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INSTITUTE OF

TECHNOLOGY

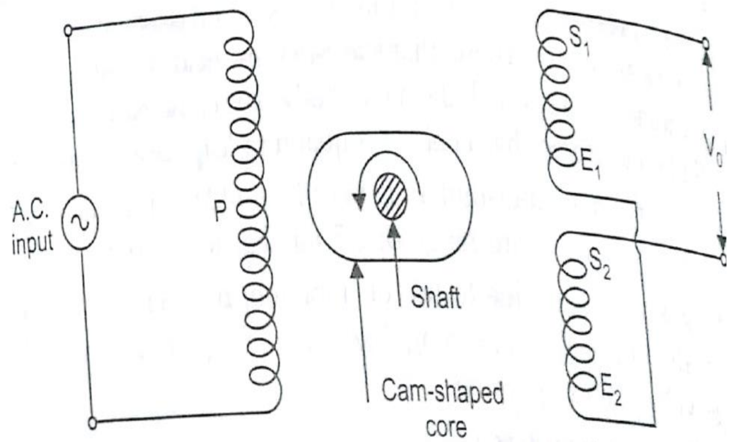
USN

Internal Assesment Test - I					
Sub:	SENSORS & TRANSDUCERS			Code:	15EE562
Date:	20/04/2019	Duration: 90 mins	Max Marks: 50	Sem: 6	Branch: EEE
Answer FIVE FULL Questions. Mention units wherever necessary.					

	Question	Marks	OBE CO	OBE RBT
1.	Derive the gauge factor of a single uniform length of a conductor	[10]	CO2	L3
2.	Obtain the mathematical expression for the output voltage of strain gauges using wheat stone bridge for, (i) Quarter bridge (ii) Full bridge.	[10]	CO2	L3
3.	(a) Describe a general measurement system with neat block diagram and hence explain signal conditioning & its necessity.	[06]	CO3	L2
	(b) Define load cell. Explain briefly hydraulic load cell	[04]	CO2	L3
4.	With a neat diagram explain the operation of pneumatic proximity sensor & digital encoder.	[10]	CO2	L4
5.	Explain the following with neat diagram i) RVDT ii) Synchros iii) MEMS switch	[10]	CO3	L4
6.	State the characteristics of an ideal op-amp for (i) adder amplifier (ii) differential amplifier (iii) buffer amplifier	[10]	CO3	L2
7.	A simple electrical strain gauge of resistance 120 ohms and having a gauge factor of 2 is bonded to steel having an elastic limit stress of 400MN/m^2 & modulus of elasticity is 200 GN/ m^2 . calculate the change in resistance, i) Due to change in stress equal to 1/10 of the elastic range. ii) Due to change of temperature of 20^{o}C if the material is advance alloy. The resistance temperature co-efficient of advance alloy is 20x10^{-6}/^{o}C	[10]	CO2	L3

5. i) RVDT

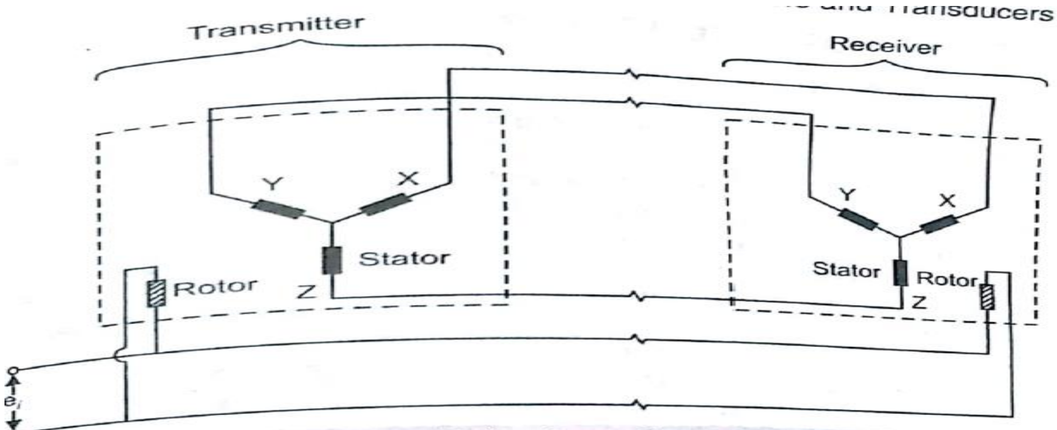
- Measurement of angular displacements. it converts angular displacements to electrical signal.
- Operating principle is similar to LVDT.
- The only difference is core is cam shaped & rotated inside the windings through a shaft.
- The core is rotated in clockwise & anticlockwise directions w.r.t the null position.
- Core rotates at clockwise- voltage increases.
- Core rotates at anticlockwise- voltage increases.



P = Primary winding ; S_1, S_2 = Secondary windings;
E_1, E_2 = Induced e.m.fs ; V_0 = Output voltage.

ii**) Synchros**

- Rotor is wound with a single phase concentrated winding.
- Stator with three-phase distributed windings in a Y configuration.
- The rotor is excited with an AC supply, an mutual induction takes place between them, v/g’s are induced in the stator coils.
- Magnitude of voltage depends on the angular position of the rotor w.r.t the stator.



- Fig. 16.74. Practical set-up of a pair of synchros.

  iii) MEMS Switch

- Combine electrical & mechanical components like microsensors, microactuators & signal transduction elements.

- Devices range from micrometers to millimeters and can be fabricated from few to millions in a particular systems.
- MEMS are used to sense , control & activate mechanical processes on the microscale & function individually or in arrays.

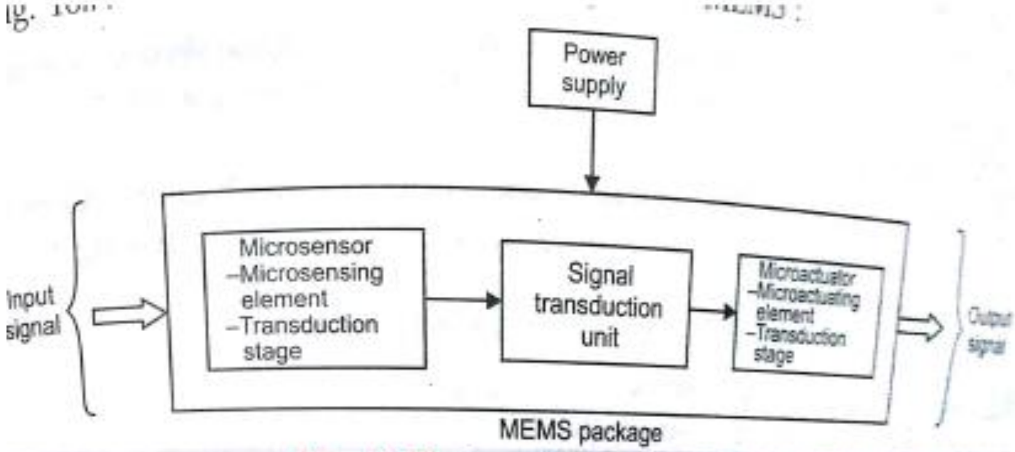


Fig. 16.77. General block diagram of MEMS.

Manufacturing of MEMS

1. Bulk micromachining
2. Surface micromachining
3. LIGA process

Advantages of MEMS

- Better stability & accuracy
- Manufactured on a large scale
- Can be miniaturized with other applications.
- Compact integration of comprehensive functionality.
- Can be designed for various signals.

1.

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Strain Gauges

when a strain Gauge is subjected to tension, its length ↑ while its cross-sectional area ↓.

$$\therefore R \propto \frac{L}{A}$$

Increases the positive strain.

The change in the value of resistance of strained conductor is more than what can be accounted for an increase in resistance due to dimensional changes.

The extra change in the value of resistance is attributed to a change in the value of resistivity of a conductor when strained.

strain Gauges are most commonly used in wheatstone bridge circuits to measure the change of resistance of grid of wire for calibration purposes.

The Gauge factor is defined as the ratio of per unit change in resistance to per unit change in length

$$\text{Gauge factor } (G_f) = \frac{\Delta R/R}{\Delta L/L}$$

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

A = Cross sectional area of the wire
$= KD^2$, K & D being a constant & diameter of the wire respectively.

when the wire is strained, its length ↑ & lateral dimension is ↓ as a f'n of poisson's ratio (m)

There is an increase in resistance.

$$R = \frac{\rho L}{K D^2}$$

$$dR = \frac{KD^2 [\rho\, dL + L\, d\rho) - \rho L (2 K D . dD)}{(KD^2)^2}$$

$$\frac{dR}{R} = \frac{\frac{1}{KD^2}[\rho . dL + L . d\rho - 2\rho L . \frac{dD}{D})}{\frac{\rho L}{KD^2}}$$

$$= \frac{dL}{L} + \frac{d\rho}{\rho} - 2\frac{dD}{D}$$

possion's ratio μ = $\frac{\text{lateral strain}}{\text{longitudinal strain}} = \frac{-dD/D}{dL/L}$

$$\frac{dD}{D} = -\mu \times \frac{dL}{L}$$

For small variations,

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

Gauge Factor, $G_f = \frac{\Delta R/R}{\Delta L/L}$

$$\frac{\Delta R}{R} = G_f . \frac{\Delta L}{L} = G_f \times e$$

e = strain $= \frac{\Delta L}{L}$

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The Gauge factor can be written as,

$$G_f = 1 + 2\mu + \frac{\Delta\rho/\rho}{\epsilon}$$

= Resistance change due to change of length + Resistance change due to change in area + Resistance change due to piezo-resistive effect.

The strain is usually expressed in terms of microstrain:

1 micro strain = 1 $\mu m/m$

If the change in the value of resistivity of a material is neglected, the G.f can be written as

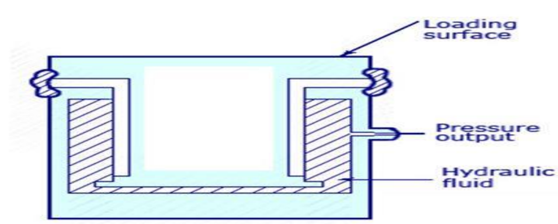
$$G_f = 1 + 2\mu$$

Eq'n is valid only when piezo-resistive effect is almo[st] negligible.

2. B) A load cell is a transducer that is used to convert a force into electrical signal.
   Load cell uses an elastic member as the primary transducer and strain gauges as secondary transducers, this combination used for weighing known as load cell
   Hydraulic Load Cell
   The liquid medium contained in a confined space has a pressure of 2 bar.
   On the application of the force the liquid pressure increases and equals the force magnitude divided by the effective area of the diaphragm.
   The pressure transmitted to and read on an accurate gauge calibrated directly on the force unit.
   These cells can be used to measure load upto 25MN with an accuracy of 0.1% & resolution of about 0.02%.

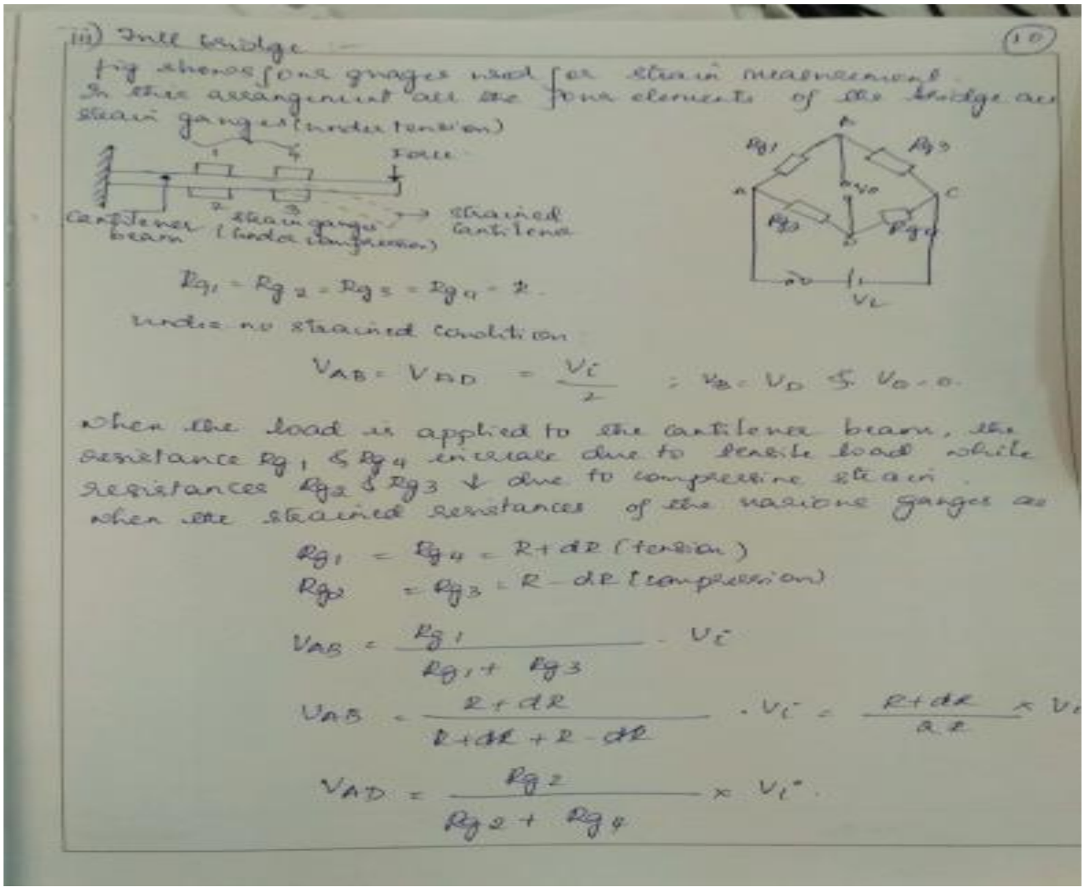
Mechanical Load Cell

Hydraulic load cells are force balance-devices, measuring weight as a change in pressure of the internal filling fluid. It is ideal for use in hazardous areas as there are no any electrical component in it.



Hydraulic Load Cell
www.InstrumentationToday.com

3. i)Full bridge



(iii) Full bridge

Fig shows four gauges used for strain measurement. In this arrangement all the four elements of the bridge are strain gauges (under tension)

$R_{g1} = R_{g2} = R_{g3} = R_{g4} = R$.

under no strained condition

$$V_{AB} = V_{AD} = \frac{V_i}{2} \; ; \; V_B = V_D \;\&\; V_o = 0.$$

When the load is applied to the cantilever beam, the resistance R_{g1} & R_{g4} increase due to tensile load while resistances R_{g2} & R_{g3} ↓ due to compressive strain. when the strained resistances of the various gauges are

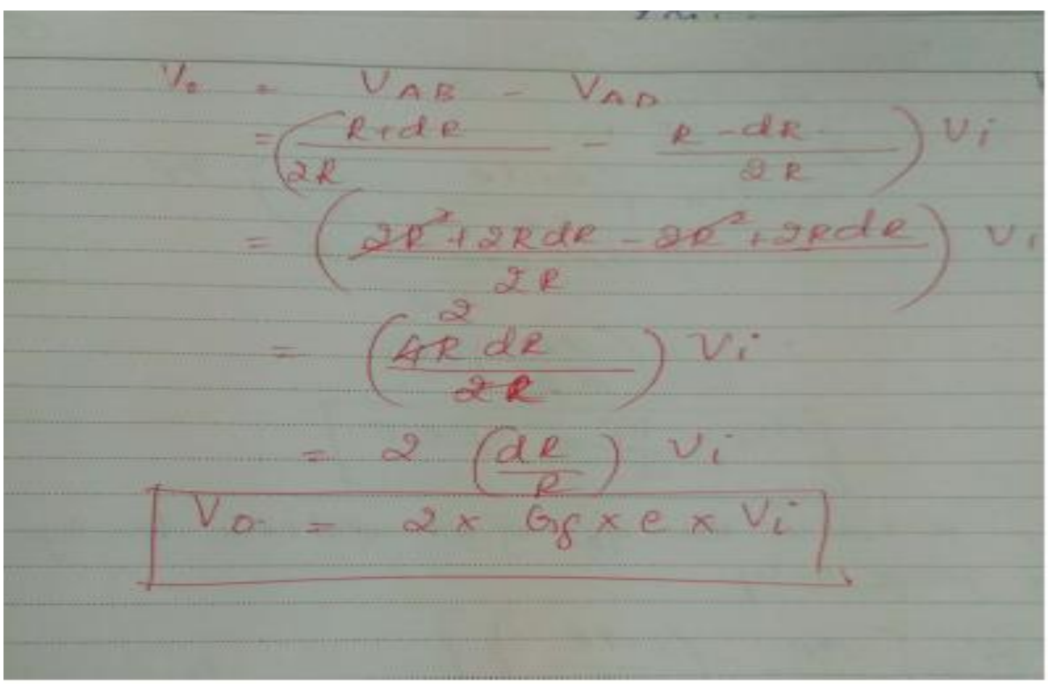
$R_{g1} = R_{g4} = R + dR$ (tension)

$R_{g2} = R_{g3} = R - dR$ (compression)

$$V_{AB} = \frac{R_{g1}}{R_{g1} + R_{g3}} \cdot V_i$$

$$V_{AB} = \frac{R + dR}{R + dR + R - dR} \cdot V_i = \frac{R + dR}{2R} \times V_i$$

$$V_{AD} = \frac{R_{g2}}{R_{g2} + R_{g4}} \times V_i.$$



$$V_o = V_{AB} - V_{AD}$$

$$= \left(\frac{R + dR}{2R} - \frac{R - dR}{2R}\right) V_i$$

$$= \left(\frac{2R^2 + 2RdR - 2R^2 + 2RdR}{2R^2}\right) V_i$$

$$= \left(\frac{4R\,dR}{2R^2}\right) V_i$$

$$= 2\left(\frac{dR}{R}\right) V_i$$

$$\boxed{V_o = 2 \times G_f \times e \times V_i}$$

i) Quarter Bridge

i) Quarter bridge.

Fig shows single gauge used for strain measurement. Single gauge is used & other three elements of the bridge as fixed resistor.

Current flowing through limbs AB & BC, $I_1 = \frac{V_i}{R_{g1}+R_3}$

$$V_{AB} = I_1 \cdot R_{g1}$$

$$= \frac{V_i}{R_{g1}+R_3} \cdot R_{g1}. \qquad \text{IIIly } I_2 = \frac{V_i}{R_2+R_4}$$

$$V_{AD} = \frac{R_2}{R_2+R_4} \times V_i.$$

$$R_{g1} = R_2 = R_3 = R_4 = R.$$

$$V_{AB} = V_{AD} = \frac{V_i}{2}$$

$$V_0 = V_{AB} - V_{AD} = 0.$$

When the bridge is strained, unbalancing happens.

$$V_{AB} = \left[\frac{R_{g1}+dR_{g1}}{(R_{g1}+dR_{g1})+R_3}\right] V_i = \left(\frac{R+dR}{2R+dR}\right) V_i$$

$$V_{AD} = \left(\frac{R_2}{R_2+R_4}\right) V_i = \frac{V_i}{2}$$

The change in V_0,

$$V_0 + dV_0 = \left(\frac{R+dR}{2R+dR} - \frac{1}{2}\right) V_i.$$

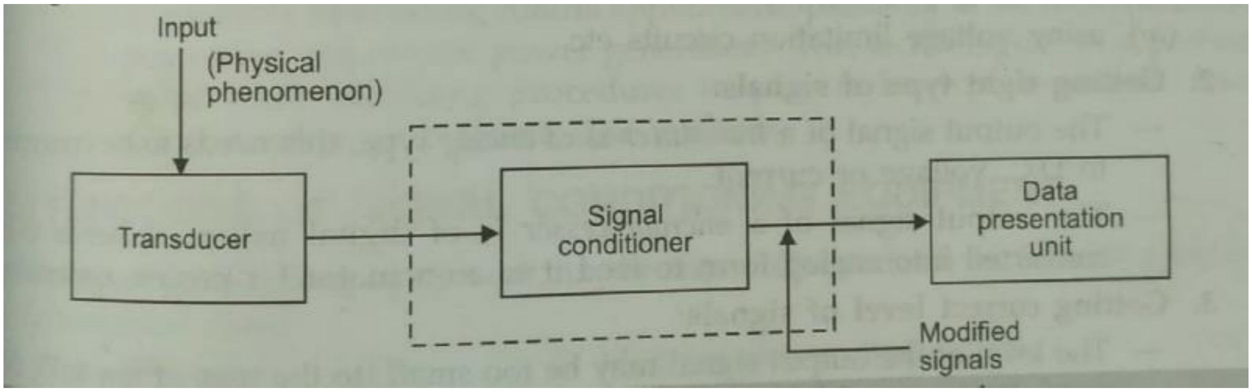
$$= \left(\frac{2R + 2dR - 2R - dR}{4R+2dR}\right) V_i$$

$$= \left(\frac{dR}{4R+2dR}\right) V_i.$$

$$= \frac{dR}{4R} \cdot V_i.$$

$$dV_0 = \left(\frac{G_f}{4}\right) e \cdot V_i$$

3.a) General measurement system

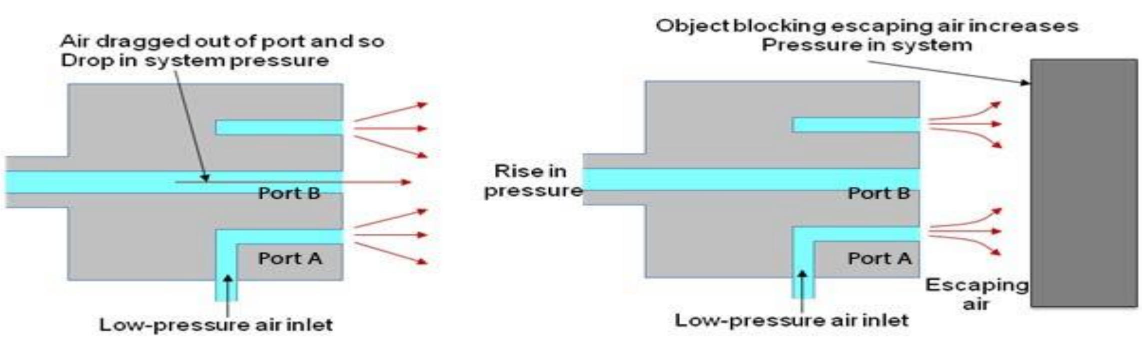


Signal Conditioning & its necessity:

1. Signal may be too noisy due to Electromagnetic Interferences.
2. Signal may be Small.
3. Signal may be Non-linear & require to be converted into digital form.
4. Signal may be Analog one and converted to digital form.
5. Signal may be Digital one and may be converted to analog one.

4. Pneumatic sensors are used to measure the displacement as well as to sense the proximity of an object close to it.
   These sensors involve the use of

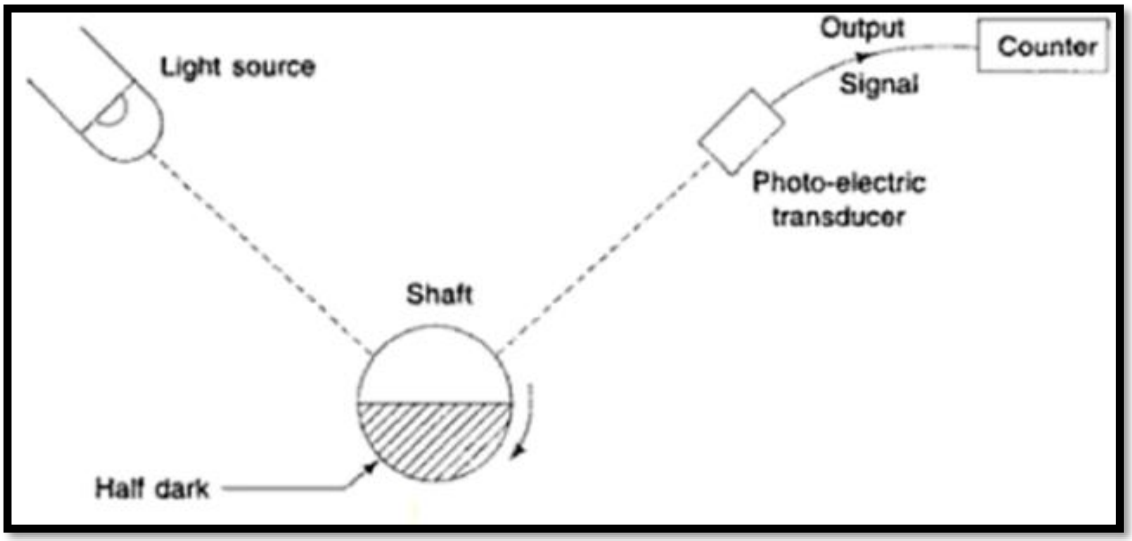
- Compressed air
- Displacement or proximity of an object beoing transformed into a change in air pessure
- The displacement and proximity are transformed into change in air pressure.
- Fig shows a schematic of construction and working of such a sensor. It comprises of three ports. Low pressure air is allowed to escape through port A. In the absence of any obstacle / object, this low pressure air escapes and in doing so, reduces the pressure in the port B.
- when an object obstructs the low pressure air (Port A), there is rise in pressure in output port B. This rise in pressure is calibrated to measure the displacement or to trigger a switch.
- These sensors are used in robotics, pneumatics and for tooling in CNC machine tools.
- These sensors are used in measurement of the displacement of fractions of millimeters in ranges of about 3-12mm.



4. DIGITAL TRANSDUCERS

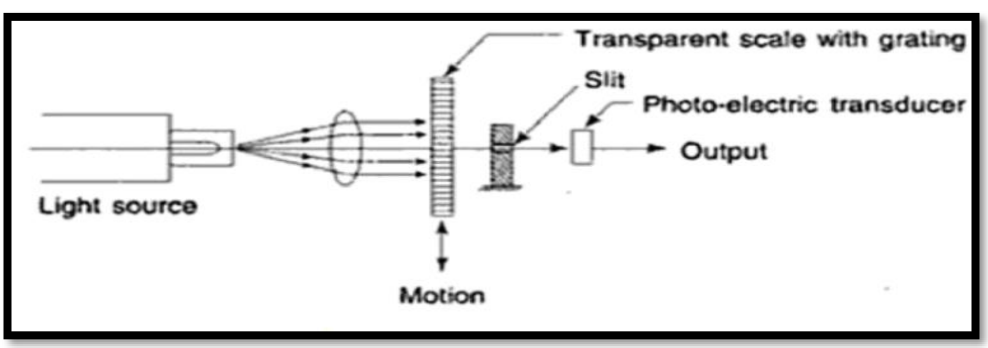
Used for both rotary and linear motion measurement.

- Shaft has half dark and half white or shining portion.
- When white portion is in front of light source, the light is reflected which falls on photo-electric transducer. It gives an electrical pulse output.
- Frequency of pulses is thus a measure of speed of rotation.



Digital encoder- Optic type encoder

- Linear motion measurement uses a transparent scale with a grating.
- Moving object is attached to transparent scale.
- Light from a source passes through the scale & a slit and then falls on photo-electric transducer.



7.

Solution. *Given:* $R = 120\ \Omega$; $G_f = 2$; Elastic limit stress = 400 MN/m^2; Modulus of elasticity = 200 GN/m^2; Resistance temperature coefficient, $\alpha_0 = 20 \times 10^{-6}/°C$.

Change in resistance:

(*i*)

$$\text{Change in stress} = \frac{1}{10} \times 400\ \text{MN/m}^2 = 40 \times 10^6\ \text{N/m}^2$$

$$\text{Modulus of elasticity} = 200\ \text{GN/m}^2 = 200 \times 10^9\ \text{N/m}^2$$

$$\text{Strain, } e = \frac{\text{Stress}}{\text{Modulus of elasticity}} = \frac{40\times10^6}{200\times10^9} = \frac{1}{5}\times10^{-3}$$

$$\text{Gauge factor } G_f = \frac{\text{Per unit change in resistance}}{\text{Per unit change in length}}$$

$$G_f = \frac{\Delta R / R}{e} \quad \text{or} \quad \Delta R = R\,G_f\,e$$

$$\Delta R = 120\times2\times\frac{1}{5}\times10^{-3} = 48 \times 10^{-3}\ \Omega = \mathbf{45\ m\Omega}\ \textbf{(Ans.)}$$

(*ii*)

$$R_{t2} = R_{t1}\,[1 + \alpha_0(t_2 - t_1)]$$

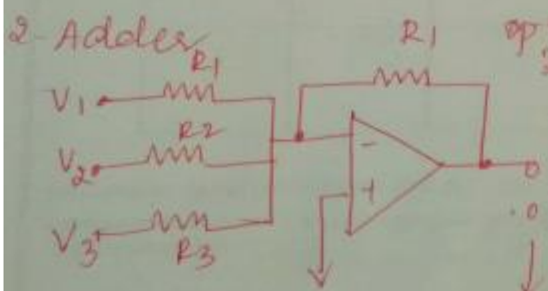
$\therefore$ Change in resistance $R_{t2} - R_{t1} = R_{t1}\,\alpha_0(t_2 - t_1)$

$$\Delta R = R_{t2} - R_{t1} = 120 \times 20 \times 10^{-6} \times (20)$$

$$= 48 \times 10^{-3}\ \Omega = \mathbf{48\ m\Omega}\ \textbf{(Ans.)}$$

6.

2 Adder



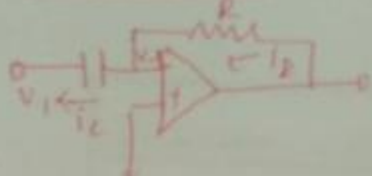
op amp performs with the signal that performs amp using superposition theorem

$$V_0 = -\left(\frac{R_f}{R_1} V_1 + \frac{R_f}{R_2} V_2 + \frac{R_f}{R_3} V_3\right)$$

$R_f = R_1 = R_2 = R_3$

$$V_0 = -(V_1 + V_2 + V_3)$$

Differentiator :-



by interchanging the position of R & C

At V_- node,

$i_c = i_R$

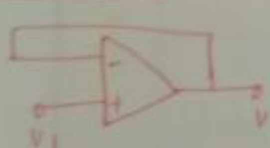
$$C\frac{d(V_- - V_1)}{dt} = \frac{V_0 - V_-}{R}$$

$$-C\frac{dV_1}{dt} = \frac{V_0}{R}$$

$$V_0 = -RC\frac{d(V_1)}{dt}$$

→ ↓ the signal to Noise ratio.

Buffer amplifier



Impedance transformer converts at high Z at same V/g to low Z.

The ckt of a unity gain buffer amplifier is called V/g follower

greatly ↓ the loading eff in measurement s/m