the change in length divided by the original length,

i.e. $$\sigma = \frac{\Delta l}{l}$$

Eq. (13.1) can be written as

$$K = \frac{\Delta R / R}{\sigma} \qquad (13.2)$$

where σ is the strain in the lateral direction.
The resistance of a conductor of uniform cross-section is

$$R = \rho \frac{\text{length}}{\text{area}}$$

$$R = \rho \frac{l}{\pi r^2}$$

Since $$r = \frac{d}{2} \quad \therefore \quad r^2 = \frac{d^2}{4}$$

$$\therefore \quad R = \rho \frac{l}{\pi d^2 / 4} = \rho \frac{l}{\pi / 4\, d^2} \qquad (13.3)$$

where ρ = specific resistance of the conductor

l = length of conductor

Contd..

When the conductor is stressed, due to the strain, the length of the conductor increases by Δl and the simultaneously decreases by Δd in its diameter. Hence the resistance of the conductor can now be written as

$$R_s = \rho \frac{(l+\Delta l)}{\pi/4(d-\Delta d)^2} = \frac{\rho(l+\Delta l)}{\pi/4(d^2-2d\,\Delta d+\Delta d^2)}$$

Since Δd is small, Δd^2 can be neglected

$$\therefore \qquad R_s = \frac{\rho(l+\Delta l)}{\pi/4(d^2-2d\,\Delta d)}$$

$$= \frac{\rho(l+\Delta l)}{\pi/4d^2\left(1-\frac{2\Delta d}{d}\right)} = \frac{\rho l(1+\Delta l/l)}{\pi/4d^2\left(1-\frac{2\Delta d}{d}\right)} \qquad (13.4)$$

Now, Poisson's ratio μ is defined as the ratio of strain in the lateral direction

Contd..

to strain in the axial direction, that is,

$$\mu = \frac{\Delta d/d}{\Delta l/l} \tag{13.5}$$

$$\therefore \quad \frac{\Delta d}{d} = \mu \frac{\Delta l}{l} \tag{13.6}$$

Substituting for $\Delta d/d$ from Eq. (13.6) in Eq. (13.4), we have

$$R_s = \frac{\rho l\,(1 + \Delta l/l)}{(\pi/4)\,d^2\,(1 - 2\mu\Delta l/l)}$$

Rationalising, we get

$$R_s = \frac{\rho l\,(1 + \Delta l/l)}{(\pi/4)\,d^2\,(1 - 2\mu\Delta l/l)} \frac{(1 + 2\mu\Delta l/l)}{(1 + 2\mu\Delta l/l)}$$

$$\therefore \quad R_s = \frac{\rho l}{(\pi/4)\,d^2}\left[\frac{(1 + \Delta l/l)}{(1 - 2\mu\Delta l/l)} \frac{(1 + 2\mu\Delta l/l)}{(1 + 2\mu\Delta l/l)}\right]$$

$$\therefore \quad R_s = \frac{\rho l}{(\pi/4)\,d^2}\left[\frac{1 + 2\mu\Delta l/l + 2\Delta l/l + 2\mu\,\Delta l/e\,\Delta l/l}{1 - 4\mu^2\,(\Delta l/l)^2}\right]$$

$$\therefore \quad R_s = \frac{\rho l}{(\pi/4)\,d^2}\left[\frac{1 + 2\mu\Delta l/l + \Delta l/l + 2\mu\Delta l^2/l^2}{1 - 4\mu^2\Delta l^2/l^2}\right]$$

Since Δl is small, we can neglect higher powers of Δl.

$$\therefore \quad R_s = \frac{\rho l}{(\pi/4)\,d^2}\,[1 + 2\,\mu\,\Delta l/l + \Delta l/l]$$

Contd…

$$\therefore \quad R_s = \frac{\rho l}{(\pi/4)\, d^2}\,[1 + 2\,\mu\,\Delta l/l + \Delta l/l]$$

$$R_s = \frac{\rho l}{(\pi/4)\, d^2}\,[1 + (2\,\mu + 1)\,\Delta l/l]$$

$$R_s = \frac{\rho l}{(\pi/4)\, d^2}\,[1 + (1 + 2\,\mu)\,\Delta l/l]$$

$$\therefore \quad R_s = \frac{\rho l}{(\pi/4)\, d^2} + \frac{\rho l}{(\pi/4)\, d^2}\,(\Delta l/l)\,(1 + 2\,\mu)$$

Since from Eq. (13.3), $R = \dfrac{\rho l}{(\pi/4)\, d^2}$

$$\therefore \quad R_s = R + \Delta R \tag{13.7}$$

where $\Delta R = \dfrac{\rho l}{(\pi/4)\, d^2}\,(\Delta l/l)\,(1 + 2\,\mu)$

∴ The gauge factor will now be

$$K = \frac{\Delta R/R}{\Delta l/l} = \frac{(\Delta l/l)(1 + 2\mu)}{\Delta l/l}$$

$$= 1 + 2\,\mu$$

$$\therefore \quad K = 1 + 2\,\mu \tag{13.8}$$

Assignment Questions

- Define strain gauge. Define gauge factor.
- Define the operation and construction of strain gauge.
- State the limitations of strain gauge.
- Explain how temperature compensation can be achieved using strain gauge.
- Explain with diagram the working of a resistance wire gauge.

Conceptual Questions

- Strain gauge is a __________
  a) inductive transducer
  b) resistive transducer
  c) capacitive transducer
  d) mechanical transducer
- Strain is defined as __________
  a) change in height per unit height
  b) change in weight per unit weight
  c) change in length per unit length
  d) change in diameter per unit diameter
- Electrical strain gauge works on the principle of
  ____
  a) variation of resistance
  b) variation of capacitance
  c) variation of inductance
  d) variation of area

Contd..

- Bonding element in a strain gauge must have ___________
  a) zero insulation resistance
  b) low insulation resistance
  c) high insulation resistance
  d) infinite insulation resistance
- Dynamic strain measurements use ___________
  a) brass iron alloy
  b) iron aluminium alloy
  c) nickel cadmium alloy
  d) nickel chromium alloy
- Commonly used elements for wire strain gauges are ___________
  a) nickel and copper
  b) nickel and gold
  c) gold and brass
  d) silver and aluminum

THANK YOU