

Displacement, position and proximity sensor

Displacement sensors are concerned with the measurement of amount by which some object has moved

Position sensors are concerned with the determination of the position of some object with reference to some reference point

Proximity sensors are a form of position sensors. They are used to determine when an object has moved to within some particular critical distance of the sensor

When selecting these sensors its essential to care of :

-The size of displacement

-Nature of the displacement

-The required resolution & accuracy

-The material of the measured object

-cost

Displacement, position and proximity sensor

Contact sensors

The movement of the sensor element's is used to cause a change in electrical volatge, resistance, capacitance or mutual inductance

Non-contacting sensors

The presence in the vicinity of the measured object cause change in air pressure or change in inductance or capacitance

The commonly used displacement sensors are given below

1-10

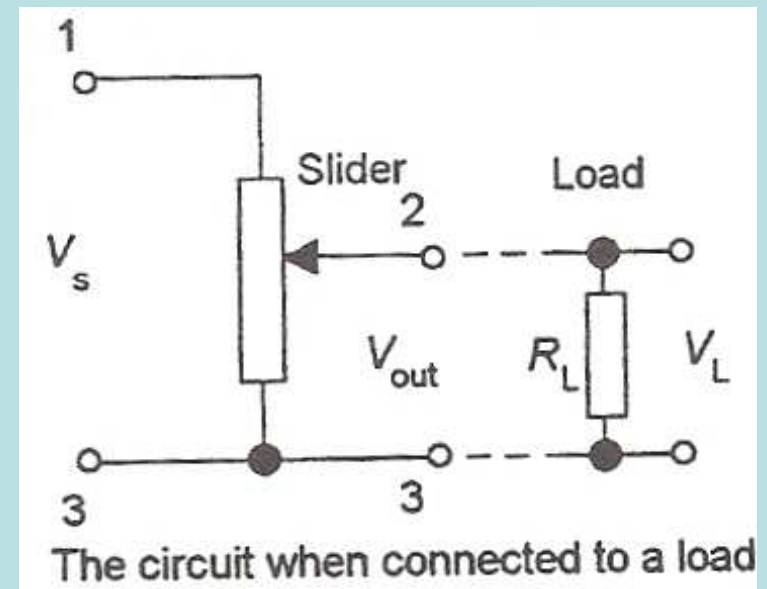
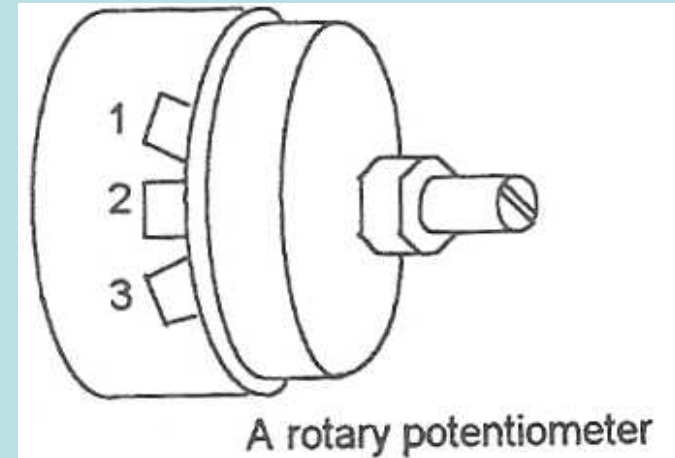
1-Potentiometer sensors (1)

It consist of a constant resistance per unit length with sliding contact which can be moved over the length of the element. It can be used for linear or rotary displacements

With a constant source voltage V_s , the output voltage V_o is a fractional of the input voltage

$$\frac{V_o}{V_s} = \frac{R_{23}}{R_{13}}$$

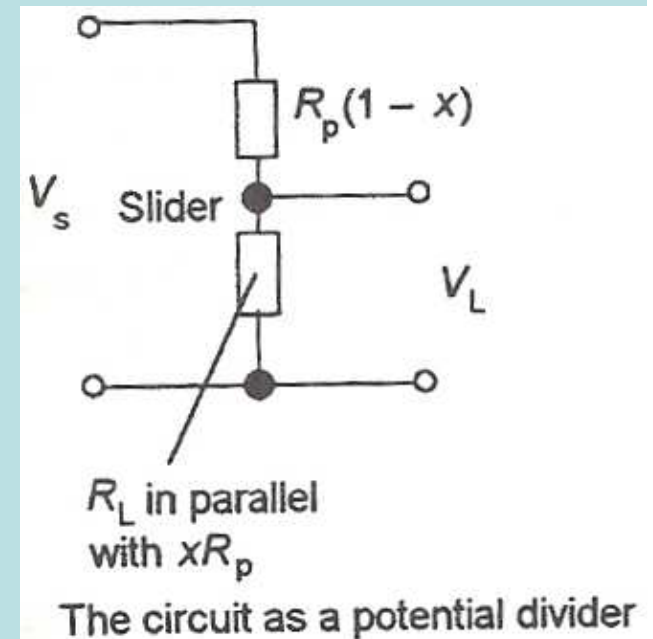
So, for rotary potentiometer the output voltage is proportional to the angle through which the slider has rotated, hence an angular displacement can be converted into a potential difference



1-Potentiometer sensors (2)

It is very important to consider the effect of the load resistance R_L connected across the output. The load voltage V_L is only directly proportional to V_0 if the load resistance is infinite.

Assuming that the total potentiometer resistance is R_p , find the error in the output reading in terms of x as suggested in the shown figure. And if $V_s=4$ volt, $R_p=500$ ohm and the slider is in the middle of the traveling range with a load resistance of 10 k Ohm. Find the value of the error (in volt)



$$\text{total resistance} = R_p(1-x) + R_L x R_p / (R_L + x R_p)$$

$$\begin{aligned} \frac{V_L}{V_s} &= \frac{x R_L R_p / (R_L + x R_p)}{R_p(1-x) + x R_L R_p / (R_L + x R_p)} \\ &= \frac{x}{(R_p/R_L)x(1-x) + 1} \end{aligned}$$

$$\begin{aligned} \text{error} &= x V_s - V_L = x V_s - \frac{x V_s}{(R_p/R_L)x(1-x) + 1} \\ &= V_s \frac{R_p}{R_L} (x^2 - x^3) \end{aligned}$$

$$\text{error} = 4 \times \frac{500}{10000} (0.5^2 - 0.5^3) = 0.025$$

2-Strain gauged element (1)

Strain gauge is a metal wire, metal foil or a strip of semiconductor material, these elements can be stuck onto surfaces like a postage stamp. When subjected to strain, its resistance R changes, the fractional change in resistance being proportional to the strain ϵ , i.e

$$\frac{\Delta R}{R} = G\epsilon$$

G is the gauge factor typical values are 2 for metal foil or wires +100 for P-type, -100 for N-type semiconductor

For $R=100$, $G=2$, the change in resistance due to 0.001 strain is $\Delta R=RG\epsilon=0.2$ ohm

Strain is the ratio of change in length / original length

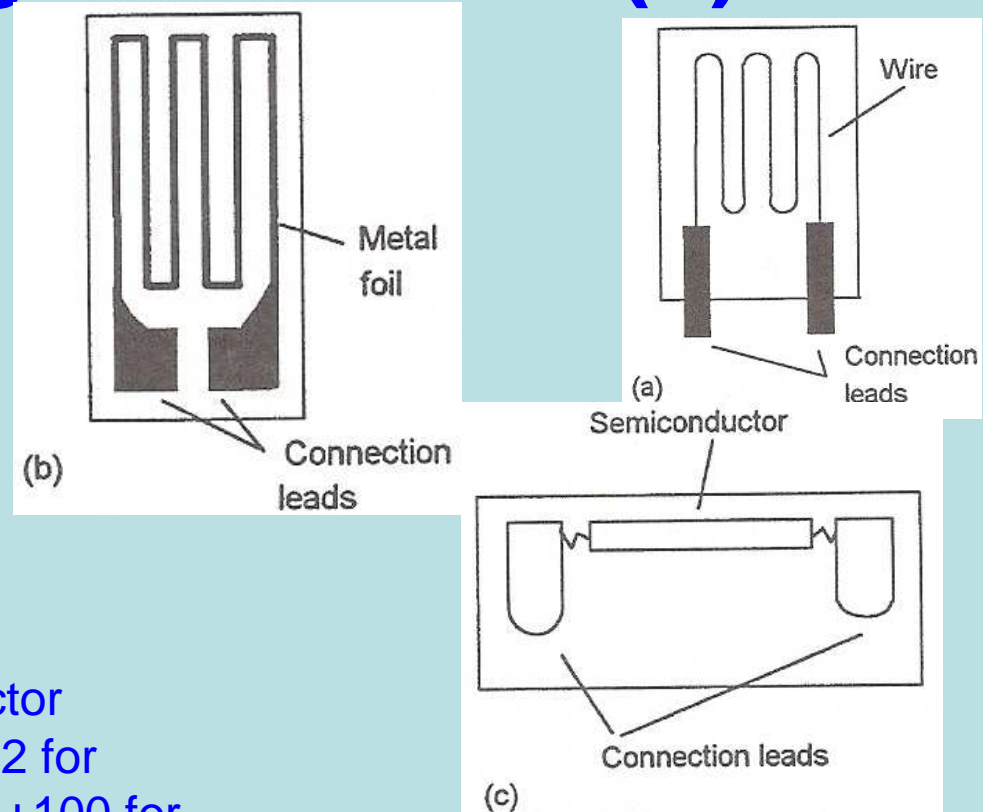
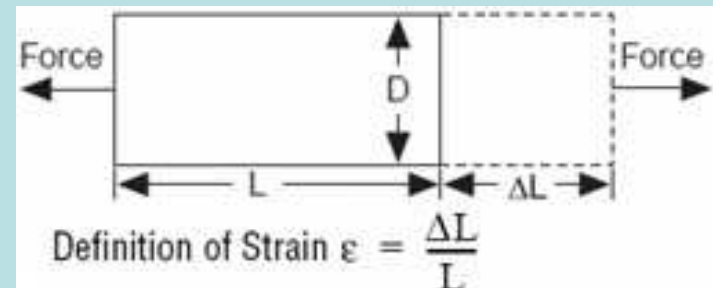
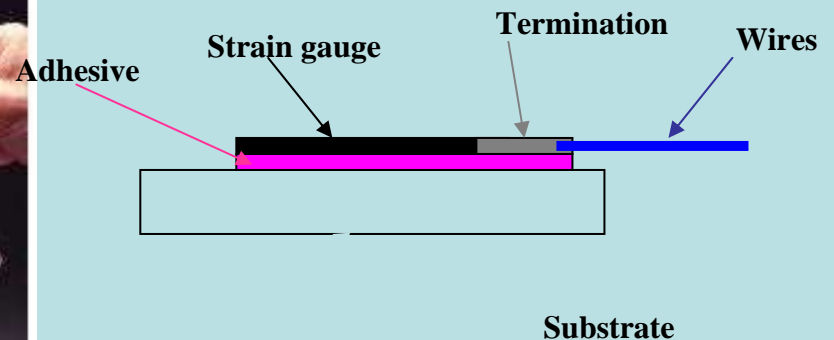
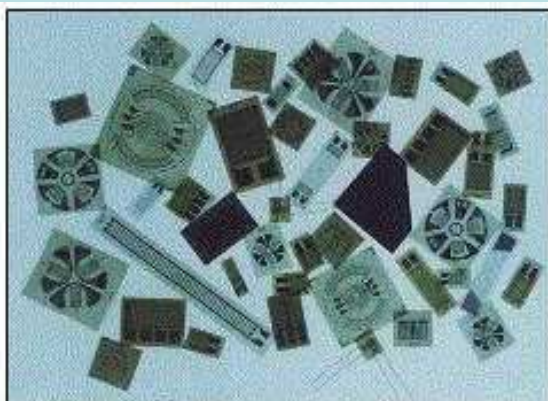
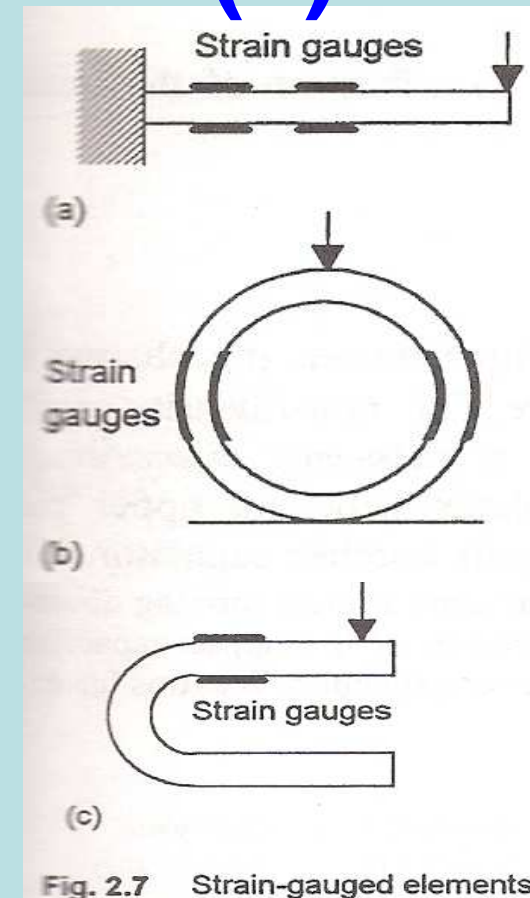


Fig. 2.6 Strain gauges: (a) metal wire, (b) metal foil, (c) semiconductor



2-Strain gauged element (2)

When the flexible element is bent or deformed as a result of forces being applied by a contact point being displaced, then the electrical resistance strain gauges mounted on the element are strained and so give a resistance change, which can be monitored. The change in resistance is thus a measure of the displacement or deformation of the flexible element



3- Capacitive element (1)

- Since capacitance C of a parallel plate is given by:
- Capacitive sensors for monitoring of linear displacements might take the forms shown.

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

In (a) if d is changed by a displacement x then capacitance is

$$C + \Delta C = \frac{\epsilon_r \epsilon_0 A}{d + x}$$

The change in the capacitance value is non linear relationship

$$\frac{\Delta C}{C} = -\frac{x/d}{1 + x/d}$$

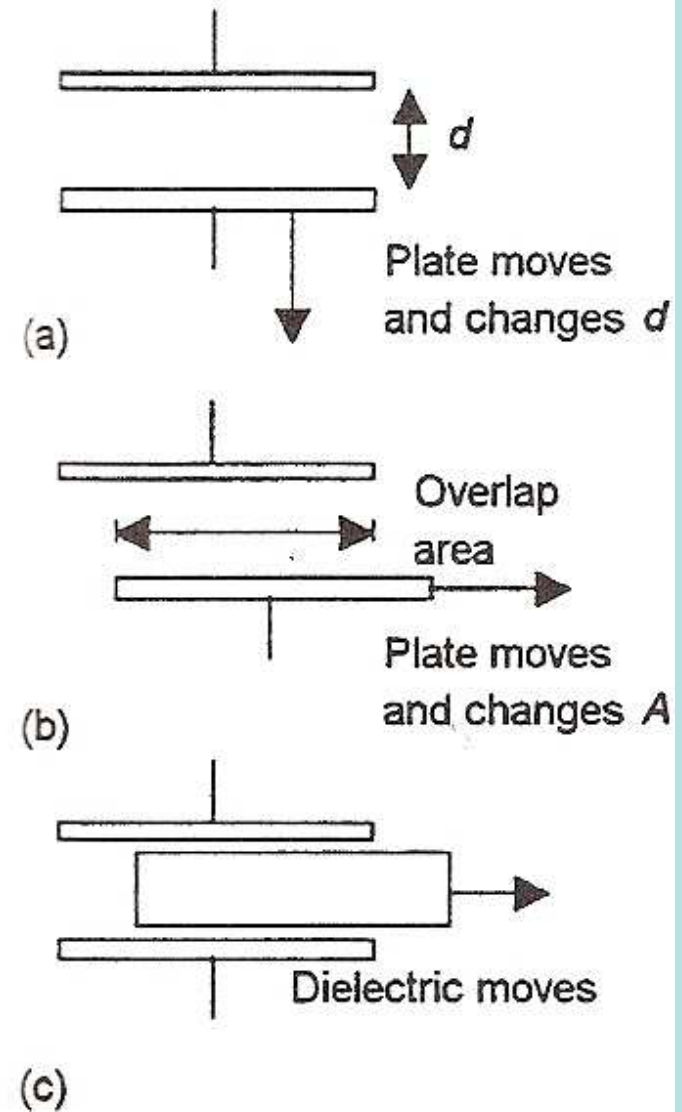


Fig. 2.8 Forms of capacitive sensing element

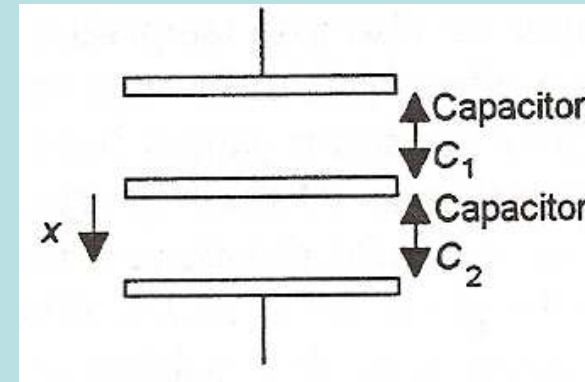
3- Capacitive element (2)

This nonlinearity can be overcome by using a push-pull displacement sensor shown. The displacement moves the central plate between the two outer plates so if initially the distance between plate 1 & 2 equal the distance between plate 2 & 3 then $C_1=C_2$

And for small displacement x

$$C_1 = \frac{\epsilon_0 \epsilon_r A}{d+x}$$

$$C_2 = \frac{\epsilon_0 \epsilon_r A}{d-x}$$



So when C_1 is in one arm of an ac bridge and C_2 in other arm then the result out balance voltage is proportional to x

$$V=a+bx \text{ ???}$$

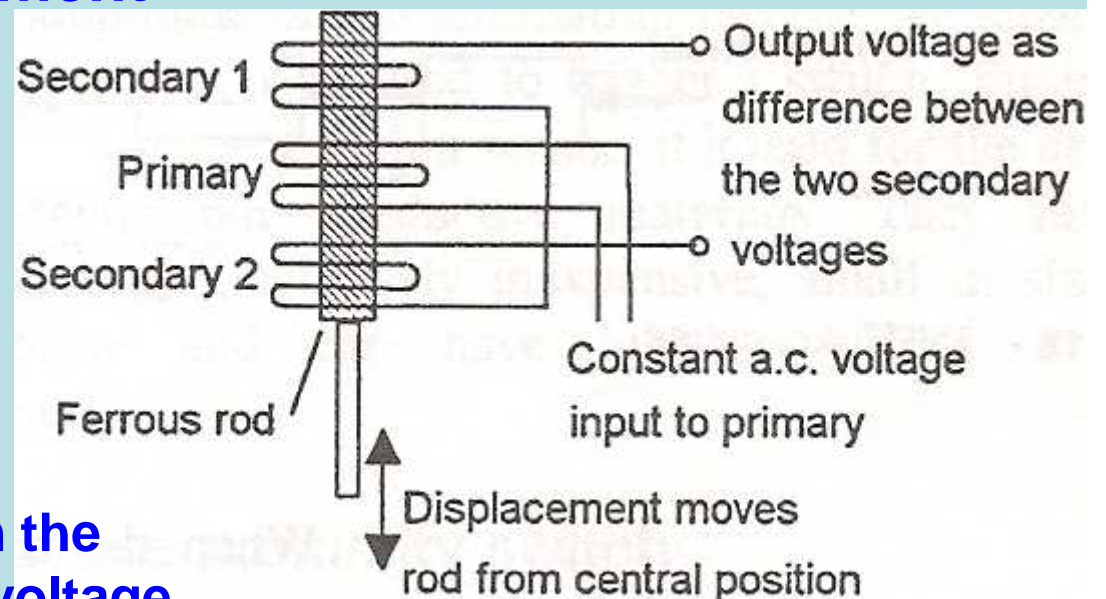
Show how

4- Differential Transformers(1)

- **Linear Differential Transformer “LVDT”** : it consist of three coils symmetrically spaced along an insulated tube. The two identical secondary coils are connected in series in such a way that their outputs oppose each other. **A magnetic core is moved through the central tube in response to a displacement**

If ac voltage is applied to the primary winding, equal and opposite voltages will be generated in the secondary winding and the net output voltage is zero

When the core is displaced from the center there is resultant output voltage



4- Differential Transformers(2)

The emf induced in the coil is given by

$$e = M \frac{di}{dt}$$

Where M is mutual inductance (depends on the number of turns and the core). For sinusoidal input current, the induced voltages can be written as:

$$v_1 = k_1 \sin(\omega t - \phi) \text{ and } v_2 = k_2 \sin(\omega t - \phi)$$

And the net output voltage with $v_1 > v_2$ is

$$\text{output voltage} = v_1 - v_2 = (k_1 - k_2) \sin(\omega t - \phi)$$

Or

$$\text{output voltage} = -(k_1 - k_2) \sin(\omega t - \phi)$$

with $v_2 > v_1$ is

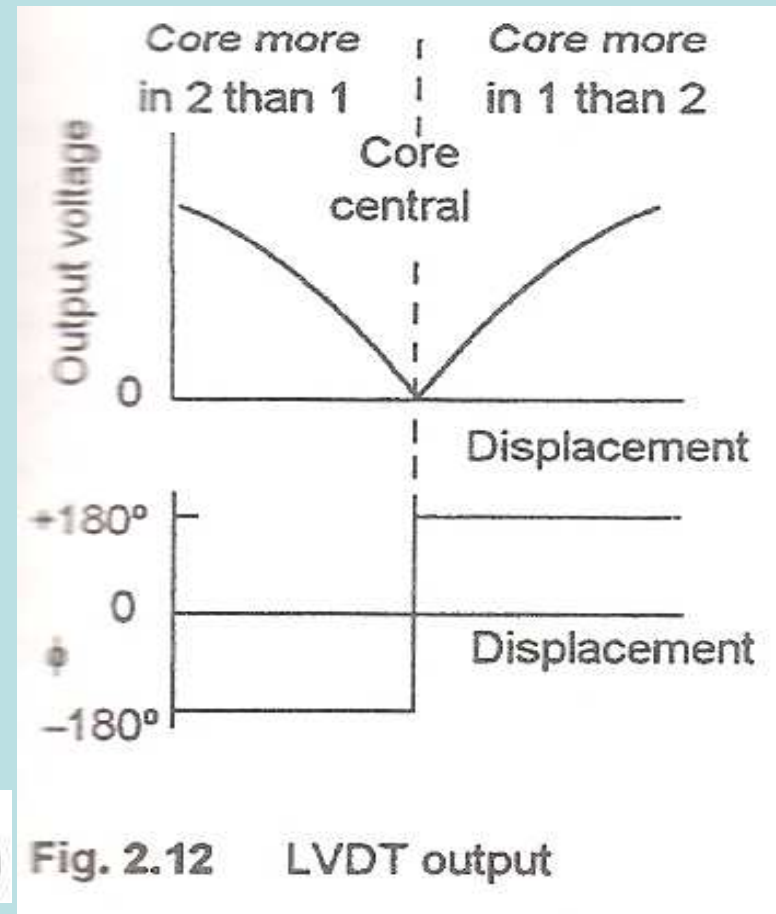
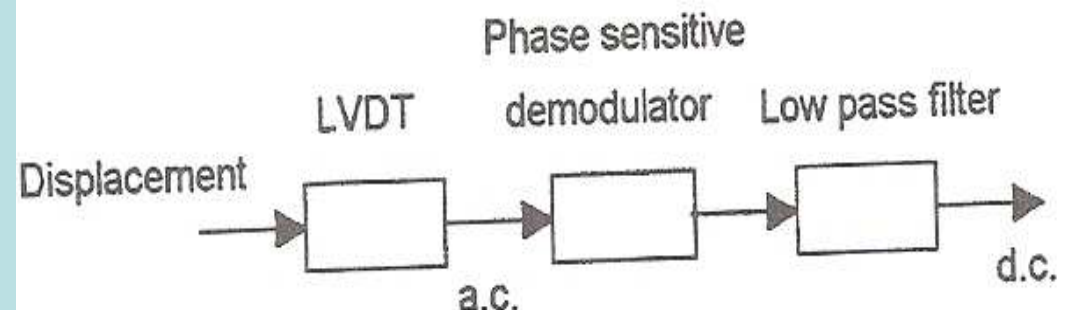
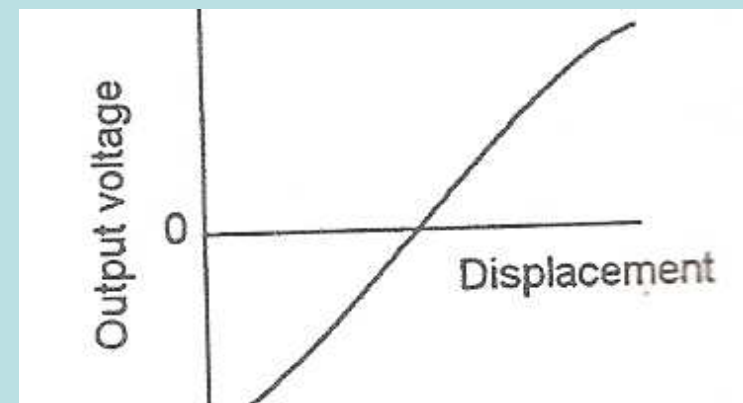


Fig. 2.12 LVDT output

4- Differential Transformers(3)

Normally a phase sensitive demodulator, with a low pass filter is used to convert the output into a dc. voltage which gives a unique value for each displacement.

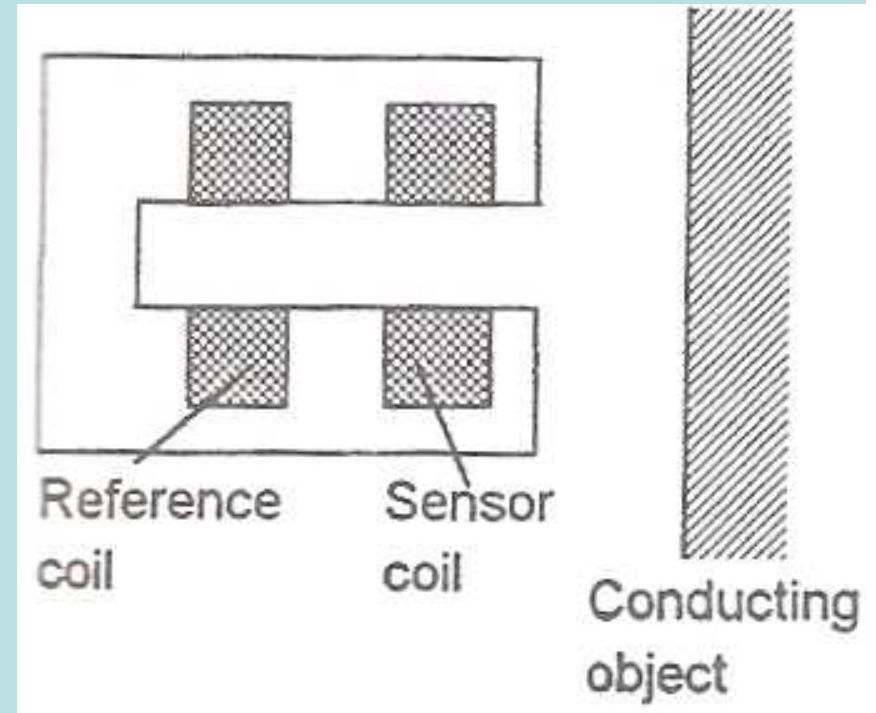
The free end of the core may be spring loaded for contact with the surface being monitored, so it used as sensor to monitor displacement . It can also be used as secondary transducers in the measurement of force, weight and pressure



Typical operating ranges $\pm 2\text{mm}$ to $\pm 400\text{mm}$ with nonlinearity errors $\pm 0.25\%$

5- Eddy current proximity sensors

If a coil is supplying an alternating magnetic field is in close proximity to a metal object, then an eddy current is produced in the object, which in turn produces a magnetic field. As a result the impedance of the coil change and so the amplitude of the alternating current. At some preset level, this change can be used to trigger a switch. It is used for detection of non-magnetic, but conductive materials



6- Inductive proximity sensor

- It consist of a coil wound a core. When the end of the coil is close to a metal object, its **inductance change**. This change can be monitored by its effect on **a resonant circuit** to trigger a switch. It can only be used **for detection of metal objects** and is best with ferrous metals.

7- Optical position encoders (1)

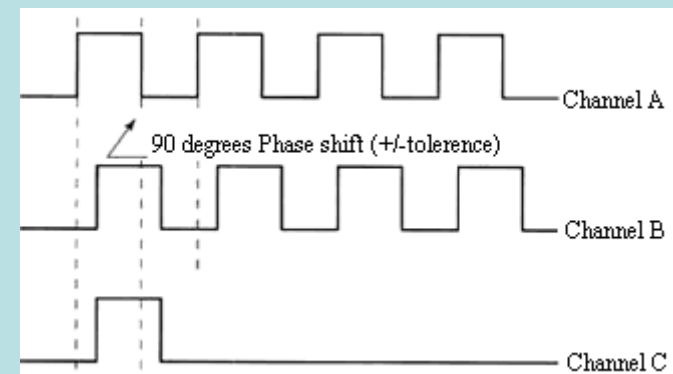
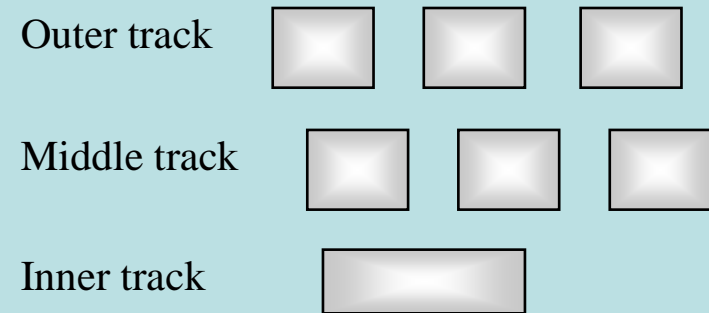
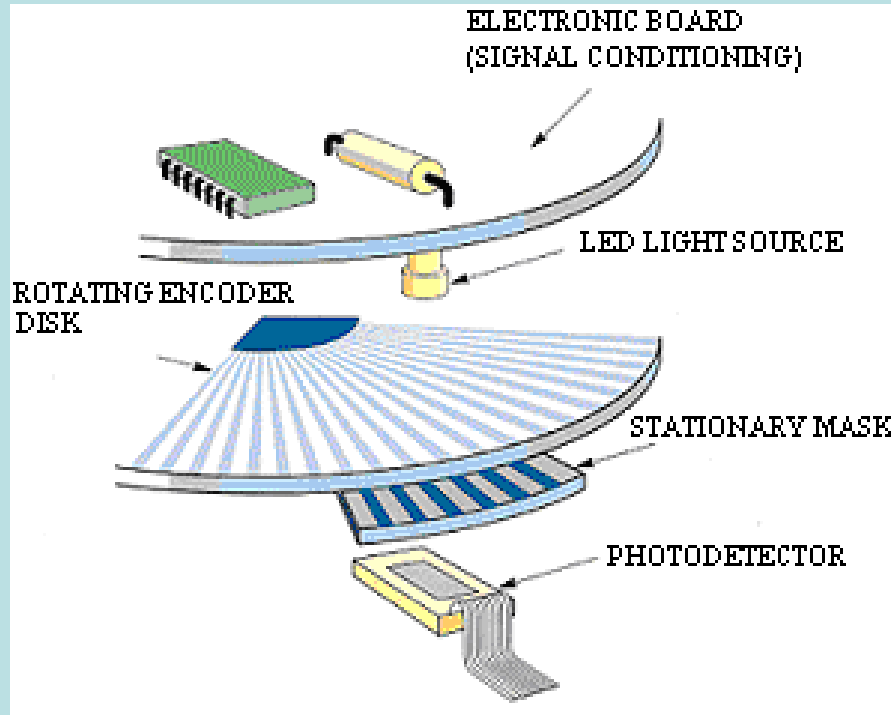
- An encoder sensor is a device that provides a digital output as a result of a linear or or angular displacement.

Position encoders are of two types:

- Incremental encoders: detect change s in rotation from some datum position
- Absolute encoders: gives the actual angular position

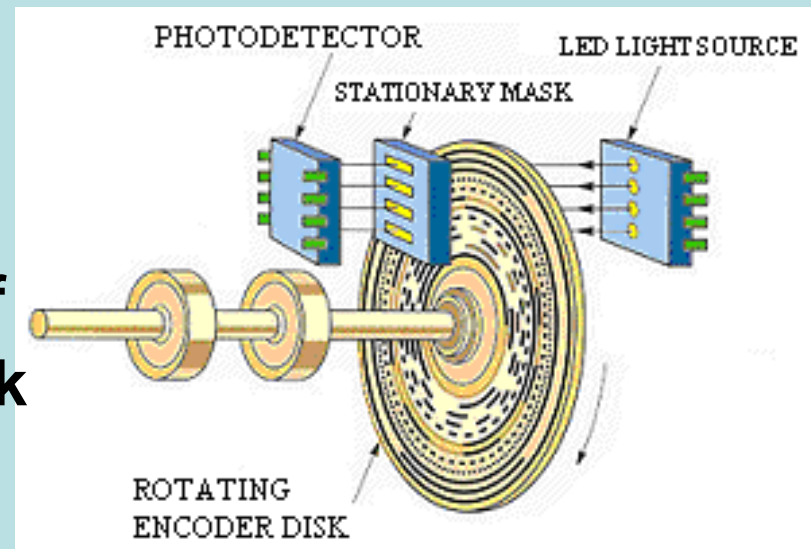
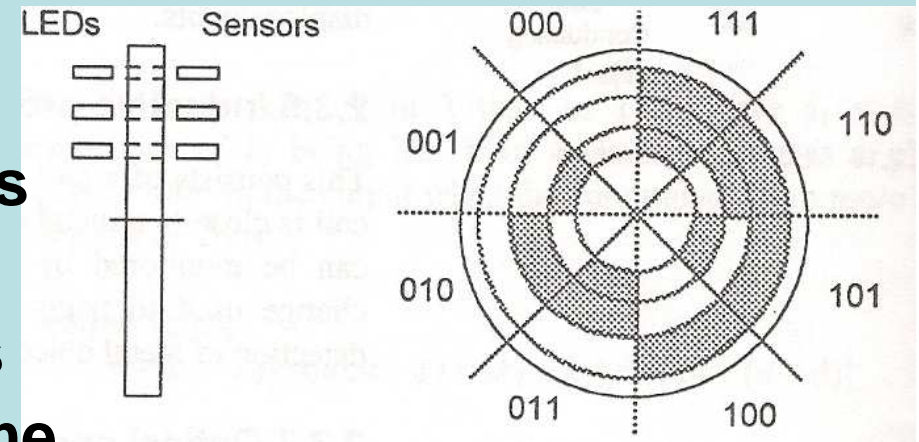
7- Optical position encoders (2)

- Incremental encoder:** A beam of light passes through slots in a disc and is detected by a suitable light sensor. When the disc is rotated, a pulsed output is produced by the sensor with the number of pulses being proportional to the angle through which the disc rotates. Normally three tracks are used to monitor the position



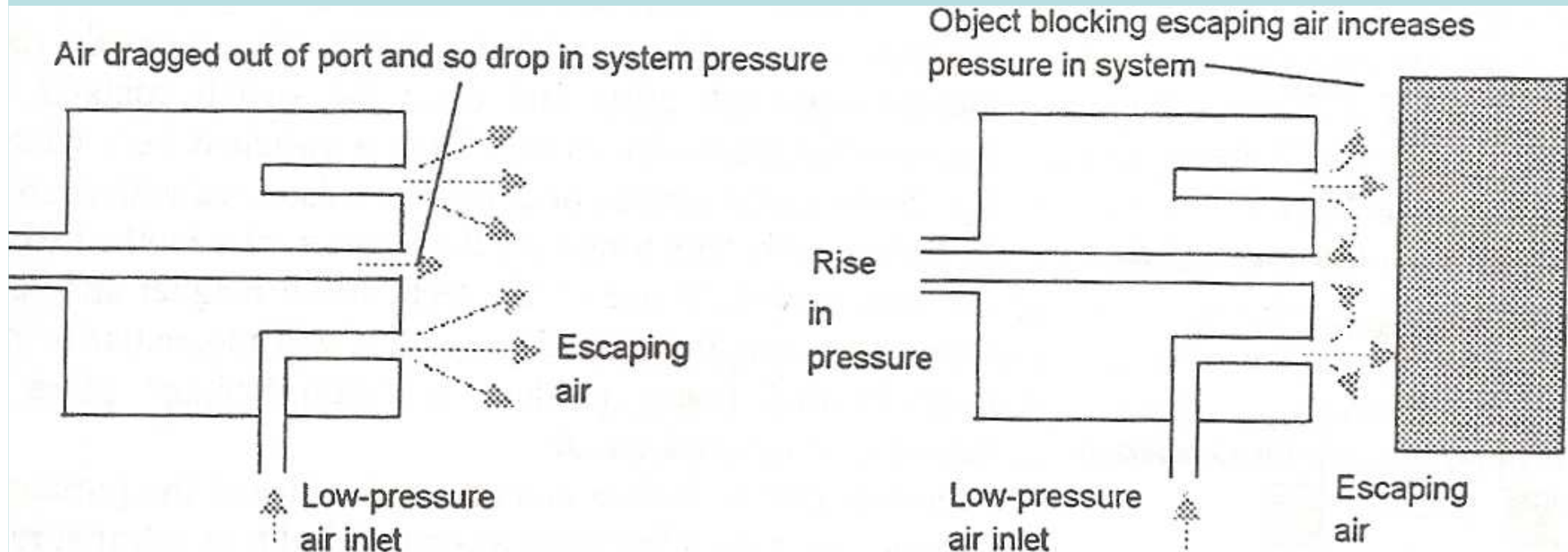
7- Optical position encoders (3)

Absolute encoder: output a unique digital numeric for any given position of the encoder's rotation. They are used in applications where a device is inactive for long periods of time or moves at a slow rate, such as flood gate control, telescopes, cranes, valves, etc. The rotary absolute encoder design uses a precision wheel with a number of concentric tracks, with each track representing one bit of accuracy



8- Pneumatic sensors

It involves the use of compressed air, displacement or the proximity of an object being transformed into a change in air pressure

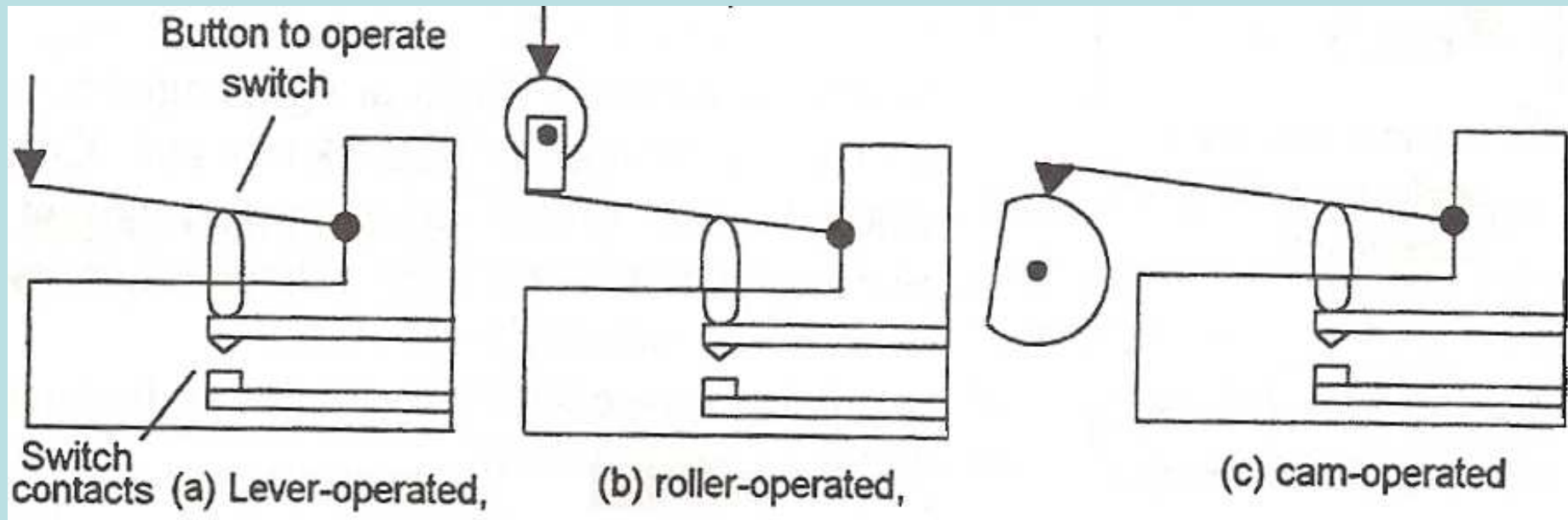


Low pressure is allowed to escape through a port in front of the sensor. So if there is a close by object, the air can not so readily escape and the result is that, the pressure increases in the sensor output port. Such sensor are used for measurement of displacements of fractions of millimeters (3-12 mm)

9- Proximity switches (1)

These are switches which can be activated by the presence of an object

Mechanical devices:



These are micro switches, which can be activated by the presences of an object, require physical contact and a small operating force to operate.

9-Proximity switches (2)

Reed switch:

It consists of two magnetic switch contacts sealed in a glass tube. When a magnet is brought close to the switch, the magnet reeds are attracted to each other and close the switch contacts. It is a non contact proximity switch.

Photosensitive devices:

Can be used to detect the presence of an opaque object that breaks a beam of light or infrared radiation falling upon such device or by detecting a light reflected from the object.

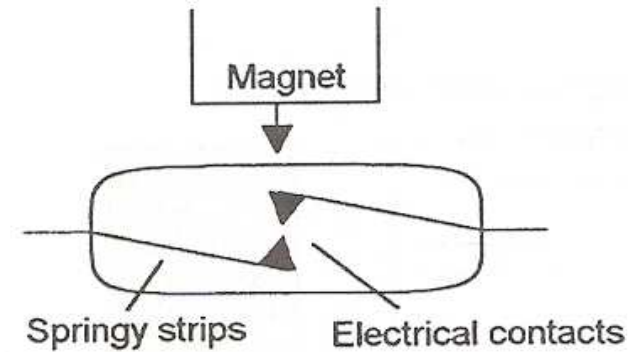
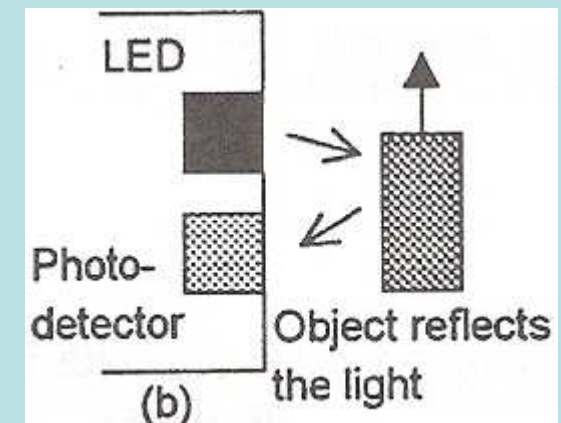
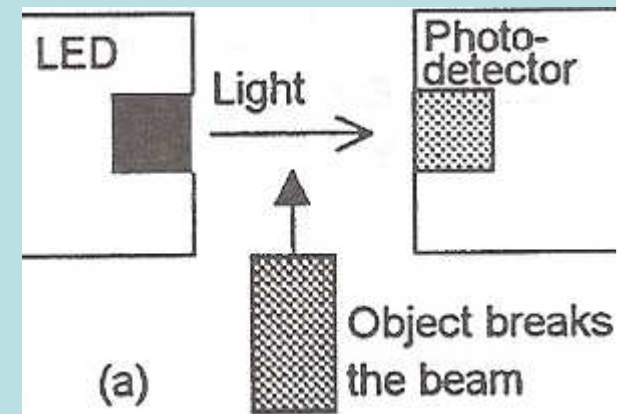


Fig. 2.21 Reed switch

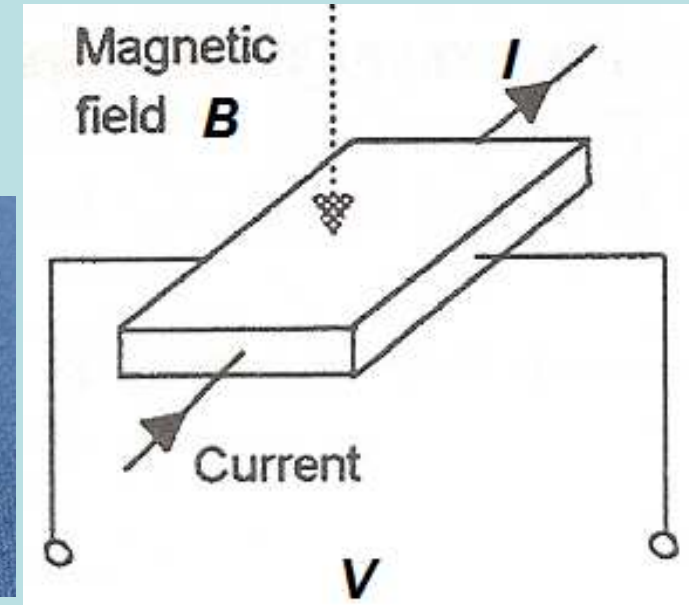
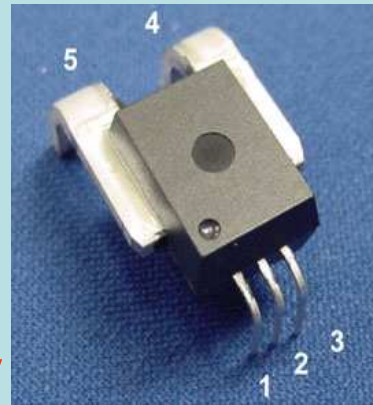


10- Hall effect sensors

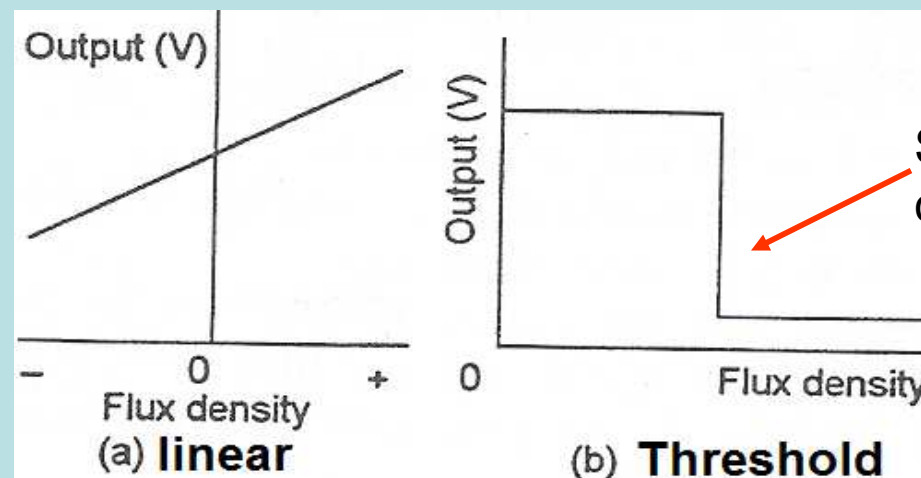
The function of the Hall Sensor is based on the principle of Hall Effect. A Voltage is generated transversely to the current flow direction, if a magnetic field is applied perpendicularly to the conductor.

- The value of this voltage is given by:
- Where t is the plate thickness and K_H is hall constant
- At constant current source, the voltage difference is a measure of magnetic flux density

$$V = K_H \frac{BI}{t}$$



Form of hall sensor:



Sharp drop at certain flux value

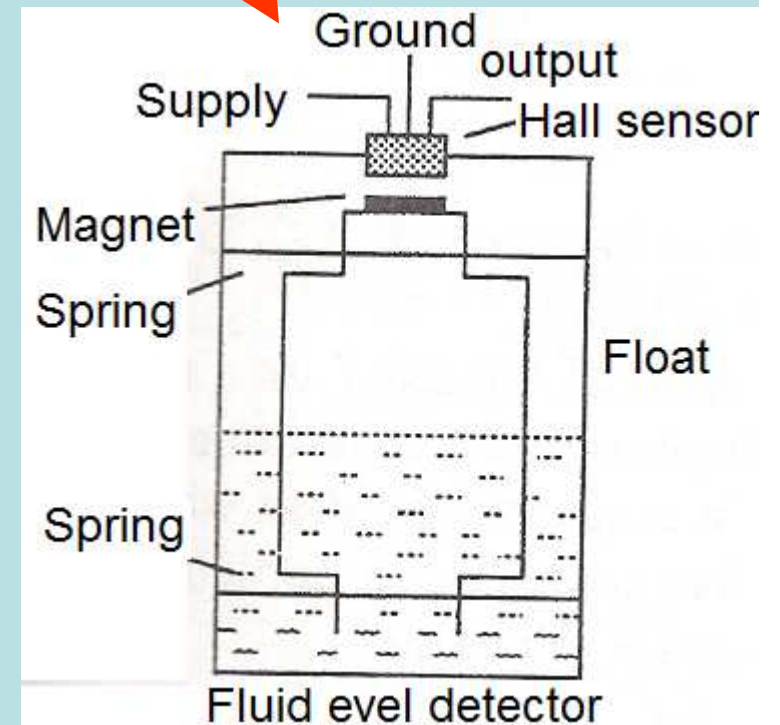
• can be used as switches up to 100 kHz

10- Hall effect sensors (application)

- Can be used as position, displacement and proximity sensors
- Can be used to measure the level of fluid

- **Other applications**

- commutation of BLDC motors
- Current and voltage measurement
- wheel speed sensors
- angle sensor
- Rotor position measurement
- distance measurement



Temperature sensors (1)

The temperature sensor can be grouped as:

- Bimetallic strips
- Thermocouples
- Resistance Temperature Detectors (RTD)
- Thermistors
 - Thermo-diodes & transistor

Bimetallic strips: The metals have different coefficients of expansion and when the temperature changes, the composite strip bends into curved strip, with the high coefficient metal on the outside of the curve. This deformation is used as a temperature switch as in the simple thermostat used in heating system.

Temperature sensors (2)- RTD

RTD are simple resistive elements in form of coils of wires of such material as platinum and nickel-copper alloys. They are available in many configurations and sizes

RTD follow the well known relationship

$$R_t = R_o (1 + \alpha \Delta T)$$

where;

R_t = resistance of the conductor at temp t ($^{\circ}\text{C}$)

R_o = resistance at the reference temp.

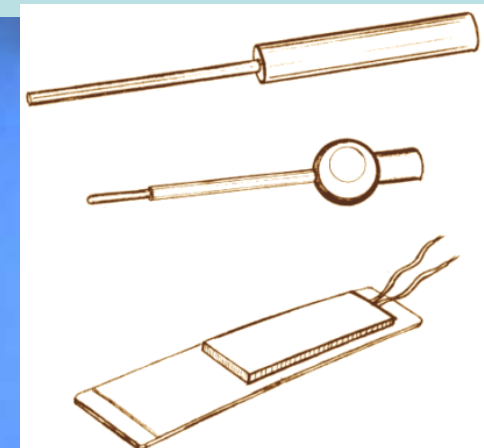
α = temperature coefficient of resistance

ΔT = difference in temperature ($T_t - T_o$)

Example:

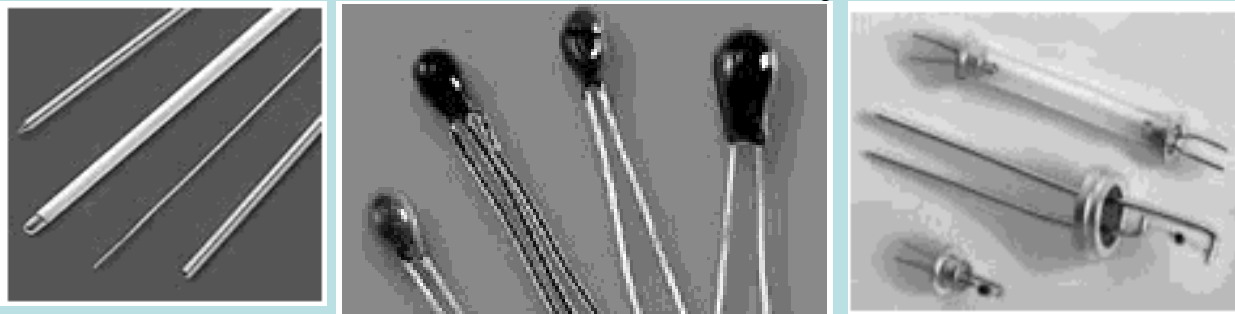
A platinum resistance thermometer has a resistance of 220Ω at 20°C . Calculate the resistance at 50°C ?

Given that $\alpha_{20^{\circ}\text{C}} = 0.00392$.



Temperature sensors (1)- Thermistors

- A **Thermistor** is a type of resistor used to measure temperature changes, relying on the change in its resistance with changing temperature. In the range of $(-40 \sim 150) ^\circ\text{C}$ with accuracy = ± 0.35



- Thermistors are of two types; NTC, negative thermal coefficient, and PTC, positive thermal coefficient.

The resistance of NTC thermistors decreases with increases in temperature.

The resistance of PTC thermistors increases resistance with increases in temperature

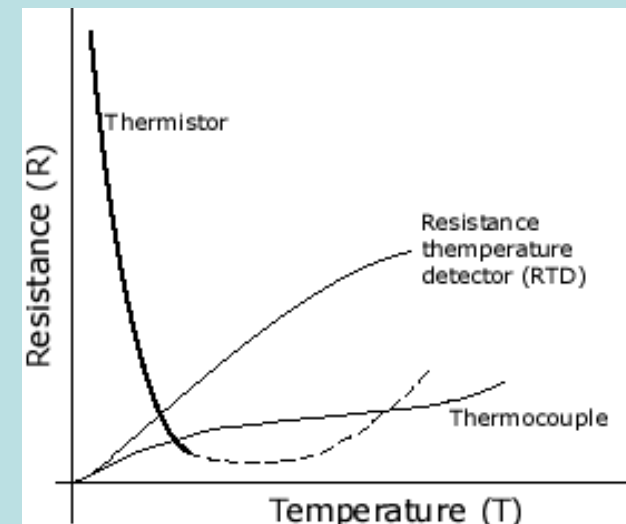
Temperature sensors (2)- Thermistors

- NTC are made from the oxides of metals such as manganese, cobalt, nickel and copper. Some NTC thermistors are crystallized from semiconducting material such as silicon and germanium.

PTC Thermistors are generally made by introducing small quantities of semiconducting material into a polycrystalline ceramic.

The change in resistance/ degree change in temperature can be described as:

$$R_t = ke^{B/t}$$

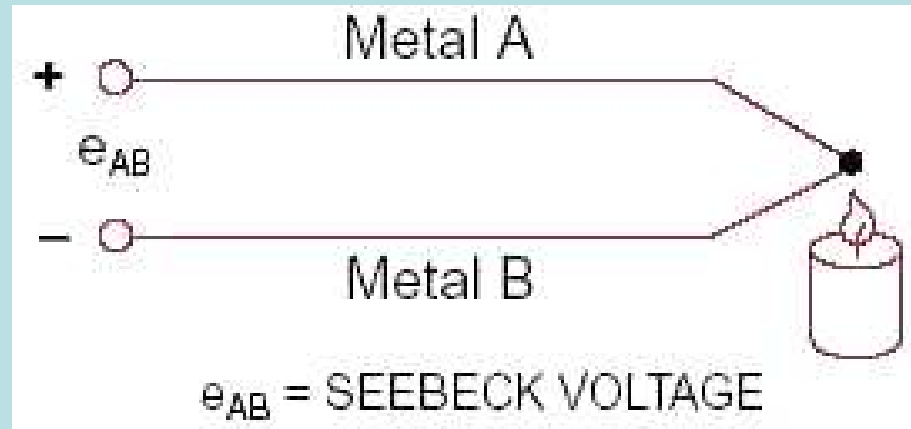


Temperature sensors (3)- Thermistors

- **PTC:** They are used as fuses, time delay circuits, motor starting circuits and as 'liquid level' and 'flow sensors'.
- **NTC:** Industrial process controls, Hot mold equipment, Solar energy, Engine temperatures. Fever Thermometers, Fluid temperature, Dialysis Equipment, refrigeration and air conditioning, Fire detection, Oven temperature control
- **Advantage of NTC:** rugged, can be very compact, they respond very rapidly to changes in temp., they give very large changes in resistance per degree temp.
- **temperature range**, typically $-100 \sim 150 \text{ }^{\circ}\text{C}$
- **Disadvantage of NTC:** Nonlinear resistance-temperature relationship, unlike RTD which have almost linear relationship.

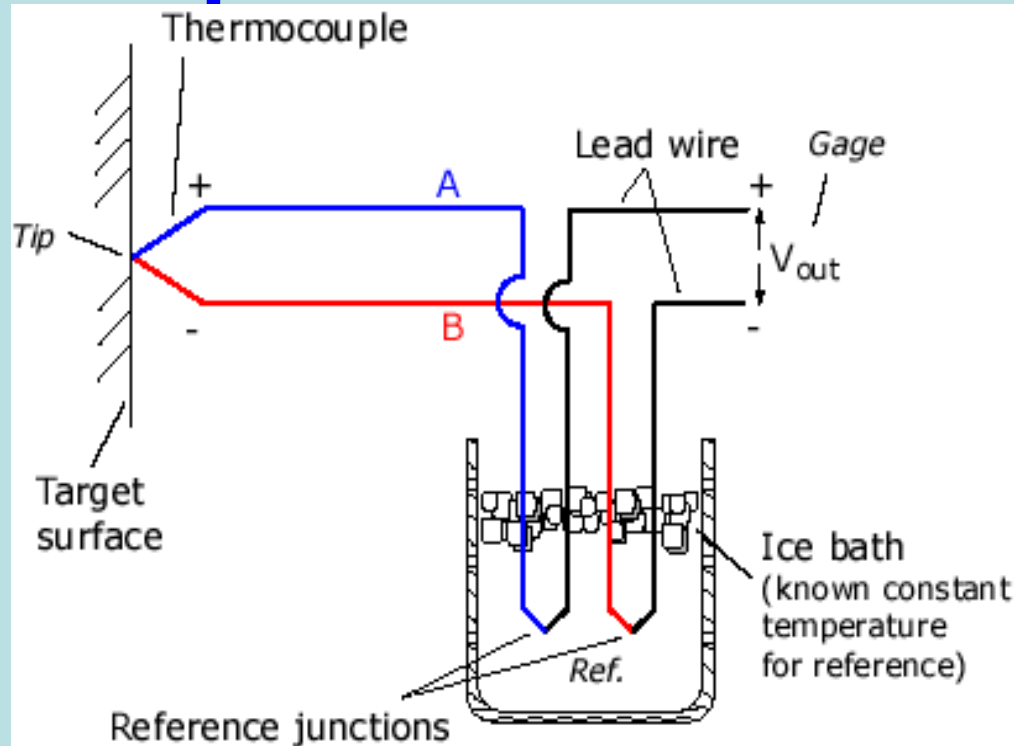
Temperature sensors (4)-thermocouple

It based on **Seebeck effect** that: if the junction of two different metals are heated, a potential difference occurs across the junction.



A thermo-couple is a complete circuit involving two such junctions. If both junctions are at the same temperature there is no net emf, however, if there is a different in temperature between the two junctions, there is an emf

Temperature sensors (4)-thermocouples



Normally one junction is held at 00C and to a reasonable extent the following relationship holds:

$$V=at + bt^2 ; a \& b \text{ are constant}$$

- **Example :** During experiment with a copper- constantan thermocouple, it was found that $a= 3.75 \times 10^{-2} \text{ mV/}^\circ\text{C}$ and $b = 4.50 \times 10^{-5} \text{ mV/}^\circ\text{C}$. If $T_1= 100^\circ\text{C}$ and the cold junction T_2 is kept in the ice, compute the resultant electromotive force, emf?

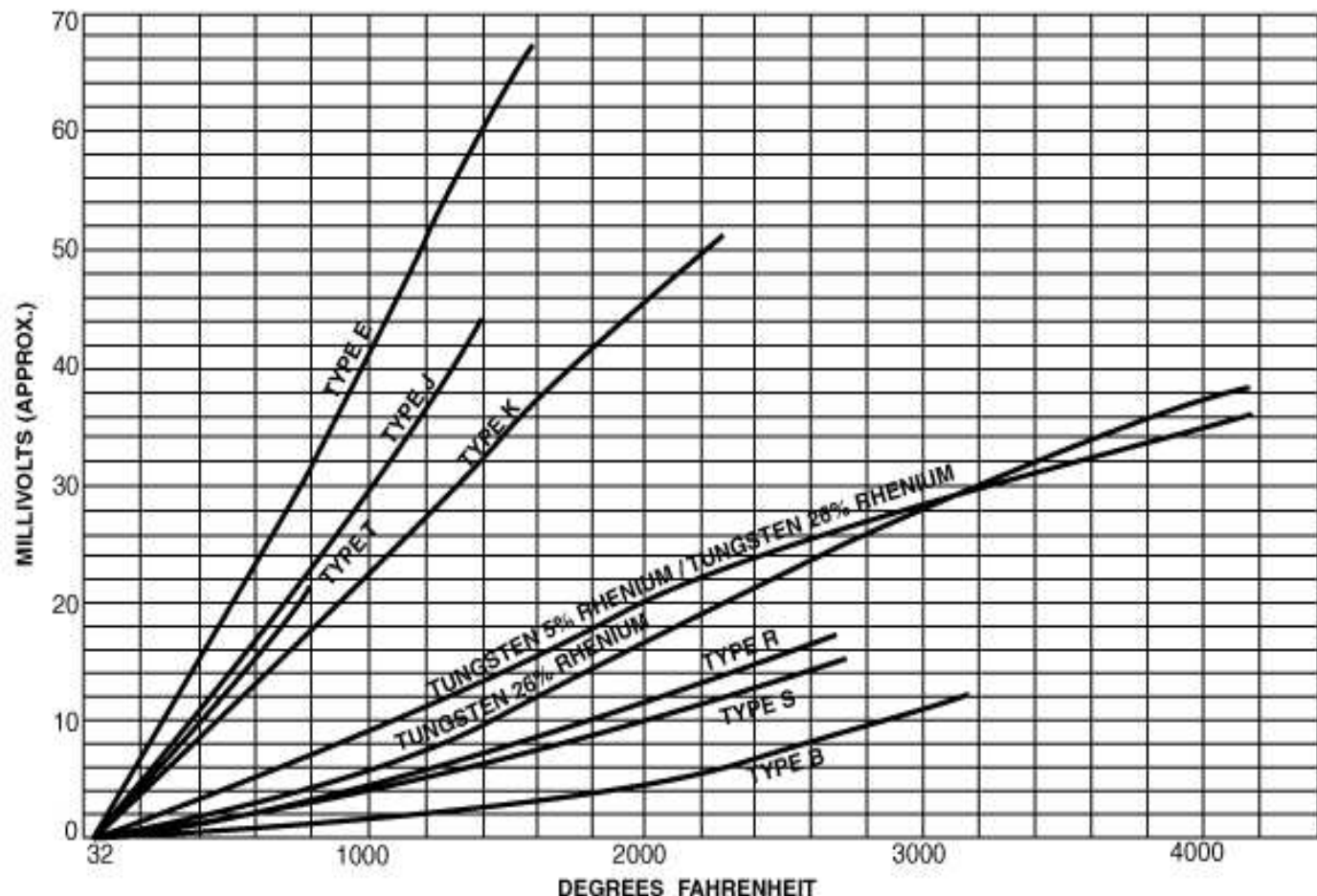
Temperature sensors (4)-thermocouples

Types of thermocouple

Type E, J, K, and T are base-metal thermocouples and can be used up to about 1000°C (1832°F).

Type S, R, and B are noble-metal thermocouples and can be used up to about 2000°C (3632°F).

Ref.	Range	$\mu\text{V}/^\circ\text{C}$
B	(0-1800)	3
E	(-200-1000)	63
J	(-200-1300)	53
K	(-200-1300)	41
N	(-200-1300)	28
R	(0-1400)	6
S	(0-1400)	6
T	(-200-400)	43



Velocity and Motion sensors (1)

- Many sensors is now under operation to monitor linear and angular velocity and detect motion however the most used are

- Encoders, **Tacho-generators** Pyroelectric sensors

Both
incremental and
absolute
encoders

Is used to measure
angular velocity :
1-Variable reluctance
2-Ac generator

It is based on pyroelectrical
materials that produces
charge in respond to heat
flow

Velocity and Motion sensors (2)

Tacho-generator:

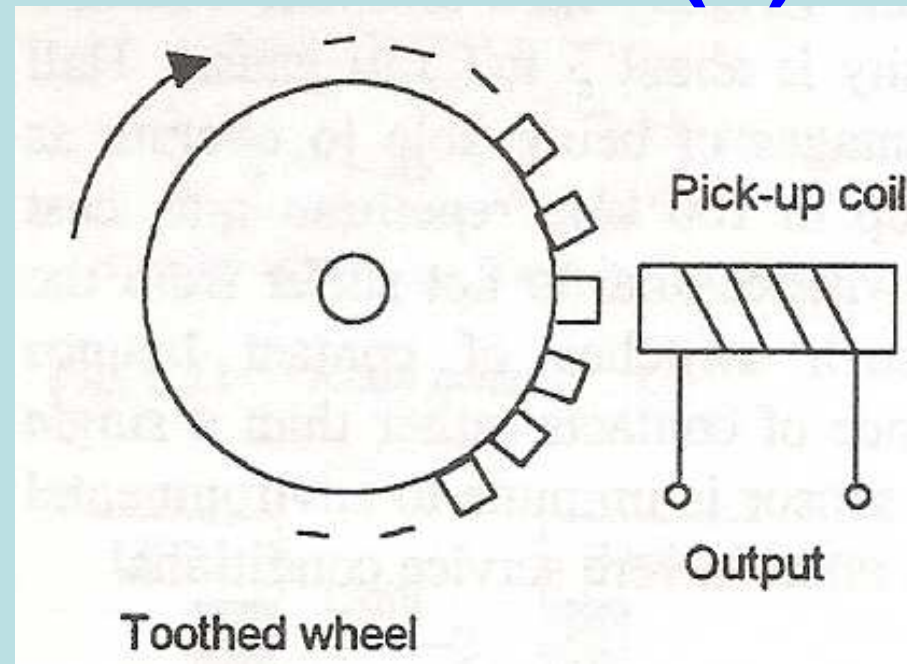
Is used to measure angular velocity

Can be of two types: variable reluctance or ac generator

The variable reluctance one consist of toothed wheel of ferromagnetic material which is attached to the rotating shaft. As the wheel rotates, the air-gap between the coil and the Ferro-magnet changes. Thus the flux linked by the a pickup coil changes. This result in alternating emf in the coil. If the coil has n teeth and rotates with angular velocity w, then the flux and the induced voltage is given by

$$\Phi = \Phi_0 + \Phi_a \cos n\omega t$$

Φ_0 is the mean value of the flux



$$e = -N \frac{d\Phi}{dt} = -N \frac{d}{dt} (\Phi_0 + \Phi_a \cos n\omega t) \\ = N\Phi_a n\omega \sin n\omega t$$

$$e = E_{\max} \sin \omega t$$

E_{\max} is measure of the angular velocity. A pulse shaping circuit can be use to transform the output into sequence of pulses which can be counted