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COURSE :- BASIC ELECTRONICS

CODE :- 22EC13

Transducers:

All the successful achievements in science and technology are entirely due to the ability to measure state, condition, characteristics of the physical systems in quantitative terms with sufficient accuracy.

LORD KELVIN stressed the Importance of measurement by saying

"When you can measure what you are speaking about, and express it in numbers, you know something about it, if you are unable to express it, then your knowledge is meagre and unsatisfactory"

Why do we MEASURE

Measurement are generally made

* to understand an event or an operation
* to monitor an event or an operation
* to collect data for future analysis
* to validate an engineering design

Fundamental methods of Measurements

1. Direct comparision with either a primary or a secondary standard.

   Ex:- To measure a length of bar we use scale (ruler) [Vernier, compass]

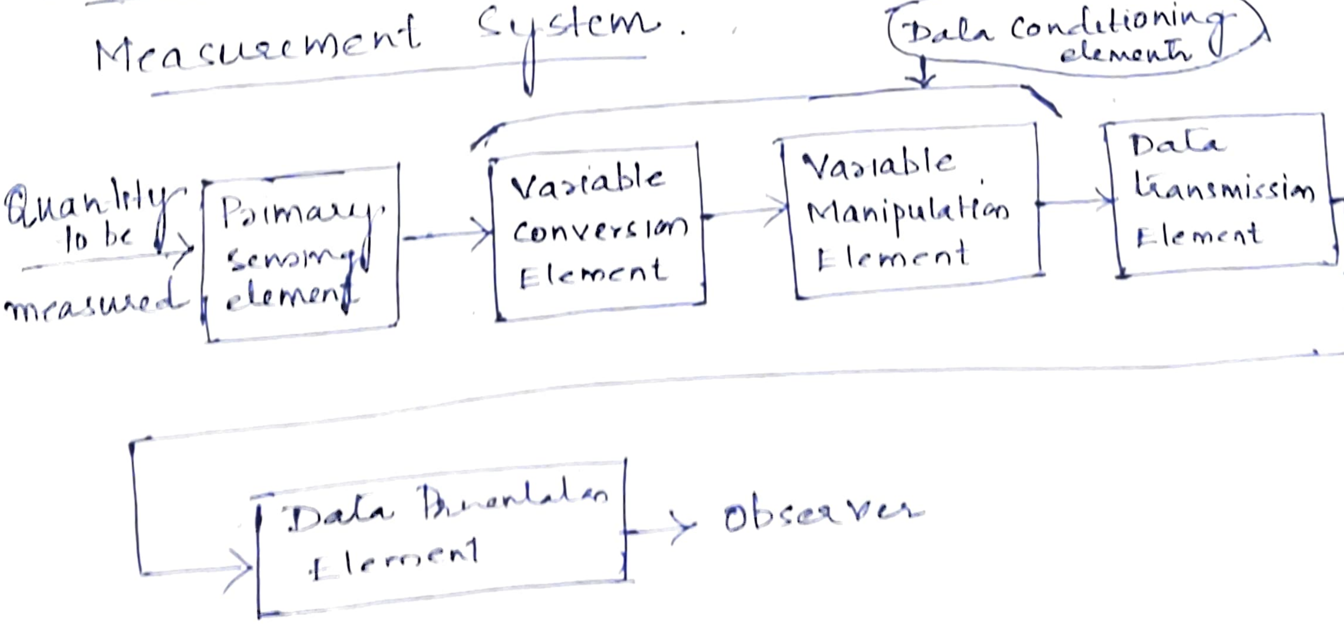
   The quantity to be measured is compared directly with a standard (an agreed unit of measurement)

2. Indirect comparision through the use of calibrated system

   Ex:- Transfer the measurement from the work piece to the direct measuring Instruments, then the comparision is made.

   Divider, surface guage etc...

Functional Elements of an Instrument or a Measurement System.



Most of the measurement systems contain 03 main functional elements. They are:

i) primary sensing element
ii) Variable Conversion element Eg
iii) Data presentation element

Primary sensing element: Quantity under measurement makes its first contact with Primary sensing element of a measurement system. ie measurand (the unknown quantity which is to be measured). This measurand is first detected by primary sensor which gives output in a different analogous form. This output is then converted into an electrical signal by transducer (which converts energy from one form to another)

Variable Conversion element:

The output of primary sensing element may be electrical signal of any form, it may be voltage, frequency or some other electrical parameter. For the Instrument to perform the desired function, it may be necessary to convert this output to some other form, which is done by this variable conversion element.

Variable Manipulation element : The function of this element is to manipulate the signal presented to it preserving the original nature of the signal. Processes like modulation, sampling, filtering, chopping etc., are performed on signal to bring it to the desired form so that it can be accepted by next stage.

Sensors & Transducers

Instrument Society of America defines a sensor or transducer as a device which provides a usual output in response to a specified measurand.
Here the measurand is a physical quantity and the output may be electrical quantity, mechanical and optical.

SENSORS: An element that senses a variation in input energy to produce a variation in another or same form of energy is called a sensor.

TRANSDUCERS: It converts a specified measurand into usable output using transduction principle.

Example :- a properly cut piezo electric crystal can be called a sensor, where as it becomes a transducer with appropriate electrodes and input / output mechanisms attached to it. So the sensor is the primary element of a transducer.

All sensors are transducers, but not all transducers are sensors.

As explained earlier, a generalized measurement system consists of 03 major components.

i) an input device
ii) a signal conditioning or processing device
iii) an output device.

The Input device receives the measurand or the quantity under measurement and delivers a proportional or analogous electrical signal to signal conditioning device. Here the signal is amplified, attenuated, filtered, modulated or modified in format acceptable to the output device.

Since the Input quantity for most of the Instrumentation systems is "non-electrical quantity", This is converted into "Electrical form" by a device called TRANSDUCER

Transducers when actuated transforms energy from one form to another.

→ It converts mechanical force into an electrical signal

→ Many other physical parameters such as heat, Intensity of light, flow rate, liquid level, humidity and PH value may also be converted into electrical form by means of transducer.

Transducers consists of two Important and closely related parts:

i) Sensing Element

ii) Transduction Element

In addition there may be auxiliary parts like amplifiers, signal processing equipments, power supplies and calibrating sources

Sensing or Detector Element: is that part of a transducer which responds to physical phenomena or a change in physical phenomena

Transduction Element: It transforms the output of sensing element to an electrical output. The transduction element in a way acts as Secondary Transducer.

CLASSIFICATION OF TRANSDUCERS

They are classified on the basis of

i) transduction form used
ii) Primary and Secondary transducers
iii) Passive and Active transducers
iv) Analog and Digital transducers

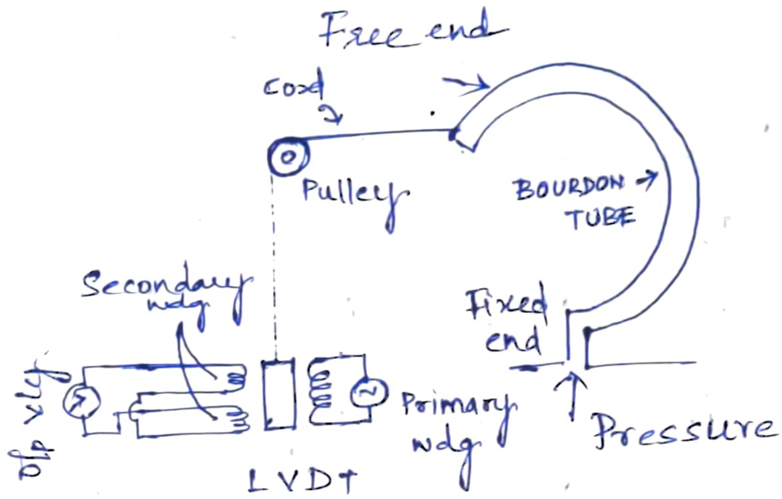
Classification based upon principle of Transduction

Based on the principle of transduction as resistive, inductive, capacitive etc., depending upon how they convert the input quantity into resistance, inductance or capacitance respectively. They are classified as piezoelectric, thermoelectric, magnetorestrictive, electrokinetic and optical

Example:

	Electrical Parameter	Principle of operation	Applications
1)	Resistance Resistance thermometer	Resistance of metal varies with temperature	Temperature measurement
2)	Inductance Magnetic ckt transducer	Self or mutual Inductance of coil is varied by changes in magnetic circuit	Displacement measurement

Primary & Secondary Transducer



1) Bourdon tube acting as primary detector senses the pressure and converts the pressure into a displacement of its free end.

2) The displacement of the free end moves the core of the linear variable differential transformer (LVDT), which produces an output voltage which is $\propto$nal to the movement of the core, which is $\propto$nd to the displacement of the free end, which in turn is $\propto$nal to the pressure.

3) Here firstly pressure is converted into a displacement by Bourdon tube then, Displacement is converted into analogous voltage by L.V.D.T.

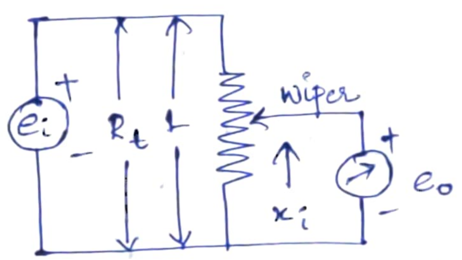
4) Bourdon Tube is called Primary Transducer while LVDT is called Secondary Transducer

Passive & Active Transducers

Passive transducers: They derive the power required for transduction from an auxiliary power source. They are also known as "externally powered transducers"

Examples are resistive, Inductive and capacitive transducers.

"POT" which is used for measurement of displacement.
A POT is a resistive transducer powered by a source voltage e_i. This pot is used for measurement of linear displacement x_i



Linear potentiometer (POT)
Passive transducer

Suppose L is the length of potentiometer, whose total resistance (R_t). Input displacement is x_i

$\therefore$ output voltage

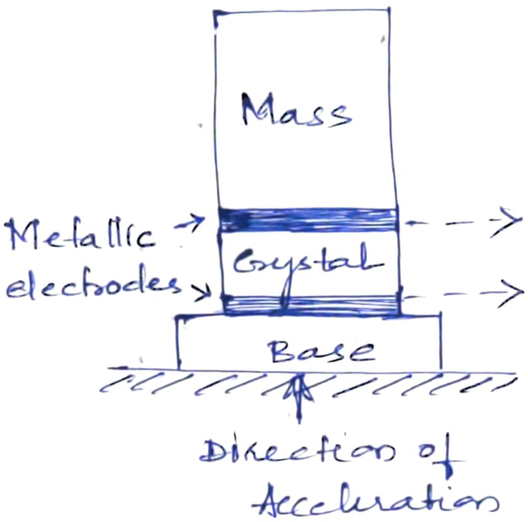
$$\boxed{e_o = \frac{x_i}{L} e_i \quad \text{or} \quad x_i = \left(\frac{e_o}{e_i}\right) L}$$

In the absence of external power, the transducer cannot work and hence it is called as passive transducer.

Active transducer: Active transducers are those which do not require an auxiliary power source to produce their output. They are also known as "self generating type", since they develop their own voltage or current output.

Examples are Thermocouples, photovoltaic cells & Piezoelectric crystals.

Piezoelectric crystals



Piezoelectric crystal measuring acceleration - An Active Transducer

The crystal is sandwiched between two metallic electrodes & the entire sandwich is fastened to a base which may be the floor of a rocket. A fixed mass is placed on the top of the sandwich.

The property of piezo electric crystals is that when a force is applied to them, they produce an output voltage.

The mass exerts a certain force on account of acceleration on the crystal, due to which a voltage is generated.

The acceleration is applied to the base, due to which the mass produces a force. The mass being fixed, the force is proportional to acceleration.

The voltage output is proportional to force & hence is proportional to acceleration (mass being fixed)

It should be noted from the explaination that this transducer called as "accelerometer" which converts acceleration into electrical voltage, does not need any auxiliary power source to convert a physical phenomenon (acceleration) to an electrical output (voltage in this case) & therefore is an active transducer

Analog & Digital Transducers

Analog Transducers:- They convert Input quantity into an analog output which is a continuous function of time.

Ex:- strain guage, L.V.D.T, thermocouple or thermistor may be called as "Analog Transducers" as they give an output which is continuous function of time.

Digital Transducers: They convert the Input quantity into an electrical output which is in the form of pulses.

Resistance Thermometers:

The resistance of a conductor changes, when its temperature is changed. This property is utilized for measurement of temperature.

The variation of resistance R with temperature T (°K) can be represented by the following relationship for most of the metals as:

$$R = R_0 (1 + \alpha_1 T + \alpha_2 T^2 + \dots + \alpha_n T^n + \dots)$$

where R_0 = resistance at temperature T = 0

& α_1, α_2, α_3 are constants.

The resistance thermometer uses the change in electrical resistance of conductor to determine the temperature.

Platinum to this day is used as the primary element in all high accuracy resistance measurements, since it can withstand high temperatures while maintaining excellent stability. As a noble metal it shows limited susceptibility to contamination.

Platinum Resistance Temperature detector (PRTD) is the resistance thermometer used until today often called as RTD.

All metals produce a +ve change in resistance with temperature. This is the main function of RTD

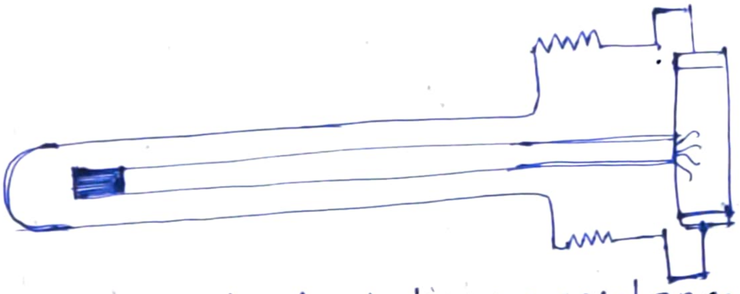
Few requirements of conductor materials to be used in RTDs are:

* change in resistance of material / unit change in temperature should be as large as possible
* Material should have high value of resistivity
* Resistance of materials should have a continuous & stable relationship with temperature.

The most common materials used for RTDs are platinum, Nickel or Nickel alloys & copper.

The value of RTD is 100Ω at 0°C, with a resistance temperature co-efficient of 0.00385/°C.

RTD is also called as Pt - 100 since Platinum shows a resistance of 100Ω @ 0°C



Industrial platinum resistance Thermometer

Variable Inductance Transducers

They work generally on one of the following 03 principles

i) change of self Inductance
ii) change of mutual Inductance &

iii) production of eddy currents.

An Inductive transducer working on the principle of variation of mutual inductance uses multiple coils

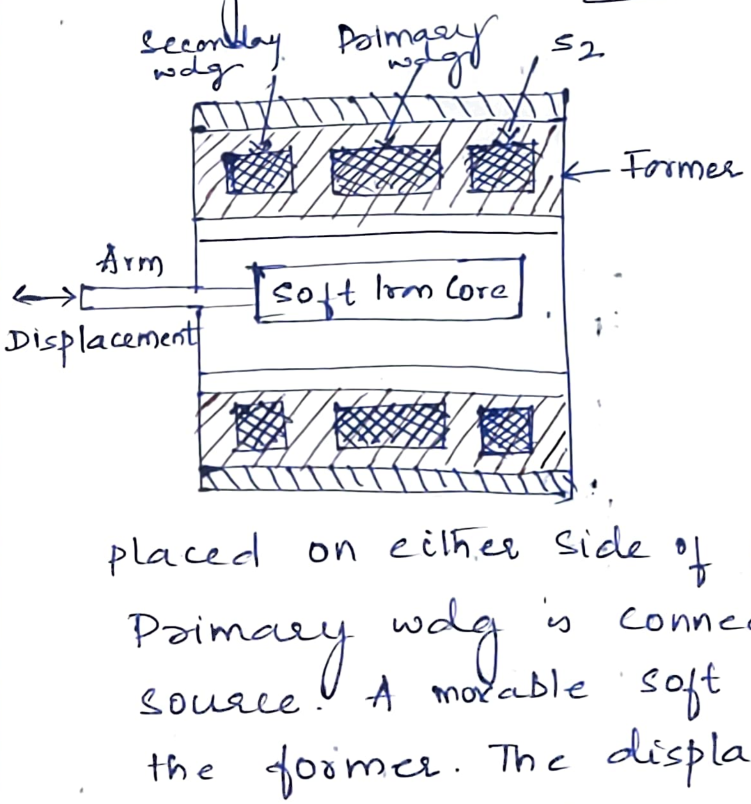
Mutual Inductance between two coils

$$M = K\sqrt{L_1 L_2}$$

where L_1 & L_2 are the self Inductance of two coils and k is co-efficient of coupling.

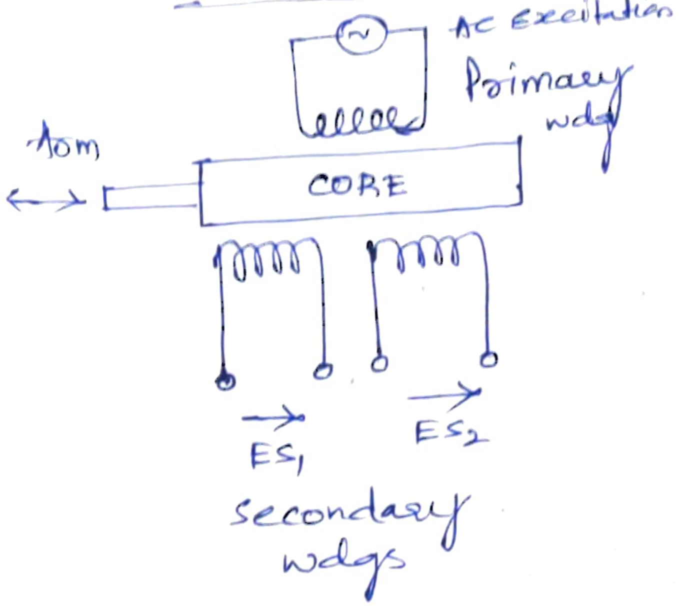
Linear Variable Differential Transformer (LVDT)

The most widely used inductive transducer to translate the linear motion into electrical signals is the LVDT

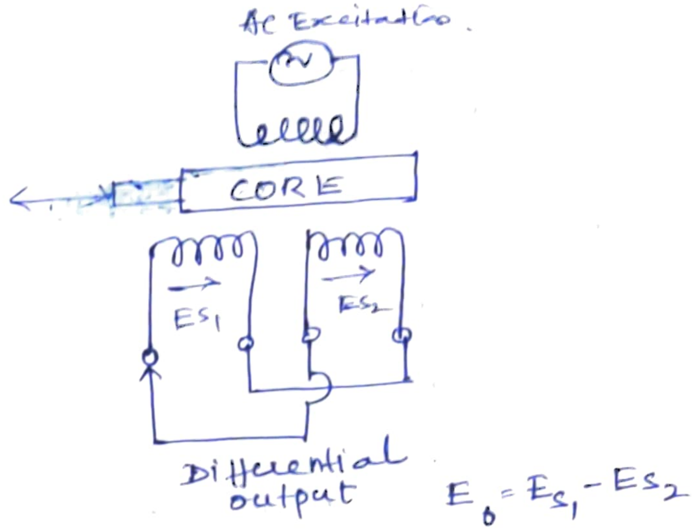


The transformer consists of single primary wdg P and two secondary wdgs S_1 & S_2 wound on a cylindrical former. The secondary wdgs have equal no of turns and are Identically placed on either side of primary wdg. The Primary wdg is connected to alternating current source. A movable soft iron core is placed inside the former. The displacement to be measured is applied to the arm attached to the soft Iron core.

CIRCUITS OF LVDT



(a)



(b)

Since the primary wdg is excited by an alternating current source, it produces an alternating magnetic field, which in turn induces alternating current voltages in the two secondary wdg.

The output voltage of secondary S_1 is E_{S_1} and secondary S_2 is E_{S_2} as shown in fig. (a). In order to convert the outputs from S_1 and S_2 into a single voltage signal, the two secondaries S_1 & S_2 are connected in series opposition as shown in fig(b).

Thus o/p voltage of transducer is the difference of the two voltages

Differential output voltage

$$E_0 = E_{S1} - E_{S2}$$

Case i :- when the core is at its normal (NULL) position, the flux linking with both the secondary wdgs is equal and hence equal emfs are induced in them.

Thus at Null position, E_0 is 0, since the o/p vlg in the difference of the two voltages E_s @ Null position $E_{S1} = E_{S2}$ as shown in fig ⓐ

<u>case 2:</u> core is moved to the left of the NULL position, more flux links with winding S_1 and less with wdg S_2, as shown in fig ⓑ. Accordingly output voltage E_{S1} of wdg S_1 is more than E_{S2} of wdg S_2.

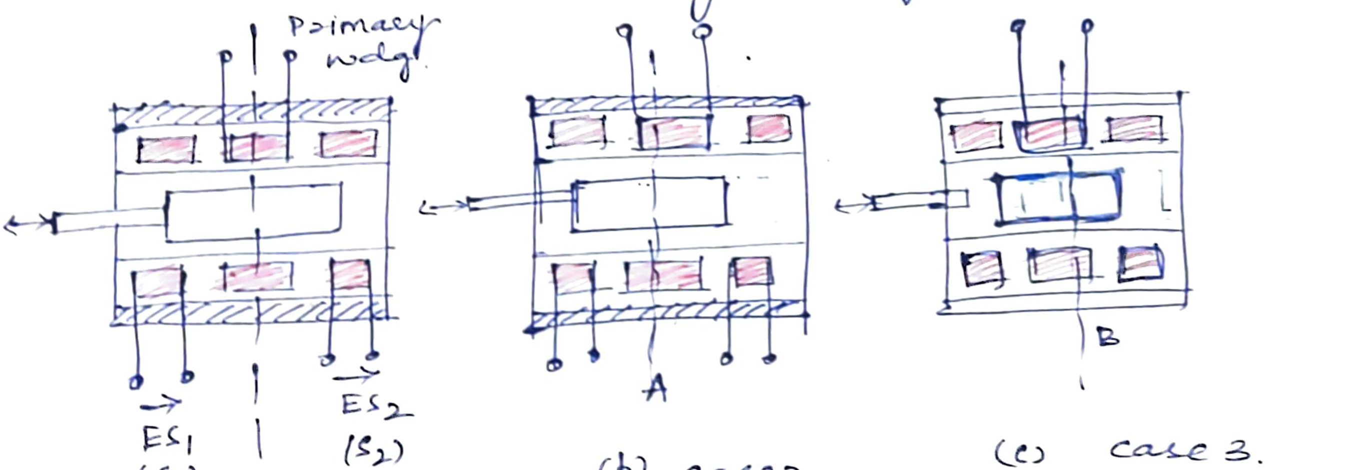
The magnitude of o/p voltage

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

<u>Case 3:</u> If the core is moved to the right of the NULL position, more flux links with wdg S_2 and less with wdg S_1, as showin fig ⓒ. Accordingly output voltage E_{S2} of wdg S_2 is more than E_{S1} of wdg S_1.

The magnitude of o/p voltage

$E_0 = E_{S1} - E_{S2}$ and it is 180° out of phase with primary voltage.



(a) case 1 (b) case2 (c) case 3.

The amount of voltage change is proportional to the amount of movement of the core, indicating the amount of linear motion. By noting whether the output voltage is increasing or decreasing, we can determine the direction of Motion.

Note: (1) As the core is moved in one direction from the null position, the differential v/g ie $E_0 = E_{S1} - E_{S2}$ will increase, while maintaining in phase relationship with i/p voltage

(2) In other direction, from the null position, the differential v/g ie $E_0 = E_{S1} - E_{S2}$ will increase, but will be 180° out of phase with i/p voltage.

(3) With reference to the o/p v/g E_0, the amount and direction of movement of the core and hence displacement may be determined.

The output voltage of an LVDT is a linear function of core displacement within a limited range of motion, say abt 5mm from null position.

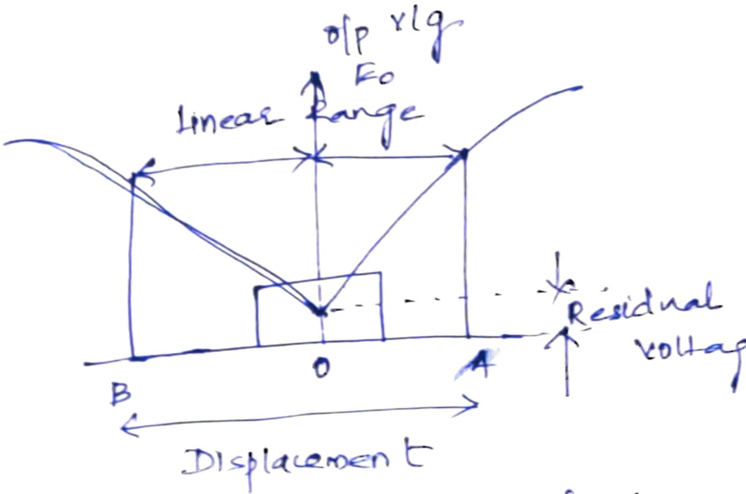


Figure shows the variation of output voltage against displacement for various positions of core.

The curve is practically linear for small displacements. Beyond this range of displacement the curve starts to deviate from a st. line.

Advantages of LVDT

1) High Range
2) Immunity from External Effects
3) High sensitivity
4) Ruggedness
5) Low power consumption

Disadvantages of LVDT

1) Sensitive to stray magnetic fields, but shielding is possible
2) Transducer performance is affected by vibrations.
3) Large displacements are required for appreciable differential output

Proximity Transducers

Capacitive Transducers: The principle of operation of capacitive transducers is based upon the familiar equation for capacitance of parallel plate capacitor.

capacitance

$$C = \varepsilon A / d$$
$$= \varepsilon_0 \varepsilon_r A / d$$

where A = overlapping area of plates : m^2

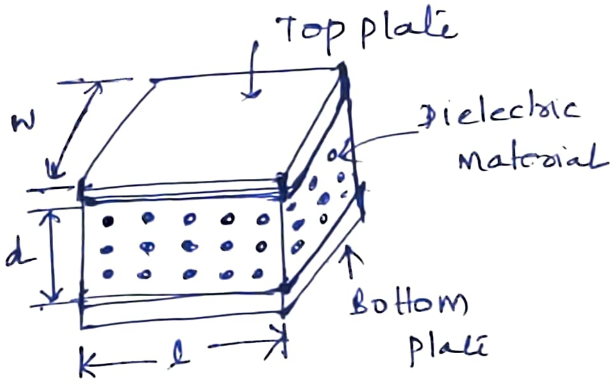
d = distance between two plates : m

ε = $\varepsilon_r \varepsilon_0$ = permittivity of Medium ; F/m

ε_r = relative permittivity

ε_0 = permittivity of free space

8.85×10^{-12} F/m.



Schematic diagram of parallel plate capacitive transducer

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

i) change in overlapping A

ii) change in distance d between the plates

iii) change in dielectric constant

These changes are caused by physical variables like displacement, force and pressure.

The change in capacitance may be caused by change in dielectric constant.

The capacitance may be measured with Bridge ckts, The output Impedance of a capacitive transducer is:

$$X_C = \frac{1}{2\pi f C}$$

C = capacitance
f = frequency of excitation in Hz.

Capacitive transducers are commonly used for measurement of linear displacement.

Piezo-Electric Transducers

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

This effect is reversible ie conversely, if a varying potential is applied to the proper axis of the crystal, it will change the dimensions of the crystal thereby deforming it.

This effect is known as piezo-electric effect.

Elements exhibiting piezo-electric qualities are called as electro-resistive elements.

Common piezoelectric materials include Rochelle salt, ammonium dihydrogen phosphate, lithium sulphate.

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

$$E = Q/C$$

charge $Q = d \times F$ Coulomb

d = charge Sensitivity & F = Force in N

$$F = \frac{AE}{t} \Delta t \quad \text{in} \quad N$$

A = Area of crystal

E = Youngs Modulus N/m^2

$$E = \frac{\text{Stress}}{\text{Strain}} = \frac{F/A}{\Delta t/t} = \frac{Ft}{A \Delta t} \quad N/m^2$$

$A = wl$

w = width of crystal : m and

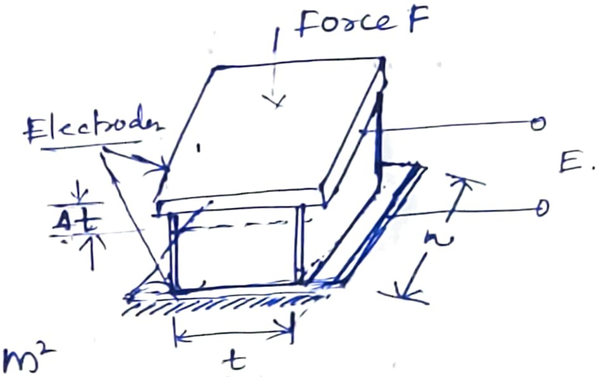
l = length of " : m

$$\therefore \quad Q = d \times AE(\Delta t/t)$$

$$E = Q/C$$

$C = \epsilon_r \epsilon_0 A/t$ — Capacitance

$$\therefore \quad E = \frac{dF}{\epsilon_r \epsilon_0 A/t}$$



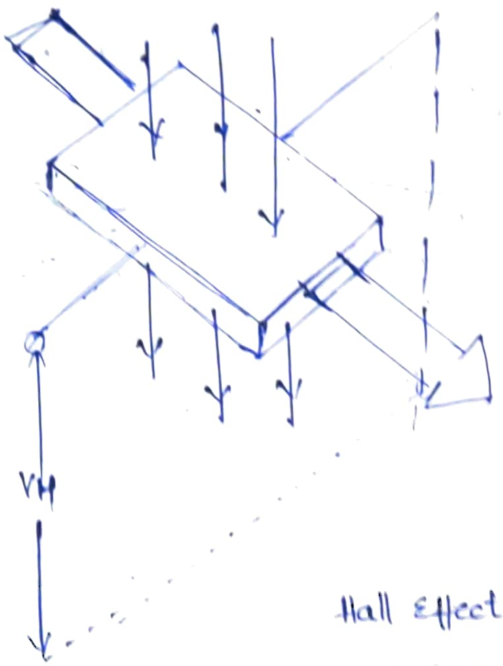
$$E = \frac{dt}{\epsilon_r \epsilon_0} \frac{F}{A}$$

$\boxed{F/A = P}$ in N/m^2

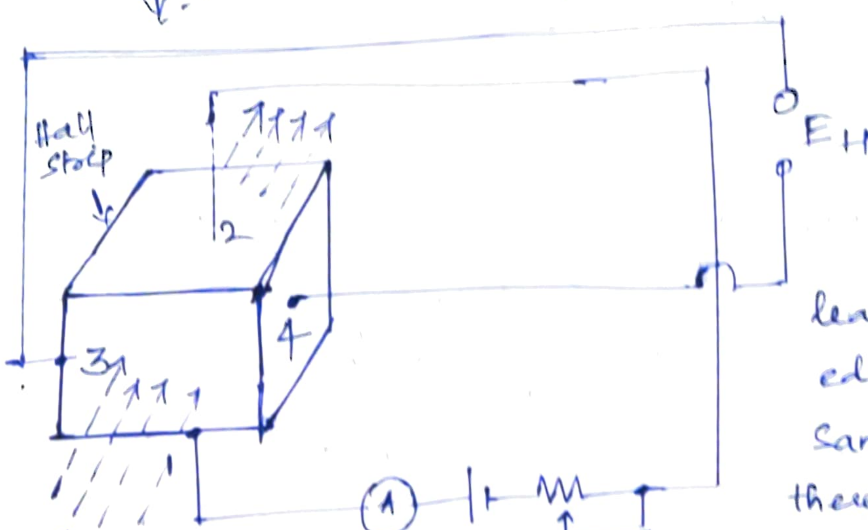
$$\therefore \boxed{E = \frac{dt}{\epsilon_r \epsilon_0} \times P}$$

Hall Effect Transducer

If the strip of conducting material carries current in the presence of transverse magnetic field as shown below, an emf is produced between two edges of conductor. The magnitude of the voltage depends upon the current, flux density and a property of conductor called "Hall Effect co efficient"



Hall Effect Element



Transverse magnetic field

As shown in the figure, current is passed through leads 1 & 2 of the strip. The o/p leads connected to edges 3 & 4 are at same potential, when there is no transverse magnetic field passing through the strip.

When the transverse magnetic field passes through the strip, an output voltage appears across the output leads. This voltage is $\propto^{nal}$ to current and the field strength.

Output voltage is,

$$E_H = K_H IB/t$$

K_H = Hall Effect co-efficient ; $\frac{V - m}{A - Wb m^{-2}}$

t = thickness of strip m

I & B are respectively the current in Ampere & flux density in wb/m^2

Thus the voltage produced may be used for measurement of either the current I or the magnetic field strength B.

Applications of Hall Effect transducer

1) Magnetic to Electric Transducer
2) Measurement of Displacement
3) Measurement of current
4) Measurement of Power.

Ex:- A Hall Effect transducer is used for the measurement of a magnetic field of $0.5\ wb/m^2$. The 2 mm thick slab is made of Bismuth for which the Hall's co-efficient is $-1 \times 10^{-6}\ Vm/(A - wb\ m^{-2})$ and the current is 3 A.

Soln: o/p vlg is given by,

$$E_H = K_H IB/t$$

$$= -1 \times 10^{-6} \times 3 \times 0.5 / (2 \times 10^{-3})$$

$$\boxed{E_H = -0.75 mV}$$