MODULE 4

Measurement of Industrial Parameters

Measurement of temperature: thermistor and LM35, Measurement of pressure: strain gauge and piezoelectric type, Measurement of distance: ultrasonic, linear variable differential transformer and capacitance type, proximity sensor, Infrared sensor, Pulse oximeter and Tachometer.

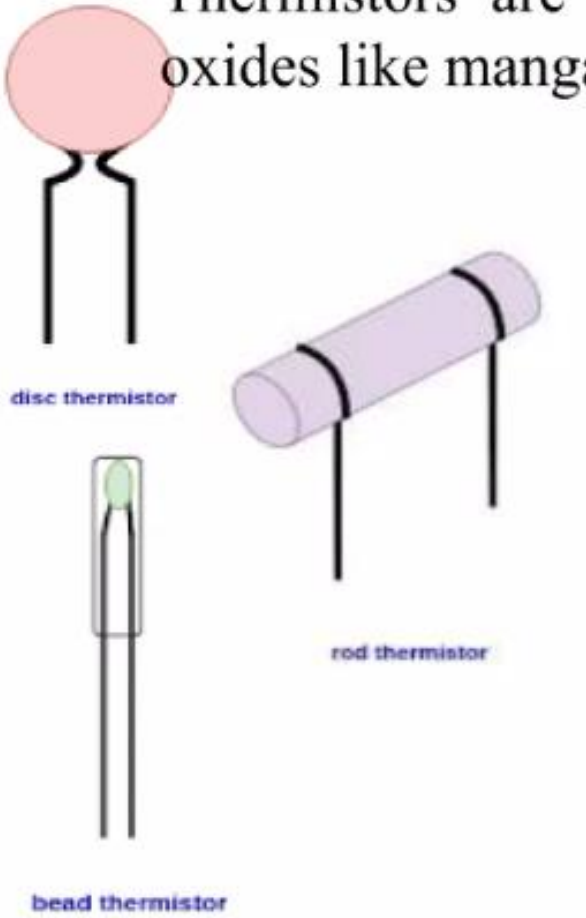
MEASUREMENT OF TEMPERATURE

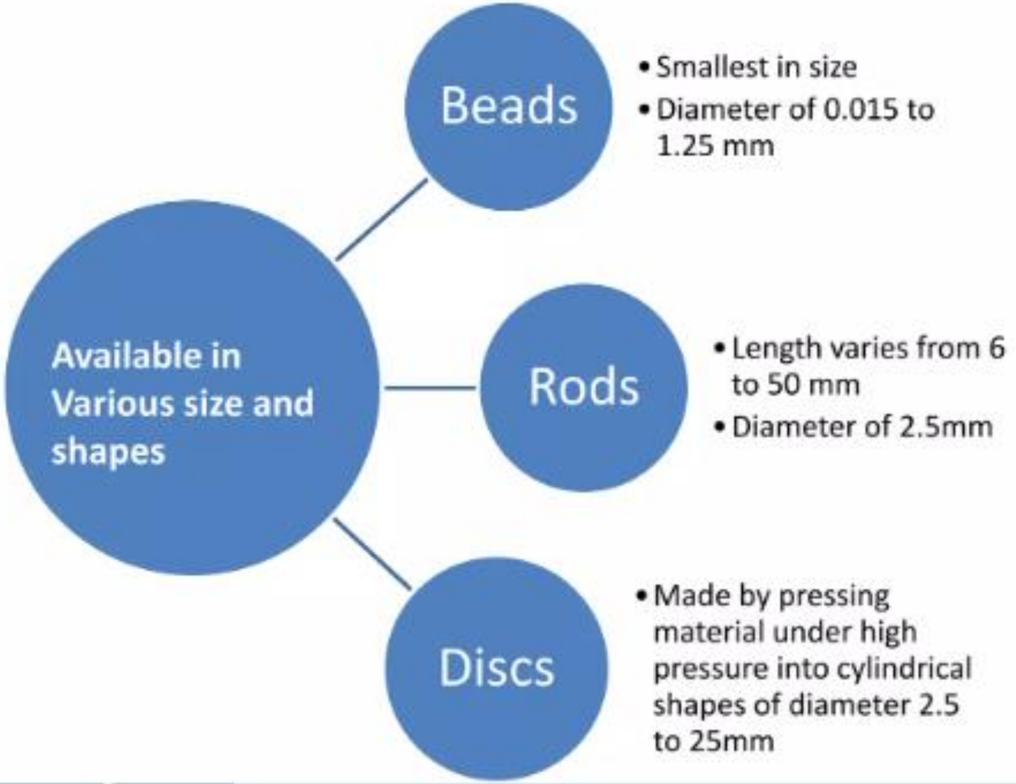
- Thermistor
- LM35

THERMISTORS

- A temperature sensing element which measures temperature according to change in resistance
- Usually made up of sintered semiconductor material
- Thermistors are based on the temperature dependence of a semiconductor's resistance, which is due to the variation in the number of available charge carriers and their mobility.
- When the temperature increases, the number of charge carriers increases too and the resistance decreases, thus yielding a negative temperature coefficient.
- This dependence varies with the impurities;
- When the doping is very heavy, the semiconductor achieves metallic properties and shows a Positive Temperature Coefficient over a limited temperature range.

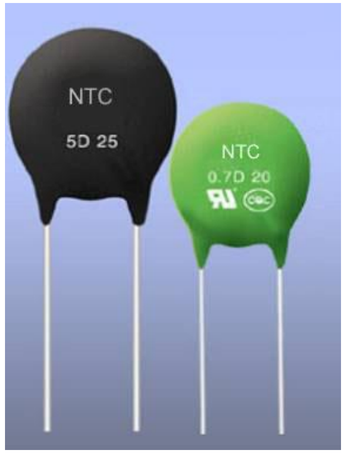
- Thermistors are composed of sintered mixture of metallic oxides like manganese, nickel, cobalt, iron and uranium.

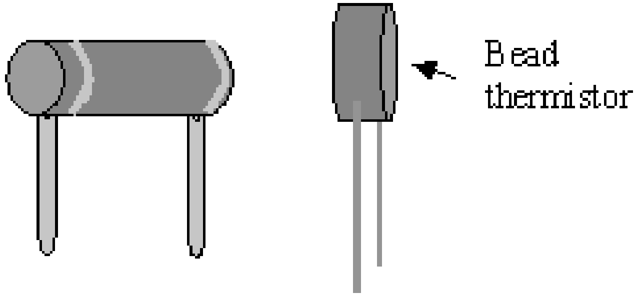


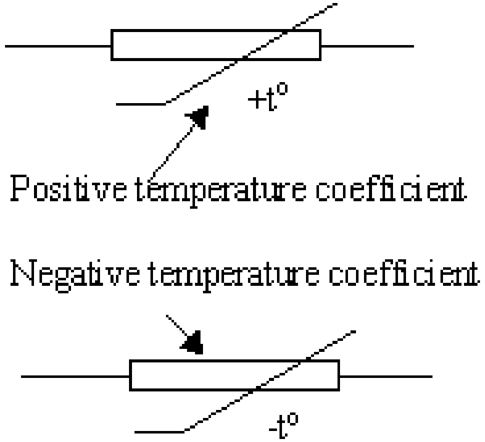


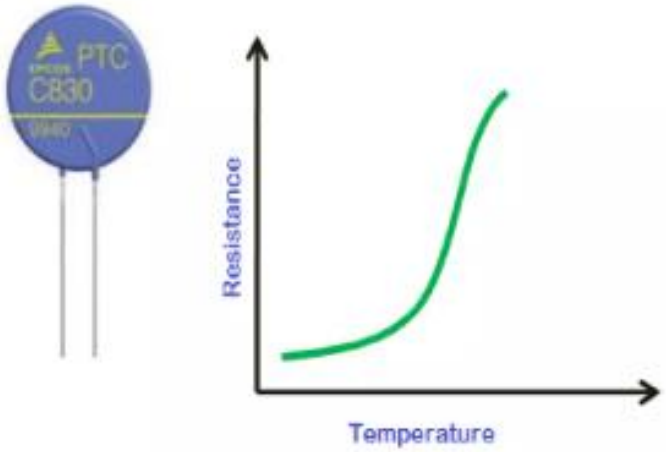
Thermistors

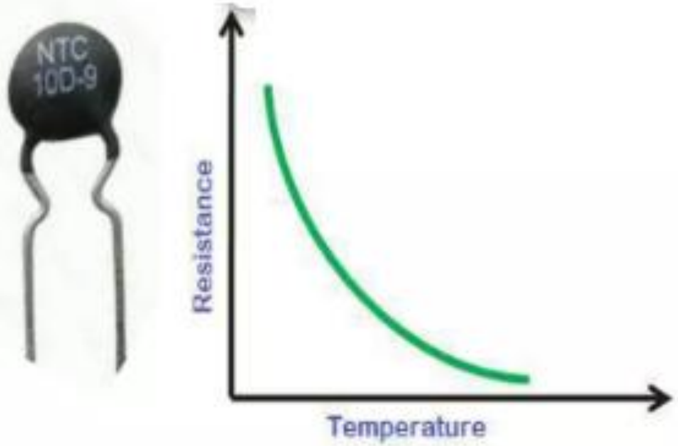
- **<u>Thermally Sensitive Resistor</u>**
- The most common type of thermistor that we use has a resistance that falls as the temperature rises.
- It is referred to as a negative temperature coefficient device(NTC).
- A positive temperature coefficient(PTC) device has a resistance that increases with temperature.











- PTC stands for *Positive Temperature Coefficient*. As temperature rises, resistance increases . This type of thermistor is used in
- Current limiting devices
- Self regulating heaters
- Timer in degaussing coil
- Motors

- NTC stands for *Negative Temperature Coefficient*. As temperature rises, resistance decreases . These are employed in
- Very low temperature thermometer
- Digital Thermostats
- Battery pack monitors
- In-rush protection devices

Thermistors Analysis

- The thermistor resistance-temperature relationship can be approximated by,

$$R = R_{Ref}.\,e^{\beta\left(\frac{1}{T}-\frac{1}{T_{Ref}}\right)}$$

where: T is temperature (in kelvin),

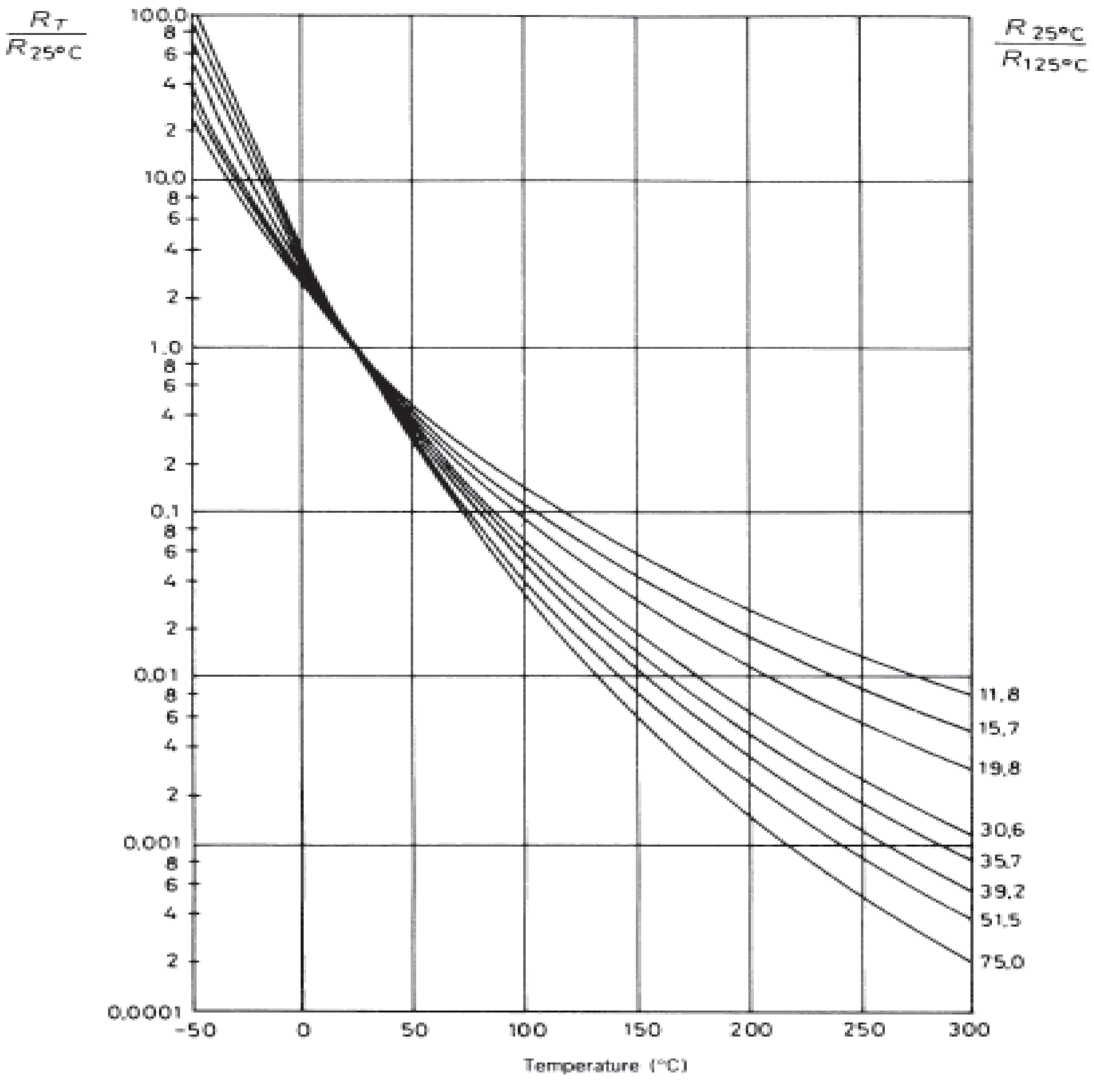
T_{Ref} is the reference temperature, usually at room temp. (25 °C; 77 °F; 298.15 K),

R is the resistance of the thermistor (Ω),

R_{Ref} is the resistance at T_{Ref},

β is a calibration constant depending on the thermistor material, usually between 2,000 and 3,000 K.

Resistance temperature curve for several NTC thermistors



- For a typical thermistor, a two-parameter model yields a ±0.3°C accuracy for a 50° C span.
- A three-parameter model reduces the error to ±0.01°C in a100°C span.
- The model is then described by the empirical equation of Steinhart and Hart,

$$R_T = e^{(A+B/T+C/T^3)}$$

2 parameter model

$$R_T = \exp\left(\sqrt[3]{-\frac{m}{2}+\sqrt{\frac{m^2}{4}+\frac{n^2}{27}}}+\sqrt[3]{\frac{m}{2}-\sqrt{\frac{m^2}{4}+\frac{n^2}{27}}}\right)$$

3 parameter model

$m = (a - 1/T)/c$ and $n = b/c$

NTC Thermistors Application

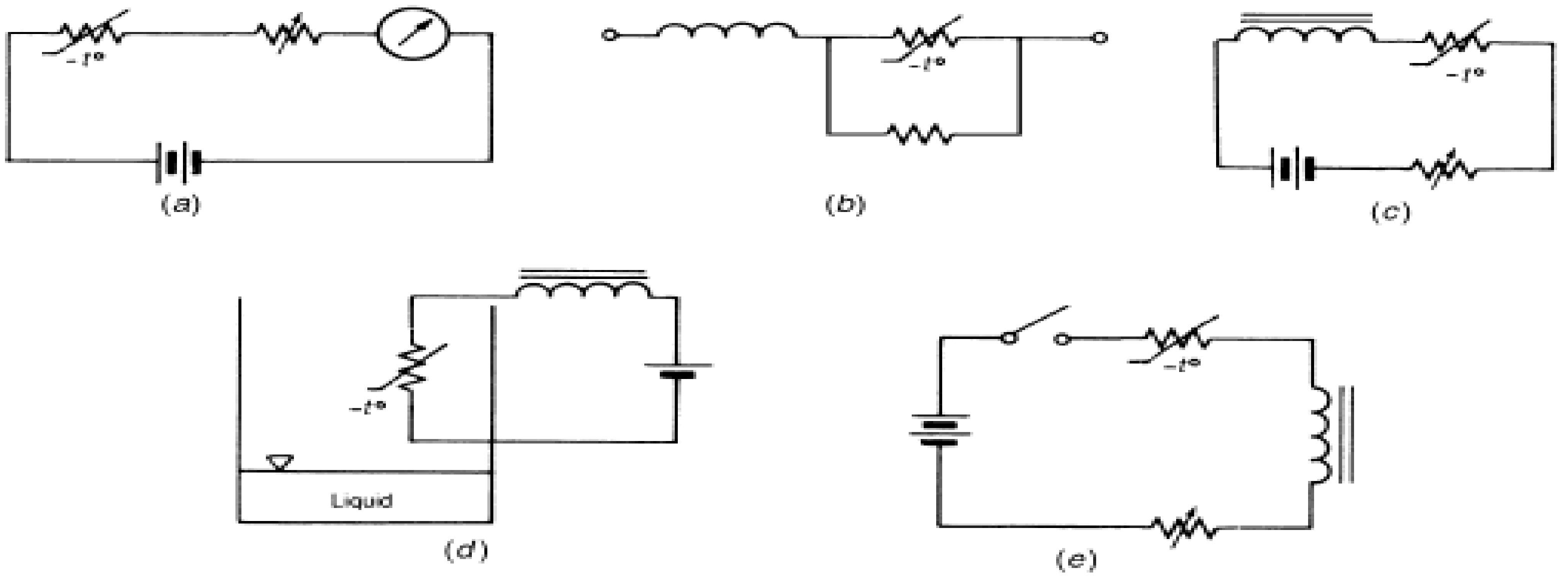
(a) Temperature measurement.

(b) Temperature compensation.

(c) Temperature control.

(d) Level control.

(e) Time delay when connecting.

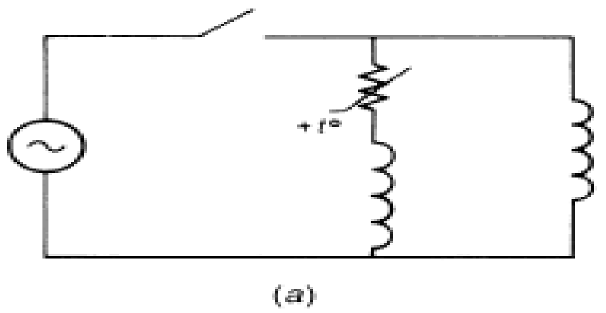


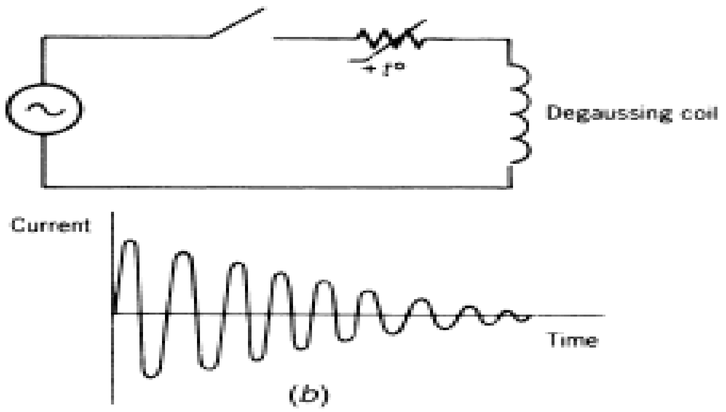
PTC Thermistors Application

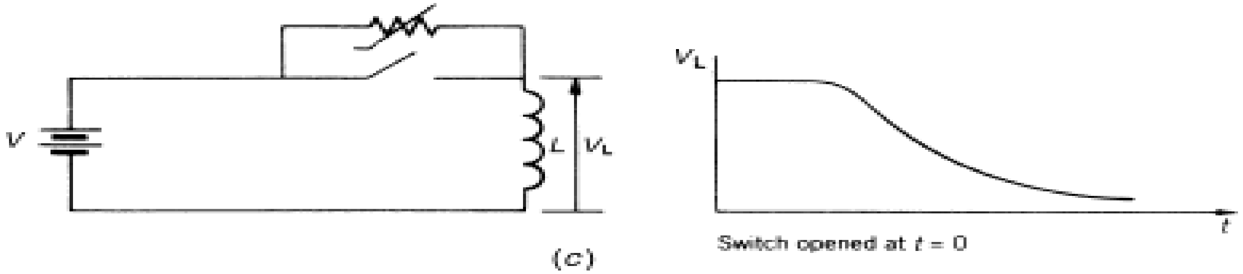
(a) Single-phase motor Starting

(b) Circuit for automatic degaussing

(c) Arc suppression for switch contacts







LM35 TEMPERATURE SENSOR

- LM35 is an integrated analog temperature sensor whose electrical output is proportional to Degree Centigrade.
- LM35 Sensor does not require any external calibration or trimming to provide typical accuracies.
- The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy.
- LM stands for linear monolithic
- Main advantage of LM35 is that it is linear i.e.
  - 10mv/°C which means for every degree rise in temperature the output of LM35 will rise by 10mv. So if the output of LM35 is 220mv/0.22V the temperature will be 22°C. So if room temperature is 32°C then the output of LM35 will be 320mv i.e. 0.32V.

Working of LM35

- A temperature sensor measures the hotness or coolness of an object.
- The sensor's working base is the voltage that's read across the diode.
- The temperature rises whenever the voltage increases.
- The operating temperature range is from -55°C to 150°C.

Features of LM35 Temperature Sensor

- Calibrated directly in Degree Celsius (Centigrade)
- Linear at 10.0 mV/°C scale factor
- 0.5°C accuracy guarantee-able (at a25°C)
- Rated for full -55°C to a 150°C range
- Suitable for remote applications
- Low cost due to wafer-level trimming
- Operates from 4 to 30 volts
- Less than 60 mA current drain
- Low self-heating, 0.08°C instill air
- Non-linearity only 0.25°C typical
- Low impedance output, 0.1Ωfor 1 mA load

MEASUREMENT OF PRESSURE

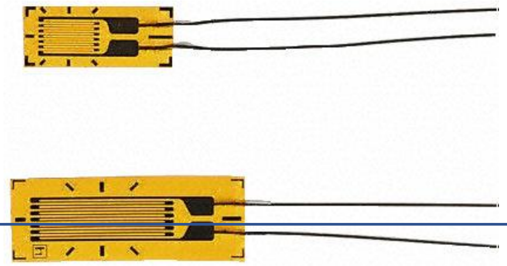
- Strain Gauge
- Piezoelectric type

STRAIN GAUGE

- A **strain gauge (or strain gage)** is a device used to measure strain on an object. It is also termed as Load cell

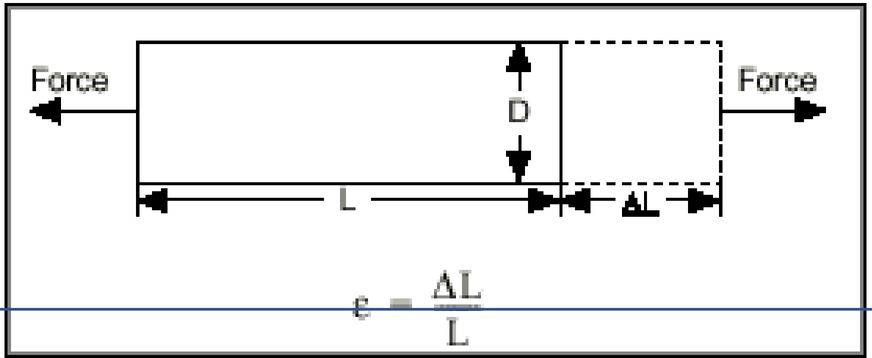
- Invented by Edward E. Simmons and Arthur C. Ruge in 1938

- The most common type of strain gauge consists of an insulating flexible backing which supports a metallic foil pattern.



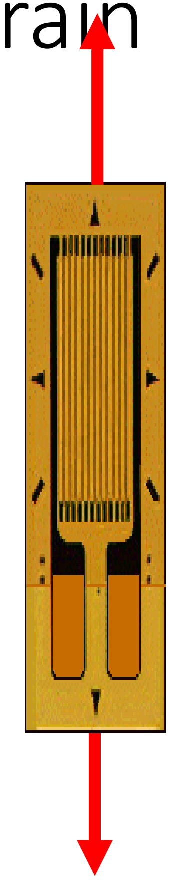
What is strain

- Strain is the amount of deformation due to an applied force. More specifically strain is defined as the **fractional change in length**.
- Strain can be negative (compressive) or positive (tensile) whereas dimensionless strain is sometime expressed in units such as in/in or mm/mm.
- In practice magnitude of strain is very small therefore it is expressed as microstrain.



Strain Gauge

Tension



$l \uparrow$

$R \uparrow$

$$R = \rho \frac{l}{A} \quad \Rightarrow \quad R \propto l$$

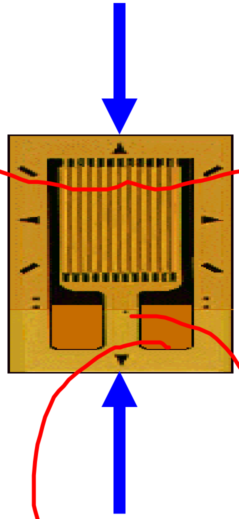
$R =$ Resistance

$\rho =$ Property of material

$l =$ Length of wire

$A =$ Effective cross sectional area of wire

Compression



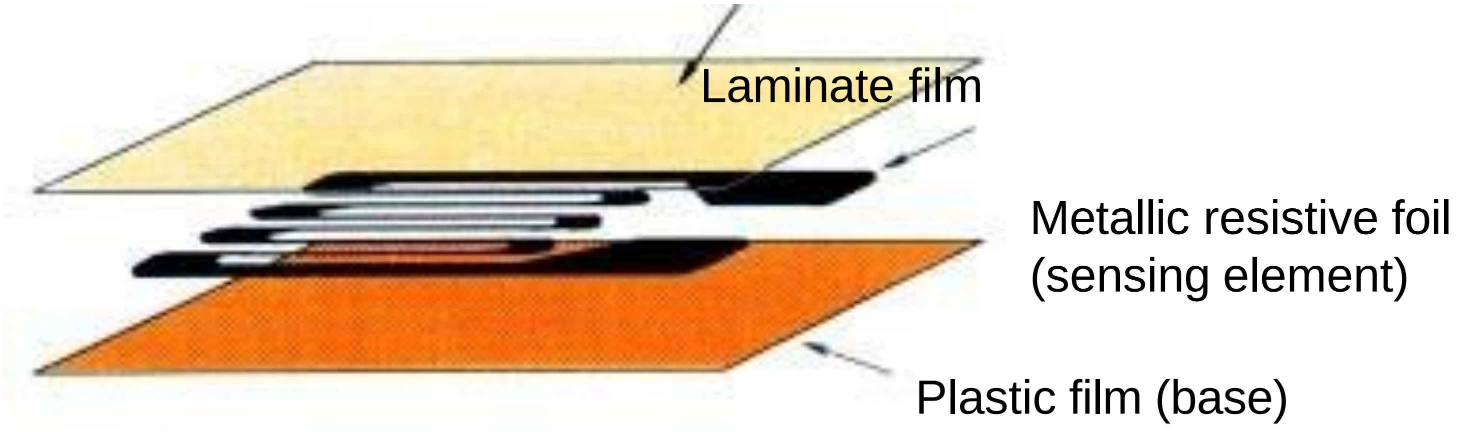
$l \downarrow$

$R \downarrow$

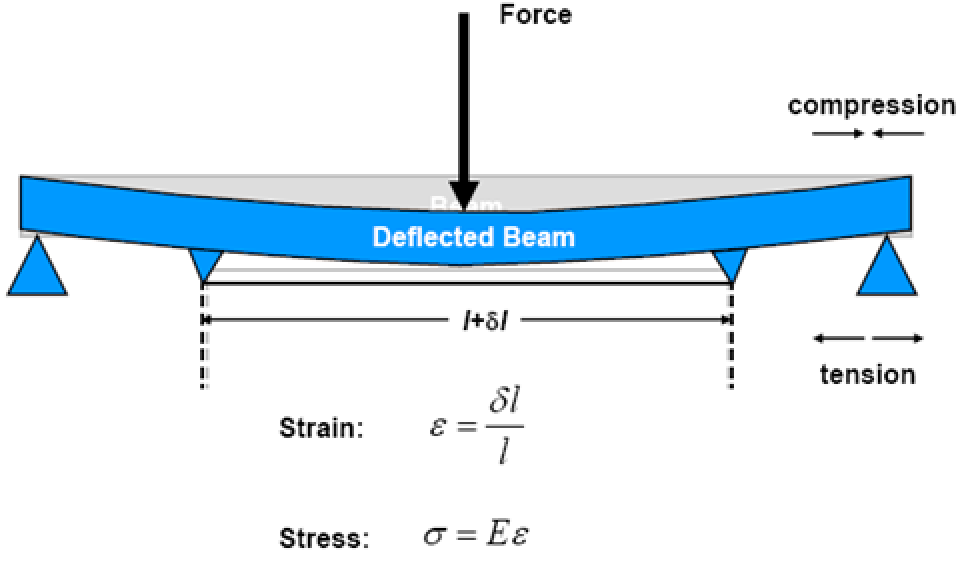
$R \propto l$

- Strain gauge: it is an electrical conductor whose resistance changes as it is strained.
- Structure of Strain Gauges

There are many types of strain gauges. Among them, a universal strain gage has a structure such that a grid-shaped sensing element of thin metallic resistive foil (3 to 6μm thick) is put on a base of thin plastic film (15 to 16μm thick) and is laminated with a thin film.



PRINCIPLE OF STRAIN GAUGE



The strain gage is tightly bonded to a measuring object so that the sensing element (metallic resistive foil) may elongate or contract according to the strain borne by the measuring object.

When bearing **mechanical elongation or contraction**, most metals undergo a **change in electric resistance**

Cont.…

- The strain gage applies this principle to strain measurement through the resistance change. Generally, the sensing element of the strain gage is made of a copper-nickel alloy foil.
- The alloy foil has a rate of resistance change proportional to strain with a certain constant.
- Let's express the principle as follows:

$$\frac{\Delta R}{R} = K.\varepsilon$$

where, R: Original resistance of strain gage, Ω (ohm)

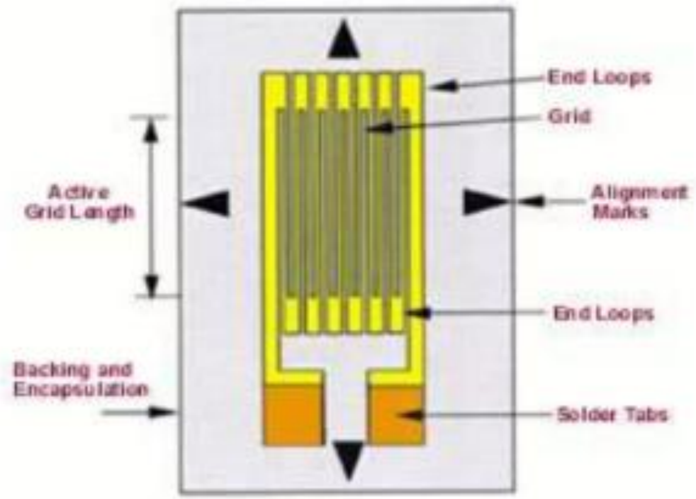
ΔR: Elongation- or contraction-initiated resistance change, Ω (ohm)

K: Proportional constant (called gage factor)

ε: Strain

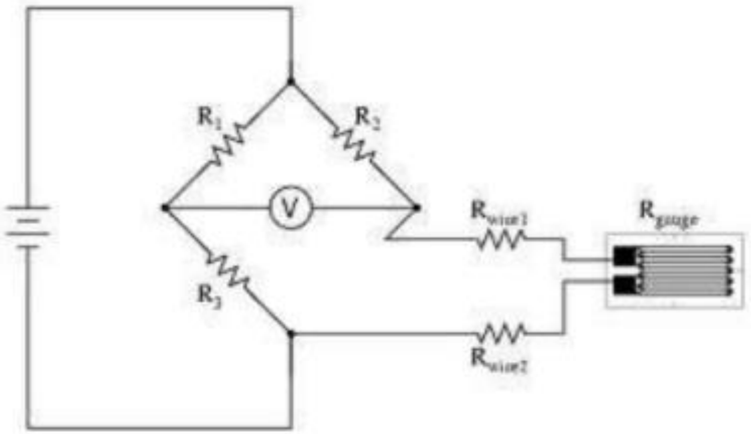
Structure of a Strain Gauge

- The majority of strain gauges are foil types, available in a wide choice of shapes and sizes to suit a variety of applications. They consist of a pattern of resistive foil which is mounted on a backing material.
- They operate on the principle that as the foil is subjected to stress, the resistance of the foil changes in a defined way.



Working of a strain gauge

- The strain gauge is connected into a Wheatstone Bridge circuit. The change in resistance is proportional to applied strain and is measured with Wheatstone bridge.



- The sensitivity of a strain gauge is described in terms of a characteristic called the gauge factor, defined as unit change in resistance per unit change in length, or

$$K = \frac{\Delta R/R}{\Delta l/l}$$

- Gauge factor is related to Poisson's ratio μ by,

$$K=1+2\mu$$

Problem

A resistance wire strain gauge uses a soft iron wire of small diameter. The gauge factor is +4.2. Neglecting the Piezoresistive effect, calculate the Poisson's ratio.

Gauge factor = $1 + 2v + \frac{\Delta\rho/\rho}{\epsilon}$

Gauge factor= $1 + 2v$ (neglecting Piezoresistive effect)

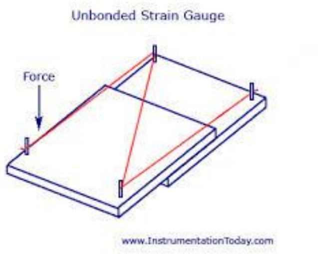
$\therefore Poisson's\ ratio \quad v$=(4.2-1)/2 = 1.6

Types of Strain gauge

- **Unbonded Strain Gauge**
- **Bonded wire Strain Gauge**
- **Bonded Metal Foil Strain gauge**
- **Vacuum Deposit Strain Gauge**
- **Semiconductor strain gauge**
- **Diffused metal strain gauge**

Unbonded strain gauge

- Wire Diameter 0.003mm
- Length of wire 25mm
- Resistance of each arm 120-1000 ohms
- Input Voltage 5-10V DC



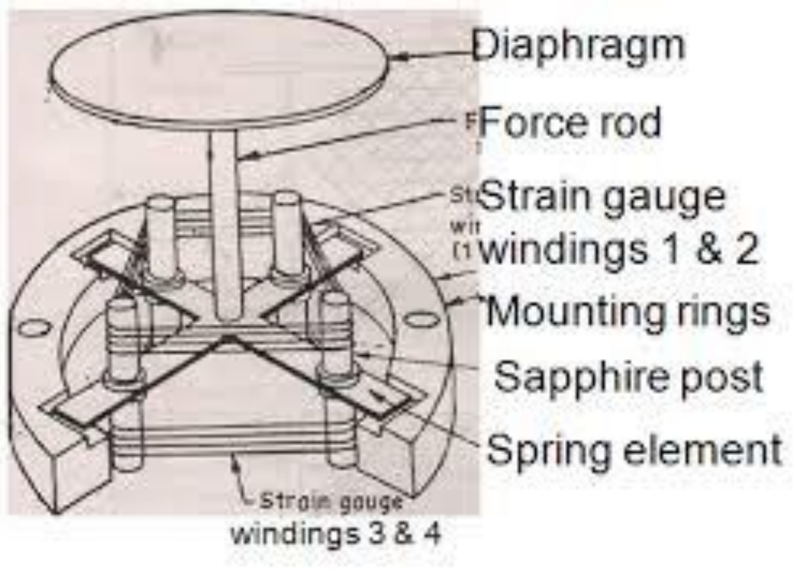
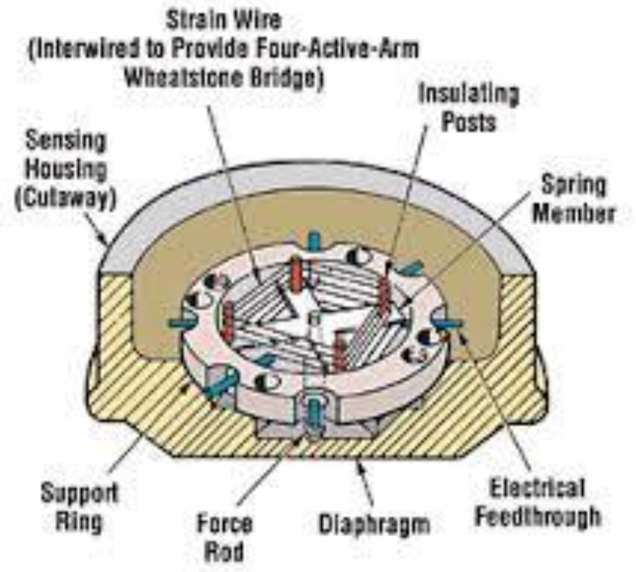
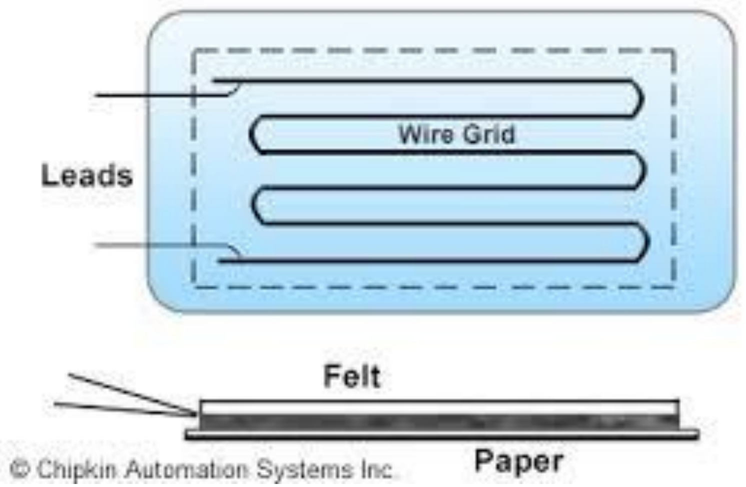


Fig. 2



Bonded Wire Strain Gauge

- Fine wire with diameter about .025 mm
- Grid of wire is cemented to the carrier (Base)- sheet of paper, thin sheet of Bakelite or Teflon
- Small as 3X3mm, larger 25X12.5mm

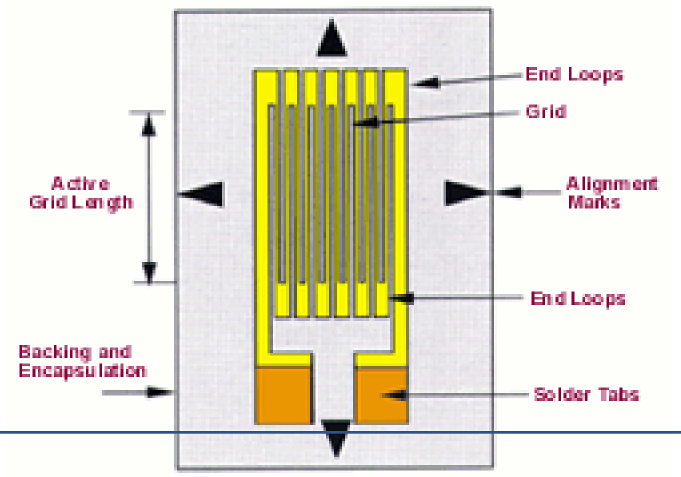


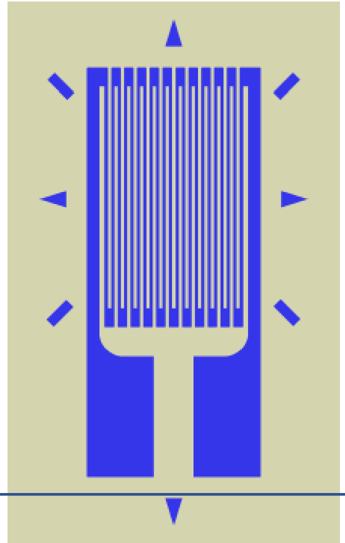
Materials used for wire Strain Gauge

Materials	Composition	Gauge Factor	Resistivity ohm m
Nichrome	Ni: 80% Cr:20%	2.0	100×10^{-8}
Constantan	Ni:45% Cu:55%	2.1	48×10^{-8}
Isoelastic	Ni:36% Cr:8% Mo:05%	3.6	105×10^{-8}
Nickel		-12.1	6.5×10^{-8}
Platinum		4.8	10×10^{-8}

Bonded metal foil strain gauge

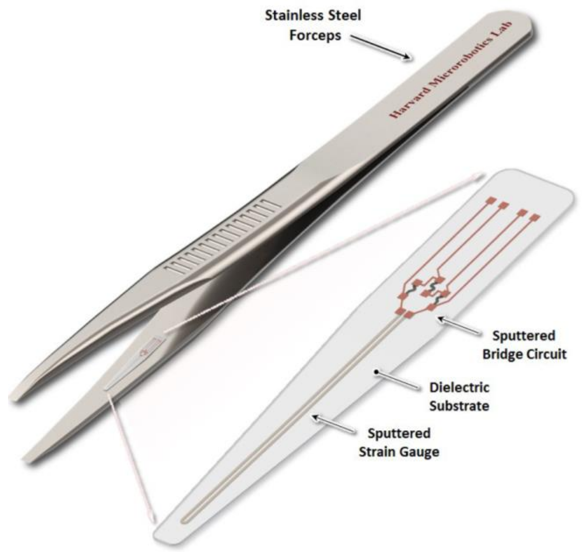
- Grater heat dissipating capacity
- Formed from a sheet of metal less than 0.005mm thick by photo-etching process
- Easy manufacturing process
- Can be apply in curved surface
- 10 million cycles at +- 1500 micro-strain can be applied to foil gauge





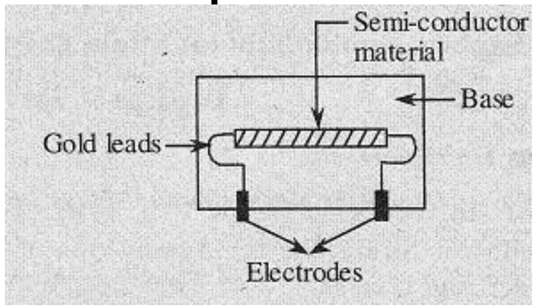
Vacuum Deposit Strain Gauge

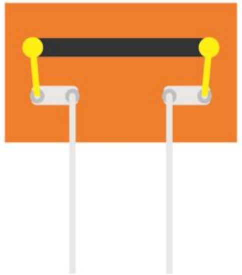
- Thin film vacuum deposition process to bond strain gauges directly to stainless steel etc for 30 years.
- The process begins by preparing the surface with remove all surface pinholes and cracks.
- The next step is the deposition of an oxide layer to insulate the circuit from the metal substrate.
- Following this, a thin film resistive alloy is sputtered over the oxide layer.
- This film is laser trimmed under power to produce the four resistors of the Wheatstone bridge



Semiconductor Strain gauge

- semiconducting wafers or filaments of length varying from 2 mm to 10 mm and thickness of 0.05 mm are bonded on suitable insulating substrates (for example Teflon).
- The gold leads are usually employed for making electrical contacts.
- The electrodes are formed by vapour deposition.
- The assembly is placed in a protective box.





Advantages of Semiconductor Strain Gauge

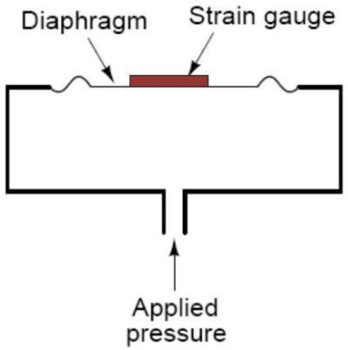
- The gauge factor of semiconductor strain gauge is very high, about ±130.
- Semiconductor strain gauge exhibits very low hysteresis i.e., less than 0.05%.
- They are useful in measurement of very small strains of the order of 0.01 micron
- The semiconductor strain gauge has much higher output, but it is as stable as metallic strain gauge.
- It has a large fatigue life i.e., 10×10^6 operations can be performed.
- It possesses a high frequency response of 1012 Hz.
- can be manufactured in very small sizes, their lengths ranging from 0.7 to 7.0 mm.

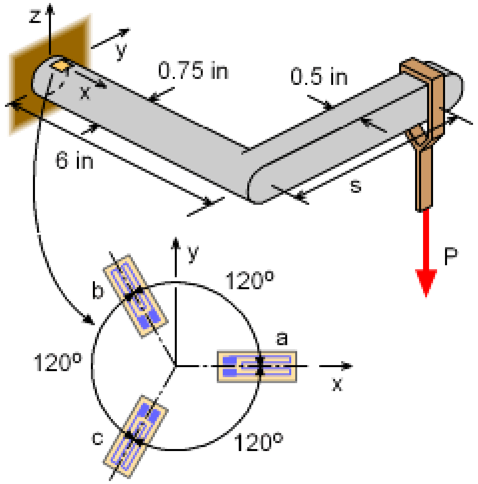
Diffused semiconductor Strain gauge

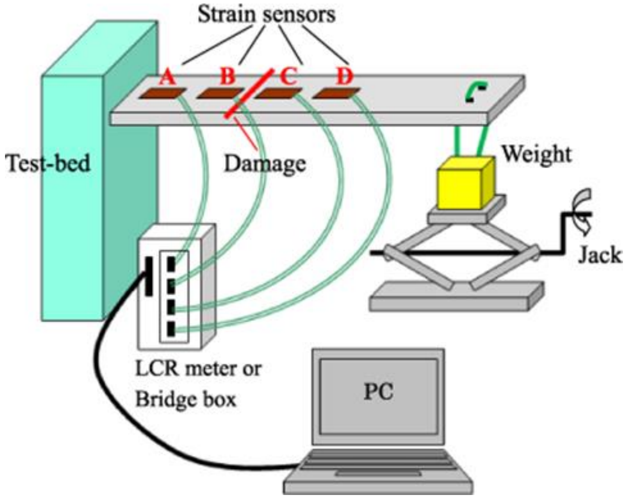
Thin film element molecularly bounded (no adhesive) into a ceramic layer which is deposited directly onto the force detector

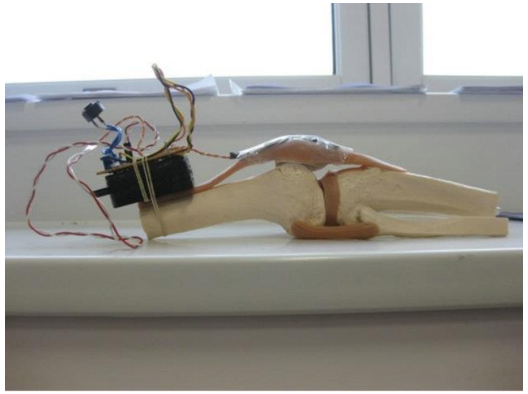
Strain Gauge Applications

- Measurement of pressure
- Measurement of force
- Measurement of small displacement
- Measurement of Torque
- Measurement of Load etc.









PIEZOELECTRIC SENSORS

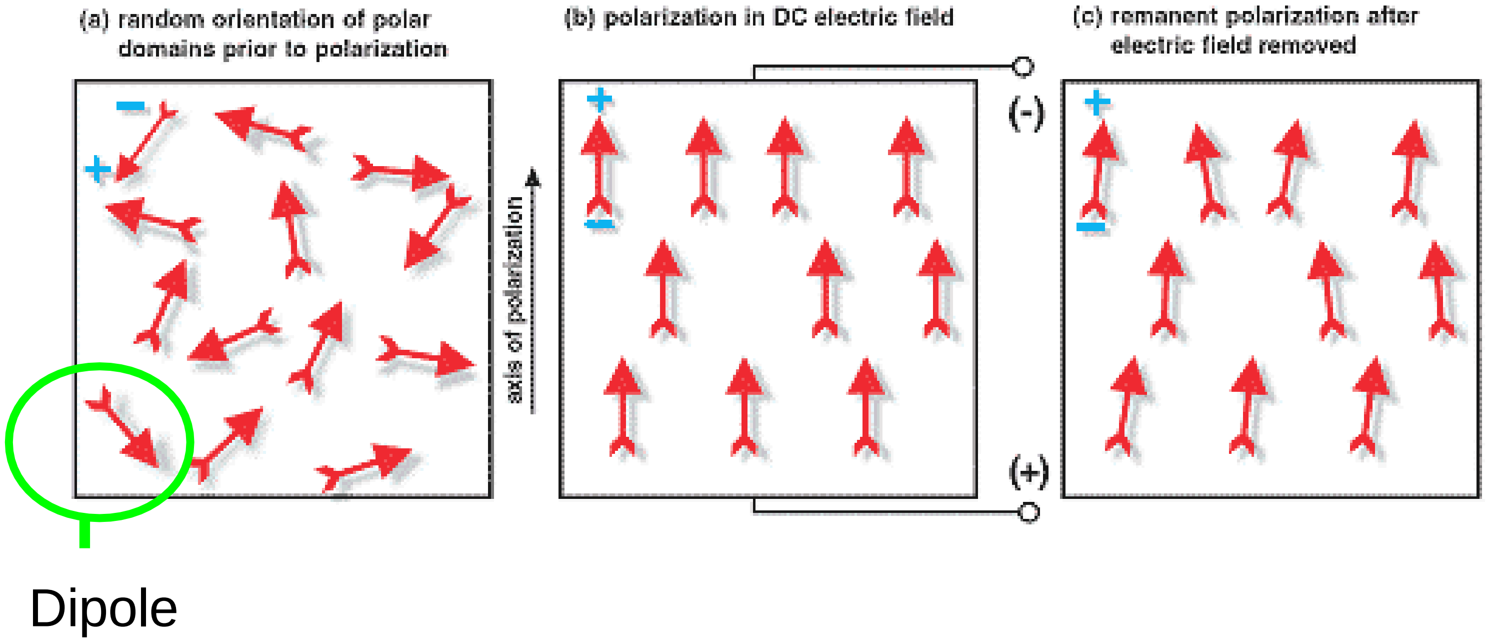
- Piezoelectric effect states that when mechanical stress or forces are applied on quartz crystal, produce electrical charges on quartz crystal surface.
- Greek word piezen, which means to squeeze or press
- Discovered by Pierre and Jacques curie.
- The rate of charge produced will be proportional to rate of change of mechanical stress applied on it.

PIEZOELECTRIC SENSOR

- A piezoelectric sensor is a device that uses the piezoelectric effect, to measure changes in pressure, acceleration, temperature, strain, or force by converting them to an electrical charge.
- When force is applied to stretch or bend it, an electric potential is generated.
- **Examples of Piezoelectric Material**
    - Barium Titanate.
    - Lead zirconate titanate (PZT).
    - Rochelle salt.

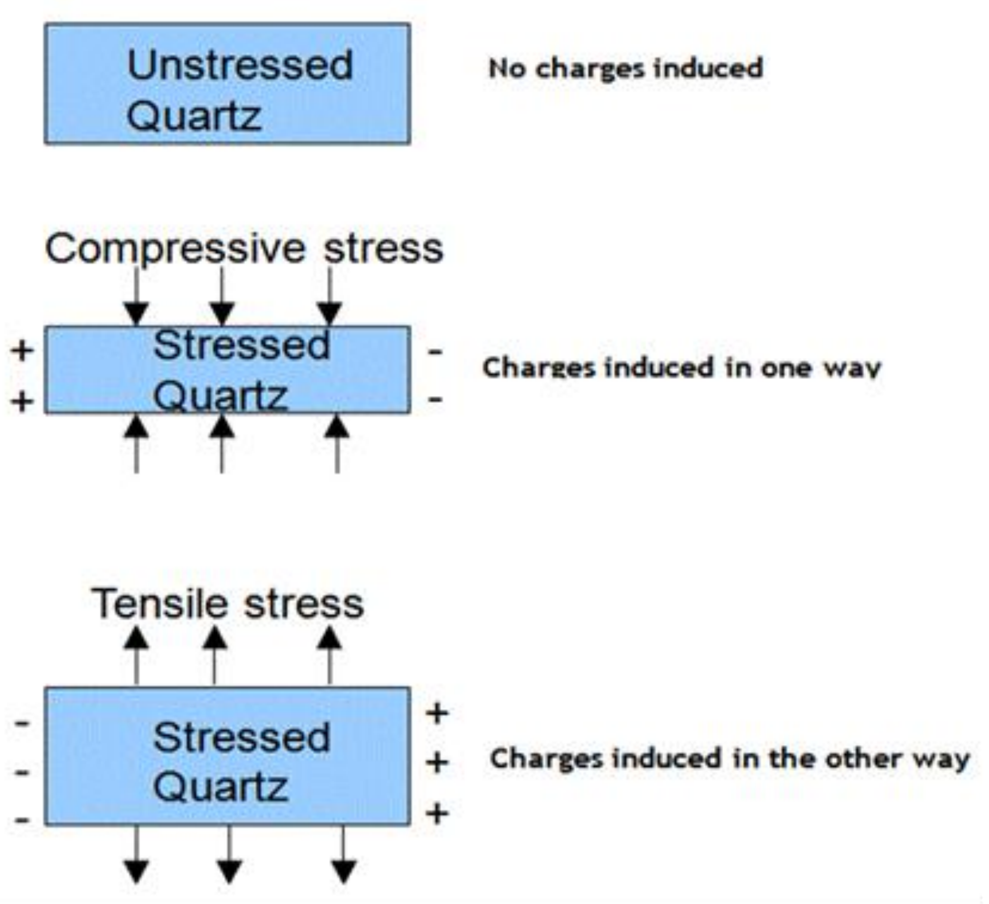
Polarisation of a piezoelectric material

- Subject a piezoelectric material to a large voltage near the Curie temperature then the dipoles align



- Curie temperature is the temperature above which the material loses its piezoelectric property

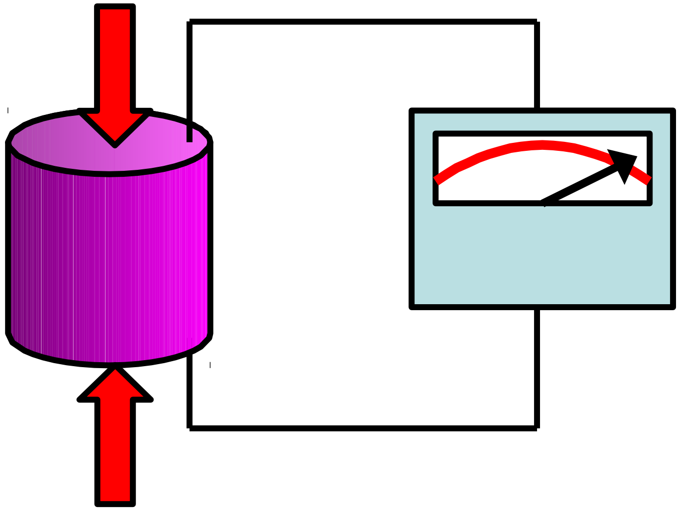
PIEZOELECTRIC SENSOR



Piezoelectric actuators and sensors

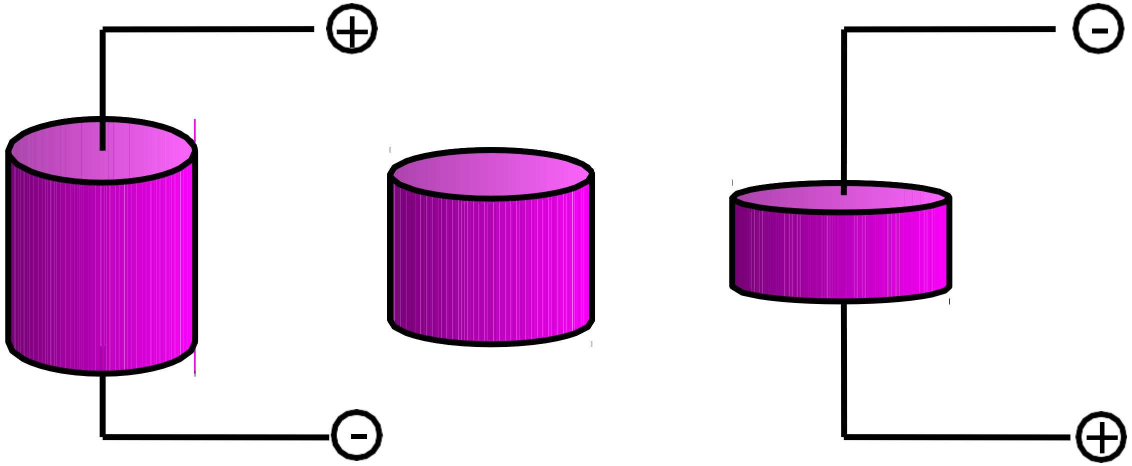
Piezoelectric effect
(sensor)

An electric field is generated due to a change in dimensions of a material
(Curie brothers 1880)

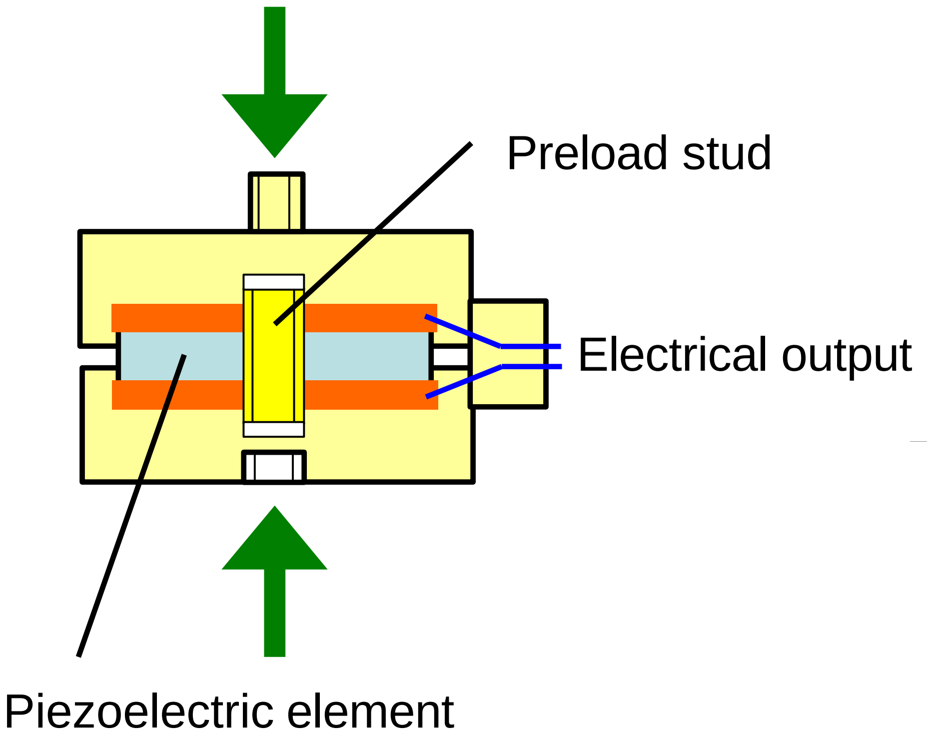


Converse Piezoelectric effect
(actuator)

A change in dimensions of a material due to the Application of an electric field

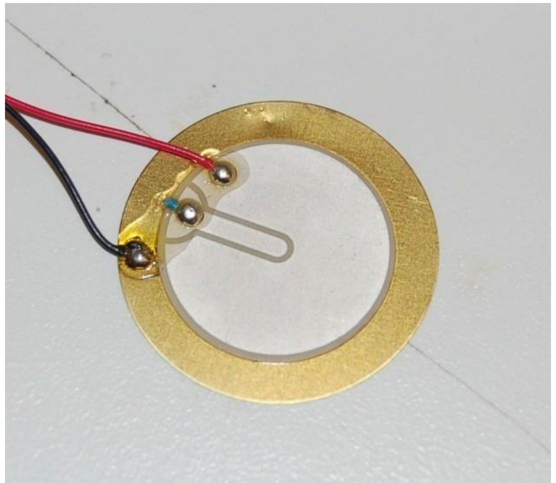


Piezoelectric Force Transducer



- Can be used in tension and compression
- Fragile to moments

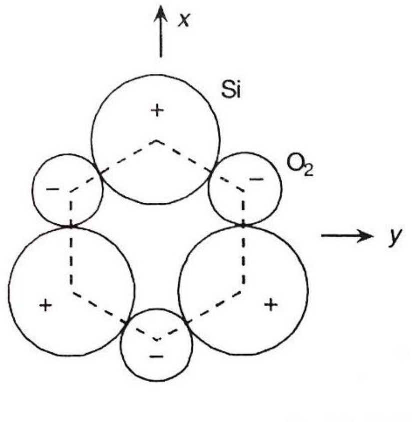
PIEZOELECTRIC SENSORS



Piezoelectric effect

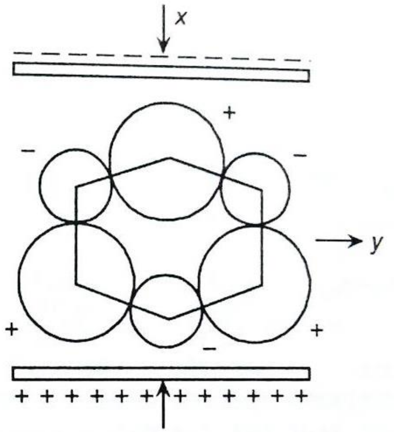
Piezoelectric effect : A phenomena resulting from a coupling between the electric and mechanical properties of a material. When mechanical stress is applied to a piezoelectric material, an electric potential will be produced.
Reversible Effect: Likewise, when an electric potential is applied to the material a mechanical change will occur.

Piezoelectric **crystals** involve a non-uniform charge distribution within the unit cell of the crystal. When exposed to an electric field, this charge distribution shifts and the crystal will change its shape.



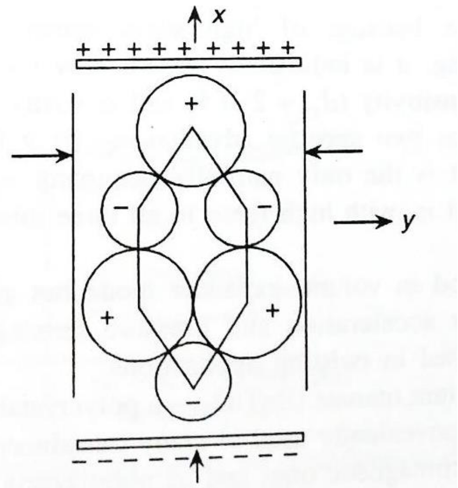
(a)

Quartz Crystal Model



(b)

Charge generation when ‘F’ applied parallel to electrodes



(c)

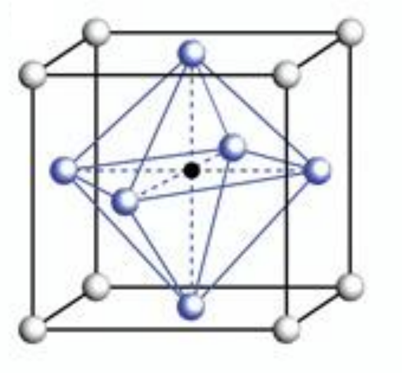
Charge generation when ‘F’ applied perpendicular to electrodes

Piezoelectric Materials

The piezo effect exhibited by
NATURAL MATERIALS such as quartz, tourmaline, Rochelle salt, etc. is very small.
MAN-MADE Polycrystalline ferroelectric ceramic materials such as barium titanate ($BaTiO_3$) and lead (plumbum) zirconate titanate (PZT) with improved properties have been developed.

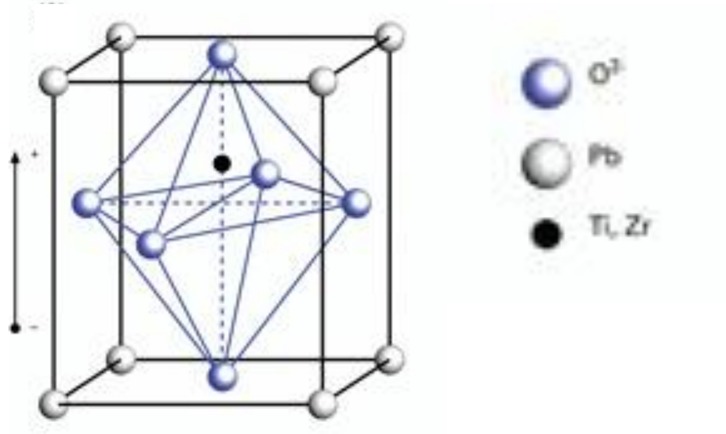
Unit Cell of $Pb(Zr,Ti)O_3$

Before Polarization



Symmetric cubic state above Curie temperature

After Polarization



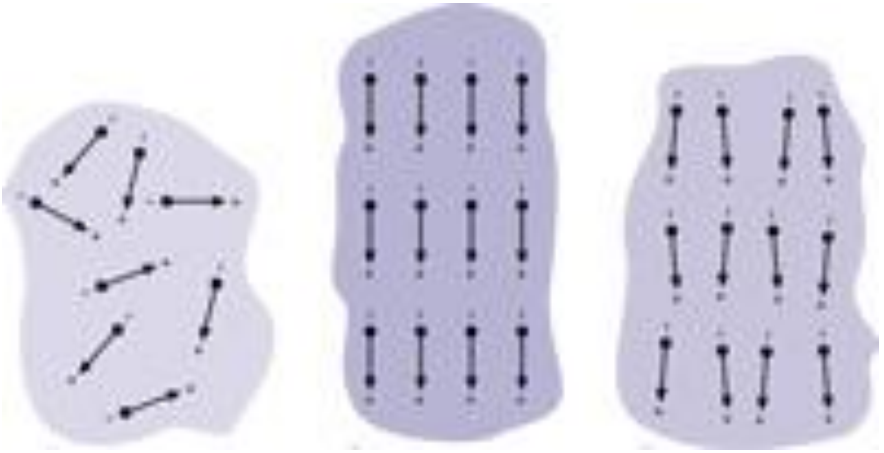
Tetragonally distorted unit cell below the Curie temperature

Before polarization, PZT crystallites have symmetric cubic unit cells. At temperatures below the Curie temperature*, the lattice structure becomes deformed and asymmetric. The unit cells exhibit spontaneous polarization (see Figure above), i.e. the individual PZT crystallites are piezoelectric.

*A transition temperature marking a change in the magnetic or ferroelectric properties of a substance

Polarizing Treatment- POLING

Due to the ferroelectric nature of the material, it is possible to force permanent alignment of the different domains using a strong electric field. This process is called poling (see Figure below). Some PZT ceramics must be poled at an elevated temperature. The material now has a remnant polarization (which can be degraded by exceeding the mechanical, thermal and electrical limits of the material).



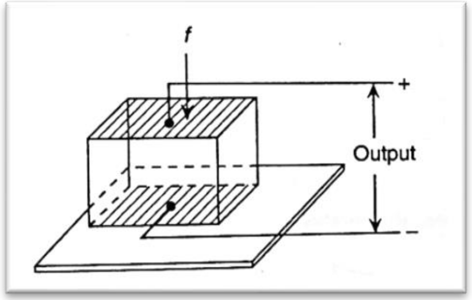
(1) (2) (3)

Electric dipoles in domains:
(1) Unpoled ferroelectric ceramic, (2) during and (3) after poling (piezoelectric ceramic).

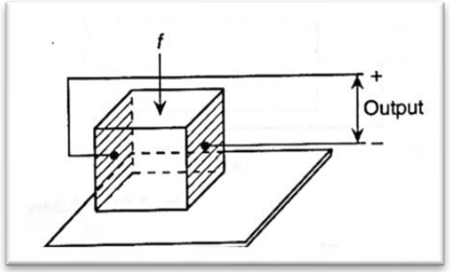
Different Deformation Modes

Piezoelectric effect can be made to **respond** OR **cause**
→mechanical deformation of material in <u>different modes</u>

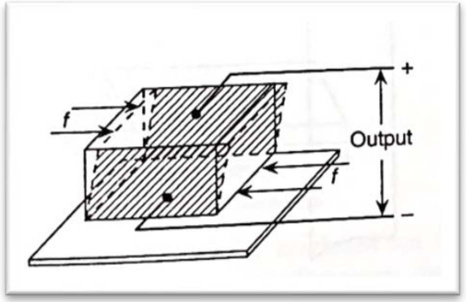
Thickness Expansion



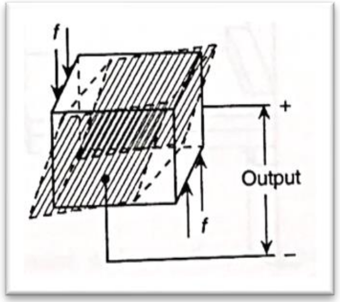
Transverse Expansion



Thickness Shear



Crystal face Shear

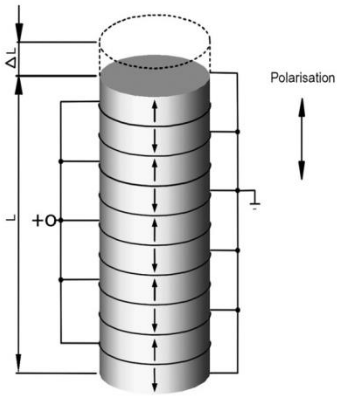


Desirable Properties of Piezoelectric Crystal

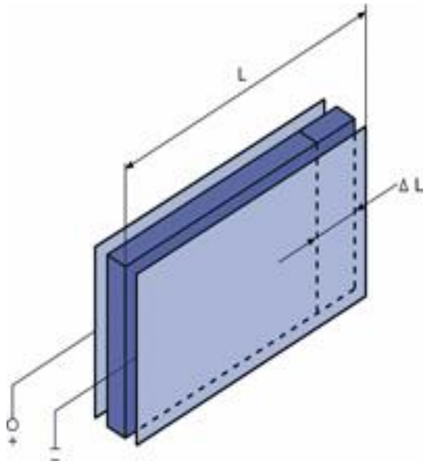
- Stability
- High Output
- Linear deformation as fn. of E (applied field strength)
- Stability over ‘operating’ Temperature & Humidity range
- Formation into variety of shapes and sizes

Formation into variety of shapes and sizes

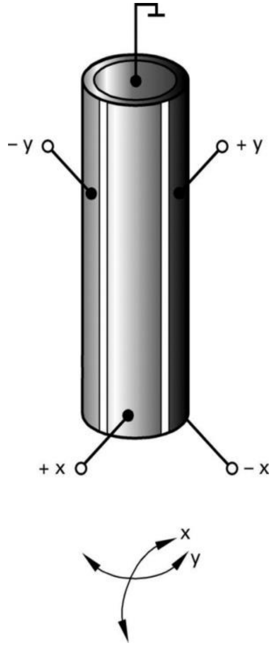
Stacked Disks



Laminar Rectangular Strips



Tubes



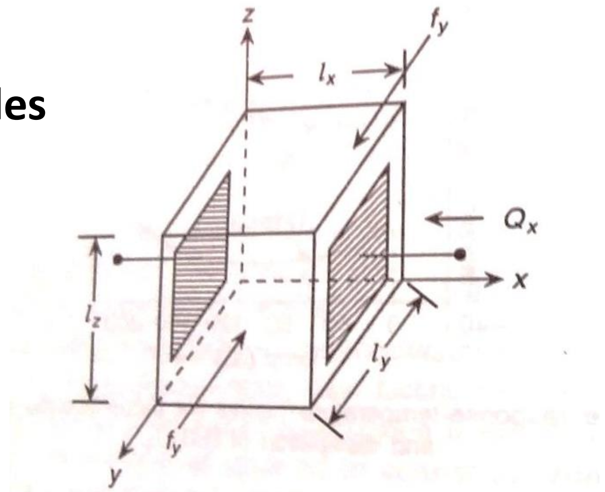
APPLICATIONS

Stacked Discs → Used as High- Voltage or Low-Voltage Translator Actuators depending upon thickness of discs.

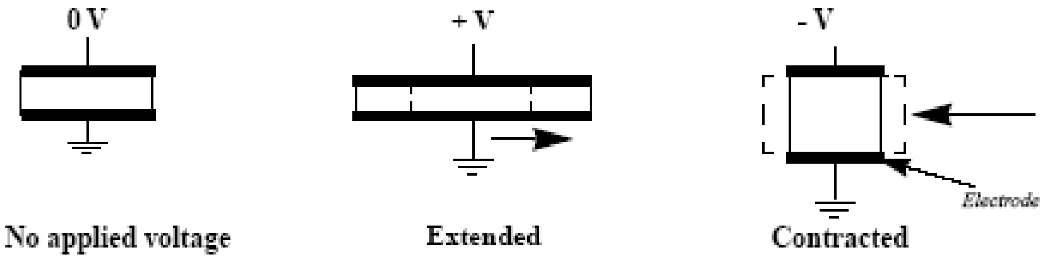
Laminar & Tube shapes → Used as Nanopositioners Scanners for Atomic Force Microscope instruments.

Piezoelectric effect-DIRECTION **SENSITIVE**

Crystal with electrodes & dimensions



- Tensile force produces a voltage of one polarity while a compressive force produces a voltage of opposite polarity



Definition of Piezoelectric Coefficients

d_{ij}: *Strain coefficients [m/V] or charge output coefficients [C/N]:*

Strain developed [m/m] per unit of electric field strength applied [V/m] or (due to the sensor / actuator properties of PZT material) charge density developed [C/m2] per given stress [N/m2].

EXAMPLE: For d_{ij},
i is the direction of the stimulus and
j is the direction of the reaction of the system.

Click to add text

For e.g. d_{31} MEANS that the electric field is in direction of axis 3 (Polarization axis) and the deflection of interest is along axis 1 (orthogonal to the polarization axis).

g_{ij}: Voltage coefficients or field output coefficients [Vm/N]:

Open-circuit electric field developed [V/m] per applied mechanical stress [N/m2] or (due to the sensor / actuator properties of PZT material) strain developed [m/m] per applied charge density [C/m2].

Relation between 'd' and 'g'

Magnitude and Polarity of Induced Surface Charge ∝ F (magnitude and Direction)

→ **Charge 'Q' = d.F**

where ***<u>'d' Charge Sensitivity of Crystal (C/N) and is a constant for a crystal</u>***

→ **E = Stress/ Strain =** $\frac{F/A}{\Delta t/t}$ $\Rightarrow$ **F =** $\frac{AE}{t}\Delta t$

→ **Therefore, Q=** $\frac{dAE\Delta t}{t}$ **Coulombs**

→ **Also Charge at electrode gives rise to Voltage 'E_o'**

$$\Rightarrow E_o = Q/C_p, \text{ where } C_p = \frac{\varepsilon_o\varepsilon_r A}{t}$$

$$\Rightarrow E_o = \frac{dF}{\varepsilon_o\varepsilon_{rA/t}} = \frac{d}{\varepsilon_o\varepsilon_r}tP = gtP \quad \text{where } P = \frac{F}{A};$$

$$g = \frac{d}{\varepsilon_o\varepsilon_r}$$

where ***<u>'g' is Voltage Sensitivity of cut of crystal (Vm/N) and is a constant for a crystal</u>***

Numerical

A barium Titanate ($BaTiO_3$) crystal has the dimensions of 5 mm X 5 mm X 1.25 mm. The force acting on it is 5N. The charge sensitivity of $BaTiO_3$ is 150 pC/N and its $\varepsilon_r = 12.5 \times 10^{-9}$ F/m. If the modulus of elasticity of $BaTiO_3$ is 12×10^6 N/m^2, Calculate the strain. Also calculate charge and capacitance.

Solution:

Area of plates =A = 5 X 5 mm^2 = 25 X 10^{-6} m^2

Pressure P = F/A = 5/ (2.5 x 10-6) N/m2 = 0.2 MN/m2

Voltage sensitivity g = $d/(\varepsilon_o\varepsilon_r)$ = 150 X 10^{-12}/ (12 X 10^{-9}) = 12 x 10^{-3} Vm/N

Voltage generated E_o = g t P = 12 X 10^{-3} X 1.25 X 10^{-3} X 0.2 X 10^6 = 3 V

Strain = Stress/ Modulus of elasticity = 0.2 X 10^6 /12 X 10^6 = 0.0167 m/m

Charge = Q = d F = 150 X10-12 X 5 = 750 pC

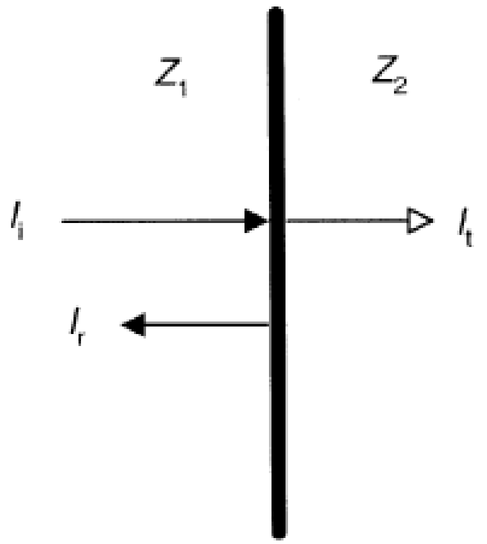
Capacitance = C_p = Q/E_o = 750 pC/ 3V = 250 pF

MEASUREMENT OF DISTANCE

- Ultrasonic sensors
- Linear Variable Differential Transformer
- Capacitance type
- Proximity Sensor
- Infrared Sensor
- Pulse oximeter
- Tachometer

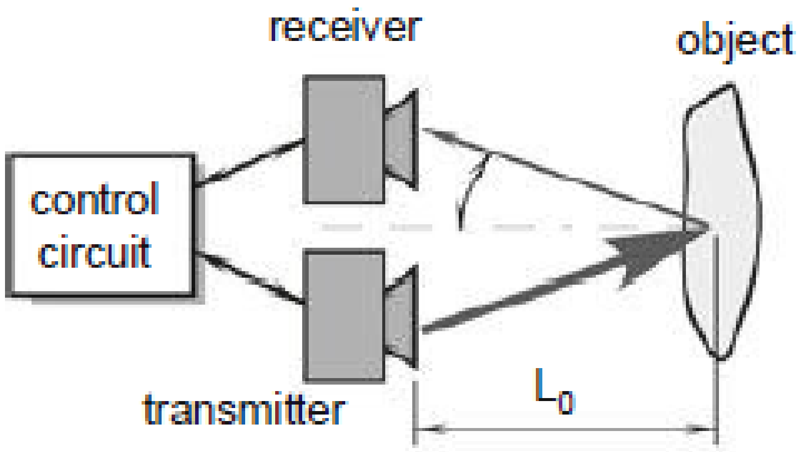
ULTRASONIC SENSORS

A plane wave (intensity *I_i*) with normal incidence on a boundary
$\rightarrow$ Partially reflected (*I_r*) &
$\rightarrow$ partially transmitted (*I_t*)



- Ultrasound is a mechanical radiation with a frequency above the human hearing range (about 20 kHz).
- As for any radiation, when ultrasound strikes an object, part is reflected, part is transmitted, and part is absorbed
- In addition, when the radiation source moves relative to the reflector, there is a shift in received frequency (Doppler effect)

Ultrasonic distance measurement:
Basic arrangement

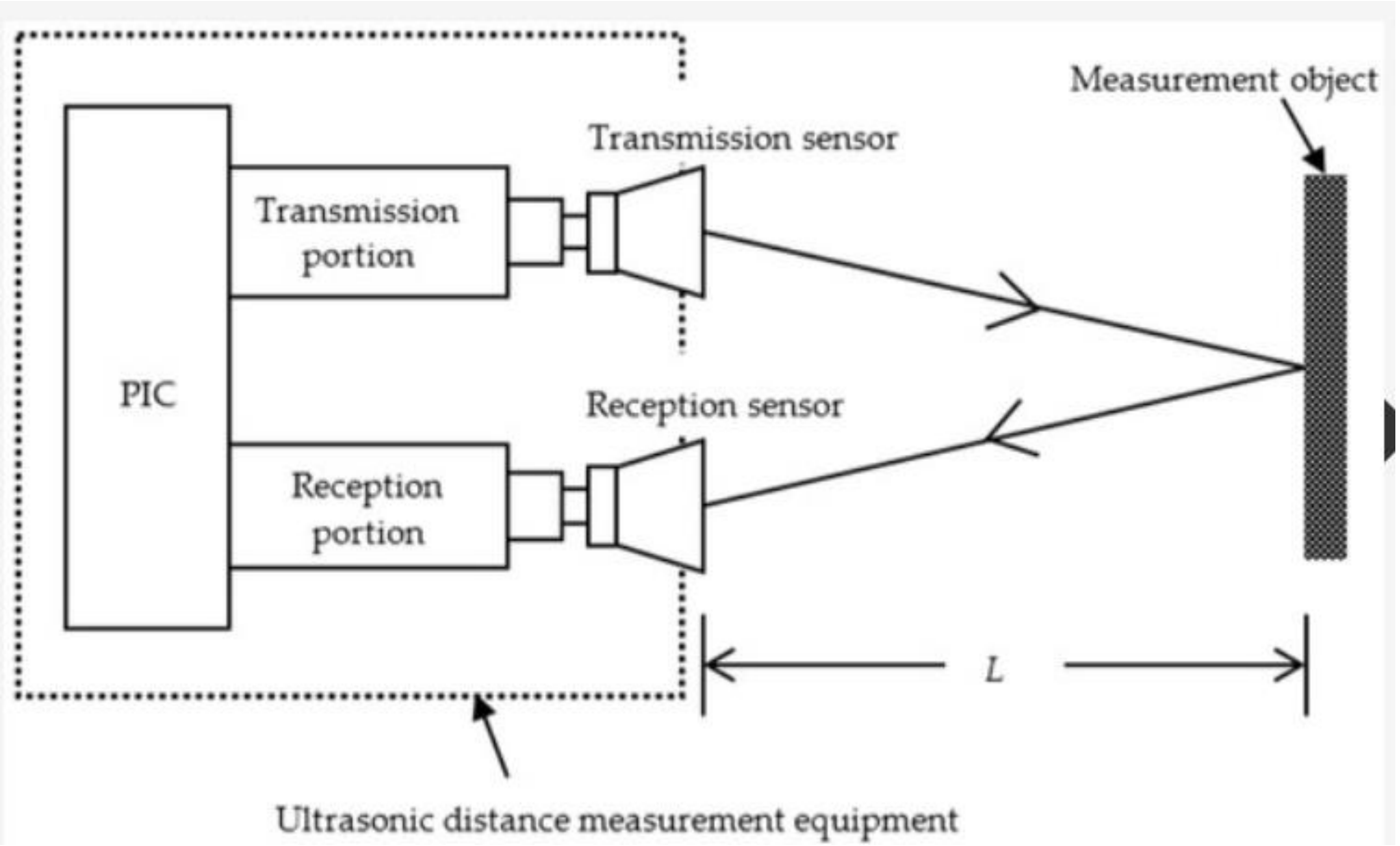


- Properties of ultrasound radiation & object interaction have been applied to the measurement of several physical quantities such as DISTANCE, FLOW RATE,….

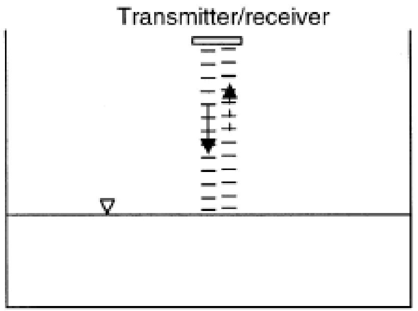
- **Applications**

Penetration power for ultrasound permits non-invasive such as

$\rightarrow$ Explosive and radioactive environments
$\rightarrow$ Medical applications
$\rightarrow$ Prevents contamination of the medium


Measurement object
Transmission sensor
Transmission portion
PIC
Reception sensor
Reception portion
L
Ultrasonic distance measurement equipment

Transit time ultrasonic sensors



Sensors determine the distance from the transducer to an impedance discontinuity by measuring the elapsed time between the emission and reception of a signal burst.

→ Emit an ultrasonic burst and measure the elapsed time between transmission and reception

→ Reflecting surface must be parallel to the sensing face-i.e., perpendicular to the direction of sensing

→ Frequency is selected according to the range and reflector surface (Greater ranges need low frequencies because of the increased attenuation)

  → For example:23 kHz for a 30 m range & 40 kHz for a 12 m range

→ Smooth and Nonporous surfaces preferred

→ Transit time sensors yield highly linear and accurate outputs when measuring distance

Applications:

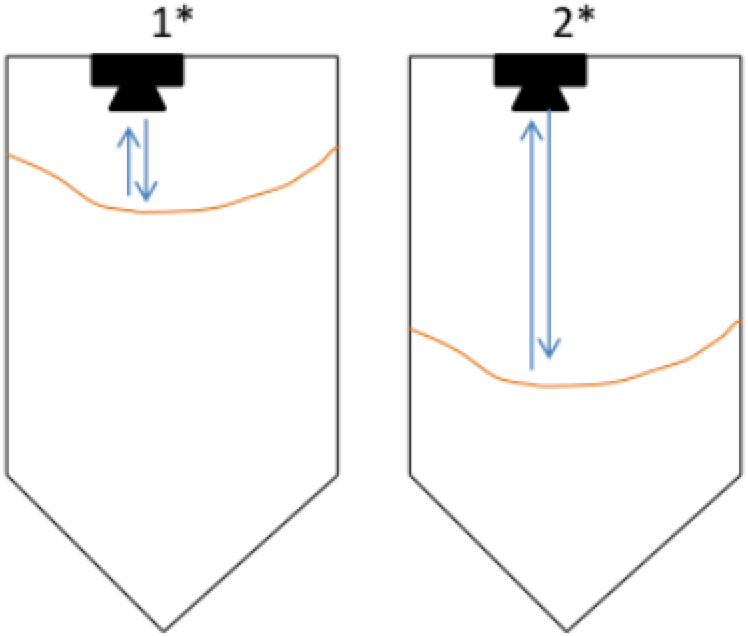
- Ultrasonic attenuation have been applied to air or foam bubble detectors in plastic, glass, or metal tubing

- Ultrasonic sensors are not suitable for outdoor use (air turbulence may blow of echoes)

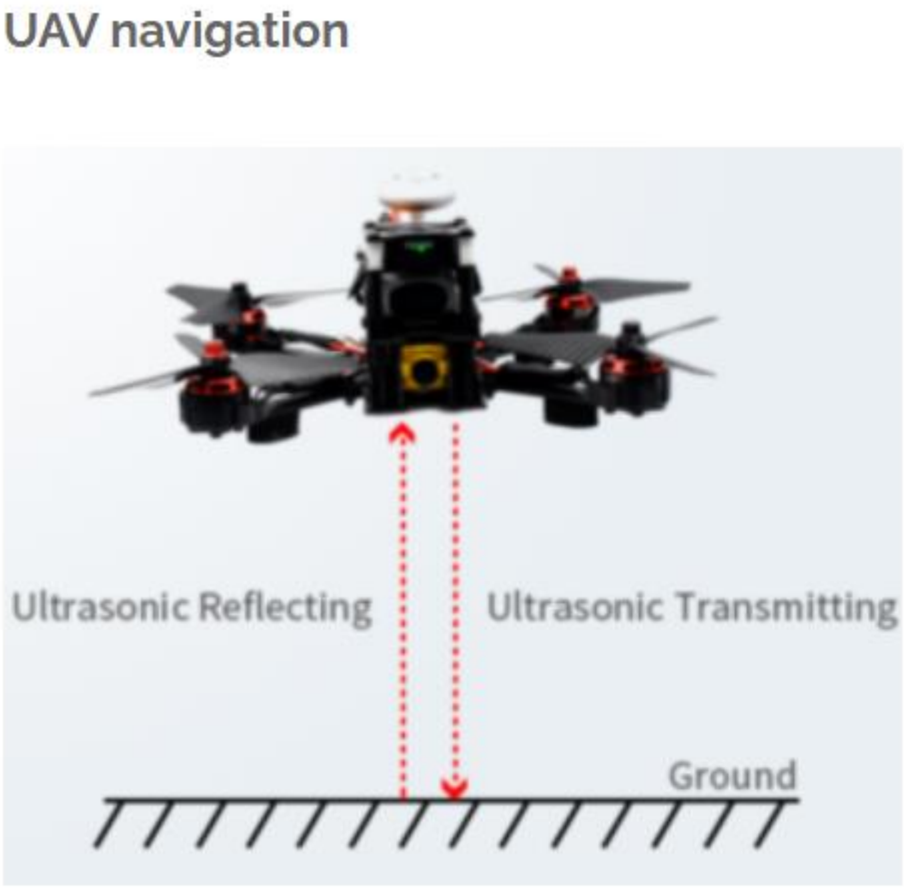
Uses

- To estimate arterial blood flow rate noninvasively
- Used in industry to measure liquids, gases, and two-phase or multiphase fluids
- Distance:20mm to 10m
- The distance can be calculated with the following formula:
- **Distance L = 1/2 × T × C**
- where L is the distance, T is the time between the emission and reception, and C is the sonic speed. (The value is multiplied by 1/2 because T is the time for go-and-return distance.)

Grain Detection



UAV Navigation



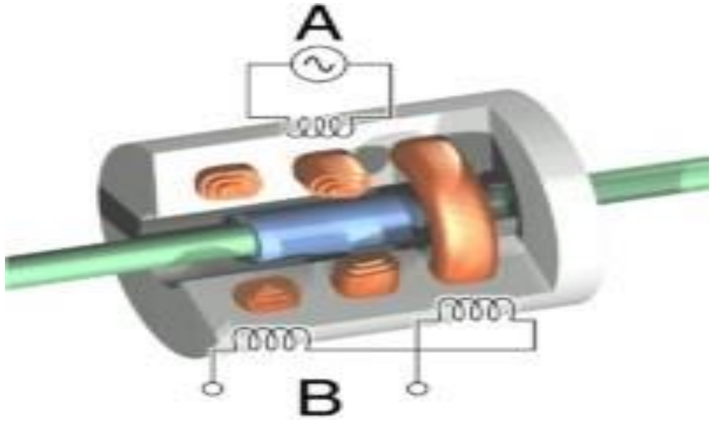
UAV Navigation

Ultrasonic Sensors are best used in the non-contact detection of

- Presence
- Level
- Position
- Distance

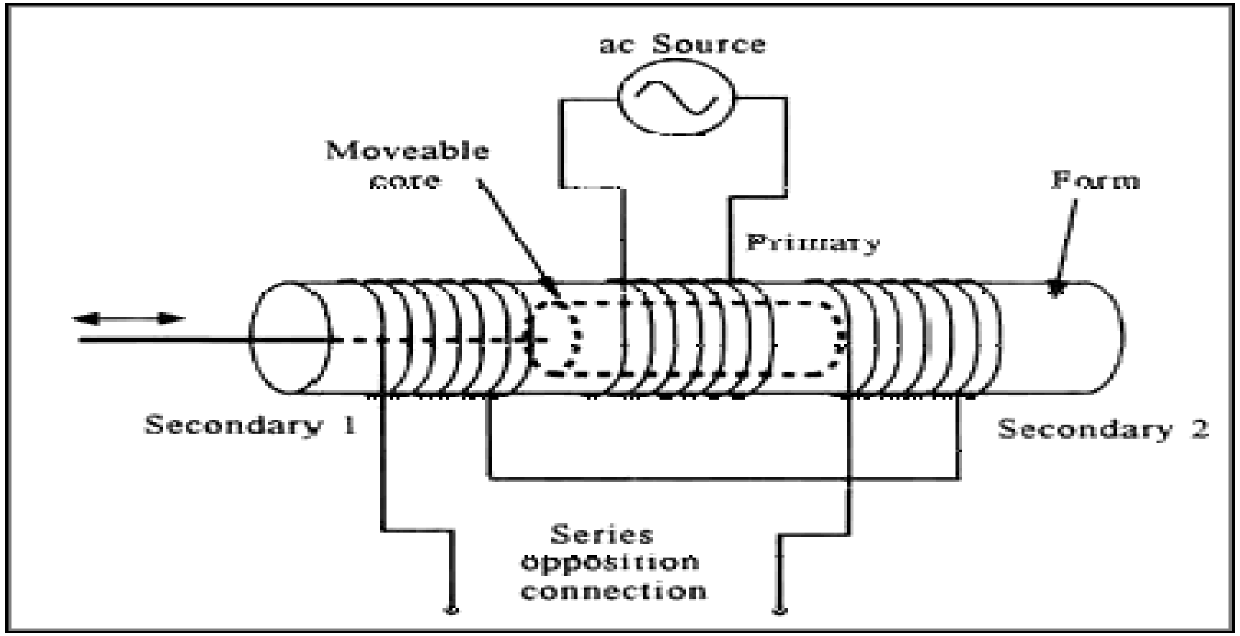
LINEAR VARIABLE DIFFERENTIAL TRANSFORMER

- Linear variable differential transformers (LVDT) are used to measure displacement.
- LVDT works under the principle of mutual induction, and the displacement which is a non-electrical energy is converted into an electrical energy.



LVDT- Architecture

- LVDT consists of a coil assembly and a core.
- The coil assembly is typically mounted to a stationary form, while the core is secured to the object whose position is being measured.

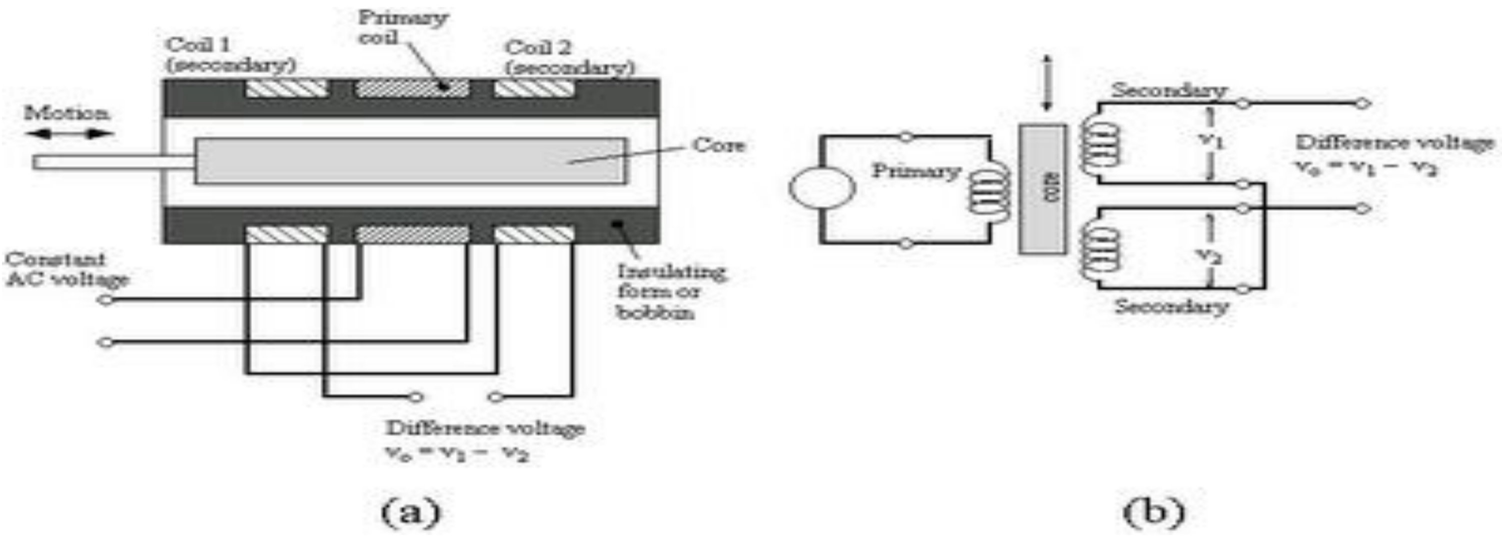


LVDT- Architecture

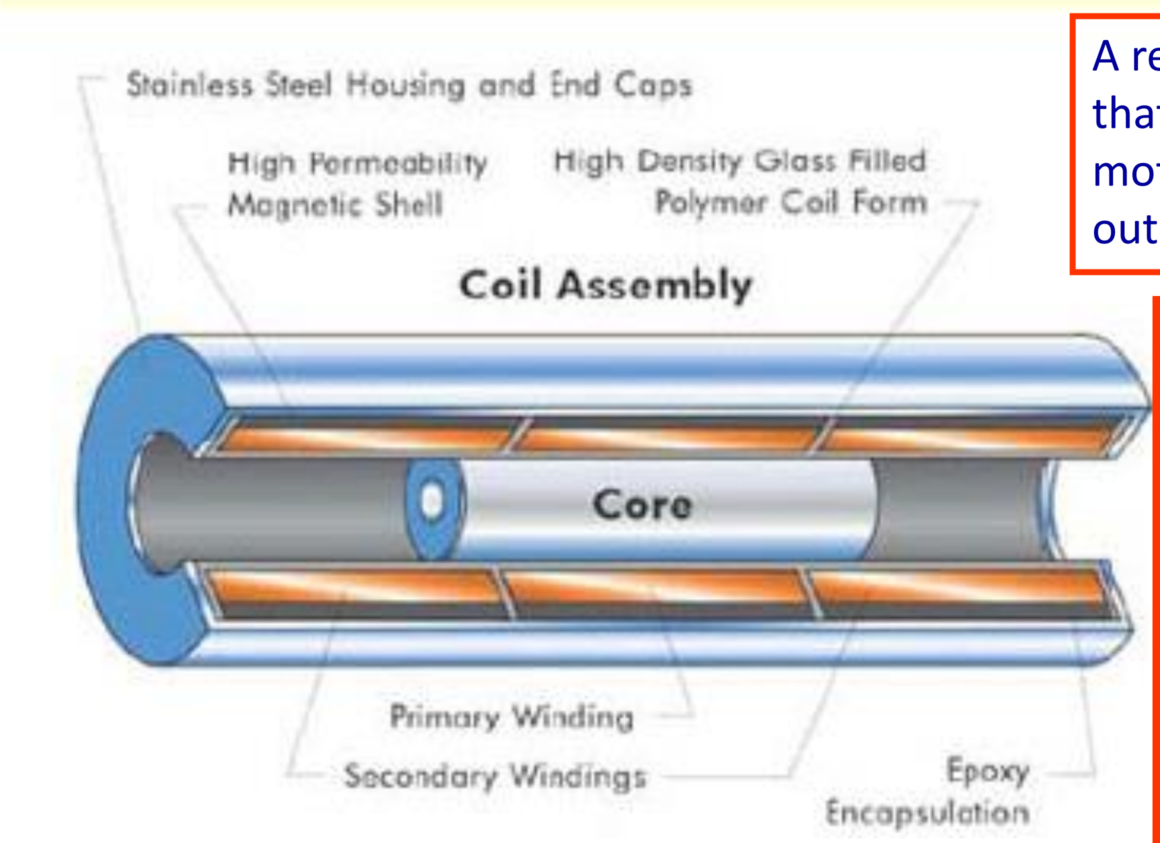
- The coil assembly consists of three coils of wire wound on the hollow form.
- A core of permeable material can slide freely through the center of the form.
- The inner coil is the primary, which is excited by an AC source as shown.
- Magnetic flux produced by the primary is coupled to the two secondary coils, inducing an AC voltage in each coil.

LVDT- Architecture

- The number of turns in both the secondary windings are equal, but they are opposite to each other.
- If the left secondary windings is in the clockwise direction, the right secondary windings will be in the anti-clockwise direction, hence the net output voltages will be the difference in voltages between the two secondary coil.



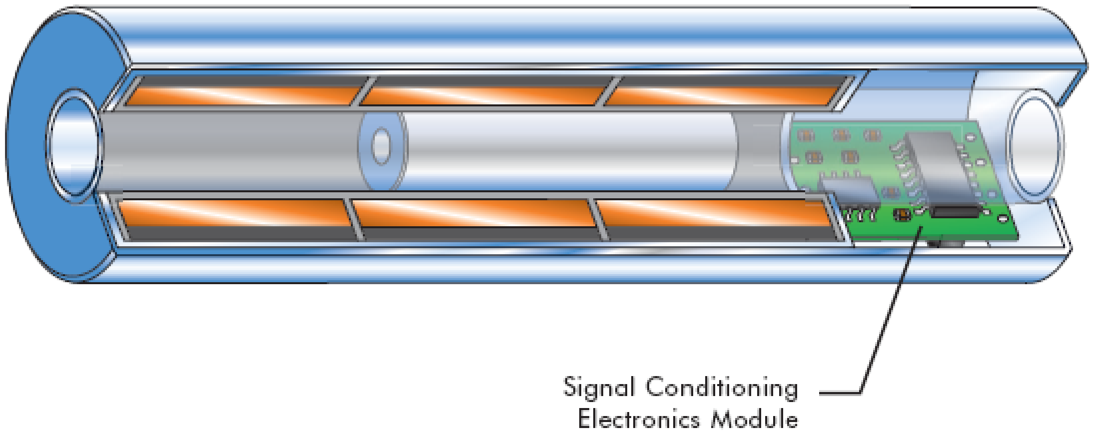
LVDT- Architecture



A reliable and accurate sensing device that converts linear position or motion to a proportional electrical output.

- Primary winding centered between a pair of identically wound secondary windings
- The coils are wound on a one-piece hollow form
- Cylindrical stainless steel housing
- The moving element of an LVDT is a separate tubular armature of magnetically permeable material called the core

LVDT



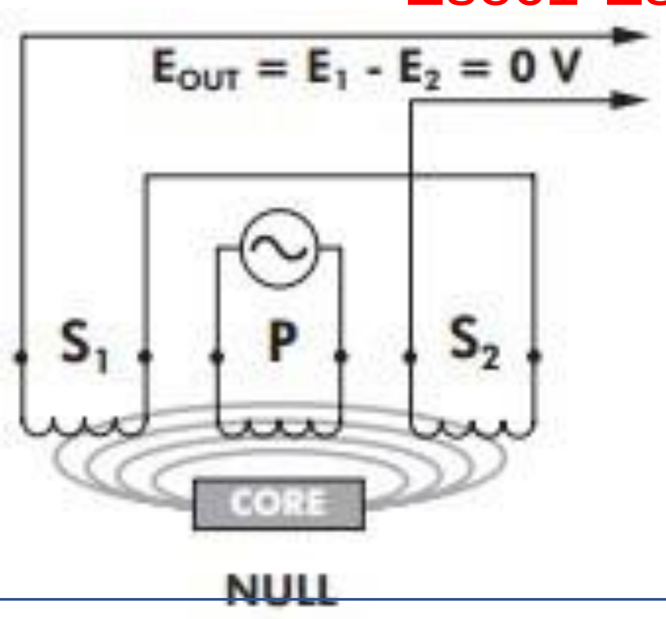
The cross sectional view of the DC LVDT at left shows the built-in signal conditioning electronics module. The module is secured with a potting compound that is not shown in this drawing

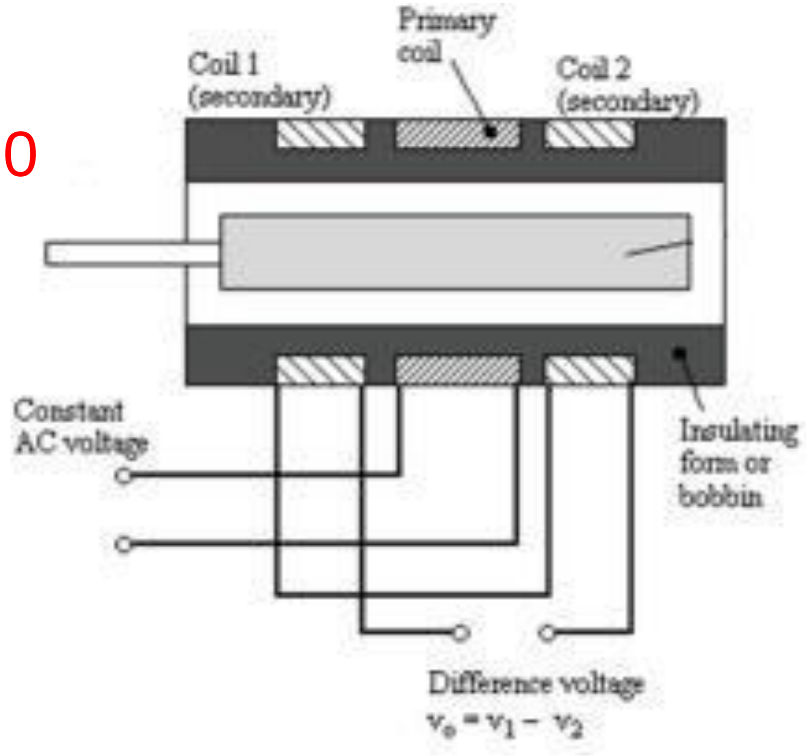
Working of LVDT:

Case 1:

On applying an external force which is the displacement, if the core remains in the null position itself without providing any movement then the voltage induced in both the secondary windings are equal which results in net output is equal to zero

Esec1-Esec2=0



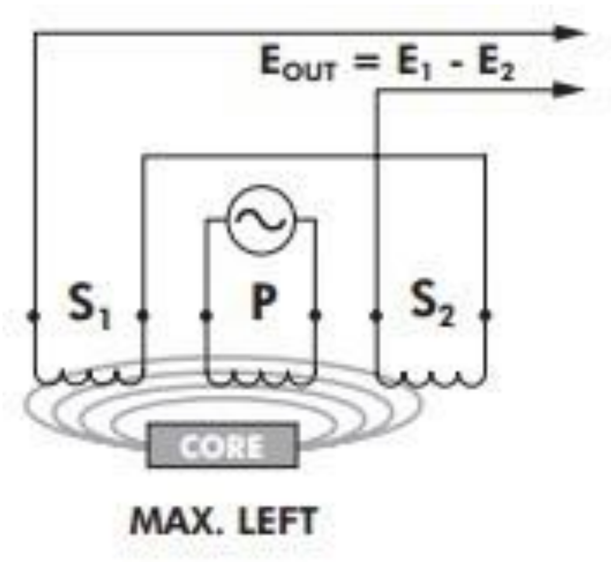


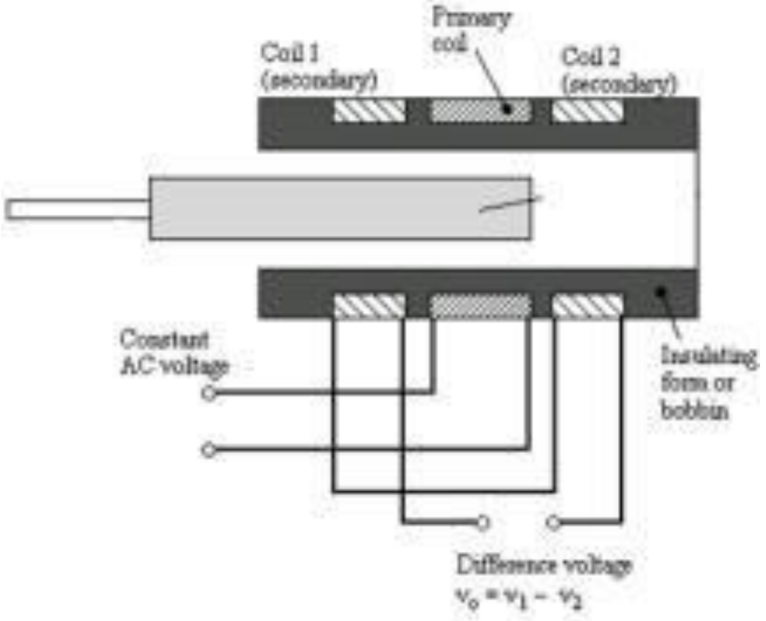
Working of LVDT:

Case 2:

When an external force is applied and if the steel iron core tends to move in the left hand side direction then the emf voltage induced in the secondary coil is greater when compared to the emf induced in the secondary coil 2.

Therefore the net output will be Esec1-Esec2





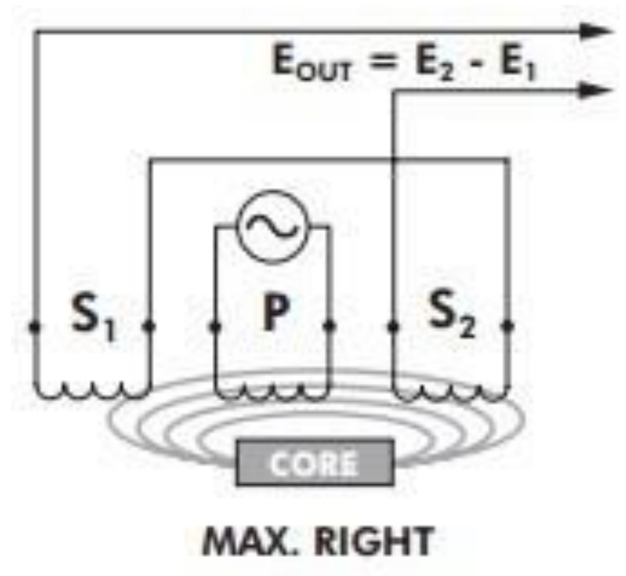
Working of LVDT:

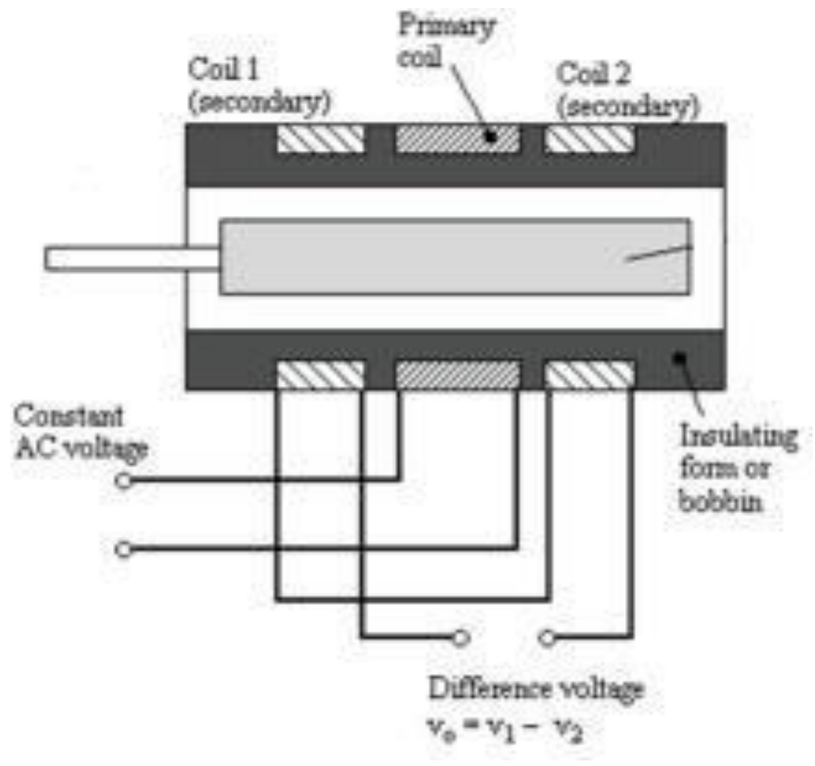
Case 3:

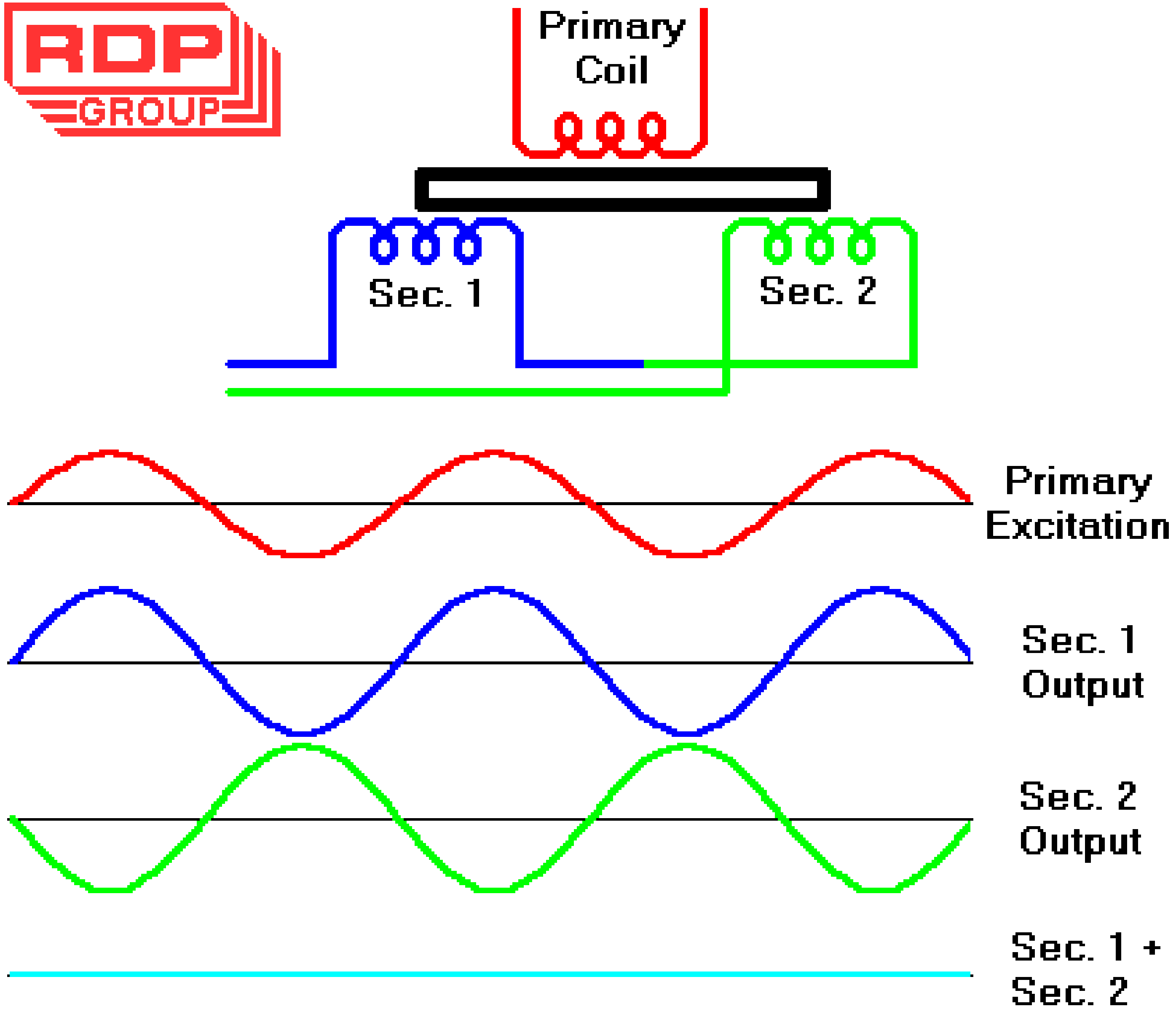
When an external force is applied and if the steel iron core moves in the right hand side direction then the emf induced in the secondary coil 2 is greater when compared to the emf voltage induced in the secondary coil 1.

The net output voltage will be

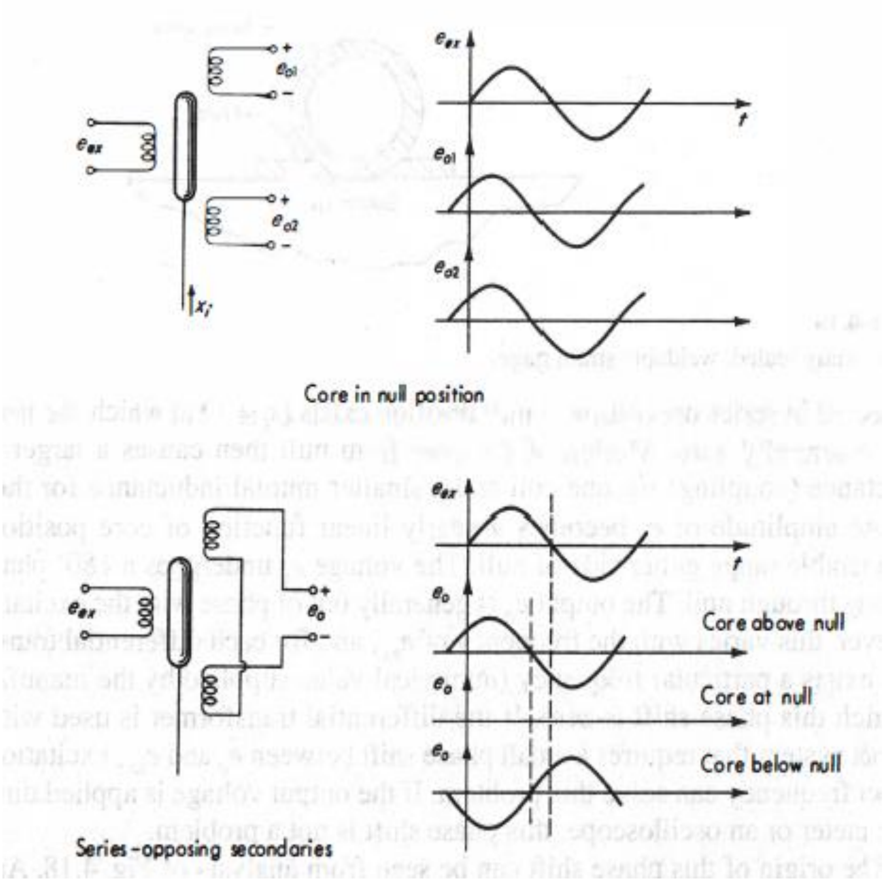
Esec2-Esec1






Primary Coil
Sec. 1
Sec. 2
Primary Excitation
Sec. 1 Output
Sec. 2 Output
Sec. 1 + Sec. 2

LVDT Operation



Case1:

If the core at the center, e_{O1}=e_{O2}, e_O=0

Case 2:

When the core is away from center toward e_{O1}, is greater than e_{O2} and the output voltage e_O will have the polarity e_{O1}. $e_{O} = e_{O1} - e_{O2}$

Case 3:

When the core is away from center toward S_2, e_{O2} is greater than e_{O1} and the output voltage e_O will have the polarity e_{O2}. $e_{O} = e_{O2} - e_{O1}$

LVDT Operation

- Voltage induced in the secondary coils is given by

$$e_{s1} = M_1 \frac{di_p}{dt}$$

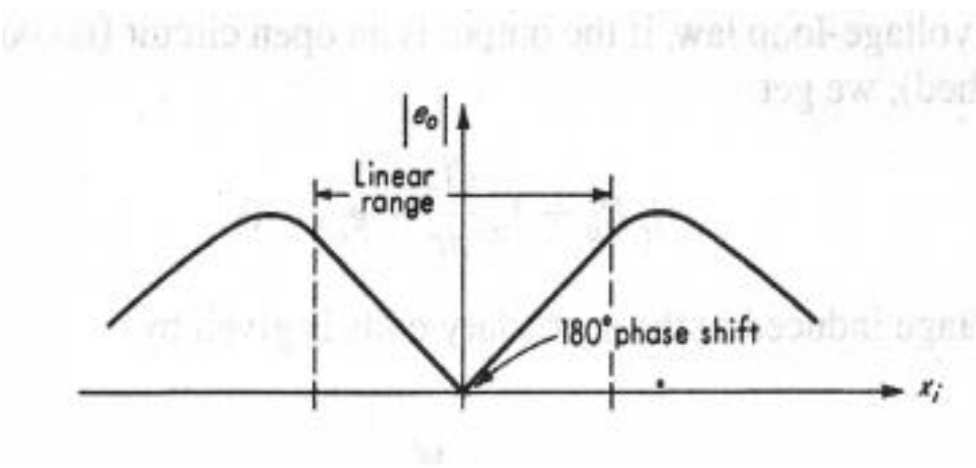
$$e_{s2} = M_2 \frac{di_p}{dt}$$

where M1 and M2 are the respective mutual inductances.

- The net secondary voltage e_O is then given by

$$e_s = e_{s1} - e_{s2} = (M_1 - M_2)\frac{di_p}{dt}$$

LVDT Operation



That is, the output ac voltage *inverts* as the core passes the center position

The farther the core moves from center, the greater the ***difference*** in value between $e_{O\,1}$ and e_{O2}, consequently the greater the value of e_O.

Thus, the amplitude of e_O is a function of the distance the core has moved, and the ***polarity*** or ***phase*** indicates which direction is has moved.

If the core is attached to a moving object, the LVDT output voltage can be a measure of the position of the object.

Advantages of LVDT:

1) Infinite resolution is present in LVDT
2) High output
3) LVDT gives High sensitivity
4) Very good linearity
5) Ruggedness
6) LVDT Provides Less friction
7) Low hysteresis
8) LVDT gives Low power consumption.

LVDT

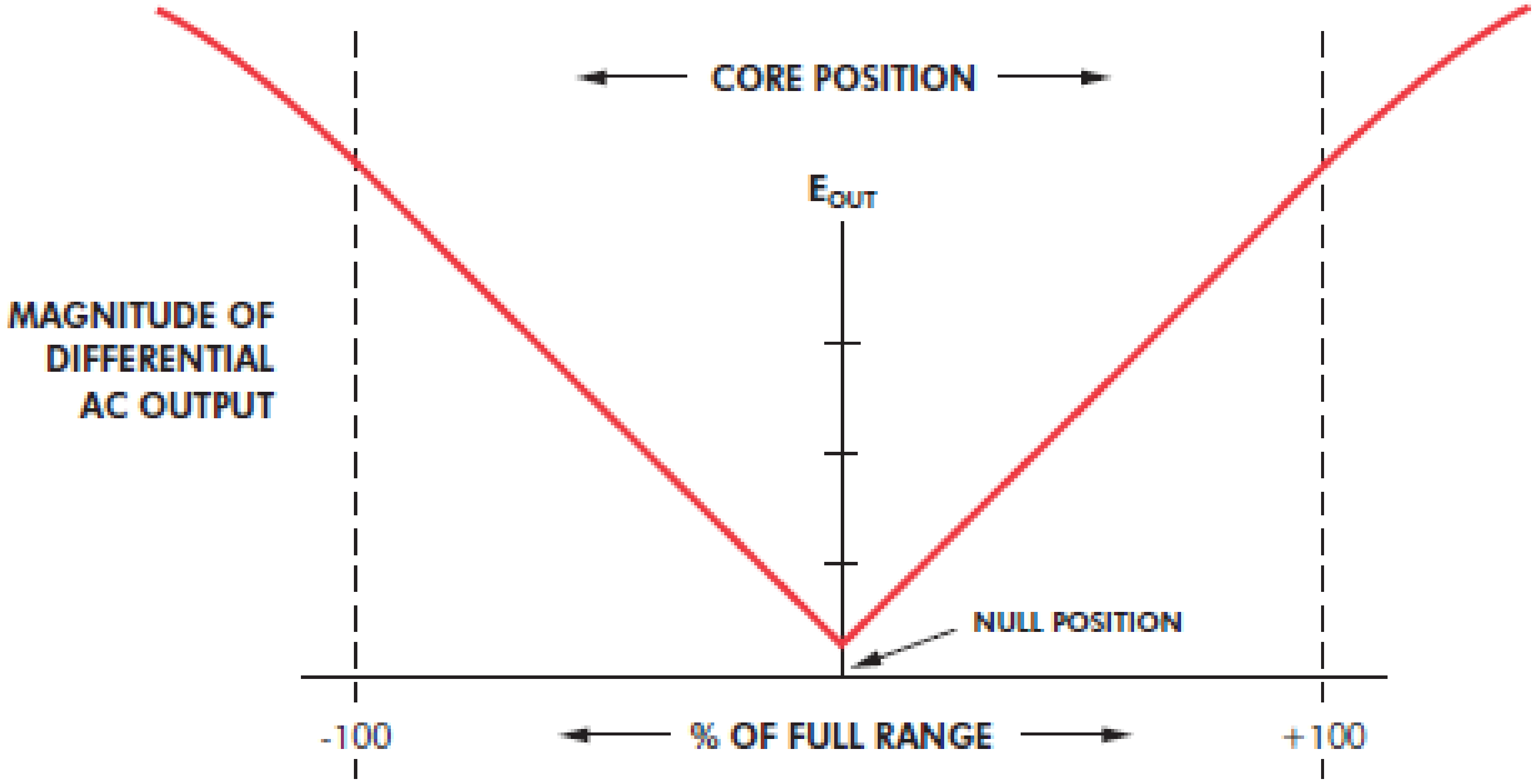
The disadvantages of LVDT are as follows:

- Very high displacement is required for generating high voltages.
- Shielding is required since it is sensitive to magnetic field.
- Its is greatly affected by temperature changes

Applications of LVDTs

- LVDT is used to measure displacement ranging from fraction millimeter to centimeter.
- Acting as a secondary transducer, LVDT can be used as a device to measure force, weight and pressure,

Characteristics of LVDT:



Numerical

The output of an LVDT is connected to a 5V voltmeter through an amplifier whose amplification factor is 250. An output of 2mV appears at the terminal of LVDT when the core moves through a distance of 0.5mm. Calculate the sensitivity of the LVDT and that of the whole set up. The milli-voltmeter scale has 100 divisions. The scale can be read to 1/5 of a division. Calculate the resolution of the instrument in mm.

Numerical

Solution:

Sensitivity of LVDT = Output voltage / Displacement = 2mV/0.5mm

= 4 mV/mm

Sensitivity of instrument = Amplification factor * Sensitivity of LVDT

= 1000 mV/mm

1 scale division = 5/100 = 50 mV

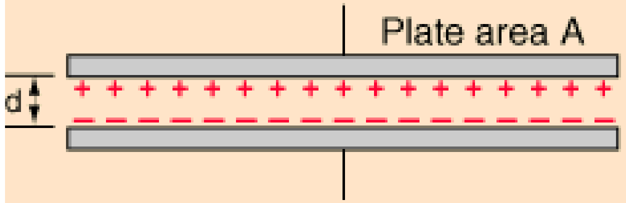
Minimum voltage that can be read by the voltmeter = 1/5 * 50 = 10mV

Resolution of the instrument = 1/1000 * 10 = 1×10^{-2} mm

CAPACITIVE SENSOR

- The principle operation of capacitive sensor is based upon the familiar equation for capacitance of a parallel plate capacitor.

$$\varepsilon_0 = 8.854 \;\; x \;\; 10^{-12} \quad F/m$$



$$C = \frac{\varepsilon A}{d} = \frac{k\varepsilon_0 A}{d}$$

= permittivity of space

K= relative permittivity of the dielectric material between the plates, k=1 for free space, k>1 for all media, approximately =1 for air.

CAPACITIVE SENSOR

- The capacitive transducer works on the principle of change of capacitance which may be caused by

  i. Change in overlapping area, A.
  ii. Change in the distance d between the plates.
  iii. Change in dielectric constant.

- These changes are caused by physical variables like pressure, displacement, force, etc. .
- Variation in capacitance is also there when the dielectric medium between the plates changes, as in the case of measurement of liquid or gas levels.

Measurement of Linear Displacement

1. Change in capacitance due to change in overlapping area of plates.

2. Change in capacitance due to change in distance between the two plates.

Change in Area of Plates

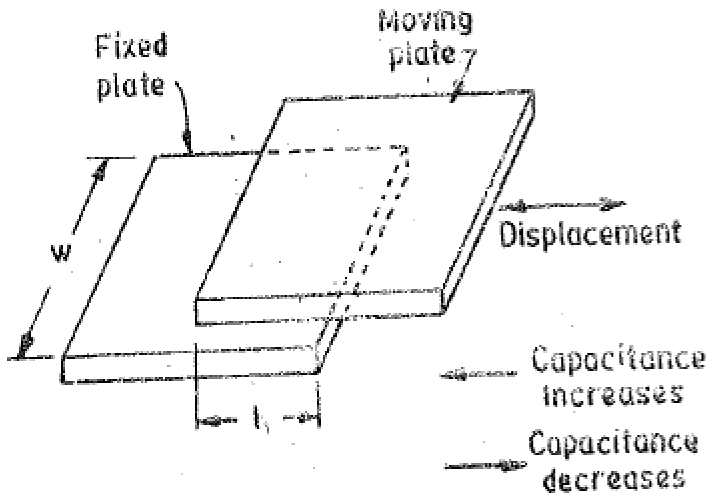
Parallel Plates

- Examining the equation for capacitance, it is found that the capacitance is directly proportional to the area, A of the plates.
- Thus, the capacitance changes linearly with change in area of plates.

$$C = \frac{\varepsilon A}{d} = \frac{\varepsilon l w}{d} F$$

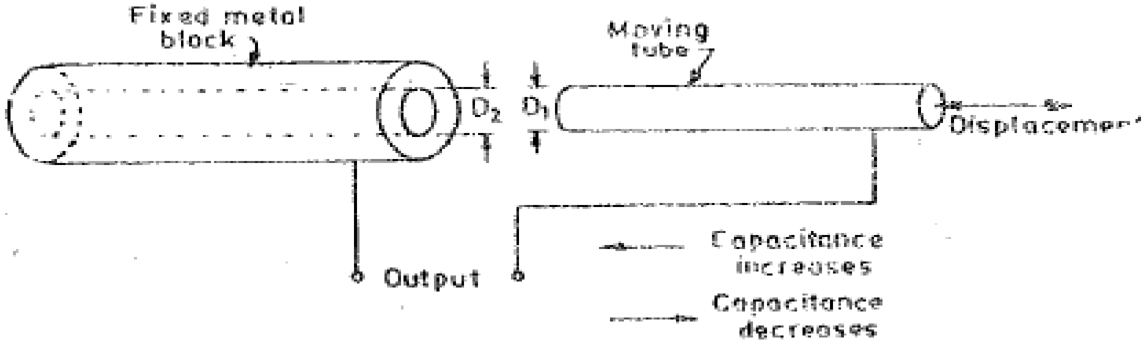
l = length of overlapping part of plates; m

w = width of overlapping part of plates; m



Change in Area of Plates

Cylindrical Capacitor



$$C = \frac{2\pi\varepsilon L}{\ln(\frac{b}{a})}$$

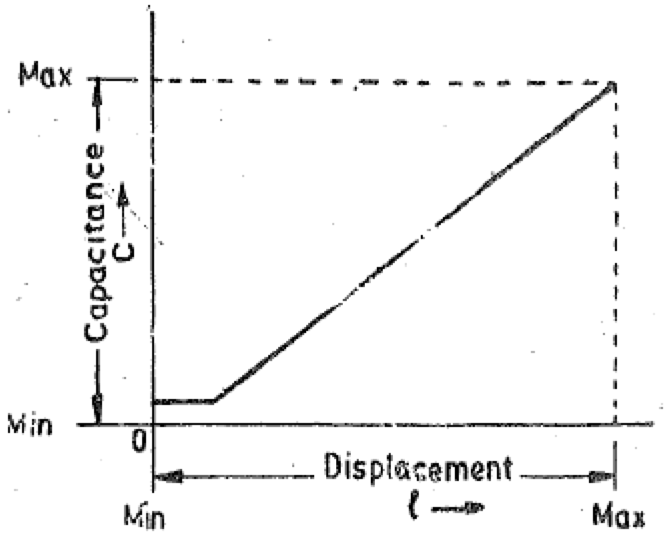
$$S = \frac{\partial C}{\partial l} = \frac{2\pi\epsilon}{\log_e (D_2/D_1)} \text{ F/m}$$

- L= length of overlapping part of the cylinders, m.
- b(D2) – inner diameter of the outer circle, m
- a(D1) – outer diameter of the inner circle, m

Change in Area of Plates

- Hence this type of capacitive transducer is useful for measurement of moderate to large displacements say from 1 mm to several cm.

$$S = \frac{\partial C}{\partial l} = \varepsilon \frac{w}{d} F/m$$

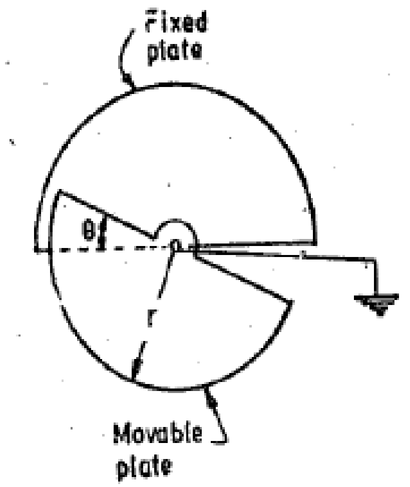


- The sensitivity is constant and therefore there is linear relationship between capacitance and displacement.

Change in Area of Plates

Measurement of Angular Displacement

- The angular displacement changes the effective area between the plates and thus changes the capacitance.
- The capacitance is maximum when the two plates are complete overlapped. i.e. when θ = 180 degree.



∴ Maximum value of capacitance $C_{max} = \frac{\epsilon A}{d} = \frac{\pi \epsilon r^2}{2d}$

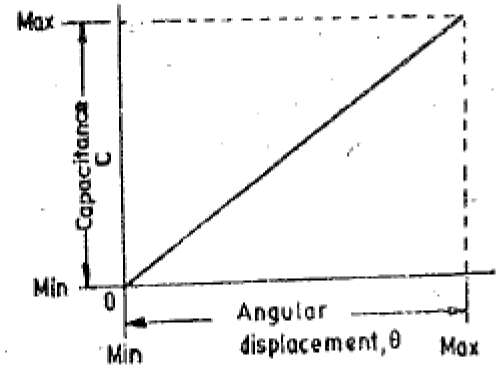
Change in Area of Plates

Measurement of Angular Displacement

Capacitance at angle θ is $$C = \frac{\epsilon r^2}{2d}\,\theta$$

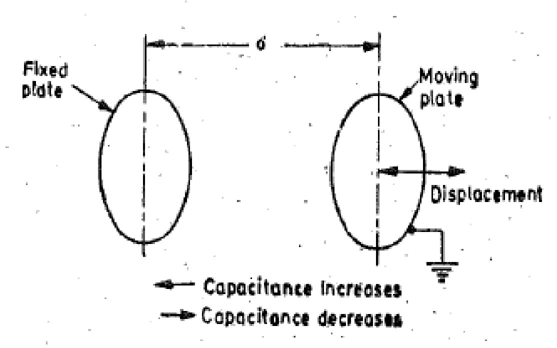
where θ = angular displacement in radian.

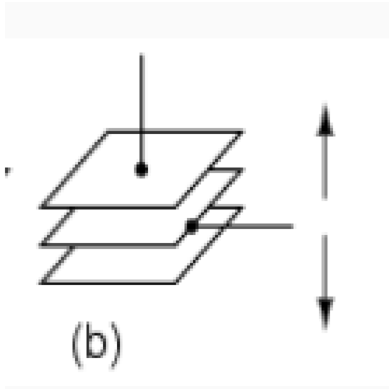
Sensitivity $$S = \frac{\partial C}{\partial \theta} = \frac{\epsilon r^2}{2d}$$



Change in Distance b/w Plates

- One plate is fixed and the displacement to be measured is applied to the other plate which is movable.
- Since, the capacitance, C, varies inversely as the distance d, between the plates the response of this transducer is not linear.
- Thus this transducer is useful only for measurement of extremely small displacements.

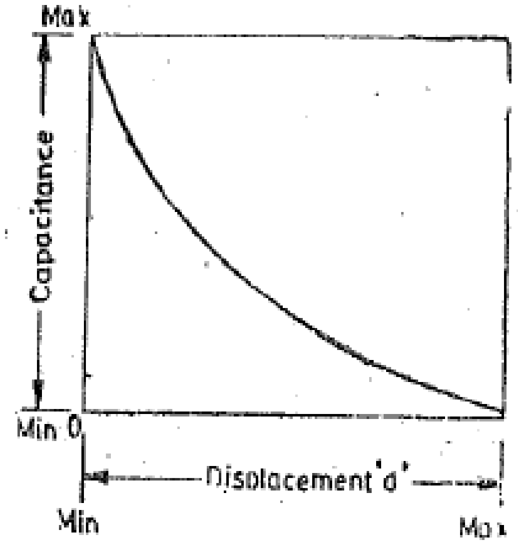




Change in Distance b/w Plates

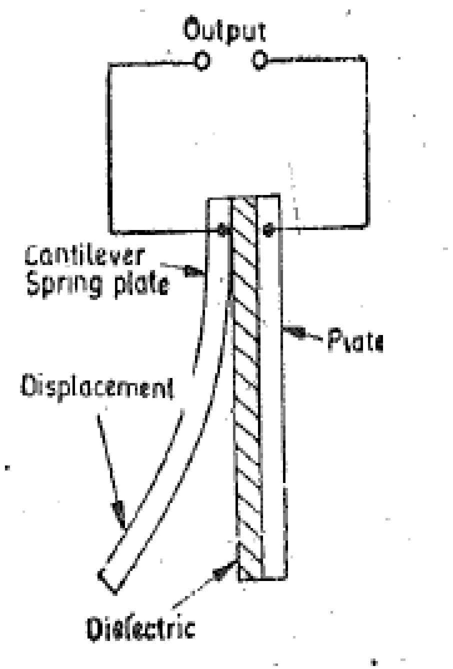
- Thus the sensitivity of this type of transducer is not constant but varies over the range of the transducer.
- It is only approximately linear over a small range of displacement.
- The linearity can be closely approximated by use of a piece of dielectric material like mica having a high dielectric constant, such as, a thin piece of mica.

$$S = \frac{\partial C}{\partial d} = -\frac{\varepsilon A}{d^2}$$

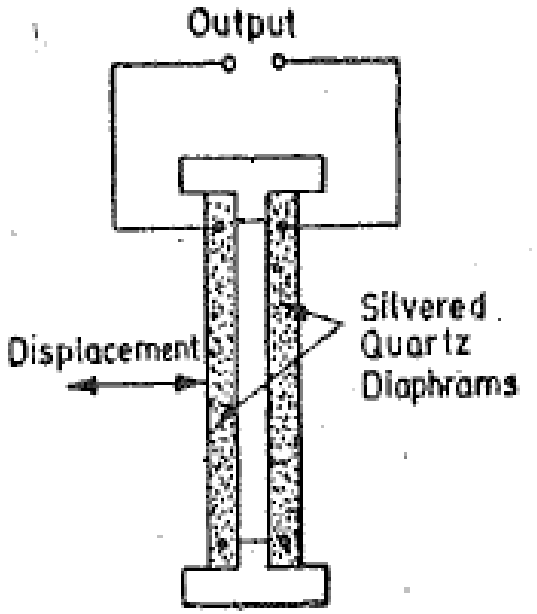


Change in Distance b/w Plates

Using Cantilever Spring Plate



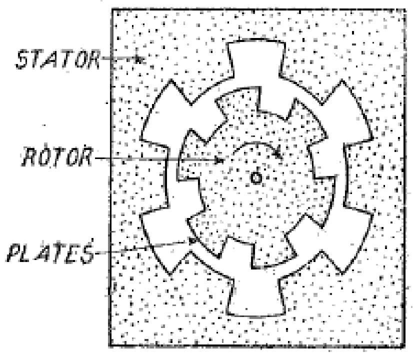
Using Quartz Diaphragm

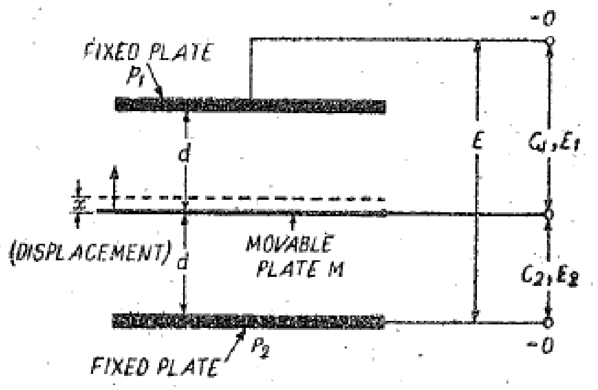


Change in Distance b/w Plates

Differential Arrangement

- A linear characteristic curve can be achieved by using differential arrangement.
- ***Three plates***, P1 and P2 are fixed and M is movable to which the displacement to be measured is applied.
- Thus we have two capacitors, whose differential output is taken.





Change in Distance b/w Plates

$$C_1 = \frac{\epsilon A}{d} \text{ and } C_2 = \frac{\epsilon A}{d}.$$

An alternating current voltage E is applied across plates P_1 and P_2 and the difference of the voltages across the two capacitances is measured.

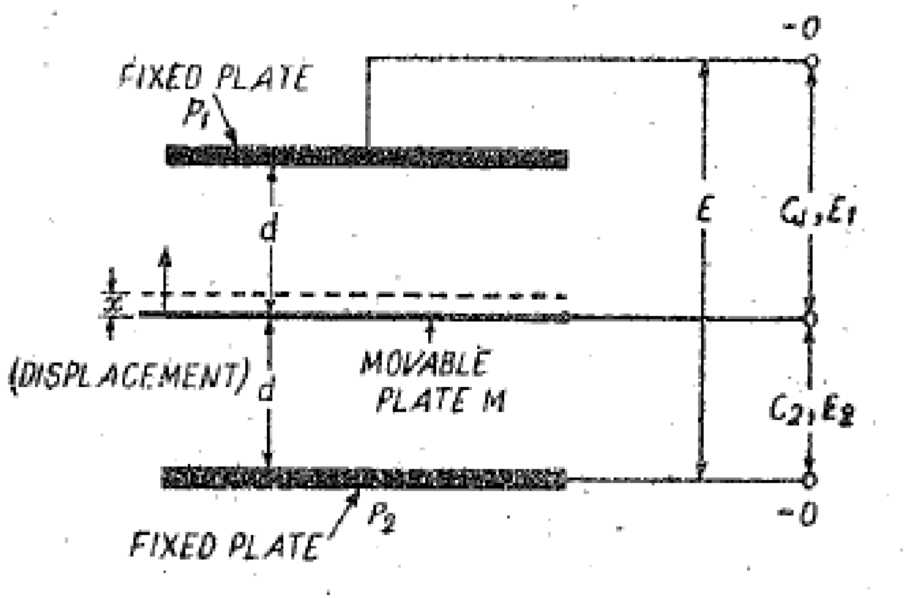
Voltage across C_1 is $$E_1 = \frac{EC_2}{C_1 + C_2}$$

and voltage across C_2 is $$E_2 = \frac{EC_1}{C_1 + C_2}$$

When the movable plate is midway between the two fixed plates $C_1 = C_2$ and therefore $E_1 = E_2 = E/2$.

$\therefore$ Differential output when the movable plate is midway $\Delta E = E_1 - E_2 = 0$.

Change in Distance b/w Plates



Change in Distance b/w Plates

Let the movable plate be moved up due to displacement x. Therefore the values C_1 and C_2 become different resulting in a differential voltage output.

Now $C_1 = \frac{\epsilon A}{d-x}$ and $C_2 = \frac{\epsilon A}{d+x}$.

$$\therefore \quad E_1 = \frac{C_2 E}{C_1 + C_2} = \frac{\epsilon A/(d+x)}{\epsilon A/(d-x) + \epsilon A/(d+x)} E = \frac{d-x}{2d} \cdot E$$

$$\text{and} \quad E_2 = \frac{C_1 E}{C_1 + C_2} = \frac{(\epsilon A/d-x)}{\epsilon A/(d-x) + \epsilon A/(d+x)} E = \frac{d+x}{2d} E$$

$$\therefore \text{ Differential output voltage} = \Delta E = E_2 - E_1 = \frac{d+x}{2d} E - \frac{d-x}{2d} E = \frac{x}{d} E \qquad \ldots(25.52)$$

Therefore the output voltage varies linearly as th displacement x.

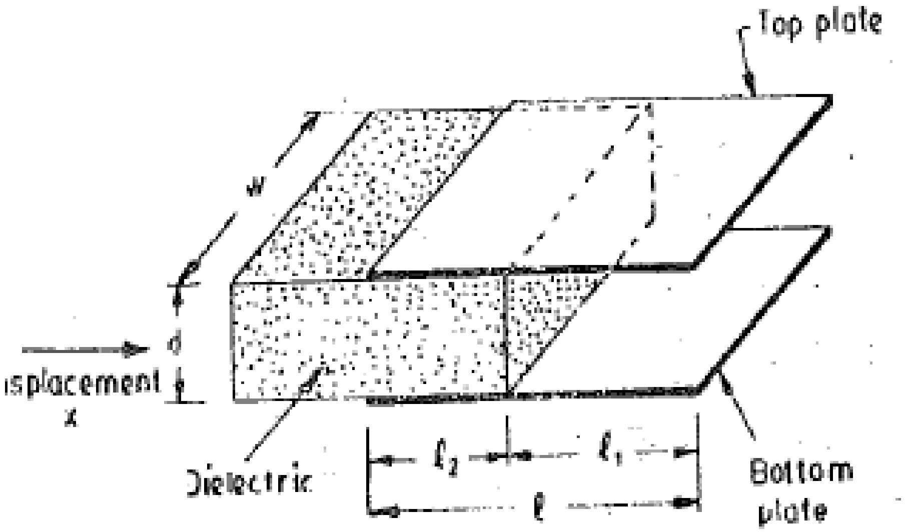
$$\text{Sensitivity } S = \frac{\Delta E}{x} = \frac{E}{d} \qquad \ldots(25.53)$$

The differential method can be used for displacements of 10^{-8} mm to 10 mm with an accuracy of 0.1%.

Change in Dielectric Constant

- It has a dielectric relative permittivity ϵ_r.

$$\text{Initial capacitance of transducer} = C = \epsilon_0 \frac{wl_1}{d} + \epsilon_0\epsilon_r \frac{wl_2}{d} = \epsilon_0 \frac{w}{d}[l_1 + \epsilon_r l_2]$$



Change in Dielectric Constant

Let the dielectric be moved through a distance x in the direction indicated. The capacitance changes from C to $C+\Delta C$.

$$\therefore \quad C+\Delta C=\epsilon_0 \frac{w}{d}(l_1-x)+\epsilon_0\epsilon_r \frac{w}{d}(l_2+x)=\epsilon_0 \frac{w}{d}[l_1-x+\epsilon_r(l_2+x)]$$

$$=\epsilon_0 \frac{w}{d}[l_1+\epsilon_r l_2+x(\epsilon_r-1)]=C+\epsilon_0 \frac{wx}{d}(\epsilon_r-1) \qquad \ldots(25\cdot55)$$

Change in capacitance $\Delta C=\epsilon_0 \frac{wx}{d}(\epsilon_r-1)$ ...(25·56)

Hence the change in capacitance is proportional to displacement.

Numerical

An electrode-diaphragm pressure transducer has plates whose area is *5 x 10*$^{-3}$ m^2 and whose distance between plates is 1 X 10^{-3} m. Calculate its capacitance if it measures air pressure. The dielectric constant of air is k =1.

$$C = \frac{kA\varepsilon_o}{d}$$

$$= \frac{(1)(5x10^{-3}m^2)(8.854x10^{-12}\ F/m)}{1x10^{-3}\ m}$$

$$= 44.25\,pF$$

Numerical

A capacitive transducer uses two quartz diaphragm of area 750mm^2 separated by a distance of 3.5mm. A pressure of 900 kN/m^2 when applied to the top of a diaphragm produces a deflection of 0.6mm. The capacitance is 370pF when no pressure is applied to the diaphragms. Find the value of capacitance after the application of a pressure of 900 kN/m^2

- C_1 and C_2 are the capacitor before and after application of pressure
- d_1 and d_2 be the distance between the diaphragm for the corresponding pressure value
- $C_1 = \varepsilon A/ d_1$ and $C_2 = \varepsilon A/ d_2$
- $d_1 = 3.5$mm, $d_2 = 3.5 – 0.6 = 2.90$mm
- $C_2 / C_1 = d_1/ d_2$; $C_2 = C_1 \times (d_1/ d_2)$
- $C_2 = 370(3.5/2.9) = 446.5$ pF

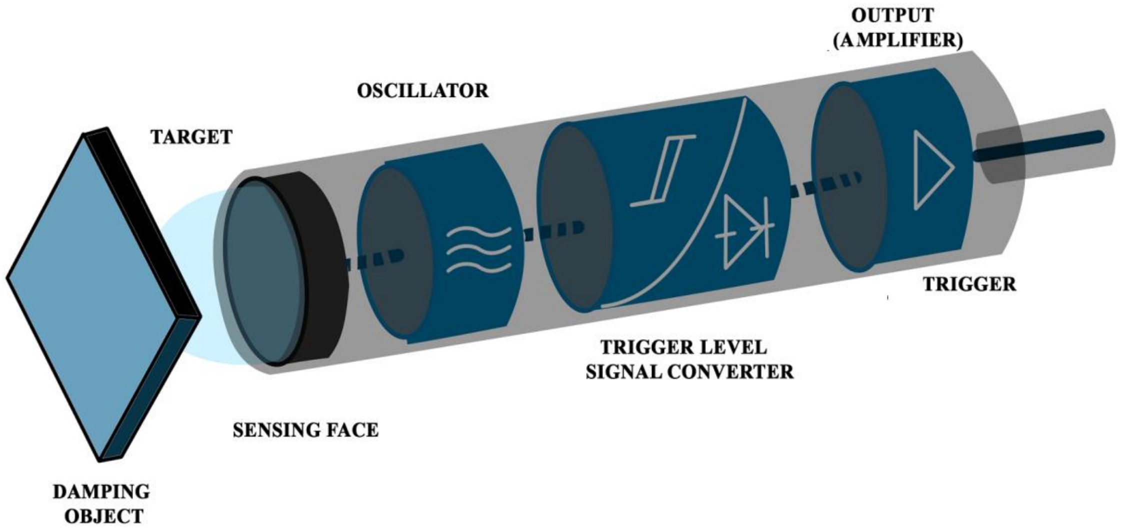
PROXIMITY SENSOR

- A **proximity sensor** is an electronic solid-state device used to indicate the presence of an object without making physical contact.
- The proximity sensor is a very useful device in hazardous areas such as oil refineries and not so hazardous areas such as car door detection systems.
- Proximity sensors do not use any type of physical moving parts instead they allow signals to transmit through them when something that is being monitored comes in close proximity of the sensing area.

Inductive Proximity Sensor

- Inductive proximity sensors operate under the electrical principle of magnetism when a fluctuating current induces the voltage in a target object.
- The inductive proximity sensor contains a certain type of solid-state control system.
- It contains an oscillator circuit that generates a high-frequency magnetic field. When the metal object enters the field, it disturbs the magnetic field, this disturbance results in a change of state in the high-frequency circuit.

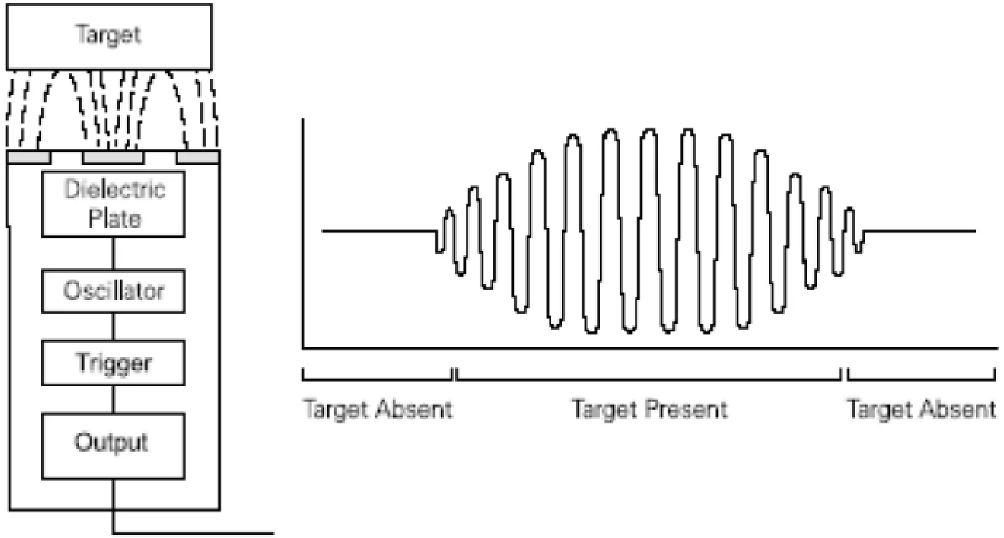
- **The oscillator generates an electromagnetic field that radiates out from the sensing face, inducing eddy currents in nearby metallic objects. This causes a change in the oscillation amplitude that triggers a change in the output state.**



- Inductive proximity sensors detect the presence of metallic objects.
- Their operating principle is based on a **coil and high frequency oscillator** that creates a field in the close surroundings of the sensing surface. The presence of metal in the operating area causes a **change in the oscillation amplitude**. This change is identified by a **threshold circuit**, which changes the output of the sensor. The operating distance of the sensor depends on the coil's size as well as the target's shape, size and material.

Capacitive Proximity Sensor

- The **capacitive proximity sensor** is similar to the inductive proximity sensor and uses the variation of capacitance between sensor and the object being detected
- The **main difference** between the two, capacitive proximity sensor produces an electrostatic field instead of a magnetic field and the sensing area of the capacitive proximity sensor can be actuated by both conductive and non-conductive materials.
- A capacitive proximity sensor contains a high-frequency oscillating circuit along with a sensing surface formatted by two metal plates.
- When an object or some type of material gets in the sensing range it disturbs the electrostatic field of the metal plates, changing the capacitance of the proximity sensor, this change results in a change of state in the operation of the proximity sen-or



Applications

- phones, recycling plants,
- self-driving cars,
- anti-aircraft systems, and
- assembly lines.

INFRARED SENSOR

- An infrared (IR) sensor is an electronic device that measures and detects infrared radiation in its surrounding environment.
- Infrared radiation was accidentally discovered by an astronomer named William Herchel in 1800.
- While measuring the temperature of each color of light (separated by a prism), he noticed that the temperature just beyond the red light was highest.
- IR is invisible to the human eye, as its wavelength is longer than that of visible light (though it is still on the same electromagnetic spectrum).
- Anything that emits heat (everything that has a temperature above around five degrees Kelvin) gives off infrared radiation.

Types of Infrared Sensor

- There are two types of infrared sensors: active and passive.
- Active infrared sensors both emit and detect infrared radiation. Active IR sensors have two parts: a light emitting diode (LED) and a receiver.
- When an object comes close to the sensor, the infrared light from the LED reflects off of the object and is detected by the receiver.
- Active IR sensors act as proximity sensors, and they are commonly used in obstacle detection systems (such as in robots).

Passive infrared (PIR) sensors only detect infrared radiation and do not emit it from an LED.

- Passive infrared sensors are comprised of:
- Two strips of pyroelectric material (a pyroelectric sensor)
- An infrared filter (that blocks out all other wavelengths of light)
- A fresnel lens (which collects light from many angles into a single point)
- A housing unit (to protect the sensor from other environmental variables, such as humidity)
- PIR sensors are most commonly used in motion-based detection, such as in-home security systems.
- When a moving object that generates infrared radiation enters the sensing range of the detector, the difference in IR levels between the two pyroelectric elements is measured.
- The sensor then sends an electronic signal to an embedded computer, which in turn triggers an alarm.

Components of IR Sensor

There are different types of infrared transmitters depending on their wavelengths, output power and response time.

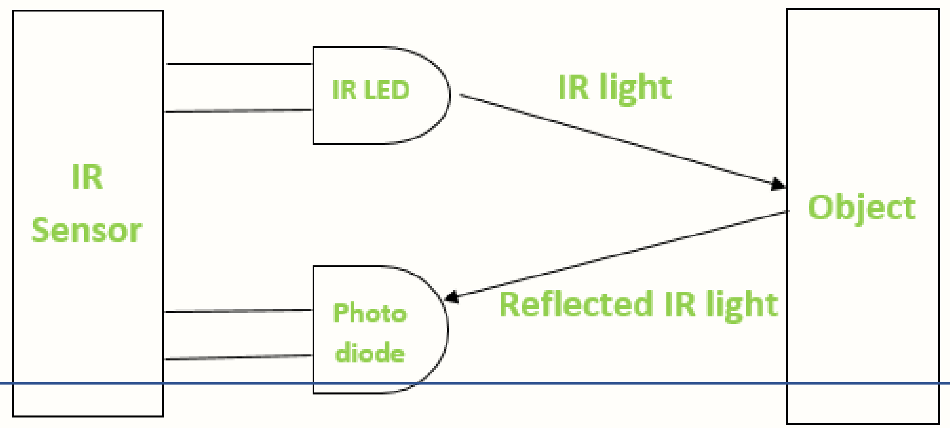
- An IR sensor consists of an IR LED and an IR Photodiode, together they are called as PhotoCoupler or OptoCoupler.

IR Transmitter or IR LED

- Infrared Transmitter is a light emitting diode (LED) which emits infrared radiations called as IR LED's.
- Even though an IR LED looks like a normal LED, the radiation emitted by it is invisible to the human eye.

IR Receiver or Photodiode

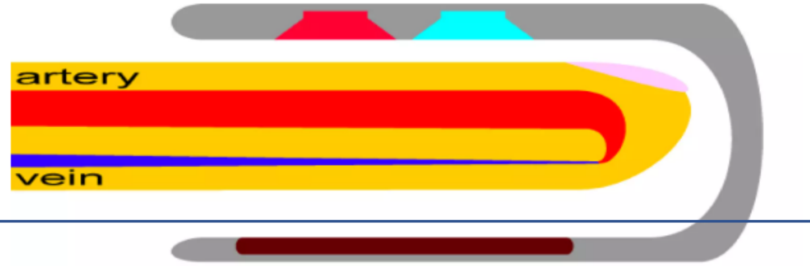
- Infrared receivers or infrared sensors detect the radiation from an IR transmitter. IR receivers come in the form of photodiodes and phototransistors. Infrared Photodiodes are different from normal photo diodes as they detect only infrared radiation.



- Different types of IR receivers exist based on the wavelength, voltage, package, etc.
- When used in an infrared transmitter – receiver combination, the wavelength of the receiver should match with that of the transmitter.
- The emitter is an IR LED and the detector is an IR photodiode. The IR photodiode is sensitive to the IR light emitted by an IR LED.
- The photo-diode's resistance and output voltage change in proportion to the IR light received. This is the underlying working principle of the IR sensor.
- When the IR transmitter emits radiation, it reaches the object and some of the radiation reflects back to the IR receiver.
- Based on the intensity of the reception by the IR receiver, the output of the **sensor** defines.

PULSE OXIMETER

- **Pulse oximetry is a noninvasive monitoring technique used to estimate the measurement of arterial oxygen saturation (Sao2) of hemoglobin.**
- **Oxygen saturation is an indicator of the percentage of hemoglobin saturated with oxygen at the time of the measurement .**
- **The reading, obtained through pulse oximetry, uses a light sensor containing two sources of light (red and infrared) that are absorbed by hemoglobin and transmitted through tissues to a photodetector.**
- **Oxygenated and deoxygenated hemoglobin absorbs more infrared light and deoxygenated hemoglobin absorbs more red light**

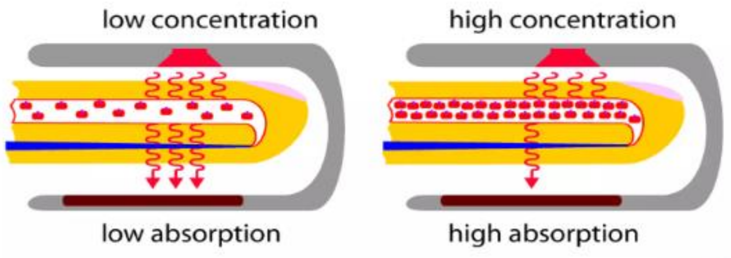


The amount of light absorbed depends on three physical properties:

1. concentration of the light absorbing substance.
2. length of the light path in the absorbing substance
3. oxyhemoglobin and deoxyhemoglobin absorbs red and infrared light differently

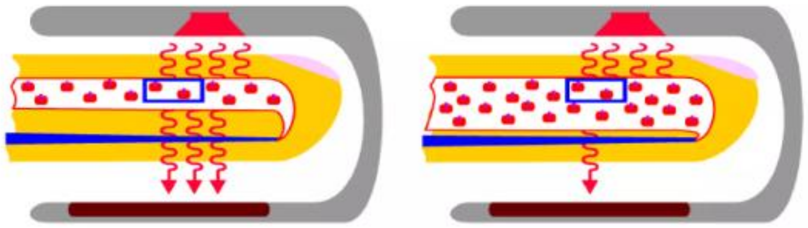
Property No.1

Amount of light absorbed is proportional to the concentration of the light absorbing substance.



Property No.2

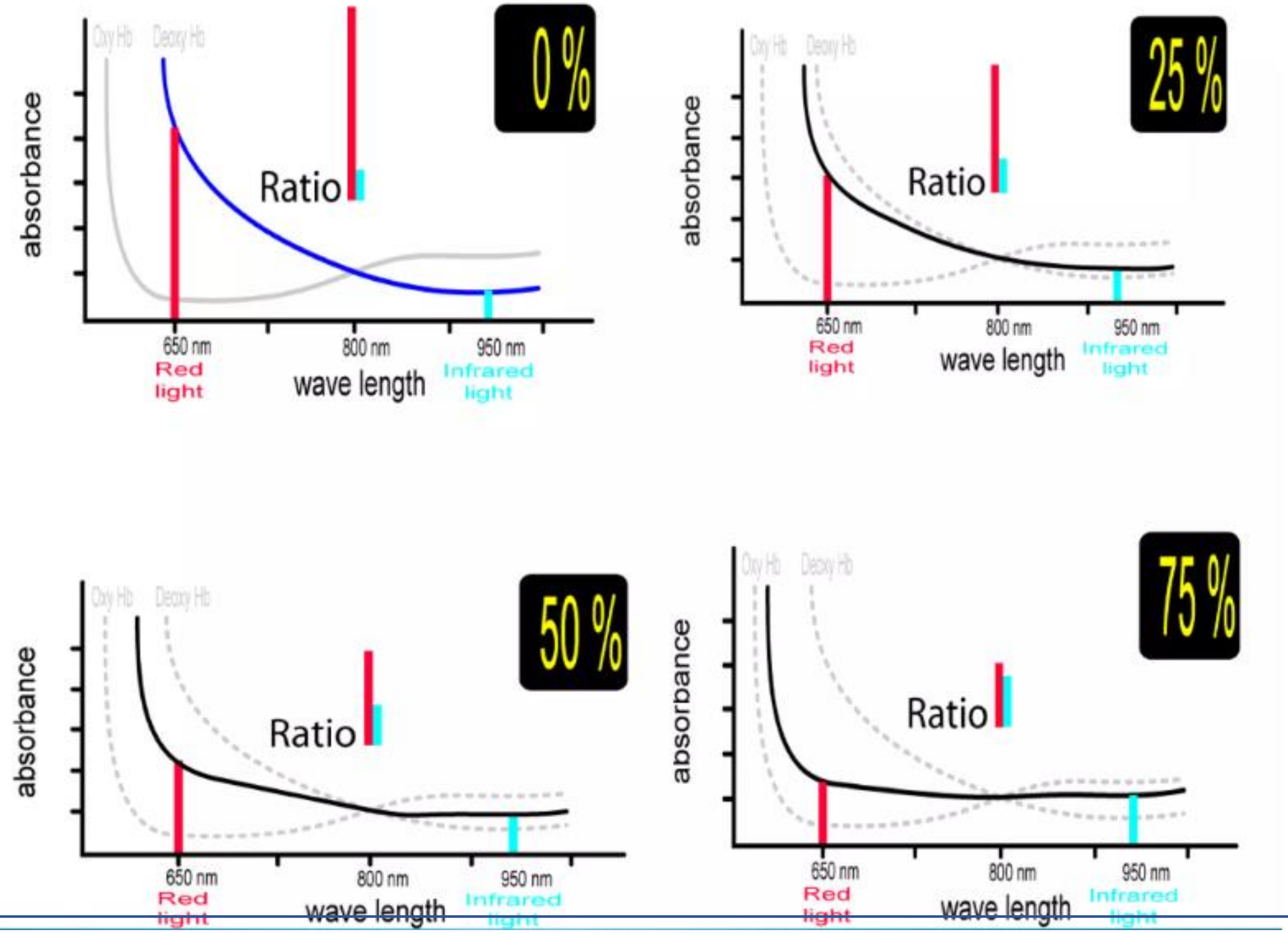
Amount of light absorbed is proportional to the length of the light path.

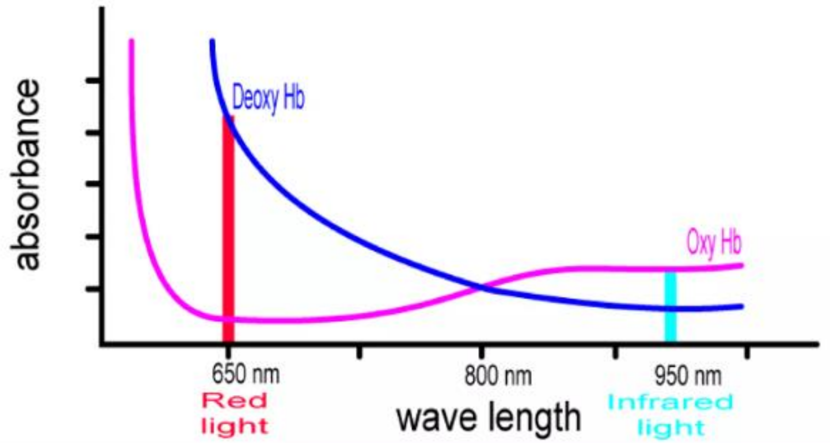


Property No.3

oxyhemoglobin absorbs more infrared light than red light & deoxyhemoglobin absorbs more red light than infrared light.

- **The infrared light is absorbed by the oxyhemoglobin ,and the red light is absorbed by the reduced hemoglobin.**
- **The amount and type of light transmitted through the tissue is converted to a digital value representing the percentage of hemoglobin saturated with oxygen.**





TACHOMETER

- A tachometer is a device that is useful in measuring the rotation speed of a shaft or disk as in a motor or other machine.
- A Tachometer is a device that is useful in measuring the operating speed of an engine at the revolution of RPM and is helpful for planes, both cars, and other types of vehicles.

❖ Tachometer is used for measuring rotational speed

❖ Can be used to measure speed of a rotating shaft

❖ Can also be used to measure flow of liquid by attaching a wheel with inclined vanes

Working Principle of Tachometer

- A Tachometer works on the principle of relative motion.
- The device operates between the shaft of the device and the magnetic field.
- It works as a generator and produces the voltage as per the velocity of the stick.
- The device counts the number of rotations that the shaft makes per minute.

Classification of tachometers

- Tachometers can be classified on the basis of data acquisition – contact or non contact types
- They can also be classified on the basis of the measurement technique – time based or frequency based technique of measurement
- They can also be classified as analog or digital type

Analog Tachometer

- Has a needle and dial type of interface
- No provision for storage of readings
- Cannot compute average, deviation, e tc

Digital Tachometer

- Has a LCD or LED readout
- Memory is provided for storage
- Can perform statistical functions like averaging, etc

Analog Tachometer


Digital Tachometer

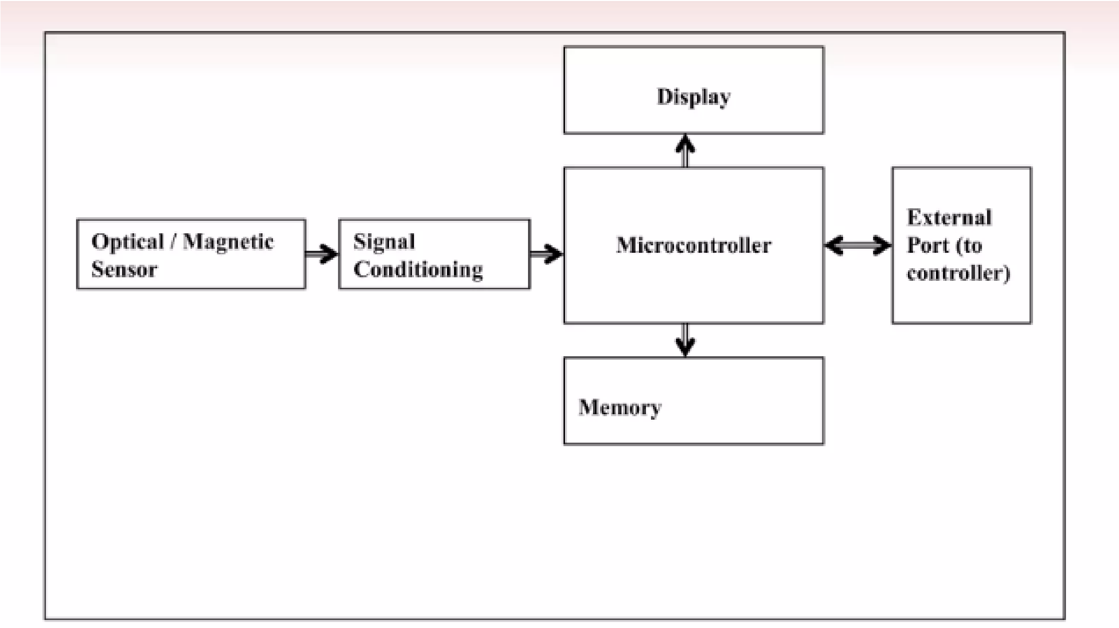
- Analog Tachometer-Measurement Technique

❖ Generally speed is converted to voltage through the use of an external frequency to voltage converter

❖ The tachometer can also act as a generator and produce a voltage that is proportional to the speed of the shaft

❖ Voltage is then displayed by an analog voltmeter

- Digital Tachometer-Block Diagram



Classification Based on data acquisition technique

- Contact type

- The contact type of the Tachometer comes built-in or fixed with the electric motor and works by bringing the freely spinning wheel in contact with the shaft or disc that is rotating.
- They generate the pulses with the help of the shaft that drives the wheel and then Tachometer reads the pulses that the shaft generates and measures them in the RPM.
- Depending on the model, it also uses an optical encoder or a magnetic sensor which provides an accurate reading with the help of direct contact with the shaft on the rotating component.
- It is also helpful in determining and calculating the distance and linear speed.

- Non contact type

- The non-contact type of Tachometer is also known as the **Photo Tachometer**.
- This type of Tachometers don't require any physical contact with the shaft that is rotating.
- It uses infrared light, laser, and other resources to find accurate measurements.
- Non-contact type of Tachometer sends a beam of light that reflects each time on a tape and makes a full rotation.
- The receiver counts the reflection during the whole process and measures the rotational speed in RPM.
- It is a type of Tachometer that is compact, accurate, and efficient.

Classification based on measurement

- **Time Measurement** – The tachometer calculates speed by measuring the time interval between the incoming pulses
- **Frequency Measurement** – The tachometer calculates speed by measuring the frequency of the incoming pulses

Applications

- Automobiles
- Laser Instruments
- Medical Devices
- Analog audio recording