UNIT – VI

Transducers

Instrumentation System generally consist of three major elements.

1. Primary Sensing element
2. Data conditioning element
3. Data Presentation element.

The Primary sensing element receives the quantity under measurement and delivers a proportional electrical signal to the data conditioning element. Here the signal is amplified, filtered or modified to a format which is acceptable to the output device.

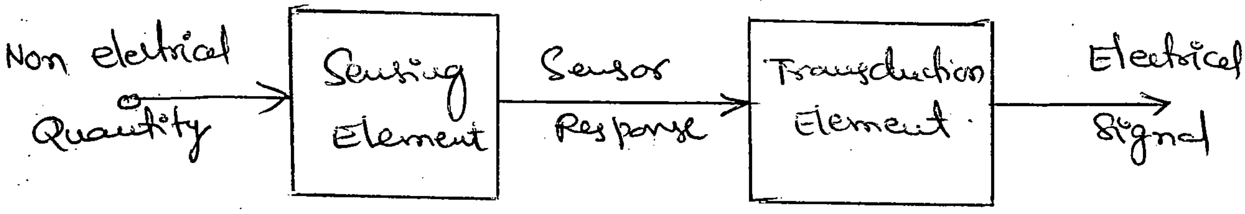
The input quantity for most instrumentation system is non-electrical. However in order to use electrical methods for measurement, manipulation and control, non-electrical quantity is generally converted into electrical signal by a device called a 'TRANSDUCER'.

Transducer is a device, which when actuated by energy in one form supplies energy either in the same form or in another form. The signal produced may be a voltage, current or frequency. A transducer uses many effects to produce such conversion. The process of transforming signal from one form to other is called 'Transduction'. A transducer is also called PICK UP.

A device which converts a physical quantity into proportional electrical signal is called Transducer.

which are very closely related to each other. These two parts are Sensing (or) detecting element and transduction element. The sensing element is commonly known as Sensor.

Sensor is a device that produces a measurable response to a change in a physical ~~system,~~ condition. The transduction element transforms the output of the sensor to an electrical output as shown below.



Many times, the transducer is a part of a circuit and works with other elements of that circuit to produce the required output. Such a circuit is called signal conditioning circuit (Data conditioning circuit)

Advantages of Electrical Transducers :-

The main advantages of electrical transducers (conversion of Physical quantity into electrical quantity) are as follows.

(1) Amplification and attenuation of electrical signal can be done easily.

(2) Mass - inertia effects are minimized

(3) The effects of friction are minimized

(4) The Power requirement of transducers is very small. The electrical system can be controlled with a small level of Power.

(5) The electrical output of transducers can be easily used, transmitted and processed for the purpose of measurement.

(6) The output can be indicated and recorded remotely at a ~~[illegible]~~ distance from the sensing medium

(7) The signal can be conditioned or mixed to obtain any combination with output of similar transducer or control signals

(8) The output can be modified to meet the requirements of the indicating or controlling units. The signal magnitude can be related in terms of the Voltage & Current.

The main disadvantage of electrical transducer is its cost. And while designing the circuit the effect of ageing and drifts of Parameter of active components must be considered.

Characteristics of ...

A transducer is a sensing device by which the physical, mechanical or optical quantity to be measured is transformed directly by a suitable mechanism into an electrical voltage or current proportional to the input measured.

A transducer must have the following characteristics.

1. Linearity:

The relationship between a physical parameter (quantity to be measured) and the resulting electrical signal must be linear i.e output of the transducer should be linearly proportional to the input quantity.

2. Accuracy:

The closeness with which the reading approaches an accepted standard value (or) true value, of the variable being measured.

3. Sensitivity:

This is defined as the electrical output per unit change in physical parameter. High sensitivity is generally desirable for a transducer.

4. Repeatability:

The output of the transducer must be exactly the same, under same environmental conditions, when the same quantity is applied at the input repeatedly.

5. Size :

The transducer should have smallest possible size and shape with minimal weight and volume. This will make measurement system very compact.

6. High stability and reliability :-

The output of the transducer should ~~have~~ be highly stable and reliable so that there will be minimum error in the measurement. The output must remain unaffected by environmental conditions such as change in temp., pressure etc.

7. Dynamic range :-

For a transducer, the operating range should be wide, so that it can be used over a wide range of measurement conditions.

8. Ruggedness :-

The transducer should be mechanically rugged to withstand overloads. It should have overload protection.

9. Speed of response :-

It is the rapidity with which the transducer responds to changes in the measured quantity. The speed of response of the transducer should be as high as possible.

10. High output :-

The transducer should give resonably high output signal so that it can be easily processed and measured. The output must be much larger than the noise. Now-a-days, digital output is preferred

Selecting the transducer for a given measurement application involves considering the transducer's characteristics, desired system performance, and input requirements. The following should be consider while selecting a transducer.

1. Nature of Measurement :

The selection of transducer will naturally depend upon the nature of quantity to be measured.
For example, the temperature measurement, temp. sensors will be used. For measuring stress and strain, strain guages will be utilized.

2. Loading effect :-

The transducer changes the value of the parameter under measurement, errors may be introduced. The transducer is selected to have minimum loading effect to keep the error to minimum.

3. Environmental compatibility :-

A careful study be made of the conditions under which a transducer is expected to give satisfactory output. The troublesome aspects of the transducer location are the temperature changes, shock and vibration, and electromagnetic interference.

Temperature compensation is used to minimize the errors due to temperature changes. Beyond 300°F such temp. compensation becomes extremely difficult to design, and special materials are used for the transducer internal construction and bonding.

The errors due to shock and vibration can not be eliminated completely. To minimize these errors, transducers should be selected with a minimum movable mass in the sensing mechanism. Proper damping may ~~be~~ extended the range of a transducer's usefulness under high shock and vibration conditions.

Transducers are required to operate in the presence of varying strong electromagnetic fields. Transducers with low output impedance, high output voltage, and short cable length are less affected to such interferences.

Other considerations for transducer environments include :-

(i) Simplicity of mounting and cable installation.

(ii) Convenient size, shape and weight.

(iii) Resistance of corrosion.

(iv) Accessibility of the transducer for later repairs.

4. Measuring System Compatibility :-

The transducer selected and the electrical system used for measurement should be compatible. The output impedance of the transducer and the impedance imposed by the measuring system must be such that one does not adversely affect the other.

5. Cost and availability :-

General factors involved in selection are cost, availability, basic simplicity, reliability and low maintenance.

While selecting transducers of comparatively equal merits for a given application, the one that is most simple in operation and contain minimum no. of moving parts would be usually selected.

Transducers are selected which do not require excessive repair (or) continuous calibration checking.

Classification of transducers :-

Basically transducers are basically classified into Electrical transducers and mechanical Transducers.

The mechanical transducers are those primary sensing elements that respond to changes in the physical condition of a system and gives output in different form. The mechanical transducers are distinguished from the electrical transducers on the basis of the output signal generated. The mechanical transducers generate output signal which is mechanical by nature.

The electrical transducers ~~can be~~ respond to non-electrical quantities but generate output signal which is electrical by nature.

Electrical transducers can be broadly classified into two major categories.

(1) Active transducers

(2) Passive transducers.

1. Active Transducers :-

These transducers generate an electrical signal ~~sto~~ directly in response to the physical parameter and does not require an external Power source for its operation. Active transducers are self generating devices, which operate under energy conversion principle and generate an equivalent output signal.

Ex :- 1. Piezo Electric transducers – used for generation of charge corresponding to pressure)

2. Photo Voltaic Cells – used for generation of Voltage in response to illumination).

3. Thermo electric 4. Electromagnetic

2. Passive Transducers :-

These transducers do not generate any electrical signal by themselves. To obtain an electrical signal from such transducers, an external source of Power is necessary. These operate under energy controlling principles. They depend upon the change in an electrical Parameter (R, L & C)

Electrical transducers are used mostly to measure non-electrical ~~Components~~ quantities. For this purpose a sensing element is used, which converts the physical quantity into a displacement. This displacement actuates an electric transducer, which acts as a secondary transducer and give an output that is electrical in nature. This electrical quantity is measured by the standard method used for electrical measurement. The electrical signals may be current

R, L and C effects.

A transducer which converts a non-electrical quantity into an analog electrical signal may be considered as consisting of two parts, the sensing element and the transduction element.

The transducers may be further classified into different categories depending upon the principle employed by their transduction elements to convert physical phenomena into output electrical signal.

The different electrical phenomena employed in the transduction element of transducer are

1. Resistive.
2. Inductive.
3. Capacitive.
4. Electro magnetic
5. Piezo electric
6. Photo-emissive
7. Photo-resistive
8. potentiometric.
9. Thermo-electric
10. Frequency generating.

Resistive Transducer :- $R = \rho \frac{l}{A}$

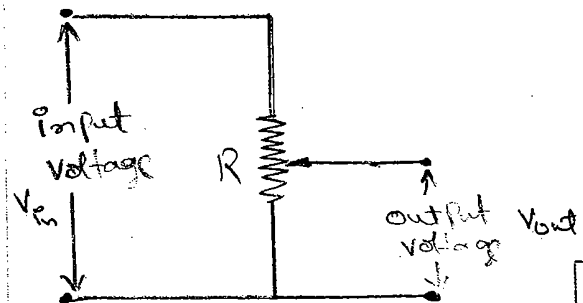
Resistive transducers are those in which the resistance changes due to a change in some physical phenomenon. The change in the value of the resistance with a change in the length of the conductor can be used to measure displacement.

The resistivity of material changes with change in temperature. This property can be used for the measurement of temperature.

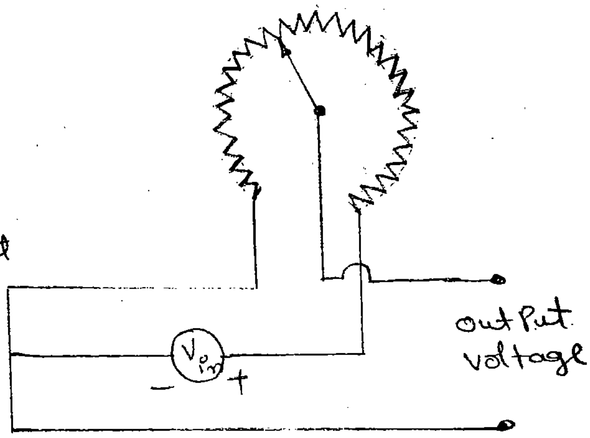
Strain guages work on the principle that the resistance of a conductor or semi-conductor changes when strained. This can be used for the measurement of displacement, force and pressure.

The resistive transducers can be used either as primary transducers and secondary transducers.

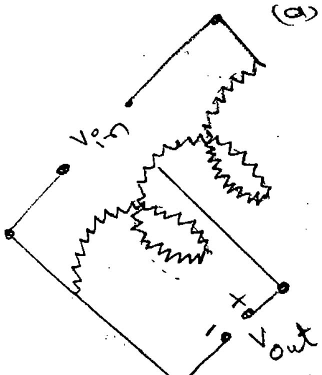
Potentiometric Resistance Transducers :-



(a) Linear type



(b) Rotational type



(c) Heli pot

generally used to measure linear (or) angular displacement. A resistive potentiometer (pot) consists of a resistance element provided with a sliding contact, called a wiper. The motion of the ~~sliding~~ sliding contact may be translatory (or) rotational. Some have a combination of both, with resistive elements in the form of a helix. They are known as helipot. A wire is made up of platinum (or) nickel alloy with diameter as small as 0.01mm. The resistive element is made up of cement, hot moulded carbon (or) carbon film. The wire is wound ~~on~~ on insulating former.

A resistive potentiomer used to convert mechanical displacement into an electrical output. Translatory resistive elements are linear (straight) devices shown in fig (a).

Rotational resistive devices are circular and are used for measurement of angular displacement as shown in fig (b).

Helical resistive elements are multi turn rotational devices which can be used for the measurement of either translatory (or) rotational motion.

Potentiometer is a passive transducer since it requires an external power source for its operation.

Advantages :-

1. They are inexpensive
2. Simple to operate and are very useful for applications where the requirements are not particularly severe.
3. They are useful for the measurement of large amplitudes of displacement
4. High electrical efficiency.

Disadvantages :-

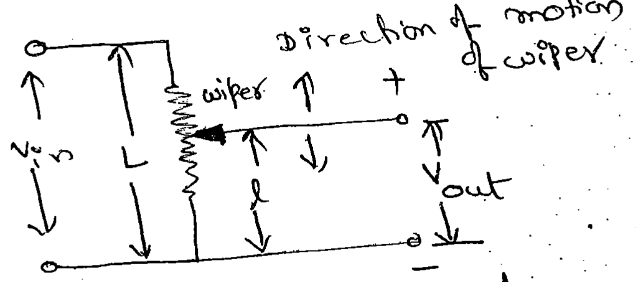
(1) In linear potentiometers, large force is required to move wiper (sliding contact)

(2) The sliding contact can wear out, become misaligned and generate noise

(3) Limited resolution.

If a potentiometer is excited by d.c (or) a.c voltage The output of the potentiometer is given by

$$V_{out} = \left[\frac{l}{L}\right] V_{in}$$



where V_{out} = voltage between wiper contact and fixed reference Ref. end

V_{in} = Total voltage applied to potentiometer wire

l = Length of wire b/w wiper contact and reference end

L = Length of the potentiometer wire.

Applications :-

(1) It can be used for measurement and control of large displacement (about 5mm to 500mm). It can be used in hydraulic jacks for shaft position control, in pen recorders in servo-balance position control.

(2) It has higher signal output inherently hence additional amplifier circuitary is not required to drive indicating or recording devices at output. Some times buffers are used for low impedance indicators

(3) It can be used as electric sensing element in

instruments etc.

(P-1) A linear resistance potentiometer is 5cm long and uniformly wound with a wire having a resistance of 10 kΩ. under normal conditions, the slider is at the centre of the potentiometer. What still the linear displacement be when the resistance of potentiometer as measured by bridge circuit is
(i) 3.8 KΩ (ii) 8.3 KΩ

Sol:- For linear displacement measurement,

$$V_{out} = \frac{l}{L} V_{in}$$

But same current passes through loop, the voltage is proportional to corresponding resistance, so that

$$\frac{V_{out}}{V_{in}} = \frac{R_o}{R_{in}} = \frac{\text{Resistance of output circuit}}{\text{Resistance of input circuit}}$$

$$= \frac{R_o}{10 \times 10^3}$$

Now we can write

$$\frac{V_{out}}{V_{in}} = \frac{l}{L} = \frac{R_o}{R_{in}} = \frac{R_o}{10 \times 10^3}$$

$$\therefore \quad l = \frac{R_o}{10 \times 10^3} L$$

(i) when $R_o = 3.8K$, $L = 5cm$, then

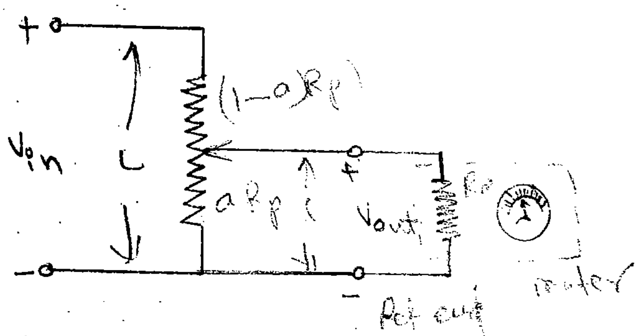
Linear displacement $l = \frac{3.8 \times 10^3}{10 \times 10^3} \times 5 = 1.9\,cm$

(ii) when $R_o = 8.3K$ $L = 5cm$ then

$$l = \frac{83 \times 10^3}{10 \times 10^3} \times 5 = 4.19\,cm.$$

1. Loading Effect :-

Practically the output terminals of transducers of potentiometers are unloaded is connected to output devices like panel meter (or) recorder etc and such output devices have finite and low input impedance. Such internal impedance of a output device acts as a load to the transducer. Because of such internal impedance, the linearity of the potentiometer get affected considerably. Thus the plot of V_{out}/V_{in} Vs l/L will not be straight line. The error in reading because of internal impedance of a output device is called loading error



Considere that the output terminals of potentiometer are connected to a meter having internal impedance R_m as shown in the figure.

Let R_p be the total resistance of potentiometer.

Let R_m be the internal resistance of meter.

Let $\frac{l}{L} = a$ is a constant such that $0<a<1$ and it varies linearly with the position of wiper. Then R_p be the fraction of R_p below wiper.

The equivalent resistance between wiper and fixed reference end of potentiometer is given by

$$R_{eq} = (a R_p) \,||\, R_m$$

$$R_{eq} = \frac{a R_p R_m}{a R_p + R_m}$$

By voltage division rule

$$V_{out} = \left[\frac{R_{eq}}{R_{eq} + (1-a) R_p}\right] V_{in}$$

Substituting value of R_{eq} in above Equation

$$V_{out} = \left[\frac{\dfrac{a R_p R_m}{a R_p + R_m}}{\dfrac{a R_p R_m}{a R_p + R_m} + (1-a) R_p}\right] V_{in}$$

$$= \frac{V_{in}\, a R_p R_m}{a R_p R_m + [(1-a) R_p][a R_p + R_m]}$$

$$= \frac{V_{in}\, a R_p R_m}{a R_p R_m + a R_p^2 - a^2 R_p^2 + R_m R_p - a R_p R_m}$$

$$= \frac{V_{in}\, a R_p R_m}{a R_p^2 (1-a) + R_m R_p}$$

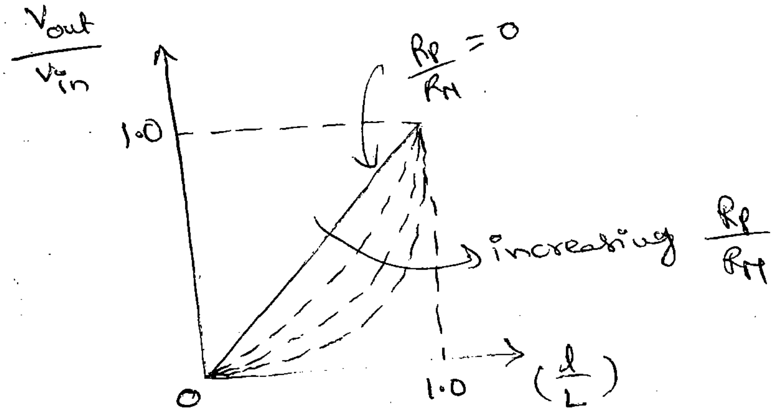
$$V_{out} = \frac{a R_p R_m V_{in}}{R_m R_p \left[a(1-a) \frac{R_p}{R_m}\right] + R_m R_p}$$

$$= \frac{a R_p R_m V_{in}}{R_p R_m \left[a(1-a) \frac{R_p}{R_m} + 1\right]}$$

$$V_{out} = \frac{a V_{in}}{1 + a(1-a) \frac{R_p}{\ldots}} \quad \text{--- (1)}$$

$$V_{out} = a V_{in} = \left(\frac{l}{L}\right) V_{in}$$

From Eq ① it is clear that when ratio $\frac{R_p}{R_m}$ is very small, the output is almost ideal one. But as the value of ratio $\frac{R_p}{R_m}$ increases, the non-linearity increases as shown in fig. below. Hence to have linear output for linear displacement, the meter impedance should be as large as possible.



Loading Error :-

The error in output voltage due to loading effect is defined as

$$\text{Error} = \begin{bmatrix}\text{output voltage} \\ \text{with full load}\end{bmatrix} - \begin{bmatrix}\text{output voltage} \\ \text{with no load}\end{bmatrix}$$

Substituting values of output voltage with full load and no load, we get

$$\text{Error} = \frac{a V_{in}}{1 + a(1-a)\frac{R_p}{R_m}} - a V_{in}$$

$$= V_{in}\left[\frac{a - a\left\{1 + a(1-a)\frac{R_p}{R_m}\right\}}{1 + a(1-a)\frac{R_p}{R_m}}\right]$$

$$\text{Error} = \left[\frac{a^2(1-a)\frac{R_p}{R_m}}{1+a(1-a)\frac{R_p}{R_m}} \right] V_{in}$$

$$\%\ \text{Error} = V_{in} \left[\frac{a^2(1-a)\frac{R_p}{R_m}}{1+a(1-a)\frac{R_p}{R_m}} \right] \times 100.$$

Resolution:- Practically the output voltage of the wire wound potentiometric displacement transducer is not continuous for the given input with wiper movement but varies in steps giving a staircase waveform as shown in fig(a) below.

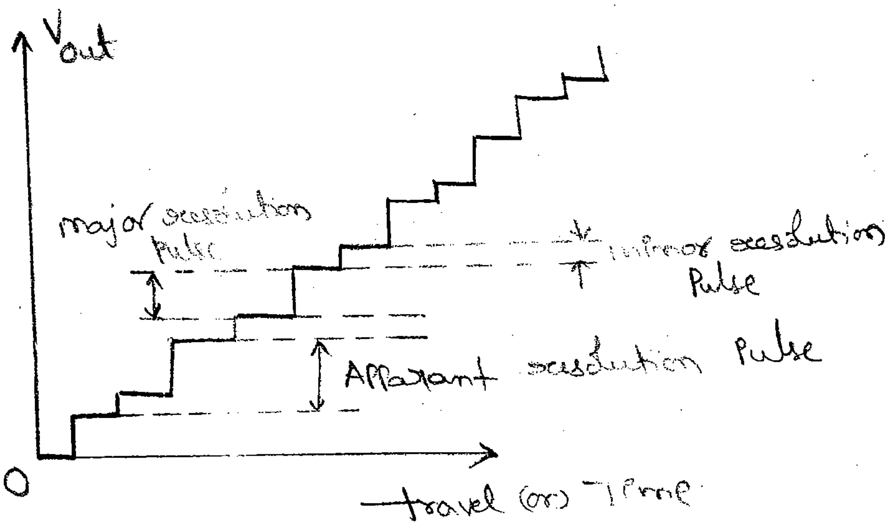


fig.(a) Resolution of potentiometer.

The main reason for the non-continuous output is that the change in resistance between winding is not continuous with wiper movement. The wiper may be located either exactly on the wire or across the two wires. Practically the resolution of a wire wound potentiometric displacement transducer is given by

$$\Delta l = 2ld + \delta$$

where Δl = resolution over wiper travel from reference end
d - wire thickness, δ - space between every two wires or individual

On the basis of materials used, the Potentiometers are classified as

(i) wire wound Potentiometers

(ii) Non-wire Potentiometers.

(i) **wire-wound Potentiometers :-**

The wirewound Potentiometer is used for large Currents at high temperature. The materials used for wire wound Potentiometer are Platinum and nickel-chromium, nickel-copper (or) any other Precious resistance element.

→ The temp. coefficient of such materials is very low and is of the order of $20 \times 10^{-10}/°C$ (or) even less.

→ The resolution of wire wound potentiometer is about 0.025 mm to 0.05 mm. The resolution is limited by the no. of turns accomodated.

→ The disadvantage of wire wound Potentiometer is that its usage is limited to the high frequency only, because of Capacitance between windings and shaft, two turns of the winding etc.

(ii) **Non-wire Potentiometer :-** (Continuous Potentiometer)

It consists a continuous resistance element without any wire winding. Hence its resolution is increased compared with wire wound Potentiometer. The movement of the wiper is along a continuous surface and hence the wearing of body parts, failure due to bouncing Problems of wire (from turn to turn) are considerably decreased. Due to continuous surface no noise is observed in non-wire potentiometer.

The main <u>disadvantages</u> of non-wire potentiometer are as follows.

(a) It is sensitive to small temperature changes

(b) It has very high wiper contact resistance which is variable. Hence it cannot carry large currents.

The main materials used for non-wire (or) continuous potentiometer are as follows.

(i) <u>Thin metal film</u>:

In this type the resistance element is formed by depositing a very thin layer of metal on proper insulating material like glass, ceramic etc. The potentiometers with thin metal film are less expensive and change in resistance due to environmental changes is very less. Moreover such potentiometers can be used for d.c as well as a.c voltages.

(ii) <u>Carbon Film</u>:-

In Carbon film potentiometer, a thin film of Carbon is deposited on a proper insulating material like glass, Ceramic etc. The advantage of Carbon film potentiometers are low cost and low temp. coefficient upto $1000 \times 10^{-6} / ^\circ C$.

(iii) <u>Hot moulded Carbon</u>:-

In such type of potentiometers, a resistance element is formed by moulding a mixer of Carbon and plastic. Such hot moulded carbon potentiometers are most extensively used in a.c applicatio

is formed by fusing precious metal particles in the ceramic base. The main disadvantages of such potentiometers is large power rating at high temperatures. They are also low cost potentio-meters with moderate temperature coefficients of their order of $150 \times 10^{-6}/^{\circ}C$ to $250 \times 10^{-6}/^{\circ}C$.
These are also useful in a.c application.

Inductive Transducers:-

Inductive transducers may be either of the self generating (or) the passive type.

The self generating type utilises the basic electrical generator principle i.e a motion between a conductor and magnetic field induces a voltage in the conductor. This relative motion between the field and the conductor is supplied by changes in the measurand.

An inductive electromechanical transducer is a device that converts physical motion into a change in inductance.

The transducers of the variable inductance type work upon one of the following principles

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

Inductive transducers are mainly used for the measurement of displacement. The displacement to be measured is arranged to cause variation in any of three variables.

1. No. of turns (N)
2. Geometric configuration (l, A)
3. permeability of the magnetic material (μ)

Self inductance of an inductor $L = \frac{N^2}{S}$

where N – No. of turns
S – Reluctance of the coil, $S = \frac{l}{\mu a}$

$$L = \frac{N^2 \mu a}{l}$$

The mutual inductance ~~of an i~~ between two coils is given by $M = K\sqrt{L_1 L_2}$

K - coefficient of coupling.

The mutual inductance b/w two coils can be varied by varying either self inductances of the coils or coefficient of coupling.

In general inductive transducers ~~are~~ are used for the measurement of physical quantities such as displacement, force, pressure, velocity, position, variation etc.

__Transducer based on change in self inductance with number of turns:-__

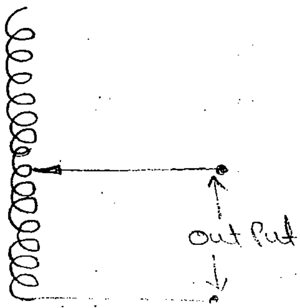


fig (a) Linear displacement

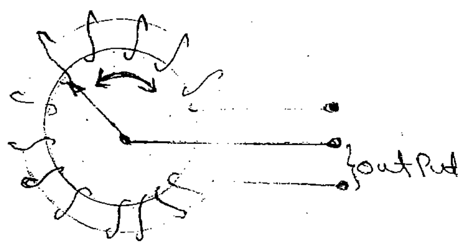


fig (b) Angular displacement

we know that L is directly proportional to N^2 i.e square of no. of turns. This property can be used to measure linear as well as angular displacement

In both the cases, as the no. of turns changes, the value of self inductance changes and hence the output voltage also changes.

Fig (a) is an air cored transducer for measurement of linear displacement.

fig (b) is an iron cored coil used for measurement of angular displacement.

Transducer working on the principle of change in self inductance with change in Permeability:-

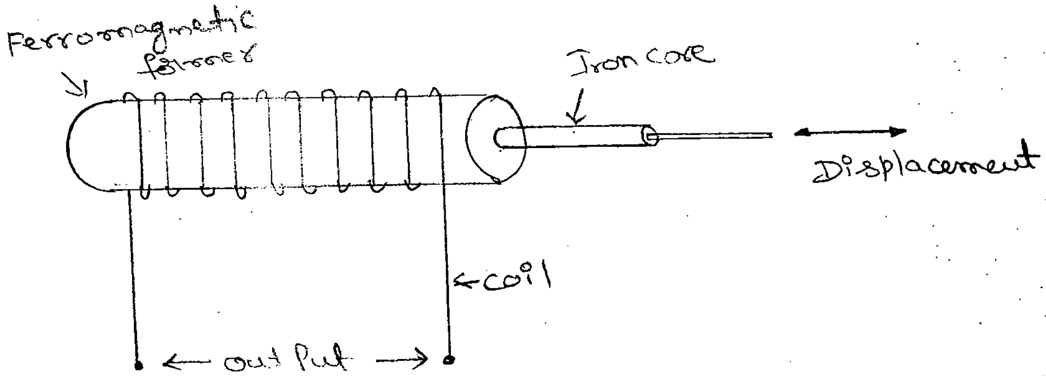
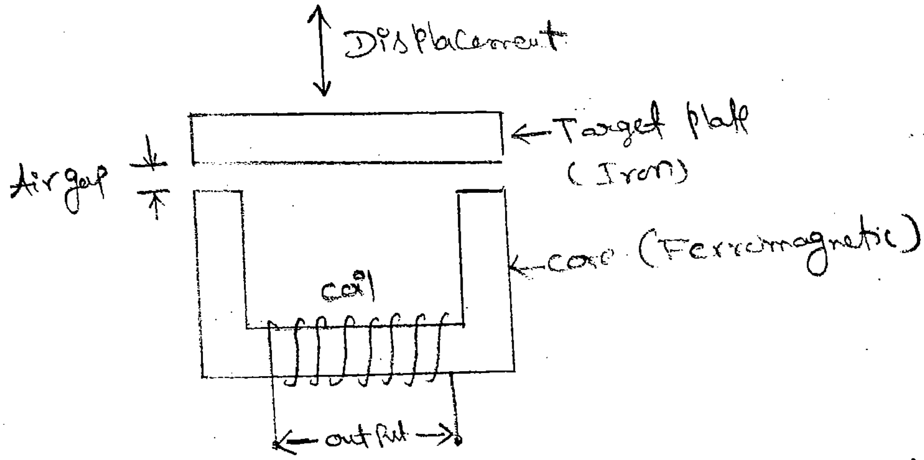


fig.

Above figure shows an inductive transducer which works on the principle of the variation of permeability causing a change in self inductance. The iron core is surrounded by a winding. If the iron core is inside the winding, its permeability is increased, and so is the inductance. When the iron core is moved out of the winding, the permeability decreases, resulting in a reduction of the self inductance of the coil. This transducer can be used for measuring displacement.

Variable Reluctance Type Transducer:-



A transducer of variable reluctance type consists of a coil wound on a ferromagnetic core.

is applied to a ferromagnetic target. The target does not have any physical contact with the core on which it is mounted. The core and target are separated by an air gap as shown in above fig.

The reluctance of the magnetic path is determined by the size of the air gap. The inductance of the coil depends upon the reluctance of the magnetic circuits.

The self inductance of the coil is given by

$$L = \frac{N^2}{S_i + S_g}$$

N – No. of turns
S_i – Reluctance of iron parts
S_g – reluctance of air gap.

$S_i << S_g$, therefore $L = \frac{N^2}{S_g}$

$$S_g = \frac{l_g}{\mu_0 A_g}$$ where l_g – length of airgap
A_g – Area of the flux gap through air
μ_0 – Permeability

S_g is proportional to l_g as μ_0 and A_g are constants

Hence L is proportional to $1/l_g$ i.e $L \propto \frac{1}{l_g}$

When the target is nearer the core, the length is small and therefore the self inductance is large. But when the target is away from the core the reluctance is large, resulting in a smaller self inductance value. Hence the inductance of the coil is a function of length of the air gap.

Since it is the displacement which changes the length of the air gap, the self inductance is a function of displacement, al

Differential output Transducers :-

The differential output transducers consists of a coil which is divided into two parts as shown in fig. below.

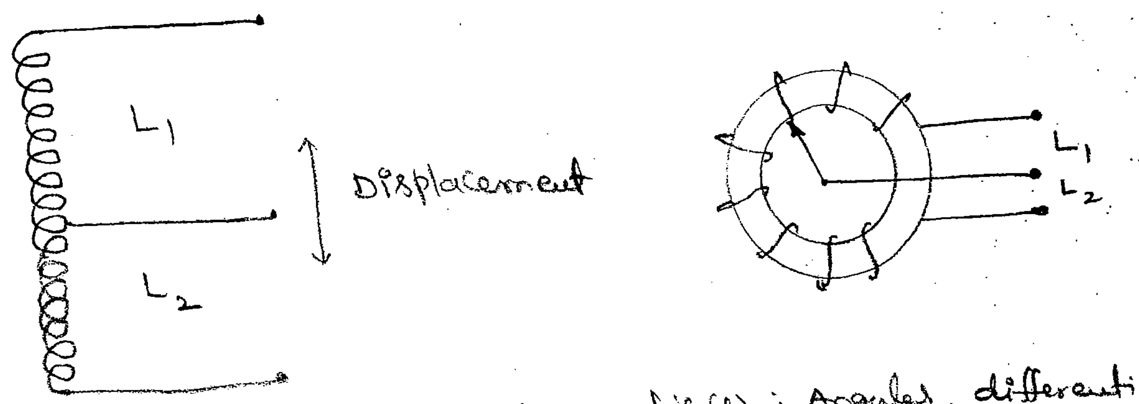


fig (a) : Linear differential output Transducer

fig (b) : Angular differential output transducer.

Normally the change in self inductance, ΔL for inductive transducers is not sufficient for detection of subsequent stages of the instrumentation system.

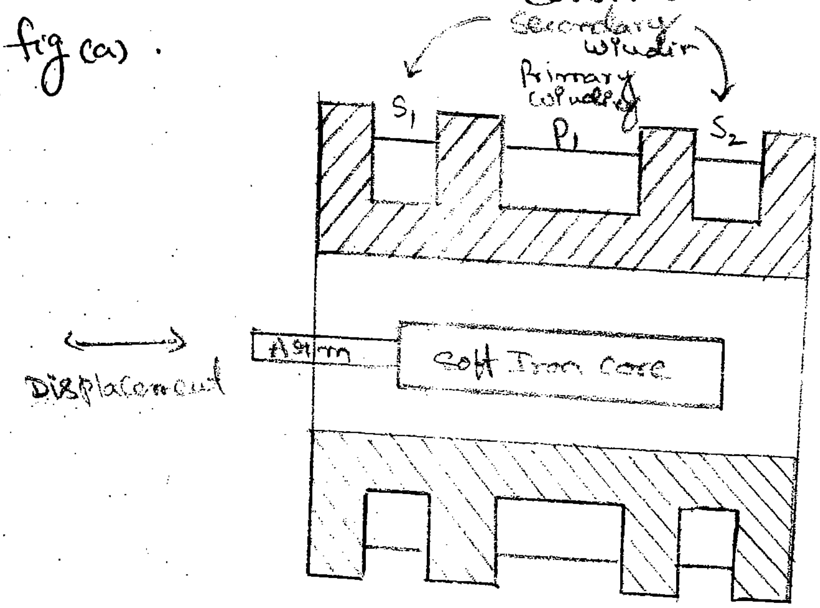
However, if successive stages of the instrument respond to ΔL (or) Δm, rather than L+ΔL, m+Δm, the sensitivity and accuracy will be much higher.

The transducers can be designed to provide two outputs, one of which represents increase in inductance (self or mutual) and the other the decrease in inductance (self or mutual). The succeeding stages of the instrumentation system measure the difference between these outputs. This is known as differential output

1. Sensitivity and accuracy are increased
2. output is less affected by external magnetic fields
3. Effective variations due to temperature changes are reduced
4. Effects of change in supply voltages and frequency are reduced.

Linear variable Differential Transducer (LVDT):

Construction :- The differential transformer is a passive inductive transformer. It is also known a LVDT. The basic construction is as shown in fig (a).



The transformer consists of a single primary winding P_1 and two secondary windings S_1 and S_2 wound on a hollow cylindrical former. The secondary windings have an equal no. of turns and are identically placed on either side of the primary winding. These two secondary windings are connected in series opposition so that the emf's induced in coils oppose each other. The primary is connected to an a.c source whose frequency may range from 50 Hz to 20 [illegible]

An movable soft iron core slides within the hollow former and therefore affects the magnetic coupling between the primary and the two secondaries. The core made up of nickel-iron alloy is slotted longitudanally to reduce eddy current loss.

Working of LVDT :-

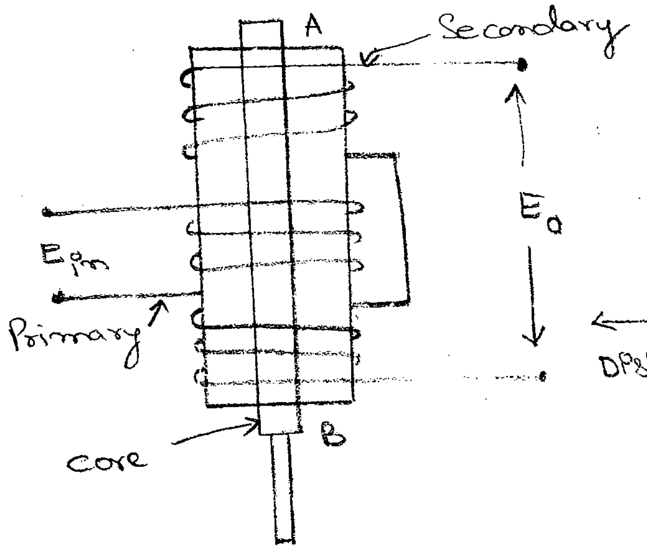


fig (a) construction.

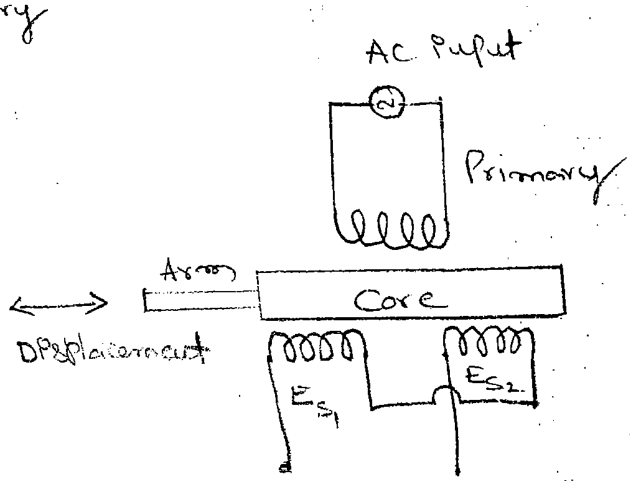


fig (b) Basic Circuit

The displacement to be measured is applied to an arm attached to the soft iron core. When the core is in normal position (null), equal voltages induced in the two secondaries and since they opposes each other, the output voltage is zero volts.

$E_0 = E_{S_1} \sim E_{S_2} = 0 \quad (E_{S_1} = E_{S_2})$.

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_{S_1} of the secondary winding S_1 is greater than E_{S_2}. The magnitude of the output voltage of the secondary is then equal to $E_{S_1} - E_{S_2}$ and is inphase with E_{S_1}.

the null position, the flux linking with winding S_2 becomes greater than that linked with winding S_1. This results in E_{S_2} becoming larger than E_{S_1}. The output voltage in this case is $E_0 = E_{S_2} - E_{S_1}$ and is in phase with E_{S_2}.

When the core is at centre we get output voltage as zero which is called null position. In general the output of LVDT is given by

$$E_0 = E_{S_1} \sim E_{S_2}$$

The amount of voltage change in either secondary winding is proportional to the amount of movement of the core. Hence, we have an indication of the amount of linear motion. By noting which output is increasing or decreasing, the direction of motion can be determined. The output AC voltage inverts as the core passes the centre position.

By comparing the magnitude and phase of the difference output voltage with that of the source, the amount and direction of the movement of the core and hence the displacement may be determined.

The output voltage of LVDT is a linear function of the core displacement within a limited range of motion. (5mm from the null position)

Fig (c), (d), (e) shows core of an LVDT of three different position. Fig (f) shows the variation of the output voltage against displacement for various position of the core. The curve is practically linear for small displacements (up to 5mm)

Beyond this range, the curve starts to deviate.

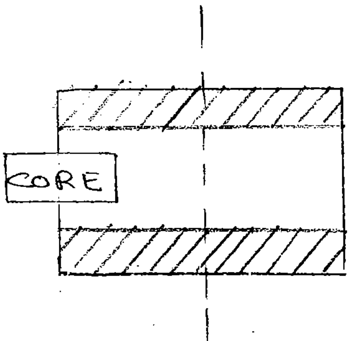


fig (c)

CORE at A

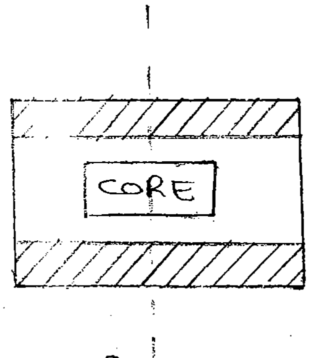


fig (d)

CORE at NULL position.

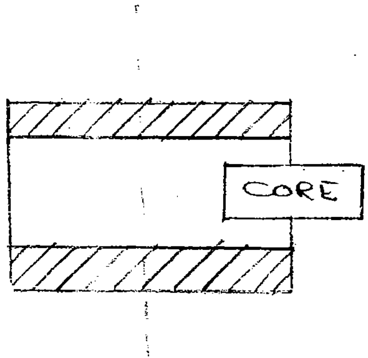


fig (e)

Core at B

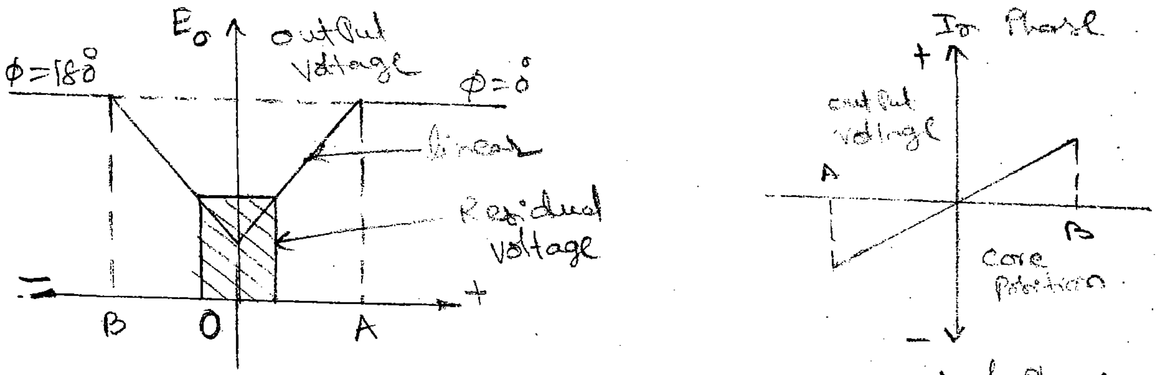


Fig (f): Variation of output voltage Vs displacement

In fig (d), the core is at O, i.e. at null position, $E_{S_1} = E_{S_2}$ and $E_0 = 0$

When the core is moved to the left, as in fig(c) and is at A, E_{S_1} is more than E_{S_2} and E_0 is positive. This movement represents a positive value and therefore the phase angle is $\phi = 0^\circ$

When the core is moved to the right towards B as in fig(e), $E_{S_2} > E_{S_1}$ & hence E_0 is negative. Therefore the output voltage is 180° out of phase with the voltage which is obtained when the core is moved to the left. The characteristics are linear from O–A and O–B, but after that they become non-linear.

±0.05 in. to as high as ± 25 in. They are sensitive to be used to measure displacements of well below 0.001 in. They can be obtaine for operation at temperatures as low as −265°C and as high as +600°C and are also available in radiation resistance designs for nuclear operation.

Advantages of ~~VLDT~~ LVDT :-

1. Linearity : The output voltage of LVDT is practically linear for displacements upto 5mm.

2. Infinite resolution : The change in output voltage is stepless (continuous). The effective resolution depends more on the test equipment than on the transducer.

3. High output : It gives a high output. Therefore there is frequently no need for intermediate amplification devices.

4. High sensitivity :- It has high sensitivity of about 300 mV/mm i.e a 1mm displacent of the core produces a voltage output of 300mV.

5. Ruggedness : These transducers are mechanically rugged and can tolerate a high degree of vibrations and shocks.

6. Less Friction :- There is no sliding contacts, hence the friction is very less

7. Low Hysteresis :- This transducer has a low hysteresis, hence repeatability is excellent under all conditions.

(8) Low Power consumption :-

Most LVDTs consume less than 1w of Power

(9) The LVDT transducers are small, simple and light in weight. They are stable and easy to align and maintain.

Dis Advantages :-

1. Large displacements are required for appreciable differential output.
2. They are sensitive to stray magnetic fields. However this interference can be reduced by shielding
3. The dynamic response is limited mechanically by the mass of the core
4. Temperature also affect the transducer.

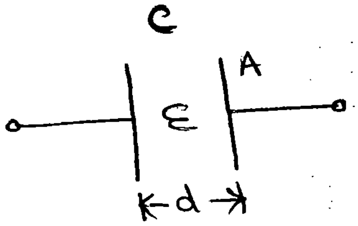
Capacitive Transducers

Capacitive transducers works on the fundamental principle of electrical capacitance. The capacitance C of a system depends on the dielectric medium used and properties of a capacitor.

The important capacitances used in the capacitive transducers are

1. Capacitance of a parallel plate capacitor

$$C = \frac{\epsilon A}{d} \text{ F}$$



where $\epsilon = \epsilon_0 \epsilon_r$

$\epsilon_0 = 8.854 \times 10^{-12}$

ϵ_r – Relative permittivity of material

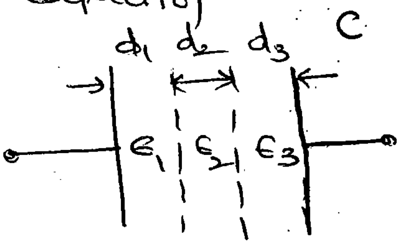
A – common cross-sectional area of plates

d – plate separation.

By using simple methods, the capacitance of capacitor can be varied and change in its value can be used for transduction in a transducer

2. Capacitance of a composite capacitor

$$C = \frac{\epsilon_0 A}{\frac{d_1}{\epsilon_1} + \frac{d_2}{\epsilon_2} + \frac{d_3}{\epsilon_3}}$$

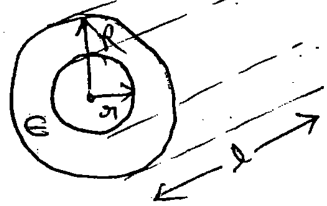


ϵ_1, ϵ_2 & ϵ_3 — Relative permittivities of dielectrics

d_1, d_2, d_3 – Thickness of dielectrics.

3. Cylindrical capacitor

$$C = \frac{2\pi \epsilon l}{\ln\left(\frac{R}{r}\right)} \text{ F}$$



r – outer radius of inner cylinder R – Inner radius of outer cylinder

Plates :-

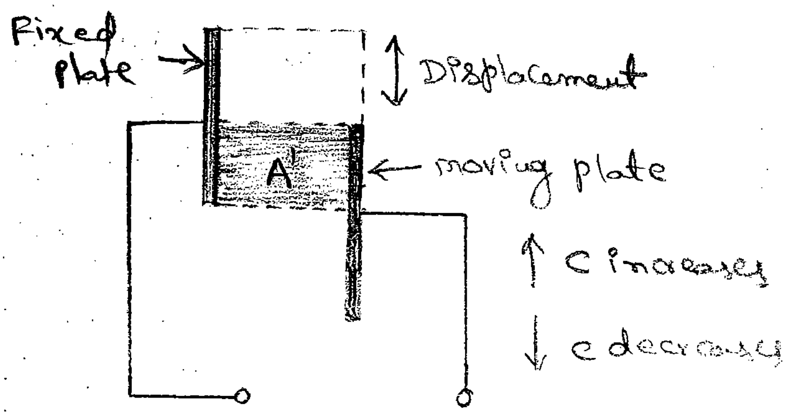


fig (a) change in common plate area

By keeping the one plate moving and changing its position parallel to the other plate, common plate area can be varied. This shown in fig (a). By varying area A, the capacitance can be varied. The common area can be changed by employing the serrated electrodes as shown in fig (b).

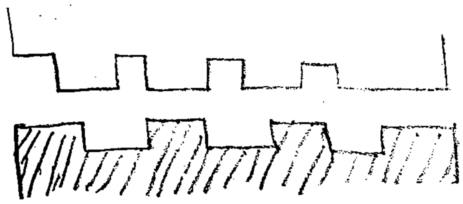


Fig (b) change in area.

From equation of capacitance, we know

$$C \propto A.$$

i.e the capacitance linearly varies with change in plate area. So this type of capacitive transducers is useful for displacement measurement in the range from few 'mm' to few 'cm'.

Let us consider Capacitive transducer based on the principle of change in Capacitance with change in plate area as shown in fig (c) & fig (d).

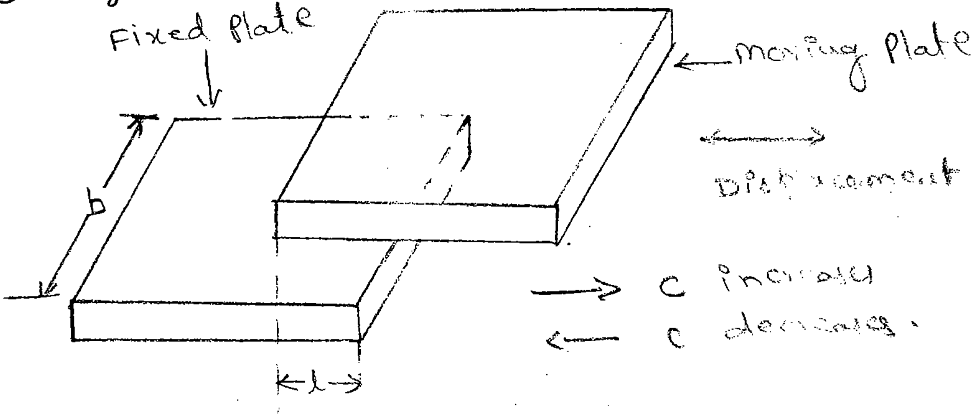


Fig (c)

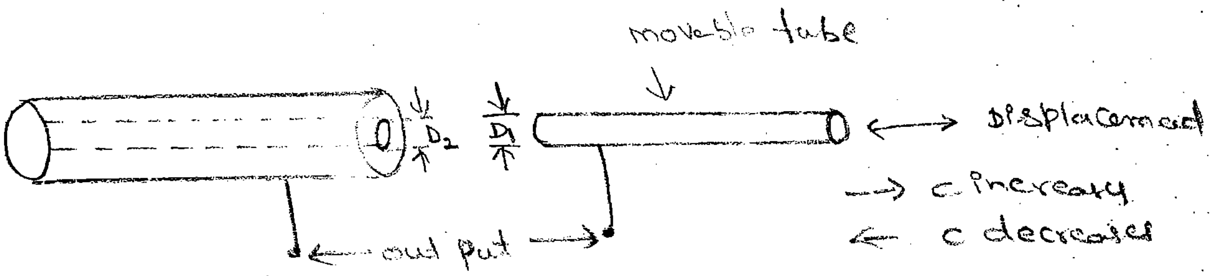


Fig (d)

Fig (c) & (d) : Capacitive transducer based on change in 'C' with change in area 'A'.

Consider fig (c), the area of overlapping part of a moving plate over fixed plate is,

$$A' = l\,b$$

Thus overall C is given by

$$\boxed{C = \frac{\epsilon A'}{d} = \frac{\epsilon l b}{d} \quad F} \qquad \text{——} (1)$$

where l - length of overlapping part of plate in meter
b - Breadth or width of overlapping part of plate in meter.

The sensitivity of Capacitor is given by

$$\boxed{S = \frac{\partial C}{\partial l} = \frac{\partial}{\partial l}\left(\frac{\epsilon l b}{d}\right) = \epsilon \frac{b}{d} \quad F/m} \qquad \text{——} (2)$$

relationship between capacitance and displacement.
The sensitivity for a fractional change in capacitance is given by,

$$S' = \frac{1}{c}\frac{dc}{dl} = \frac{1}{\left(\frac{\epsilon l b}{d}\right)}\left(\frac{\epsilon b}{d}\right) = \frac{1}{l}$$

Such type of capacitive transducer is suitable for linear measurement ranging from 1mm to 10 mm with the accuracy of 0.005%.

Consider cylindrical capacitor as shown in fig (d)
D_1 — outer dia. of inner electrode
D_2 - inner dia. of outer electrode.

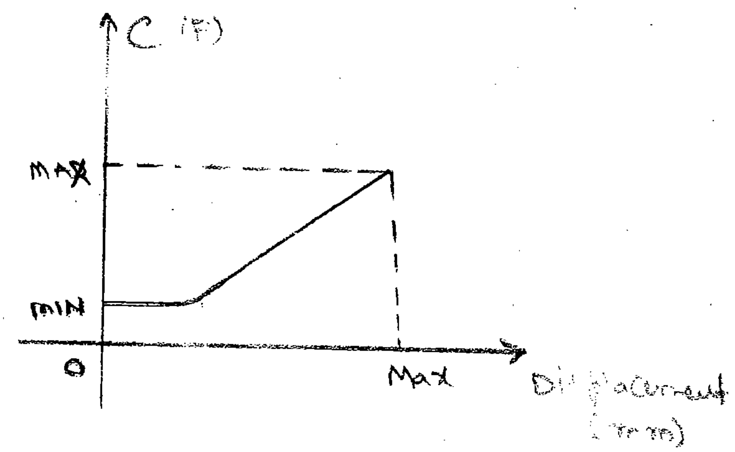
Then the capacitance of cylindrical capacitor is given by

$$C = \frac{2\pi\epsilon l}{\ln\left(\frac{D_2}{D_1}\right)} \quad F$$

where l is the length of overlapping part of cylinder in meters

Sensitivity of a cylindrical capacitor is given by

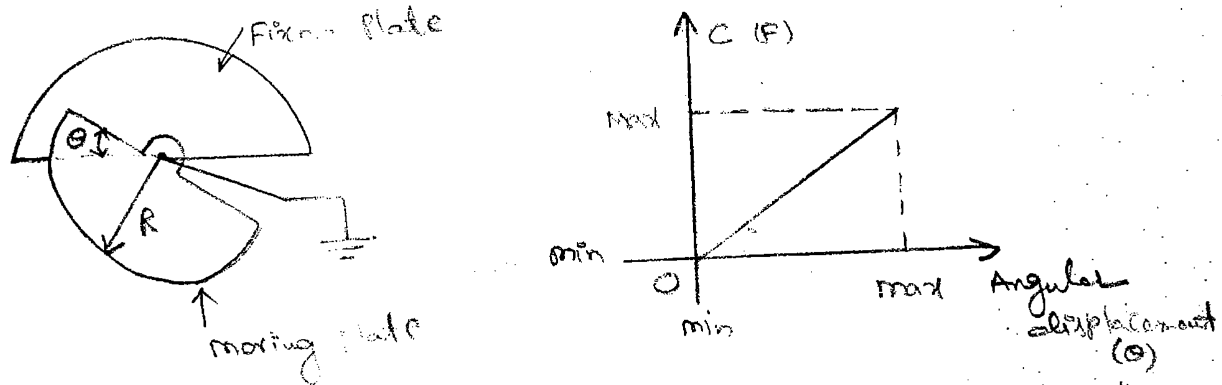
$$S = \frac{dc}{dl} = \frac{d}{dl}\left[\frac{2\pi\epsilon l}{\ln\left(\frac{D_2}{D_1}\right)}\right] = \frac{2\pi\epsilon}{\ln\frac{D_2}{D_1}} \; F/m .$$



Thus for cylindrical Capacitor also sensitivity is constant and the Capacitance and displacement relationship is linear.

we can use above type of Capacitor for the measurement of angular displacement also.

consider a Capacitive transducer used for angular displacement as shown in fig below.



(a) Rotating moving Plate Capacitive transducer

(b) Relation between Capacitance and angular displacement (θ)

The angular displacement to be measured is applied to movable plate. Due to this, the effective area between movable or moving plate and fixed plate changes which intern changes Capacitance between plates. when the two plates overlaps each other completel i.e $\theta = 180^\circ$, we get max. value of Capacitance given by

$$C_{max} = \frac{\epsilon A}{d} = \frac{\epsilon (\pi R^2)}{2d}$$

In general, the Capacitance at angular displacement is given by

$$C = \frac{\epsilon \theta R^2}{2d}$$

Sensitivity $S = \frac{\partial C}{\partial \theta} = \frac{\partial}{\partial \theta}\left[\frac{\epsilon \theta R^2}{2d}\right] = \frac{\epsilon R^2}{2d}$

is constant, so we can say that variation of capacitance with angular displacement is linear as shown in fig (b).

Capacitive Transducer based on change in distance between Plates :-

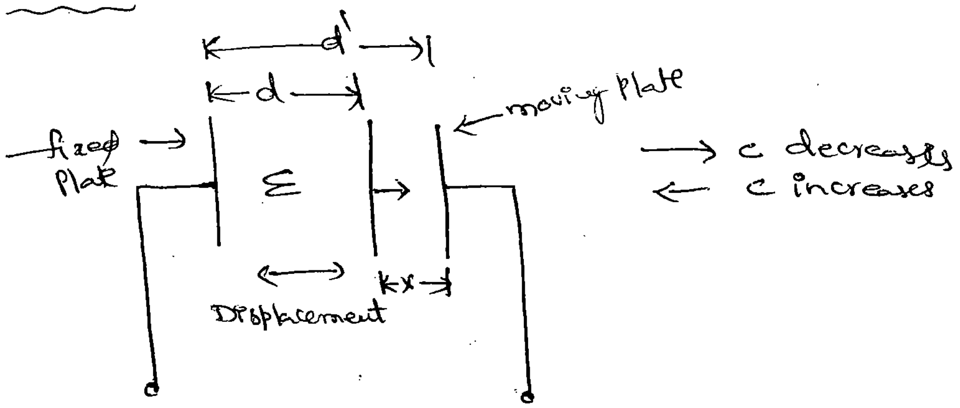


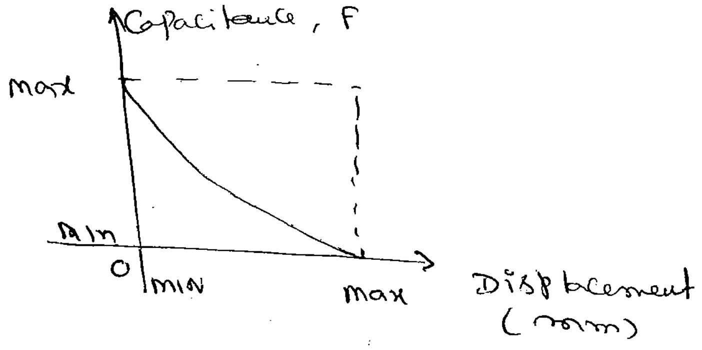
fig (a)

The Capacitance 'C' depends on separation between the plates. Thus by varying the distance of separation, C can be varied. The system is shown in fig (a) in which distance is varied by keeping one plate fixed and other plate moving. As the distance increases from 'd' to 'd'', the capacitance decreases from C to C'.

Let the displacement be x, then

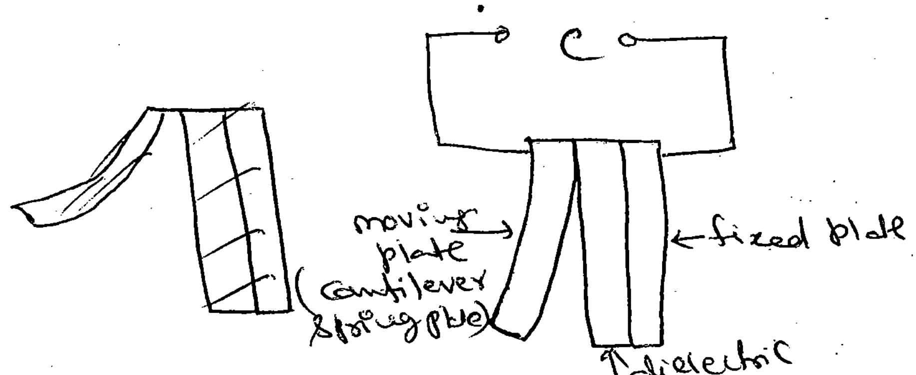
$$\text{Sensitivity} = \frac{dc}{dd} = \frac{dc}{dx} = \frac{d}{dx}\left(\frac{\epsilon A}{x}\right) = \epsilon A\left(-\frac{1}{x^2}\right) = -\frac{\epsilon A}{x^2}$$

Thus for the capacitive transducers based on change in capacitance due to change in distance between parallel plates, the sensitivity is not constant. The sensitivity inversely proportional to the square of the ~~displacem~~ distance between the plates and it exhibits square law property.



The sensitivity can be increased by reducing the distance between the plates. But there is a limit upto which distance can be decreased and it is the electric field between air gap does not exceed the breakdown voltage of value 3 kV/mm.

Another method of varying the distance is employing cantilever spring plate as shown below



When the displacement is applied to the spring plate it moves towards the fixed plate with decrease in the distance of separation between the plates. So capacitor value increases. When the dielectric between parallel plates is air, the capacitance does not vary ~~with~~ linearly with corresponding displacement, so it is also a non-linear system. But one achieve almost ideal linearity by using a medium of high dielectric constant or by keeping the change in distance between plates smaller constant :-

By Inserting a slab of Variable Permittivity, gives rise to the Capacitance Can be varied. Iutroducing of slab of variable permittivity gives rise to a composite Capacitor. This arrangement is shown in fig. below. This method is used in Capacitance type level meter.

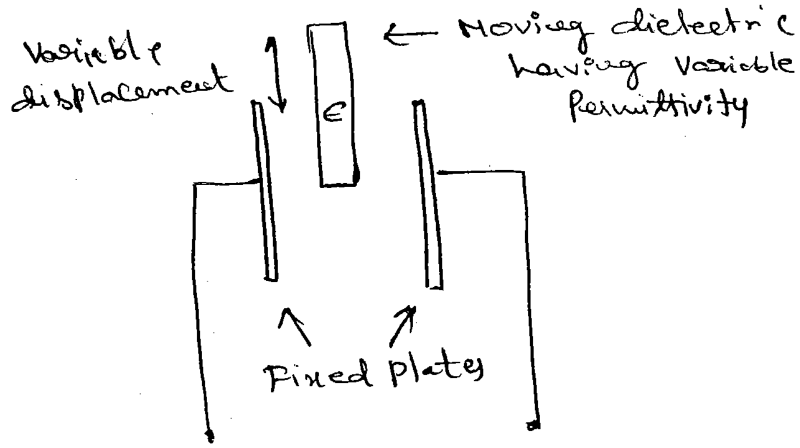


fig. change in dielectric

Capacitive Level meter :-

The Capacitive transducer using the method of change in dielectric is used for the measurement of the liquid levels.

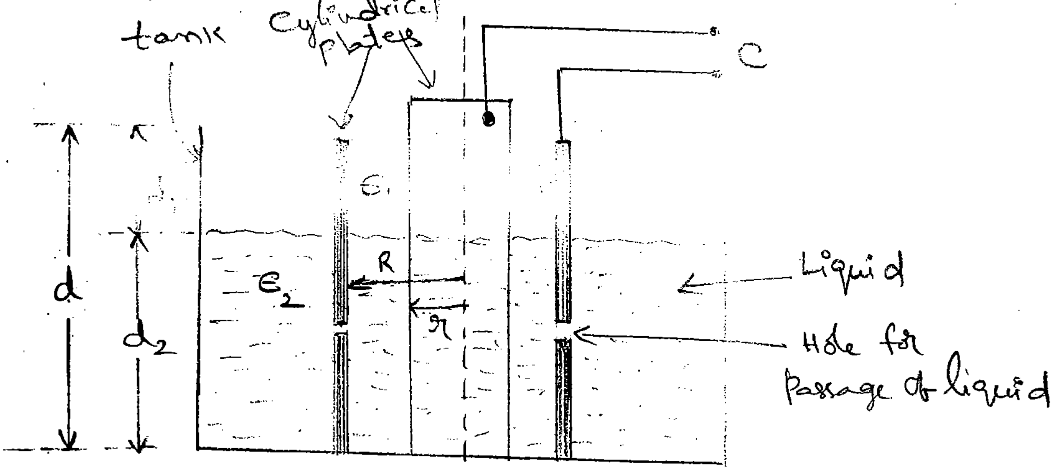


fig : Capacitance type level meter.

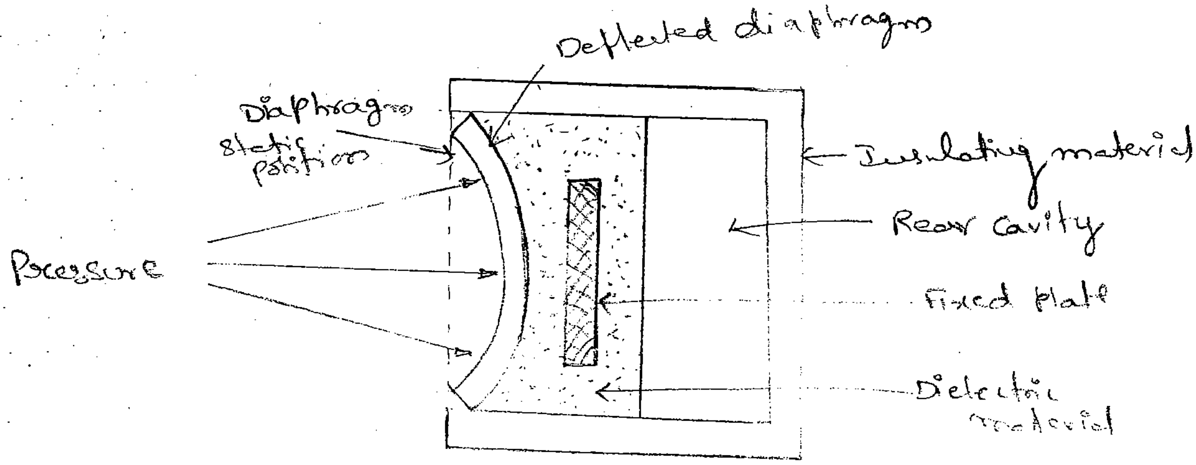
It uses concentric cylindrical ... two plates are cylindrical using the dielectric material with a permittivity ϵ_1. Most of the times, the dielectric is an air with $\epsilon_r = 1$. The outer cylindrical plates have holes at the bottom through which passage of liquid is possible between the plates.

let
R - inner radius of outer cylinder
r - outer radius of inner cylinder
d - Height of the tank
d_2 - Level of liquid in tank
ϵ_2 - Permittivity of liquid

As the liquid level d_2 changes, the composite capacitor ~~condenser~~ formed experiences change in its value. The value of capacitance is given by

$$C = \frac{2\pi \epsilon_0 [\epsilon_1 d_1 + \epsilon_2 d_2]}{\ln\left[\frac{R}{r}\right]}$$

Thus change in the liquid level causes the change in the capacitance measured between the cylinders. This change in capacitance is detected by ~~the~~ some other circuit ~~and~~ with which the electrical signal proportional to the liquid level ~~or~~ can be obtained.



Above fig. shows a transducer that makes use of the variation in capacitance resulting from a change in spacing between the two plates. In this type diaphragm acts as one of the plates of a two plate capacitor while other plate is fixed. The fixed plate and diaphragm are separated by a dielectric material. When the force is applied to diaphragm, it changes its position from initial static position applied with no force applied. Due to this, the distance of separation between the fixed plate and the diaphragm changes hence the capacitance also changes. The change in capacitance can be measured by using any simple a.c bridge. But practically the change in the capacitance is measured using an oscillator circuit where capacitive transducer is part of that circuit. Hence when capacitance changes, the oscillator frequency changes accordingly.

Advantages of Capacitive Transducers :-

(1) The force requirement is very small, hence the power required to operate is small and very useful in small systems.

(2) They are highly sensitive

(3) They are good frequency response and very high input impedance, so loading effects are minimum.

(4) They are useful in the applications where stray magnetic fields affect the performance of the inductive transducers

Disadvantages :-

(1) Proper insulation is required between the mettalic parts of the capacitive transducers

(2) The stray capacitance affect the performance of the transducer. It can be overcome by properly earthing the frame of the transducer.

(3) They show non-linear behaviour due to edge effects and stray electric fields. These can be eliminated by using guard rings.

(4) Due to long leads and the cables used, loading effect makes low frequency response poor and reduce sensitivity.

(5) For low value capacitances (PF) the output impedance tend to very high value which causes loading effects.

(1) They can be used for measurement of force and pressure along with displacement. The force and pressure to be measured are converted to displacement which causes change in capacitance effectively.

(2) They can be used for measurement of linear as well as angular displacements.

(3) In the situations where dielectric constant of a medium changes with pressure, the capacitive transducers can be directly used as pressure transducer.

(4) As the dielectric constant of gas changes with humidity, the capacitive transducer can also be used directly for the measurement of humidity in gases. Eventhough the change in capacitance is small, it is detectable by the transducer.

Strain Gauges:-

The Strain guage is a passive transducer that uses the variation in electrical resistance in wires to sense the strain produced by a force on the wires.

Stress is defined as force per unit area. The stress is measured in pressure units. The strain is defined as elongation or compression per unit length. Strain is measured in microstrains. Stress and strain in a member under pressure is directly proportio to the modulus of elasticity. Since strain can be measured more easily by using variable resistance transducers, it is a common practice to measure strain instead of stress. Such transducers are properly known as strain gauges.

If a metal conductor is stretched or compressed, its resistance changes on account of the fact that both the length and diameter of the conductor changes. When a conductor is subjected to strain, the resistivity of the conductor changes. This property is called Piezo-resistive effect. Therefore resistance strain guages are also known as piezo resistive gauges.

When a gauge is subjected to a positive stress, its length increases while its area of cross-section decreases. Since the resistance of a conductor is direcly proportional to its length and inversely proportional to its area of cross-section, the resistance of the gauge increas

of a ...
an increase in resistance due to its dimensional changes. This property is called Piezo-resistive effect.

The desirable characteristics of the strain guage are gauge sensitivity, range of measurement, accuracy, frequency response and the ambient conditions it can withstand. Sensitivity is defined as the smallest value of strain that can be measured.

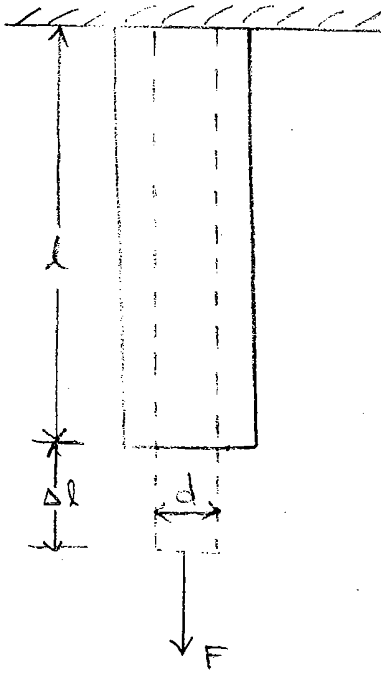
The measurement of sensitivity of a material to strain is called the guage factor.

Gauge Factor:-
It is the ratio of the change in resistance $(\Delta R/R)$ to the change in length $(\Delta l/l)$

$$K = \frac{\Delta R/R}{\Delta l/l} \quad \text{——} \quad (1)$$

where
- K – Gauge factor (or) sensitivity
- R – the initial resistance in (Ω) (without strain)
- ΔR – the change in the initial resistance in 'Ω'.
- Δl – the change in length in 'm'
- l – the initial length in 'm' (without strain)

Consider the resistance wire is under tensile stress and it is deformed by Δl as shown in fig. When uniform stress is applied to this wire along the length, the resistance R changes to $R+\Delta R$ because of change in length and cross-sectional area.



Since strain is defined as the change in length divided by the original length.

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

Eq ① Can be written as

$$K = \frac{\Delta R / R}{\sigma} \qquad \text{—— ②}$$

The Resistance of a conductor of uniform crossection is $R = \rho \frac{l}{a} = \rho \frac{l}{\pi r^2}$

$$r = \frac{d}{2}$$

$$\therefore R = \rho \frac{l}{\left(\frac{\pi}{4} d^2\right)} \qquad \text{—— ③}$$

When the conductor is stress, due to the strain, the length of the conductor increased by Δl and diameter decreased by Δd. Hence the resistance of the conductor can now be written as

$$R_s = \rho \frac{l + \Delta l}{\pi/4 (d - \Delta d)^2} = \frac{\rho (l + \Delta l)}{\frac{\pi}{4} (d^2 - 2d(\Delta d) + \Delta d^2)}$$

$$\therefore \quad R_s = \frac{\rho(l+\Delta l)}{\frac{\pi}{4}(d^2 - 2d\,\Delta d)}$$

$$= \frac{\rho(l+\Delta l)}{\frac{\pi}{4} d^2 \left[1 - \frac{2\Delta d}{d}\right]}$$

$$= \frac{\rho l\left(1+\frac{\Delta l}{l}\right)}{\frac{\pi}{4} d^2\left(1 - \frac{2\Delta d}{d}\right)} \quad \text{—— (4)}$$

Now poisson's ratio (μ) for the wire is defined as the ratio of strain in lateral direction to strain in the axial direction.

$$\mu = \frac{\Delta d / d}{\Delta l / l}$$

$$\frac{\Delta d}{d} = \mu \cdot \frac{\Delta l}{l}$$

substitute $\frac{\Delta d}{d}$ in eq 4, we have

$$R_s = \frac{\rho l\left(1+\frac{\Delta l}{l}\right)}{\frac{\pi}{4} d^2\left(1 - 2\mu\frac{\Delta l}{l}\right)}$$

rationalising, we get

$$R_s = \frac{\rho l\left(1+\frac{\Delta l}{l}\right)}{\frac{\pi}{4} d^2\left(1-2\mu\frac{\Delta l}{l}\right)} \frac{\left(1+2\mu\frac{\Delta l}{l}\right)}{\left(1+2\mu\frac{\Delta l}{l}\right)}$$

$$= \frac{\rho l}{(\pi/4)d^2}\left[\frac{1+\frac{\Delta l}{l}2\mu + \frac{\Delta l}{l} + 2\mu\frac{\Delta l}{l}\cdot\frac{\Delta l}{l}}{1 - 4\mu^2\left(\frac{\Delta l}{l}\right)^2}\right]$$

$$= \frac{\rho l}{\frac{\pi}{4}d^2}\left[\frac{1+2\mu\frac{\Delta l}{l} + \frac{\Delta l}{l} + 2\mu\frac{(\Delta l)^2}{l^2}}{1 - 4\mu^2\left(\frac{\Delta l}{l}\right)^2}\right]$$

Since Δl is small, we can neglect higher power of Δl

$$R_s = \frac{\rho l}{(\pi/4)d^2}\left[1 + 2\mu \frac{\Delta l}{l} + \frac{\Delta l}{l}\right]$$

$$= \frac{\rho l}{(\frac{\pi}{4})d^2}\left[1 + (2\mu + 1)\frac{\Delta l}{l}\right]$$

$$= \frac{\rho l}{(\pi/4)d^2}\left[1 + (1+2\mu)\frac{\Delta l}{l}\right]$$

$$= \frac{\rho l}{(\pi/4)d^2} + \frac{\rho l}{\pi/4\, d^2}(\Delta l/l)(1+2\mu)$$

from Eq ③ $\quad R = \frac{\rho l}{(\pi/4)d^2}$

$$R_s = R + \Delta R$$

where $\quad \Delta R = \frac{\rho l}{(\frac{\pi}{4})d^2}\left(\frac{\Delta l}{l}\right)(1+2\mu)$

∴ The gauge factor will now be

$$K = \frac{\Delta R/R}{\Delta l/l} = \frac{(\Delta l/l)(1+2\mu)}{(\Delta l/l)}$$

$$= 1 + 2\mu$$

$$\boxed{K = 1 + 2\mu}$$

The internal resistance value R of a strain gauge is typically around 120Ω and the guage factor may be from (for Nickel) −12 to +6. A gauge factor of 2 is reasonable for most strain gauges. Semiconductor gauges have higher sensitivity

Depending upon the principle of operation and their constructional features, strain gauges are classified as

1. Mechanical strain gauges
2. Optical strain gauges
3. Electrical strain gauges

In mechanical gauges, the change in length, Δl is magnified mechanically using levers or gears. These are comparatively larger in size and are employed for static strain measurements only.

Optical strain gauges are similar to mechanical strain gauges except that the magnification is achived with multiple reflectors using mirrors or prisms. The measurement accuracy is high and independent of temp. variations.

Electrical strain gauges measure the changes that occurs in resistance, capacitance or inductance due to the strain transferred from the specimen to the basic gauge element.

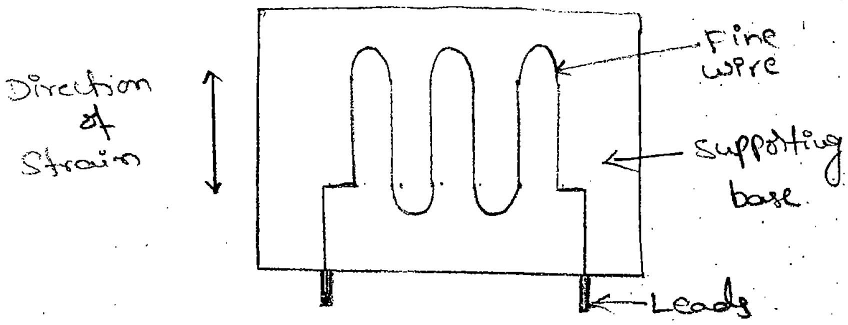
The following types of strain gauges are the most important

1. Wire strain gauges
2. Foil strain gauges
3. Semiconductor strain gauges.

Resistance wire gauges :-

Resistance wire gauges are used in two basic forms, the unbonded type and the bonded type. The most commonly used strain gauge is the bonded resistance type of strain gauge.

1. Bonded Resistance wire Strain gauge :-

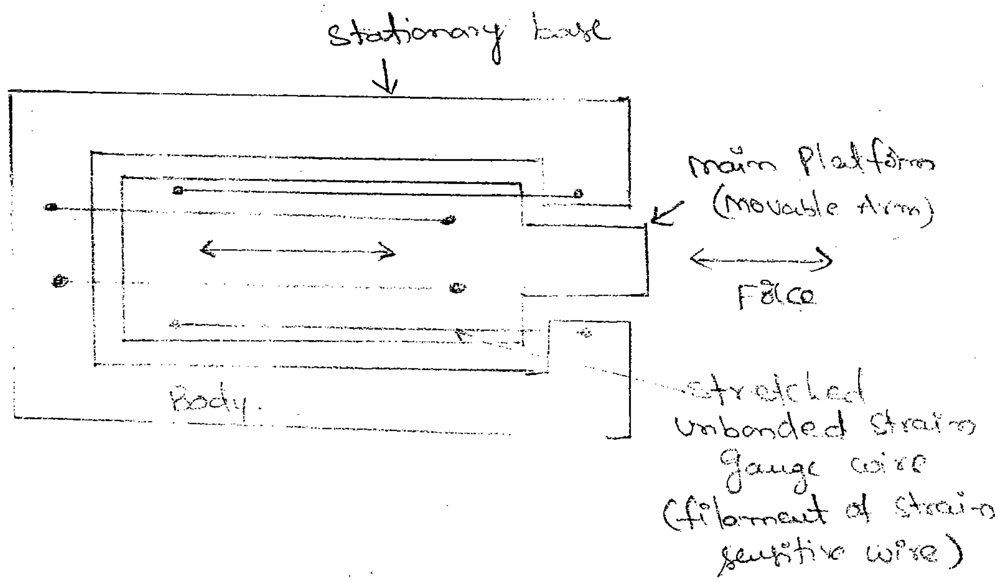


A metallic bonded strain gauge is shown in fig. above. In this type resistive element is cemented to the base which may be a thin sheet of paper, bakelite or teflon. The resistive element may be in the form of wire, foil or film of the material.

In metallic bonded strain gauge a fine wire element about 25 μm (or) less in diameter is looped backed and forth on a Carrier (or) mounting plate which is cemented to the member undergoing stress. The wire is covered on the top with a thin material, so that it is not damaged mechanically.

A tensile stress tends to elongate the wire and there by increase its length and decrease its cross-sectional area. The combined effect is an increase in resistance.

Unbonded Resistance wire strain gauge:-

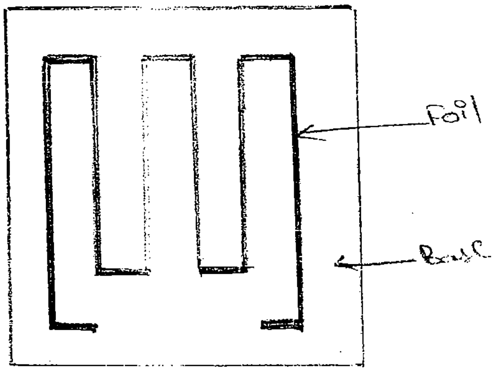


An unbonded strain gauge consists of a wire streched between two Points in ~~the~~ an insulating medium, such as air. The diameter of the wire used is about 25 μm. The wires are kept under tension so that there is no sag and no free vibration. unbonded strain gauges are usually connected in a bridge circuit. The bridge is balanced with no load applied as shown in fig.

When an external load is applied the resistance of the strain gauge changes, causing an unbalance of the bridge circuit resulting in an output voltage. This voltage is proportional to the strain. A displacement of the order of 50 μm can be detected with these strain gauges

Foil Strain Gauges :- (Bonded type)

This type of strain gauges is an extension of the 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 constantan (Ni+Cu), isoelastic (Ni+Cr+Mo), nickel and platinum.



Foil gauges have a much higher dissipation capacity than wire wound gauges because of their larger surface area for the same volume. Therefore they can be used at a higher operating temperatures ranges.

The characteristics of foil type and wire type strain gauges are similar and their gauge factors are typically the same.

The Advantage of foil type strain gauge is that they can be fabricated on a large scale, and in any shape. The foil can be etched on the base

The etched foil strain gauges can be made thinner than comparable wire units. Also they are more flexible. Because of these properties, the etched foil can be mounted in remote and restricted places & especially on curved surfaces. The resistance film formed is typically 0.2 cm thick. The resistance value of commercial foil gauges is between 50 and 1000 Ω

1. The strain gauge should have a high value of gauge factor, which means a large change in resistance for particular of strain.

2. The resistance of the strain gauge should ~~have~~ be large enough to minimise the effect of undesirable variations of resistance in the measurement circuit. Typical values are 120Ω, 350Ω and 1000Ω.

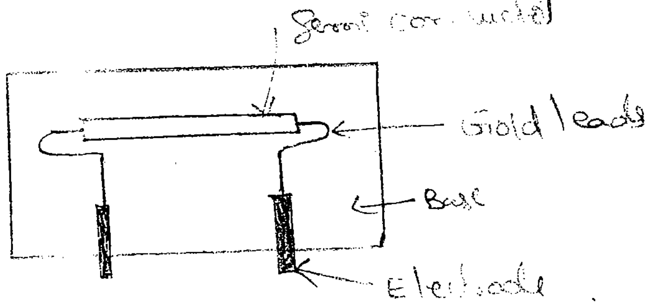
3. The strain gauge should have a low temperature coefficient of resistance. This minimize errors on account temprature variation, which affects the accuracy of measurements.

4. It should have linear characteristics i.e variation in resistance should be a linear function of the strain

5. Strain gauges are frequently used for dynamic measurements and their frequency response must be better over the entire frequency range, the characteristics should be linear.

6. Leads of strain gauges must be of materials which have low and stable resistivity and low temp. coefficient.

Semi-conductor Strain gauges :-



These type strain gauges are used when a very high gauge factor is required. Their gauge factor is 50 times as high as that of wire gauges.

Semi-conductor strain gauges works on the principle of piezo-resistive effect, i.e change in value of resistance due to change in resistivity of the semiconductor when strained. However, in metallic gauges, the change in resistance is mainly due to change in dimentions when strained. Semiconductor materials used are germanium and silicon.

A typical semiconductor strain gauge consists of a strain material and leads that are placed in protective box as shown in fig. Semiconductor wafer or filament used has a thickness of 0.05 mm. They are bonded on suitable insulating substrates, such as teflon. Gold leads are used for making contacts.

The gauge factor of this type of semiconductor strain gauges is 130 ± 10%. for a unit of 350 Ω, 1" long, ½" wide and 0.005" thick. The gauge factor is determined at room temperature. The gauge is stable and can be operated with conventional indicating and recording systems. It can measure small strains from 0.1 to 500 microstrains.

1. Semiconductor strain gauges have a high gauge factor of about +130. This allows measurement of very small strains, of the order of 0.01 microstrains.

2. These have excellent hysteresis characteristics i.e less than 0.05%.

3. Life of the semiconductor strain gauge is long, more than 10^7 operations and a frequency response of 10^{12} Hz.

4. These are very small in size, ranging in length 0.7 to 7.0 mm.

Disadvantages :-

1. They are very sensitive to change in temp.
2. Linearity of semiconductor strain gauges is poor
3. They are more expensive.

Temperature Transducers :-

Active Transducers :-

Active transducers generates an electrical signal directly in response to the physical parameter and does not require any external power source for its operation. Active transducers are self generating devices, which operate under energy conversion principle. These are further classified into thermoelectric transducer, Piezo-electric transducers and Photoelectric transducers.

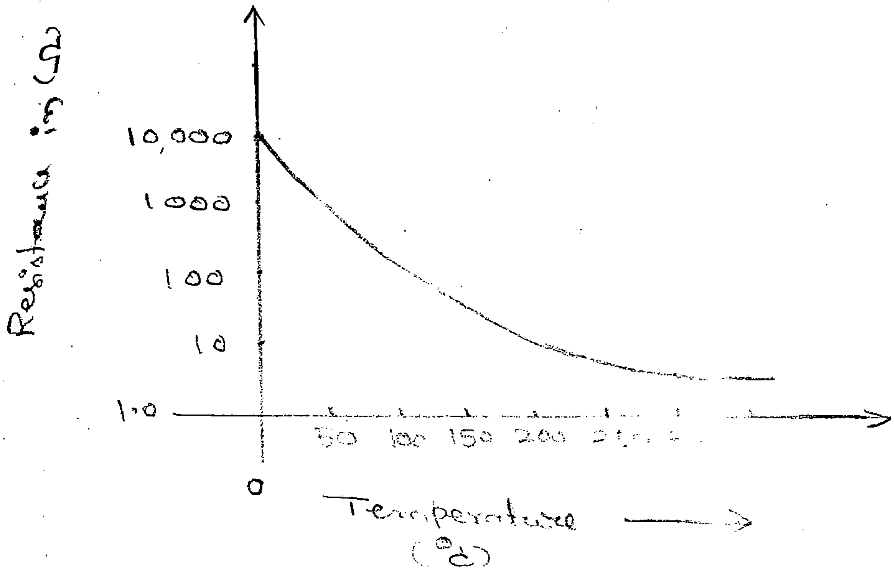
THERMISTOR :-

The electrical resistance of most materials changes with temperature. By selecting materials that are very temperature sensitive, devices that are useful in temperature control circuit and for temperature measurement can be made.

Thermistors (THERMally sensitive resISTOR) are non-metallic resistors (semiconductor materials), made by sintering mixtures of metallic oxides such as manganese, nickel, cobalt, copper and aluminimum.

Thermistors have negative temp. coefficient i.e resistance decreases as temp. increases.

The resistance at room temp (25°c) for typical commercial units ranges from 100 Ω to 10 MΩ. They are suitable for use only upto about 300°c. In some cases, the resistance of thermistors at room temp. may decrease by 5% for each 1°c rise in temperature. This high sensitivity to temperature changes makes the thermistor extremely useful for precision temp. measurements, control and compensation.



The mathematical relationship according to which the resistance of thermistor varies with temperature is given by,

$$R_1 = R_2 \, e^{\beta\left(\frac{1}{T_1} - \frac{1}{T_2}\right)}$$

where
R_1 = Resistance at T_1 °K
R_2 = Resistance at T_2 °K
β = constant depends on thermistor material ranging between 3500 to 4500 °K

The Resistance - Temperature characteristics of a thermistor is shown in fig. The equation consists of an exponential term and shows that it is highly non-linear in nature. It has high negative temp. coefficient characteristics. Though the characteristics is highly non-linear, for small range of temperatures, can be assumed to be linear.

Voltage - Current characteristics :-

The voltage - Current characteristics of thermistor shown in fig. It can be seen that as current increases, the voltage across thermistor increases, attains a peak value and then decreases, when it decreases, the negative resistance region starts.

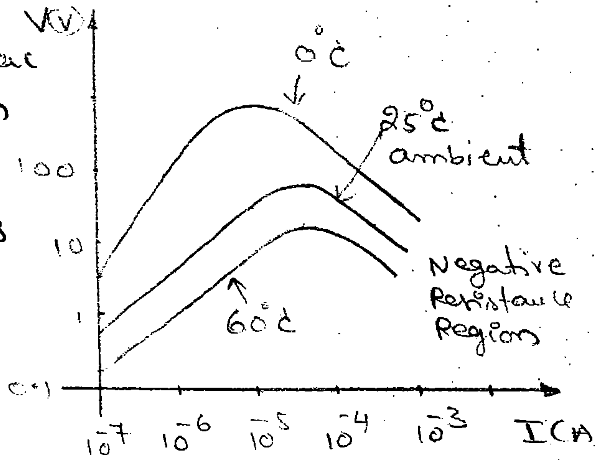
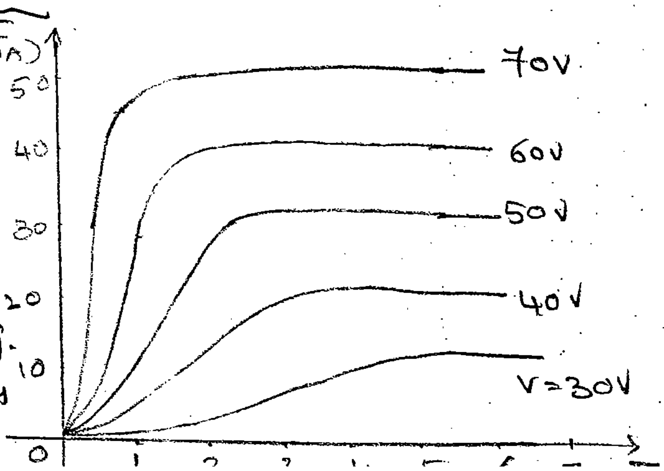


fig. V-I characteristics

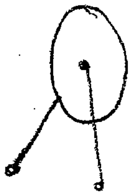
When small voltage is applied to thermistor, small current flows. This does not produce heat so as to change resistance of thermistor. Under this condition, it follows ohms law and V∝I. But large currents produce large heat. This increases temp. to such a value where resistance of thermistor decreases and draws more current. The current continues to increase till heat dissipation of thermistor equals the power supplied to it. This is called self heat characteristics of thermistor. This makes it suitable to measure flow, pressure, liquid level etc. If rate of heat removal is fixed then thermistor is sensitive to power input and used for voltage or power level control.

Current - Time characteristics :-

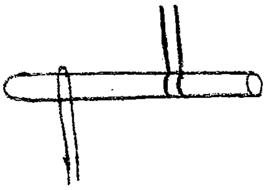
At low voltages, the thermistor takes long time to reach peak current. As voltage level increases, the time to reach peak current decreases. These characteristics shown in fig. Controlling the voltage, the thermistor can be used to produce time delays



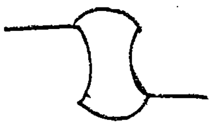
Construction of



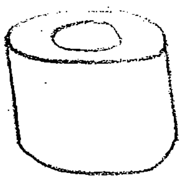
(a) Disc Type



(b) Rod Type



(c) Bead Type



(d) Washer Type

The smallest thermistors are made in the form of beads. Some are as small as 0.15 mm (0.006 in) in diameter. These may come in a glass coating or sealed in the tip of solid glass probes. Glass probes have a diameter of about 2.5 mm and a length which varies from 6 – 50 mm. The probes are used for measuring the temperature of liquids.

For greater power dissipations, thermistors may be obtained in disc, washer or rod forms. Disc thermistors about 10 mm in diameter, either self supporting or mounted on a small plate are mainly used for temp. control. These have resistance values of 1Ω to 1 MΩ. Washer thermistors are made like disc thermistors, except that a hole is formed in the centre in order to make them suitable for mounting on a bolt. Their resistance usually varies from 1 – 50 kΩ.

The advantage of rod thermistors over other configurations is the ability to produce high resistance units with moderately high power handling capability.

A thermistor in one arm of wheatstone bridge provides precise temperature information. Accuracy is limited in most applications, only by the readout devices.

Thermistors are non-linear devices over a temperature range, although now units with better than 0.2 % linearity over the 0-100°C temp range are available.
The typical sensitivity of a thermistor is approximately 3 mV/°C at 200°C.

Advantages of Thermistor :-

1. Small size and low cost
2. Fast response over narrow temp. range
3. Good sensitivity in a Negative temp. coeff. regi[on]
4. cold junction compensation not required due to dependence of resistance on absolute temp.
5. contact and lead resistance problems not encountered due to large resistance.

Limitations of Thermistor :-

1. Non-linearity in resistance Vs Temp. characteristics
2. unsuitable for wide temp. ranges
3. Very low excitation current to avoid self-heating
4. Need for shielded power lines, filters etc due to high resistance.

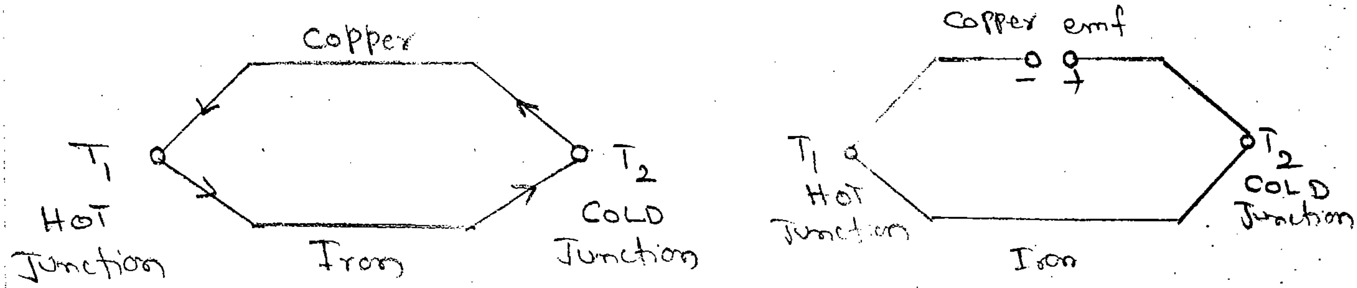
1. Useful for temp. transducers
2. Ideal for remote measurement (or) control
3. measurement of power at high frequencies
4. To compensate the effects of temp. on circuit performance due to negative Temp. Coffi. (NTC)
5. For pressure, flow, liquid level measurements
6. For measurement of thermal conductivity
7. For providing time delays
8. For vacuum measurements
9. For measurement of composition of gases.

Thermo couple :-

Thermo couple is a temperature transducer (Thermoelectric transducer) which converts thermal energy into an electrical energy. Thermo couple is generally used as a primary transducer for temp. measurement in which changes in temp. are directly converted into an electrical signal. Temperature measurement with thermo couple is based on the Seebeck effect. The thermo-couple behaviour can be explained on the basis of thermoelectric phenomena namely Seebeck effect, Peltier effect and Thompson effect.

Thermoelectric Phenomena :-

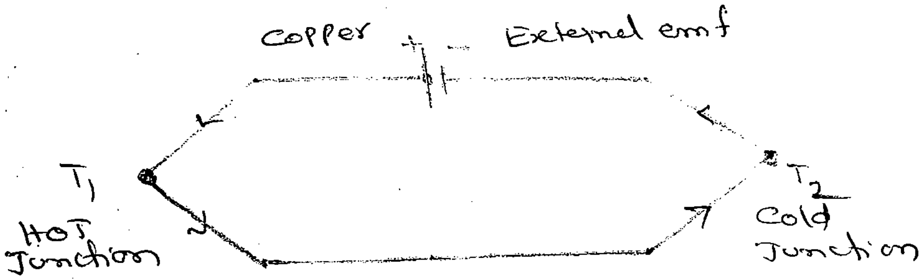
Seebeck Effect:- If two wires of different metals are joined together forming closed circuit and if the two junctions formed are at different temperatures, an electric current flows around a closed circuit. This is called seebeck effect. This effect is discovered by scientist Prof. Seebeck in 1821.



(a)

He also observed that if the two metals used are copper and iron, then current flows from copper to iron at hot junction and from iron to copper across the open Circuit as shown in fig (b). This emf is commonly known as Seebeck emf. This seebeck emf is Proportional to the difference in the temperature of two junctions.

Peltier Effect :-

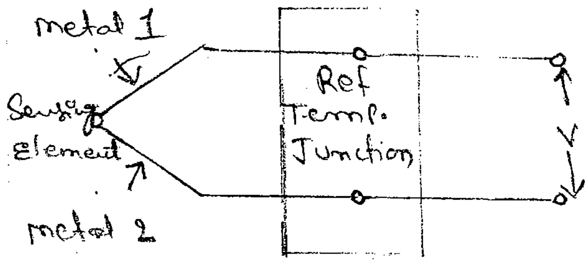


In 1824, Prof. Peltier discovered a reverse phenomenon. He observed that when two dissimilar metals form two junctions as shown in above fig. and if an external emf is connected as shown, then the Current flows through the junctions. When current flows through copper-iron junction (T_1) from copper to iron, heat is absorbed making junction T_1 hot and when Current flows through iron-copper junction (T_2) from iron to copper, heat is liberated making junction T_2 Cold. this effect is Called Peltier Effect.

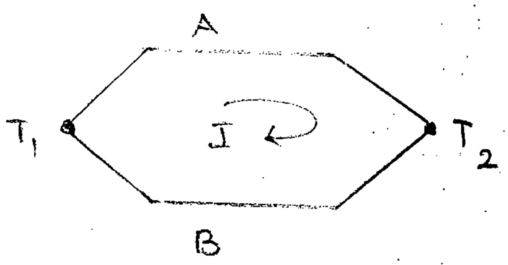
The amount of heat absorbed (or) liberated when unit Current flows for unit time is Called Peltier Coefficient.

Thompson Effect :- Prof. Thompson Postulated another reversible heat flow effect known as thompson effect. According to thompson effect when a Current flows through a copper conductor having thermal gradient along length of the conductor, heat is released at a point where the current is in the ~~same~~ direction same ~~direct~~ as the heat flow, while heat is absorbed at a point where current flows in the direction opposite to that of heat flow.

Construction of Thermocouple :-



(a) Basic Thermocouple connection



(b) Current through two dissimilar metals.

A thermocouple is the most commonly used thermoelectric transducer. Thermocouple is made up of two wires of dissimilar ~~and~~ metals joined together to form two junctions as shown in fig (b).

Out of two junctions T_1 and T_2, T_2 is kept at constant reference temperature. Hence it is refered as <u>cold junction</u>. While the temperature changes to be measured are subjected to the junction T_1 which is refered as <u>hot junction</u>. When the hot junction temp. is greater as compared to the cold junction, an emf is generated due to the temp. gradient. The magnitude of the emf generated depends on the material used for the wires and temp. difference between the two junctions. Generally a meter or recorder is used to measure emf across the terminals as shown in fig(a). The hot junction is also called measuring junction while the cold junction is called reference junction.

The two wires of the thermocouple are generally twisted and welded together. In general a junction may be formed by two methods, namely twisted weld and Butt weld. Twisted welding is used for large sized wires which gives mechanical strength. In Butt weld, two wires of small sizes are fused in to a round bead.

To measure higher temperature, the wire used should be heavier. But if the size of the wire increases, the response time of the thermo-couple increases. So size of the wire is selected such that above mentioned two conditions are satisfied. usually for noble metals, the wire of dia. 0.5mm is selected, while for the base metals, the diameter of the wire ranges from 1.5 to 3mm.

A Thermocouple, consists of a pair of dissimilar metal wires joined together at one end (sensing or hot junction) and terminated at the other end (reference or cold junction), which is maintained at a known constant temperature (ref. temp). When a temp. difference exists between the sensing junction and ref. junction, an emf is produced which causes current in the circuit.

Materials used for Thermocouples :-

The thermocouples are made from a no. of different metals including copper-constantan, iron-constantan, chromel-constantan, Platinum-Platinum-rhodium, etc. They cover wide range of temp. i.e from -200°c to 2800°c.

Thermocouples and Temp. ranges :-

Material used	Type	Temp. range
Copper - Constantan	T	-250°c to 400°c
Iron - constantan	J	-200°c to 850°c
Chromel - Alumel	K	-200°c to 110°c
Chromel - Constantan	E	-200°c to 850°c
Platinum - Platinum - rhodium	S	0°c to 1400°c
Tungsten - Molybdenum	-	0°c to 2700°c
Tungstem - Rhenium	-	0°c to 2600°c.

⇒ Out of all the materials used in thermocouples Platinum is the most stable material even in the oxidizing atmosphere. Its sensitivity is very high.

⇒ Constantan (Ni-40% & Cu-60%) is another alloy that can be used with copper, iron and chromel (Ni-90% & Cr-10%

⇒ Copper- constantan thermocouple gives highest output with max. sensitivity and also inexpensive.

⇒ Iron - constantan is another inexpensive thermo- -couple which is most widely used in industrial application. But the iron oxidizes rapidly above 750°C temp.

⇒ Chromel - alumel thermocouple is very resistant to oxidation within 700°c to 1300°c non reducing environment temperature.

For higher temp measurements, ...
molybdenum is used. Sometimes alloys of tungsten and rhenium also used upto 2600°C temp.

The two conductors or wires of thermocouple must be insulated from each other at cold junction. Hot junction must be insulated from the measuring instrument. Some of the insulating materials with temp. ranges are as follows.

Insulating material	Temp. Limit
Enamel and cotton	250°F
Asbestos	900°F
Glass	900°F
Ceramic Insulators	2600°F.

As the thermocouple measures the temp. difference between the hot and cold junction temperatures, the ref. junction (or) cold junction temp. must be maintained accurately. Generally for ref. junction ice bath technique is used. For most accurate measurements, the ref. junction is kept in a triple-point-of-water apparatus.

Advantages:-

1. It has rugged construction
2. It has temp. range from −270°C to −2700°C.
3. Using extension leads and and compensating cables, long distances transmission for temp. measurement is possible.
4. Bridge circuits are not ~~Possible~~ required for temp. measurement

5) Comparatively cheaper in cost
6) Calibration checks can be easily performed
7) Thermocouples offer good reproducibility
8) Speed of response is high compared to the filled system thermometer
9) measurement accuracy is quite good.

Disadvantages :-

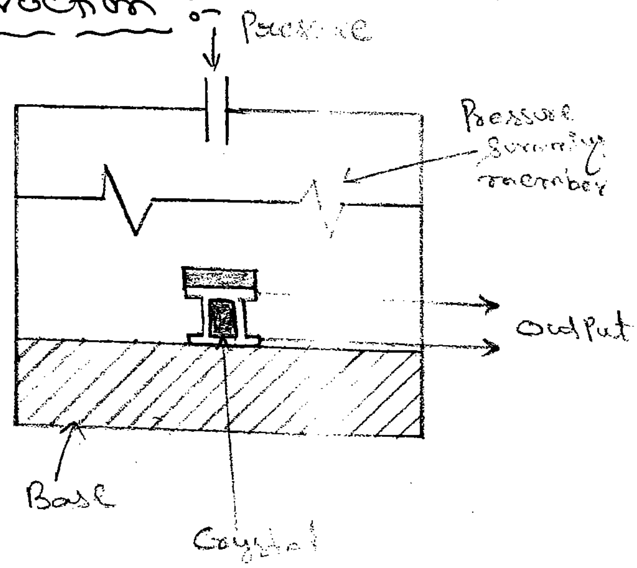
1. Cold junction and other compensation is essential for accurate measurement
2. They exhibit non-linearity in the emf versus temp. characteristics
3. To avoid stray electrical signal pick up, proper separation of extension leads from thermocouple wire is essential
4. Stray voltage pick-up are possible
5. In many applications signals need to be amplified.

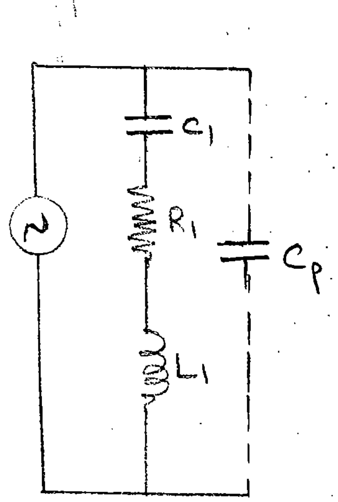
Piezoelectric Transducers :-

A symmetrical crystalline such as quartz, Rochelle salt and Barium titanate produce an emf when they are placed under stress. This property is used in piezoelectric transducers, where a crystal is placed between a solid base and the force-summing member.

In 1880, J. Curie showed that when two opposite face of a thin slice of certain crystals are subject to a mechanical force, then opposite charges are developed on the two faces of the slice. The magnitude of the electric potential between the two faces is proportional to the deformation produced. The polarity of the potential produced across the faces gets reversed if the direction of deformation is reversed. This phenomenon is called "Piezo electric effect" and materials exhibiting this effects are called "Piezo electric materials".

Construction :-





Equivalent Circuit of Crystal

A crystal is placed between solid base and force summing member. metal electrodes plated onto faces of piezoelectric crystal are taken out to measure output.

An externally applied force, entering the transducer through its pressure port, applies pressure to the top of a crystal. This produces an emf across the crystal proportional to the magnitude of applied pressure. The basic expression for output voltage E is given by

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

where Q - generated charge
C_p - Shunt capacitances.

This transducer is inherently a dynamic responding sensor and does not measure static conditions.

For a piezoelectric element under pressure, part of the energy is converted to an electric potential that appears on opposite faces of the element, analogous to a charge on the plates of a capacitor. The rest of the applied energy is converted to mechanical energy, analogous to a compressed spring. When the pressure is removed, it returns to its original shape and loose its electric charge.

coupling coefficient, K is given by

$$K = \frac{\text{mechanical Energy converted to electrical Energy}}{\text{Applied mechanical Energy}}$$

(or)

$$K = \frac{\text{Electrical Energy converted to mechanical Energy}}{\text{Applied electrical Energy}}.$$

An alternating voltage applied to crystal causes it to vibrate at its natural resonance frequency. Since the frequency is a very stable quantity, piezo electric crystals are principally used in HF accelerometer.

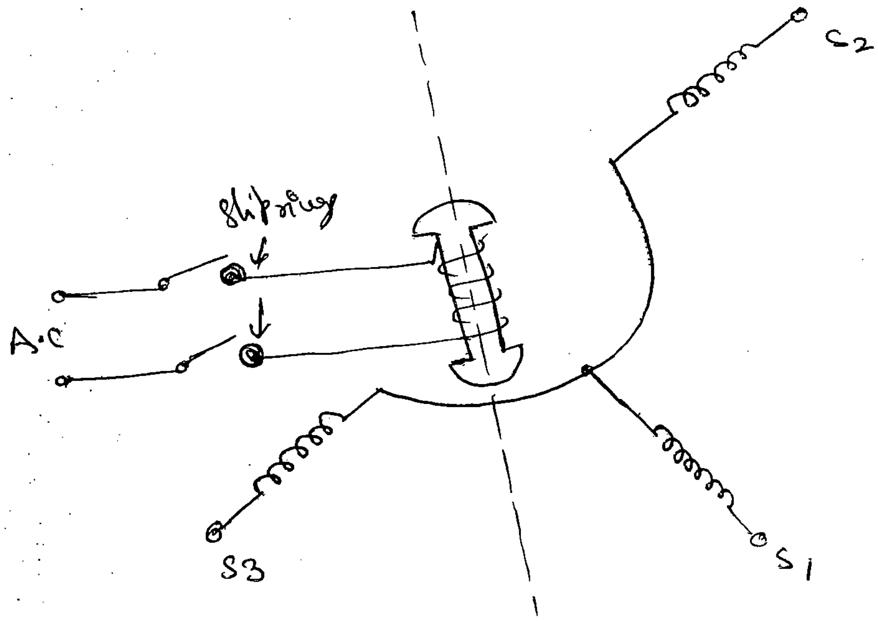
The main disadvantage is that voltage will be generated as long as the pressure applied to the piezo electric element changes.

Synchros :- (Inductive Position Transducers)

Synchro's are normally used in control system. Synchro's is a name of inductive devices which can be connected in various ways to form shaft angle measurement. All these devices work essentially on the same principle, that is of a rotating transformer. A synchro appear like an A.C motor consisting of a rotor and a stator.

A synchro can be an angular position transducer working on inductive principle, wherein a variable coupling between primary and secondary windings is obtained by changing the relative orientation of the windings.

Synchro have a rotor with one or three windings capable of revolving inside a fixed stator. The rotor may be a salient pole (or) a wound rotor type.



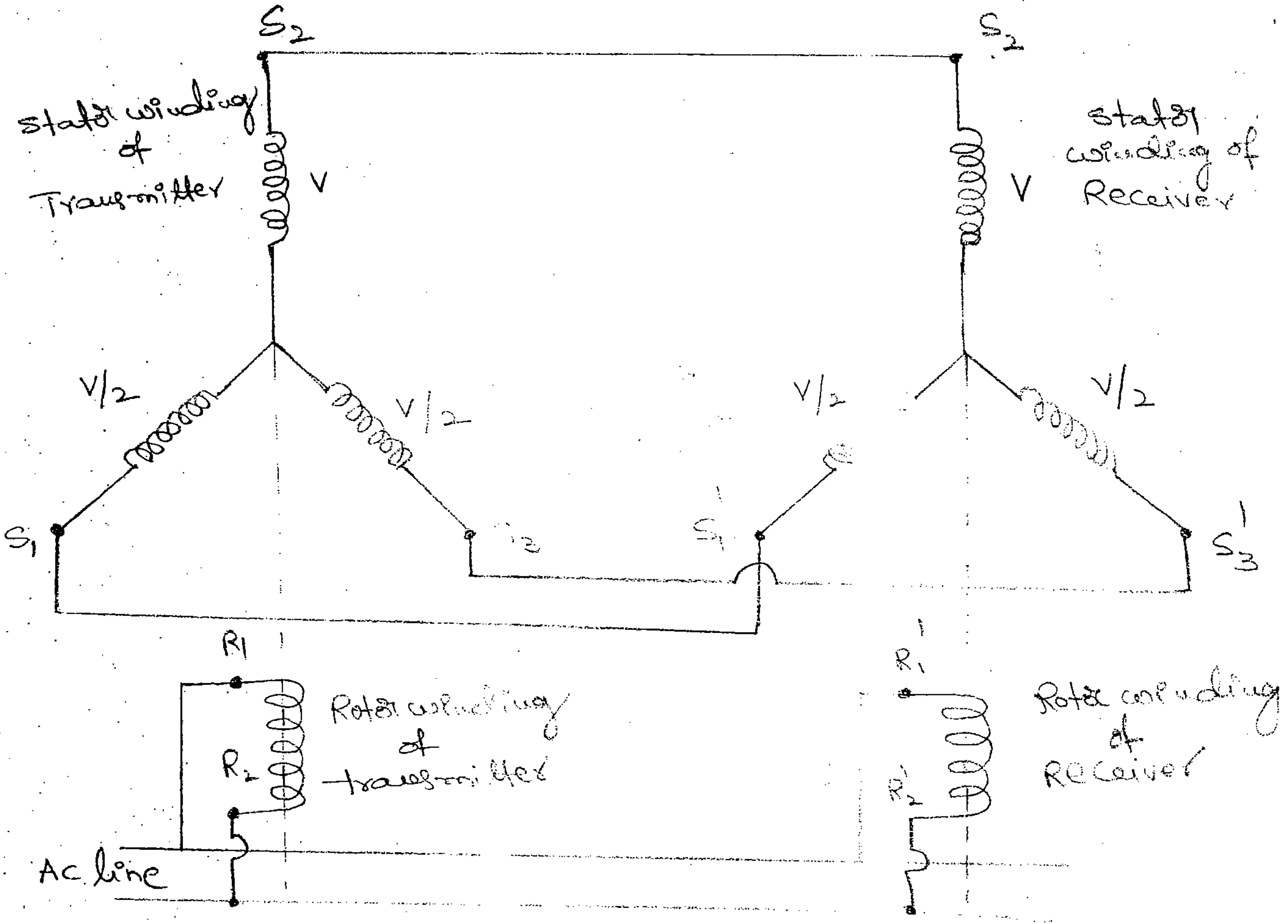
The stator has a 3-Phase winding with the three windings displaced at 120°. Rotor is made of laminations and wound with a single phase winding. The connection to the rotor windings are made through precision slip rings. The Synchro may be viewed as a variable coupling transformer. A synchro is also called as "Selsyn"

The rotor is energized by an a.c voltage and coupling between rotor and stator windings varies as a trigonometric or linear function of the rotor position.

Synchro Transmitter:-

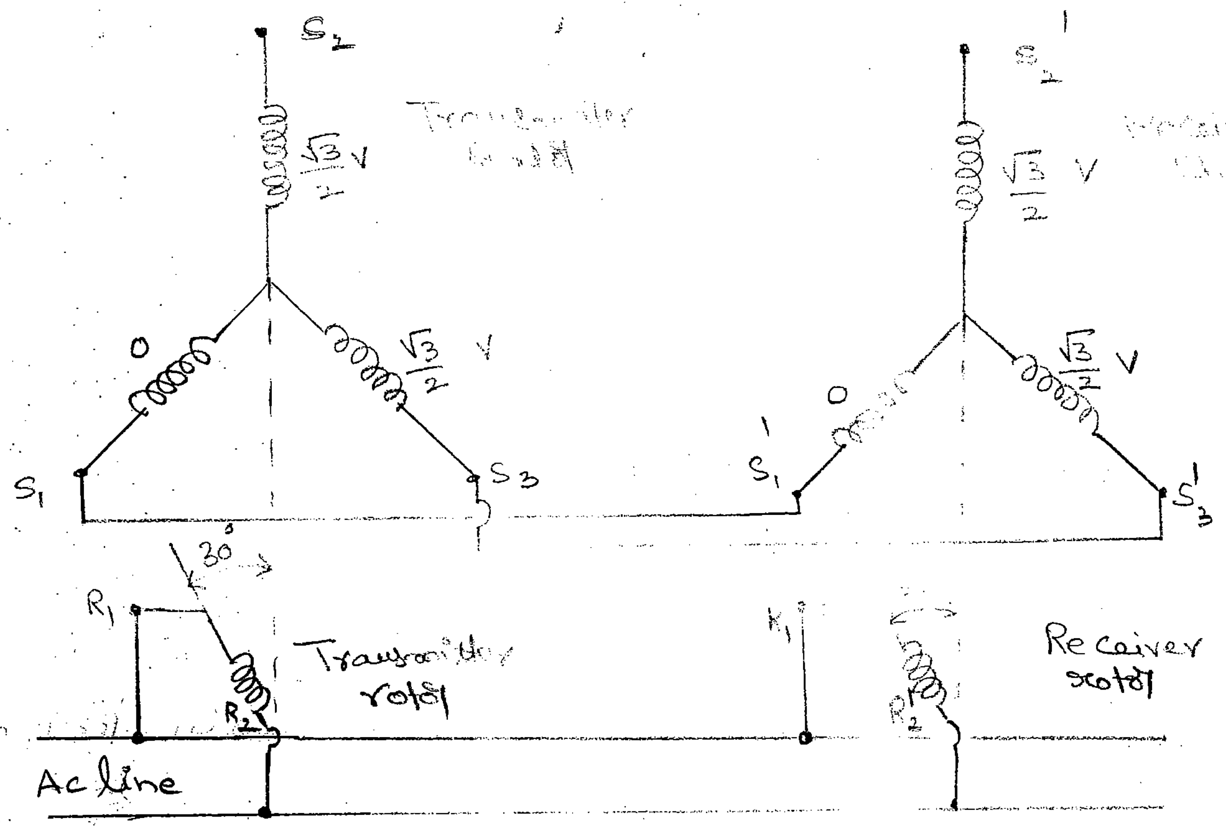
A synchro system formed by interconnection of the devices called Synchro Transmitter and Synchro control Transmitter. It is most widely used error detector in feedback control system. It measures and compares two angular displacements and its output ~~is~~ voltage is approximately linear with angular displacement.

The Synchro Transmitter uses as salient pole rotor with sleeved slots. When the rotor excited by an a.c voltage, the current produces a magnetic field and voltages induced in stator coils by transformer action. The voltage induced in any stator coil depends upon the angular position of the coil axis w.r.t rotor axis.



S2
S2'
stator winding of Transmitter
V
stator winding of Receiver
V
V/2
V/2
V/2
V/2
S1
S3
S1'
S3'
R1
R2
Rotor winding of transmitter
R1'
R2'
Rotor winding of Receiver
Ac line

(a)



S2
S2'
√3/2 V
√3/2 V
0
√3/2 V
0
√3/2 V
S1
S3
S1'
S3'
30°
R1
R2
Transmitter rotor
R1
R2'
Receiver rotor
Ac line

(b)