Transducers
UNIT-V

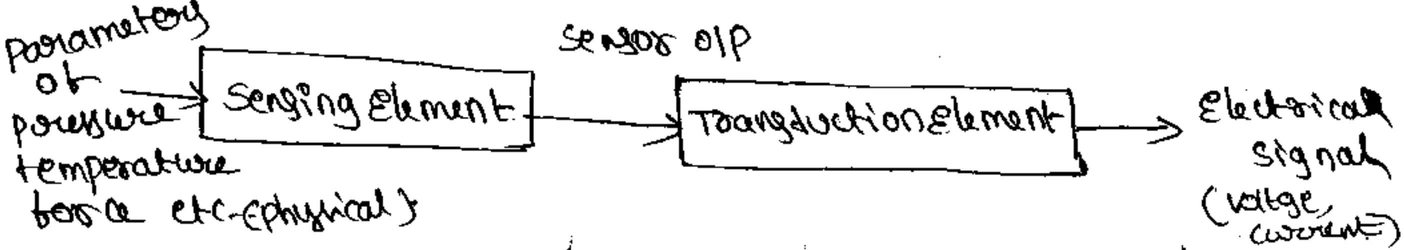
Transducer

→ It is a device that receives energy from one system and transmit it to another form. The energy may be electrical or mechanical. (convert physical quantity in to electrical s/e)

→ The output from the transducer depends on the principle involved in the design. The output may be analog, digital or frequency modulated.

→ Transducers are two types electrical & mechanical

→



→ sensing element is called as sensor. It produces a output that is change in physical quantity. Transduction element convert the sensor output to electrical signal.

Electrical Transducer (parameters)

→ It have the following parameters

1) **Linearity**:

The relation between a physical parameter and electrical signal must be linear.

2) **Sensitivity**:

It is defined as the electrical output per unit change in the physical parameter.

3) **Dynamic range**:

The operating range of the transducer should be wide, And it is used in wide range of measurement conditions.

(4) Repeatability:

The input and output relationship for a transducer should be predictable over a long period of time.

(5) Physical size

Transducer must have minimum weight and volume,

ADvantages of Electrical Transducers

1) Electrical amplification and attenuation can be easily done
2) Mass inertia effects are minimised.
3) Effects of friction are minimised.
4) Output can be easily recorded
5) The output can be modified to meet the requirements of indicating unit.
6) Electrical or electronic system can be controlled with a small power level.
7)

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Electrical Transducers (Types)

Classified into a) active transducer
b) passive transducer.

Active Transducer:

→ It generates an electrical signal and it does not require an external power source for its operation.

→ active transducers are self generating devices, which operate under energy conversion principle & generate an equivalent output signal (Ex: pressure to charge).

Typical Example of active transducers are piezo Electric Sensors.

Passive Transducers

-> Operate under Energy Controlling principles. They depend upon the change in an Electrical parameter (R, L & C)
-> Example of passive transducer are Strain gauges and ~~thermometers~~, thermistors.
-> Electrical transducers are used to measure non-Electrical quantities. For this purpose a sensing element is used, which Converts the physical quantity into a displacement. The electrical signals may be current, voltage, their production is based on R, L & C Effects.
-> A transducer which converts a non-Electrical quantity into an analog electrical signal consisting of two parts, the sensing element, and the transduction Element.
-> The transduction Elements of transducers are as follows.

1) Resistive
2) inductive
3) capacitive
4) piezo-Electric
5) photo-emissive
6) photo-resistive
7) Photovoltaic

Selecting a Transducer (Transducer selection factors)

The following should be considered while selecting a transducer

1) operating range:
chosen to maintain range requirements and good resolution.

(2) <u>Sensitivity</u>:

Chosen to allow sufficient output.

(3) <u>Frequency response and resonant frequency</u>:

Flat over the entire desired range.

(4) <u>Environmental Compatability</u>:

Temperature range, pressure, size

(5) <u>minimum sensitivity</u>:

To expected stimulus, other than the measurand.

(6) <u>Accuracy</u>:

Repeatability and calibration errors as well as errors expected due to sensitivity to other stimuli

(7) <u>Electrical parameters</u>:

length & type of cable required, signal to noise ratio when combined with amplifiers.

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(i) RESISTIVE TRANSIDUCER (potentiometric transiducer)

-> Resistance changes due to change in some physical phenomenon.

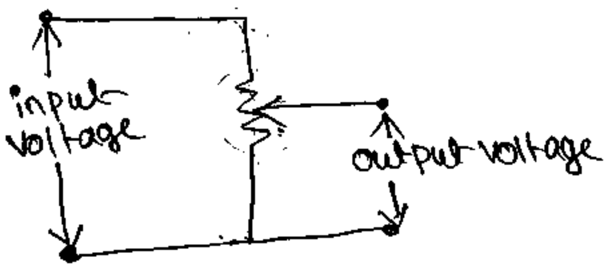
-> The change in value of resistance with a change in the length of the conductor can be used to measure displacement.

-> The resistivity of material changes with the changes in temperature. This property used for <u>measurement of temperature</u>.

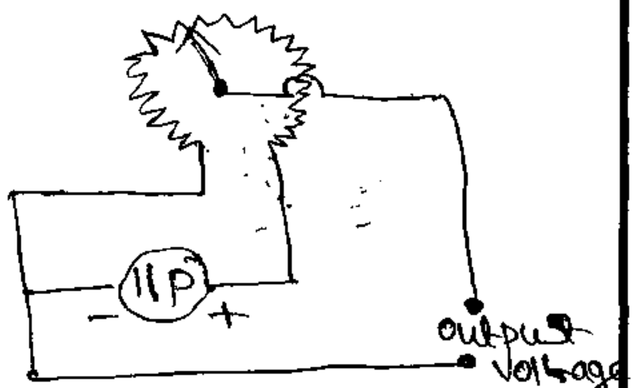
(a) <u>Resistive potentiometer</u>:

It consists of a resistance element provided with a sliding contact, called a wiper.

The motion of the sliding contact may be translatory or rotational. Some have a combination of both, with resistive elements in the form of a helix, as shown in figure. They are known as helipots.



(a) Translatory Type.



(b) Rotational Type

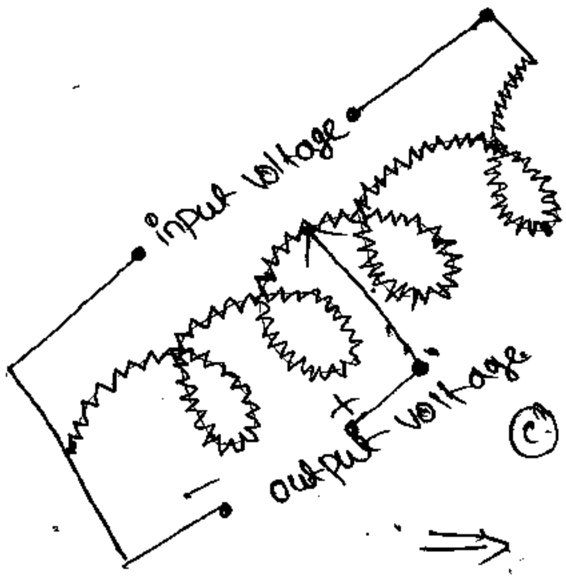
(Resistance of conductor)

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

→ ρ is resistivity of conductor

→ L is length of conductor

→ A is area of crosssection.



(c) Helipot (Rotational)

$$\Longrightarrow \quad V_o = \left(\frac{l}{L}\right) V_{in}$$

→ Translatory type (fig a) are linear devices,

Rotational type (fig b) are circular and are used for measurement of angular displacement.

as Helipot (fig b) are Multiturn rotational devices which can be used for measurement of either translatory or rotational motion.

→ A potentiometer is a passive transducer it requires an external power source for its operation.

→ $V_o = \left(\frac{l}{L}\right) V_{in}$; → L is total length

→ l is length of wire b/n wiper contacts reference end.

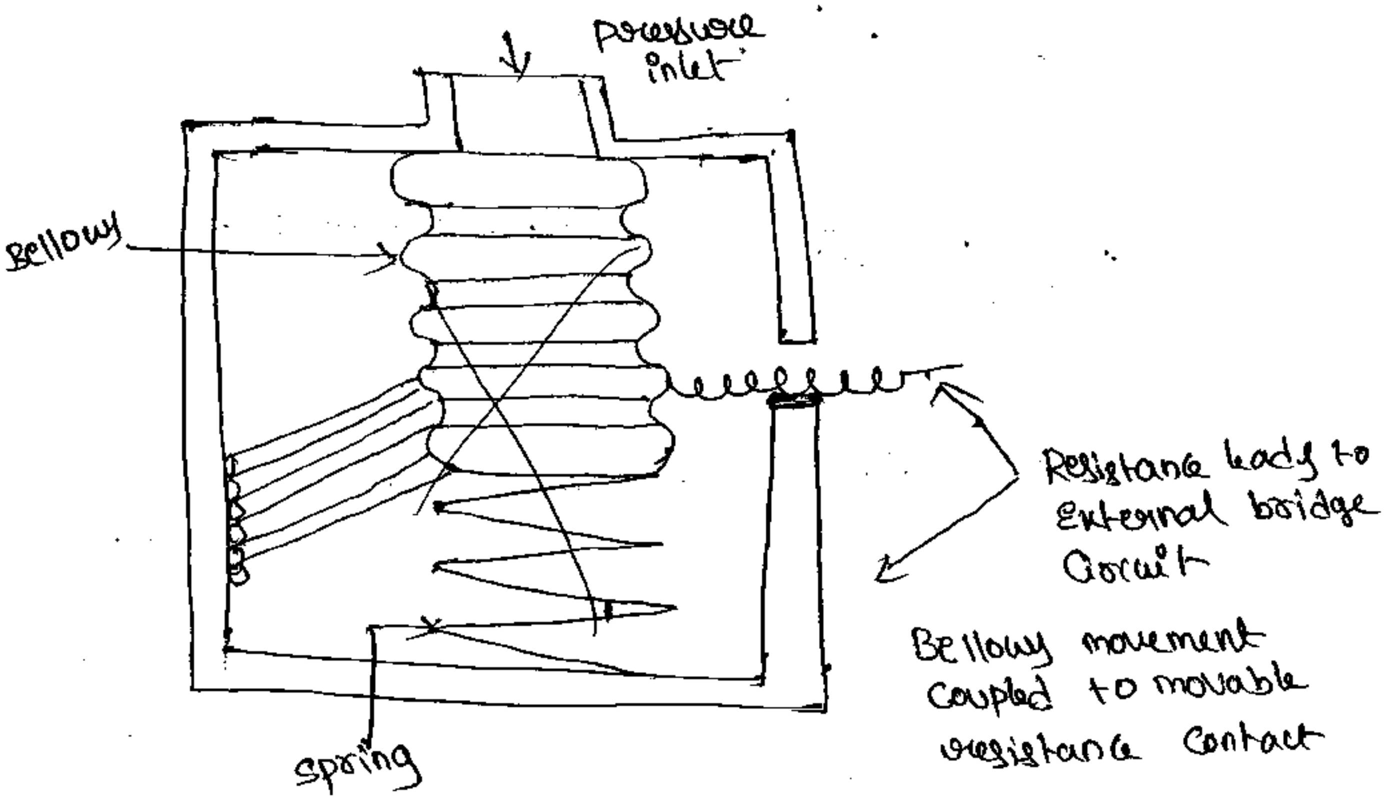
Advantages of potentiometer

1) They are inexpensive.
2) Simple to operate
3) useful for measurement of large amplitudes of displacement
4) Electrical efficiency is very high.

Disadvantages:

1) A large force is required to move the sliding contact.
2) The sliding contact can wear out, become misaligned and generate noise.

Resistance pressure transducer

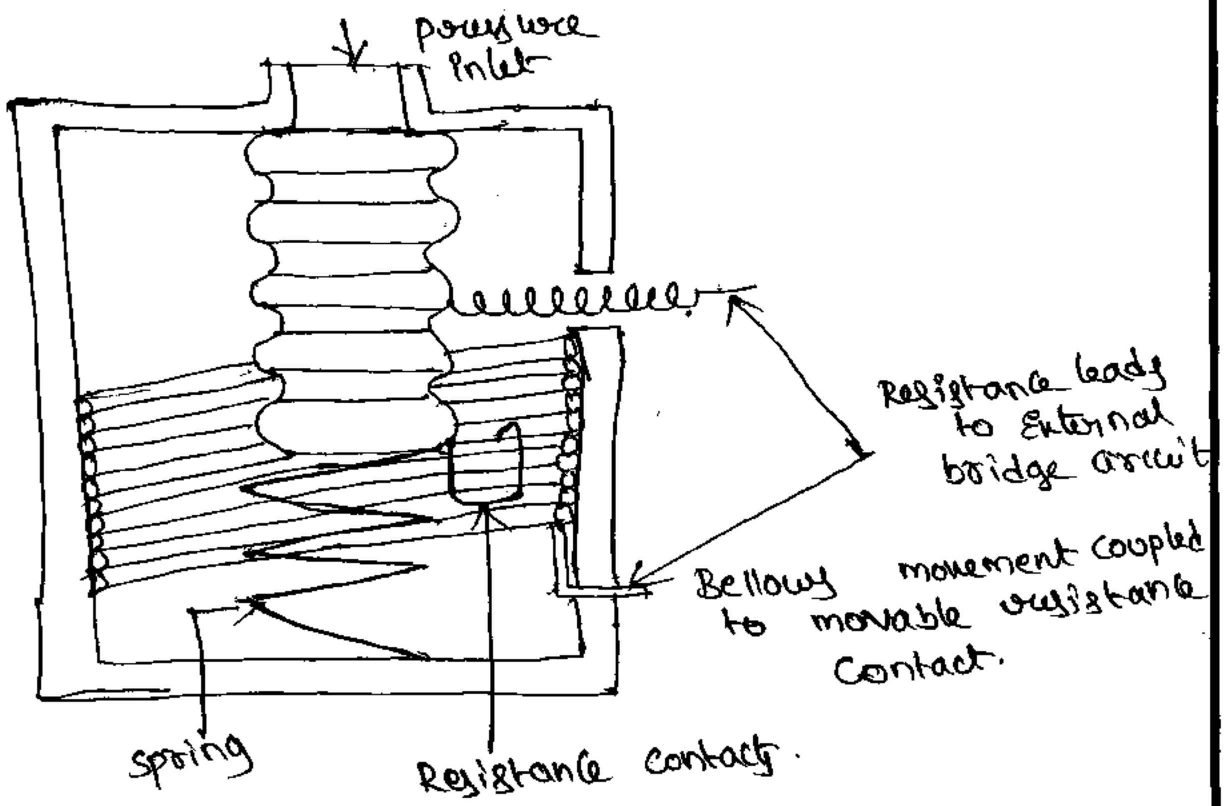


(b) Resistance pressure transducer

→ measurement in the resistive type of transducer is based on the fact that a change in a pressure result in a resistance change in the sensing element.

→ Resistance pressure transducer are of two main types. first the electromechanical resistance transducer in which a change of pressure, stress, position, displacement is applied to a variable resistor.

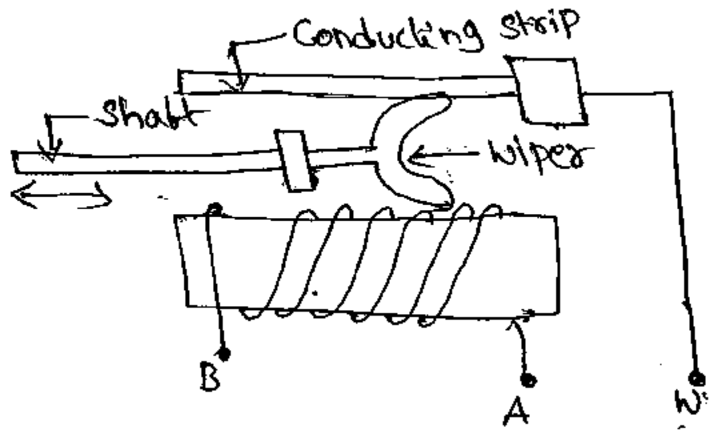
→ The other resistance pressure transducer is the strain guage, where the stress act directly on the resistance.



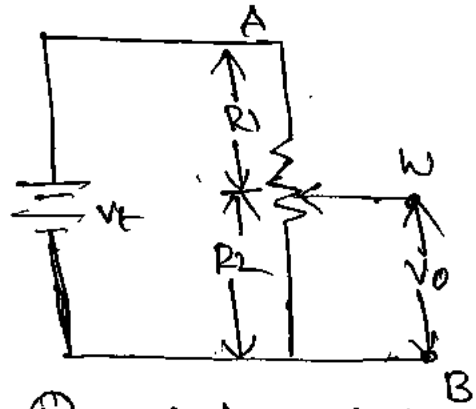
(c) Resistive position Transducer

→ The principle of the resistive transducer is that the physical variable under measurement causes a resistance change in the sensing element.

→



(a) Construction of resistance position transducer



(b) Typical method.

→ One type of displacement transducer uses a resistive element with a wiper linked to the object being measured. Thus the resistance between the slider and one end of the resistance element depend on the position of the object.

→ In the typical method output voltage depends on wiper position, and it is a function of shaft position. This voltage is applied to a voltmeter calibrated in cms for visual display.

$$\frac{V_o}{V_t} = \frac{R_2}{R_1 + R_2}$$

→ Output voltage is proportional to R_2, ie, the position of wiper of potentiometer.

② Capacitive transducer (pressure)

→ A linear change in capacitance with changes in the physical position of the moving element may be used to provide an electrical indication of the element's position.

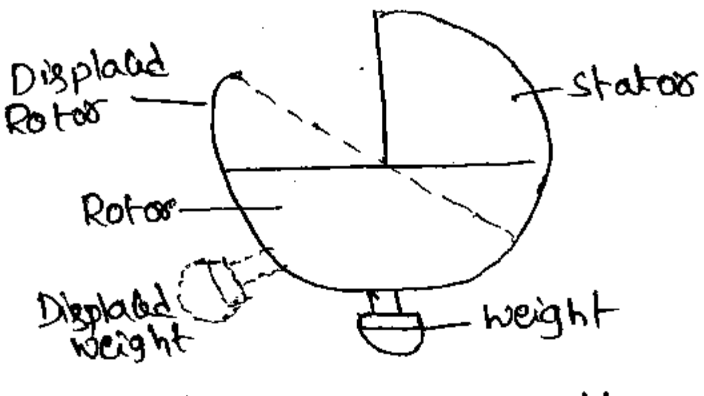
capacitance is given by

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

C is resultant capacitance
K is dielectric constant
A is total area of capacitor surface
d is distance between two capacitive surfaces.

-> The capacitance increases
(i) If the effective area of the plate is increased.
(ii) If the material has a high dielectric constant.

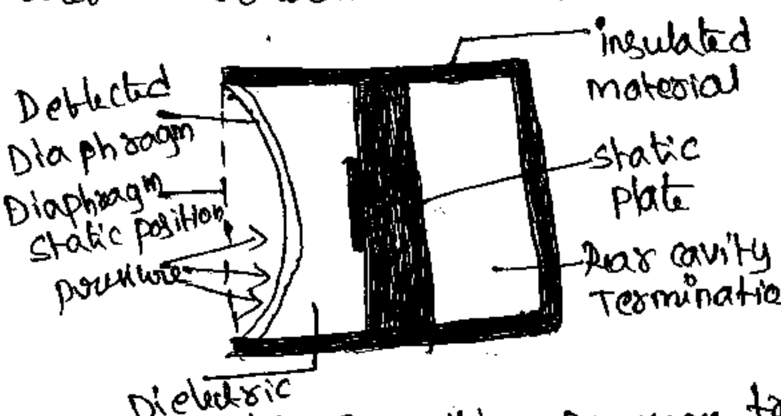
-> The capacitance reduced
if the spacing between the plates is increased.



(a) Capacitive transducer.

-> A variable plate area transducer is made up of a fixed plate called stator and a movable plate called the Rotor.

-> The rotor is mechanically coupled to the member under test. As the member moves, the rotor changes its position relative to the stator, & changing the effective area between the plates.



(b) Capacitive pressure transducer

$$C = 0.885 \frac{K(n-1)A}{t} \, pf$$

-> A is area of one side of one plate in cm^2
-> n is number of plates
-> t is thickness of dielectric in cm.
-> K is dielectric constant.

— o —.

Inductive transducer:

An inductive transducer is a device that converts physical motion into a change in inductance. Inductive transducers working on the following principles.

(1) Variation of self inductance
(2) Variation of mutual inductance.

→ Inductive transducers are used for measurement of displacement.

→ The displacement is to be measured, is arranged to cause variation in any of three variables.

1. Number of turns
2. Geometric configuration
3. permeability of the magnetic circuit.

→ For example inductive transducer has N turns & a reluctance R, when a current i is passed through it, the flux is

$$\phi = \frac{Ni}{R}$$

$$\frac{d\phi}{dt} = \frac{N}{R} \times \frac{di}{dt} - \frac{Ni}{R^2} \times \frac{dR}{dt}$$

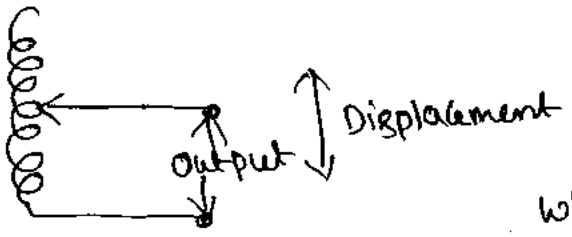
$$\frac{d\phi}{dt} = \frac{N}{R} \times \frac{di}{dt}$$

→ emf in coil is $e = N \times d\phi/dt$

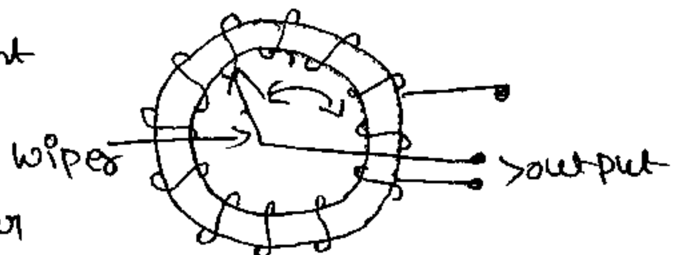
$$e = N \times \frac{N}{R} \times \frac{di}{dt} = \frac{N^2}{R} \times \frac{di}{dt}$$

→ self inductance is $L = \frac{e}{di/dt} = \frac{N^2}{R}$

→ output of an inductive transducer can be in the form of either a change in voltage or a change in inductance.



(a) linear inductive transducer



(b) angular inductive transducer

-> linear inductive transducer is an air cored transducer for measurement of linear displacement
-> Angular inductive transducer is an iron cored coil used for the measurement of angular displacement,
-> In both cases, the number of turns are changed, the self inductance and the output also changes.

Strain gauges:

-> It is an Example of a passive transducer that uses electrical resistance variation in wires to sense the strain produced by a force on the wire.
-> It is a very versatile detector and transducer for measuring weight, pressure, displacement.
-> Strain can be measured more easily by using variable resistance transducers, such transducers are known as strain gauges.
-> If a metal conductor is stretched, its resistance changes on the fact of both length & diameter of chang conductor changes, And also there is a change in the value of resistivity of the conductor ~~is~~ & this property called piezo-resistive effect. Resistance strain gauges are known as piezo-resistive gauges.

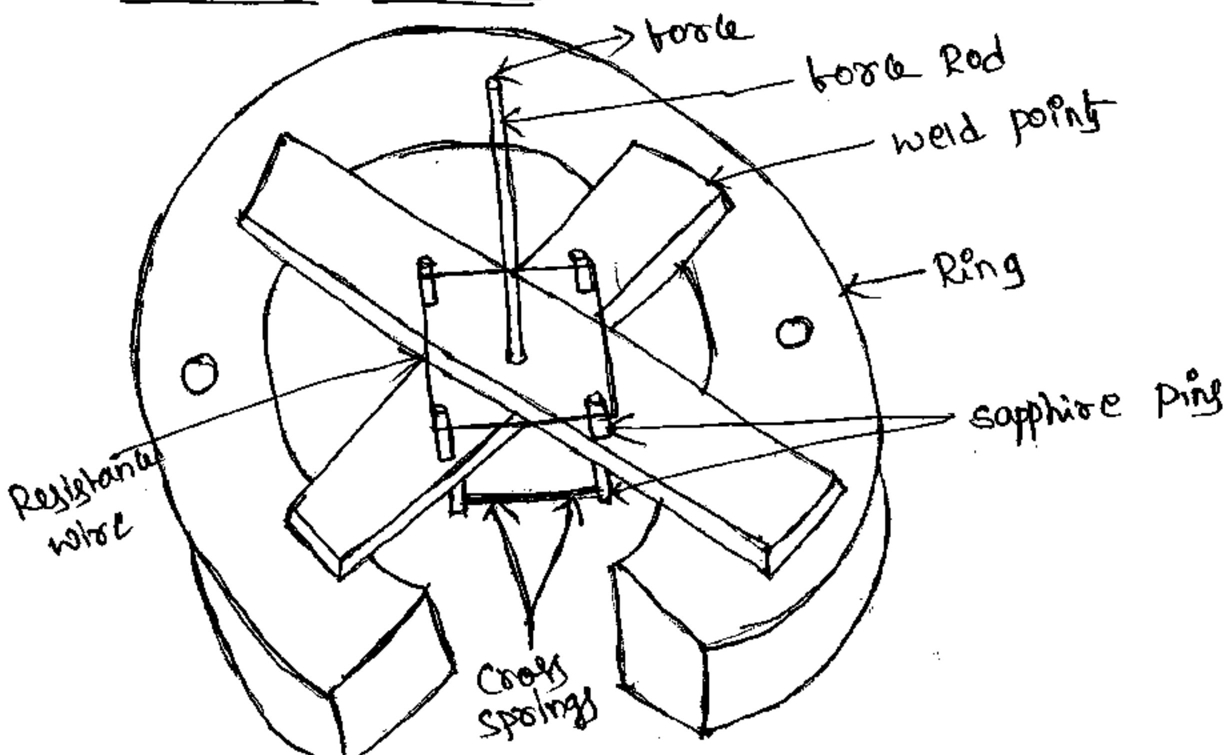
→ When a gauge is at positive stress, its length increases while its area of cross section decreases. Since the resistance of a conductor is directly proportional to its length and inversely proportional to its area of cross section, the resistance of the gauge increases with positive strain. This property is called piezo-resistive effect.

→ Types of strain gauges
1) Wire strain gauges
2) Foil strain gauges
3) Semiconductor strain gauges.

1) Wire strain gauges or Resistance wire gauges.

→ There are two forms
a) unbonded type
b) bonded type

a) Unbonded Resistance wire strain gauge:



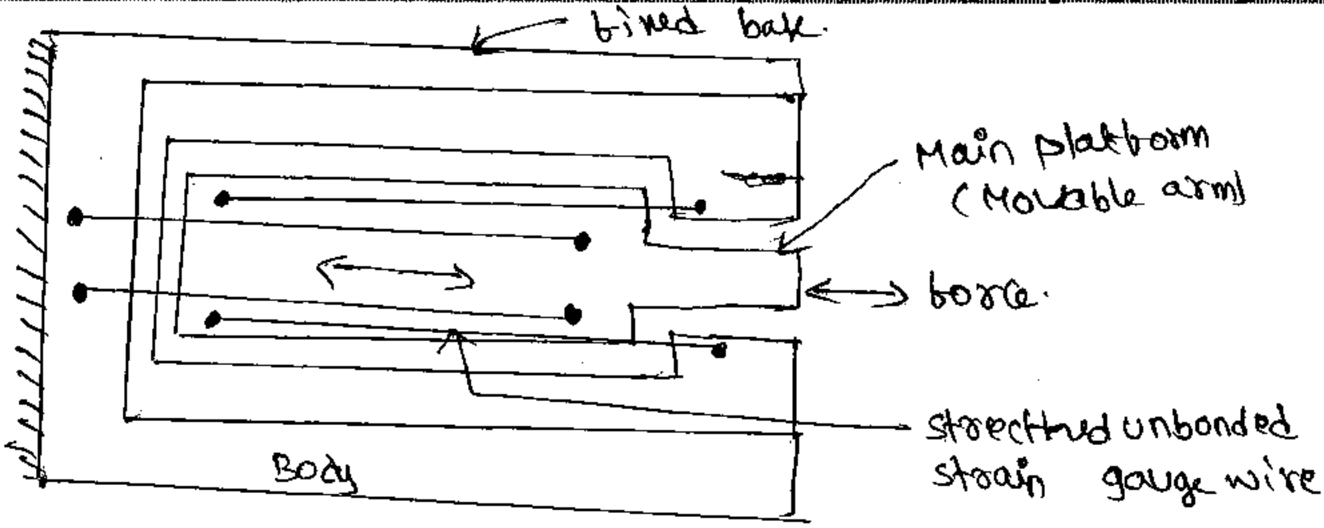
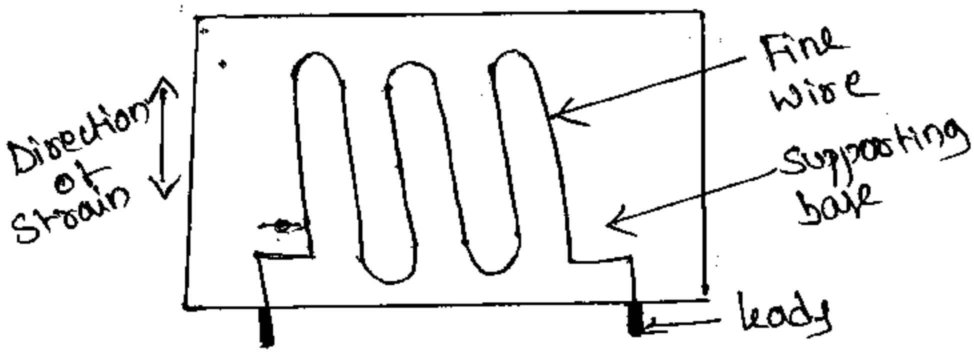


Fig: Unbonded strain gauge

→ Unbonded strain gauge consist of wire stretched between two point in an insulating medium, such as air. These unbonded strain gauges are connected in a bridge circuit. The bridge is balanced with no load applied as shown in figure.

→ When an external load is applied, the resistance of the strain guage changes, causing an unbalance of the bridge circuit resulting in an output voltage. This voltage is proportional to strain.

(b) Bonded type Resistance Wire strain gauges:



→ In this bonded type fine wire having leads and supporting base. The spreading of wire have uniform distribution of stress.

$$Resistance\ (R) = \frac{\rho \times l}{A}$$

→ ρ is the specific resistance of material in Ωm

→ l is the length of the conductor in m.

→ A is the area of the conductor in m^2

→ As a result of strain are
1) The change in gauge resistance
2) The change in length.

Gauge factor

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

$$GF(K) = \frac{\Delta R/R}{\Delta l/l}$$

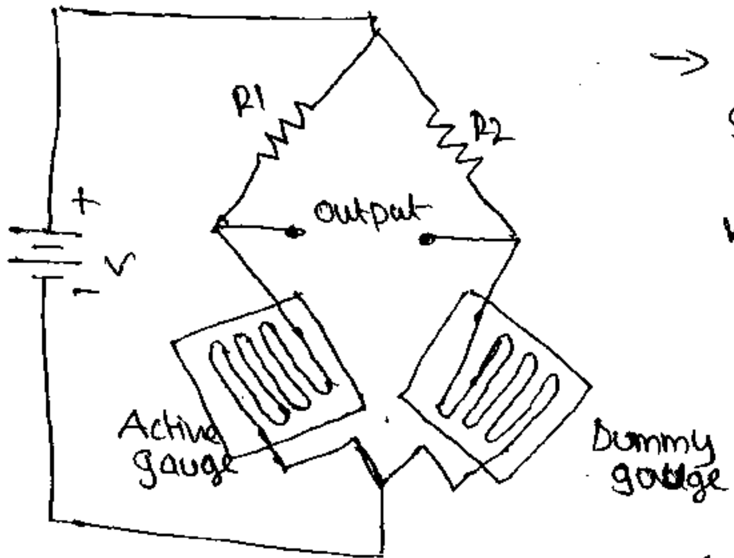
K is gauge factor
ΔR is change in initial resistance in Ω's
R is the initial resistance in Ω (without strain)
Δl is the change in the length in m.
l is the initial length in m (without strain)

→ 'Strain' is defined as the change in length divided by original length.

$$\sigma = \frac{\Delta L}{L}$$

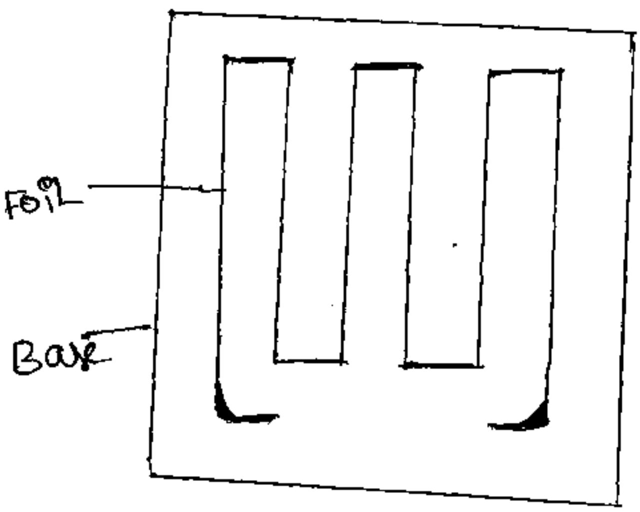
Strain gauge used in ~~bridge~~ arrangement:

→ Strain gauge used in a bridge arrangement in which the gauge forms one arm of the bridge. The bridge may be ac or dc



→ In active and dummy gauges only one gauge is an active element, & its producing an output proportional to the strain. The other gauge is not strained, but balances the bridge.

(2) Foil strain gauge:



→ It is an Extension of resistance wire strain gauge. The strain is sensed with the help of a metal foil, The metals and alloys used for the foil and wire are nichrome, nickel and platinum.

Fig: Foil type strain gauge.

→ Foil gauges are have much greater dissipation Capacity than wire wound gauges.

→ The advantage of foil type strain gauge is that they can be fabricated on a large scale and in any shape. The foil can also etched on a Carrier,

→ Etched foil gauge consist of first bonding a layer of strain sensitive material to a thin sheet of paper.

→ This method of Construction enables etched foil strain to be made thinner than comparable wire unit.

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③ Semiconductor Strain gauge.

→ To have a high sensitivity, a high value of gauge factor is desirable. A high gauge factor means relatively higher change in resistance, which can be easily measured with a good degree of accuracy.

→ Semiconductor strain gauges are used when a very high gauge factor is required. They have a gauge factor 50 times as high as wire strain gauges. The resistance of the semiconductor changes with change in applied strain.

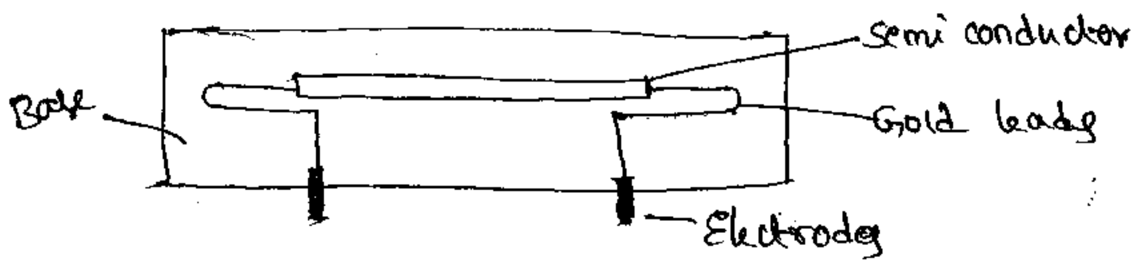

Fig: Semiconductor strain gauge.

→ Semiconductor strain gauge depend on the action of piezo resistive effect. ie change in value of the resistance due to change in resistivity.

→ This strain gauge consist of a strain material and leads that are placed in a protective box, semiconductor wafer filaments which have a thickness of ~~0.05m~~ 0.05mm are used.

→ Gold leads are used for making contacts.

→ This strain gauge is as stable as the metallic type, but has a much higher output.

The Semiconductor strain gauge also has low hysterisis.

Advantages of Semiconductor strain gauge:

1) Semiconductor strain gauge have a high gauge factor of about +130.
2) Hysterisis characteristic of semiconductor strain gauges are Excellent, ie less than 0.05%.
3) These are very small in size.

Disadvantages

1) They are very sensitive to changes in temperature
2) Linearity of semiconductor strain gauge is poor.
3) They are more Expensive.

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* LVDT (Linear Variable Differential transducer)

→ The differential transformer is a passive inductive transformer. It is also known as a linear variable Differential transformer (LVDT).

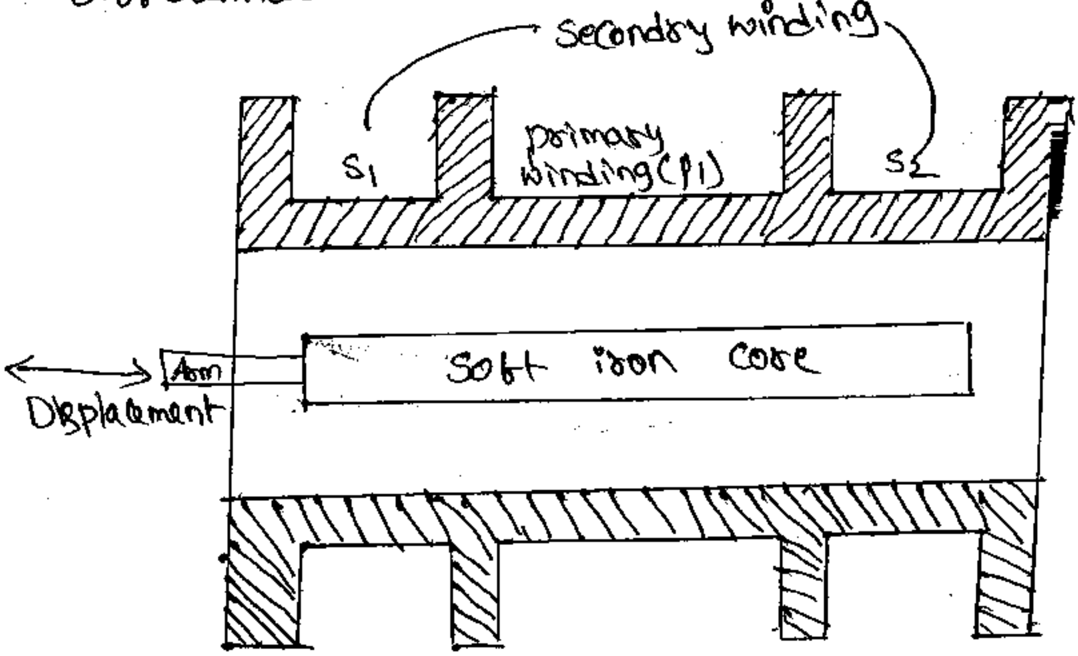


Fig: Construction of LVDT

→ The transformer consist of a single primary winding P_1 & two secondry windings S_1 & S_2 wound on a hallow cylindrical former.

→ The secondry windings have an equal number of turns and are identically placed on either side of primary windings. The primary winding is connected to an ac source.

→ An movable soft iron core slides within the hollow former and affect the magnetic coupling between the primary and two secondries.

→ The displacement to be measured is applied to an arm attached to the soft iron core.

→ When the core is in null position, equal voltages are induced in two secondry windings

→ The frequency of the ac applied to the primary winding range from 50Hz to 20kHz.

→ The output voltage of secondry windings S_1 is E_{S1} and that of secondry winding S_2 is E_{S2}

→ In order to convert the output from S_1 to S_2 into a single voltage signal the two secondaries S_1 & S_2 are connected in series opposition.

→ Hence the output voltage of transducer is the difference of two voltages.

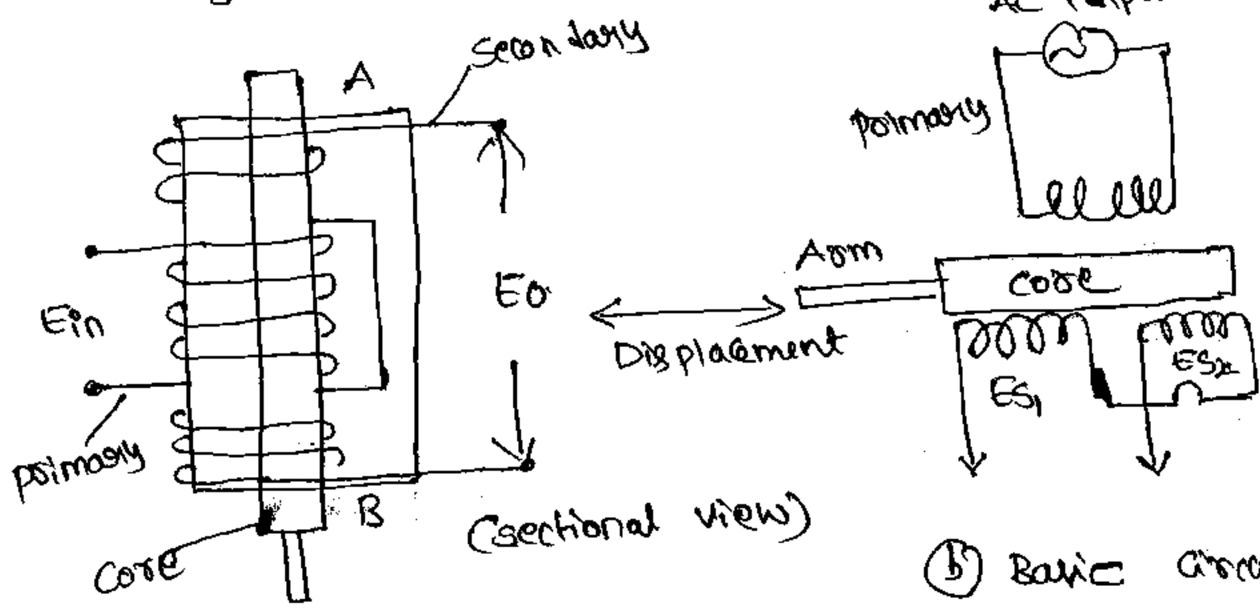
The differential output voltage

$$E_0 = E_{S1} \sim E_{S2}$$

→ When core is at normal position, the flux linking with both secondary windings is equal, hence equal emfs are induced in them. At null position $E_{S1} = E_{S2}$.

→ Since the output voltage of the transducer is the difference of the two voltages, the output voltage E_0 is zero at null position.

→ Now if the core is moved to the left of the null position, more flux links with winding S_1 and less with winding S_2. Hence, output voltage E_{S1} of the secondary winding S_1 is greater than E_{S2}. The magnitude of the output voltage of the secondary is then $E_{S1} - E_{S2}$, output voltage of secondary in phase with E_{S1} (the output voltage of secondary winding S_1).

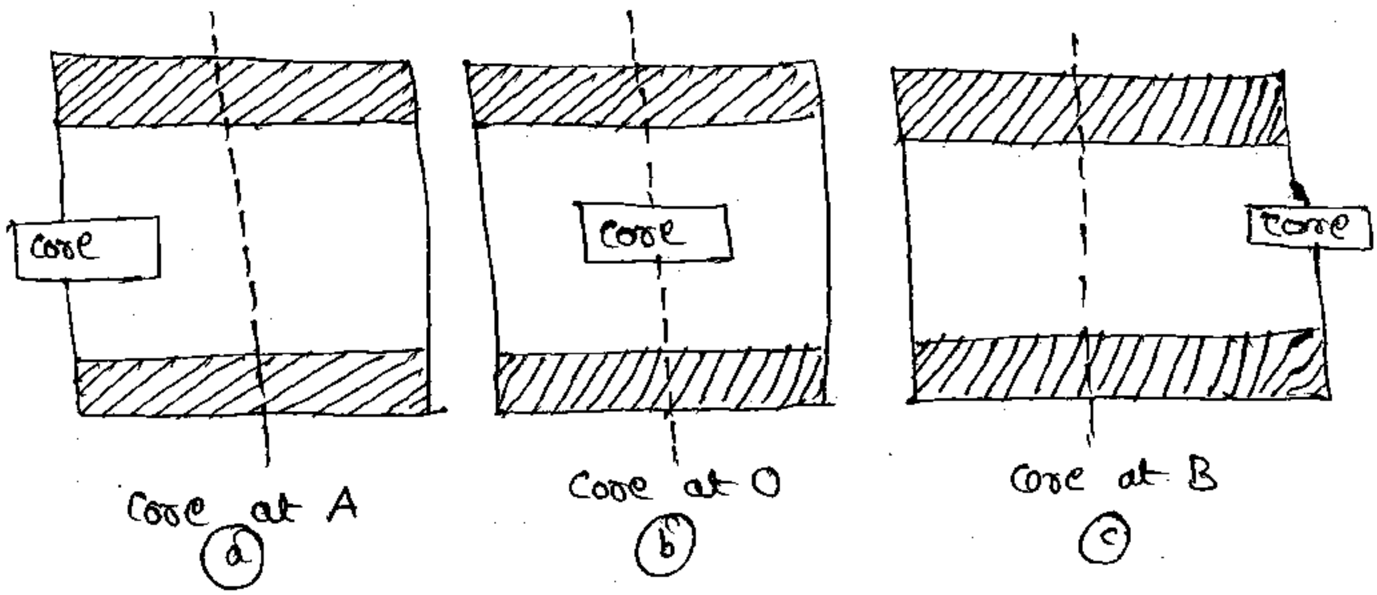


(sectional view)

(a) construction

(b) Basic circuit.

→ If the core is moved to the right of the null position, the flux linking with winding S_2 becomes greater than that linked with winding S_1. This result in E_{S2} becoming larger than E_{S1}. The output voltage in this case is $E_0 = E_{S2} - E_{S1}$ and is in phase with E_{S2}.



→ Core of LVDT at three positions. Core at O which is the null position. Therefore $E_{S1} = E_{S2}$ and $E_0 = 0$.

→ when the core is moved to left, and is at A, E_{S1} is more than E_{S2} and E_0 is positive.

→ when the core is moved to right towards B, E_{S2} is greater than E_{S1} and E_0 is negative.

__Advantages of LVDT__

1) output Voltage for this transducer is linear
2) Infinite resolution
3) High output
4) High sensitivity
5) Ruggedness
6) less friction
7) Low hysteresis
8) low power consumption.

__Disadvantages__

1) large displacement required for differential output

2) They are sensitive to stray magnetic fields
3) The dynamic response is limited mechanically by the mass of the core and electrically by the applied voltage.
4) Temperature also affects the transiducer.

PIEZO ELECTRICAL TRANSIDUCER

→ A crystalline materials such as Quartz, Rochelle salt produce an emf when are placed under stress.

→ This property is used in piezo-electric transiducery, where a crystal is placed between a solid base and the force semming member as shown in below figure.

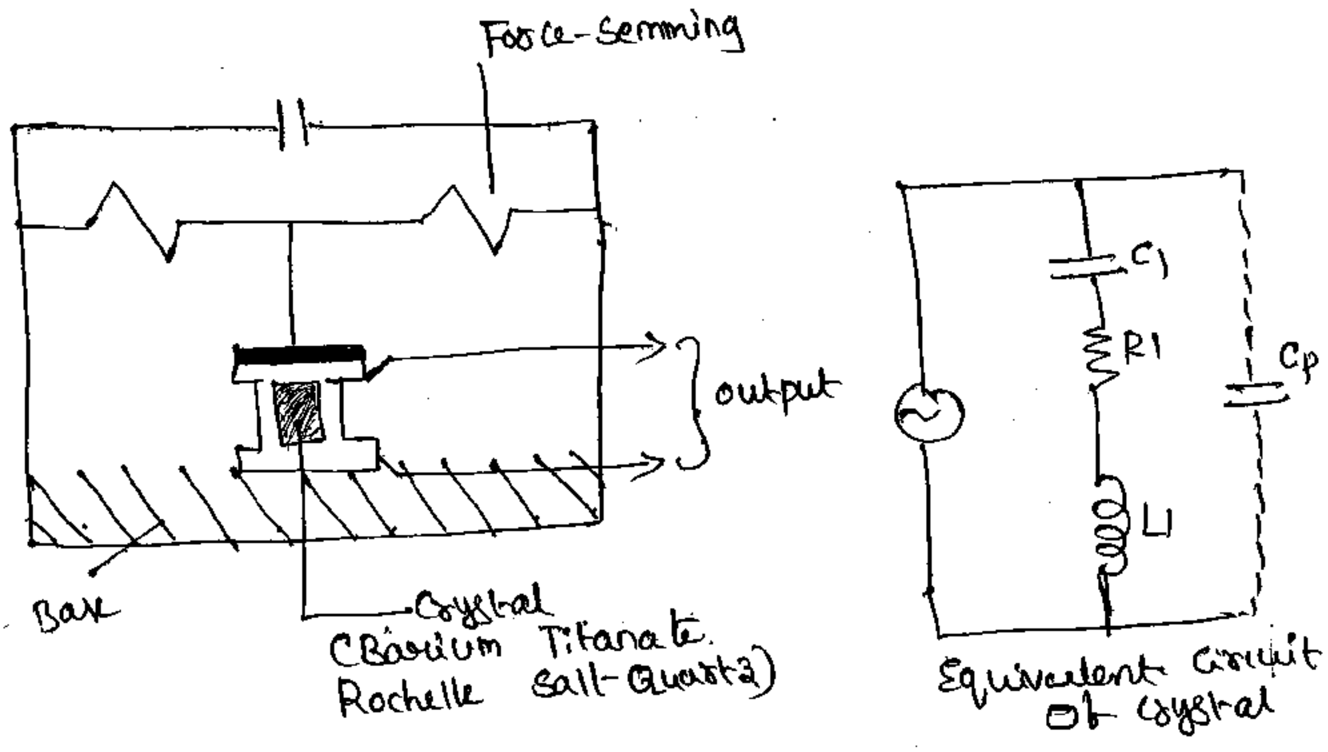


Fig: piezo electrical transiducer.

→ An external force applied to the transiducer through its pressure port, ie applied pressure to the top of crystal, This produce an emf across the crystal proportional to the magnitude of applied pressure.

-> The output voltage of transducer is

$$E = \frac{Q}{C_p}$$

Q is generated charge

C_p is shunt capacitance.

-> For piezo electric element under pressure, part of energy is converted to electrical potential that is analogous to charge on the plates of the capacitor.

-> The rest of the applied energy is converted to mechanical energy, that is analogous to a compressed spring.

-> When the pressure is removed, it returns to its original shape and loses its electric charge.

$$k = \frac{\text{Mechanical energy converted to electrical energy}}{\text{Applied mechanical energy}}$$

or

$$k = \frac{\text{electrical energy converted to mechanical energy}}{\text{Applied electrical energy}}$$

-> Disadvantage is that voltage will be generated as long as the pressure applied to piezo electric element changes.

RESISTANCE THERMOMETER

-> The Resistance of a conductor changes when its temperature is changed.

-> This property is used for measurement of temperature.

→ Resistance thermometer is used to measure electrical resistance in terms of temperature.

→ The main part of the resistance thermometer is its sensing element. The characteristics of sensing element determines the sensitivity and operating temperature range of the instrument.

→ The sensing element of resistance change with change in temperature.

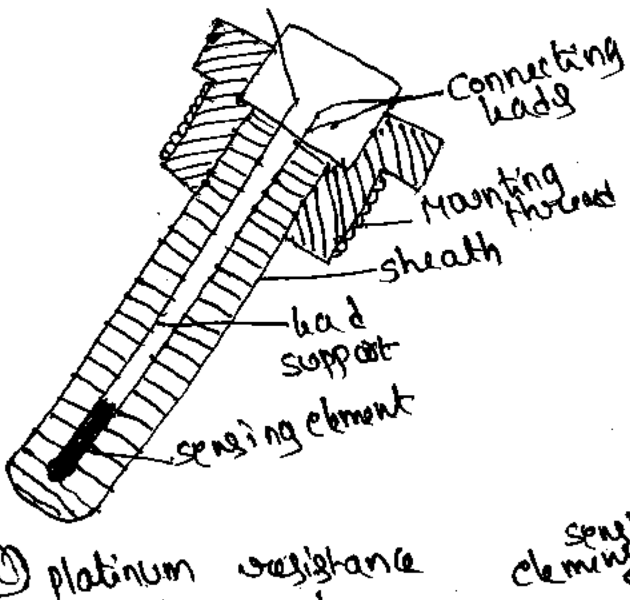
→ In this Resistance thermometer mainly consider the stability. The need for stability frequently limits the temperature range over which the sensing element may be used.

→ Another characteristic for a sensing element is a linear change in resistance with change in temperature.

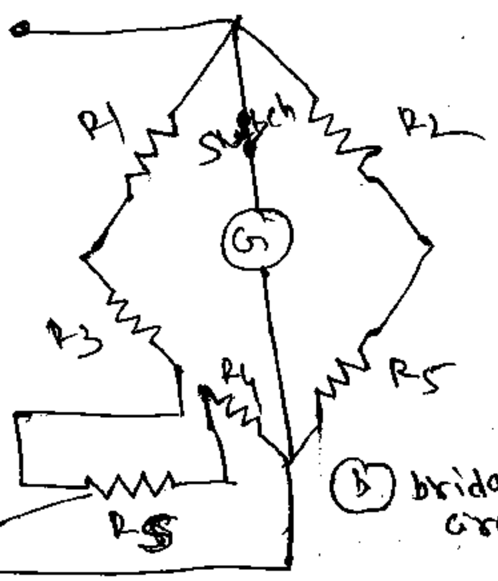
→ Platinum, nickel are the metals most commonly used to measure temperature.

→ The resistivity of platinum tends to increase less rapidly at high temperature than for other metals, Hence it is a commonly used material for resistance thermometers.

→ The change in resistance caused by change in temperature are detected by wheatstone bridge.



(a) platinum resistance thermometer



(b) bridge circuit

→ The sensing element Rs, then

$$\frac{R1}{R_2} = \frac{Rs}{R_5}$$

When no current flows through the galvanometer, wheatstone's bridge states the ratio of resistance.

→ In normal condition, sensing element is away from the indicator, and its leads have a resistance R_3, R_4

$$\frac{R1}{R_2} = \frac{R_3 + R_s + R_4}{R_5}$$

→ If R_s changes, balance can't be maintained galvanometer shows deflection..

ADVANTAGES of Resistance thermometer:

1) The measurement is very accurate
2) It has a lot of flexibility with regard to measuring equipment
3) The temperature resistance element can be easily installed and replaced.
4) Resistive elements can be used to measure differential temperature.
5) They are best suited for remote indication.
6) The resistive element response time is of the order of 2 to 10 s.
7) Extremely accurate temperature sensing
8) stability of performance over long period of time.

Limitations of Resistance Thermometer

1) High cost
2) possibility of self heating
3) large bulk size, compared to a thermocouple.

Thermistor :

→ The resistance of materials changes with temperature.

→ Thermistor means thermally sensitive resistor are non metallic resistors made by metallic oxides such as nickel, Cobalt and Copper.

→ thermistors have negative temperature co-efficient ie resistance decreases as temperature rises.

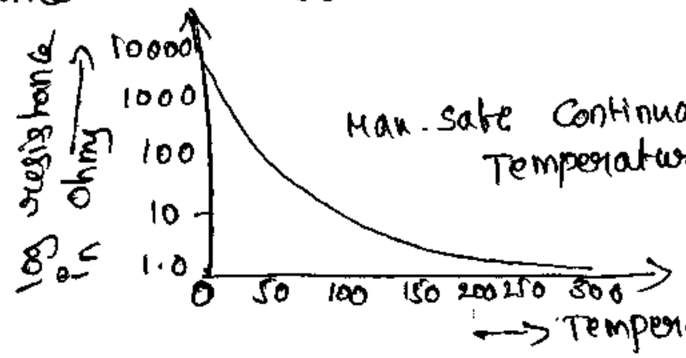
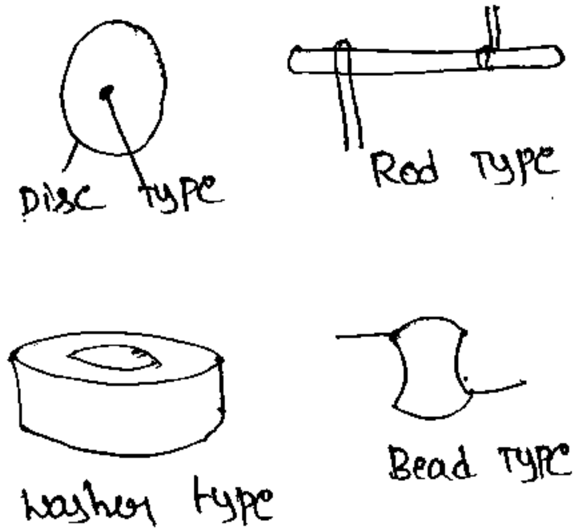
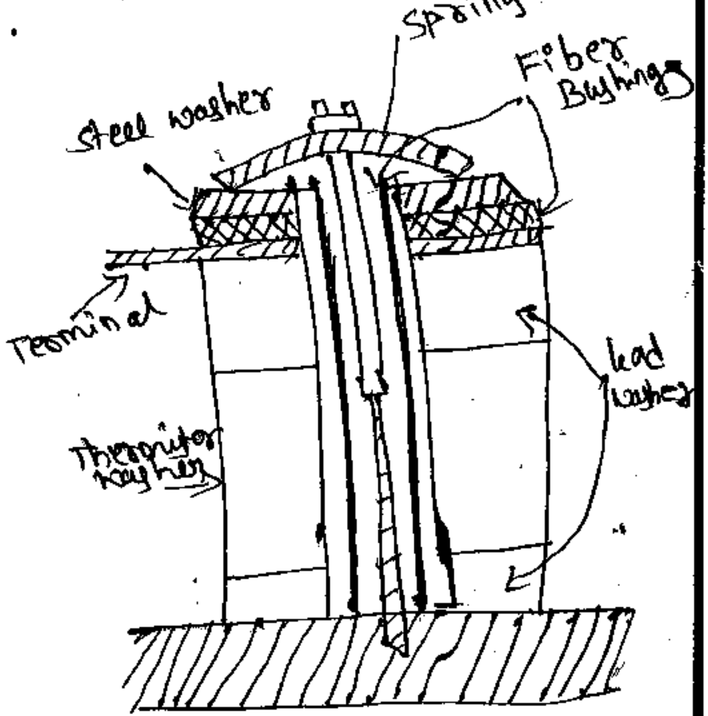


Fig: Resistance vs temperature graph of a thermistor

→ Thermistors can be connected in series/parallel Combinations for applications requiring increased power handling Capability.



(a) various Configurations of thermistor.



(b) Bush type thermistor.

→ Disc type thermistors about 10mm in diameter. either self supporting or mounted on a small plate, are mainly used for temperature control.

→ Washer thermistors are like disc thermistors, except that a hole is formed in the centre in order to make them suitable for mounting on a bolt.

→ For Rod thermistors, leads are attached to the end of the rods.

Advantages of thermistor

1) Small size and low cost
2) Fast response over narrow temperature range
3) Good sensitivity
4) Contact and resistance problems not encountered due to large Rth (resistance).

Limitations of Thermistor

1) Non linearity in resistance vs temperature characteristics.
2) Unsuitable for wide temperature range
3) Very low excitation current to avoid self heating
4) Need of shielded power lines, due to high resistance.

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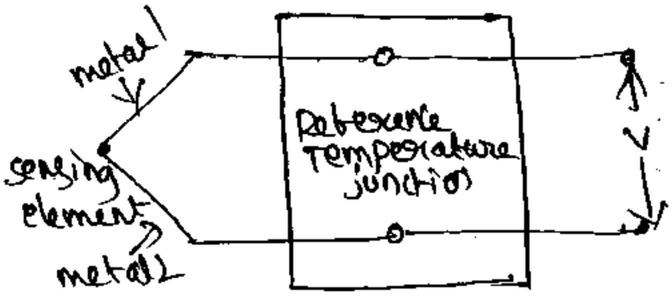
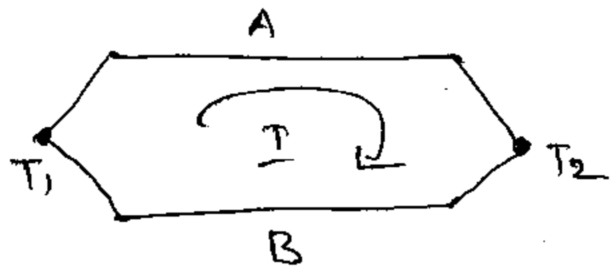
Thermo Couples:

→ Thermocouples are thermoelectric sensors that basically consist of two junctions of dissimilar metals, such as copper and constantan that are welded together. It is used to generate a voltage corresponding to the heat that is generated at junction of 2 dissimilar metals



(a) Basic thermocouple Connection



(B) current through two dissimilar metals.

→ when the junction is heated, a voltage is generated, this is known as seebeck effect. The Seebeck voltage is linearly proportional for small changes in temperature. Various combinations of metals are used in Thermocouples.

→ The magnitude of this Voltage depends on the materials used for the wires and the amount of temperature difference between the joined ends and the other ends.

→ The junction of wires of thermocouple is called the sensing junction, and this junction is normally placed in or on the unit under test.

→ If the junction is kept at a constant temperature called reference junction (cold) while other the measuring junction (hot).

→ when the two junctions (T1 & T2) are at a different temperatures, a voltage is developed across the junction.

→ when a temperature difference exist between two junctions an emf is produced, which cause the current in the circuit.

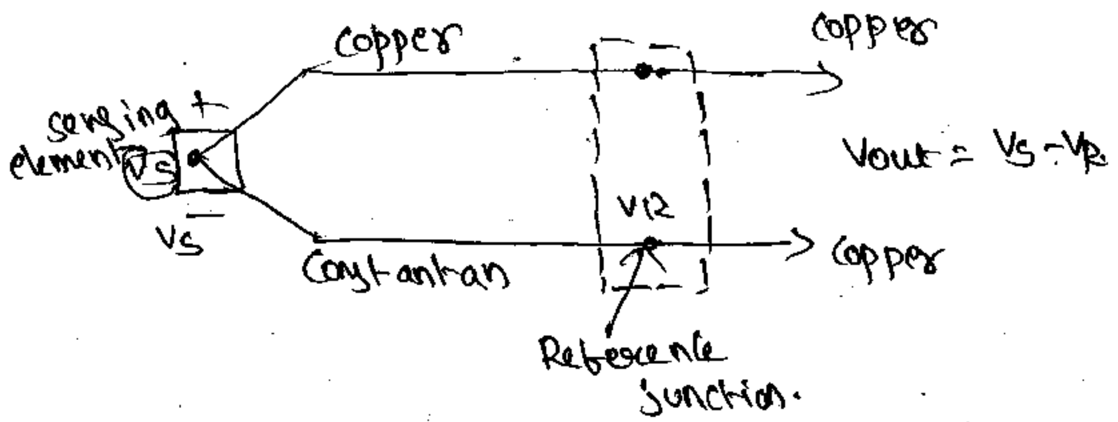


Fig: A type t thermocouple with reference junction

-> Copper used is an element and constantan used is an alloy of nickel and copper.

-> The copper side is positive and constantan side is negative.

-> Assuming copper wires used to connect the thermocouple to next stage, a second copper constantan junction is produced. This junction is called as reference junction. It generates a Seebeck voltage that opposes the voltage generated by the sensing junction.

-> If both junctions are at same temperature, the output voltage V_{out} will be zero. If the sensing junction is at higher temperature, V_{out} will be proportional to the difference between the two junction temperature. The temperature can't be delivered directly from the output voltage alone, i.e. error caused by the voltage produced by the reference junction.

- This can be overcome by placing the reference junction in an ice bath to keep it at a known temperature. This process is called as cold junction compensation.

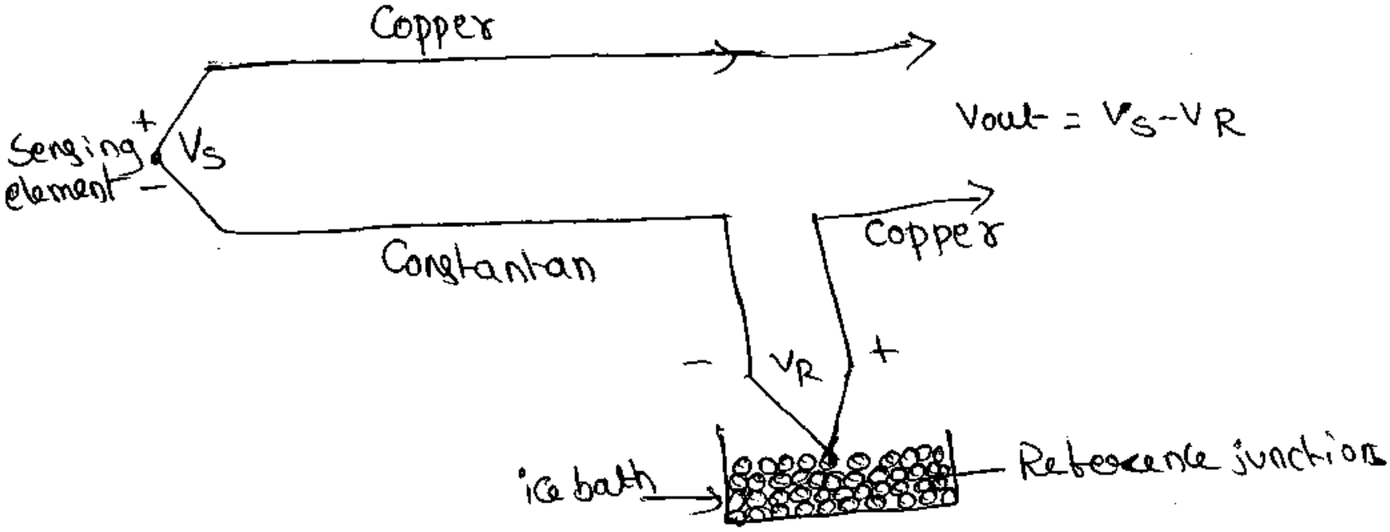


Fig: Cold junction Compensation.

→ The reference voltage is maintained at 0°C. The reference voltage is now predictable from the Calibration Curve of the type 'T' thermocouple.

Advantages of thermocouple

1) It has a rugged Construction
2) It has a temperature range from -270°C - 2700°C
3) Bridge Circuit are not required for temperature measurement
4) cheaper in cost
5) calibration checks can be easily performed.
6) Thermocouples offer good reproducibility.
7) speed of response is high compared to the filled system thermometer.
8) Measurement accuracy is quite good.

Disadvantages:

1) Cold junction and other Compensation is essential for accurate measurement.

2) They Exhibit non-linearity in the emf versus temperature characteristic.
3) stray voltage pick-up are possible.
4) signals need to be amplified.

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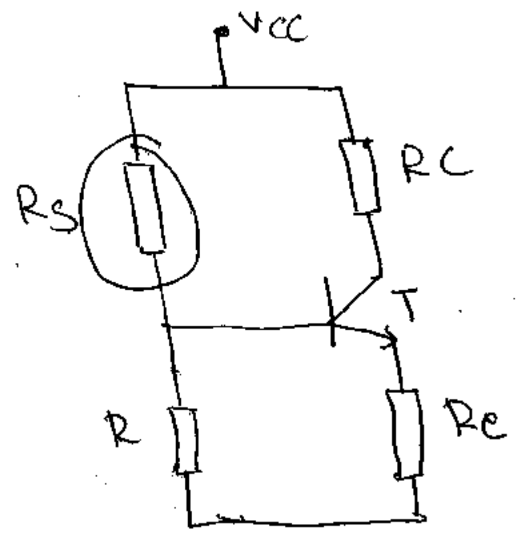
Sensistors:

→ It is a resistor whose resistance changes with temperature.
→ The resistance increases with Exponentially with temperature, that is the temperature co-efficient is positive.
→ Sensistors are used in electronic circuits for Compensation of temperature influence or as sensors of temperature for other circuit.
→ Sensistors are made by using very heavily doped semiconductors so that their operation is similar to PTC-type thermistors.



→ It is a heavily doped semiconductor that has positive temperature co-efficient. The resistance of a sensistor increases with the increase in temperature and decreases with the decrease in temperature.

Applications

→ Sensistors are used in temperature compensation circuits.

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