# UNIT-I

# SENSORS & TRANSDUCERS

## Measurement System

A system used for making measurements; it has the input as the quantity being measured and the output as a measured value of that quantity.

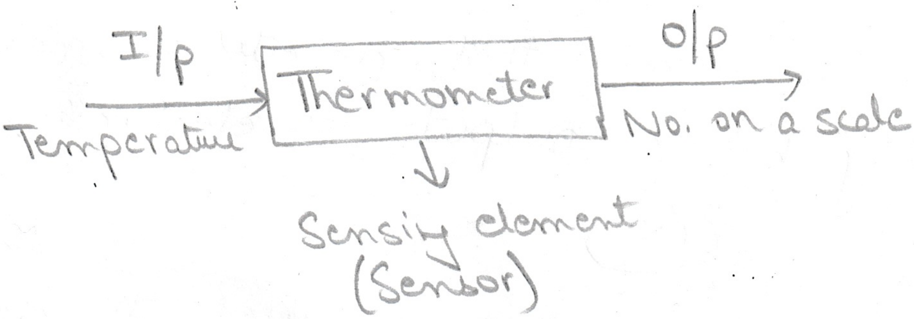



Fig1.: A measurement system

## Elements of Measurement Systems:

Measurement system consists of the following three elemen

a) Sensor
b) Signal Conditioner
c) Display System

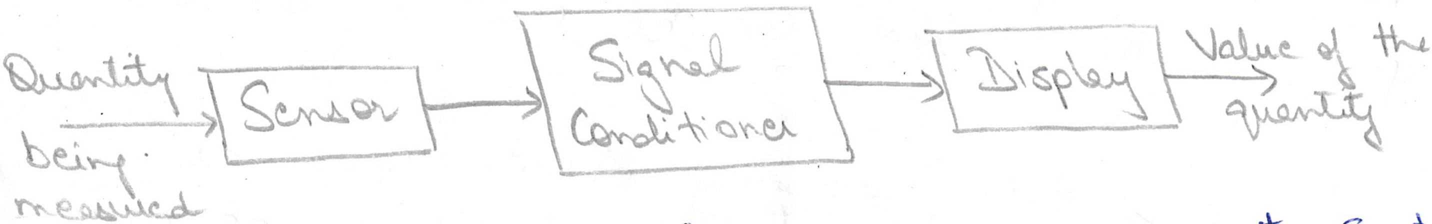



Fig2.: Elements of measurement system

# SENSOR

According to the Instrument Society of America, Sensor can be defined as " A device which provides a usable output in response to a specified measurand."

Here, the output is usually an electrical quantity and measurand is a physical quantity which is to be measure

OR

A sensor is a device that detects or measures a physical quantity whose output is electrical.

OR

A sensor is a device that is used to detect a parameter in one form and report it in another form of energy.

for eg. * A pressure sensor detect pressure (mechanical form of energy) and convert it to electricity for display at a remote gauge.

* A thermocouple converts temperature to an output voltage which can be read by a voltmet

Sensors are used in everyday objects such as touch-sensitive elevator buttons and lamps and many more.

## Classification of Sensors

Sensors can be classified as active or passive.

† An ~~passive~~ active sensor does not need any additional energy source and directly generates an electric signal in response to an external stimulus.

Eg. Thermocouple, photodiode, piezoelectric sensor.

† ~~An active~~ A passive sensor requires external power for their operation, which is called an excitation signal.

For eg., a thermistor is a temperature sensitive resistor. It does not generate any electric signal, but by passing an electric current through it (excitation signal), its resistance can be measured by detecting variations in current/voltage across the thermistor.

Eg. Resistive strain gauge; to measure the resistance of a sensor, electric current must be applied to it from an external power source.

## TRANSDUCERS

A transducer is a device that converts one type of energy to another. The conversion can be to/from electrical, electro-mechanical, electromagnetic, photovoltai[c] or any other form of energy.

While the term transducer commonly implies use as a sensor/detector, any device which converts energy can be considered a transducer.

A sensor differs from a transducer in the way that a transducer converts one form of energy into other form whereas a sensor converts the received signal into electrical form only.

## MEASUREMENT SYSTEM PERFORMANCE

The measurement system characteristics can be divided into two distinct categories viz:

i) Static Characteristics    ii) Dynamic characteristics

### Static Characteristics

Criteria when applications involve the measurement of quantities that are either constant or vary very slowly with time. Usually obtained by a process called static calibration.

The main static characteristics are:-

i) Accuracy :- It is the closeness with which an instrument reading approaches the true value of the quantity being measured.

ii) Precision :- It is a measure of the reproducibility of the measurements, i.e given a fixed value of a quantity, precision is a measure of the degree of agreement within a group of measurements.

iii) Sensitivity $^{D^*}$ :- It is the ratio of the magnitude of the output signal or response to the magnitude of the input signal or the quantity being measured. (3)

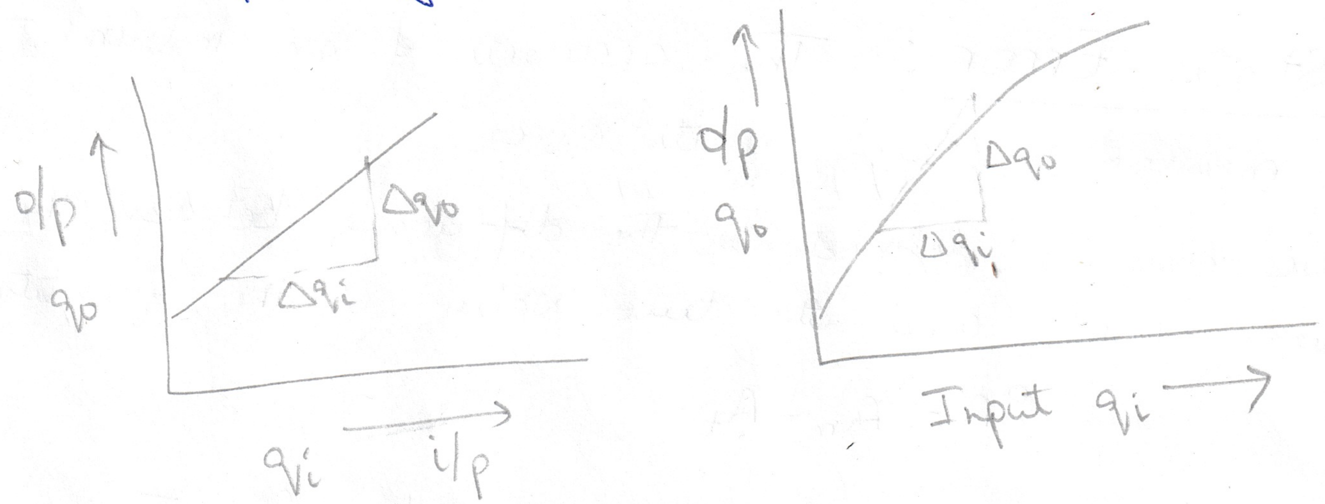



Fig 3: Definition of sensitivity

In general,

$$\text{Static sensitivity} = \frac{\text{infinitesimal change in o/p}}{\text{infinitesimal change in i/p}} = \frac{\Delta q_o}{\Delta q_i}$$

→ The sensitivity of an instrument should be high and therefore, the instrument should not have a range greatly exceeding the value to be measured.

iv) Reproducibility and Drift $^{D^*}$

Reproducibility : It is the degree of closeness with which a given value may be repeatedly measured. Perfect reproducibility means that the instrument has no drift. No drift means that with a given i/p the measured values do not vary with time.

Drift is an undesirable quality in industrial instruments because it is rarely apparent and cannot be easily compensated for.

v) <u>Static Error</u> : The accuracy of an instrument is measured in terms of its error.

Static error is defined as the difference between the measured value and the true value of the quantity.

$$\delta A = A_m - A_t$$

where $\delta A$ = error ; $A_m$ = measured value ; $A_t$ = True value

vi) <u>Dead Zone</u> : It is defined as the largest change of i/p quantity for which there is no o/p of the instrument.

The term 'dead zone' is sometimes used interchangeably with term hysteresis.

## Dynamic Characteristics

Meas$^m$ systems especially in aerospace, industrial are subjected to i/ps which are not static but dynamic in nature ie i/ps vary with time and so does the o/p. The behaviour of such system is described by dynamic response of system.

∴ the dynamic characteristics of any meas$^m$ system are :-

i) Speed of response :- It is the rapidity with which an instrument responds to changes in the measured quantity.

ii) Measuring Lag : The delay in the response of an instrument to a change in the measured quantity. This lag is usually quite small but it becomes highly important where high speed measurements are required.

iii) Fidelity : The ability of the system to reproduce the o/p in the same form as the input. Ideally, a system should have 100 percent fidelity and the o/p appears in the same form as the i/p and there is no distortion produced by the system.

v) Dynamic Error :- It is the difference b/w the true value of the quantity changing with time and the value indicated by the instrument if no static error is assumed.

# CLASSIFICATION OF ELECTRICAL TRANSDUCERS

There are many basis on which electrical transducers may be classified. They can be classified according to application, method of energy conversion, nature of o/p signals and so on.

## Primary and Secondary Transducers

Primary Transducers are detectors which sense a physical phenomenon. Basically, a transducer which converts physical phenomenon to an electrical output.

Eg. Thermocouple

Secondary Transducers basically converts an analogous output into an electrical signal.

Eg. LVDT along with a Bourdon tube is used for meas$^{m}$ of pressure.

## Active and Passive Transducers

Active transducers also known as self generating type transducers. These transducers develop their own voltage or current. Eg. Piezoelectric.

Passive transducers are known as externally powered transducers.

## Analogue and Digital Transducers

Differentiated on the basis of the type of output that may be a continuous function of time or may be in discrete steps.

Analogue Transducers convert the input physical phenomenon into an analogous output which is a continuous function of time. Eg Strain gauge, LVDT, thermocouple.

Digital Transducers convert the i/p physical phenomenon into an electrical o/p which is in the form of pulses

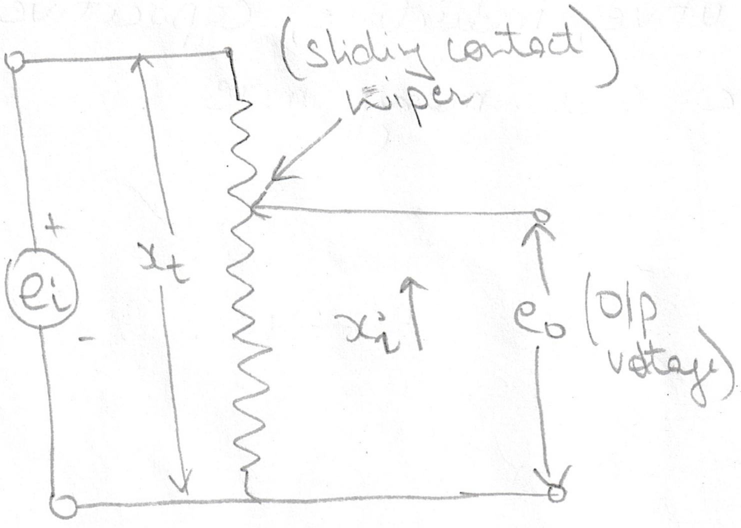
Also, acc. to electrical principles involved, transducers can be classified as resistive, inductive, capacitive, electromagnet, piezoelectric and many more.

# DISPLACEMENT MEASUREMENT

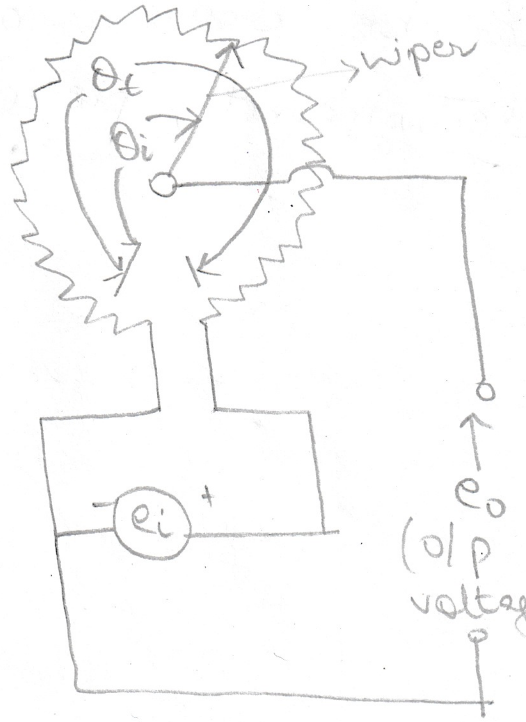
Basically, a resistive potentiometer, or simply a pot consists of a resistance element provided with a sliding contact known as wiper. The motion of wiper may be translatory or rotational.

The translational resistive elements are straight devices whereas the rotational resistive devices are circular in shape and are used for the meas$^m$ of angular displacement. The resistive element of a potentiometer may be excited either with a d.c. or an a.c. voltage source.

The pot, is thus a passive transducer since it requires an external power source for its operation.




(a) Translational




(b) Rotational

Fig 4 : Resistive Potentiometers

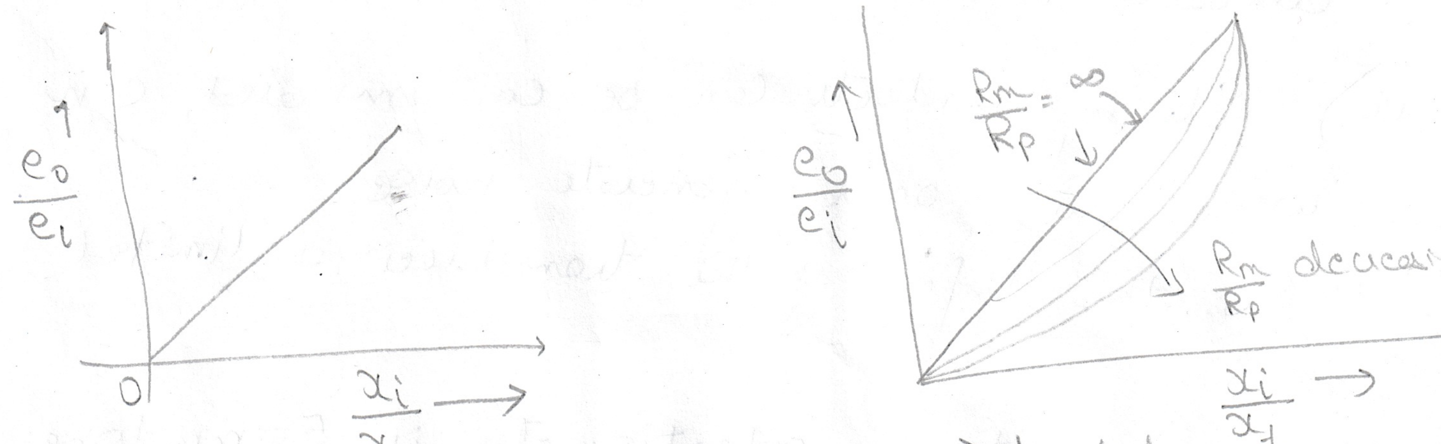
Let $e_i$ = i/p voltage
$R_p$ = total resistance of potentiometer
$x_t$ = total length of pot
$x_i$ = displacement of slider from its 0 posn.
$e_o$ = o/p voltage

O/p voltage under ideal condition;

$$e_o = \left(\frac{\text{Resistance at o/p terminals}}{\text{Resistance at i/p terminals}}\right) \times \text{i/p voltage}$$

$$e_o = \left[\frac{R_p/x_t \times x_i}{R_p}\right] \times e_i$$

$$\boxed{e_o = \frac{x_i}{x_t} \times e_i}$$




a) Under ideal condn

b) Loaded pot

Figure 5: Characteristics of potentiometers

$$\text{Sensitivity} = \frac{\text{Output}}{\text{input}} = \frac{e_o}{x_i}$$

In order to get high sensitivity, the ~~resistance~~ o/p voltage of potentiometer ~~Rp~~ should be as ~~low~~ high as possible, which in turn requires high i/p voltage $e_i$.

But in order to achieve good linearity, $R_p$ should be as low as possible.

But, $R_p$ cannot be made low because if we do so the power dissipation goes up.

## Advantages of Potentiometer

i) Simple to operate

ii) Inexpensive

iii) Useful for meas$^{m}$ of large amplitudes of displacement

## Disadvantages

i) They require a large force to move their sliding contacts.

ii) Sliding contacts can be contaminated, can wear out, and generate noise.
So, the life of the transducer is limited.

# A linear resistance potentiometer is 50 mm long and is uniformly wound with a wire having a resistance 10,000 Ω. Under normal cond$^{ns}$ the slider is at the centre of potentiometer. Find the linear displacement when resistance of pot as measured by Wheatstone bridge for two cases i) 3850 Ω ii) 7560 Ω. Are two displacement in the same dir$^{n}$

Normal po$^{n}$ 10,000/2 = 5000 Ω

Resistance of wire/length = 10,000/50 = 200 Ω/mm

5000 − 3850/200 = 5.75 mm

7560 − 5000 = 2560/200 = 12.55 mm

# Linear Variable Differential Transformer

The most widely used inductive transducer to translate linear motion into electrical signal is LVDT.

<u>Construction:-</u> The transformer consists of a single primary winding $P_1$ and two secondary windings $S_1$ and $S_2$ wound on a cylindrical former. The secondary windings have equal number of turns and are identically placed on either side of the primary windings. The primary winding is connected to an alternating current source. A movable soft iron core is placed inside the former. The displacement to be measured is applied to an arm attached to the soft iron core.

When the core is in its normal (NULL) position, equal voltages are induced in two secondary windings. The freq. of a.c applied to primary windings may be between 50 Hz to 20kHz.

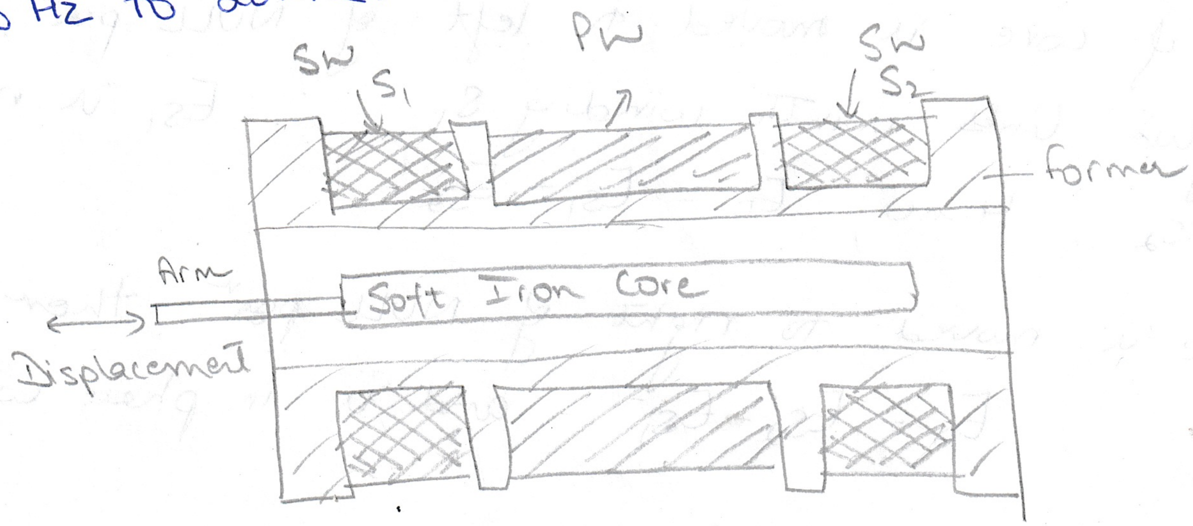



Fig 6: LVDT

Output voltage of $S_1$ is $E_{S1}$

—"— $S_2$ is $E_{S2}$

Differential o/p voltage = $E_{S1} - E_{S2}$

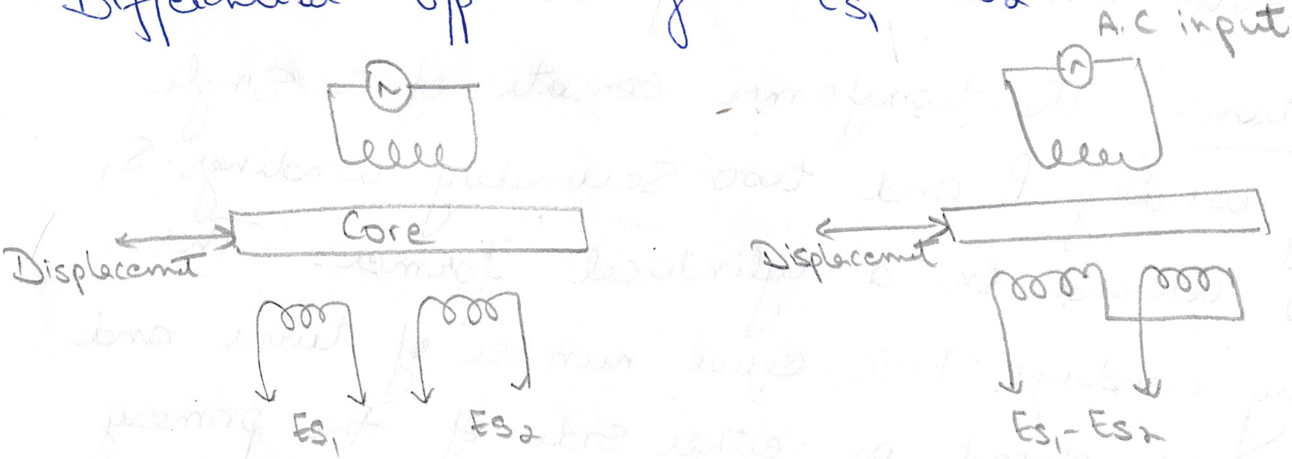



Fig 7: Circuits of an LVDT

<u>Working</u>:

When the core is at the NULL position, the flux linking with both the secondary windings is equal & hence equal emfs are induced in them.

Thus, at NULL position

$$E_{S1} = E_{S2}$$

∴ o/p voltage is zero at null position.

Now, if core is moved to left of NULL posn, more flux links with winding $S_1$ ∴ $E_{S1}$ is more than $E_{S2}$. Hence, $E_0 = E_{S1} - E_{S2}$

If core is moved to right of NULL posn then

$E_0 = E_{S2} - E_{S1}$ and is in phase with $E_{S2}$.

8

The amount of voltage change in either secondary winding is proportional to the amount of movement of the core. Hence, we have an indication of amount of linear motion.

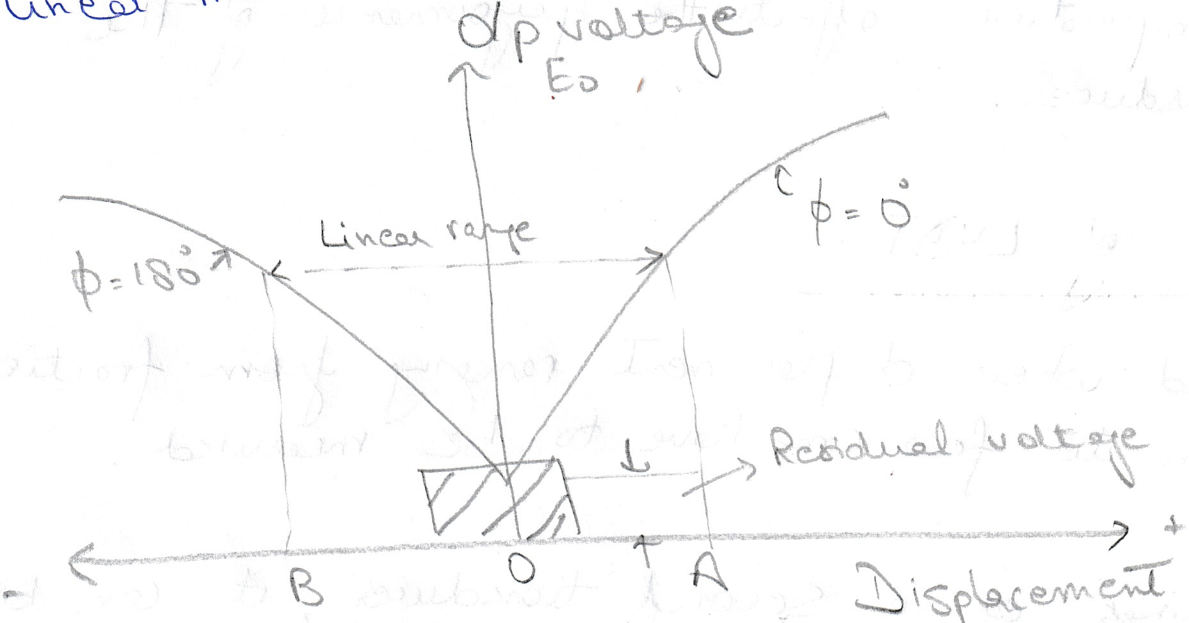



Fig 8: Variation of output voltage with linear displacement for an LVDT.

Ideally, the o/p voltage at null posn should be equal to zero. However, in actual practise there exists a small voltage due to presence of harmonics in i/p supply voltage, or harmonics produced at o/p voltage or electrical imbalance. It is generally less than 1% of max. voltage in the linear range.

## Advantages of LVDT

1. Linearity
2. High output
3. High sensitivity (40V/mm)
4. Ruggedness
5. Less friction (No sliding contacts)
6. Low hysteresis
7. Low power consumption. (< 1W)

## Disadvantages of LVDT

1. Performance affected by vibrations.
2. For d.c output, demodulator n/w is required.
3. Temperature affects the performance of the transducer.

## Uses of LVDT

1. Used where displacement ranging from fractions of mm to few cm have to be measured.

2. Acting as a second transducer, it can be used as device to measure force, weight and pressure etc.

   * Bourdon tube as primary
   (fluid pressure → displacement)

\# O/p voltage of a LVDT is 1.5V at max$^n$ displacement. At a load of 0.5 MΩ, the deviation is max$^m$ at a ±0.003V. Find the linearity

$$\% \text{ linearity} = \frac{\pm 0.003}{1.5} \times 100$$

$$= \pm 0.2\%$$

\# O/p of an LVDT is connected to a 5V voltmeter. An o/p of 2mV appears across the terminals when core moves through distance of 0.5mm. Calculate sensitivity

$$\frac{2 \times 10^{-3}}{0.5} = 4 \times 10^{-3} \text{ V/mm}$$

$$= 4 \text{ mV/mm}$$

UNIT-I

# STRAIN GAUGE

If a metal conductor is stretched or compressed, its resistance changes on account of the fact that both length and diameter of conductor change. Also, there is a change in the value of resistivity of the conductor when it is strained and this property is called piezo resistive effect. Therefore, resistance strain gauges are also known as piezoresistive gauges.

Also, other transducers notably, temperature sensors, accelerometers, flow meters employ strain gauges as secondary transducers.

Theory: Let us consider a strain gauge made of circular wire with length L, area A, diameter D before being strained. And resistivity $\rho$.

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

Let a tensile stress S be applied to the wire. This produces a positive strain causing length to increase and area to decrease.

$\Delta L$ = change in length

$\Delta A$ = change in area

$\Delta D$ = change in diameter

$\Delta R$ = change in resistance.

Differentiating R w.r.t stress S we get:

$$\frac{dR}{ds} = \frac{\rho}{A}\frac{\partial L}{\partial s} - \frac{\rho L}{A^2}\frac{\partial A}{\partial s} + \frac{L}{A}\frac{\partial \rho}{\partial s}$$

Dividing eqn by $R = \frac{\rho L}{A}$ we get:

$$\frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\partial L}{\partial s} - \frac{1}{A}\frac{\partial A}{\partial s} + \frac{1}{\rho}\frac{\partial \rho}{\partial s} \quad \text{--- (1)}$$

Now, $A = \frac{\pi}{4} D^2$ $\quad \therefore \frac{\partial A}{\partial s} = 2 \cdot \frac{\pi}{4} D \frac{\partial D}{\partial s}$

$$\frac{1}{A}\frac{\partial A}{\partial s} = \frac{(2\pi/4)D}{(\pi/4)D^2}\frac{\partial D}{\partial s} = \frac{2}{D}\frac{\partial D}{\partial s} \quad \text{--- (2)}$$

Substituting (2) in (1) we get

$$\frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\partial L}{\partial s} - \frac{2}{D}\frac{\partial D}{\partial s} + \frac{1}{\rho}\frac{\partial \rho}{\partial s} \quad \text{--- (3)}$$

Now,

$$\boxed{\text{Poisson's Ratio, } \nu = \frac{\text{Lateral strain}}{\text{Longitudinal strain}}}$$

$$\nu = -\frac{\partial D / D}{\partial L / L}$$

or $$\frac{\partial D}{D} = -\nu \frac{\partial L}{L} \quad \text{--- (4)}$$

Putting (4) in (3) we get:

$$\frac{1}{R}\frac{dR}{ds} = \frac{1}{L}\frac{\partial L}{\partial s} + \frac{2\nu}{L}\frac{\partial L}{\partial s} + \frac{1}{\rho}\frac{\partial \rho}{\partial s}$$

for small variations

$$\frac{\Delta R}{R} = \frac{\Delta L}{L} + 2\nu\frac{\Delta L}{L} + \frac{\Delta \rho}{\rho} \quad - (5)$$

$$\boxed{\text{Gauge factor, } G_f = \frac{\Delta R / R}{\Delta L / L}}$$

$$\frac{\Delta R}{R} = G_f \frac{\Delta L}{L}$$

$$\frac{\Delta R}{R} = G_f \times \epsilon$$

$$\boxed{\epsilon = \text{Strain} = \frac{\Delta L}{L}}$$

from (5) we get

$$G_f = 1 + 2\nu + \frac{\Delta \rho / \rho}{\Delta L / L}$$

If the change in the value of resistivity of a material when strained is neglected, the

gauge factor, $\boxed{G_f = 1 + 2\nu}$

Poisson's ratio for all metals b/w 0 and 0.5
Gauge factor = 2 (approximately)

# Types of Strain Gauges

i) Wire wound strain gauges
ii) foil type strain gauges
iii) Semiconductor strain gauges

Explain in your own words with simple diagram.

# A resistance wire strain gauge with a gauge factor of 2 is bonded to a steel structural member subjected to a stress of 100 MN/m². The modulus of elasticity of steel is 200 GN/m². Calculate the % change in the value of the gauge resistance due to the applied stress.

Solⁿ

$$\text{Strain}, \; \epsilon = \frac{S}{E} = \frac{100\times10^6}{200\times10^9} = 500\times10^{-6}$$

(500 microstrain)

$$\frac{\Delta R}{R} = G_f\,\epsilon = 2\times500\times10^{-6} = 0.001 = 0.1\%$$

∴ Change in resistance is only 0.1%

# Piezo - electric Transducers

A piezo electric material is one in which an electric potential appears across certain surfaces of a crystal if the dimensions of the crystal are changed by the appl$^n$ of a mechanical force. This potential is produced by the displacement of charges.

**Piezo electric effect**:- If a varying potential is applied to the proper axis of the crystal, it will change the dimensions of the crystal thereby deforming it. This effect is known as piezo electric effect.

Common piezo electric materials include Rochelle Salts, ammonium dihydrogen phosphate, lithium sulphate, quartz.

A piezo electric material used for converting mechanical motion to electrical signals may be thought as charge generator and a capacitor. Mechanical deformation generates a charge and this charge appears as a voltage across the electrodes.

The voltage is $E_0 = Q/C$.

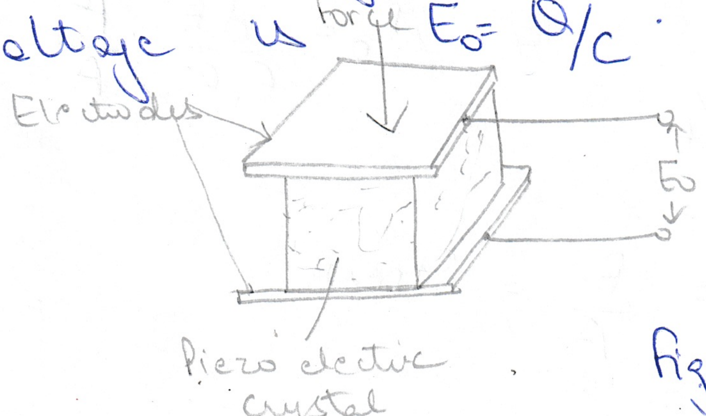



Fig 9: Piezo electric crystal used for meas$^m$ of force.

Charge $Q = dF$ coulomb

where, $d$ = charge sensitivity of crystal C/N
(constant for a given crystal)

$F$ = applied force, N.

The force $F$ cause a change in the thickness of crystal

$$\therefore \quad F = \frac{AE\Delta t}{t}$$

$A$ = area of crystal ; $A = wl$ (width & length of crystal)

$t$ = thickness of crystal

$E$ = young's modulus ; $E = \frac{\text{Stress}}{\text{Strain}}$

$$\therefore \quad Q = d\frac{AE\Delta t}{t}$$

and $E_0 = \frac{Q}{C}$

where, $C$ = Capacitance b/w electrodes

$$C = \frac{\epsilon_r \epsilon_0 A}{t}$$

$$\Rightarrow \quad E_0 = \frac{dF}{\epsilon_r \epsilon_0 A / t} \quad \Rightarrow \quad E_0 = \frac{dt}{\epsilon_r \epsilon_0} \cdot \frac{F}{A}$$

Pressure, $P = \frac{F}{A}$ = Stress

$$\Rightarrow \quad E_0 = \frac{dt}{\epsilon_r \epsilon_0} \cdot P$$

$$\boxed{E_0 = g t P}$$

where , $g = \frac{d}{\epsilon_r \epsilon_0}$ = voltage sensitivity of crystal (constant)

$$\therefore \quad g = \frac{E_0}{tP} = \frac{E_0/t}{P}$$

$$g = \frac{\text{Electric field}}{\text{Stress}} = \frac{\mathcal{E}}{P}$$

and $\quad d = \epsilon_r \epsilon_0 g$

The desirable properties of piezo electric materials are stability, high output insensitivity to temperature and humidity, and the ability to be formed into most desirable shape.

→ Quartz is the most stable piezo-electric material. However, its o/p is quite small.

→ Rochelle Salt provides highest o/p but it can be worked over a limited humidity range.

→ Barium titanate has the advantage that it can be formed into a variety of shapes and sizes.

# A quartz piezo electric crystal having a thickness of 2 mm and voltage sensitivity of 0.055 V-m/N subjected to a pressure of 1.5 MN/m². Calculate the o/p voltage. If the permittivity of quartz is 40.6×10⁻¹² F/m, calculate charge sensitivity.

Solⁿ

$E_0 = gtP = .055 \times 2\times10^{-3} \times 1.5\times10^{6} = 165\,V$

$d = \epsilon_0 \epsilon_r g$

$= 40.6\times10^{-12} \times 0.055 = 2.23\times10^{-12}\ C/N$

$= 2.23\ pC/N$

# A piezo electric crystal having dimensions of 5mm × 5mm × 1.5 mm and a voltage sensitivity of 0.055 V-m/N is used for force measurement. Cal. the force if the voltage developed is 100V.

Solⁿ

$P = \dfrac{E_0}{gt} = \dfrac{100}{0.055\times1.5\times10^{-3}} = 1.2\ MN/m^2$

$F = PA = 1.2\times10^{6} \times 5\times5\times10^{-6} = 30\ N$

**Uses of Piezo electric materials and Transducers**

1. Quartz is commonly used for stabilizing electronic oscillators.

2. Can be used in accelerometers, vibration pickups

# Measurement of Angular Velocity

Angular velocity : Rate at which an object rotates or revolves about an axis.

→ "Tachometers" are used for the measurement of angular velocity.

Tachometers
- Electrical (Electromagnetic tachometer)
  - D.C Tachometer
  - A.C Tachometer
- Mechanical

## D.C. Tachometers | D.C. Tachogenerators

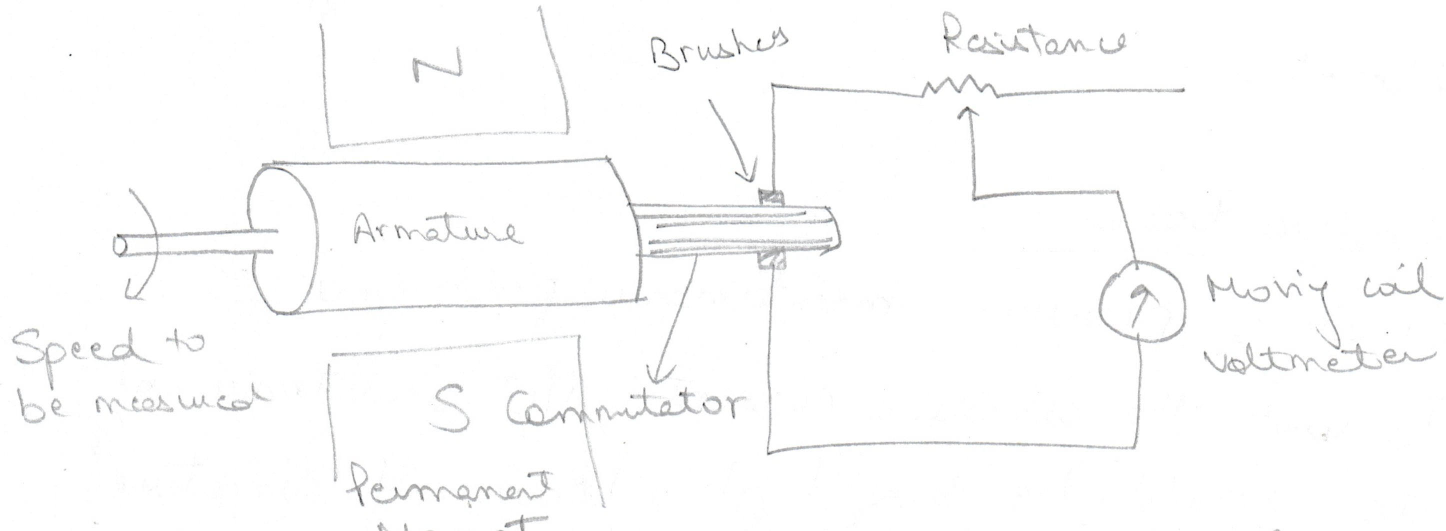



Fig DC Tachometer Generator

It consists of a small armature which is coupled to the machine whose speed is to be measured. This armature revolves in the field of a permenent magnet. The emf generated is proportional to the product of flux and speed. Since, the flux of permenent magnet is constant,

the voltage generated is propotional to speed.

The polarity of output voltage indicates the direction of rotation. This emf is measured with the help of a moving coil voltmeter having a uniform scale and calibrated directly in terms of speed.

A series resistance is used in the circuit for the purpose of limiting the current from the generator

## Advantages

1. The output voltage is typically 10mV/rpm and can be measured with conventional type d.c voltmeters.

## Disadvantages

1. Brushes produce maintenance problems
2. To limit the armature current, i/p resistance of meter should be very high, because if armature current is high, field of permenent magnet is distorted

# A.C Tachometer Generator

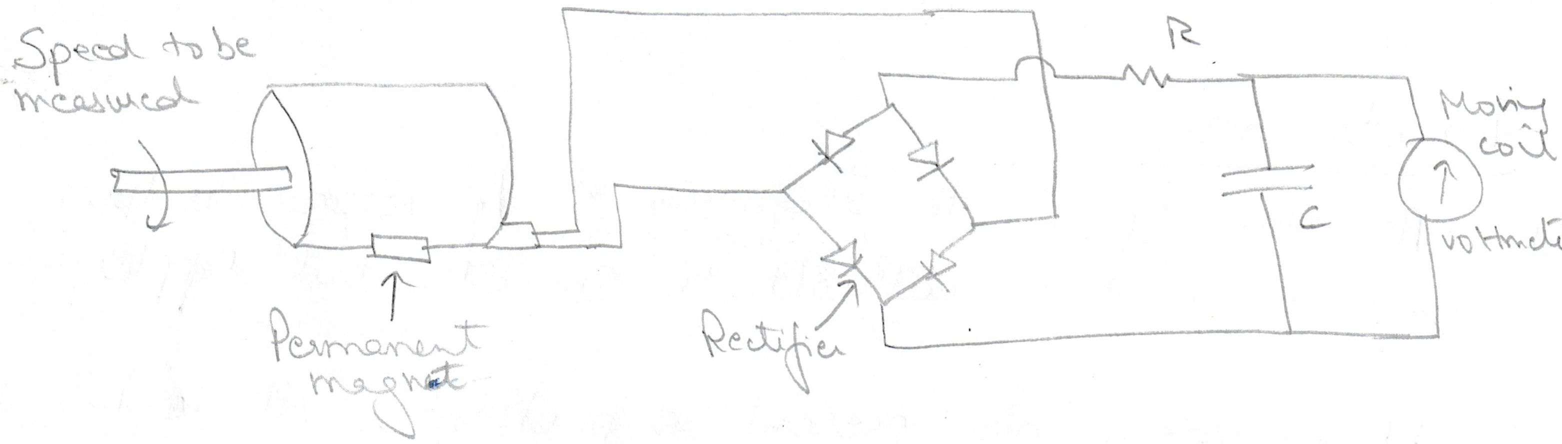



Fig: A.C Tachometer Generator

In order to overcome some of the difficulties in D.C. tachometers, a.c. tachometers are used.

The tachometer generator has rotating magnet which may be either permanent magnet or an electromagnet. The coil is wound on the stator and therefore, the problems associated with commutators are absent.

The rotation of the magnet causes an emf to be induced in the stator coil. The amplitude and frequency of this emf are both proportional to the speed of rotation. Thus either amplitude or frequency of induced voltage may be used as a measure of rotational speed.

The o/p voltage of a.c. tachometer generator is rectified and is measured with a permanent magne moving coil instrument.

## Limitations

1. At low speed, the frequency of o/p voltage is low and hence it is difficult to smooth out ripples

2. High speed also present a problem. At high speed, the frequency increases and therefore, the impedance of the coils increases.

## DIGITAL METHODS for measuri angular velocity

- Helps in measuring high speed (more than 10,000 rp
- No direct physical contact with the device whe speed has to be measured. And therefore, no load is imposed on the shaft.

- They involve digital pickups. And these can be of two types

Photo electric

Inductive

# Photo electric Tachometer

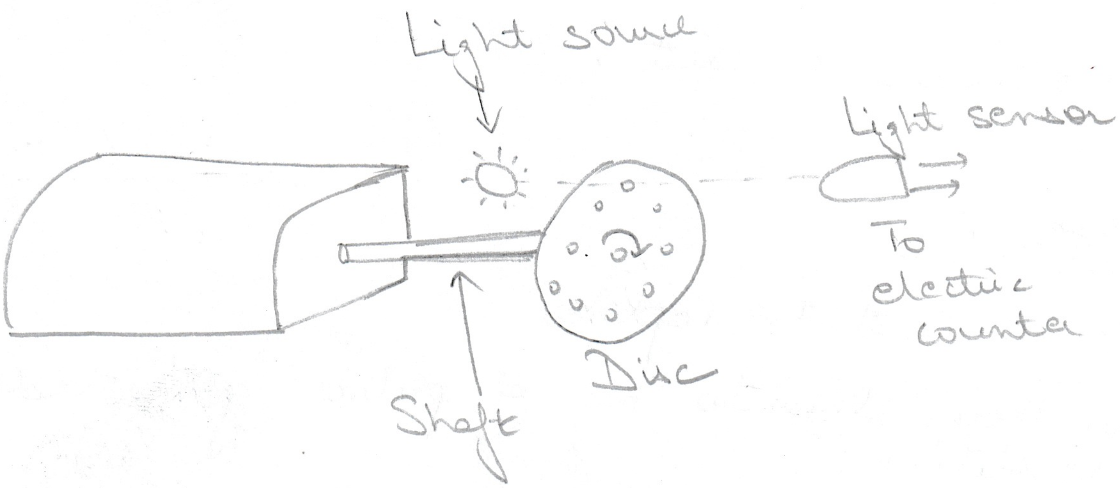



fig. Photo electric tachometer

- Light is being used for the measurement of speed
- Disc is having equidistant holes at its periphery.

When light source emits the light and if it passes through the holes of the disc, then it will be sensed by the light sensor, And when the light does not pass through the disc, then it won't be sensed and hence the speed of rotation of disc is propotional to the pulses which are generated.

And the pulses are counted by electric counter.

Therefore, speed can be calculated by the measurement of frequency of pulses.

Thus, electric counters can be calibrated in terms of rpm.

Advantages

① Since the output is in digital format, can be used in digital measurement.

② Simple electronic circuit.

Disadvantages

① Light source must be replaced

② Error is there due to no. of pulses generated per revolutions.

## Toothed rotor variable reluctance tachometer

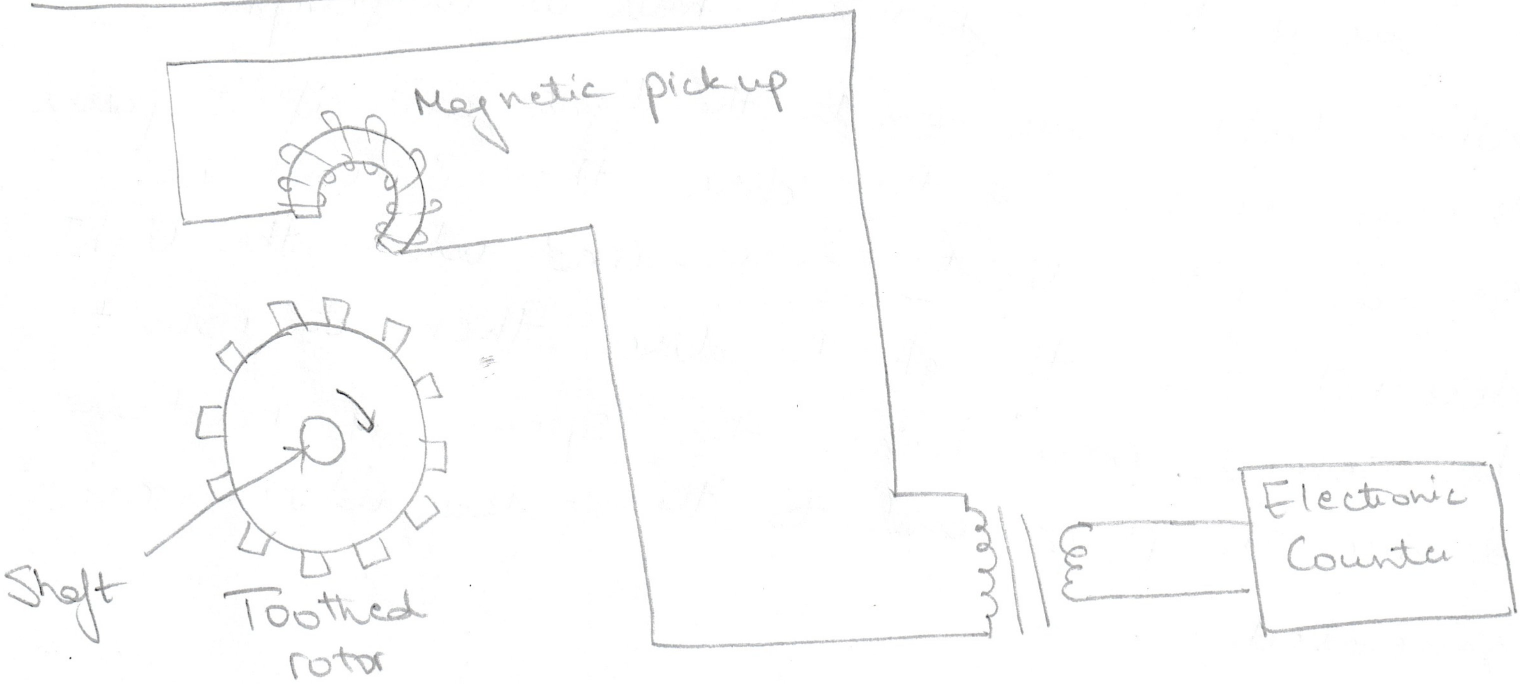



fig. Reluctance Tachometer

When the rotor rotates, reluctance of the air gap between the pick up and rotor changed.

Pick up consists of a permanent magnet with a coil wounded around it and thus emf is induced

Since, the output is in the form of pulses, the frequency is measured with the electronic counter and this frequency is proportional to the speed of rotation

$$\text{Speed},\ n = \frac{\text{Pulses per second}}{\text{No. of teeth (constant)}}$$

Advantages

1. Simple and rugged.
2. Maintenance free
3. Easy to calibrate
4. Information can be easily transmitted.

# pH Sensors

Measurement of pH helps in finding out alkanity or acidity of a solution.

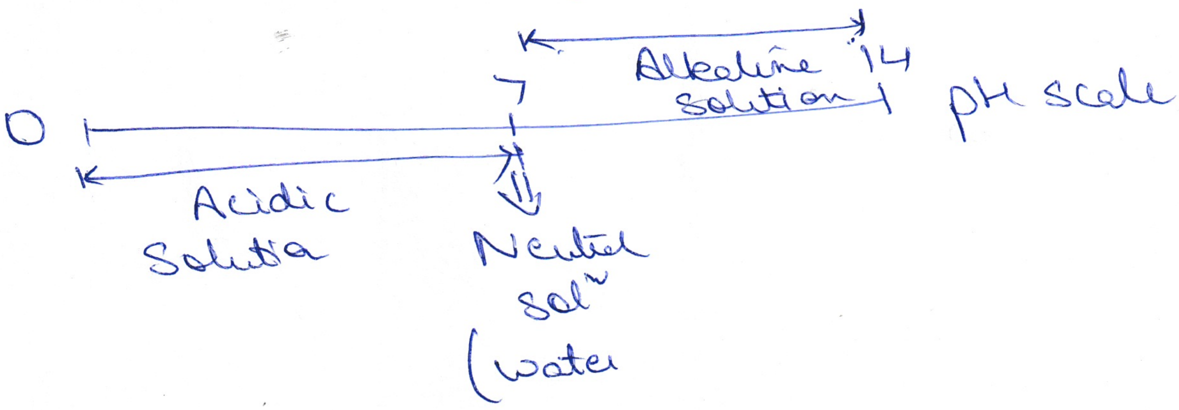
Acid $\rightarrow$ $\underset{\text{Acid}}{HA} \longrightarrow \underset{\text{Hydrogen ion}}{H^+} + \underset{\text{Anion}}{A^-}$

Bases $\rightarrow$ $\underset{\text{Base}}{MOH} \longrightarrow \underset{\text{Cation}}{M^+} + \underset{\text{Hydroxyl ion}}{OH^-}$

→ pH of a solution is defined as the negative logarithm of the hydrogen ion concentration

$$pH = -\log_{10}(H^+)$$

→ Hydrogen ion concentration is measured on a scale called pH scale.




Measurement of pH value is obtained by immersing a pair of electrodes into the solution and measuring the voltage developed across the electrodes

① Measuring electrode : whose voltage has to be measured.

② Reference electrode : Has a constant voltage irrespective of the pH of the solution.

The potential difference between the two electrodes is a measure of pH which depends on the pH of the solution.

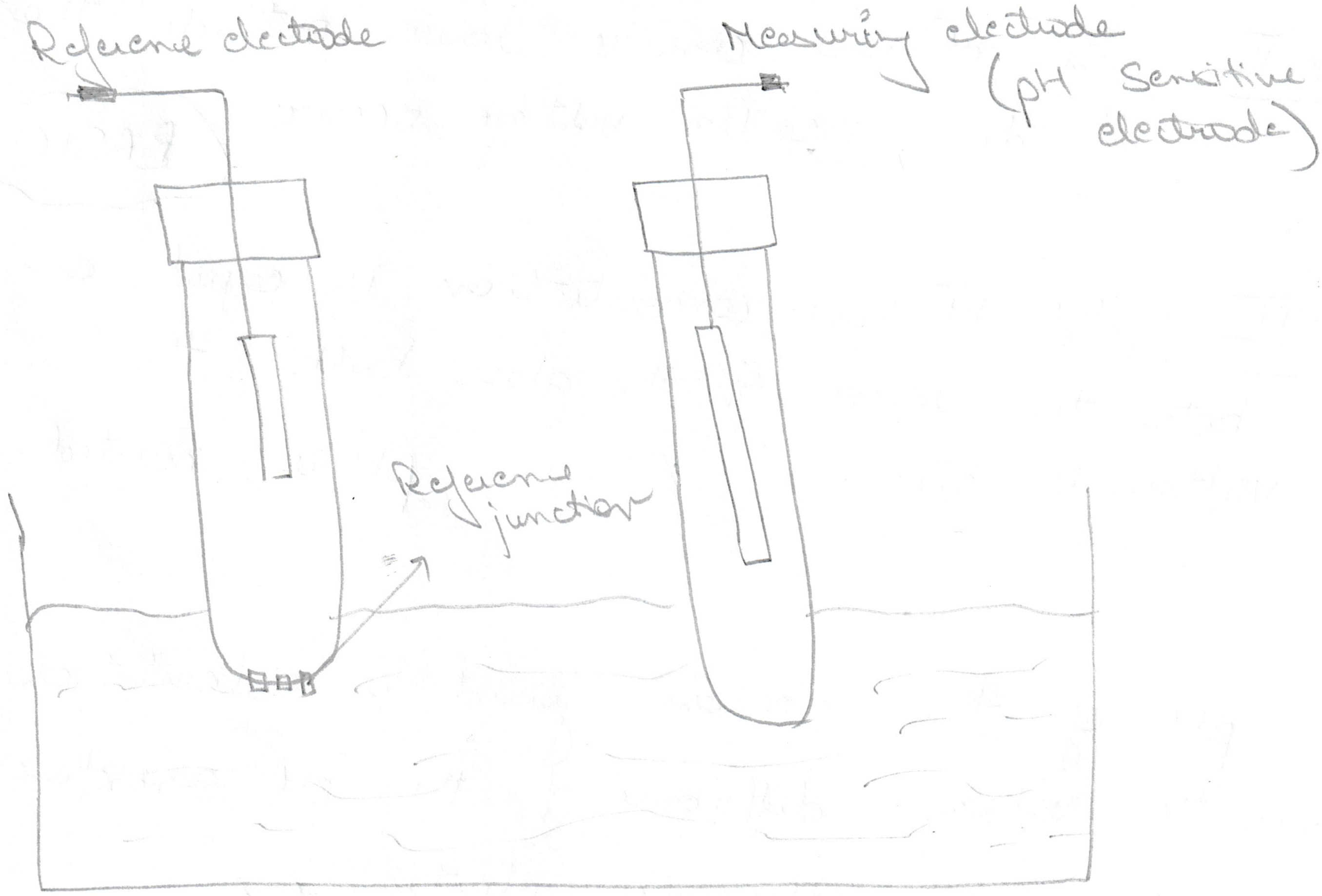



Fig.

The reference electrode maintains a ~~stable~~ steady reference voltage by allowing the small amount of ions to flow into the process fluid.

The pH sensitive electrode has a small bulb at its tip that is made of pH sensitive glass. The electrical voltage across the bulb changes in response to the hydrogen ion concentration of the process fluid around it.

Case I : If $H^+$ ion conc is more outside than inside positive voltage occurs. ACIDIC

Case II : If $H^+$ ions conc is lower outside than inside, negative voltage occurs BASIC

Case III If $H^+$ ions concentration is equal on both the sides of the glass bulb, the voltage is zero. pH is neutral.

The pH of the process fluid is calculated from the voltage difference of the pH sensitive electrode and reference electrode.

# THERMOCOUPLE

A thermocouple is a device for measuring temperature. Also called thermal junction, thermoelectric thermometer, this temperature measuring device consists of two wires of different metals joined at each end.

It works on the fact that when a junction of dissimilar metals heated, it produces an electric potential related to temperature.

The emf produced in a thermocouple circuit is given by

$$E = a(\Delta t) + b(\Delta t)^2$$

where

$\Delta t$ = difference in temperature

$a, b$ = constants.

$a$ is usually very large as compared with $b$ $(a >>> b)$

$$\therefore \quad E = a(\Delta t)$$

$$\boxed{\Delta t = \frac{E}{a}}$$

In a thermocouple temperature measuring circuit, the emf set up is measured by sending a current through a moving coil instrument, the detection being directly proportional to the emf. Since emf is a function of temperature difference $\Delta t$, the instrument can be calibrated to read the temperature.

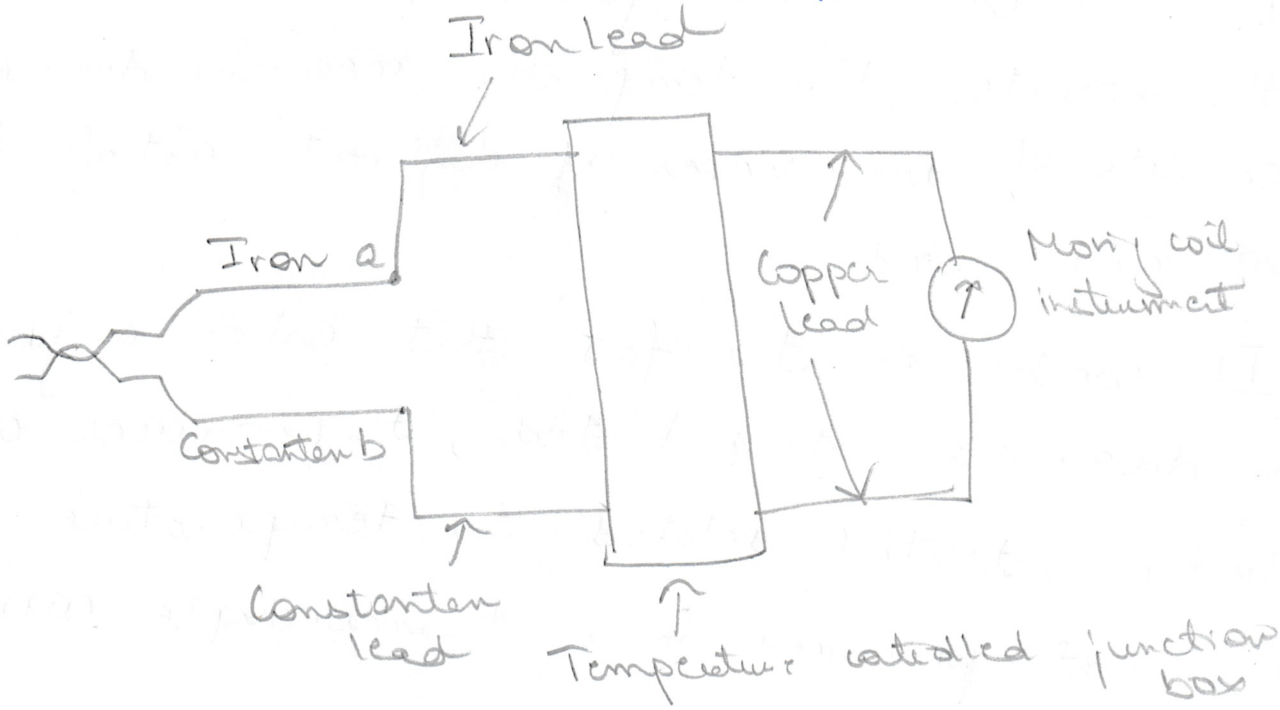



Fig : Measurement of temperature with thermocouple.

The reference junction temperature is usually 0°C. Thermocouples are used for measurement of temp. upto 1400°C.

Generally, Chromel (90% nickel and 10% chromium) are used in the manufacture of a thermocouple.

## Applications

1. To monitor temperatures, testing temperatures associated with process plants
2. Testing of heating appliance safety
3. Monitoring of temperatures throughout the production

# FLAME DETECTOR

It is a sensor designed to detect and respond to the presence of a flame or fire.
Flame detector respond faster and more accurately than a smoke or heat detector due to the mechanisms it uses to detect the flame.

There are mainly two types of flame detector.

1. Infrared Flame Detector
2. Ultraviolet Flame Detector

## Infrared (IR) Flame Detector

IR detector senses light at the extreme, high end of the light spectrum. Flicker flame detectors are infrared detectors capable of sensing the typical flicker of a flame.
It can not be installed in direct sunlight and near electric heater.

Response time: 3-5 seconds.

IR detectors are suitable for areas where combustion sources can produce intense and smoky fires. They can operate within the range of sixty metres from the fire sources.

## Advantages

1. Highly reliable
2. Designed to work as a standalone unit
3. Weather resistant
4. Quick response time.

## Applications

1. Can be used in following areas:
   a. Chemical plants
   b. Warehouses
   c. Storage tanks
   d. Pharmaceutical industry

## Ultraviolet (UV) Flame Detector

UV detectors work by detecting the UV radiation emitted by at the instant of ignition. While capable of detecting fires and explosions within 3-4 milliseconds

Sun rays and artificial rays have no effect on UV detector but electric arc has an effect, so when there is electric welding going on, it can not be installed.

UV detectors typically operate with wavelengths shorter than 300 nm to minimize the effects of natural background radiation.

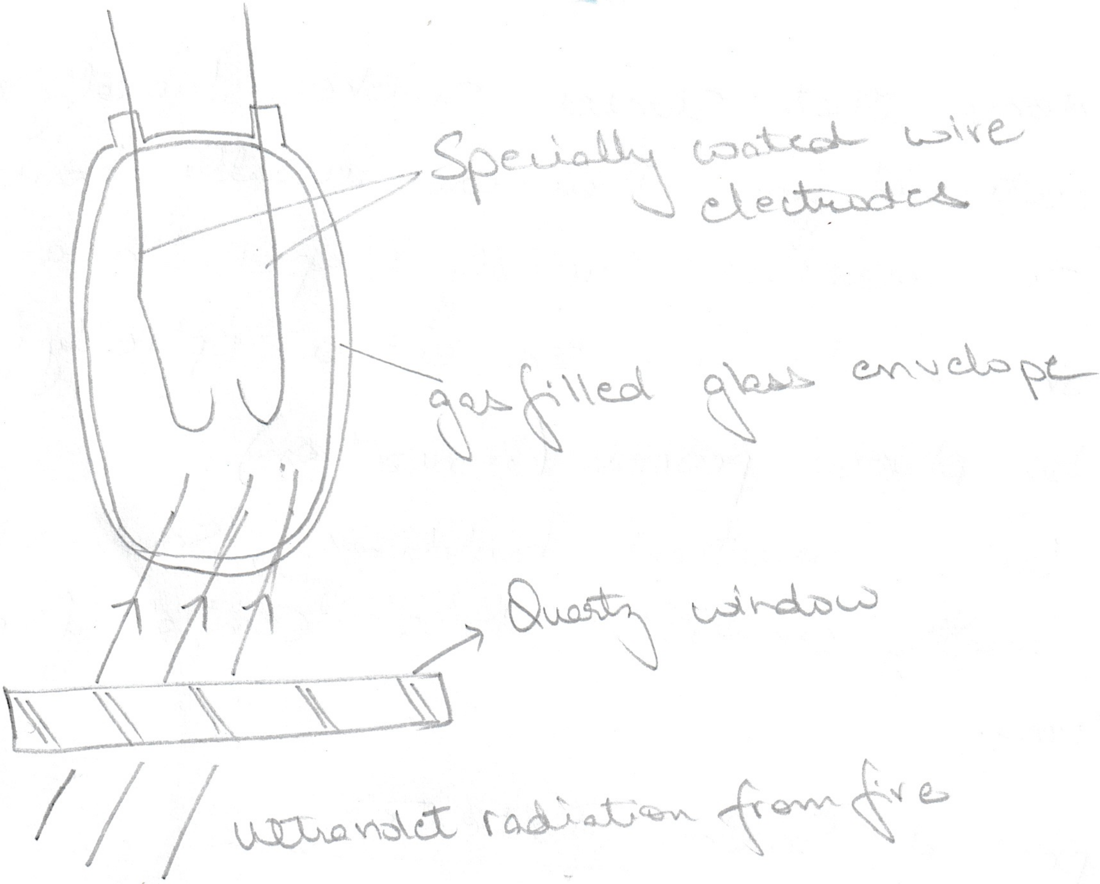



fig: Ultraviolet flame detector

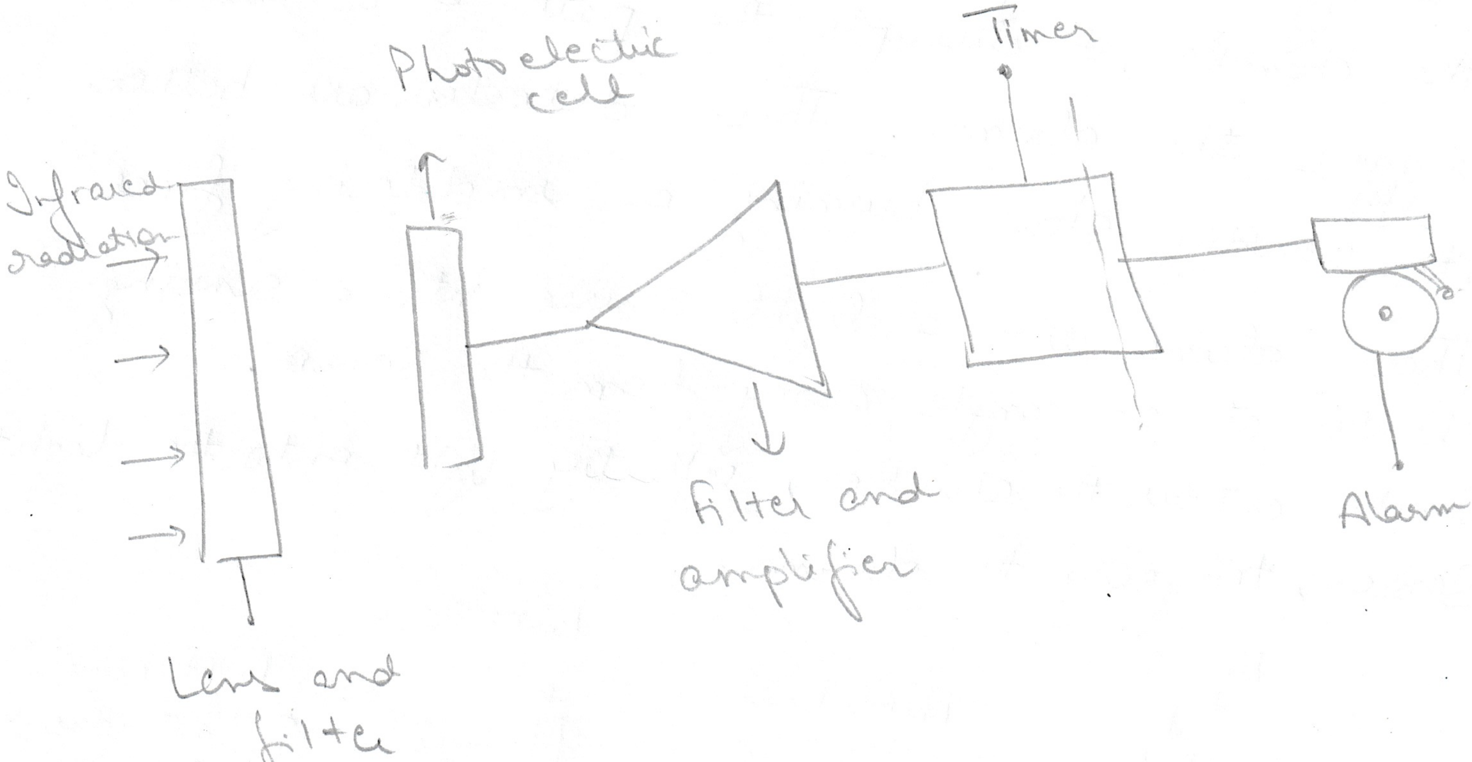



fig: IR flame Detector

# SMOKE DETECTORS

A device that senses smoke, typically as an indicator of fire. They are usually housed in plastic enclosures, typically shaped like a disk. Smoke can be detected either optically (photoelectric) or by physical process (ionization).
In large industrial buildings, smoke detectors are usually connected to a central fire alarm system.

## Types of Smoke Detector

(1) Photoelectric Detector : Work by using a light sensing chamber. As smoke enters the chamber, it disrupts the path of a laser and triggers the alarm. These detectors are better at sensing slow burning or smoldering fires.
These alarms aim a light source into a sensing chamber at an angle away from the sensor. Smoke enters the chamber, reflecting light onto the light sensor, triggering the alarm.

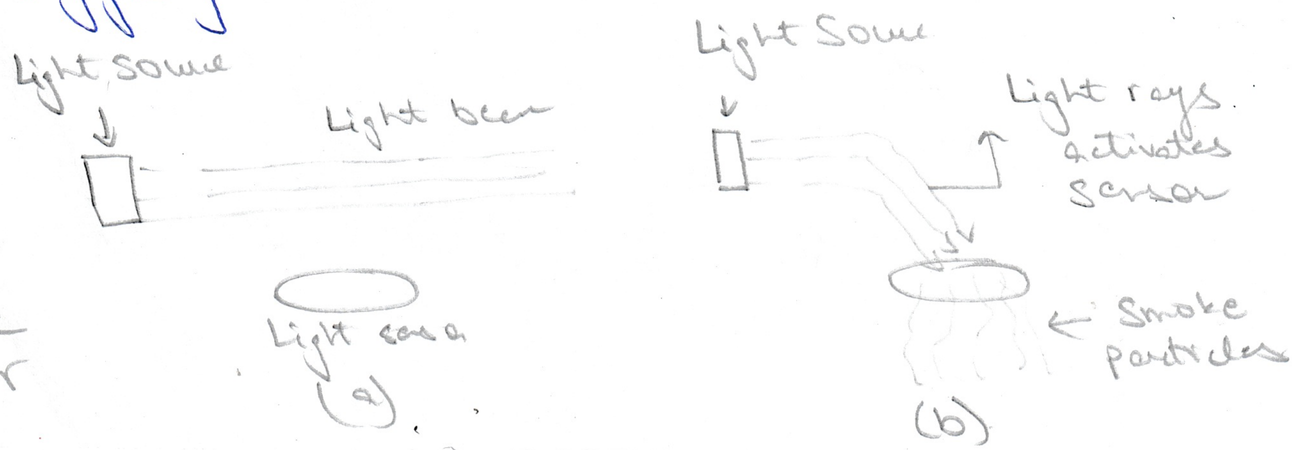



Fig: Photoelectric Detector

(2) Ionization Detectors : Used to electrical charged plates to ionize the air in the sensor When smoke enters the detector it disrupts the flow of the ions and triggers the alarm. They are stronger at detecting fast flaming fire

These smoke alarms have a small amount of radioactive material between two electrically charged plates, which ionizes the air and causes current to flow between the plates.

When smoke enters the chamber, it disrupts the flow of ions, thus reducing the flow of current and activating the alarm.

# UNIT – II

## SMART SENSORS

The integration of electronics and sensors to make an intelligent sensor is known as a smart sensor. This sensor can make some decisions.

† A smart sensor is a device that uses a transducer to gather particular data from a physical environment to perform a predefined and programmed function on the particular type of gathered data then it transmits the data through a networked connection.

$$\boxed{\text{Sensors} + \text{Interfacing hardwares} = \text{Smart sensors}}$$

Smart sensor are different from other types of sensors because they carry out functions like ranging, calibration and decision making for communication and utilization of data.

## Working Principle

Smart sensors work by capturing data from physical environments and changing their physical properties like speed, temperature, pressure or presence of humans into calculable electrical signals. These sensors include Digital Motion Processor (DMP).

DMP is a type of microprocessor that allows the sensor to perform onboard processing of the smart sensor data like filtering noise.

Mainly 4 functions are performed:

1. **Measurement** : Detecting physical signals and changing them into electrical signals.

2. **Configuration** : Allows smart sensors to detect position.

3. **Verification** : Nonstop supervision of sensor behaviour.

4. **Communication** : Allow the sensor to converse to the main microcontroller/microprocessor.

# SMART SENSOR BLOCK DIAGRAM

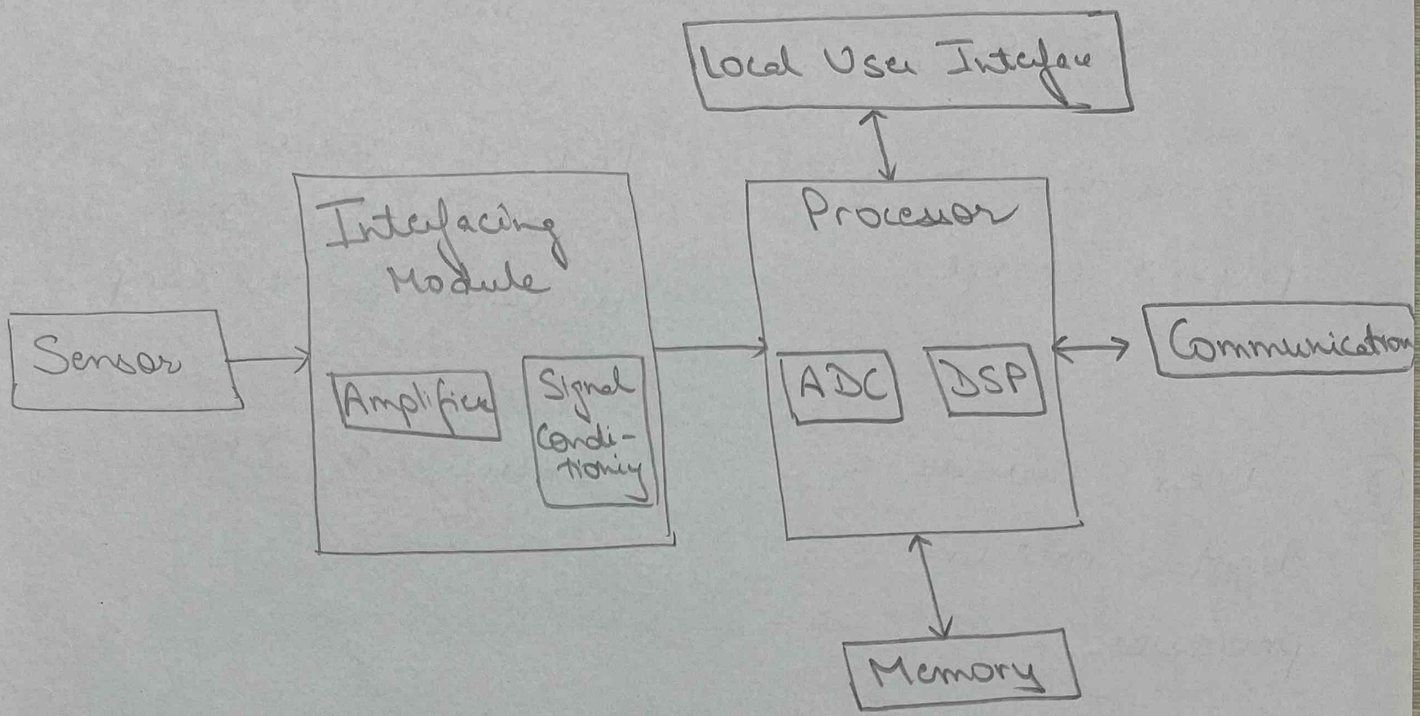



Fig 2.1 : Smart Sensor block diagram

# TYPES OF SMART SENSORS

1. Level Sensors
2. Infrared Sensors
3. Proximity Sensors
4. Air quality Detection sensors
5. Motion Sensors
6. Smart climate sensors

## Difference between normal Sensor and Smart sensor

| Sensor | Smart Sensor |
| --- | --- |
| ① Device used to detect physical change | Part of a sensor is known as a smart sensor that is used for the computer. |
| ② Doesn't include a digital motion processor. | Includes a DMP. |
| ③ Includes components like sensor element, connection and processing hardware. | Include different components like amplifiers, analog filters, excitation control. |
| ④ Normal sensor output cannot be used directly as it need to be converted into usable form. | Output of smart sensor is ready to use. |
| ⑤ Eg. Pressure, temperature, force, humidity etc. | Eg.: Level, Electric current, proximity, heat etc. |

# FABRICATION METHODS OF SMART SENSOR ③

① Electrode fabrication

ⓐ Screen Printing

ⓑ Photolithography

② Electroplating sensing film deposition

ⓐ Physical Vapor deposition

ⓑ Chemical vapor deposition

③ Anodization

④ Sol-gel Interface

Fabrication refer to manufacturing, Specifically The crafting of individual parts as a solo product or as a part of a larger combined product.

Fabrication techniques are the processes that are used to shape, cut or mould materials into items.

1.a.

## SCREEN PRINTING

The screen printing process has been evolved from batch type process to continuous production process because of the automation of industrial processes.

The screen printing process basically apply the sensor specific layers reliably and cost effectively. This technique is characterized by its simplicity and being an additive process, which makes it environment friendly.

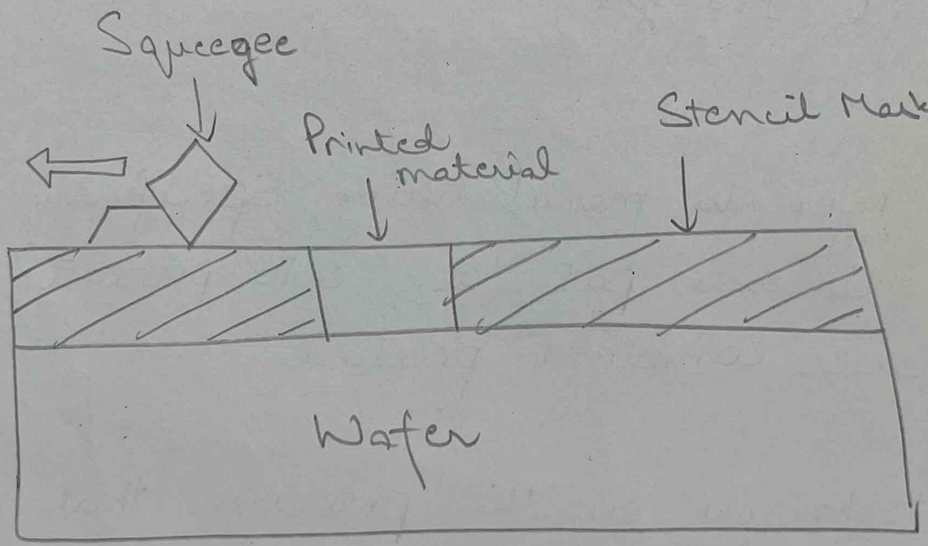



Fig. The screen printing process

It essentially consists of a framed screen, printing stage, and a squeege. The screen printer applies the paste evenly to the mask and rubs it with a squeege, which pushes the paste through the openings in the mask onto the substrate.

The Solvent system plays a significant role in determining the screenability of the resulting paste.

One of the biggest advantages of screen printing is that it can be used on almost any substrate including paper, paperboard, polymer materials, textiles, wood, metal, ceramics, glass and leather.

In addition, the screen printing process enables ink application not just to flat surfaces but to irregular ones too, as long as the thick ink adheres properly to the printed substrate and the screen can adapt to the substrate's shape consistently without distortion.

DRAWBACKS

1. Limited control over (a) the thickness of the deposited ink (b) Number of layers (c) resolution of the deposited pattern.

# PHYSICAL VAPOR DEPOSITION

It is a collective set of processes used to deposit thin layers of material typically in the range of few microns to some micrometers.

It is used for high melting point and low vapor pressure materials.

Physical coating process involve vaporization, transportation and condensation of the material to be deposited.

## PVD Techniques

- Evaporative deposition
  - Electron beam
  - Pulsed laser
- Sputter deposition
- Ion induced deposition
- Cathode arc deposition

# Chemical Vapour Deposition

† It is a chemical process used to produce high purity, high performance solid materials.

† It is a process whereby a solid material is deposited from a vapor by a chemical reaction occurring on or in the vicinity of a normally heated substrate surface.

The solid material is obtained as a coating, a powder or a single crystals.

During the process, volatile by products are also produced, which are removed by gas flow through the reaction chamber.

## Steps involved

1. Transport of reactants by forced convection to the deposition region.

2. Transport of reactants by diffusion from the main gas stream to the substrate surface.

3. Adsorption of reactants in the wafer (substrate) surface.

4. Chemical decomposition and other surface reaction takes place.

(5) Desorption of by-products from the surface.

(6) Transport of by-products by diffusion.

## Types of Chemical vapour Deposition

On the basis of operating pressure

Atmospheric pressure CVD

Low pressure CVD
- Plasma enhanced
- Photochemical vapour
- Thermal CVD

## Applications

1. Semiconductors
2. fiber optics
3. Microelectronics industry
4. Coating - Corrosion resistance, high temperature protection.

## Difference between

| | PVD | CVD |
|---|---|---|
| | - Use high electical charges and atomic collisions to deposit coating on to a tool. | Utilizes the chemical properties of the metals to transfer metallic compounds onto the tool. |
| | Deposits at a relatively low temp. 250°C - 450°C. | Run at much higher temperatures usually between 300°C and 900°C. |
| | | Deposited layer thickness can be controlled. |
| | Physical vapour deposition | Chemical vapour deposition |
| Coating material | Solid form | Gaseous form |

# ANODIZATION

Among the various methods used for the fabrication of nanostructured transition metal oxides, the electrochemical anodization technique has gained increasing attention due to its simplicity, reproducibility and low cost processing.

In simple words,

Anodizing is a process of forming a thick oxide layer of aluminium. This aluminium oxide coat makes it resistant to further corrosion.

Other nonferrous materials, such as magnesium and titanium also can be anodized.

The anodizing process can be divided into following five steps:

1. Preparing the surface
2. Anodizing itself
3. Cleaning the parts
4. Adding colour
5. Sealing the pores

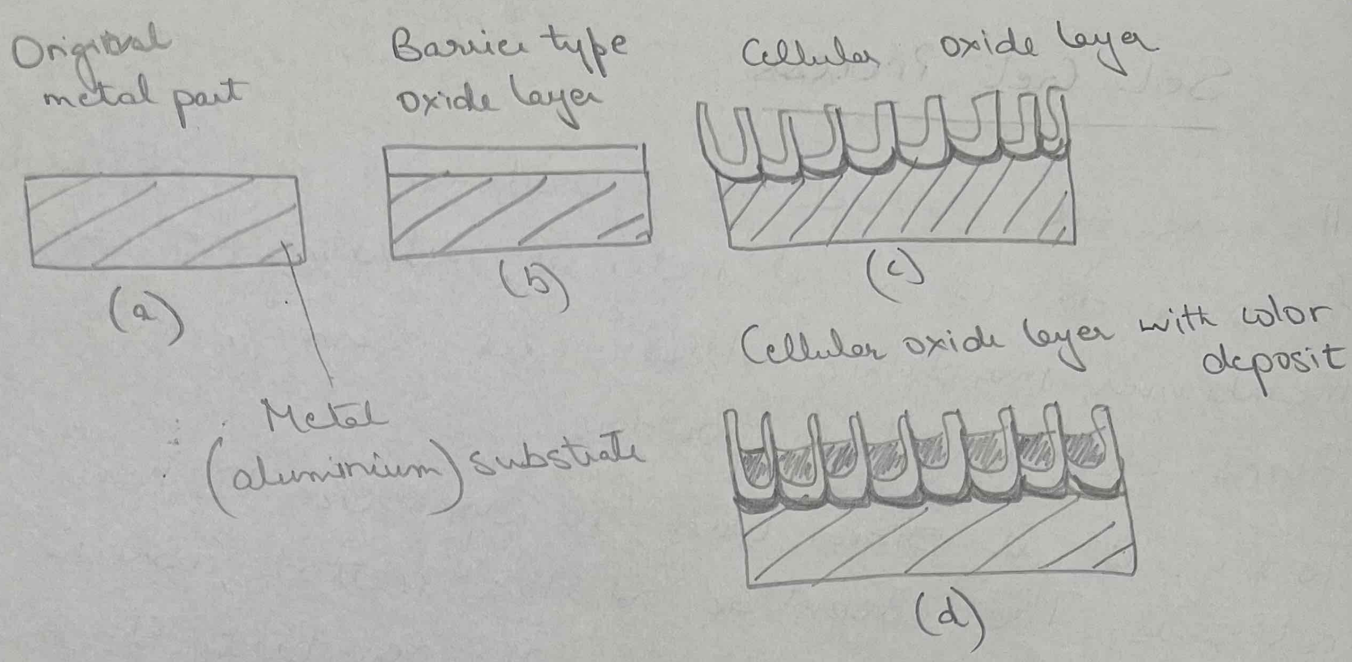



fig : Anodizing Process

## Advantages

i) Wear resistance
ii) Corrosion resistance
iii) Surface lubricity
iv) Heat dissipation
v) Adhesion

## Applications

i) In marine environment
ii) As decorative articles
iii) Common in sand papers because of its high hardness.

## Disadvantages

i) Limited to aluminium
ii) More expensive than other finishing methods due to specialized equipment and processes required.

# Sol Gel Process

The Sol gel method is a traditional method used for a wide range of materials, including inorganic membranes, monolithic glasses and ceramics, thin films and ultra fine powders.

Today, it is even used to synthesize 1D nano materials. The advantage of this method, which has made it very popular, is the possibility of doing it at room temperature and the possibility of easy chemical doping.

It is more chemical method (wet chemical method) for the synthesis of various nanostructures, especially metal oxide nanoparticles

The basis of the sol gel method is the production of a homogeneous sol from the precursors and its conversion into a gel.

The sol gel process is a bottom up synthesis method. In this process, the final products are formed by performing a number of irreversible chemical reactions. During these reactions, the primary homogeneous molecules (sol) become an infinite, heavy, three dimensional molecule called a gel.

The conversion into a gel is done through a process called 'compaction process' and leads to the production of wet gel.
Figure shows the overview of different stages of sol-gel process from precursor to aerogel.

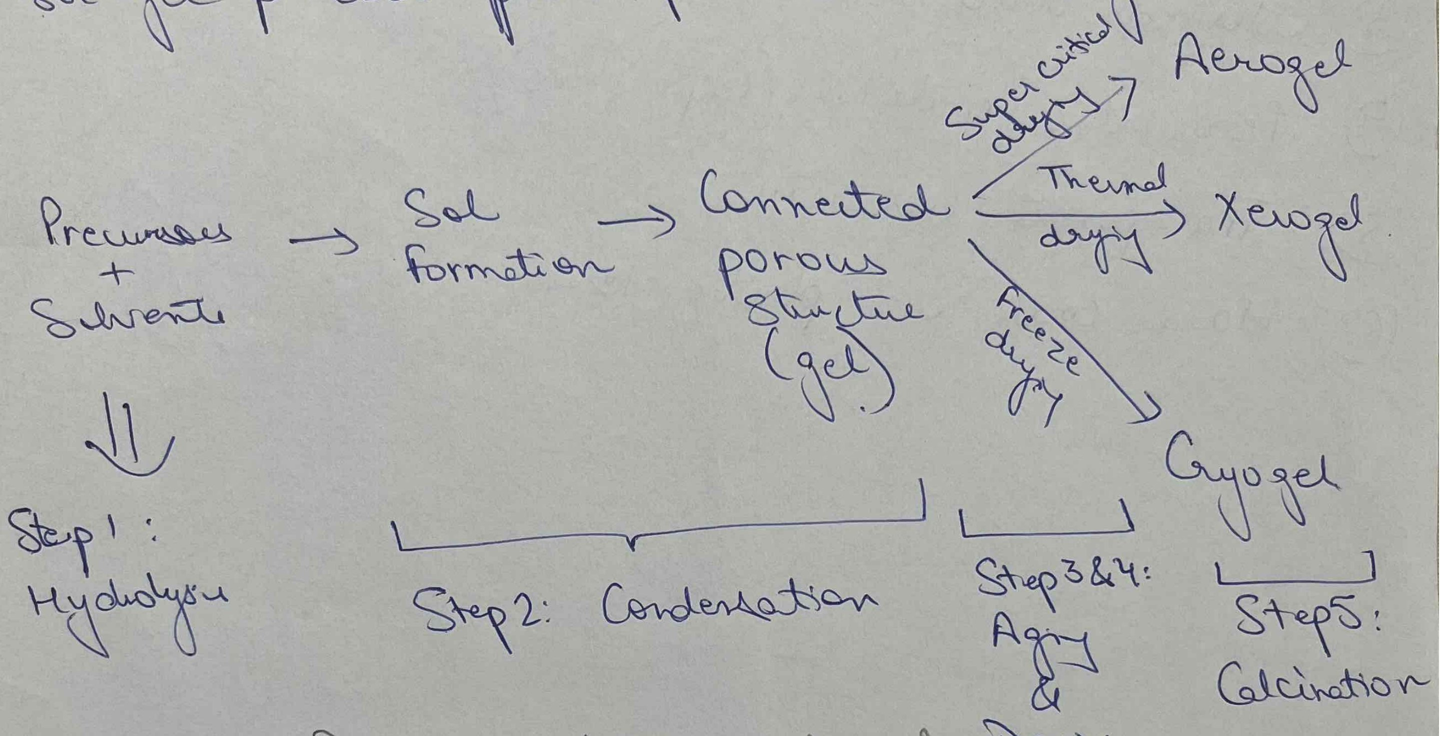



Fig: Different stage of sol-gel process.

It should be noted that by controlling the drying condition of the gel, it is possible to achieve nanosized porosity.

## Advantages

1. Low temperature of reaction
2. Good composition control
3. High purity level
4. Ability to develop processes for large area applications

Applications

1. Lasers
2. Optical fiber
3. Coloured automobile window
4. Ferroelastic material (Capacitors)
5. Transparent conductor
6. Hard coat on plastic lens