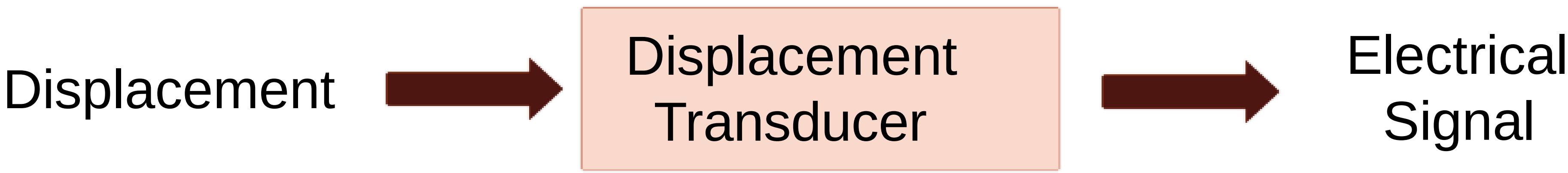
Introduction

A generalized measurement system consist of two components:

1. Sensing element which responds directly by reacting to the measurand,
2. Transducing element which is responsible for conversion of the measurand into analogous driving signal

The sensing element may also serve to the transduce the measurand and put it into a more convenient form. The unit is then called as **detector-transducer.**

DISPLACEMENT TRANSDUCER



Displacement Transducer

- Converts physical quantity into electrical quantity
- Two main parts

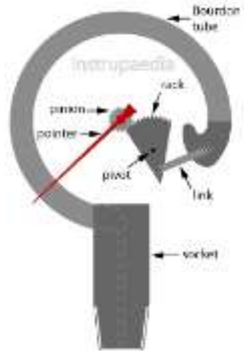
1. Sensing element or primary transducer

2. Transduction element or secondary transducer

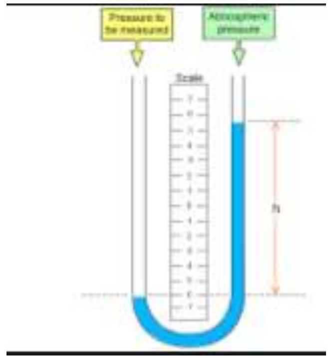
Mechanical detector transducer element

1. Elastic elements

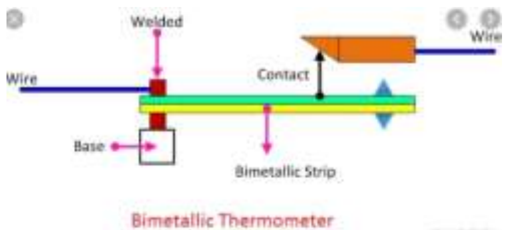




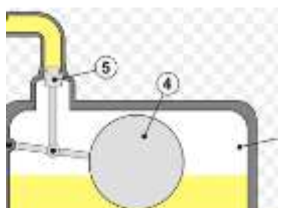
2. Mass sensing elements



3. Thermal detector



4. Hydro-pneumatic elements




Electrical transducer

1. More compact
2. Good frequency and transient response
3. Feasibility of remote indication
4. Minimum friction and mass inertia effect
5. Possibility of non contact measurement
6. Less power consumption
7. Greater amplification

Transducer classification

1. Self generating and externally powered

Example of Self generating:- thermocouples, thermopiles, piezo electric pick up, photo voltaic cell.

Example of Externally powered:- Resistance thermometer, potentiometric devices, photo emissive cell.

2. Input transducers

It converts non electric quantity into an electrical signal. (strain gauge, photo electric cell)

Output transducer

It converts the electric signal into a non electrical quantity. (movement of pointer against a graduated scale)

Transducer sensitivity

- Transducer sensitivity, $k = \dfrac{\text{Output signal increment}}{\text{Measurand increment}}$

Variable resistance transducer

- The resistance of a metal conductor is expressed as :

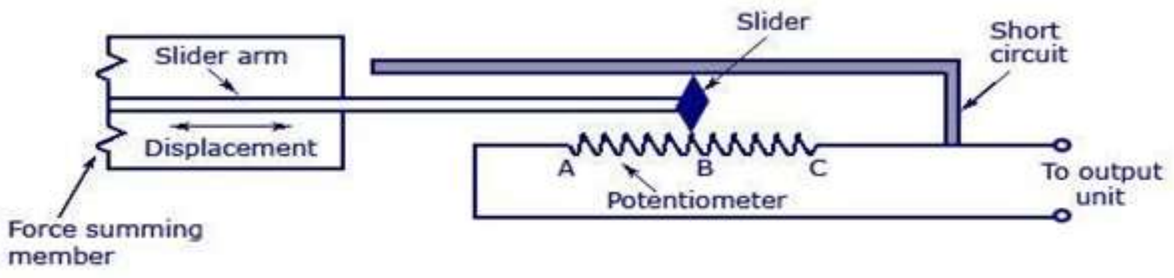
$$R = \rho \frac{l}{A}$$

Principle Of Working Of Variable Resistance Type Transducer

- L is the length ,A is cross sectional area and p is resistivity of the resistance material.
- So resistance can be changed if any of these value p ,L or A is changed.
- Measurand is connected to the resistance in such a way that it varies any one of its parameters.
- A change in the value or R is proportional to the measurand.
- Thus the measurand can be measured by measuring the change in resistance.

Linear Motion potentiometer

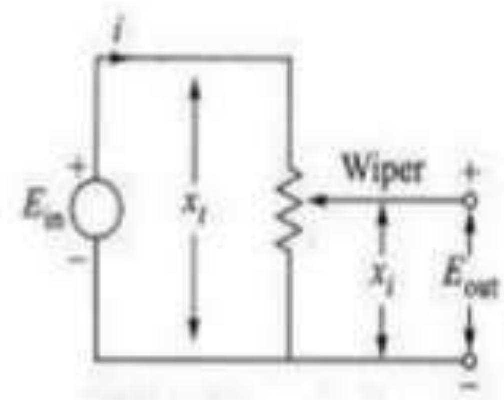
- It convert linear motion or the angular motion into changes in resistance.
- A resistive potentiometer **(or pot)** is a variable resistor whose resistance is varied by the movement of a slider over resistance element.
- Translatory device have strokes from **2mm to 50cm**, and rotational have a **full scale ranging from 10^0 to as much 60 full turns.**



Linear Potentiometer

It consists of a sliding contact which moves over the length of a resistance element.

This sliding contact connects to a plunger, which links to the object whose displacement is to be measured



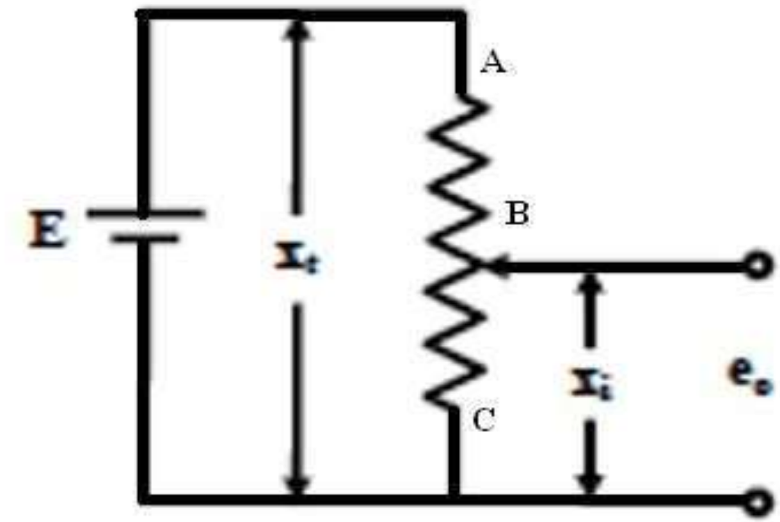
– Linear motion potentiometer

Potentiometer

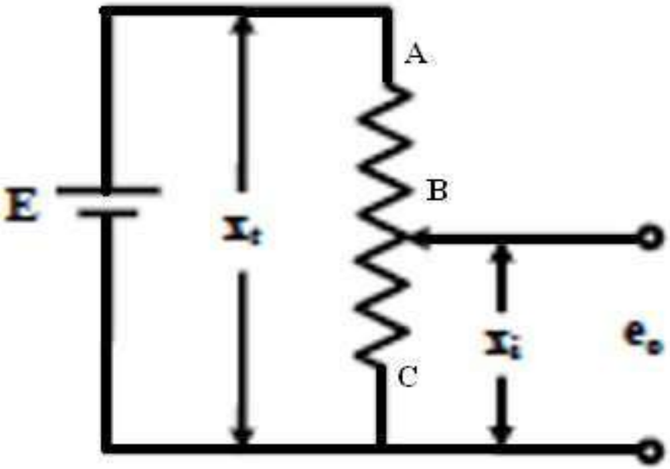
Referring to the electrical circuit shown here,

an input voltage X_t is applied across the whole resistance element, at points A and C.

The output voltage, X_i , is measured between the sliding contact at point B and the end of the resistance element at point C. A linear relationship exists between the input voltage X_t, output voltage X_i and the distance BC.



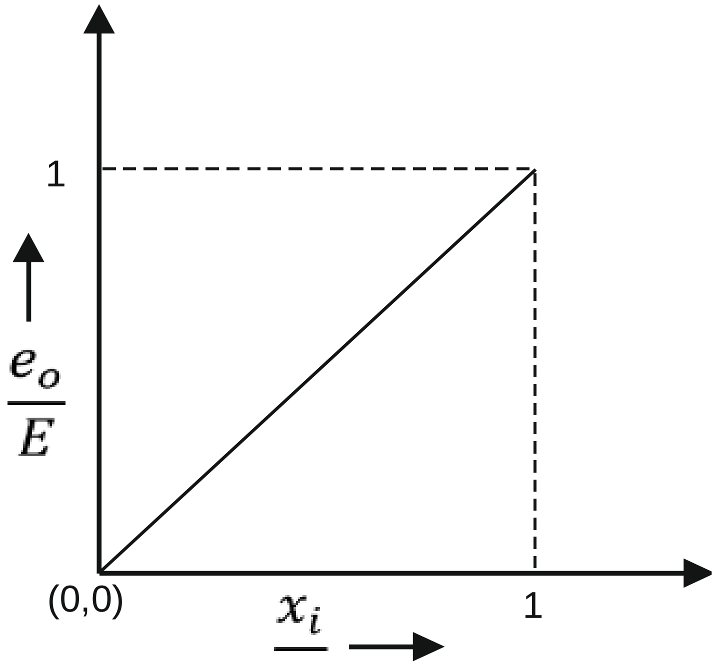
MATHEMATICAL EXPRESSION FOR POTENTIOMETER



so there is a linear relationship between input displacement and output voltage.

Since resistance of potentiometer is linearly distributed along its length.

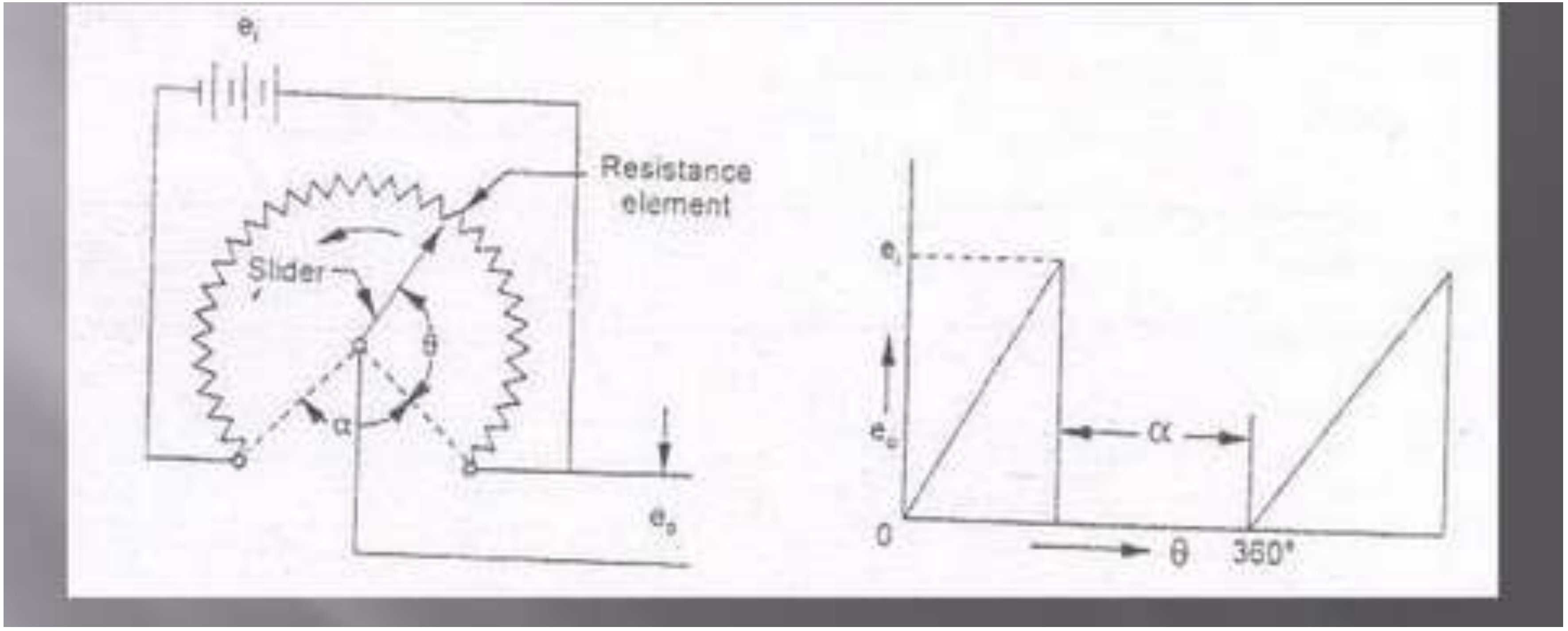
$$\text{Output } Voltage(e_o) = \frac{x_i}{x_t} E$$



Angular Potentiometer

- Rotary or angular potentiometers measure angular displacement .

- Rotational motion measured from a few seconds to 360º



- Resistance element in common use wire wound because that gives sufficiently high resistance value in small gap.

Characteristic of the resistance wire

1. Precision drawn wire with diameter of about 25 to 50 microns, and wound over a cylindrical of flat mandrel of ceramic, glass, anodzed aluminium.
2. Resistivity of wire ranges from 0.4 μΩ-m to 1-3 μΩ-m
3. Temperature coefficient varies from 0.002% per oC to 0.001% per ^{o}C
4. Wire is strong, ductile, and protected from surface corrosion by enammeling or oxidation. (material used- Alloy of copper-nickel, nickel chromium, silver- palladium)

- Typical single turn wire wound pots are 5cm in dia, having power rating upto 5W and total resistance between 100 W and 100kW.
- Output voltage is linear function of the input displacement I,e travel of the sliding arm (wiper).
- Th einput excitation voltage is limited by the sissipating wattage which causes the temperature of the winding wire to rise to specified level.
- This voltage level depends upon the cooling conditions, thermal characteristics of the potentiometer wire, transducer housing design.

is generally prescribed by the relation,

$$V_s = \sqrt{P R_m}$$

Where, Vs – Maximum source voltage

P – Maximum power dissipation

Rm- total resistance of fine wires of potentiometer winding

Linear , sine and logarithmic potentiometer

- **Linear**- Direct proportionality between the angle through which slider has rotataed and the output potential difference.
- **Sine** – Designed to have output potential difference proportional to Vs Sin θ.

  Where, θ is the angle through which slider (wiper) has moved.
- **Logarithmic-** The output potential difference is proportional to logθ

Variable inductance transducer

- Active units

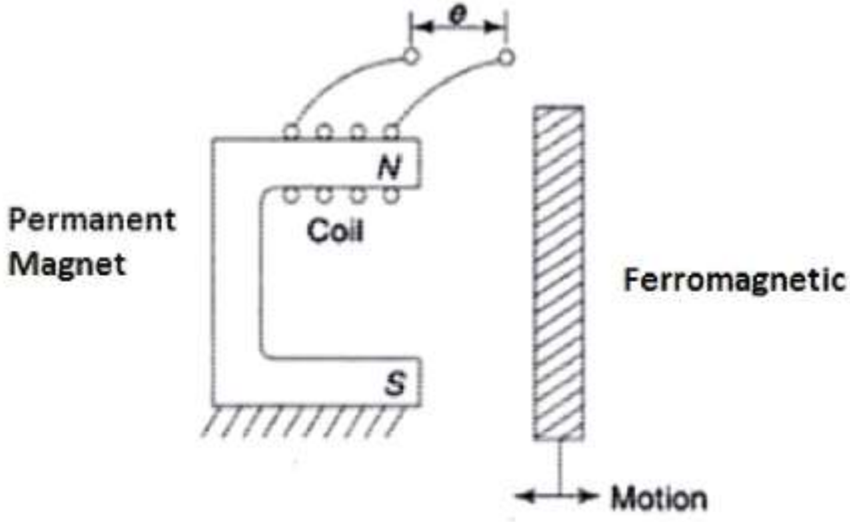
  The output signal is generated because of relative motion between a conductor and magnetic field, and without the supply of an energy from an external source.

VARIABLE INDUCTANCE TRANSDUCER

- These are based on a change in the magnetic characteristic of an electrical circuit in response to a measurand which may be displacement, velocity, acceleration, etc.
- 1.Self-generating type: Voltage is generated because of the relative motion between a conductor and a magnetic field.-Electromagnetic type -Electro-dynamic type -Eddy Current type
- 2.Passive type: Motion of an object results in the inductance of the coils of the transducer.-Variable reluctance -Mutual inductance -Differential transfer type

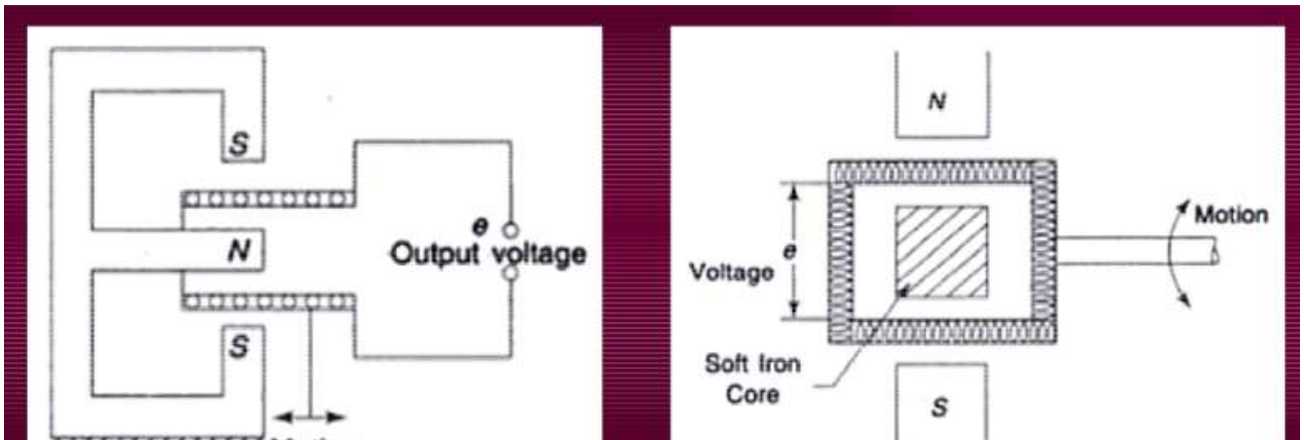
Electromagnetic Type Transducer

- •When a plate of iron or other ferromagnetic material is moved w.r.t. the magnet, the flux field expands or collapses and a voltage is induced in the coil. •Used for indication of angular speed. •Speed can be measured when the pick-up is placed near the teeth of a rotating gear.



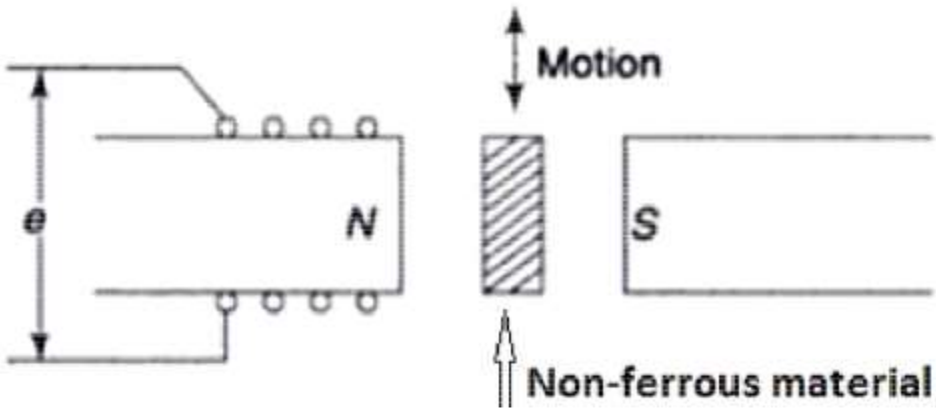
Electro-dynamic Type Transducer

- •Coil moves within the field of magnet. The turns of the coil are perpendicular to the intersecting lines of force.
- •When the coil moves it induces a voltage which at any moment is proportional to the velocity of the coil.
- •Used in magnetic flow meters



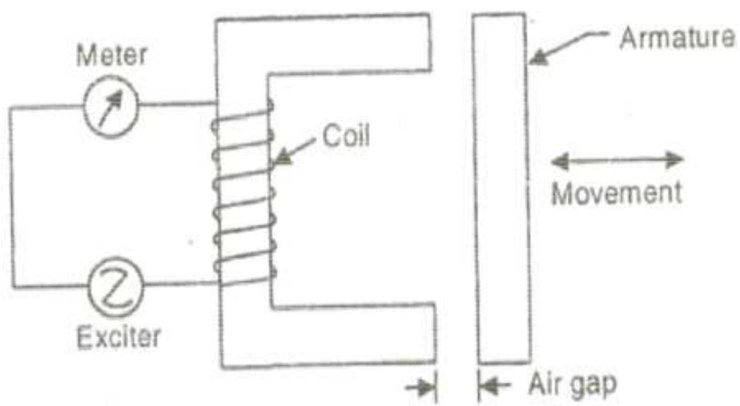
Eddy Current Type

- When a plate of nonferrous material is moved cutting magnetic flux lines, a voltage is induced in the coil.



Variable Reluctance Transducer

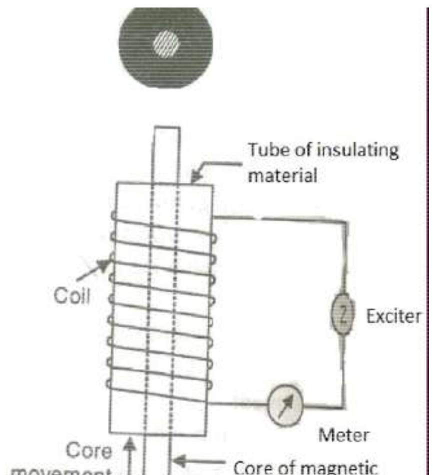
- Magneticcircuit reactance may be changed by affecting a change1.In the air gap (reluctance type) or 2.In the amplitude/type of core material (permeance type) In variable reluctance type transducer, the change in inductance may be calibrated in terms of movement of armature.
- Used for measurement of dynamic quantities such as pressure, force, displacement, acceleration, angular position, etc



In Variable Permeance type Transducer

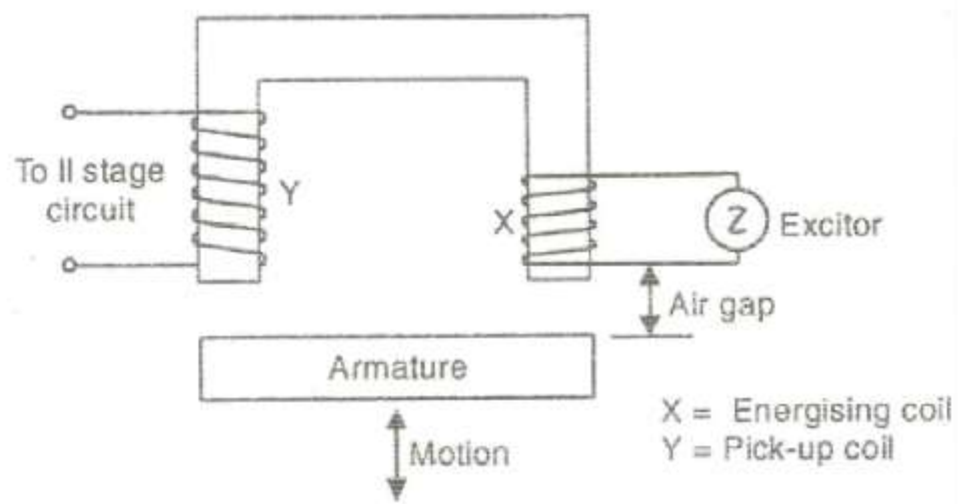
the inductance of coil is changed by varying the core material.

- When the coil on insulating tube is energized and the core enters the solenoid cell, the inductance of the coil increases in proportion to the amount of metal within the coil.
- Used for measurement of displacement, strain, force, etc.



Mutual Inductance Transducer

- A change in the position of armature by a mechanical input changes the air gap. This causes a change in output from coil Y, which may be used as measure of the displacement of mechanical input.



Linear Variable Displacement Transducer (LVDT)

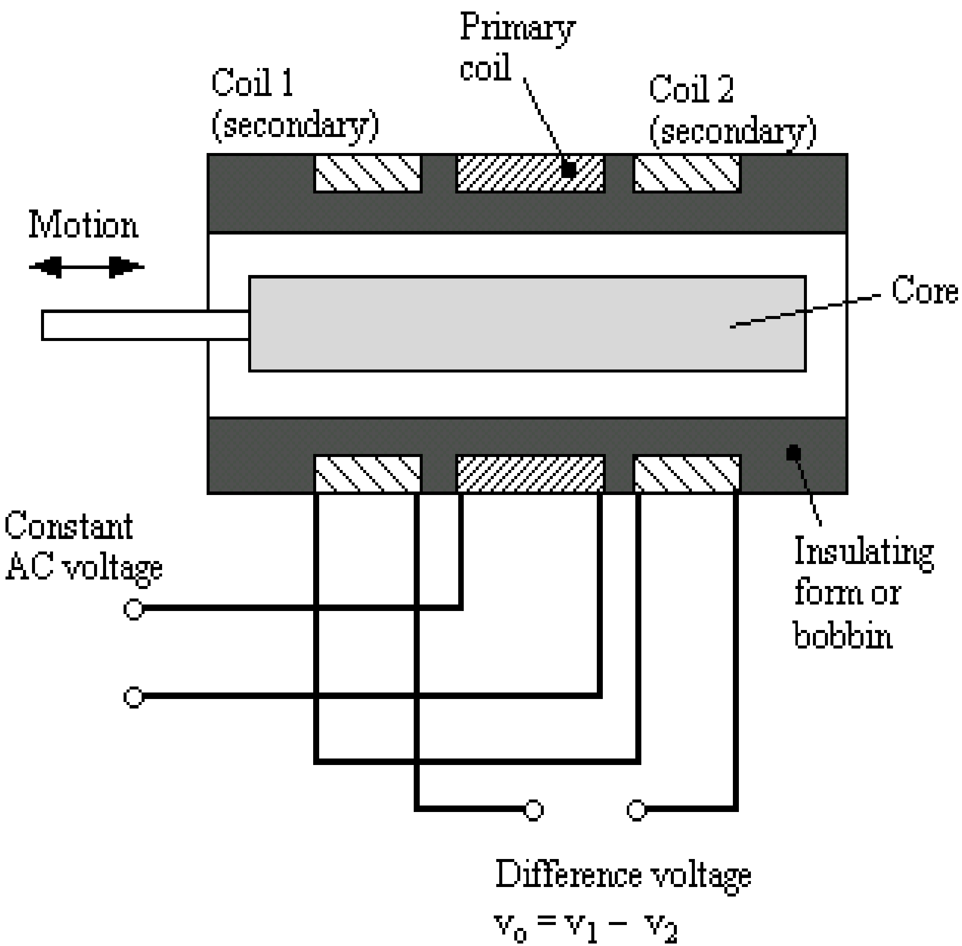
A very basic transducer which is always useful in the field of instrumentation

Principle of LVDT:

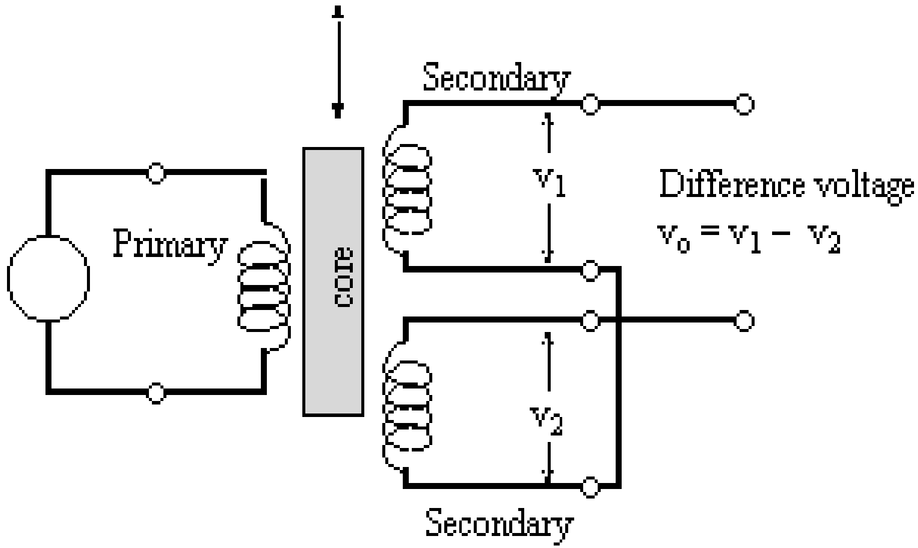
LVDT works under the principle of mutual induction, and the displacement which is a non-electrical energy is converted into an electrical energy.

And the way how the energy is getting converted is described in working of LVDT in a detailed manner.

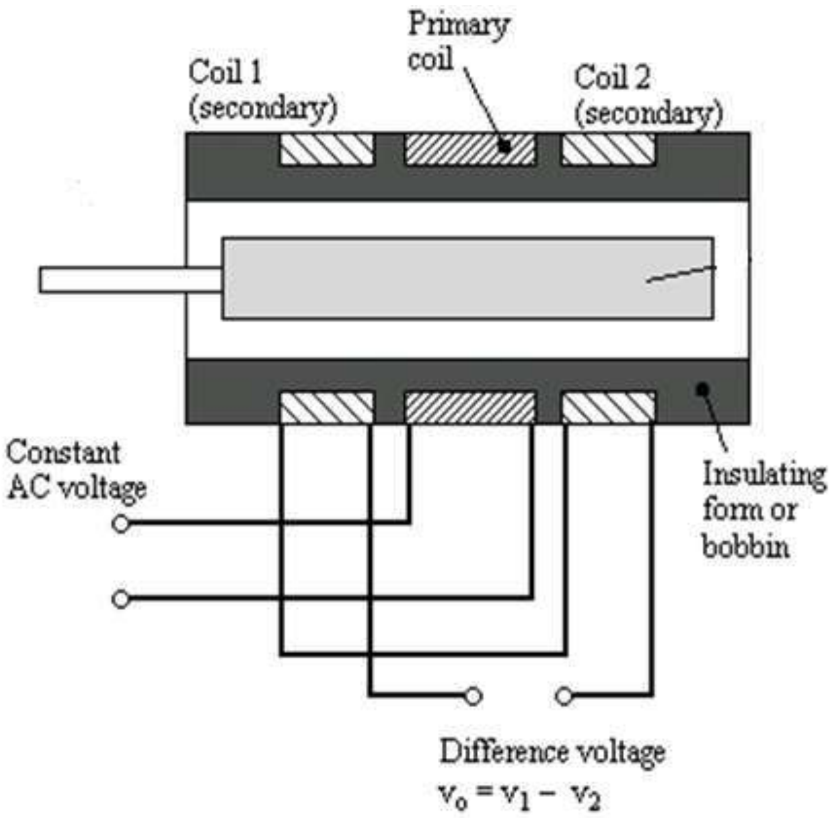
Construction of LVDT:



(a)



(b)



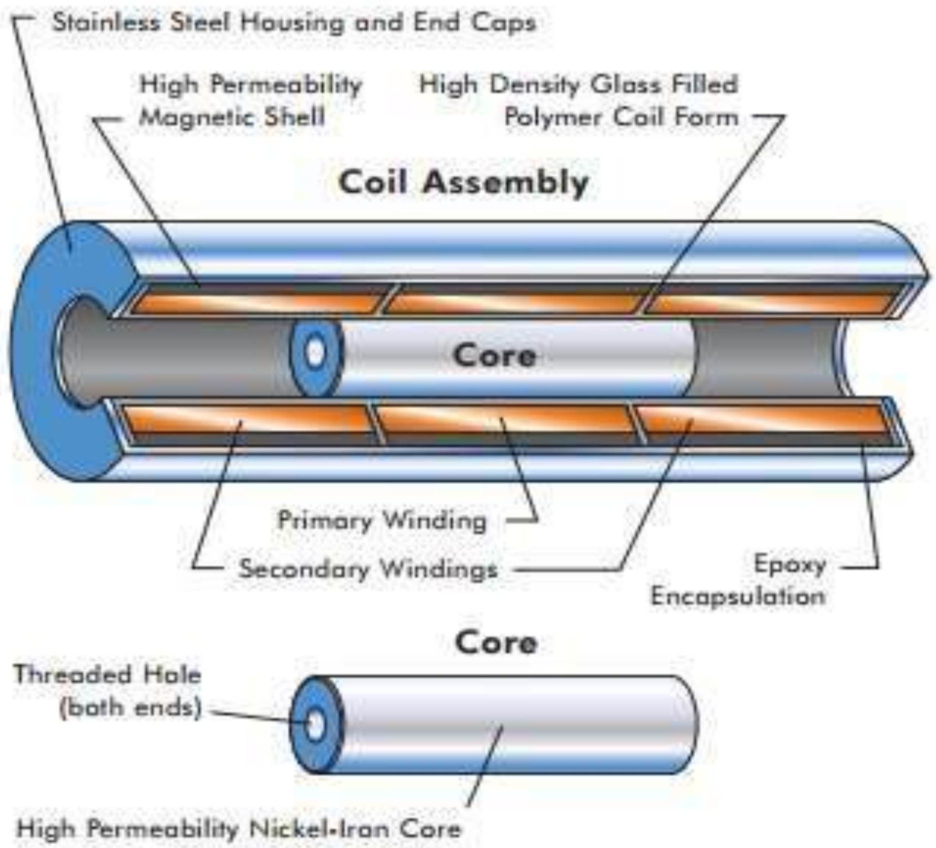
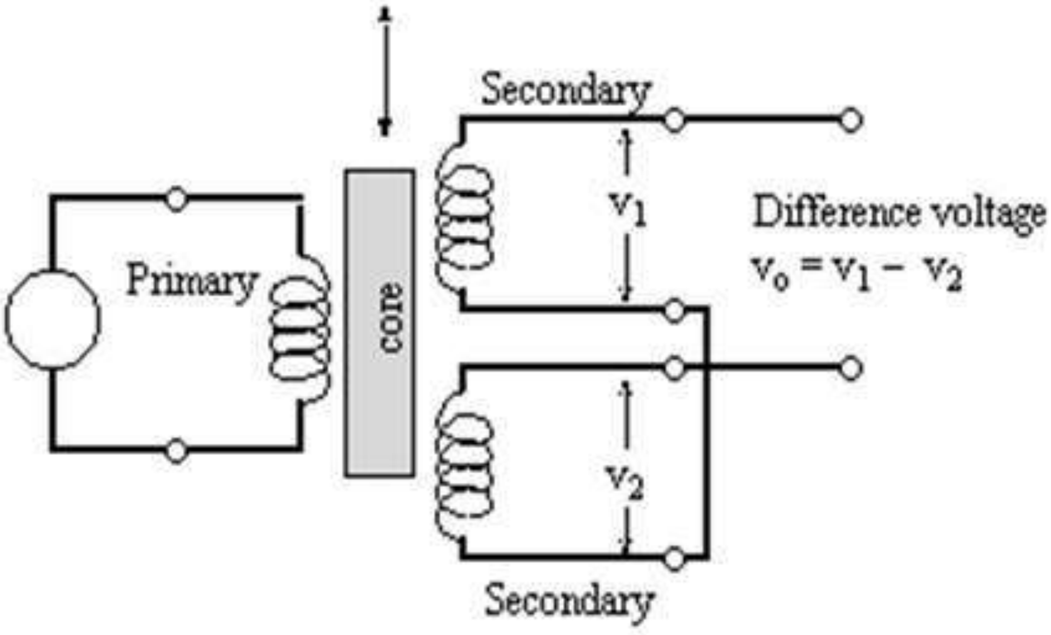


Figure 1

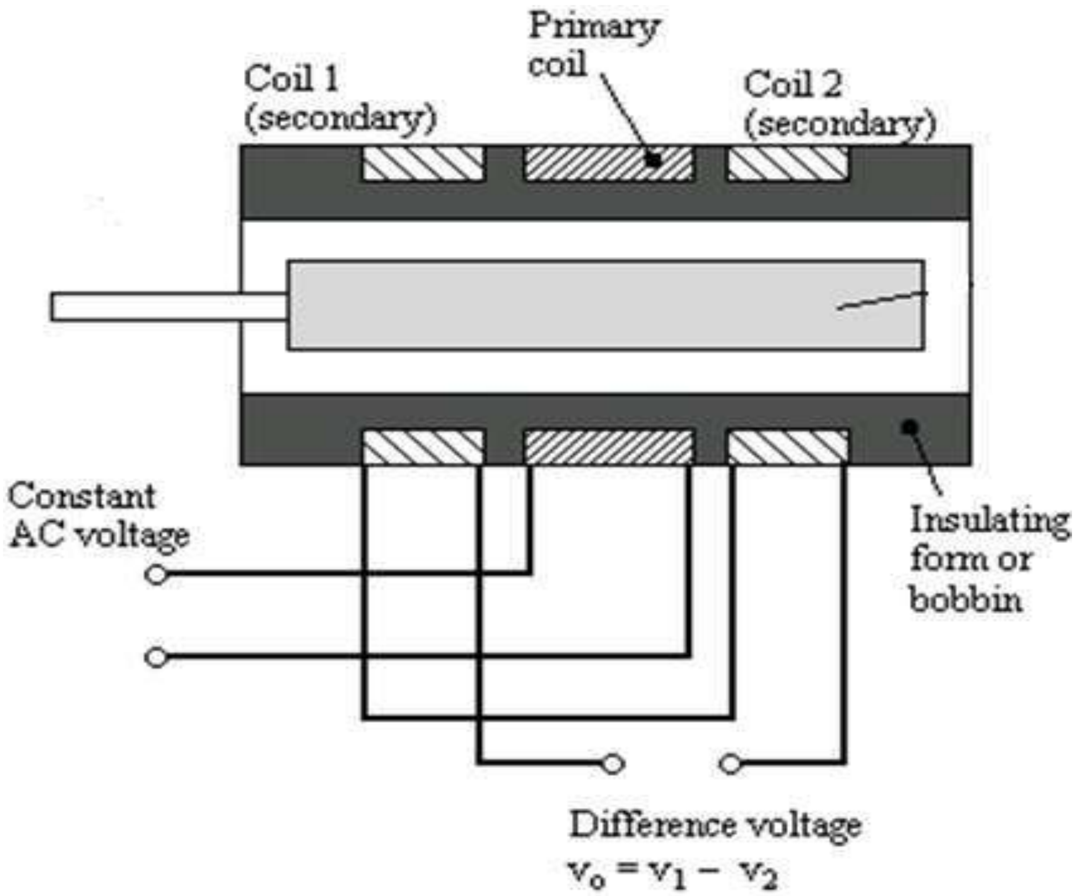
The features that make an LVDT environmentally robust are evident in this cutaway view.

- LVDT consists of a cylindrical former where it is surrounded by one primary winding in the centre



- The number of turns in both the secondary windings are equal, but they are opposite to each other.

i.e., if the left secondary windings is in the clockwise direction, the right secondary windings will be in the anti-clockwise direction, hence the net output voltages will be the difference in voltages between the two secondary coil.

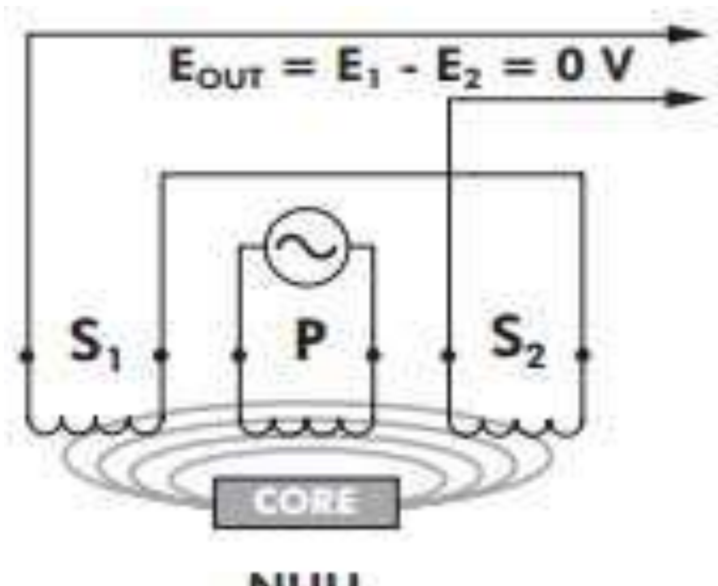


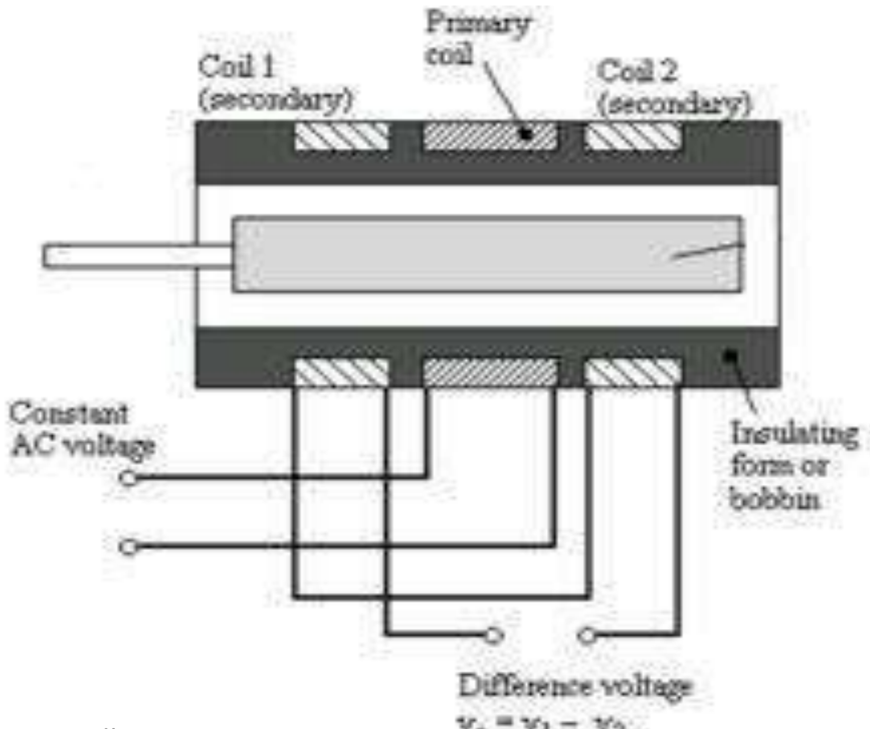
- The two secondary coil is represented as S1 and S2. Esteem iron core is placed in the centre of the cylindrical former which can move in to and fro motion as shown in the figure.

Working of LVDT:

Case 1:

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

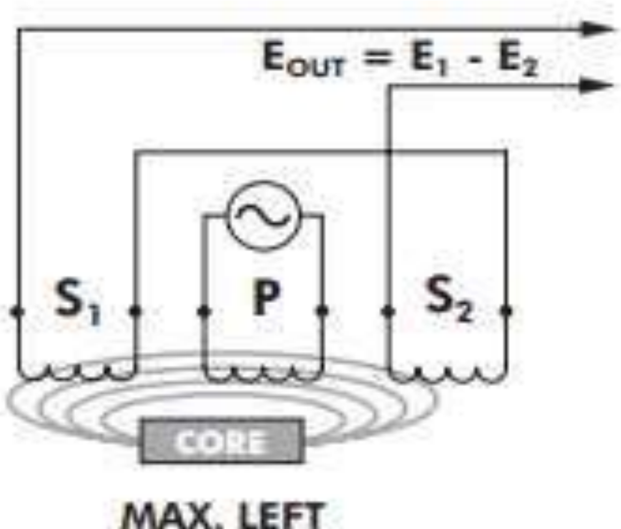


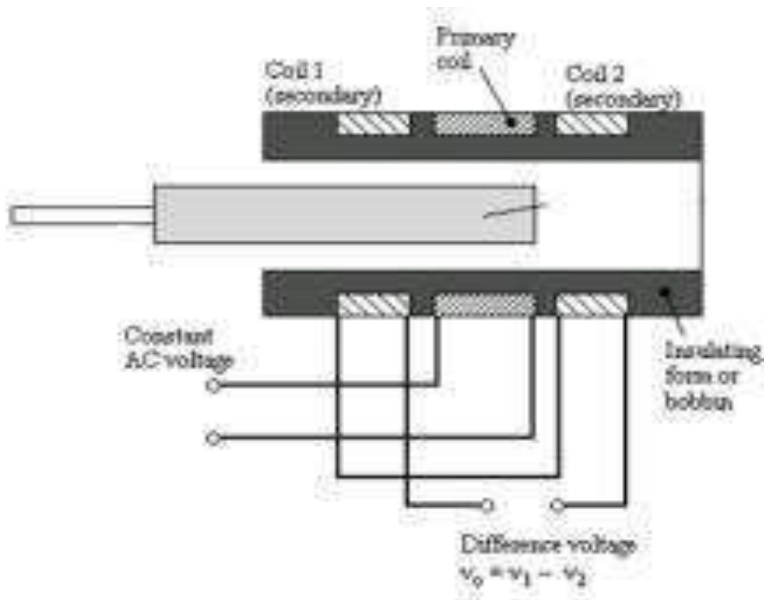


Working of LVDT:

Case 2:

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

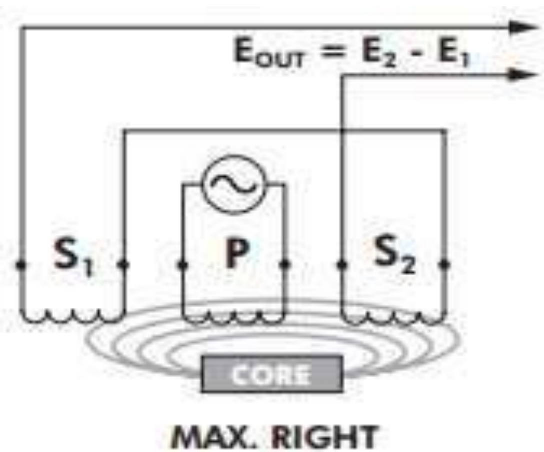


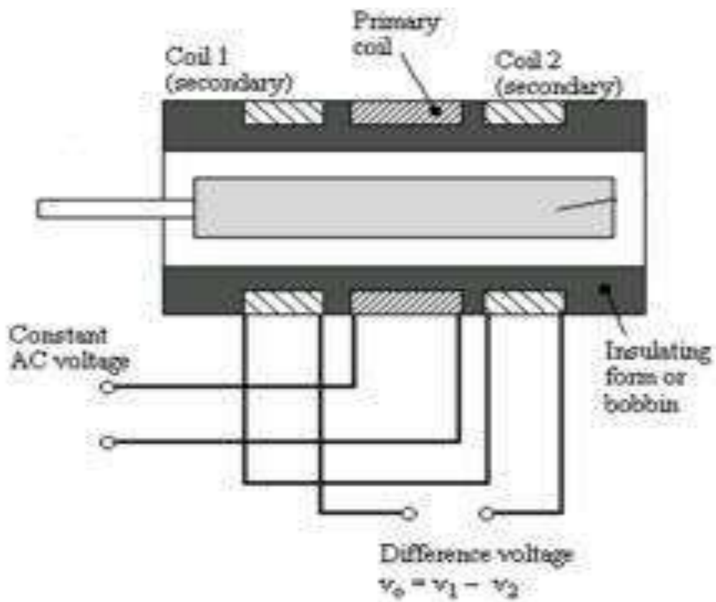


Working of LVDT:

Case 3:

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





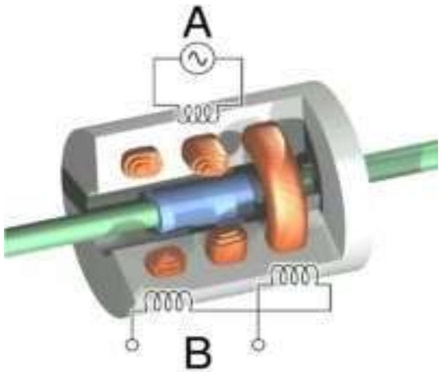
Applications of LVDT:

1) LVDT is used to measure displacement ranging from fraction millimeter to centimeter.

2) Acting as a secondary transducer, LVDT can be used as a device to measure force, weight and pressure, etc..

Construction

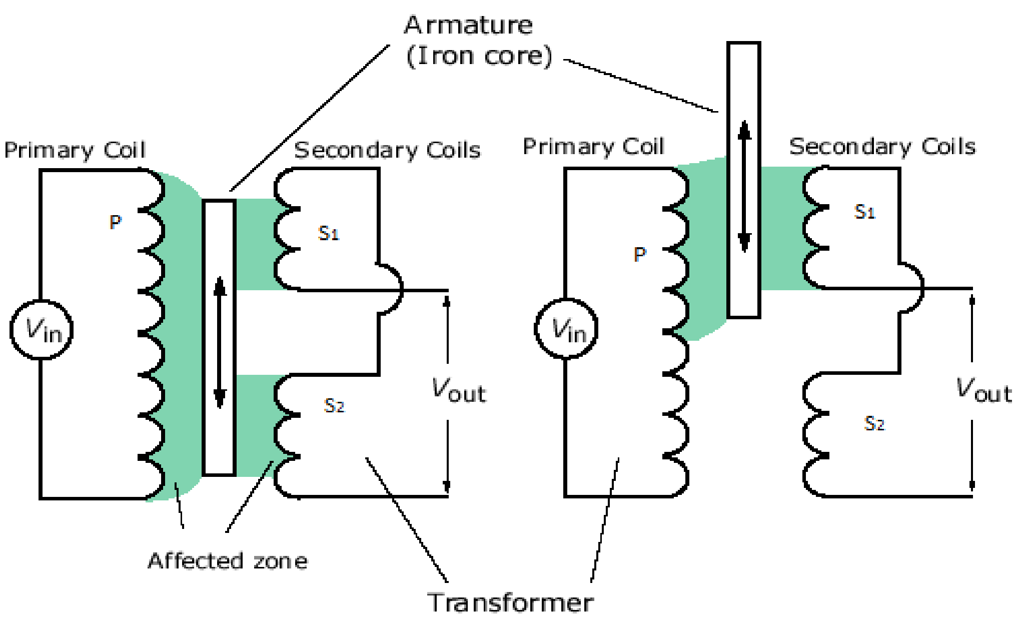
The most widely used inductive transducer to translate linear motion to electrical signals.



The transformer consist of a primary winding (P) and two secondary windings (S_1 and S_2)

The secondary windings (S_1 and S_2) have equal number of turns and are identically placed on either side of primary winding. The primary winding is connected to an alternating current source.

Working

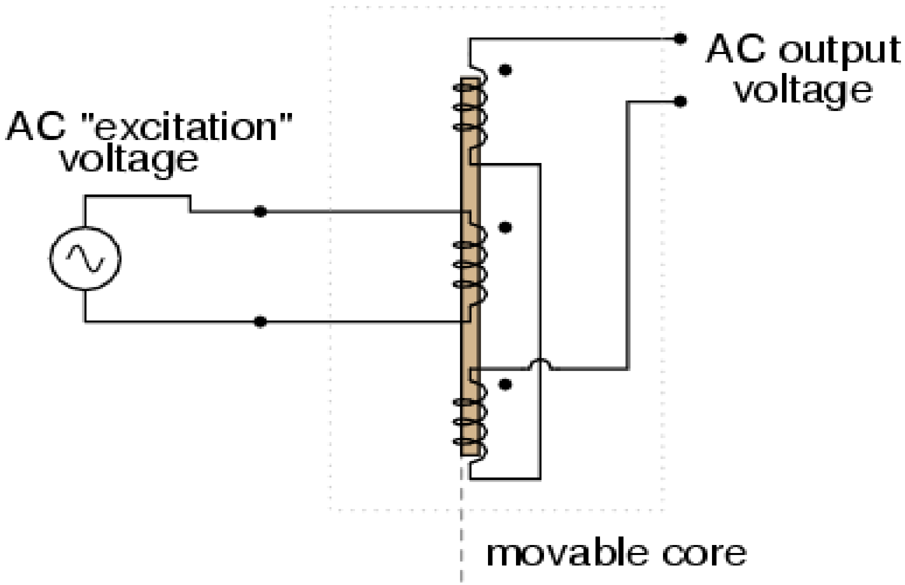


A moveable soft iron core is placed between the windings.

The frequency of a.c applied to primary windings may be between 50 Hz to 20 kHz .

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

The output voltage of secondary S1 is Es1 and that of S2 is Es2 . In order to convert the Outputs from S1 and S2 into a single voltage signal , the two secondaries S1 and S2 are connected in series opposition.

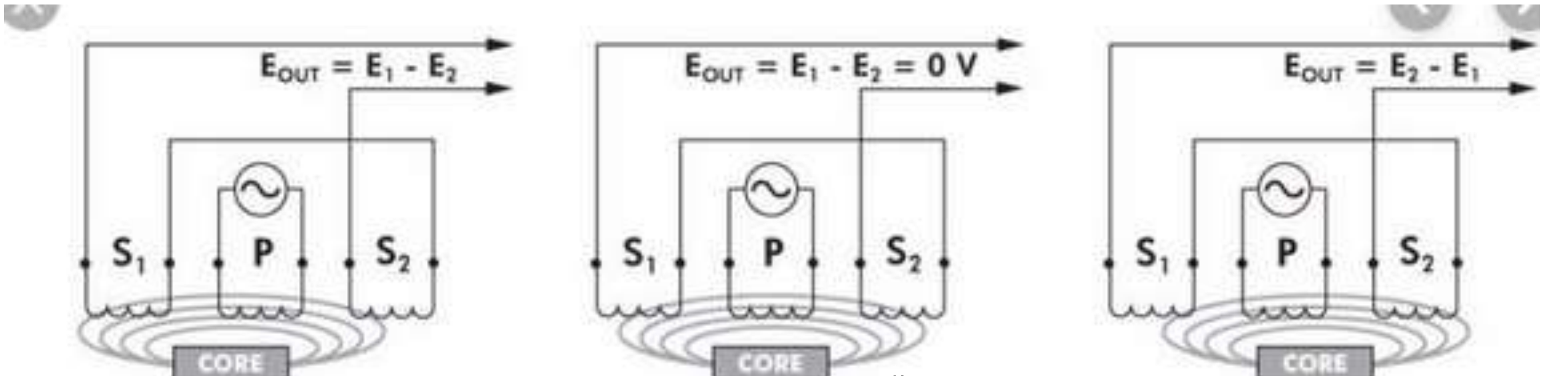


The output voltage of the transducer is the difference of two voltages .

$$E_0 = E_{s1} + E_{s2}$$

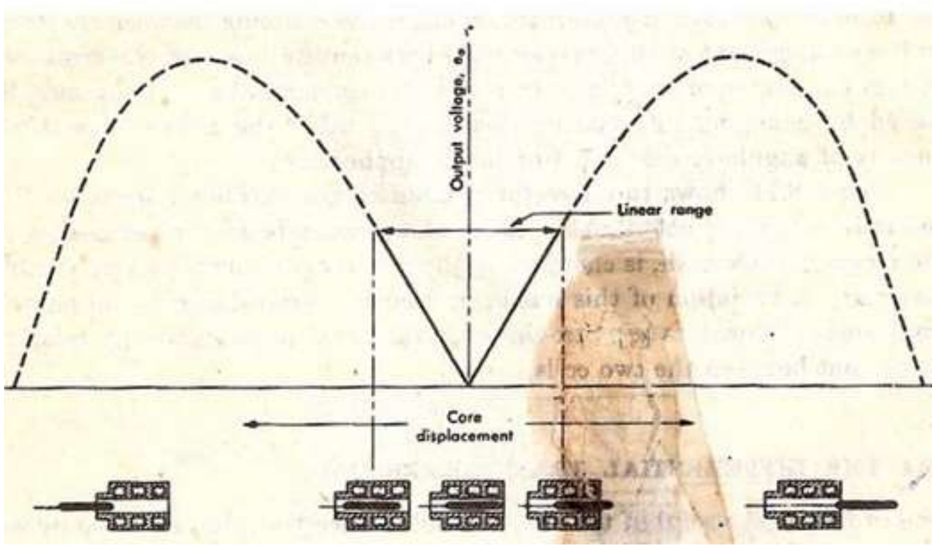
- The amount of voltage change in either secondary winding is proportional to the amount of movement of the core. Hence we have an indication of amount of linear motion.

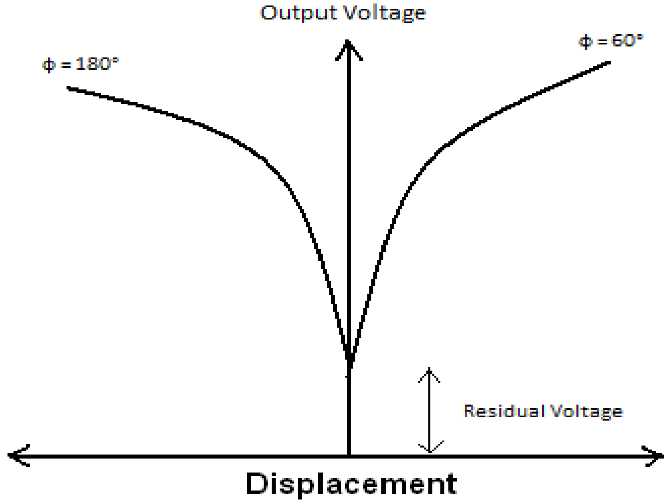
- By noting which output voltage is increasing or decreasing , we can determine the direction of motion.
- In other words , any physical displacement of the core causes the voltage of one secondary winding to increase while simultaneously educing the voltage in other secondary winding.



The output voltage of a LVDT is a linear function of core displacement within a limited range of motion .

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





Ideally output voltage at null position should be zero , but there is some residual voltage due to harmonics

Advantages

- High range
- Frictional and Electrical isolation
- Immunity from External Effects
- High input and output sensitivity
- Ruggedness (tolerate high degree of shock and vibrations)
- Low Hysteresis
- Low Power consumption

Disadvantages

- Relatively large displacements required
- Sensitive to stray magnetic fields
- May be affected by vibrations
- Operates only on a.c. signals
- Affect of temperature

Uses

- Works on wide ranges ; from fraction of mm to a few cm
- Mechanical signal converted directly into analogous Electrical signal
- Mostly used as secondary transducer
- Can be used to measure force , weight and pressure etc.

Errors and Adjustments

- Nikel iron is used generally in place of soft iron to get low harmonics , low null voltage and high sensitivity.
- Core is slotted longitudinally in LVDT to reduce eddy current losses.
- Placed in stainless steel housing and end lids provides electrostatic and electromagnetic shielding.

Capacitive Transducer

A capacitor comprises two or more metal plate conductors separated by an insulator. As voltage is applied across the plates, equal and opposite electric charges are generated on the plates. Capacitance is defined as the ratio of the charges to the applied voltage and for a parallel plate capacitor is given by :

$$C = \epsilon_0 \epsilon_r \frac{A}{t}(N-1) \text{ farads}$$

where A = overlapping or effective area between plates (m^2),
t = distance between plates (m),
N = number of capacitor plates,
ϵ_0 = permittivity of free space = 8.854×10^{-12} F/m
ϵ_r = relative permittivity (or dielectric constant) of the material between the plates.

The value of ϵ_r depends upon the insulator material and for air $\epsilon_r = 1$

For a cylindrical capacitor, the capacitance is

$$C = \epsilon_0 \epsilon_r \frac{2\pi l}{\log_e\left(\frac{r_2}{r_1}\right)} \text{ farads} \quad ....(4.10)$$

where

l = length of overlapping part of cylinders (m),
r_1 = radius of inner cylindrical conductor (m),

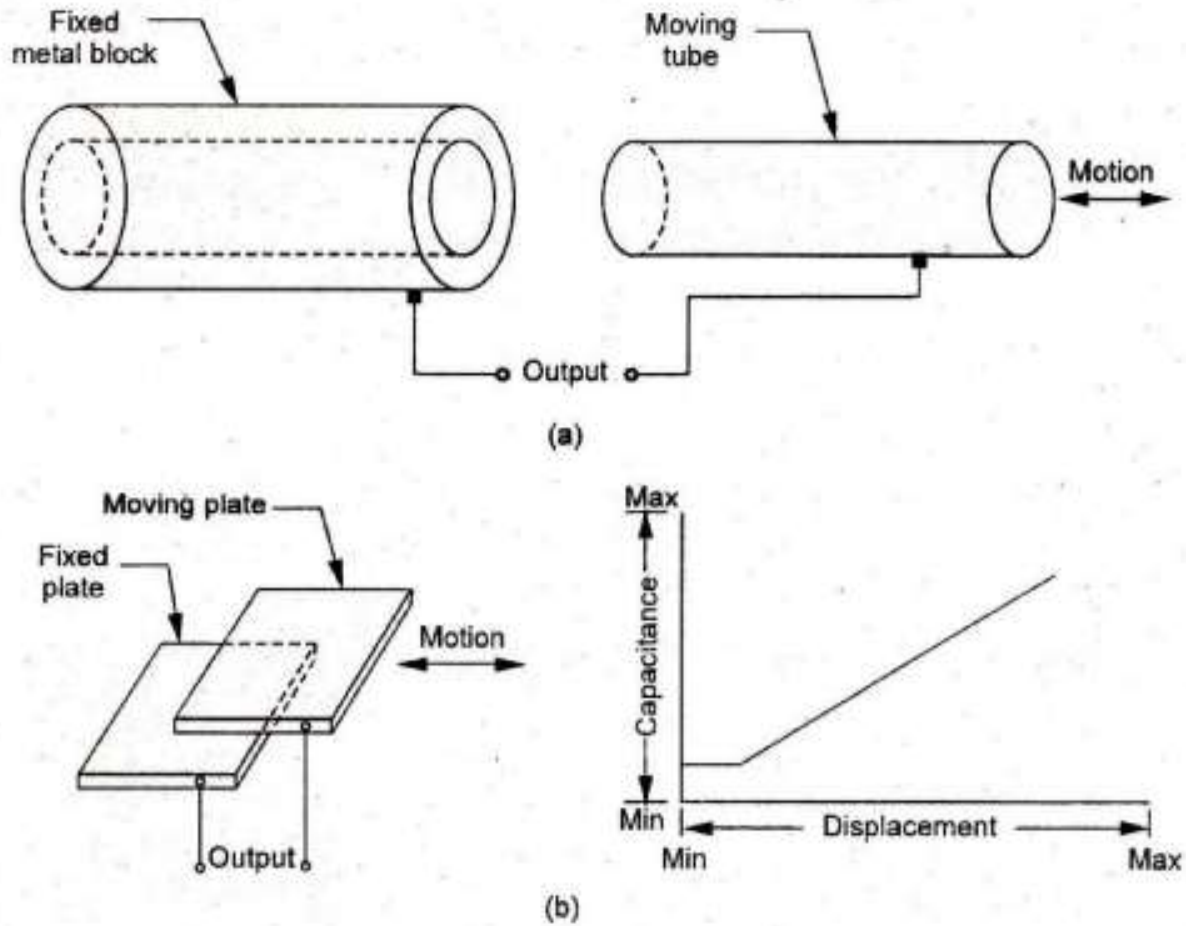


Fig. 4.12 Capacitance transducer: area change

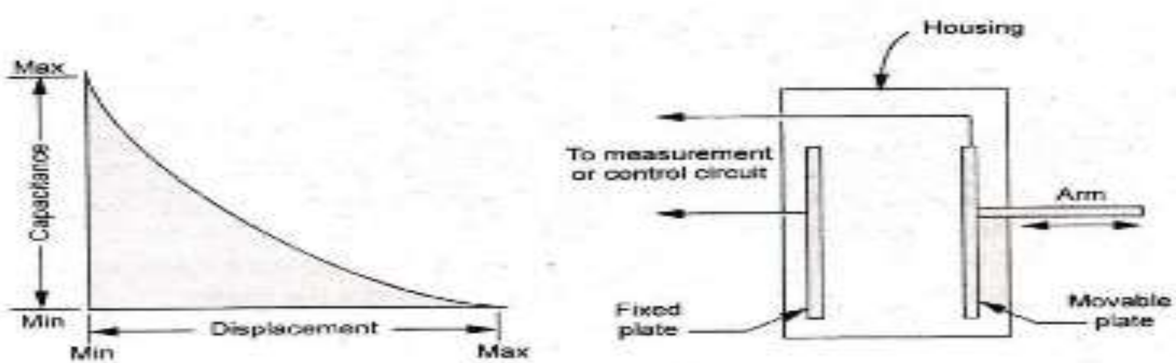


Fig. 4.13 Capacitance transducer : change in distance between the plates

In a differential capacitor, let the normal position of the central plate be represented by a line as shown in Fig. 4.14. The capacitances C_1 and C_2 are then identical, *i.e.*,

$$C_1 = C_2 = C = \epsilon_0 \epsilon_r \frac{A}{t} \qquad ...(4.11)$$

When the central plate is displaced parallel to itself through a distance x, the capacitances are :

$$C_1 = \epsilon_0 \epsilon_r \frac{A}{t+x}; \quad C_2 = \epsilon_0 \epsilon_r \frac{A}{t-x} \qquad ...(4.12)$$

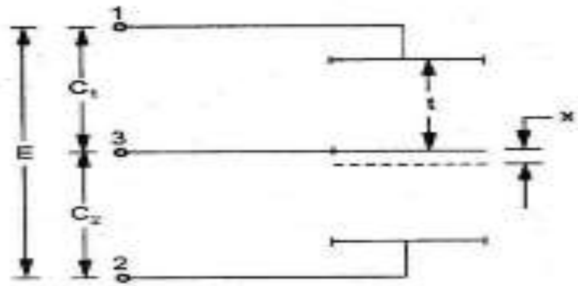


Fig. 4.14 Differential capacitor system

For an alternating voltage E applied between the terminals 1 and 2, the voltages across C_1 and C_2 are given by :

$$E_1 = \frac{E\,C_2}{C_1 + C_2} = E\frac{t+x}{2t} \qquad ...(4.13)$$

and

$$E_2 = \frac{E\,C_1}{C_1 + C_2} = E\frac{t-x}{2t} \qquad ...(4.14)$$

When the output from the terminal pairs 1 and 3, and 2 and 3 is fed into a differential measurement circuit, the voltage difference would be recorded.

$$E_1 - E_2 = E\frac{x}{t} \qquad ...(4.15)$$

The voltage difference is a linear function of the displacement of the middle plate.

Piezo electric transducer

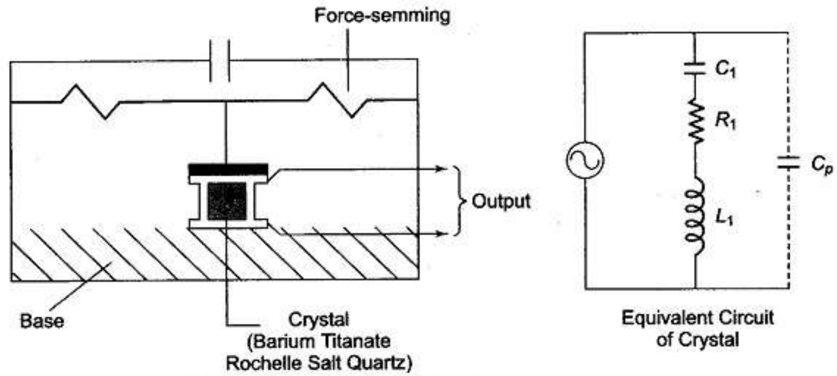


Fig. 13.31 Piezo Electric Transducer

- Applied force is given by , Q= KF ….(i)

Q-> charge in coulomb

F-> Impressed force in newtons

K-> Crystal sensitivity in C/N

- The relationship between the force ***F*** and the change ***δt*** in the crystal thickness ***t*** is given by the stress strain relationship,

Young's Modulus = stress/ strain

$$\gamma = \frac{F/A}{\delta t/ t} \quad \text{........ (ii)}$$

$$F = A\gamma \frac{\delta t}{t}$$

- The charge at electrode gives rise to voltage, such that, Vo= Q/ C

c-> capacitance between electrodes

$$C = \varepsilon_o \varepsilon_r A/t \text{ farads}$$

Combining the above equation, we obtain:

$$V_o = \frac{K}{\varepsilon_o \varepsilon_r} \frac{t F}{A}$$

$$= g \, t \, P$$

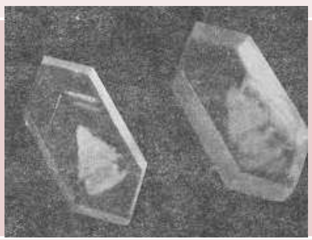
g-> Crystal voltage sensitivity in Vm/N

P-> Applied presuure in N/m^2

- Two main groups of crystals:

i. Natural crystal such as quartz and tourmaline

ii. Synthetic crystal such as

Rochelle salts	
Lithium sulphate (LS)	
ammonia dihydrogen phosphate (ADP)	
Ethylene diamine tartrate (EOT),	
dipotassium tartrate (DKT)	

Advantages	Disadvantages
High frequency response	Cannot measure static condition
High output	Output is affected by changes in temperature
Rugged construction	
Negligible phase shift	
Small size	

Application

1. Accelerometers
2. Pressure cells
3. Force cells

Photo electric transducers

- Conversion of light energy into electrical energy.
- When light falls on photosensitive element electric current is generated that is measured directly or after amplification.
- PHOTOELECTRIC EFFECT is the ejection of electrons from a metal or semiconductor surface when illuminated by light or any radiation of suitable wavelength.

TYPES OF PHOTOELECTRIC TRANSDUCERS

PASSIVE TRANSDUCERS

- 1. Photo emissive
  2.Photo conductive

- **ACTIVE TRANSDUCER**

- 3.Photo voltaic

PHOTOVOLTAIC CELLS

 Operates on the photo voltaic effect I,e when light strikes a junction of certain dissimilar metals, a potential difference is built up.

Also called barrier layer cells.

- Made up of semiconducting substances such as selenium deposited on an iron base.
- Silver or gold covers this semiconducting material & acts as a collecting electrode.

PHOTO VOLTAIC CELLS

- When radiant energy falls upon semiconductor surface,it excites the electrons at the silver-selenium interface.
- The electrons are collected at the collector cathode.

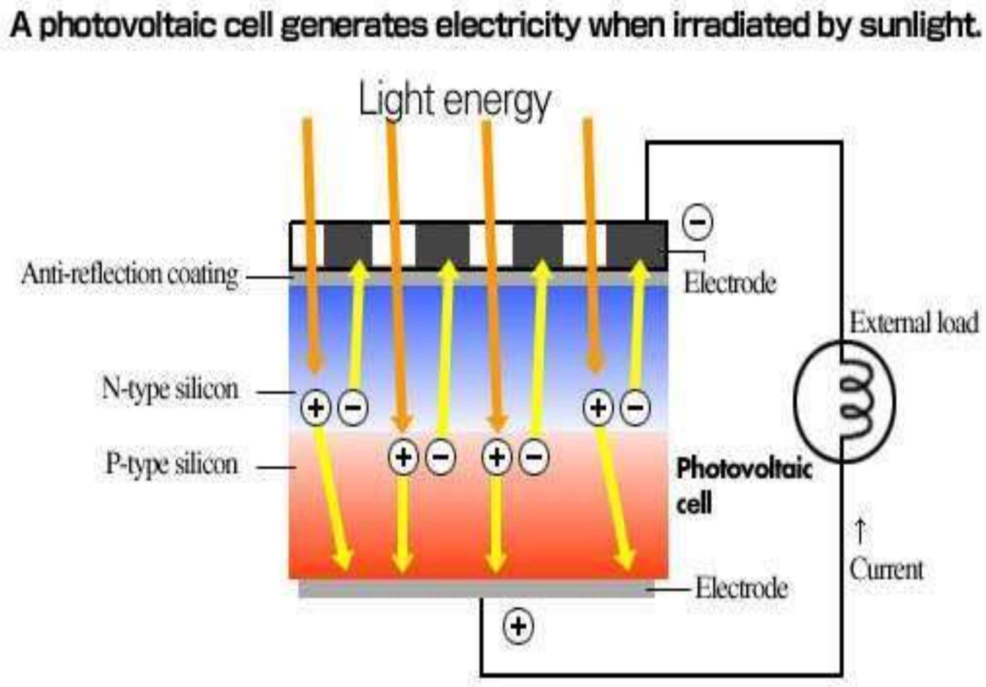


PHOTO VOLTAIC CELLS

- robust in construction.
- Need no external power supply.
- It produces photo current stronger than the photo senstive elements.

- Selenium has low internal resistance. Hence amplification is difficult.
- Very sensitive galvanometers has to be used for measurement purpose.

ADVANTAGES

DISADVANTAGES

PHOTOEMISSIVE CELLS

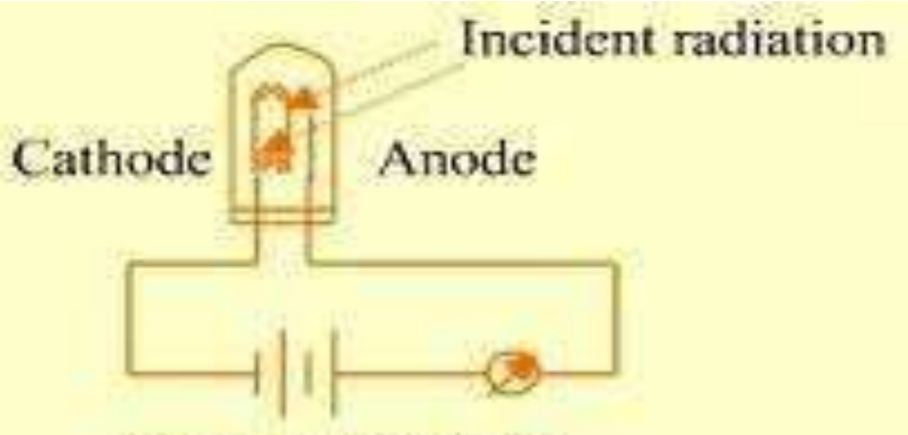
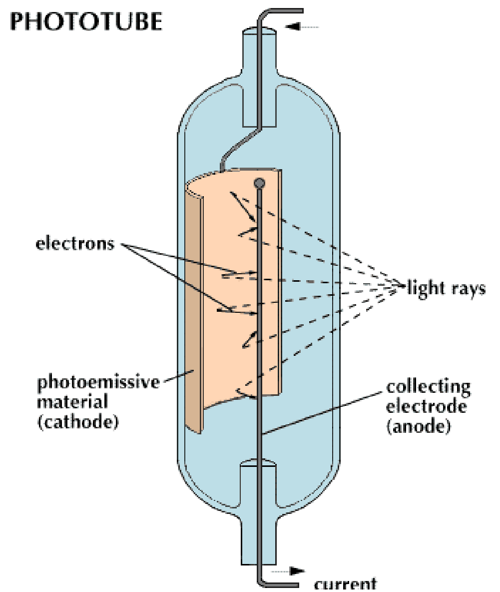


Fig: Photoemissive cell.



•It consists of a cathode and an anode mounted in a vacuum tube made of glass.

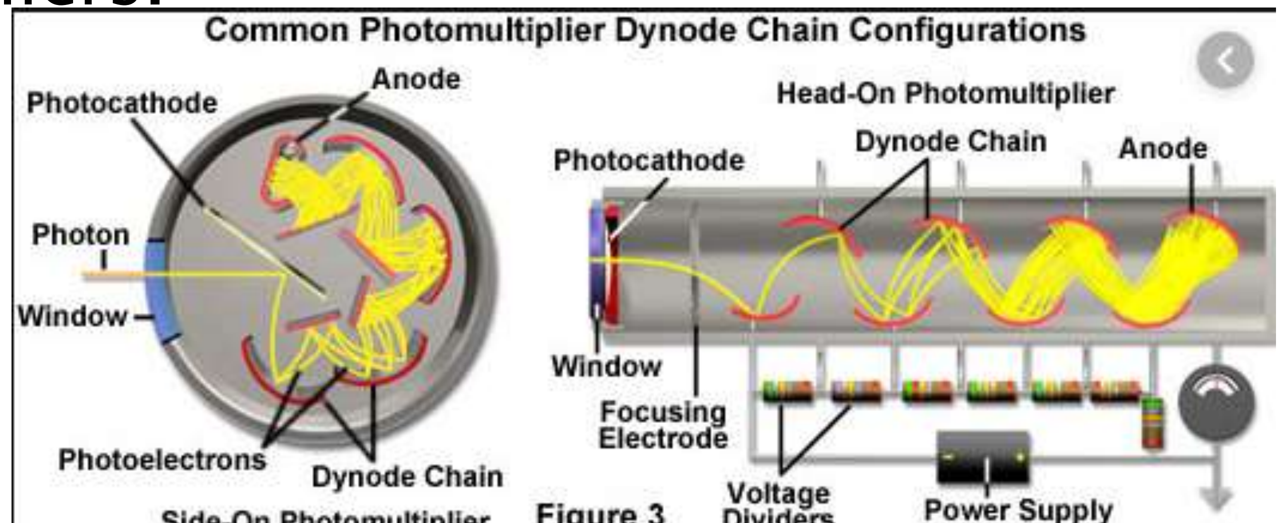
•The **cathode** consists of a curved metal plate made of photosensitive material such as **cesium** or **oxidised silver**.

• the anode is made of nickel or platinum.

•When radiation of frequency above the threshold frequency falls on the cathode, electrons are emitted and flow to the anode constituting an electric current.

PHOTOEMISSIVE CELLS

- *Gas filled photoemissive* type cells contain inert gas molecules like argon which can be ionised.
- Due to repeated collisions of electrons, produced is at even low potentials.
- The number of emitted electrons can be increased and high gains made possible by using a photo- multipliers.



PHOTOEMISSIVE CELLS

- (I) the emission is instantaneous
- (ii) the maximum current is proportional to the intensity of radiation.
- (iii)increased sensitivity.

- Generates extremely small current.
- Direct power supply required for photomultiplier.
- More expensive. Can be replaced by silicon diode detectors.

ADVNTAGES

DISADVANTAGES

PHOTOCONDUCTIVE CELLS

- Also called LDRs–Light Dependent Resistors.
- Works on the principle that the resistance of a photosensitive semiconducting material decreases with the intensity of the incident light.
- The disadvantages are that the photoconductive cells are sluggish and show hysteresis effect.

Photoconductive cell

- When light of varying intensity falls on the film, a current flows through the circuit containing a galvanometer and a battery.
- The current directly varies with the intensity of light.
- Works under two methods- transmittance & reflectance.

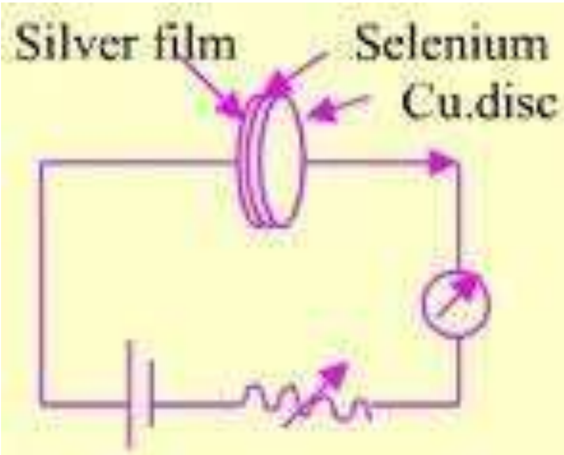


Fig: Photoconductive Cell.

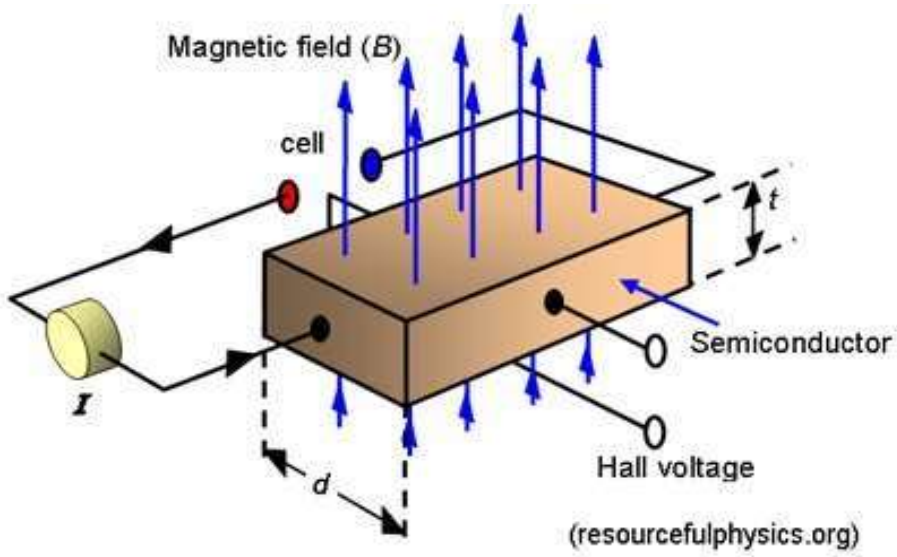
BIO-MEDICAL APPLICATIONS OF PHOTOELECTRIC TRANDUCERS

- Pulse pickups
- Pneumograph respiration–respiratory volume can be measured by measuring changes in the chest circumference with a pneumograph which has a photodetector in it.
- Measure blood pulsatile volume changes– especially LDR is used.
- In recording movements of the body due to pumping action of the heart called **ballistocardiogram.**

Hall Effect

- Hall effect relates to the **generation of transverse voltage difference on a conductor which carries current and is subjected to magnetic field in perpendicular direction.**
- The current may be due to the movement of holes or that of face electrons.

- Hall strip carries an current I in the x- direction and is subjected to magnetic field B in the z- direction.
- The thickness of the strip t is very small as compared to its length and width.
- Voltage E is set up in the transverse or y direction



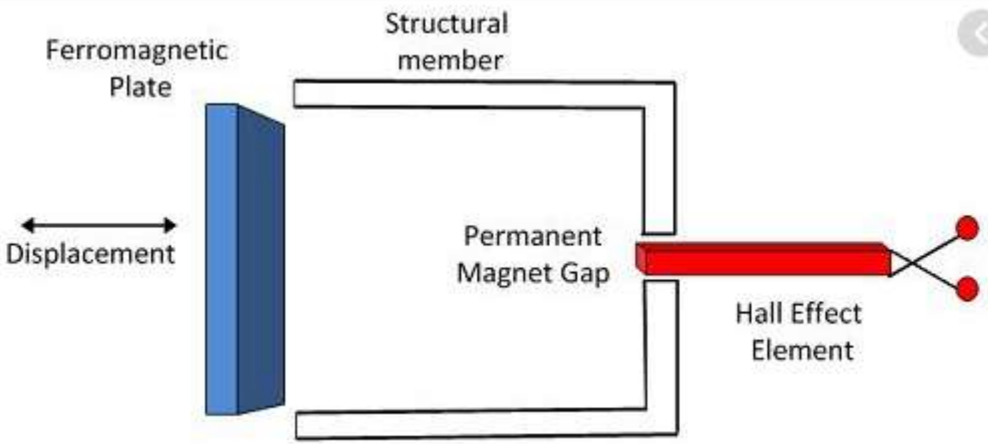
- Voltage is directly proportional to the current I, field strength B and inversely proportional to thickness t of the strip.
- That is ,

$$E = K\frac{BI}{t}$$

Proportionality constant K is called the Hall effect coefficient.

Hall effect transducers

- To determine whether the semiconductor is N type or P type
- Measure either the current or the strength of magnetic field.
- Measure the displacement where it is possible to change the magnetic field strength by variation in the geometry of the magnetic structure.



Measurement of Displacement Using Hall Efect Transducer

- In an electro mechanical transducer, the measurand changes material characteristics or physical configuration to give resistance, inductance or capacitance change.
- The transducer then employs electrical circuitry for the measurement of such changes.
- The circuitry will modify the signal so that it may eventually be displayed on an indicator or recorder.

Potentiometer (current measurement used as an indication of the value of variable resistance)

1. Current sensitive circuit

- A change in the physical variable (measurand) moves the slider across the resistor and brings about change in the resistance of the circuit.
- The resistance change is then indicated by a change in the current flow in the circuit.
- The current flow is given by,

$$I = \frac{Vs}{R + Rb} \quad ....(1)$$

Where,

Vs-> Supply or input voltage

Rb-> Resistance of the system outside the transducer

R-> Resistance of the transducer that varies with measurand

Cont...

Cont….

- Equation 1 can be written in the dimensionless form as,

Rm-> Maximum resistance of the transducer

- The operating arrangement should be such that the current output has a linear variation with the transducer resistance.

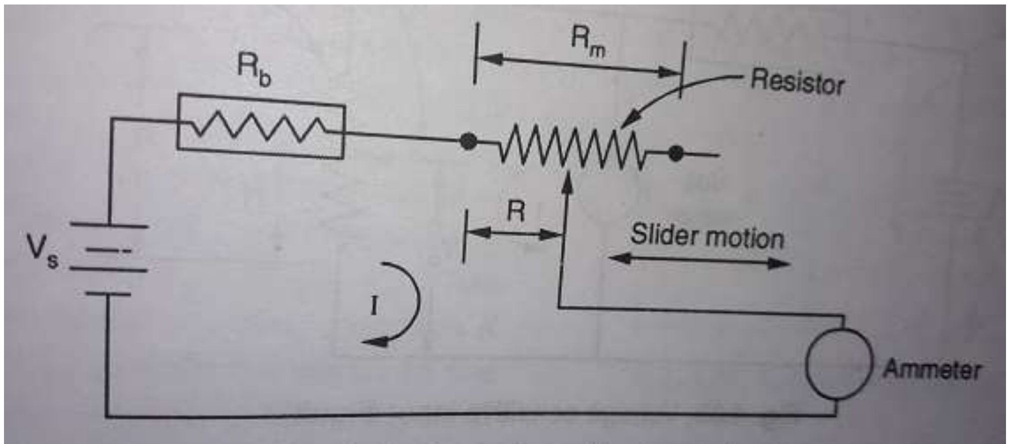


Fig. 4.32. Current sensitive input circuit

2. **Voltage sensitive circuit**

- Change in the resistance is indicated through a change in voltage.

- If Vo is voltage across transducer, then

$$I = \frac{Vs}{R + Rb}$$

$$Vo = IR = \frac{Vs}{R + Rb} R$$

Or

$$\frac{Vo}{Vs} = \frac{R}{R + Rb}$$

Cont.....

Contd….

- This circuit also **provides non linear output**, still it is preferred as the voltage measurement is easier to perform than current measurement.
- The voltage sensitive circuit is called as ballast circuit and the resistance *Rb* is called ballast resistance.
- Sensitivity of ballast circuit is defined as the rate of change of the voltage indication with respect to the transducer resistance R. Then,

$$\frac{dVo}{dR} = \frac{VsRb}{(R + Rb)^2}$$

- The appropriate value of the ballast resistance can be obtained by differentiating sensitivity with respect to Rb and setting the derivative equal to zero.Thus,

$$\frac{dS}{dRb} = \frac{Vs(R - Rb)}{(R + Rb)} = 0$$

- Thus for maximum sensitivity R= Rb
- The value of the ballast resistance *Rb* is selected for the range of *R* that will give maximum sensitivity.

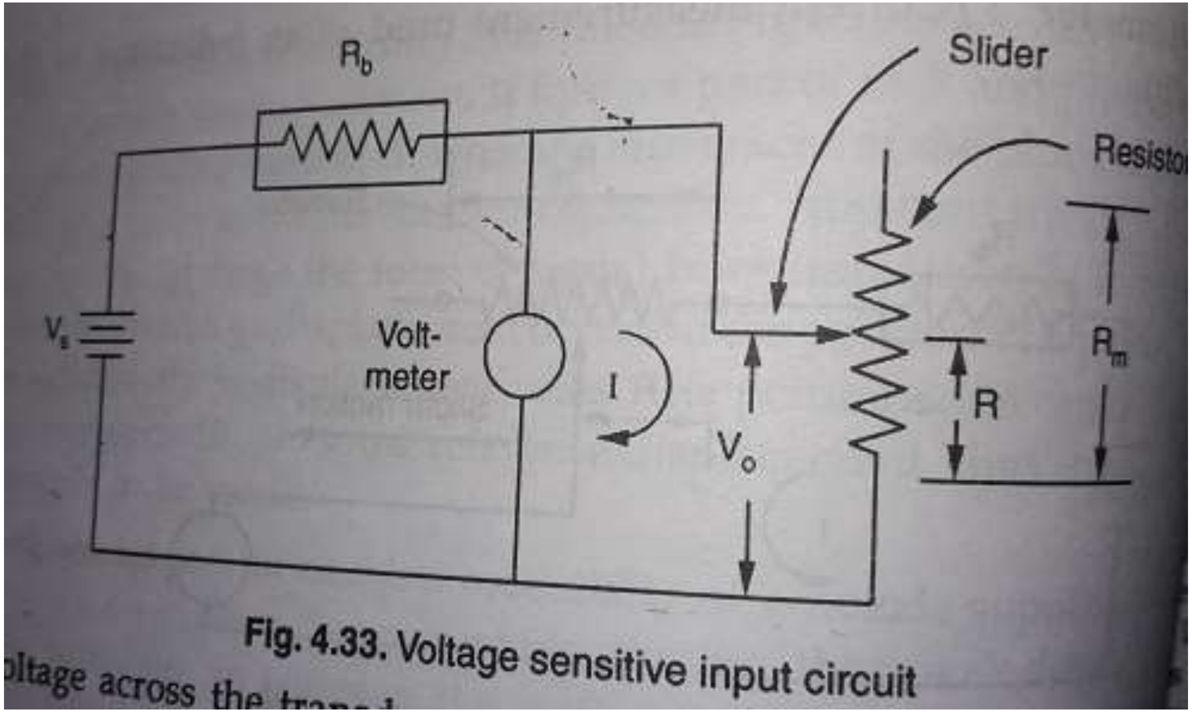


Fig. 4.33. Voltage sensitive input circuit

Potentiometer (Voltage divider circuit)

1. **Ideal or unloaded potentiometer (Measuring instrument has an infinitely high internal resistance)**

- The movement of slider against the potentiometer resistance element (length Xm and resistance Rm) results in a relatively large variation in the resistance R (due to slider displacement x) and corresponding variation in the Output voltage Vo.
- With the slider lower extreme position R=0 and Vo=0, and the slider in the upper extreme position R=Rm and Vo = Vs.
- As the slider traverses the full extent of the resistor, the output voltage varies from zero to the supply voltage Vs.

- When no current is drawn from the output terminals ,

$$Vs = IRm \text{ and } Vo = IR$$

Thus,

$$\frac{Vo}{Vs} = \frac{IR}{IRm} = \frac{R}{Rm}$$

For an absolutely uniform resistance element,

$$R \alpha x \quad \text{and} \quad Rm \alpha Xm$$

$$\frac{Vo}{Vs} = \frac{x}{Xm}$$

Since Vs and Xm are constants for a particular set up

Vo = K x where, K is a constant

Since Vs and Xm are constants for a particular set up,

Vo = K x where K is constant

- Thus there is a straight line relationship between the output voltage and the displacement of the slider.
- There are no delays or distortions of the input signal. Such devices are known as zero- order instrument.

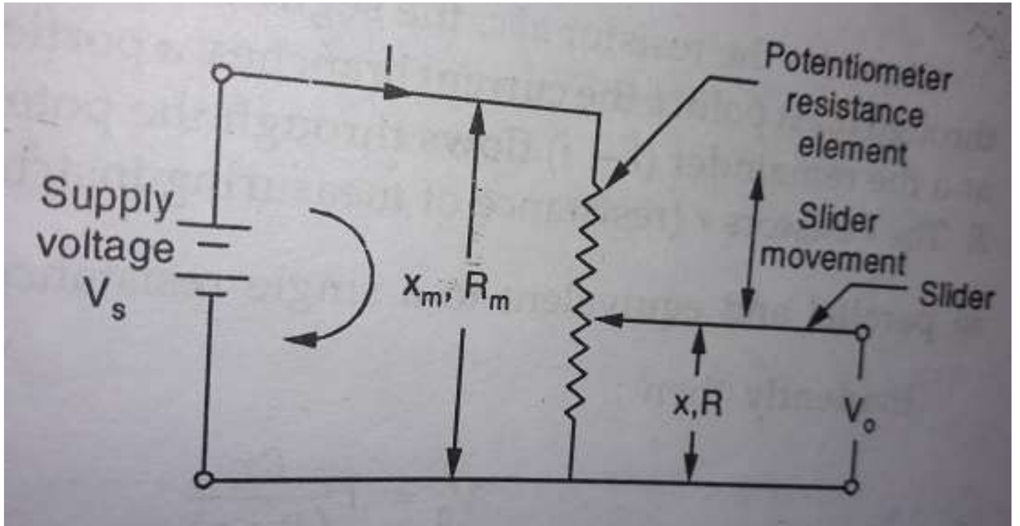


Fig. 4.34. Simple voltage-divider circuit

2. Loaded potentiometer (measuring instrument has a finite value of internal resistance)

- Voltage output from the potentiometer device is measured / by instruments which may not have infinitely high input resistance.
- Then the potentiometer is electrically loaded and that modifies the ideal circuit.
- Fig shows the circuit, For an actual measuring circuit for a potentiometer, the meter has an internal resistance r and a current I flows through it.

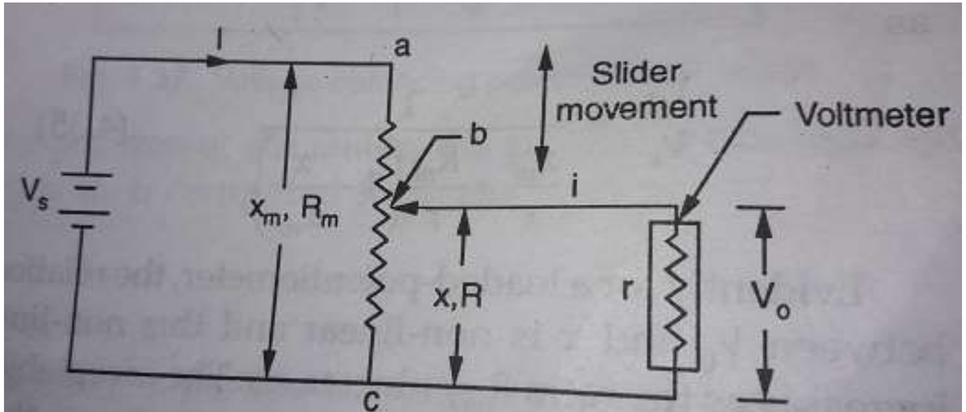


Fig. 4.35. Voltage-divider circuit for a practical potentiometer

- Consider the resistance abc, the segment ab has a resistance (Rm-R) and a current I flows through it.
- At point b the current branches, a portion *I* flows towards the measuring instrument and the remainder (I-i) flows through the potentiometer segment bc which has resistance *R*.
- The resistors r(resistance of measuring instrument) and R (resistance of segment bc) are in parallel and equivalent to a single resistance of magnitude $\frac{Rr}{(R+r)}$
- Evidently, $$Vo = I\frac{Rr}{(R+r)}$$

$$Vs = I\left[(Rm - R) + \frac{Rr}{(R+r)}\right]$$

And

$$\frac{Vo}{Vs} = \frac{Rr}{(R+r)\left[(Rm+R) + \dfrac{Rr}{R+r}\right]}$$

Or

$$\frac{Vo}{Vs} = \frac{Rr}{(Rm+R)(R+r) + Rr}$$

Or

$$\frac{Vo}{Vs} = \frac{Rr}{RmR + Rmr - R^2}$$

Dividing the numerator and denominator by Rr,

$$\frac{Vo}{Vs} = \frac{1}{\dfrac{Rm}{r} + \dfrac{Rm}{R} - \dfrac{R}{r}}$$

$$= \frac{1}{\dfrac{Rm}{R} + \dfrac{Rm}{r}\left(1 - \dfrac{R}{Rm}\right)}$$

In terms of x and Xm, this equation may be written as,

$$\frac{Vo}{Vs} = \frac{1}{\frac{Xm}{X} + \frac{Rm}{r}\left(1 - \frac{X}{Xm}\right)}$$

- Evidently for a loaded potentiometer, the relationship between Vo and x is non linear.
- This non linearity increases as the ratio Rm/r increases.
- Further analysis of loaded potentiometer indicates that,

i. Under no- load ideal potentiometer (Rm/r=0 for an open ckt)

I,e the input-output curve is a straight line.

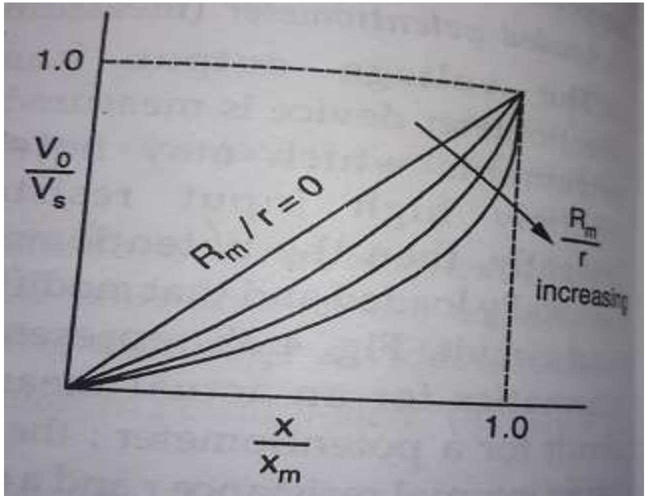


Fig. 4.36. Characteristic curve for a loaded potentiometer

ii) When Rm/r=1.0, the maximum error is about 12 percent of full scale, and drops to about 15 percent when Rm/r=0.1

The term error refers to the loading error which is defined by the relation,

$$\text{Loading error} = \frac{\left(\frac{Vo}{Vs}\right)_{true} - \left(\frac{Vo}{Vs}\right)_{ind}}{\left(\frac{Vo}{Vs}\right)_{true}}$$

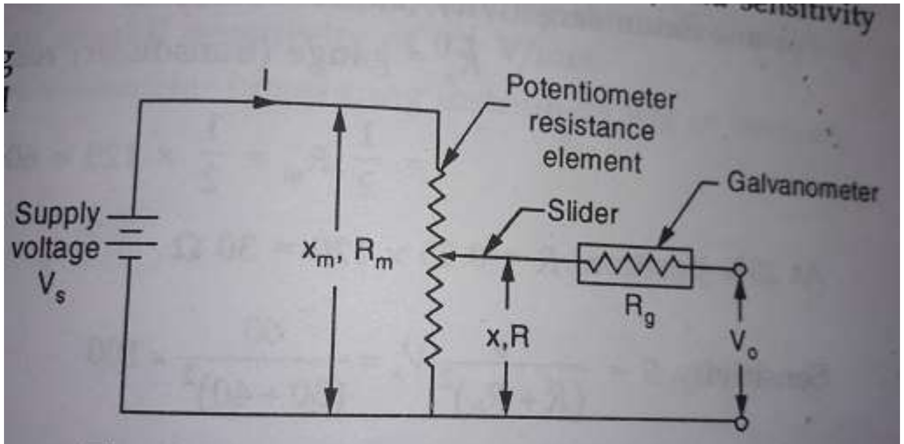


Fig. 4.37. Voltage-balancing potentiometer circuit

iii) For values of Rm/r<0.1 the position of macximum erroe occurs in the region of X/Xm=0.7.

- A voltage balancing potentiometer ckt. Is employed to aaleviate the loading effect of a simple potentiometer ckt.

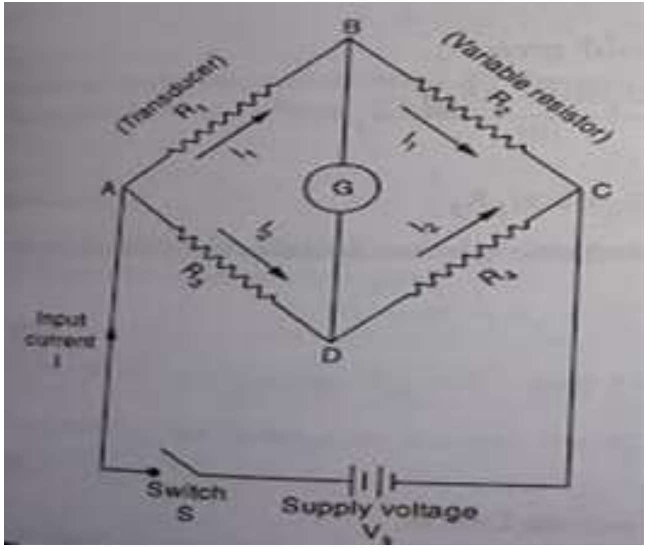
- The unknown voltage Vo is then computed from the relation,

$$\frac{Vo}{Vs} = \frac{R}{Rm}$$

WHEASTONE BRIDGE CIRCUIT

- Resistance and very small changes in resistance occuring in temperature or strain measuring system are generally measured by **Wheastone bridge.**

Basic ckt. of Wheatstone bridge



- Four resistor R1, R2, R3 and R4 are connected to form diamond shaped bridge ckt.
- Network gets energized when voltage *Vs* applied to bridge by closing switch *S*.
- Current flowing from battery divides at point A.
- Part of current I1 flows through resistors R1 and R2 to point C and back to battery.
- The other part of the current I2 flows through resistors R3 and R4 to point C and joins I1 in flowing back to battery.

1. No load condition

- Under this balanced or null condition, **potential at B equals the potential at D**.
- Since voltage drops across resistances are equal to the product of resistance and current through it, then at null:

$V_{ab} = V_{ad}$; $I_1R_1 = I_2R_3$

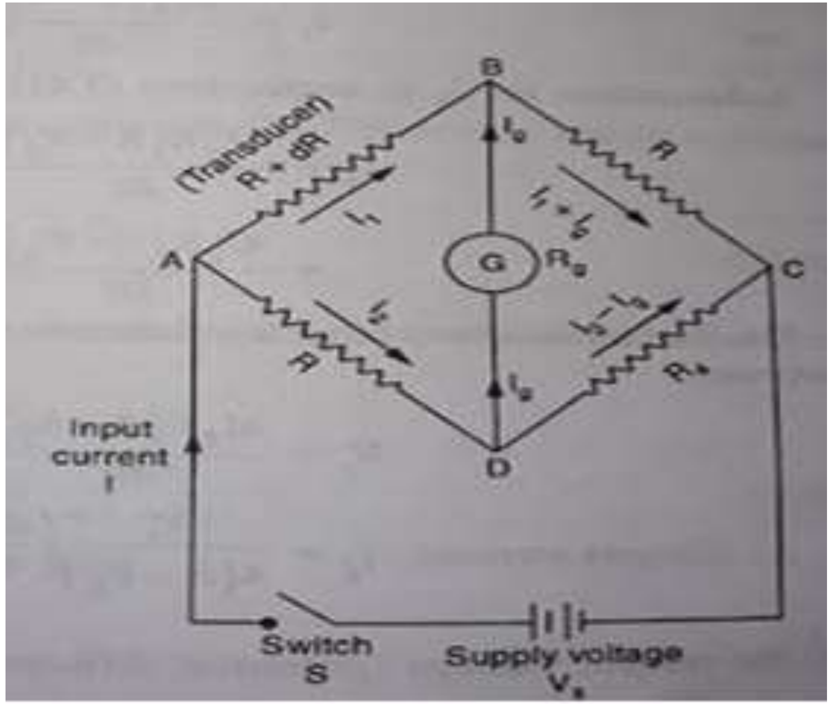
$V_{bc} = V_{dc}$; $I_1R_1 = I_2R_4$

- Eliminating current from these relation, we obtain,

$$R_1 = R_2\left(\frac{R_3}{R_4}\right)$$

- In measurement of strain generally R1 is the strain gauge transducer , R3 and R4 are fixed resistances and R2 is a variable resistances.
- The **Ratio Arm** is frequency used

in describing two unknown adjacent arms in an Wheatston bridge (here R3 and R4 called the ratio arm).



- Galvanometer is usually

Connected to the junction of these two known resistors.

- Change δR_l in the resistance R_t due to strain or temperature which is to be determined.
- This change will unbalance the bridge and the galvanometer would give deflection.
- Resistance R2 is the adjusted by an amount δR_2 to regain the balance.
- The re-balanced condition gives:

$$R_1 + \delta R_1 = (R_2 + \delta R_2)\left(\frac{R_3}{R_4}\right)$$

$$\delta R_1 = R_2\left(\frac{R_3}{R_4}\right) + \delta R_2\left(\frac{R_3}{R_4}\right) - R_1$$

$$= \delta R_2\left(\frac{R_3}{R_4}\right)$$

- Clearly δR_2 is a measure of the unknown quantity δR_1.

- In commercial bridges , R2 is generally variable upto 10000ohms in 0.1 ohm steps
- (R3/R4) is variable in decade steps from 10000:1 to 1:10000.
- These resistances are mounted in a box and the appropriate value is selected by operating a switch.

The re-balanced

$$R_1 + \delta R_1 = (R_2 + \delta R_2)\left(\frac{R_3}{R_4}\right) \quad \text{...(4.40)}$$

$$\delta R_1 = R_2\left(\frac{R_3}{R_4}\right) + \delta R_2\left(\frac{R_3}{R_4}\right) - R_1$$

$$= \delta R_2\left(\frac{R_3}{R_4}\right)$$

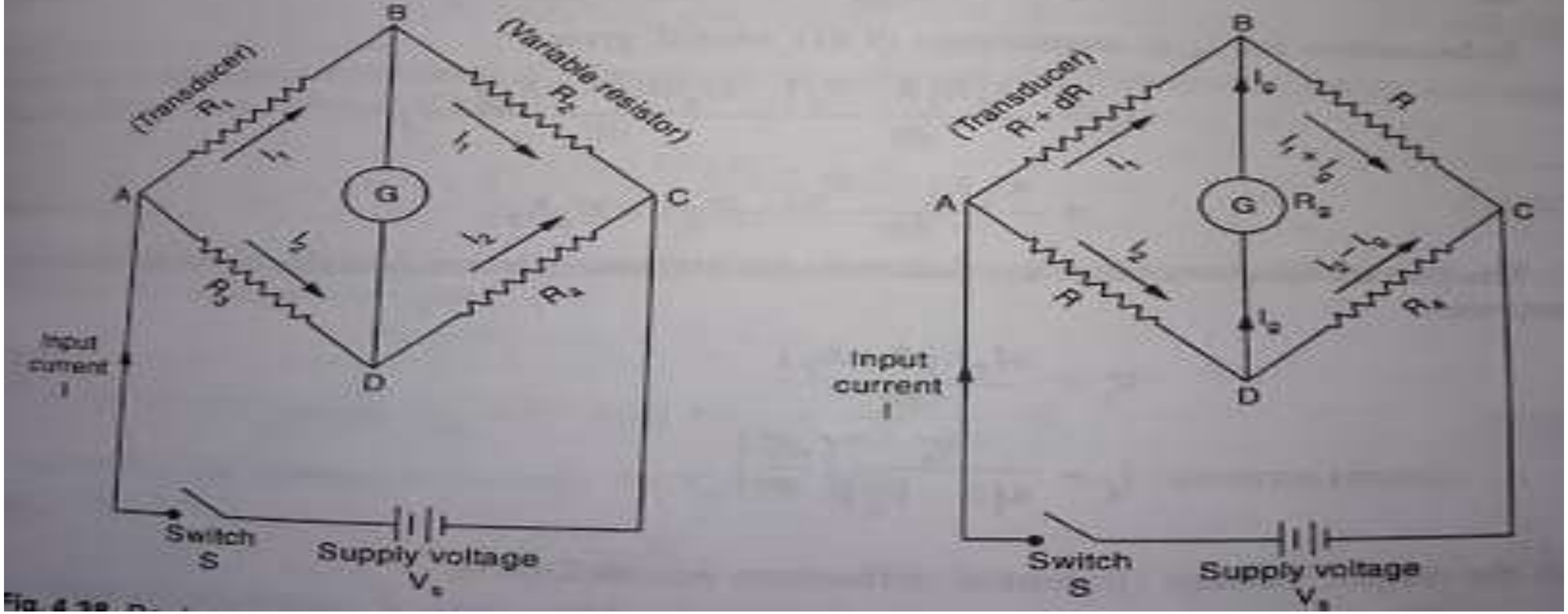


Fig. 4.38