# UNIT – I

# INTRODUCTION TO MEASURING INSTRUMENTS

# 1. MEASURING INSTRUMENTS

- “The device used for comparing the unknown quantity with the unit of measurement or standard quantity is called a Measuring Instrument.”

  OR

- “An instrument may be defined as a machine or system which is designed to maintain functional relationship between prescribed properties of physical variables & could include means of communication to human observer.”

# 2. CLASSIFICATION OF INSTRUMENTS

Electrical instruments may be divided into two categories, that are;

1. Absolute instruments,
2. Secondary instruments.

- Absolute instruments gives the quantity to be measured in term of instrument constant & its deflection.
- In Secondary instruments the deflection gives the magnitude of electrical quantity to be measured directly. These instruments are required to be calibrated by comparing with another standard instrument before putting into use.

# 2.1 CLASSIFICATION OF INSTRUMENTS

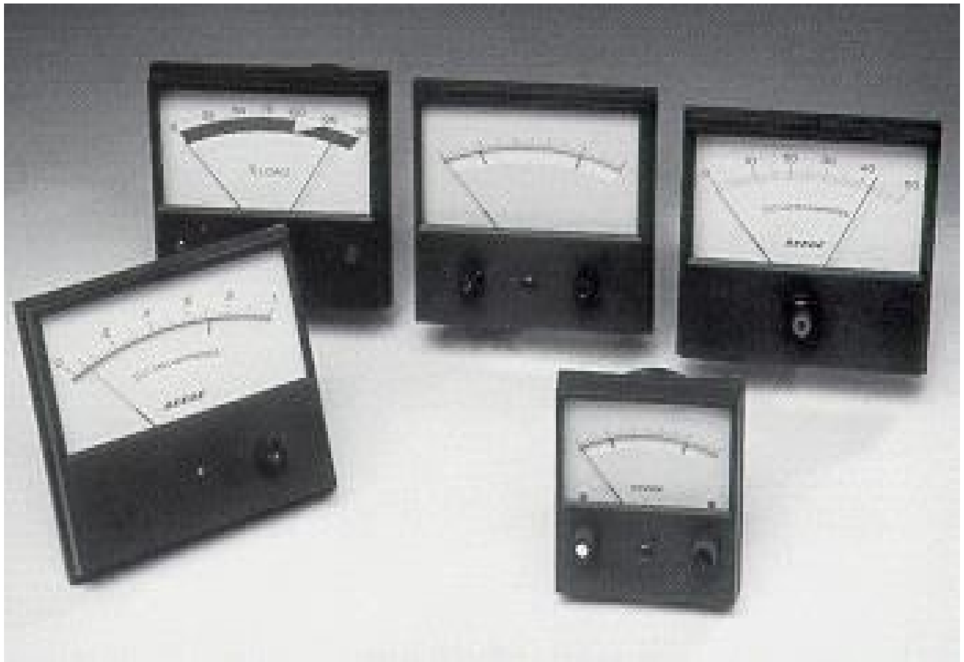

# 3. CLASSIFICATION OF SECONDARY INSTRUMENTS

Secondary instruments can be classified into three types;

i. Indicating instruments;
ii. Recording instruments;
iii. Integrating instruments

# 3.1 Indicating Instruments

It indicate the magnitude of an electrical quantity at the time when it is being measured. The indications are given by a pointer moving over a graduated dial.



# 3.2 Recording Instruments

The instruments which keep a continuous record of the variations of the magnitude of an electrical quantity to be observed over a defined period of time.

# 3.2 Integrating Instruments

The instruments which measure the total amount of either quantity of electricity or electrical energy supplied over a period of time.

For example : Energy meters

# 4. ESSENTIALS OF INDICATING INSTRUMENTS

A defined above, indicating instruments are those which indicate the value of quantity that is being measured at the time at which it is measured. Such instruments consist essentially of a pointer which moves over a calibrated scale & which is attached to a moving system pivoted in bearing.

The moving system is subjected to the following three torques:

1. Deflecting(or operating) torque
2. Controlling(or restoring) torque
3. Damping torque

# 4.1 DEFLECTING TORQUE

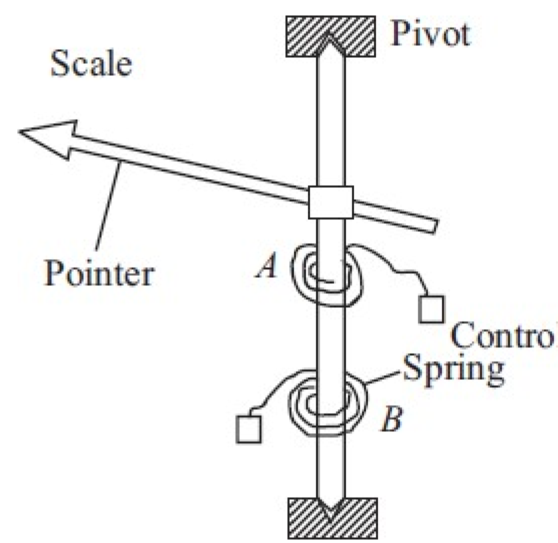
- The deflecting torque is produced by making one of the magnetic, heating, chemical, electrostatic and electromagnetic induction effect of current or voltage and cause the moving system of the instrument to move from its zero position.

# 4.2 CONTROLLING TORQUE

- The magnitude of the moving system would be some what indefinite under the influence of deflecting torque, unless the controlling torque existed to oppose the deflecting torque.
- It increases with increase in deflection of moving system.
- Under the influence of controlling torque the pointer will return to its zero position on removing the source producing the deflecting torque.
- Without controlling torque the pointer will swing at its maximum position & will not return to zero after removing the source.
- Controlling torque is produced either by **spring or gravity control.**

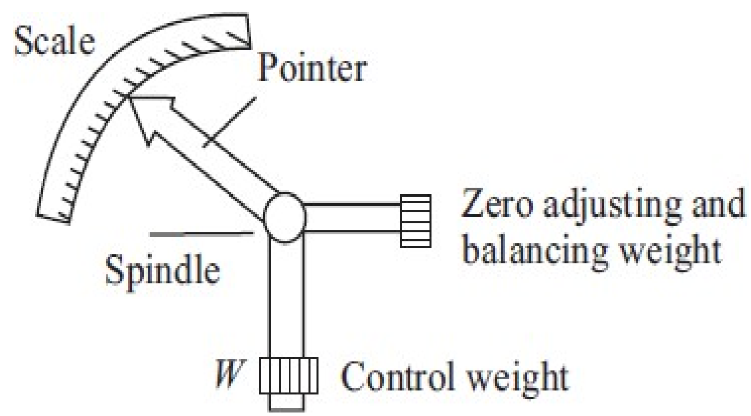
# Spring Control:

When the pointer is deflected one spring unwinds itself while the other is twisted. This twist is the spring produces restoring (controlling) torque, which is proportional to the angle of deflection of the moving systems.



# Gravity Control

- In gravity controlled instruments, a small adjustable weight is attached to the spindle of the moving system such that the deflecting torque produced by the instrument has to act against the action of gravity.
- Thus a controlling torque is obtained. This weight is called the control weight. Another adjustable weight is also attached is the moving system for zero adjustment and balancing purpose. This weight is called Balance weight.



# Continue…

- We have already seen that the moving system of the instrument will tend to move under the action of the deflecting torque. But on account of the control torque, it will try to occupy a position of rest when the two torques are equal and opposite. However, due to inertia of the moving system, the pointer will not come to rest immediately but oscillate about its final deflected position as shown in figure and takes appreciable time to come to steady state.
- To overcome this difficulty a damping torque is to be developed by using a damping device attached to the moving system.

# Unit 2

## AMMETER AND VOLTMETER

(MOVING COIL AND MOVING IRON TYPE)

# 1. TYPES OF AMMETER & VOLTMETER

**1)** Moving Iron Type Meters (AC & DC);

a) Attraction type,

b) Repulsion type.

**2)** Moving Coil Type Meters (AC & DC);

a) Permanent Magnet type,

b) Electrodynamic or Dynamometer.

**3)** Hot Wire Type (AC & DC);

**4)** Induction Type (AC & DC);

a) Split phase,

b) Shaded Pole type.

**5)** Electrostatic Type for Voltmeters Only

# 2. Moving-iron instrument

- **An attraction type of moving-iron instrument** is shown diagrammatically in Figure. When current flows in the solenoid, a pivoted soft iron disc is attracted towards the solenoid and the movement causes a pointer to move across a scale.
- **In the repulsion type moving-iron instrument** shown diagrammatically in Figure, two pieces of iron are placed inside the solenoid, one being fixed, and the other attached to the spindle carrying the pointer

# 2.1 Moving-iron instrument

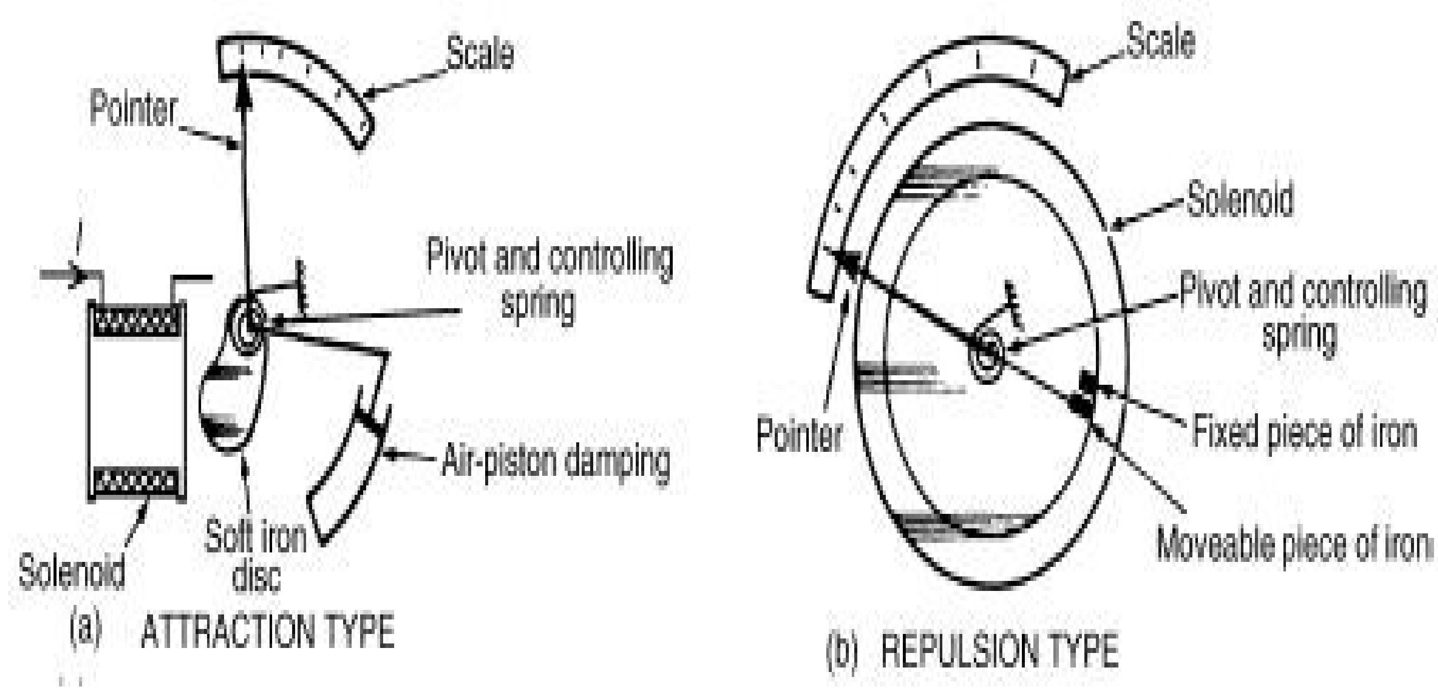



Figure 10.2

# 3. Moving Coil Instruments

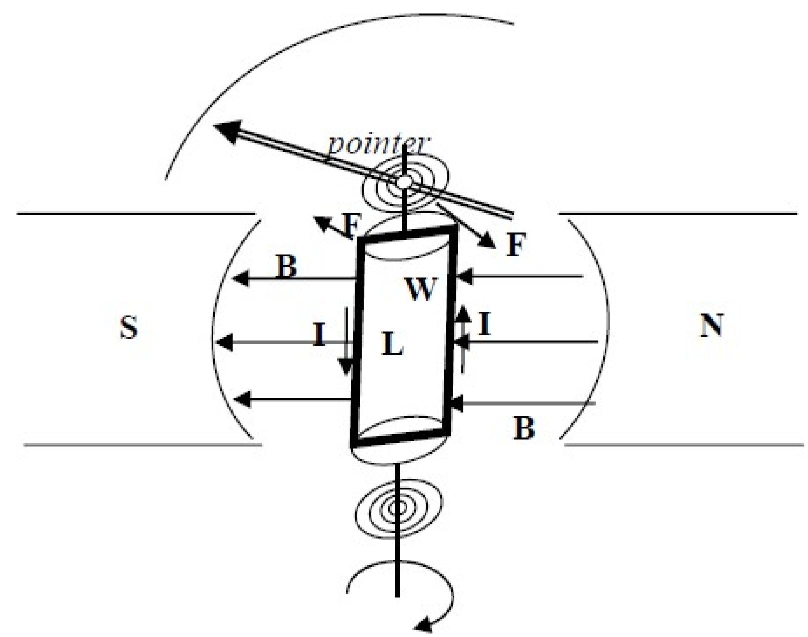
- There are two types of moving coil instruments namely, **permanent magnet moving coil type** which can only be used for direct current, voltage measurements.
- **The dynamometer type** which can be used on either direct or alternating current, voltage measurements.

# PERMANENT MAGNET MOVING COIL

The principle operation of PMMC is based upon the principle of current carrying conductor is placed in a magnetic field

it is acted upon by force

which tends to move it.”



# UNIT 3

## WATTMETER

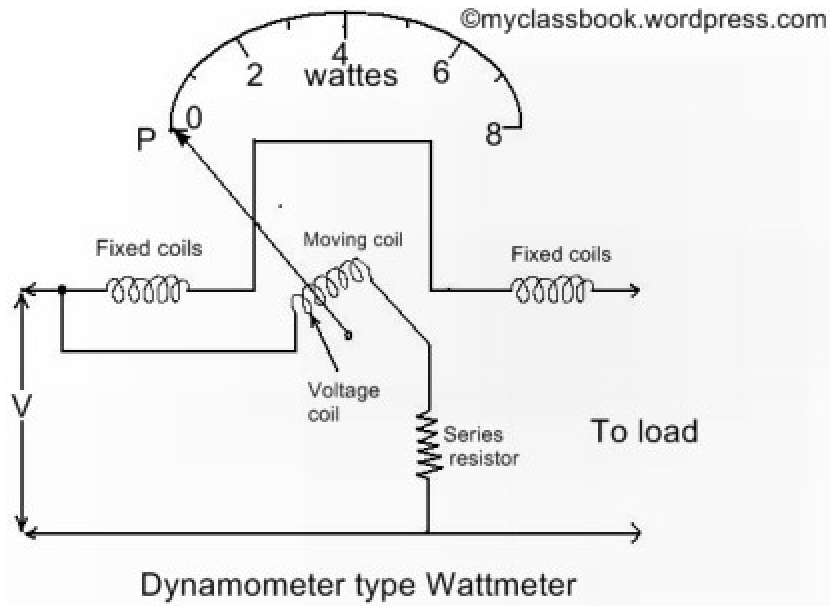
## (DYNAMOTYPE WATTMETER)

# 1. DYNAMOTYPE WATTMETER

If two coils are connected such that, current proportional to the load voltage, flows through one coil and current proportional to the load current, flows through another coil, the meter can be calibrated directly in watts. This is true because the indication depends upon the product of the two magnetic fields. The strength of the magnetic fields depends upon the values of the current flowing through the coils

# CONSTRUCTION AND WORKING OF DYNAMOTYPE WATTMETER

CIRCUIT DIAGRAM



# Continue…

Let us consider

v=supply voltage

i=load current and

R=resistance of the moving coil circuit

Current through fixed coils, i(f)=I

Current through the moving coil, i(m)=v/R

Deflecting torque,

$$T_d \propto (i_f * i_m) \propto \frac{iv}{R}$$

# Continue…

For a DC circuit, the deflecting torque is thus proportional to the power.

For any circuit with fluctuating torque, the instantaneous torque is proportional to instantaneous power. In this case, due to the inertia of moving parts, the deflection will be proportional to the average power. For sinusoidal alternating quantities,

the average power is VI COSθ

where

V = r.m.s. value of voltage,

I = r.m.s. value of current, and

θ = phase angle between V and I

Hence an electrodynamic instrument, when connected as shown in the figure, indicates the power, irrespective of the fact it is connected in an AC or DC circuit.

# Advantages and disadvantages of dynamometer type wattmeter

**Advantages:**

- In dynamometer type wattmeter, the scale of the instrument is uniform (because deflecting torque is proportional to the true power in both DC as well as AC and the instrument is spring controlled.
- 2) High degree of accuracy can be obtained by careful design; hence these are used for calibration purposes.

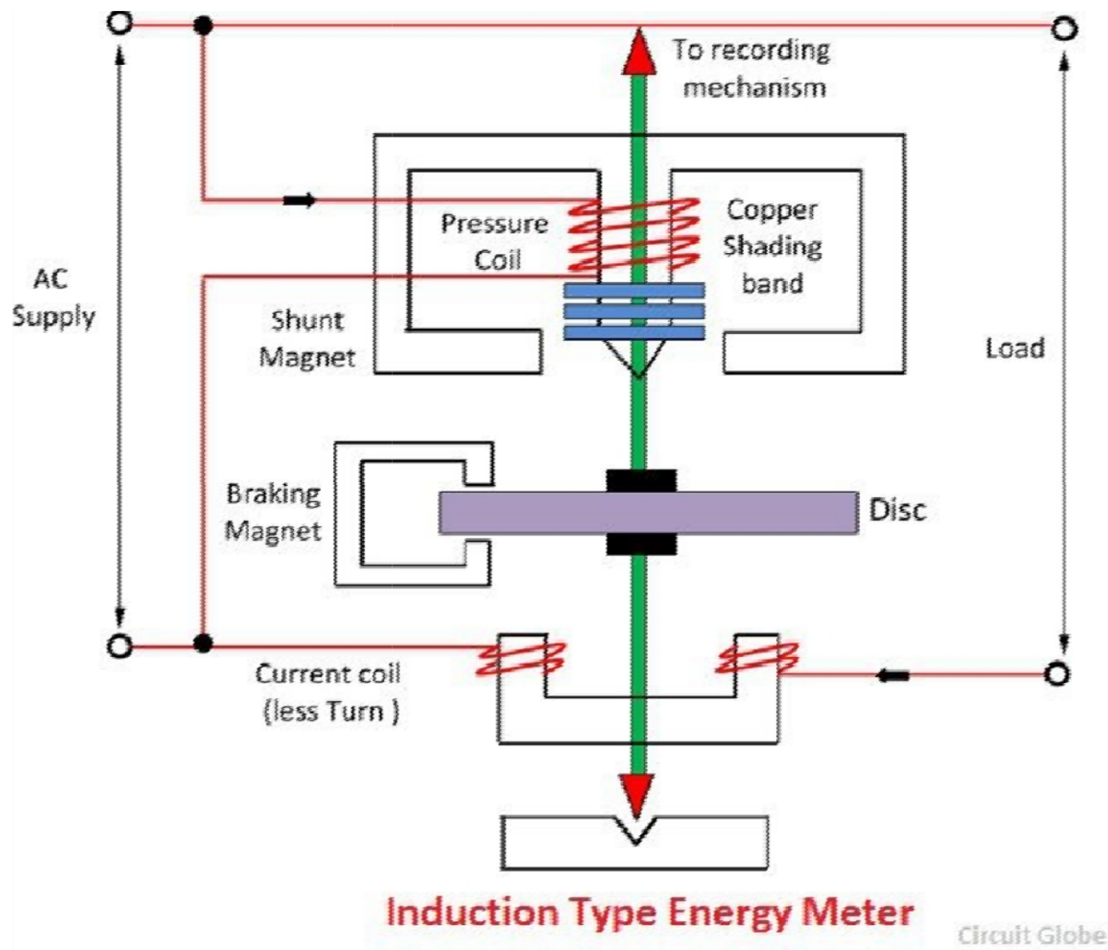
# Continue…

## Disadvantages:

- The error due to the inductance of the pressure coil at low power factor is very serious (unless special features are incorporated to reduce its effect)
- In dynamometer type wattmeter, a stray field may affect the reading of the instrument. To reduce it, magnetic shielding is provided by enclosing the instrument in an iron case.

# Unit 4-energy meter

## Single phase Induction Type energy meter



# Single phase induction type energy meter

- Single phase induction type energy meter is also popularly known as ***watt- hour meter***. This name is given to it. This article is only focused about its constructional features and its working. Induction type energy meter essentially consists of following components:
- 1. Driving system
  **2.** Moving system
  **3.** Braking system and
  **4.** Registering system
- Driving system
- It consists of two electromagnets, called ***"shunt" magnet*** and ***"series" magnet***, of laminated construction. A coil having large number of turns of fine wire is wound on the middle limb of the shunt magnet.
- This coil is known as "***pressure or voltage***" coil and is connected across the supply mains. This voltage coil has many turns and is arranged to be as highly inductive as possible. In other words, the voltage coil produces a high ratio of inductance to resistance.

# Single phase induction type energy meter

- Driving system
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# Single phase induction type energy meter

- Moving system
- The moving system essentially consists of a light rotating aluminium disk mounted on a vertical spindle or shaft. The shaft that supports the aluminium disk is connected by a gear arrangement to the clock mechanism on the front of the meter to provide information that consumed energy by the load.
- The time varying (sinusoidal) fluxes produced by shunt and series magnet induce eddy currents in the aluminium disc.

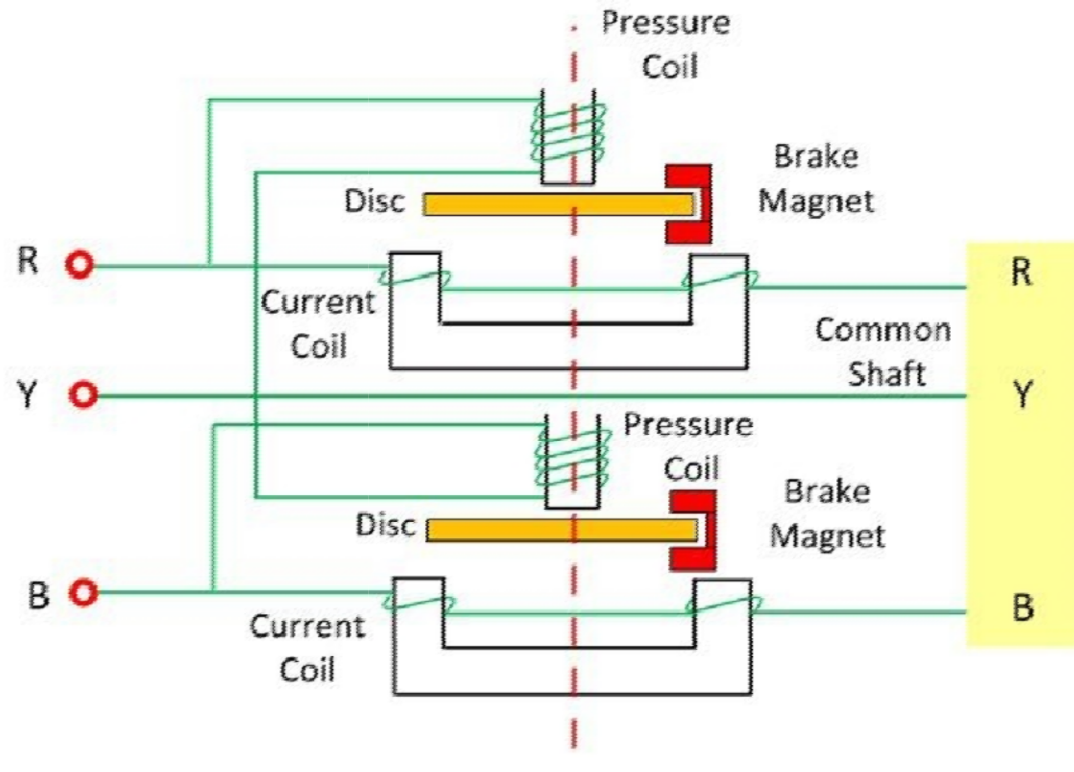
# Single phase induction type energy meter

- Braking system
- Damping of the disk is provided by a ***small permanent magnet***, located diametrically opposite to the a.c magnets. The disk passes between the magnet gaps. The movement of rotating disc through the magnetic field crossing the air gap sets up eddy currents in the disc that reacts with the magnetic field and exerts a braking torque.
- By changing the position of the brake magnet or diverting some of the flux there form, the speed of the rotating disc can be controlled.

# Single phase induction type energy meter

- he registering or counting system essentially consists of gear train, driven either by worm or pinion gear on the disc shaft, which turns pointers that indicate on dials the number of times the disc has turned.
- The energy meter thus determines and adds together or integrates all the ***instantaneous power values*** so that total energy used over a period is thus known.

# Three phase induction type energy meter



Three Phase Energy Meter

# Three phase induction type energy meter

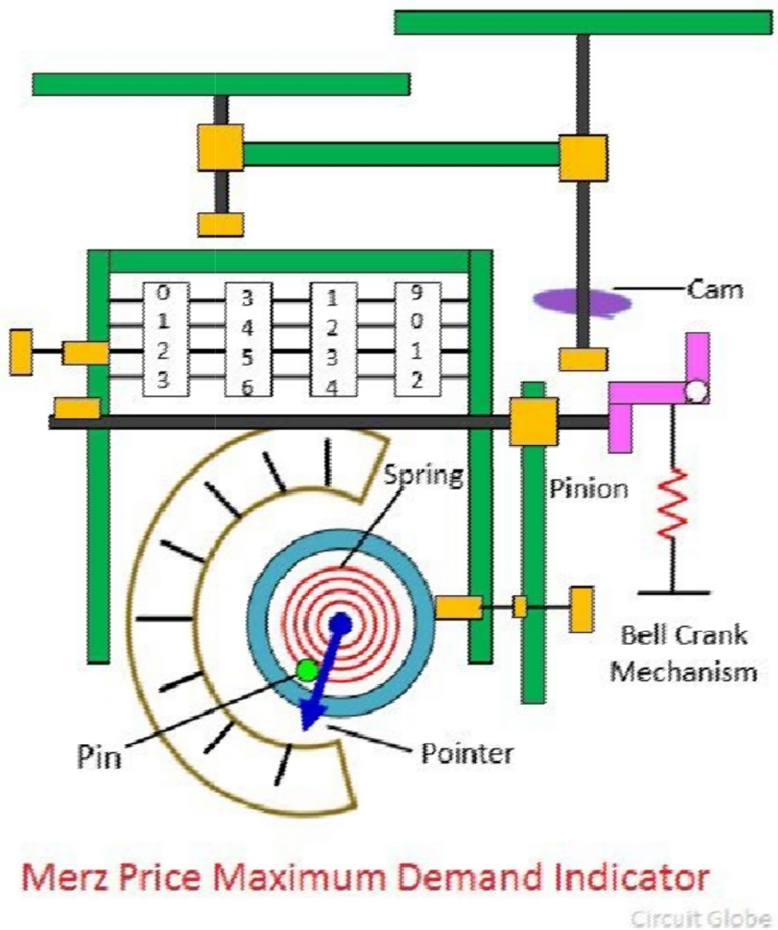
- **Definition:** The **meter** which is used for **measuring** the **power** of **three phase supply** is known as the three phase energy meter. The three phase **meter** is **constructed** by connecting the **two single phase meter** through the **shaft.** The **total energy** is the **sum** of the **reading** of **both** the **elements**.

- Working Principle of Three Phase Energy Meter
- The torque of both the elements is added mechanically, and the total rotation of the shaft is proportional to the three phase energy consumption.
- Construction of Three Phase Energy Meter
- The three phase energy meter has two discs mounted on the common shaft. Both the disc has its braking magnet, copper ring, shading band and the compensator for getting the correct reading. The two elements are used for measuring the three phase power. The construction of the three phase meter is shown in the figure belo

# Three phase induction type energy meter

- For three phase meter, the driving torque of both the elements is equal. This can be done by adjusting the torque. The torque is adjusted by connecting the current coils of both the elements in the series and their potential coils in parallel. The full load current is passed through the coil due to which the two opposite torque is set up in the coil.
- The strength of both the torques are equal, and hence they do not allow the disc to rotate. If the torque becomes unequal and the disc rotates then the magnetic shunt is adjusted. The balance torque is obtained before testing the meter. The position of the compensator and the braking magnet are separately adjusted to each of the element for obtaining the balance torque.

# Merz Price maximum demand indicator




Merz Price Maximum Demand Indicator

# Merz Price maximum demand indicator

- **Definition:** The maximum demand indicator measures the maximum amount of power requires by the consumer at the particular interval of time. The indicator is designed in such a way so that they measure the base and peak load but unable to measures the sudden short-circuit or starting high current of the motor. It is designed for recording the power over particular periods

# Merz Price maximum demand indicator

- he average demand indicator is inbuilt into the energy meter. The energy meter and average demand indicator together measures the total power consumes and the maximum value of specific power at particular interval of time. The average demand indicator consists the complex speed dial mechanism.

# Merz Price maximum demand indicator

- The pin drive moves the dial forward for small duration (say for half an hour). The total power consumes at that interval is shown on the dial. The instrument consists the cam which is controlled by the timing gears. The cam brings back the pointer at zero positions.
- The pointer records the total power consumes by the load at that particular interval of time. For the next half an hour, the pin again moved forward. But the pointer will move forward only when the total power consumed by the load is more than the previous periods.
- The formula calculates the average maximum demand,
- The maximum demand meter can measure the power regarding kVarh or kVah. This can be done by adding the suitable meter which will calculate such quantities.
- Advantages of Average Demand Indicator
- The average demand indicator has high accuracy.
- The instrument has uniform measuring scale.
- Disadvantages of Maximum Demand Indicator
- The cost of the instrument is very high.
- Their construction is very complicated.
- Nowadays, the cam is replaced by the electromagnetic relay and clutch the replaces the bell crank releasing device.

# Umit 5-Miscellaneous Measuring Instruments-Meggar

# Meggar

- Meggar is also known as megohmmeter**, The megger insulation tester is an instrument used for measuring high resistances of the order mega ohms and for testing the insulation resistance of an insulated body.
- **What is the working principle of meggar?**
- Working principle of a megger is based on the working principle of moving coil instruments, which states that when a current carrying conductor is placed in a magnetic field, a mechanical force is experienced by it.
- The magnitude and direction of this force depend upon the strength and direction of the current and magnetic field.

# Meggar

- **Construction of a Megger**
- The parts of meggar are as shown below.
- • It consists of a hand driven DC generator and a direct reading ohm meter.
- • There are two coils A and B which are fixed together at some angle and are free to rotate about a common axis between the poles of a permanent magnet.
- • The coils are connected in the circuit by means of flexible leads (or ligaments) which exerts no restoring torque on the moving system.
-

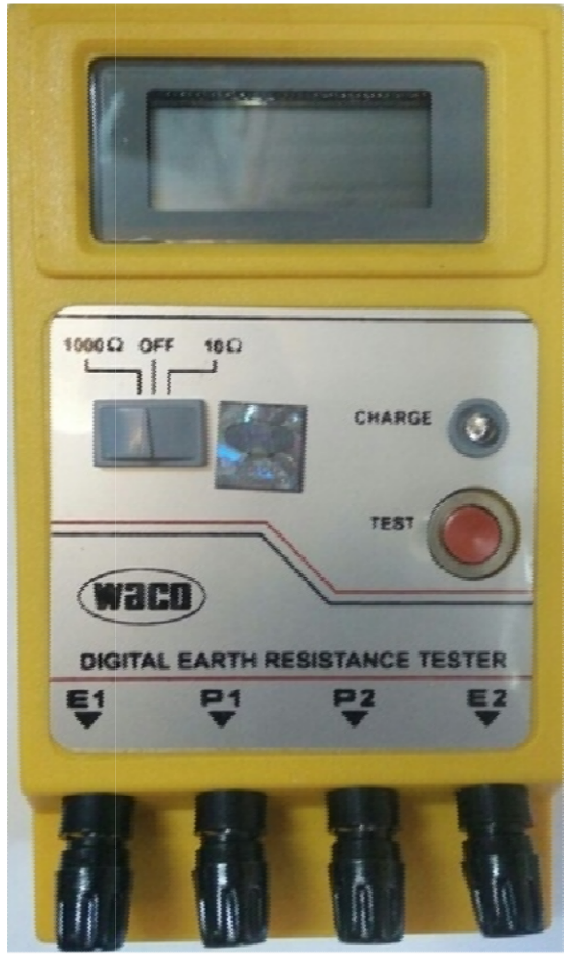
# Meggar

- The armature of the generator is rotated by the **hand driven crank lever.**
- The **clutch** mechanism is designed to slip at a predetermined speed.
- This facilitates the generator to maintain a constant speed and hence the constant voltage while testing.
- The two **coils A and B** constitutes a moving coil voltmeter and an ammeter. Both are combined to form one instrument.
- The hot terminal of the equipment whose insulation resistance has to be measured is connected to the testing **terminal X**. The terminal Y is connected to the body of the equipment, which is generally grounded.
- **How does a meggar works?**
- When the crank handle is rotated, a voltage is generated in the generator. This generator voltage is applied across the voltage coil A through a resistance R1.|
- This generator voltage is applied across the voltage coil A through a resistance R1

# Meggar

- When the terminal X & Y are free initially, no current flows through the coil B.
  The torque produced by the coil A rotates the moving element to show infinity.
-

# Earth tester



# Earth Tester

- **Definition:** The **instrument used for measuring the resistance of the earth is known as earth tester.** All the equipment of the power system is connected to the earth through the earth electrode. The earth protects the equipment and personnel from the fault current. The **resistance of the earth is very low**. The fault current through the earth electrode passes to the earth. Thus, protects the system from damage.

# Earth Tester

- The earth electrodes control the high potential of the equipment which is caused by the high lightning surges and the voltage spikes. The neutral of the three-phase circuit is also connected to the earth electrodes for their protection.
- Before providing the earthing to the equipment, it is essential to determine the resistance of that particular area from where the earthen pit can be dug. The earth should have low resistance so that the fault current easily passes to the earth. The resistance of the earth is determined by the help of earth tester instrument.
- Construction of Earth Tester
- The earth tester uses the hand driven generator. The **rotational current reverser and the rectifier are the two main parts of the earth tester**. The current reverser and the rectifier are mounted on the shaft of the DC generator. The earth tester works only on the DC because of the rectifier.

# Earth tester

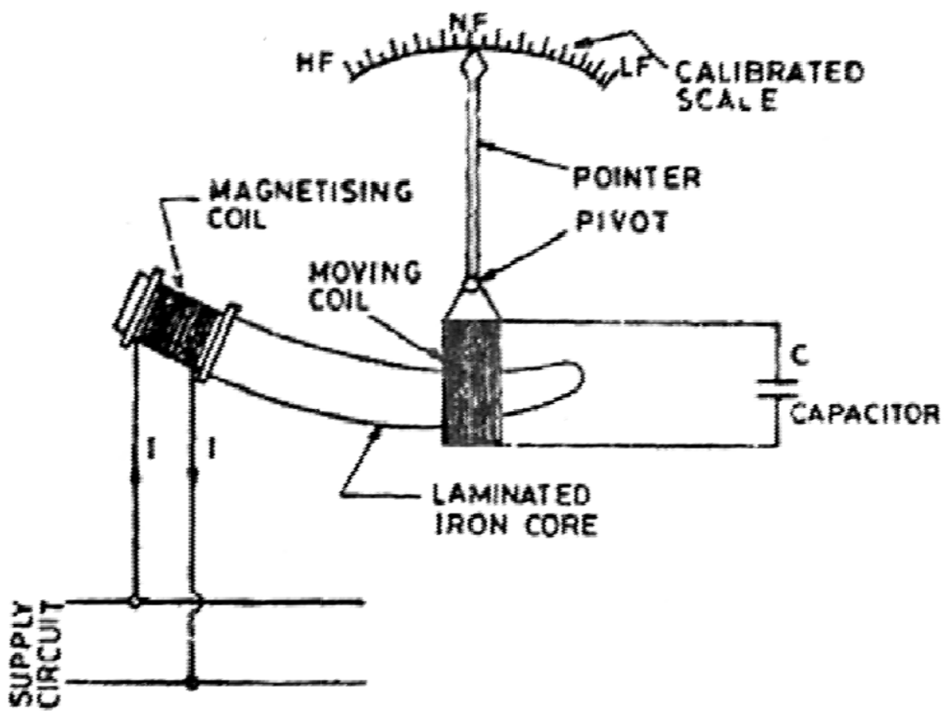
- The tester has two commutators place along with the current reverser and rectifier. The each commutator consist four fixed brushes. The commutator is a device used for converting the direction of flows of current. It is connected in series with the armature of the generator. And the brushes are used for transferring the power from the stationary parts to the moving parts of the devices.
- The arrangement of the brushes can be done in such a way that they are alternately connected with one of the segments even after the rotation of the commutator. The brushes and the commutators are always connected to each other.
- The **earth tester consists two pressures and the current coils.** The each coil has two terminals. The pair of the pressure coil and the current coil are placed across the permanent magnet. The one pair of current and pressure coil is short-circuited, and it is connected to the auxiliary electrodes.
- The one end terminal of the pressure coil is connected to the rectifier, and their other end is connected to the earth electrode. Similarly, the current coil is connected to the rectifier and earth electrode.
- The earth tester consists the potential coil which is directly connected to the DC generator. The potential coil is placed between the permanent magnet. The coil is connected to the pointer, and the pointer is fixed on the calibrated scale. The pointer indicates the magnitude of the earth resistance. The **deflection of the pointer depends on the ratio of the voltage of pressure coil to the current of the current coil.**
- The short-circuit current passes through the equipment to the earth is alternating in nature. Thus, we can say that the alternating current flows in the soil. This alternative current reduces the unwanted effect of the soil, which

# Multimeter

# Multimeter

- A **multimeter** or a multitester, also known as a VOM (volt-ohm-milliammeter), is an electronic measuring instrument that combines several measurement functions in one unit. A typical **multimeter** can measure voltage, current, and resistance. Analog **multimeters** use a microammeter with a moving pointer to display readings.

# Frequency meter




Electrical Resonance Frequency Meter.

# Frequency meter

- A **frequency meter** is an instrument that displays the frequency of a periodic electrical signal.
- Various types of frequency meters are used. Many are instruments of the deflection type, ordinarily used for measuring low frequencies but capable of being used for frequencies as high as 900 Hz. These operate by balancing two opposing forces. Changes in the frequency to be measured cause a change in this balance that can be measured by the deflection of a pointer on a scale. Deflection-type meters are of two types, electrically resonant circuits and ratiometers.
- An example of a simple electrically resonant circuit is a moving-coil meter. In one version, this device has two coils tuned to different frequencies and connected at right angles to one another in such a way that the whole element, with attached pointer, can move. Frequencies in the middle of the meter's range cause the currents in the two coils to be approximately equal and the pointer to indicate the midpoint of a scale. Changes in frequency cause an imbalance in the currents in the two coils, causing them, and the pointer, to move

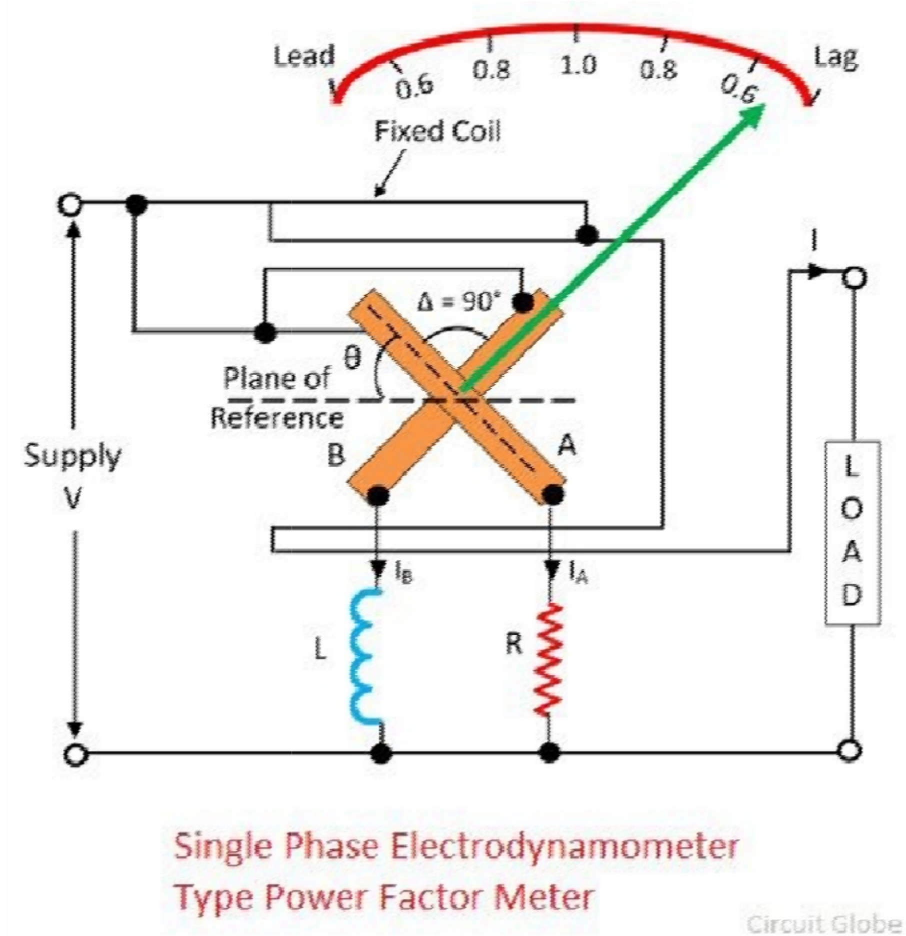
# Frequency meter

- Another type of frequency meter, Weston Frequency meter is not of the deflection type, is the resonant reed type, ordinarily used in ranges from 10 to 1,000 Hz, although special designs can operate at lower or higher frequencies.
- The main principle of working of weston type frequency meter is that "when an current flows through the two coils which are perpendicular to each other, due to these currents some magnetic fields will produce and thus the magnetic needle will deflects towards the stronger magnetic field showing the measurement of frequency on the meter". Construction of weston frequency is as compared to ferrodynamic type of frequency meter. In order to construct a circuit diagram we need two coils, three inductors and two resistors.
- Axis of both coils are marked as shown. Scale of the meter is calibrated such that at standard frequency the pointer will take position at 45o. Coil 1 contains a series resistor marked R1 and reactance coil marked as L1, while the coil 2 has a series reactance coil marked as L2 and parallel resistor marked as R2. The indcuctor which is marked as L0 is connected in series with the supply voltage in order to reduce the higher harmonic means here this inductor is working as a filter circuit. Let us look at the working of this meter.

# Frequency meter

- Now when we apply voltage at standard frequency then the pointer will take normal position, if there increase the frequency of the applied voltage then we will see that the pointer will moves towards left marked as higher side as shown in the circuit diagram. Again we reduce the frequency the pointer will start moving towards the right side, if lower the frequency below the normal frequency then it cross the normal position to move towards left side marked lower side as shown in the figure.
- Now let us look at the internal working of this meter. Voltage drop across an inductor is directly proportion to frequency of the source voltage, as we increase the frequency of the applied voltage the voltage drop across the inductor L1 increase that means the voltage impressed between the coil 1 is increased hence the current through the coil 1 increase while the current through the coil 2 decreases. Since the current through the coil 1 increases the magnetic field also increases and the magnetic needle attracts more towards the left side showing the increment in the frequency. Similar action will takes if decrease the frequency but in this the pointer will moves towards the left side.

# Single phase power factor meter

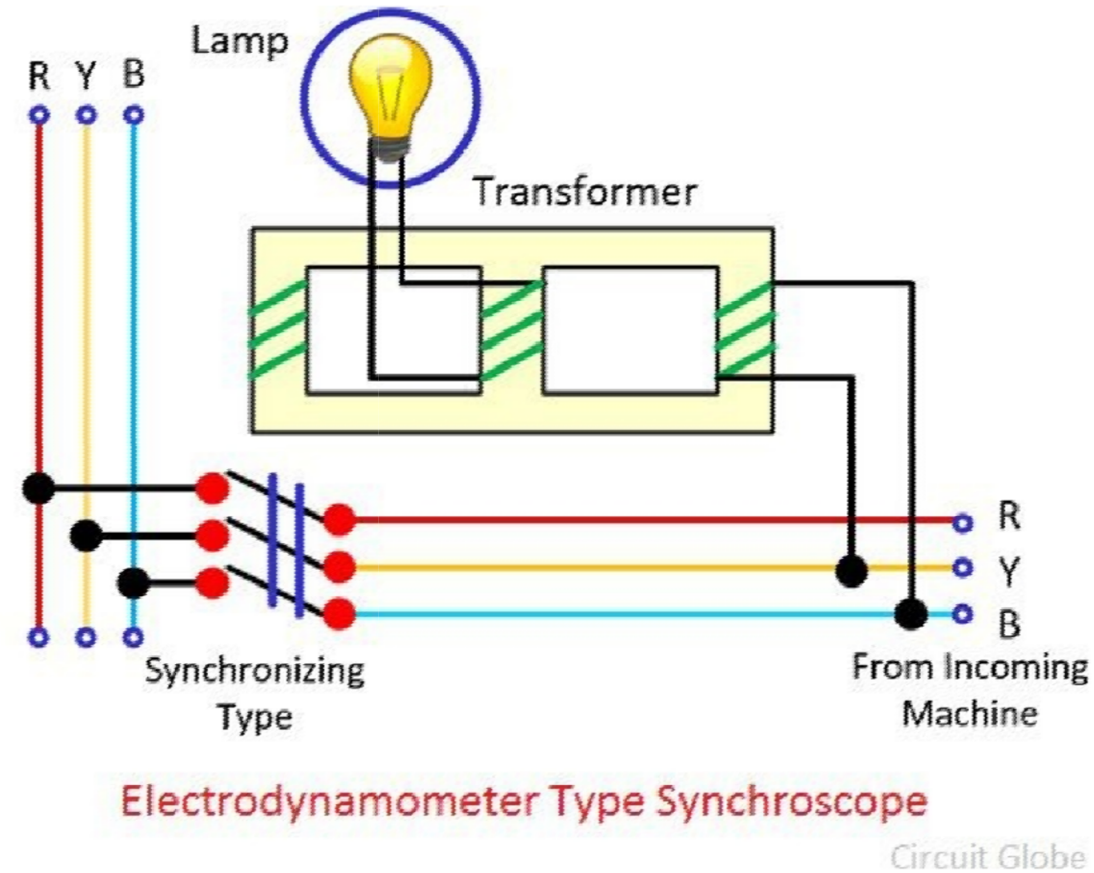



Single Phase Electrodynamometer
Type Power Factor Meter

# Single phase power factor meter

- **Electrodynamometer Type Power Factor Meter**. The general circuit diagram of **single phase electrodynamometer power factor meter** is given below. Now the pressure coil is split into two parts one is purely inductive another is purely resistive as shown in the diagram by resistor and inductor

# Synchroscope

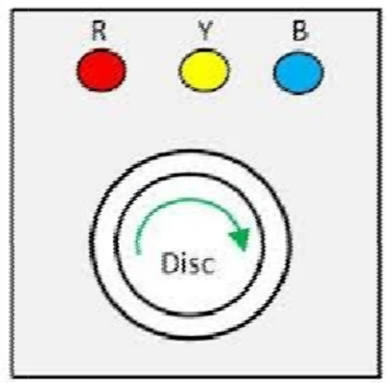



Electrodynamometer Type Synchroscope

# Synchroscope

- In AC electrical power systems, a **synchroscope** is a device that indicates the degree to which two systems (generators or power networks) are synchronized with each other.

# Phase sequence indicator




Rotating Type Phase
Sequence Indicator

# Phase sequence indicator

# Phase sequence indicator

- Phase sequence meter is used for detecting the sequence of the supply in three-phase electric circuits. Since the direction of rotation of three phase electric motors can be changed by changing the phase sequence of supply. And also the correct operation of measuring instruments like 3 phase energy meter and automatic control of devices also depend on the phase sequence. Different types of phase sequence testers are available in today's market like contact or non contact, static or rotating, etc., in a wide range of voltage or power rating

# Tong tester

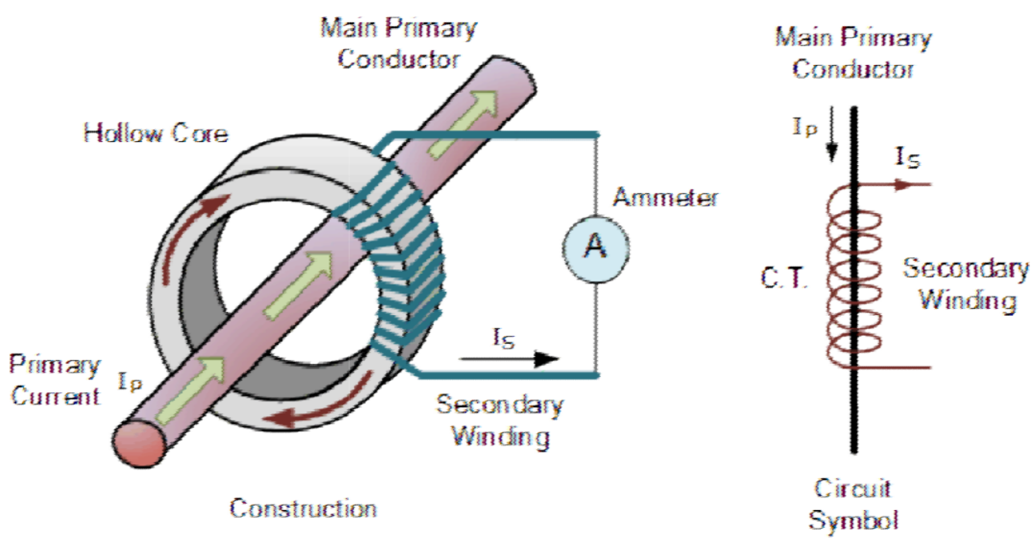
# Tong tester

- An electrical **tong tester** also known as clamp meter which measures current in a circuit in amperes which is a measurement of the electrons movement over a point during a given time period.

# Current transformer

- A **current transformer** (CT) is a type of **transformer** that is used to measure alternating **current** (AC). It produces a **current** in its secondary which is proportional to the **current** in its primary. **Current transformers**, along with voltage or potential **transformers**, are instrument **transformers**.

# Current transformer

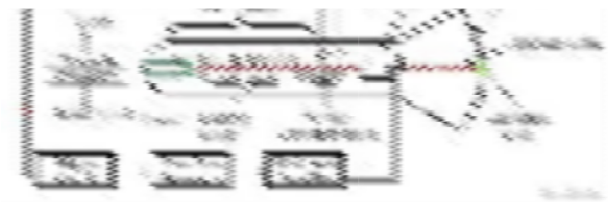


# Potential Transformer

# Potential Transformer

- **Potential transformer** is a **voltage** step-down **transformer** which reduces the **voltage** of a high **voltage** circuit to a lower level for the purpose of measurement. These are connected across or parallel to the line which is to be monitored.

# Unit 6-Electronic Instruments-Cathode Ray Oscilloscope(cro)

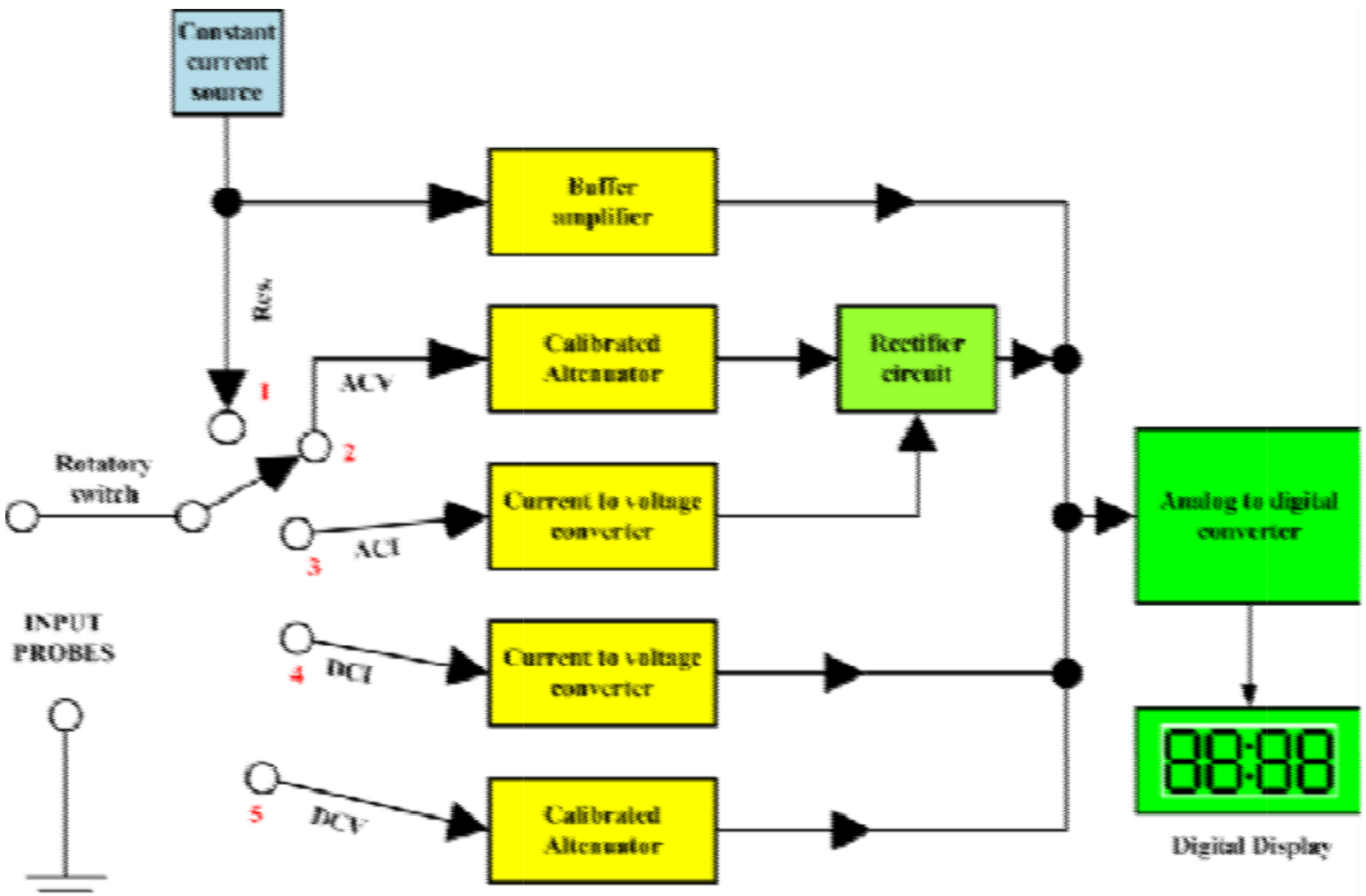


# CR

# CR

- The **CRO** stands for a **cathode ray oscilloscope**. It is typically divided into four sections which are display, vertical controllers, horizontal controllers, and Triggers. Most of the **oscilloscopes** are used the probes and they are used for the input of any instrument.

# Block digram ( Digital multimeter)



# Unit7-LCR METER

# LCR METER

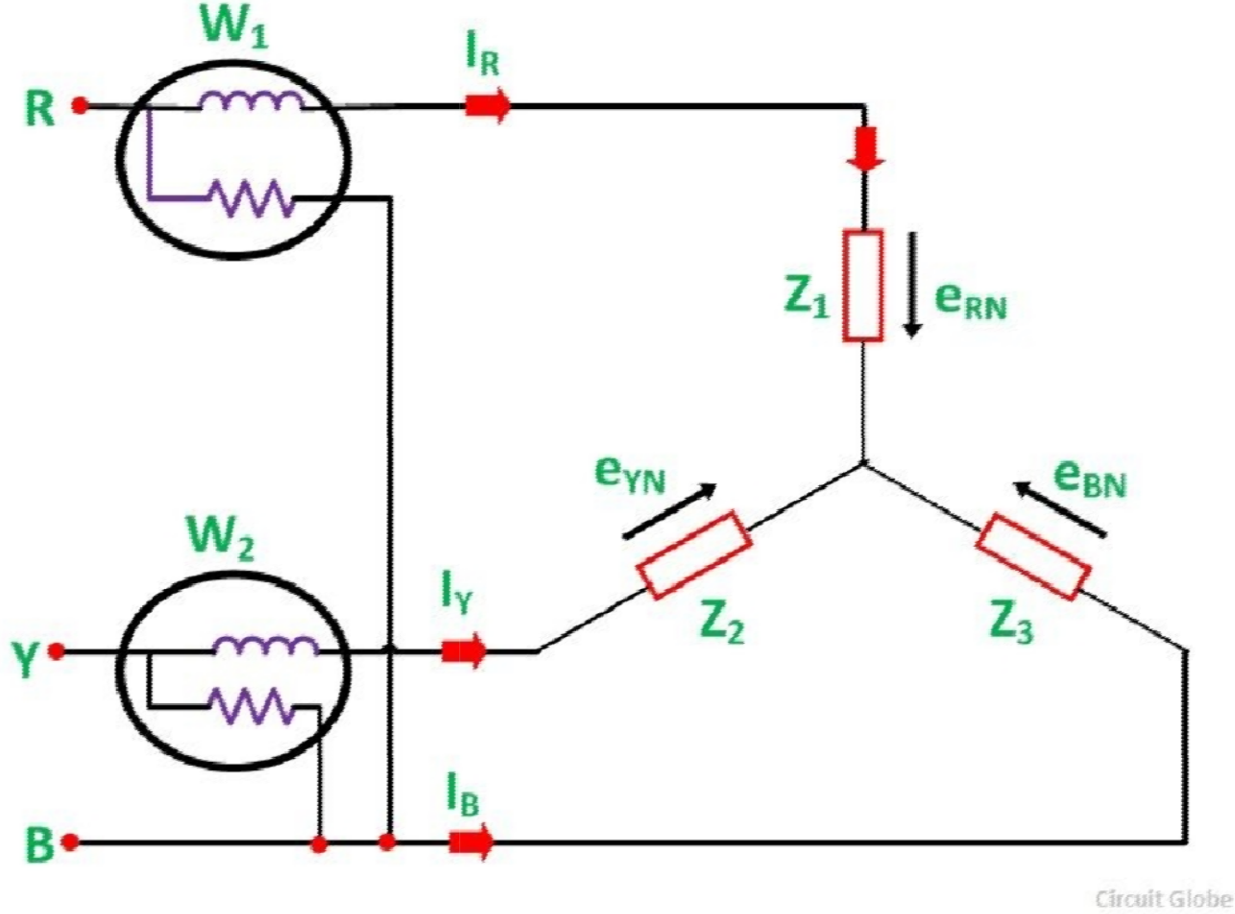
- An LCR meter is a type of electronic test equipment used to measure the inductance, capacitance, and resistance of an electronic component. In the simpler versions of this instrument the impedance was measured internally and converted for display to the corresponding capacitance or inductance value

# Unit8-Power measurement in three phase circuits

## Two Wattmeter method for power measurement

- The **two-wattmeter method** uses **two** single-phase **wattmeters** to **measure** three-phase **power**. ... Each measures the single phase **power** P1 and P2, respectively. The sum of the **two measured** values is equal to the total three-phase **power**.

# Two Wattmeter method for power measurement



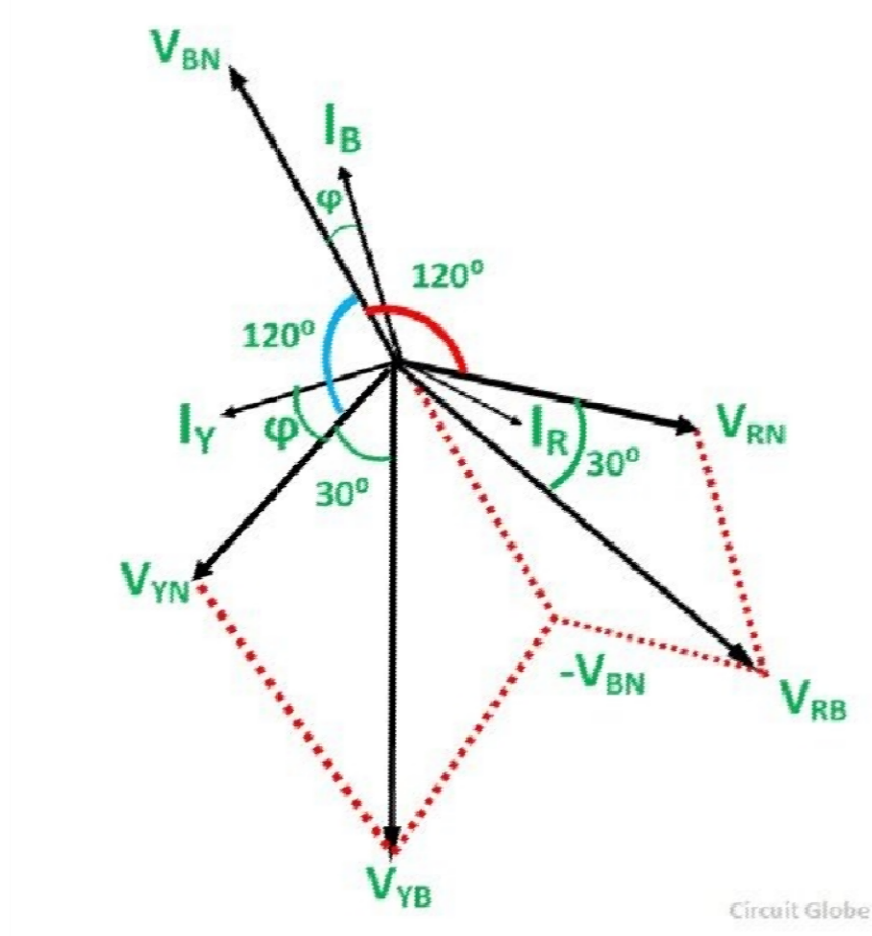
# Two Wattmeter method for power measurement

- Two Wattmeter Method – Balanced Load Condition
- The **Two Wattmeter Method** is explained, taking an example of a balanced load. In this, we have to prove that the power measured by the Two Wattmeter i.e. the sum of the two wattmeter readings is equal to root 3 times of the phase voltage and line voltage ($\sqrt{3} V_L I_L \cos\phi$) which is the actual power consumed in a 3 phase balanced load.

# Two Wattmeter method

- **Contents:**
- Determination of Power Factor from Wattmeter Readings
- Determination of Reactive Power by Two Wattmeter Method
- The load is considered as an inductive load, and thus, the phasor diagram of the inductive load is drawn below.

# Two Wattmeter method



# Two Wattmeter method

$$\cos\varphi = \cos\tan^{-1}\sqrt{3}\ \frac{W_1 - W_2}{W_1 + W_2}$$

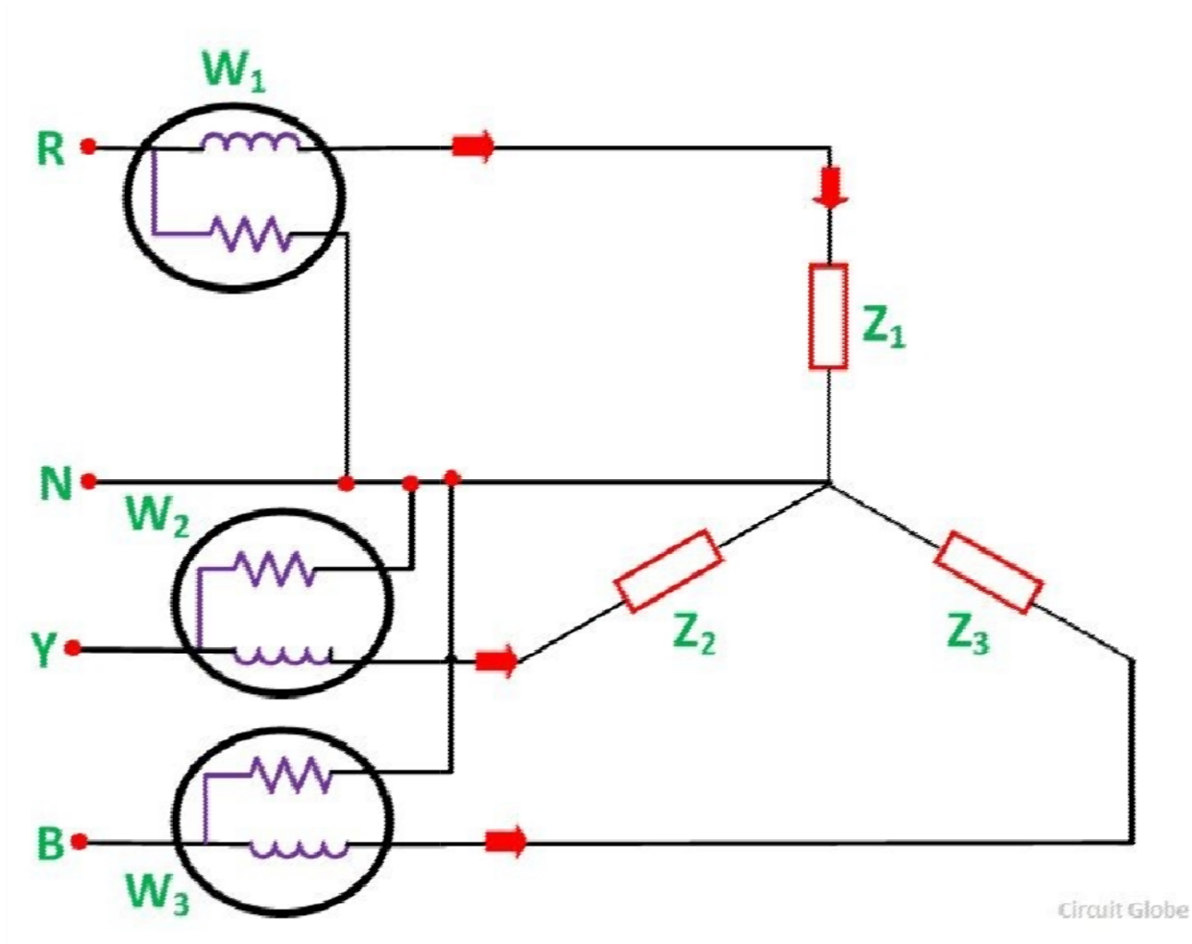
# Two Wattmeter method

- The above equation of power factor determination by two wattmeter method

# Three Wattmeter method for power measurement

- The total **power** in a **Three wattmeter method** of **power measurement** is given by the algebraic sum of the readings of **Three wattmeters**. i.e. Except for **3** phase, 4 wire unbalanced load, **3** phase **power** can be **measured** by using only Two **Wattmeter Method**.

# Three Wattmeter method for power measurement



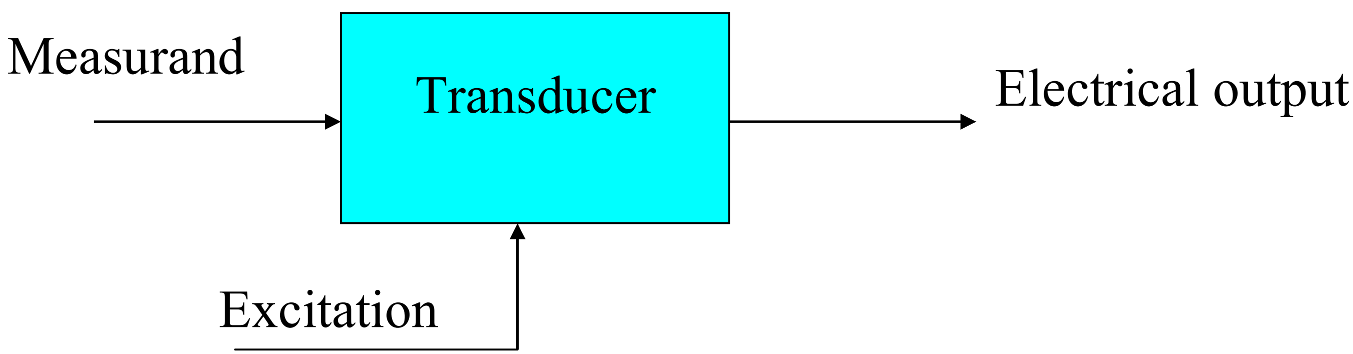
# Transducer

- Transducer is any device that converts energy in one form to another energy.
- The majority either convert electrical energy to mechanical displacement or convert some *non-electrical* physical quantity, such as temperature, sound or light to an electrical signal.

# Functions of transducer

1. To *sense* the presence, magnitude, change in, and frequency of some ***measurand***.

***2.*** To *provide* an electrical output that, when appropriately processed and applied to readout device, gives accurate quantitative data about the ***measurand.***




***Measurand*** – refers to the quantity, property or condition which the transducer translates to an electrical signal.

# Classification of transducers

Transducer can be classified into two major categories:

**A) Passive transducer:**

- requires an external power
- output is a measure of some electrical parameter, such resistance, inductance and capacitance. E.g. : condenser microphone

**B) Self generating transducer:**

- not require an external power, and they produce analog voltage or current when stimulated by some physical form of energy. E.g. : Thermocouple

# Electrical Transducers

Electrical transducer is a **sensing device** that transforms directly the physical, mechanical or optic quantity into an electrical voltage or current.

An electrical transducer must have the following parameters:

1. ***Linearity*** – Relationship between a physical parameter and the resulting electrical signal must be linear.

2. ***Sensitivity*** – High sensitivity is desirable for a transducer.

# Continued...........

3. ***Operating range*** – Operating range of the transducer should be wide, to permit its use under a wide range of measurement conditions.

4. ***Repeatability*** – Input/output ralationship for a transducer should be predictable over a long priod of time. This ensures reliability of operation.

5. ***Physical size*** – Transducer must have minimal weight and volume, so that its presence in the measurement system does not disturb the existing conditions.

The following are the different ***electric phenomena*** employed in the transduction elements of transducers:

1) Capacitive
2) Resistive
3) Inductive
4) Piezo-electric
5) Electromagnetic
6) Photo-emissive
7) Photo-resistive
8) Potentiometric
9) Thermo-electric
10) Frequency generating

# Types of Transducer

1. Resistive Position Transducers
2. Strain Gauge
3. Displacement Transducers
4. Capacitive Transducers
5. Inductive Transducers
6. Variable Inductance Transducers
7. Temperature Transducers
8. Photoelectric Transducer

Ultrasonic temperature transducer

thermistors

Thermocouples

Resistance temperature detectors (RTD)

# RESISTIVE POSITION TRANSDUCERS

A displacement transducer uses a resistance element with a ***sliding contact*** or ***wiper*** linked to an object being monitored or measured. Thus, the resistance between **slider** and one end of the resistive element depends on the position of the object.

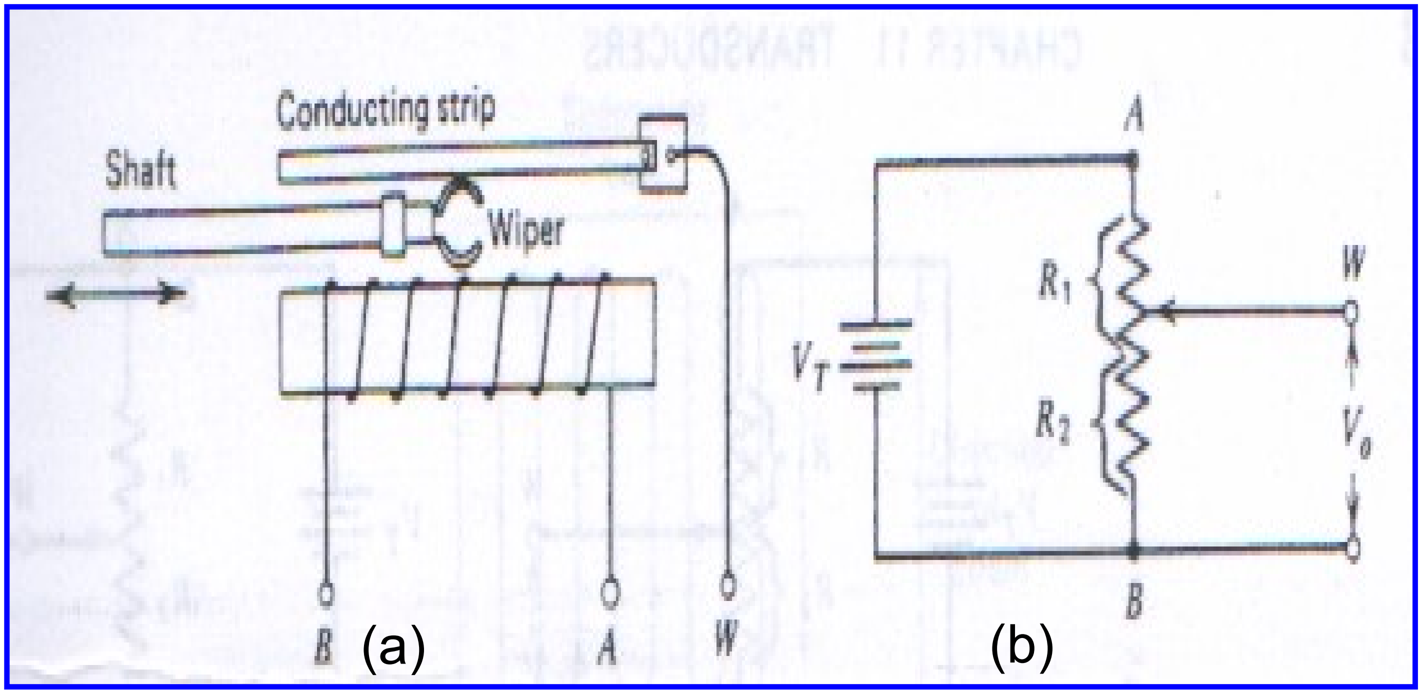



Fig.6-1: (a) Construction of a resistive position transducer and (b) typical method

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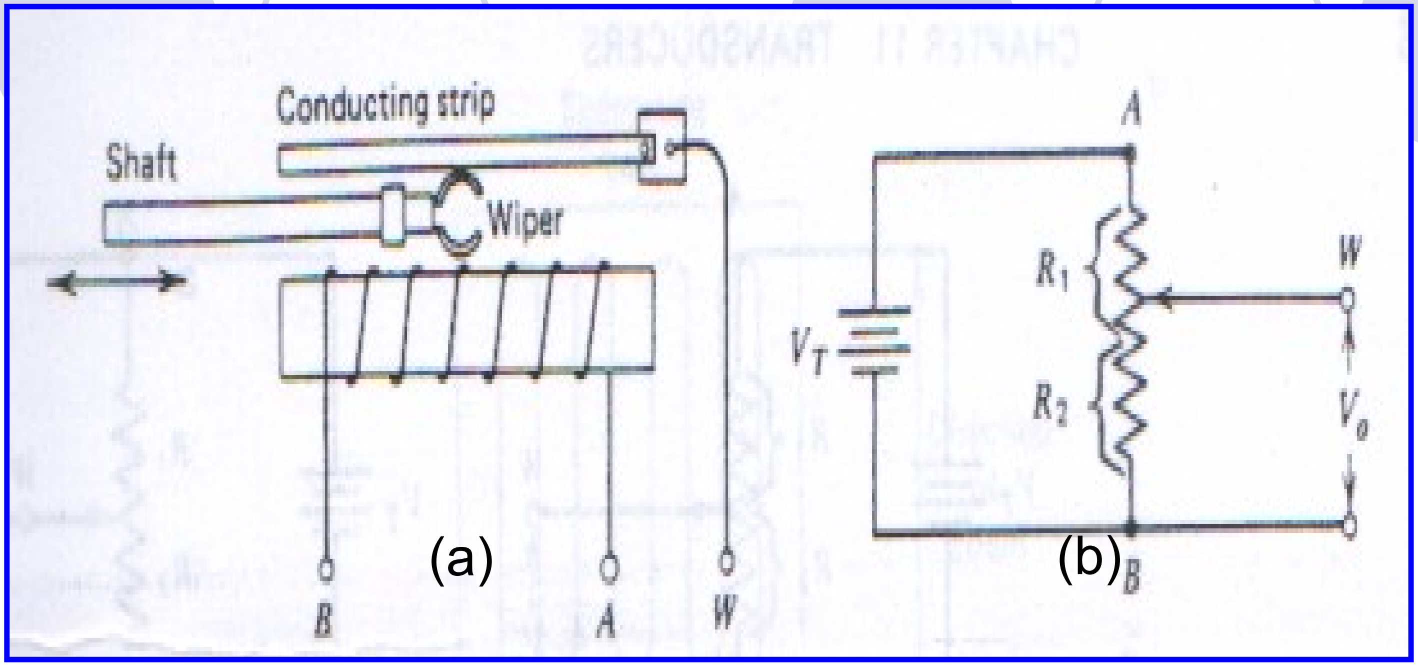



Consider Fig 1 (b), if the circuit is unloaded, the output voltage $V_0$ is a certain fraction of $V_T$, depending on the position of the wiper:

$$\frac{V_0}{V_T} = \frac{R_2}{R_1 + R_2}$$

or,

# Continued...........

$$V_0 = \frac{R_2}{R_1 + R_2} V_T \qquad (6.1)$$

This equation shows that the output voltage is directly proportional to the position of the wiper, if the resistance of the transducer is distributed uniformly along the length of travel of the wiper.

EXAMPLE-1:

A displacement transducer with a shaft stroke of 4 in. is used in the circuit of figure 1 (b). $R_1 + R_2$ is 1000 Ω and $V_T$ = 4 V. The wiper is 1.5 in from B. Find $V_0$?

# STRAIN GAUGE

- The strain gauge is an example
- of a **passive transducer** that
- uses electric resistance
- variation in wires to sense the
- strain produced by a force on
- the wires.

- It is a very versatile detector and
- used for measuring **weight,**
- **pressure, mechanical force,**
- **or displacement.**

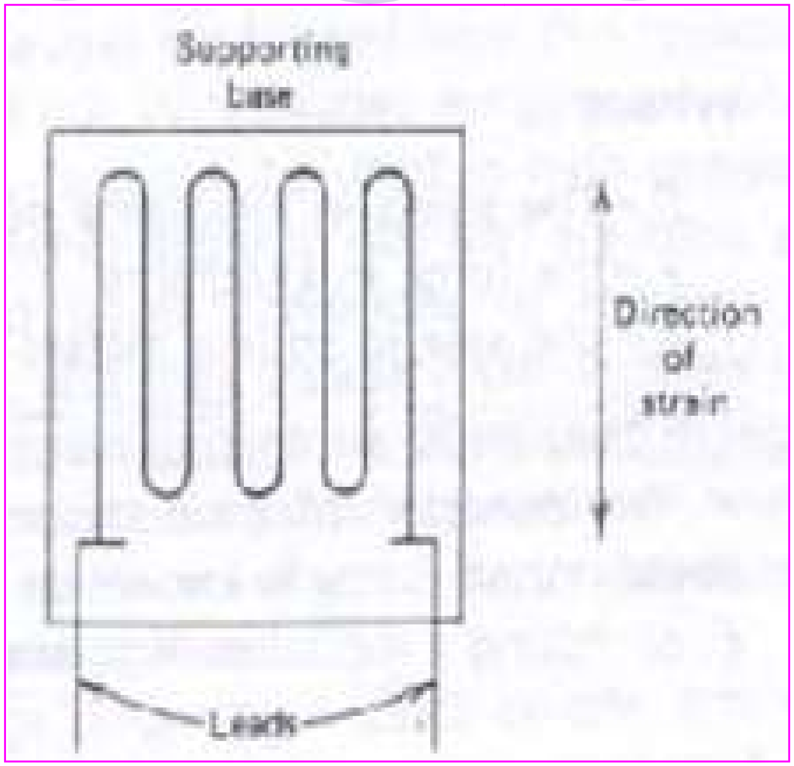



Figure 6-2: Resistive strain gauges: wire construction

# Continued...........

- The construction of a bonded strain
- gauge (see figure) shows a ***fine***
- ***wire element looped back and***
- ***forth on a mounting plate***, which
- is usually cemented to the member
- undergoing stress.

- When a gauge is subjected to a
- stress, its length increases while its
- cross-sectional area decreases.

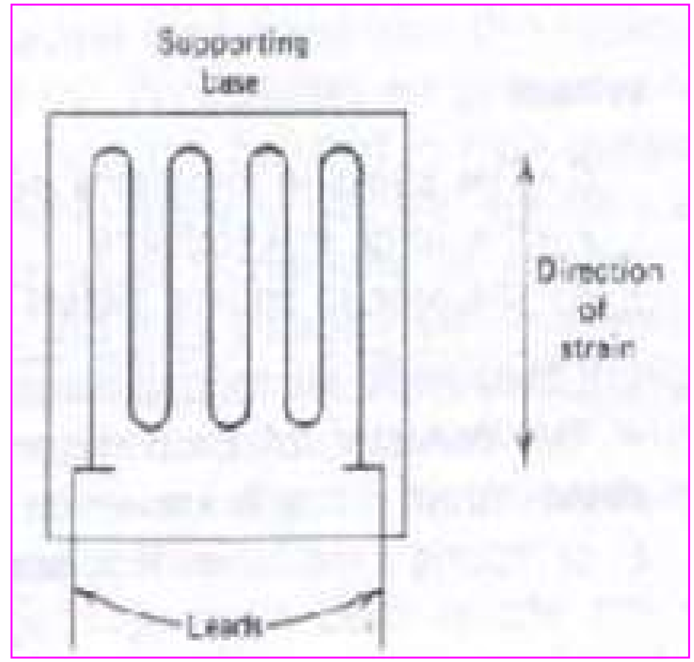



Figure 6-2: Resistive strain gauges: wire construction

From Hooke theory, stress, S, is defined as force/unit area.

$$\boxed{S = \frac{F}{A}} \tag{6.2}$$

where,

F= the force in kilograms
A= area in square meters ($m^2$)

The increase in resistance can be seen from the following equation:

$$\boxed{R = \rho \frac{L}{A}} \tag{6.3}$$

where,

$\rho$ = the specific resistance of the conductor material in ohm meters
$L$ = length of conductor (meters)
$A$ = area of conductor ($m^2$)

Since the resistance of a conductor is directly proportional to its length and inversely proportional to its cross-sectional area, the resistance of the gauge increases with strain.

Strain, G is defined as ***elongation or compression per unit length,*** or:

$$\boxed{G = \frac{\Delta L}{L}} \qquad (6.4)$$

where,

L = the initial length in meters (without strain)
$\Delta$L = the change in initial length in meters

As consequence of strain, **TWO (2)** physical qualities are of particular interest:

**1) The change in gauge resistance**

**2) The change in length**

The relationship between these two variables called gauge factor, K, is expressed mathematically as

$$\boxed{K = \frac{\Delta R / R}{\Delta L / L} = \frac{\Delta R / R}{G}} \qquad (6.5)$$

where,

K = the gauge factor

R = the initial resistance in ohms (without strain)

$\Delta$R = the change in initial resistance in ohms

The constant of proportionality between stress and strain for a linear stress-strain curve is known as the ***modulus of elasticity*** of material E or called Young's modulus. It is written as:

$$E = \frac{S}{G} \tag{6.6}$$

where,

E = Young modules in $kg/m^2$

S = the stress in $kg/m^2$

G = the strain (no units)

# DISPLACEMENT TRANSDUCERS

Most displacement transducers sense displacement by means of a **sensing shaft**, which is mechanically connected to the point or object whose displacement is to be measured.

The mechanical elements that are used to convert the applied force into a displacement are called **force-summing devices**.

Various types of displacement transducers:

(i) Reluctive transducer – used in AC measuring circuits.
(ii) Potentiometric transducer – used in DC systems.
(iii) Digital output transducer – used when very close accuracy of measurements required.

# 6.4. CAPACITIVE TRANSDUCERS

A change in capacitance with changes in position of a moving element is used to provide an electrical indication.
The general equation to determine the capacitance is given by

$$\boxed{C = \frac{kA\varepsilon_0}{d}(Farads)} \qquad (6.7)$$

where,

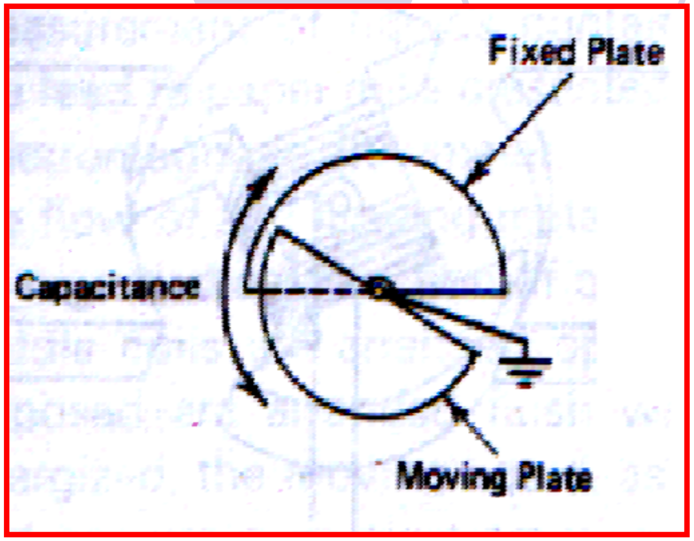
| | | |
|---|---|---|
| $k$ | = dielectric constant |
| $A$ | = the area of the plate, in $m^2$ |
| $\varepsilon_o$ | = $8.854 \times 10^{-12}$ in farads per meter (F/m) |
| $d$ | = distance between two capacitive surface in m |

# Continued...........

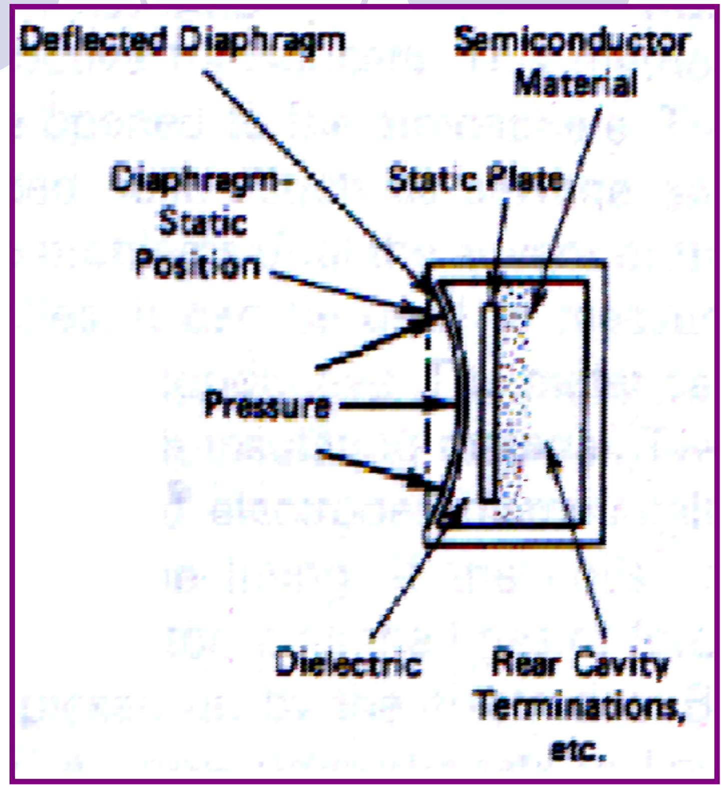
$$\boxed{C = \frac{kA\varepsilon_0}{d}(Farads)}$$

From this equation, can be seen that the capacitance increases if the effective area is increased and it decreases if the distance between two capacitive surface (usually, spacing of parallel plates) is increased.

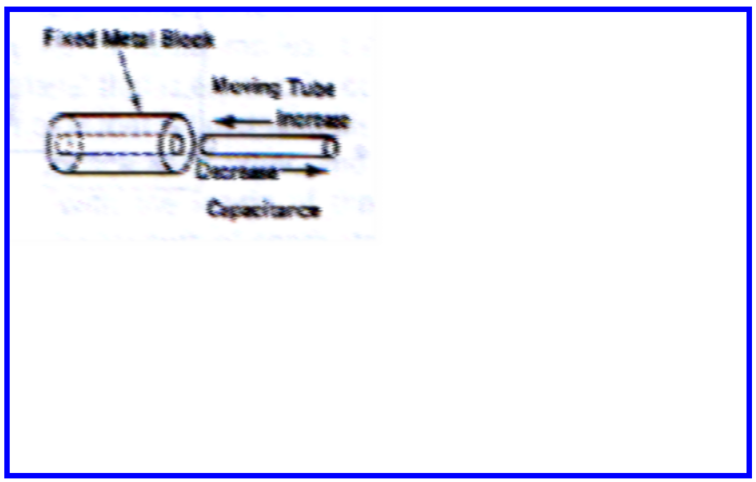
# Forms of Capacitance Transducers




**Rotary plate capacitor**

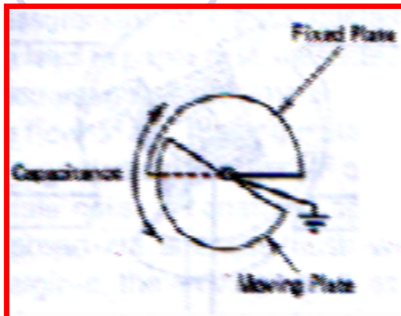



**Thin diaphragm**




**Rectilinear Capacitance Transducer**

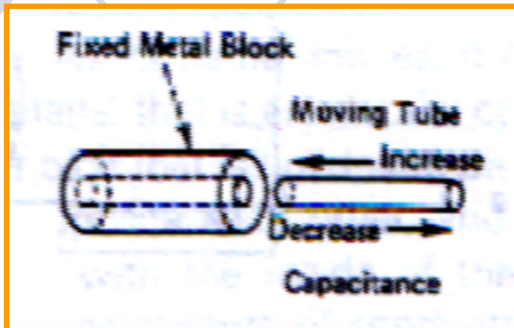
# Rotary plate capacitor




- This transducer is made up of a fixed plate called **Stator** and a movable plate called **Rotor**.

- When the rotor changes its position relative to the stator, the effective area between the plates is also changed and in turns, changing the capacitance.

# Rectilinear capacitance transducer



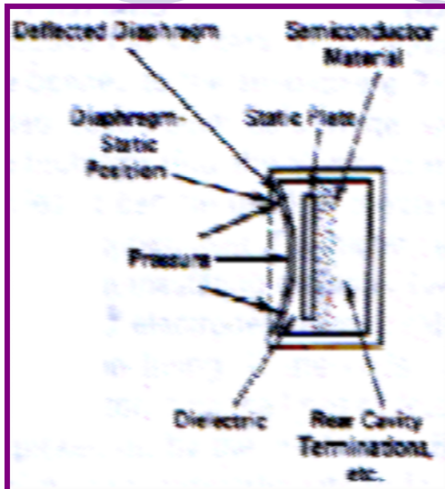

It consists of a fixed cylinder and a movable cylinder. These pieces are configured so the moving piece fits inside the fixed piece but insulated from it.

# Thin diaphragm

- Thin diaphragm is a transducer
- that makes use of variation in
- capacitance resulting from a
- change in spacing between
- capacitive surfaces.

- This transducer is designed to
- measure pressure.

- The dielectric can be either air
- or vacuum.



The change in pressure may be easily detected by the variation of capacity between a fixed plate and another plate free to move as the pressure changes.

The resulting variation follows the basic capacity formula:

$$\boxed{C = 0.085\frac{K(n-1)A}{t}} \quad (pF) \qquad (6.8)$$

where,

A = area of one side of one plate in $cm^2$

n = number of plates

t = thickness of dielectric in cm

K = dielectric constant

## Advantages:

1. Has excellent frequency response
2. Can measure both static and dynamic phenomena.
3. Simple to construct
4. Inexpensive to produce

## Disadvantages:

1. Sensitive to temperature variations.
2. Sensitive to the possibility of erratic or distortion signals owing to long lead length

## Applications:

1. As frequency modulator in RF oscillator
2. In capacitive microphone
3. Used as one part of an AC bridge circuit to produce an AC output signal

# TEMPERATURE TRANSDUCERS

Temperature transducers can be divided into four main categories:

- Resistance temperature detectors (RTDs)
- Thermocouples
- Thermistors
- Ultrasonic transducer

# Resistance Temperature Detectors (RTD)

RTD is a **passive** device whose resistance changes with temperature. This condition causes RTD needs an electrical supply to give a voltage output.

RTD commonly employ platinum, nickel or any resistance wire, whose resistance variation with temperature has high intrinsic accuracy.

They are available in many configurations and size.

The relationship between temperature and resistance of conductors in the temperature range near $0^{o}C$ can be calculated from the equation:

$$R_t = R_{ref}(1 + \alpha\Delta t) \qquad (6.9)$$

R = the resistance of the conductor at temperature t (°C)

$R_0$ = the resistance at the reference temperature, usually 20°C

α = the temperature coefficient of resistance

ΔT = the difference between the operating and the reference temperature

## Advantages of RTD:

1. Linearity over a wide operating range
2. Wide operating range
3. Higher temperature operation
4. Better stability at high temperature

## Disadvantages of RTD:

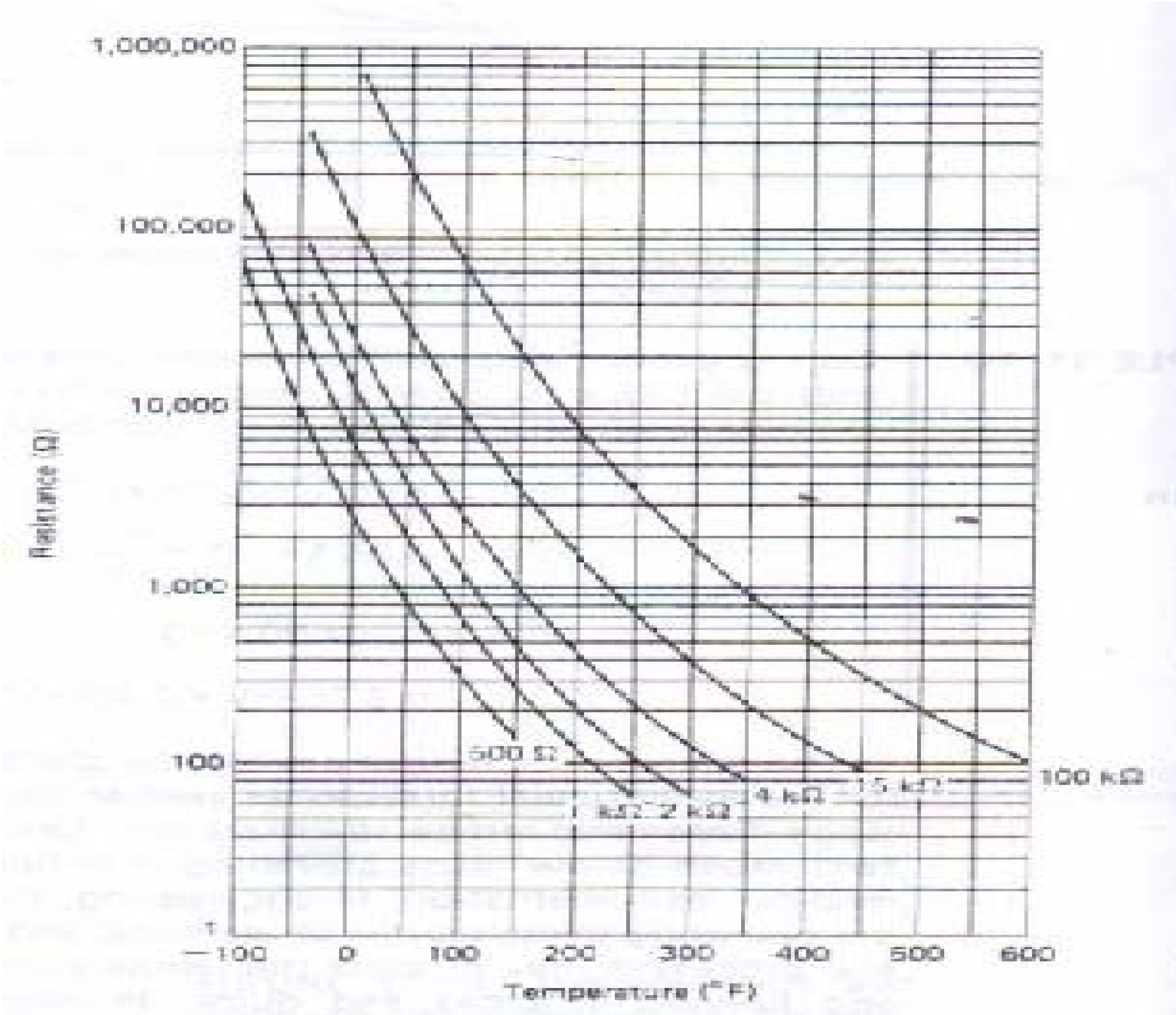
1. Low sensitivity
2. It can be affected by contact resistance, shock and vibration
3. Requires no point sensing
4. Higher cost than other temperature transducers
5. Requires 3 or 4 wire for its operation and associated instrumentation to eliminate errors due to lead resistance

# Thermally Resistor (Thermistor)

A thermistor is a thermally sensitive resistor that exhibits change in electrical resistance with change in temperature.

Thermistor is fabricated from semiconductor material by sintering mixtures of metallic oxide, such as manganese, nickel, cobalt, copper and uranium oxides.

Thermistors have Negative Temperature Coefficient (NTC), i.e. **resistance decreases as temperature rises**. Thermistor are available with Positive Temperature Coefficient (PTC), but PTC thermistor are seldom used for measurement since they have poor sensitivity.




Graph showing resistance versus temperature for a family of thermistors is given

# Advantages of Thermistor:

1. Small size and low cost
2. Fast response over narrow temperature range
3. Good sensitivity in the NTC region
4. Cold junction compensation not required due to dependence of resistance on absolute temperature.
5. Contact and lead resistance problems not encountered due to large resistance

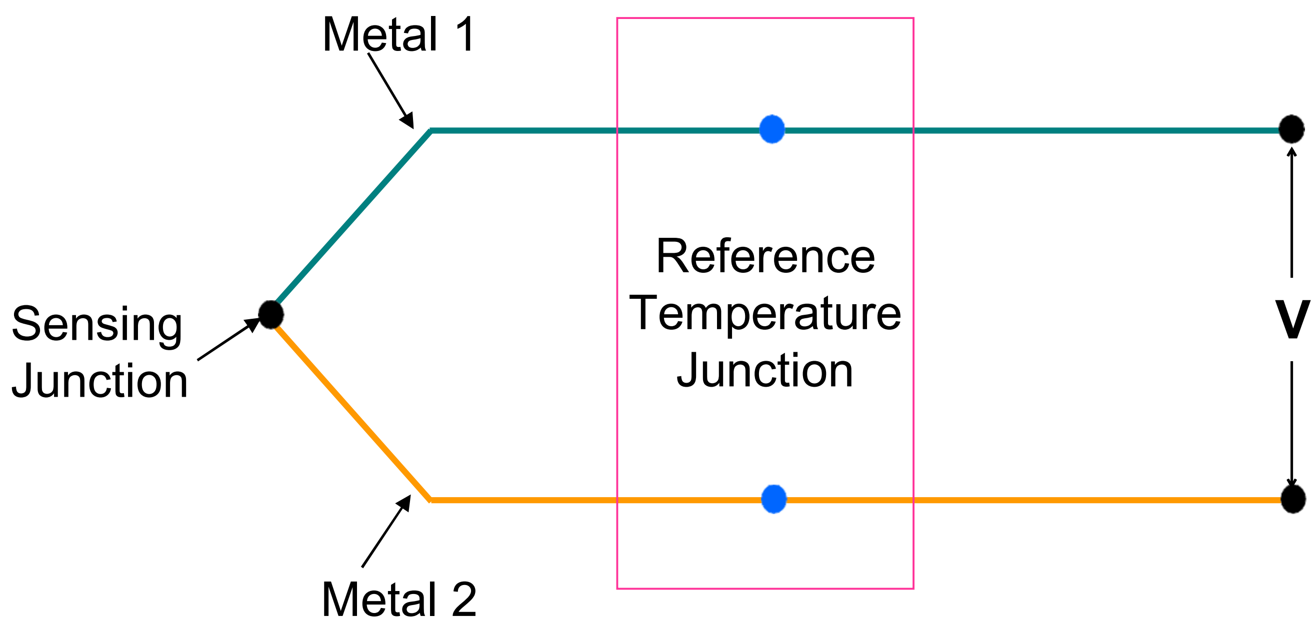
## Limitations of thermistor:

- ❖ Non linearity in resistance vs temperature characteristics
- ❖ Unsuitable for wide temperature range
- ❖ Very low excitation current to avoids self heating
- ❖ Need of shielded power lines, filters, etc due to high resistance

## Thermocouple

Thermocouple is made up of a pair of different metal wire joined together at one end.

A temperature difference between two ends of the wires produces a voltage between the wires.



The magnitude of this voltage (emf) depends on the wire materials used and on the temperature difference between the junctions.

The emf of the thermocouple is given as

$$\boxed{E = c(T_1 - T_2) + k(T_1^2 - T_2^2)} \qquad (6.10)$$

where,

c & k = constants of the thermocouple materials

$T_1$ = the temperature of the “hot” junction

$T_2$ = the temperature of the “cold” or “reference” junction

# 6.6 Photoelectric Transducer

Photoelectric devices Can be categorized as:
**photoemissive**, **photoconductive**, or **photovoltaic**.

| No. | Types | Characteristics |
|---|---|---|
| 1. | Photoemmisive | radiation falling into a cathode causes electrons to be emitted from cathode surface. |
| 2. | Photoconductive | the resistance of a material is changed when it's illuminated. |
| 3. | Photovoltaic | Generate an output voltage proportional to radiation intensity |

## Types of Photoelectric Transducer

(i) The Photomultiplier Tube

(ii) Photoconductive Cells or Photocells

(iii) The Photovoltaic Cell

THE END