1.Measuring Instruments

Basic Terminology:

Measurements: It is the process of comparison of standard quantity with the measured quantity.
Accuracy: It is defined as closeness to any value of instrument reading to true value.
Precision : It refers to the closeness of two or more measurements to each other. For example , if you weigh a given substance five times, and get 3.2 kg each time, then your measurement is very precise.
Error: Any measurement made with a measuring device is approximate. If you measure the same object two different times, the two measurements may not be exactly the same. **The difference between two measurements** is called an error. The error in measurement is a mathematical way to show the uncertainty in the measurement.
Resolution : It is defined as the smallest or least change in the input which can be detected by the measuring instrument.
Sensitivity: It is defined as **the ratio of the changes in the output of an instrument to a change in the value of the quantity being measured**. It denotes the smallest change in the measured variable to which the instrument responds.
Tolerance: Engineering tolerance is the permissible limit or limits of variation in a physical dimension; a measured value or physical property of a material, manufactured object, system, or service; other measured values (such as temperature, humidity, etc.).
Static Characteristics: These are used to measure the condition when it is not varying with respect to time.
Condition of Instruments:
The instruments can broadly classified into two types:

1) Absolute Instruments
2) Secondary Instrument

1) Absolute Instruments: These instruments give the magnitude of the physical constant of the instrument. These are generally not available in the market for public use and measurement is very time consuming.

2) Secondary Instruments: These instruments are used in general for all laboratory purposes. Some of the very widely used secondary instruments are: **ammeters, voltmeter, wattmeter, energy meter (watt-hour meter), ampere-hour meters** etc.

Deflection Controlling and Damping arrangements in indicating type instruments: In indicating type instruments a pointer is present which moves over the calibrated scale. In these types of instruments generally three types of torques are developed:

1) Deflecting Torque: One important requirement in indicating instruments is the arrangement for producing deflecting or operating torque (Td) when the instrument is connected in the circuit to measure the given electrical quantity. This is achieved by utilizing the various effects of electric current or voltage mentioned in the previous article. The deflecting torque causes the moving system (and hence the pointer attached to it) to move from zero position to indicate on a graduated scale the value of electrical quantity being measured. The actual method of producing the deflecting torque depends upon the type of instrument and shall be discussed while dealing with particular instrument

2) **Controlling Torque:**

If deflecting torque were acting alone, the pointer would continue to move indefinitely and would swing over to the maximum deflected position irrespective of the magnitude of current (or voltage or power) to be measured.

This necessitates providing some form of controlling or opposing torque (TC). This controlling torque should oppose the deflecting torque and should increase with the deflection of the moving system. The pointer will be brought to rest at a position where the two opposing torques are equal i.e. Td = TC. The controlling torque performs two functions:

(i) It increases with the deflection of the moving system so that the final position of the pointer on the scale will be according to the magnitude of current (or voltage or power) to be measured

(ii) It brings the pointer back to zero position when the deflecting torque is removed. If it were not provided, the pointer once deflected would not return to zero position on removing the deflecting torque.

The controlling torque in indicating instruments may be provided by one of the following two methods:

1. By one or more springs = spring control

2. By weight of moving parts =Gravity control

Spring Control: This is the most common method of providing controlling torque in electrical instruments. A spiral hairspring made of some non-magnetic material like phosphor bronze is attached to the moving system of the instrument as shown in Fig. A with the deflection of the pointer, the spring is twisted in the opposite direction. This twist in the spring provides the controlling torque. Since the torsion torque of a spiral spring is proportional to the angle of twist, the controlling torque is directly proportional to the deflection of the pointer i.e. $TC \propto \theta$

The pointer will come to rest at a position where controlling torque TC is equal to the deflecting torque Td i.e. Td = TC. In an instrument where the deflecting torque is uniform, spring control provides a linear or evenly-spaced scale over the whole range. For example, in a permanent-magnet moving coil instrument, the deflecting torque is directly proportional to the current flowing through the operating coil i.e. $Td \propto I$

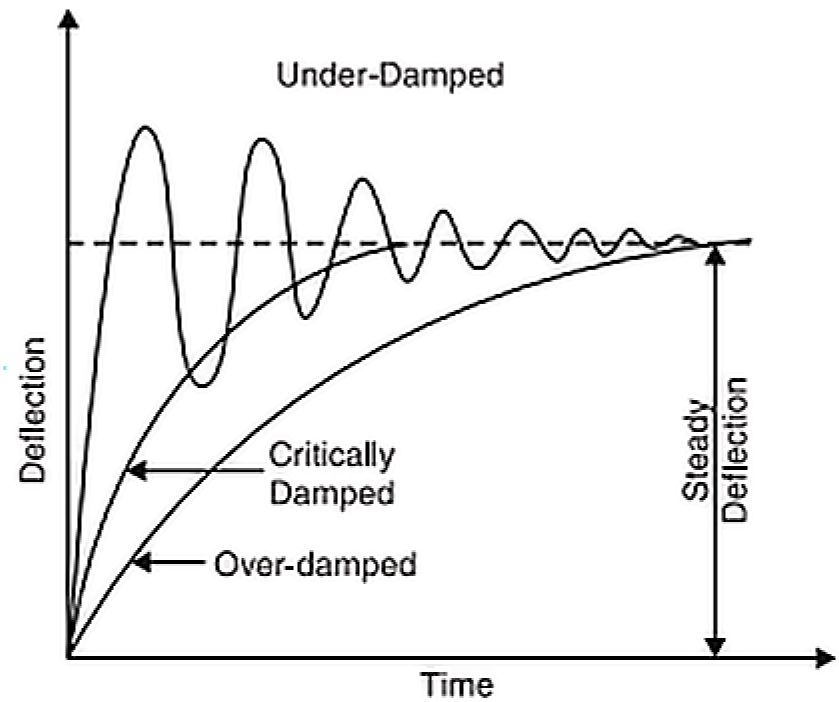
With spring control, $TC \propto \theta$

In the final deflected position, Td = TC

$$\therefore \theta \propto I$$

Since the deflection is directly proportional to I, the scale of such an instrument will be linear (uniform).

Damping Torque: If the moving system is acted upon by deflecting and controlling torques alone, then the pointer, due to inertia, will oscillate about its final deflected position for quite some time before coming to rest. This is often undesirable because it makes it difficult to obtain quick and accurate readings. In order to avoid these oscillations of the pointer and to bring it quickly to its final deflected position, a damping torque is provided in the indicated instruments. This damping torque acts only when the pointer is in motion and always opposes the motion. The position of the pointer when stationary is, therefore, not affected by damping.



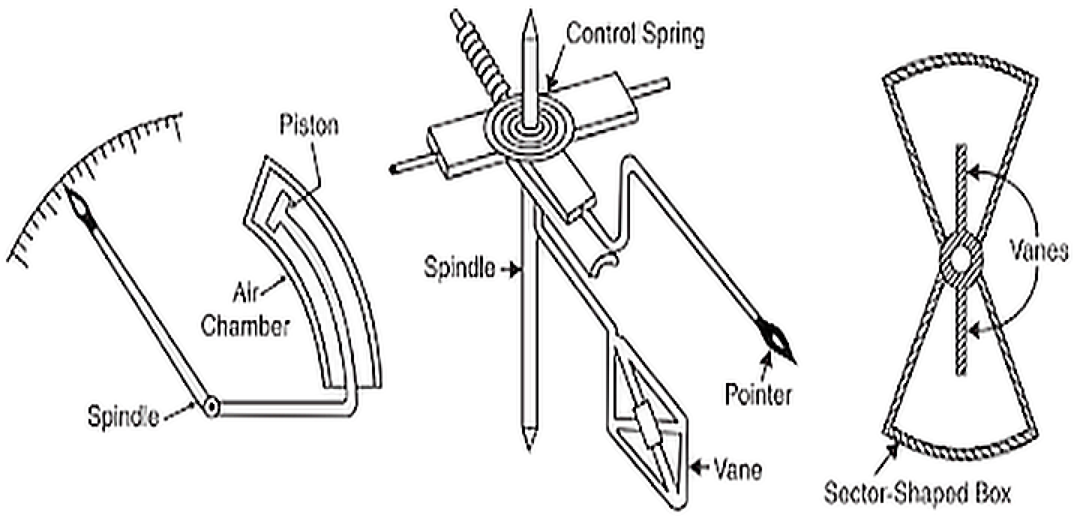
The degree of damping decides the behavior of the moving system. If the instrument is under-damped, the pointer will oscillate about the final position for some time before coming to rest. On the other hand, if the instrument is over-damped, the pointer will become slow and lethargic. However, if the degree of damping is adjusted to such a value that the pointer comes up to the correct reading quickly without passing beyond it or oscillating about it, the instrument

is said to be dead-beat or critically damped. shows graphs for under-damping, over damping and critical damping (dead-beat). The damping torque in indicating instruments can be provided by

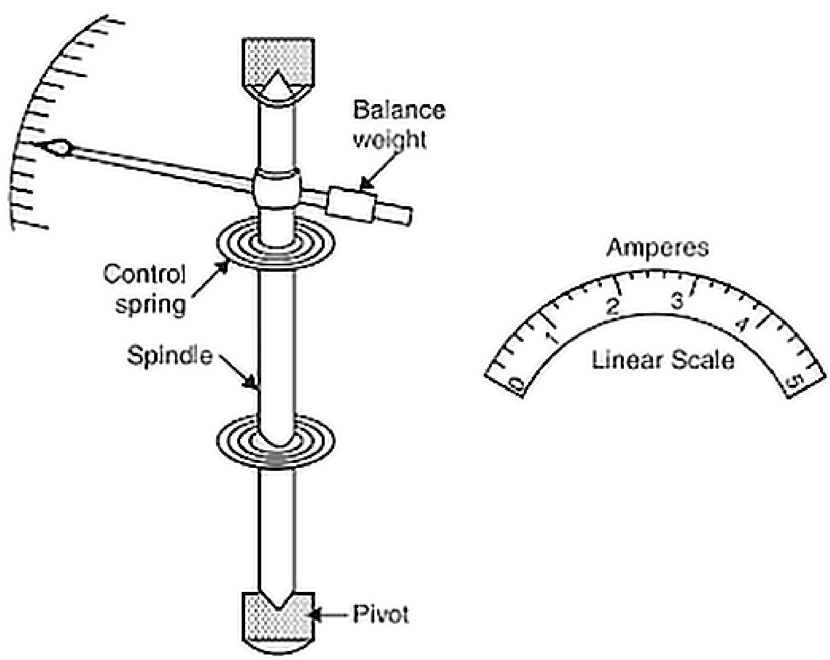
(i) Air-friction

(ii) Fluid friction

(iii) Eddy currents


Piston
Air
Chamber
Spindle
Control Spring
Spindle
Pointer
Vane
Vanes
Sector-Shaped Box

(*i*) (*ii*)


Balance
weight
Control
spring
Spindle
Pivot
Amperes
0
1
2
3
4
5
Linear Scale

(iii)

Calibration of Instruments:

It is the process of comparison of a particular instrument with known standard instruments. It is done to obtain the accuracy and errors in instruments. Static characteristics are measured by calibration method. The instruments which are used for measurement must be calibrated against a sum reference instrument of higher accuracy .Calibration is the process of configuring an instrument to provide a result for a sample within an acceptable range. Eliminating or minimizing factors that cause inaccurate measurements is a fundamental aspect of instrumentation design.

2. ANALOG AMMETERS & VOLTMETERS

1) PMMC: Permanent Magnetic Moving Coil Instrument

2) MI: Moving Coil Instruments

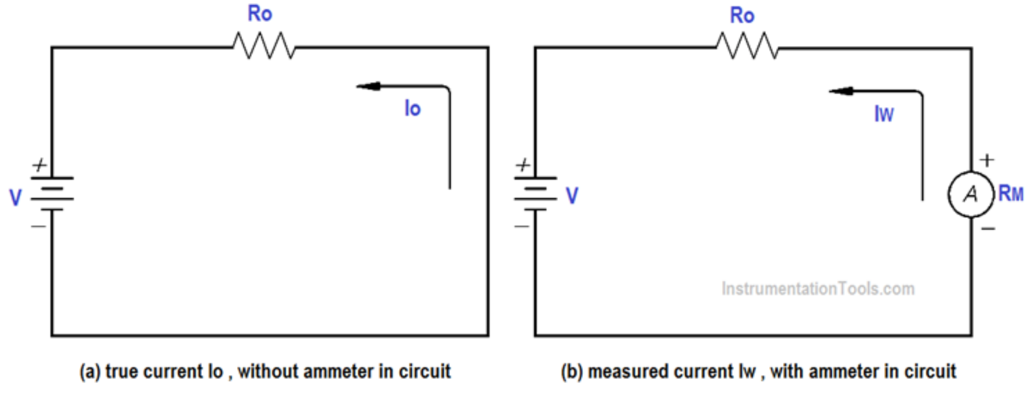
3) Dynamometers type Instruments

4) Rectifier Instruments

5) Induction Type Instruments

6) Ammeter:

The ammeter measures electric current. It may be calibrated in amperes, milli amperes, or microamperes. In order to measure current, the ammeter must be placed in series with the circuit to be tested (as shown in below Figure).



Figures: Ammeter

When an ammeter is placed in series with a circuit, it will increase the resistance of that circuit by an amount equal to the internal resistance of the meter R_m.The below Equation is the mathematical representation of the current without the meter installed.

Voltmeter:A simple DC voltmeter can be constructed by placing a resistor (R_S), called a multiplier, in series with the ammeter meter movements,and marking the meter face to read voltage (as shown in Figure).Voltmeters are connected in parallel with the load (R_L) being measured.

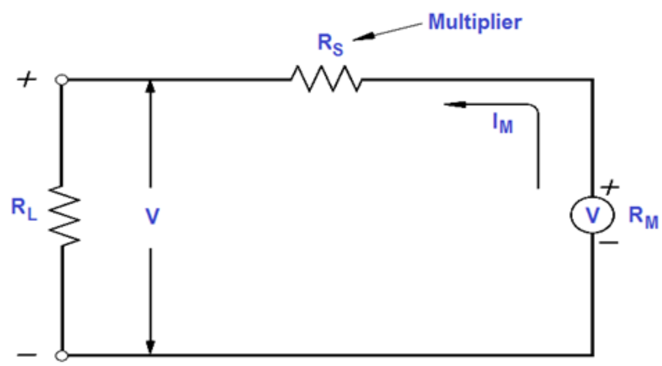


Figure: Simple Voltmeter

When constructing a voltmeter, the resistance of the multiplier must be determined to measure the desired voltage. The Equation is a mathematical representation of the voltmeter's multiplier resistance.

$$V = I_m R_s + I_m R_m$$

$$I_m R_s = V - I_m R_m$$

Where

V = voltage range desired

I_m = meter current

R_m = meter resistance

R_s = multiplier resistance or series resistance

The basic principle of working of ammeter and voltmeter is the same. In an ammeter the deflecting torque is produced by current which is to be measured. In voltmeter the deflecting torque is produced by current which is proportional to the voltage to be measured.

Errors in Voltmeters and Ammeters:

Generally two types of errors are found common in voltmeter and ammeters which are due to the friction and temperature.

Friction: Friction is a force between two surfaces that are sliding, or trying to slide, across each other. For example, when you try to push a book along the floor, friction makes this difficult.

Friction always works in the direction opposite to the direction in which the object is moving, or trying to move. To reduce the friction,the weight of the moving system must be measured as small as possible with the operating force. In the other words the ratio of torque to the weight must be very large.

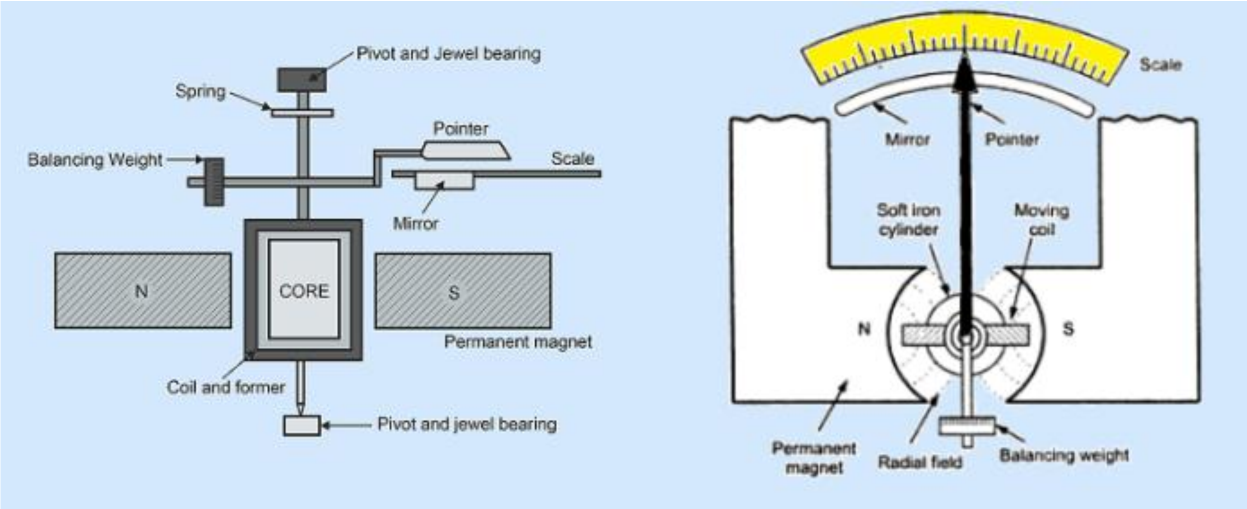
Temperature: It is possible to reduce the error which is caused by the temperature change. The instrument must be mounted in such a position such that it is properly ventilated; a swamping resistance of low temperature coefficient can be connected in series with the coil to reduce the temperature effect on the temperature.

1) Permanent magnet moving coil instruments:

Several electrical machines and panels are fitted on board so that the ship can sail from one port to another, safely and efficiently. The electrical machinery and system require scheduled maintenance and checks to avoid any kind of breakdown during sailing. Different instruments are used on board for measuring several electrical parameters to analyze and keep these machinery in proper running condition. A permanent magnet moving coil (PMMC) is one such instrument which is popularly used onboard and has several applications.

- By using Permanent magnet moving coil instruments we can measure voltage or current.PMMC is used for the measurement of direct current or voltage.
- This instrument work on principle of D.C motor. According to this law when current carrying conductor lies in magnetic field then a force work current carrying conductor. This force is directly proportional to conductor current.

Construction:-The instrument has a moving coil of circular or rectangular wire, with the N turns suspended in the uniform, horizontal and radial magnetic field of a permanent magnet in the shape of a horse shoe. It is free to rotate about its vertical axis. The coil which is place around an iron core, which is spherical if the coil is circular, and if cylindrical if the coil is rectangular. since the coil is moving and the magnet is permanent, the instrument is called PMMC instrument.



Working:-When the current is passed through the coil it produces another magnetic field. So the interaction of this filed with the magnetic field of the Permanent Magnet produced an electromagnetic torque. The amount of force experienced by the coil is proportional to the current passing through the coil. This again becomes proportional to the measured quantity that is voltage or current. This electromagnetic torque is counter balanced by the mechanical torque of control springs attracted to the movable coil. The coil is wound on an aluminum former which moves in the magnetic field of the permanent magnet to provide eddy current damping. When the torque is balanced, the pointer attached to the moving coil will stop and its angular deflection will represent the amount of electrical current to be measured against a fixed reference or scale. The pointer deflection id proportional to the current passing through the coil.

The deflection torque is given by, **Td = NBIA**

Where,

N=Numbers of turns in the coil

B=Magnetic flux intensity in wb/m^2

I=Current flowing through the coil

This torque will cause the coil to rotate until an equilibrium position is reached at an angle θ with its original orientation.

Electromagnetic torque = control spring torque

$$\mathbf{T_d = T_c}$$

$$\mathbf{NBIA = k_c\theta}$$

$$\mathbf{\theta = NBIA / k_c}$$

$$\mathbf{\theta = KI}$$

Thus the angular deflection is linearly proportional to the current (I) .

Advantages:-

1. High sensitivity
2. Accurate and reliable
3. Uniform scale
4. Low power consumption
5. Simple and effective damping mechanism

Disadvantages:-

1. Somewhat costly as compared to moving-iron instruments.
2. Cannot be used for A.C. measurements.
3. Friction and temperature might introduce errors as in case of other instruments.
4. Some errors are set in due to the aging of control springs and the permanent magnets.

Moving iron instruments:

Construction and basic principle operation:

Moving-iron instruments are generally used to measure alternating voltages and currents. In moving-iron instruments the movable system consists of one or more pieces of specially-shaped soft iron, which are so pivoted as to be acted upon by the magnetic field produced by the current in the coil. There are two general types of moving-iron instruments namely:

1. Repulsion (or double iron)

2. Attraction (or single-iron) type

The brief description of different components of a moving-iron instrument is given below:

Moving element: A small piece of soft iron in the form of a vane or rod.

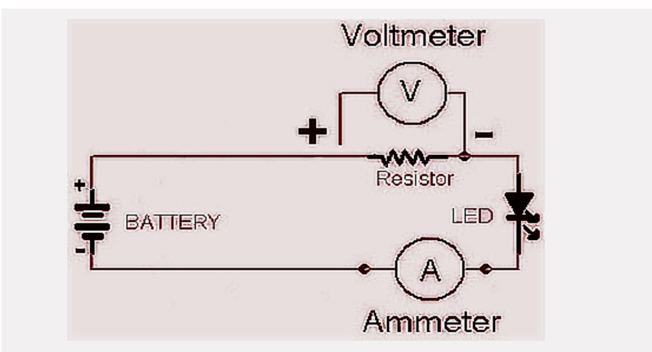
Coil: to produce the magnetic field due to current flowing through it and also to magnetize the iron pieces.

In repulsion type, a fixed vane or rod is also used and magnetized with the same polarity. Control torque is provided by spring or weight (gravity).

Damping torque is normally pneumatic, the damping device consisting of an air chamber and a moving vane attached to the instrument spindle.

Deflecting torque produces a movement on an aluminum pointer over a graduated scale.

The deflecting torque in any moving-iron instrument is due to forces on a small piece of magnetically ‘soft’ iron that is magnetized by a coil carrying the operating current. In repulsion type moving–iron instrument consists of two cylindrical soft iron vanes mounted within a fixed current-carrying coil.



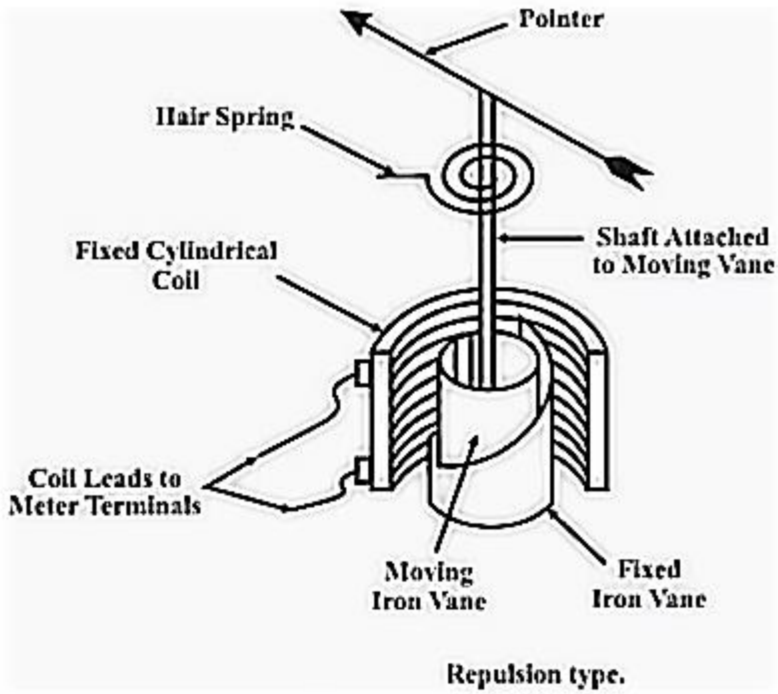
Typical scheme of measuring electrical current and voltage

One iron vane is held fixed to the coil frame and the other is free to rotate, carrying with it the pointer shaft. Two irons lie in the magnetic field produced by the coil that consists of only a few turns if the instrument is an ammeter or of many turns if the instrument is a voltmeter.

Current in the coil induces both vanes to become magnetized and repulsion between the similarly magnetized vanes produces a proportional rotation. The deflecting torque is proportional to the square of the current in the coil, making the instrument reading a true ‘RMS’ quantity Rotation is opposed by a hairspring that produces the restoring torque. Only the fixed coil carries load current, and it is constructed so as to withstand high transient current.

Moving iron instruments have scales that are nonlinear and somewhat crowded in the lower range of calibration.

Figure 1 – Repulsion moving iron-instrument



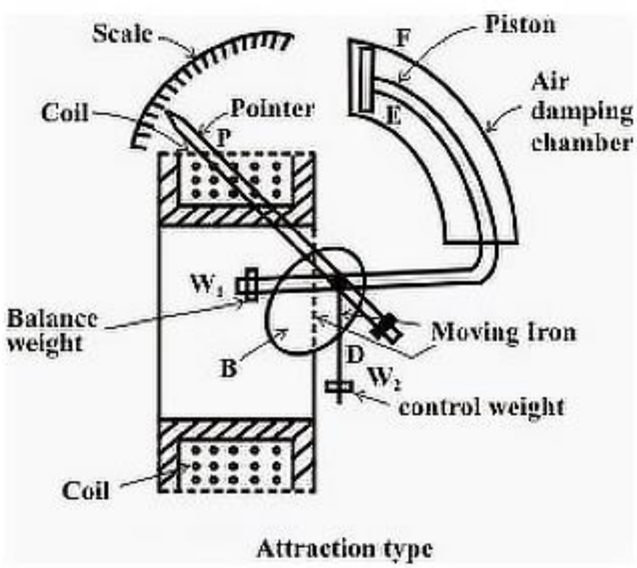


Figure 2 – Attraction moving iron instrument

Measurement of Electric Voltage and Current

Moving iron instruments are used as Voltmeter and Ammeter only.

Both can work on AC as well as on DC.

Ammeter:

- Instrument used to measure current in the circuit.
- Always connected in series with the circuit and carries the current to be measured.
- This current flowing through the coil produces the desired deflecting torque.
- It should have low resistance as it is to be connected in series.

Voltmeter:

- Instrument used to measure voltage between two points in a circuit.
- Always connected in parallel.
- Current flowing through the operating coil of the meter produces deflecting torque.
- It should have high resistance. Thus a high resistance of order of kilo ohms is connected in series with the coil of the instrument.

Advantages:

- The instruments are suitable for use in AC and DC circuits.
- The instruments are robust, owing to the simple construction of the moving parts.
- The stationary parts of the instruments are also simple.
- Instrument is low cost compared to moving coil instruments.
- Torque/weight ratio is high, thus less frictional error.

Errors:

- Error due to variation in temperature
- Error due to friction is quite small as torque-weight ratio is high in moving coil instruments.
- Stray fields cause relatively low values of magnetizing force produced by the coil. Efficient magnetic screening is essential to reduce this effect.
- Error due to variation of frequency causes change of reactance of the coil and also changes the eddy currents induced in neighboring metal.
- Deflecting torque is not exactly proportional to the square of the current due to non-linear characteristics of iron material

Advantages of moving iron instrument:-

1. They are reliable.
2. Simple in construction.
3. Cheap in cost.
4. Have high operating torque.
5. Can be used for DC as well as AC measurement.

Disadvantages of moving iron instrument:-

1. The scales of these instruments are not uniform.
2. Power construction is higher for low voltage range.
3. Change in frequency also caused errors in AC measurement.

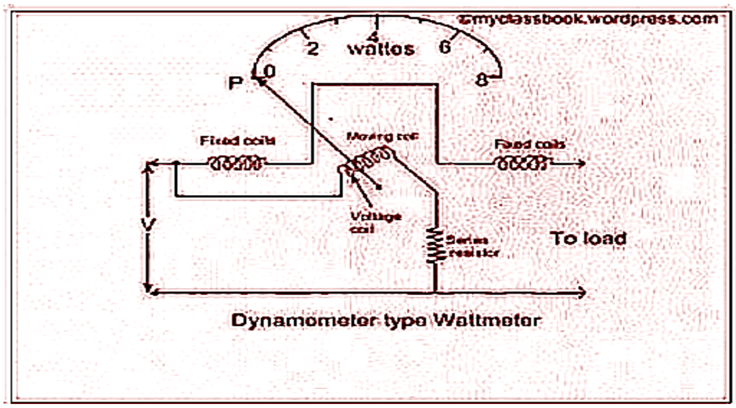
Electrodynamometer type devices:

An electrodynamometer type device is a transmission tool. The transfer tool is limited by d.c. source and used without any changes to a.c. ratings. Such a transfer tool has the same accuracy as a.c. and d.c. ratings. Electrodynamometer-type instruments are often used in accurate a.c. voltmeters and ammeters, not only at power line frequencies but also at low sound frequency frequencies. With some small adjustment, it can be used as a wattmeter for power measurements.

Why PMMC tools cannot be used for a.c. ratings?

The PMMC tool cannot be claimed by a.c. currents or voltages. If a.c. the supply is provided on these tools, it will improve the torque alternating. Due to the short-term inertia of the moving system, the indicator will not follow the ever-changing torque and will fail to show any readings. So that the tool can read a.c. values, the magnetic field in the air space must change with the current change. This principle is applied to an electrodynamometer. Instead of a permanent magnet, an electrodynamometer-type tool is currently used under measurement to produce the required field flux. The diagram shows the construction of an electrodynamometer-type metal.

Construction:



The different types of electrodynamometer types are:

Fixed Coils: The required field required for the operation of the metal is produced by fixed coils. The same field is located near the coil area due to the division of the coil into two sections. These coils are air cored. Flexible coils are damaged by fine wire for use as a voltmeter, while for ammeters and wattmeter's they are damaged by heavy wire. Coils usually have varnish. They are fastened in place to the base of the coil. This makes the construction stronger. Ceramic is often used for installed foundations. If metal parts were to be used they would weaken the constant coil field.

Moving coil: A moving coil is damaged as a reinforcing coil or other non-metallic material. If pre-metallic is used, it will add eddy currents to it. The construction of the moving coil is made simple and sturdy. Ine-air cored.

Control: Control torque is provided by springs. These springs act as a lead on a moving coil.

Moving System: A moving coil is mounted on an aluminum spindle. Contains opposition weights and a pointer. Sometimes suspension may be used, in the event of higher accuracy.

Damping: Slowing torque is provided by air collision, with pairs of aluminum vanes attached to the floor spindle. They walk in industrial rooms. Since the workspace can be distorted by eddy current damping, it is not rented.

Security: The field produced by these tools is very weak. Even the earth's magnetic field also protects us from harm. So protection is provided to protect it from magnetic fields. This is done by closing the casing high permeability alloy.

Cases and Scales: Standard laboratory tools are usually contained in polished wooden or metal cases. The case is supported by adjustable measuring screws. Air quality may be provided to ensure proper temperature. By using an electrodynamometer device as an ammeter, the constant and moving coils are connected to the series and carry the same current. The appropriate shunt is connected to these coils to limit the available power to the desired level. Electrodynamometer instruments can be used as a voltmeter by connecting fixed and moving coils in a series with high non-inductive resistance. The most accurate type of voltmeter. By using an electrodynamometer device as a wattmeter to measure power, fixed coils act as a current coil and must be connected to the series and load. Moving coils act as a voltage coil or pressure coil and should be connected to all terminals. The wattmeter indicates the power supply. When a current passes through a constant, moving coil, both coils produce magnetic fields. The field produced by a stable coil is equal to the current load while the field produced by the moving coil is equal to the electric field. Since the deviating torque is produced due to the interaction of these two fields, the deviation is accompanied by a given load force.

Advantages of Dynamometer type metal:

1) As the tool has a Square Law response so it can be used in both dc and AC.
2) These instruments have no current hysteresis and Eddy defects. ...
3) An ammeter up to 10A and a voltmeter up to 600V can be built with precision distance accuracy.
4) As air coil care coils, these steels have no hysteresis faults and current eddy faults.
5) These instruments can be used in both a.c. and d.c. and as they have a degree of accuracy, they are very useful as transmission tools.

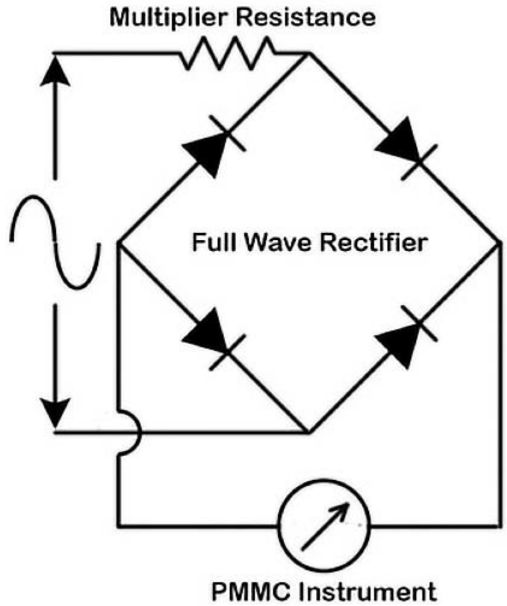
Disadvantages of Dynamometer type metal:

1)The scale is not the same as the tool uses the Square Law response.

2)These tools have a small amount of torque weight so the collision error is large.

3) Due to the loss of motion of the moving system in these instruments is somehow higher than in other metals.

Rectifier type Instruments:



It measures the alternating electric signal using the D.C. measurement tool. As the name implies, this Instrument first adjusts the A.C signal to D.C. and then scales. Although it measures the adjusted A.C signal (D.C signal), but the metal scale is limited to A.C. The sensitivity of D 'Arsonval instrument is very high. But the D'Arsonval Instrument can only be measured in D.C. Thus, to use the A.C.'s D'Arsonval movement sensitivity, we use a Rectifier type Instrument.

The sensitivity of the repair kits is high compared to the moving coil and the Electro dynamo meter steel. Thus, it is used to measure current strength and voltage. Arrangement of the repair metal circuit shown in the figure below. The device uses four diodes that act as a correction element.

Factors Affecting the Performance of Rectifier Type Instruments:

The following are the factors that affect the performance of a tool when used in AC.

1.Effects of Waveform - Adjustment of instrument measurement can be made in relation to the RMS voltage and current level. Half wave form feature and full wave adjustment tool adjustment on limited scale. And when a waveform of other form elements works on the device, a waveform error occurs in the reading.

Effect of Temperature Change - Resistance to the adjustment factor varies with temperature changes. And this repair part property causes an error in the tools.

Effect of Rectifying Instrument - The repair tool has a limited power supply. It allows high-frequency current to pass through.

Decreases in Sensitivity - The sensitivity of the AC operating type type tool is lower than that of DC performance.

Advantages of Rectifier Type Instrument

This Instrument can measure the electrical signal of very low frequencies on radio frequencies.

The instrument also has the ability to measure electrical signals up to a few mega Hz.

The sensitivity of the tool is much higher than that of any other type of measuring instruments in A.C. In fact, in order to obtain the highest sensitivity to A.C values, we use corrective type tools.

Applications of Rectifying Instrument

The following are the applications of the rectifying instrument.

The device uses a voltage gauge whose width is between 50 - 250 V.

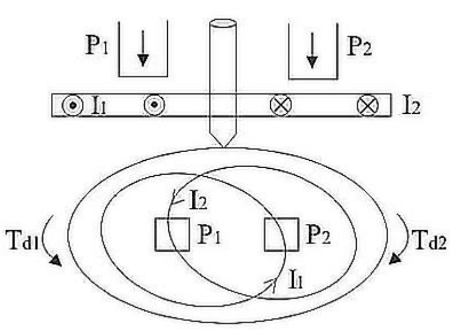
Used as a milli-ammeter or micro-ammeter.

Use of the correction tool in the communication circuit to rate.Thus, the loading effect of the ac rectifier voltmeter is higher than that of the dc voltmeter.

INDUCTION TYPE METERS

The voltmeter sensitivity of the adjustment type is less than that of the DC voltmeter sensitivity.

The principle of operation and construction of induction type meters is very simple and easy to understand which is why these are widely used in measuring energy in the domestic and industrial world. For every entry meter we have two drums produced by two different alternating waves on a metal disk. Due to fluctuations of fluxes there is an emf produced, the locally produced emf (as shown in the picture below) interacts with the alternating current currents leading to the



production of torque.

Similarly, the emf produced at the point two interacts with the alternating current at point one, resulting in the production of torque again but in opposite direction. Hence due to these two torques which are in different directions, the metallic disc moves.This is basic principle of working of an induction type meters. Now let us derive the mathematical expression for deflecting torque. Let us take flux produced at point one be equal to F1 and the flux and at point two be equal to F2. Now the instantaneous values of these two flux can written as:

$$F_1 = F_{m1} sin\omega t, \quad F_2 = F_{m2} sin(\omega t - B)$$

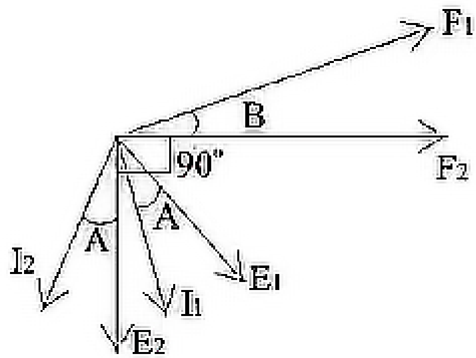
Where, Fm1 and Fm2 are respectively the maximum values of fluxes F1 and F2, B is phase difference between two fluxes. We can also write the expression for induced emf's at point one be

$$E_1 = -\frac{d(F_1)}{dt} \quad and \quad E_2 = -\frac{d(F_2)}{dt}$$

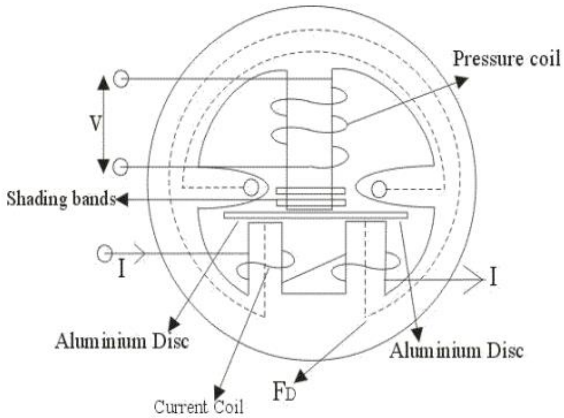
at point two. Thus we have the expression for eddy currents at point one is

$$I_1 = \frac{E_1}{Z} = K \times f \times F_1$$

Where, K is some constant and f is frequency. Let us draw phasor diagram clearly showing F1, F2, E1, E2, I1 and I2. From phasor diagram, it clear that I1 and I2 are respectively lagging behind E1 and E2 by angle A



The angle between F1 and F2 is B. From the phasor diagram the angle between F2 and I1 is (90-B+A) and the angle between F1 and I2 is (90 + B + A). Thus we write the expression for deflecting torqueas



$$T_{d1} = K \times F_2 \times I_1 \times COS(90 - B + A) = K \times F_1 \times F_2 \times \frac{f}{Z} \cos(90 - B + A),$$

Similarily the expression for T_{d2} is

$$T_{d2} = K \times F_1 \times F_2 \times \frac{f}{Z} \cos(90 + A + B)$$

The total torque is Td1 - Td2, on substituting the value of Td1 and Td2 and simplifying the expression we get

$$T_{d1} - T_{d2} = K \times F1 \times \frac{F2 \times f \sin(B)\cos(A)}{Z},$$

This is known as the general expression for the deflecting torque in the induction type meters. Now there are two types of induction meters and they are written as follows:

1) Single phase type induction meters.

2) Three phase type induction meters.

Advantages of Induction Type Meters:

Following are the advantages of induction type meters:

1. They are inexpensive as compared to moving iron type instruments.
2. They have high torque is to weight ratio as compared to other instruments.
3. They retain their accuracy over wide range of temperature as well as loads.

Disadvantages of Induction Type meters.

1) Without proper compensation measures, a considerable amount of errors are caused in the measurement due to temperature, waveform and frequency changes.
2) Induction meters can use only for AC measurements.
3) They consume a considerable amount of power.
4) They have nonlinear scales.

2.2 Extend the range of instruments by use of shunts and Multipliers.

There is no fundamental difference in the operating principles of ammeters and voltmeters. Both are current operated devices (except electrostatic type voltmeters) i.e. deflecting torque is produced when current flows through their operating coils.

In an ammeter, the deflecting torque is produced by the current to be measured or by a definite fraction of it whereas in a voltmeter torque is produced by the current proportional to the voltage to be measured.Thus, the real difference between the two instruments is in the magnitude of the currents producing the deflecting torque. The essential requirements of a measuring instrument are that its introduction into the circuit, where measurements are to be made, does not alter the circuit conditions and the power consumed by them for their operation is small.An ammeter is connected in series with the circuit whose current is to be measured. Therefore, it should have a low resistance. On the other hand, a voltmeter is connected in parallel with the circuit whose voltage is to be measured; therefore, it must have high resistance.

Thus, we conclude that the difference is only in the resistance of the instrument, in fact, an ammeter can be converted into voltmeter by connecting a high resistance in series with it.

It is already seen that the moving coil instruments can carry the maximum current of about 50 mA safely and the potential drop across the moving coil instruments is about 50 mV. However, in practice, heavy currents and voltages are required to be measured. Therefore, it becomes necessary that the current and voltage being measured be reduced and brought within the range of the instrument.There are four common devices used for the range extension of ammeter and

voltmeter namely; shunts, multipliers and current and potential transformers.The shunts and multipliers are used to extend the range of moving coil ammeters and voltmeters respectively.
Whereas in the case of moving iron ammeters,for the ranges up to 0 – 250 A, shunts are used and for the ranges higher than that, CTs are used. And also, in the case of moving iron voltmeters, for the ranges up to 0 – 750 V, multipliers are used and for the ranges higher than that, Pts are used.
It is possible to extend the range of an ammeter by using a shunt. A shunt is a low-value resistance having minimum temperature co-efficient and is connected in parallel with the ammeter whose range is to be extended. The combination is connected in series with the circuit whose current is to be measured.This shunt provides a bypath for extra current because it is connected across(i.e. in parallel with) the instrument.These shunted instruments can be used to measure currents many times greater than their normal full-scale deflection currents.The ratio of maximum current (with shunt) to the full-scale deflection current (without shunt) is known as the ‘multiplying power’ or ‘multiplying factor’ of the shunt.

Example: A moving coil ammeter reading up to 1 ampere has a resistance of 0.02 ohm. How could this instrument be adopted to read current up to 100 amperes?

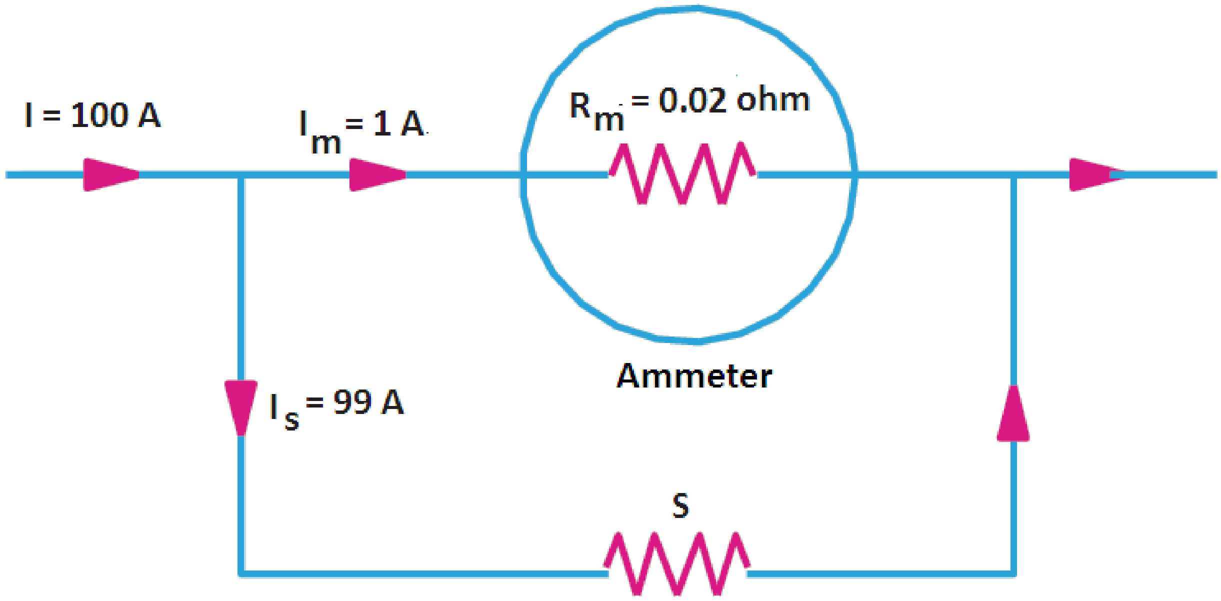
Solution: In this case,

Full-scale deflection current of the ammeter, Im = 1 A

Line current to be measured, I = 100 A

Resistance of ammeter, Rm = 0.02 ohm

Let, the required shunt resistance = S



As seen from Figure, the voltage across the instrument coil and the shunt resistance is the same since

both are joined in parallel.

∴ Im*Rm = S*Is = S(I − Im)

or S = Im*Rm/(I – Im)

= 1*0.02/(100 – 1) = 0.02/99 = 0.000202 Ans.

Range Extension of Voltmeter by Multipliers:

Multipliers are used for the range extension of voltmeters. The multiplier is a non-inductive high-value resistance connected in series with the instrument whose range is to be extended. The combination is connected across the circuit whose voltage is to be measured.

Example: A moving coil voltmeter reading up to 20 mV has a resistance of 2 ohms. How this instrument can be adopted to read voltage up to 300 volts.

Solution: In this case,

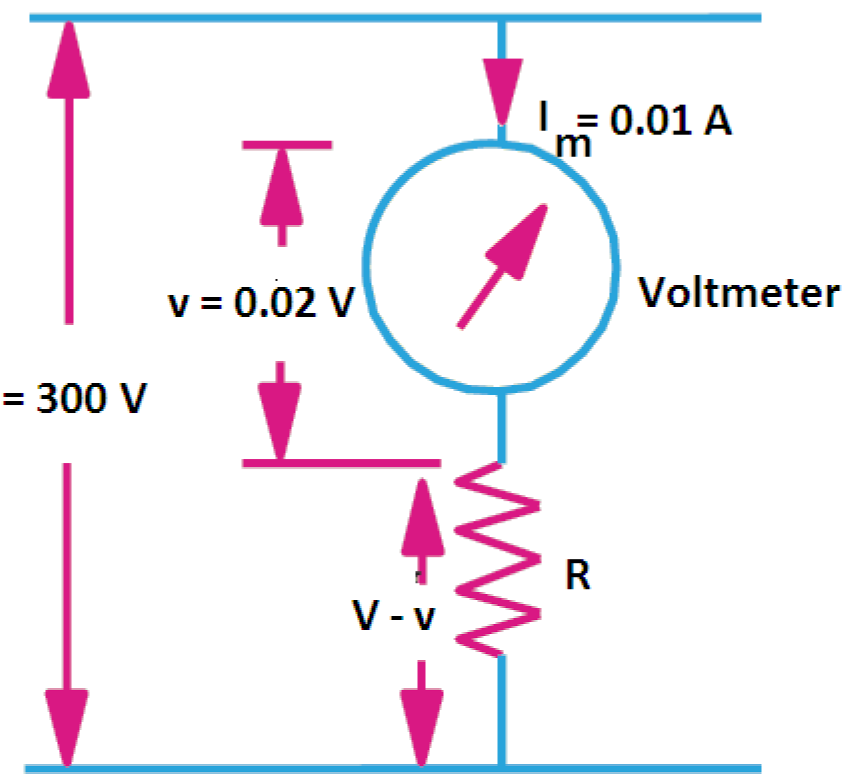
Voltmeter resistance, Rm = 2 ohm

Full-scale voltage of the voltmeter, v = RmIm = 20 mV = 0.02 V

Full-scale deflection current, Im = v/Rm = 0.02/2 = 0.01 A

Voltage to be measured, V = 300 V

Let the series resistance required = R



Then as seen from figure, the voltage drop across R is V – v

R *Im = V – v

or R = (V – v)/Im

or R = (300 – 0.02)/0.01 = 299.98/0.01 = 29998 ohms Ans.

Shunts can not be used to extend the range of moving-iron AC ammeters accurately. It is because the division of current between the operating coil and the shunt varies with frequency (since reactance of the coil depends upon frequency). In practice, the *range of moving-iron AC ammeters are extended by one of following methods:*

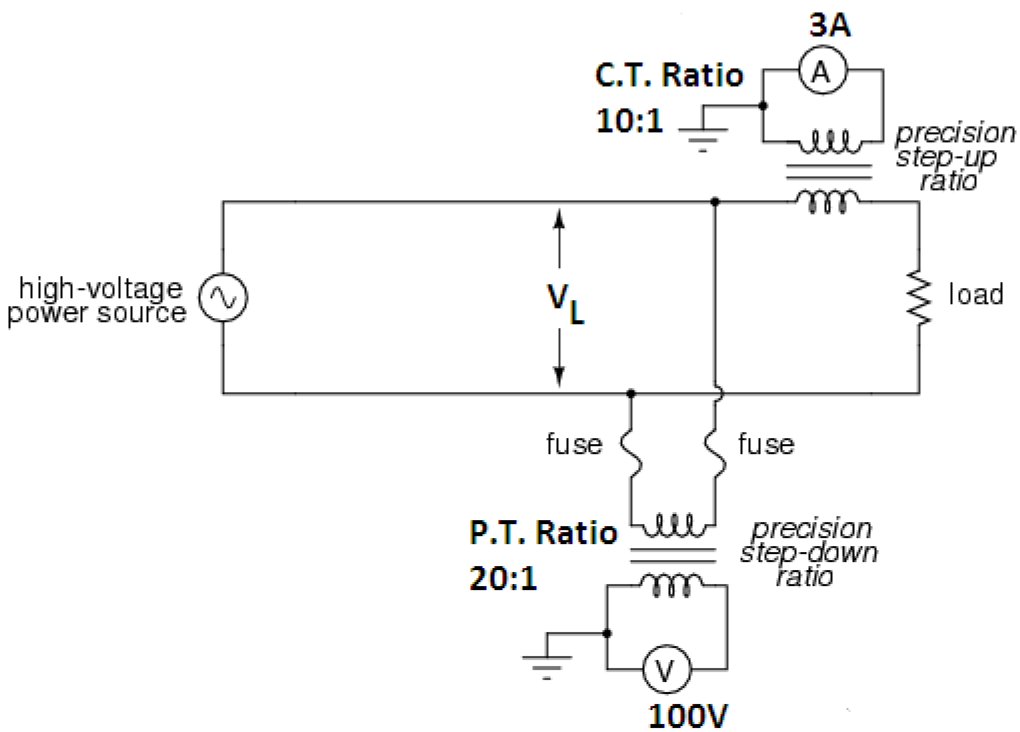
1) Range Extension of Ammeter by Coil Turns:By changing the number of turns of the operating coil. For example, suppose that full-scale deflection is obtained with 400 ampere-turns. For full-scale reading with 100A, the number of turns required would be = 400 / 100 = 4. Similarly, for full-scale reading with 50A, the number of turns required in = 400/50 = 8.

Thus the ammeter can be arranged to have different ranges by merely having a different number of turns on the coil. Since the coil carries the whole of the current to be measured, it has a few turns of thick wire. The usual ranges obtained by this method are from 0 -250 A.

Range Extension of Ammeter by Current Transformer:

For ranges above 0 – 250 A, a current transformer is used in conjunction with 0 – 5 A moving iron AC ammeter as shown in the figure. The current transformer is a step up transformer i.e. number of secondary turns is more than the primary turns.Usually, the primary winding of the transformer contains a single turn or at the most a few turns. The primary of this transformer is connected in series with the load and carries the load current. The AC ammeter is connected across the secondary of the transformer.

Since in figure, the current transformer ratio is 10:1, it means that line (or load) current is equal to 10 times the reading on the AC meter. Therefore, load current, I_L = 3 x 10 = 30 A.



Range Extension of Voltmeter by Potential Transformer:

The range of a moving-iron AC voltmeter is extended by connecting a high resistance (multiplier) in series with it.For ranges higher than 0 – 750 V, where power wasted in the multiplier would be excessive, a 0 – 110 V moving-iron AC voltmeter is used in conjunction with a potential transformer as shown in the figure.The potential transformer is a step-down transformer i.e. number of primary turns is more than the secondary turns. The primary of the transformer is connected across the load across which voltage is to be measured. The AC voltmeter is connected across the secondary.Since in figure, the potential transformer ratio is 20:1, the load voltage is equal to 20 times the reading on the AC voltmeter.

Load voltage, VL = 100 x 20 = 2000 V

Note that both secondaries of the instrument transformers are grounded as a safety measure.

UNIT 3.MEASUREMENT OF POWER & ENERGY

Dynamometer type wattmeter : It works on a very simple principle which is stated as "when any current carrying conductor is placed inside a magnetic field, it experiences a mechanical force and due to this mechanical force, deflection of conductor takes place."

Construction:

It consists of the following parts:

Moving coil - Moving coil moves the pointer with the help of spring control instrument. A limited amount of current flows through the moving coil so as to avoid heating. So in order to limit the current we have connected the high value resistor in series with the moving coil. The moving is air cored and is mounted on a pivoted spindle and can moves freely. In electrodynamometer type wattmeter, moving coil works as pressure coil. Hence moving coil is connected across the voltage and thus the current flowing through this coil is always proportional to the voltage.

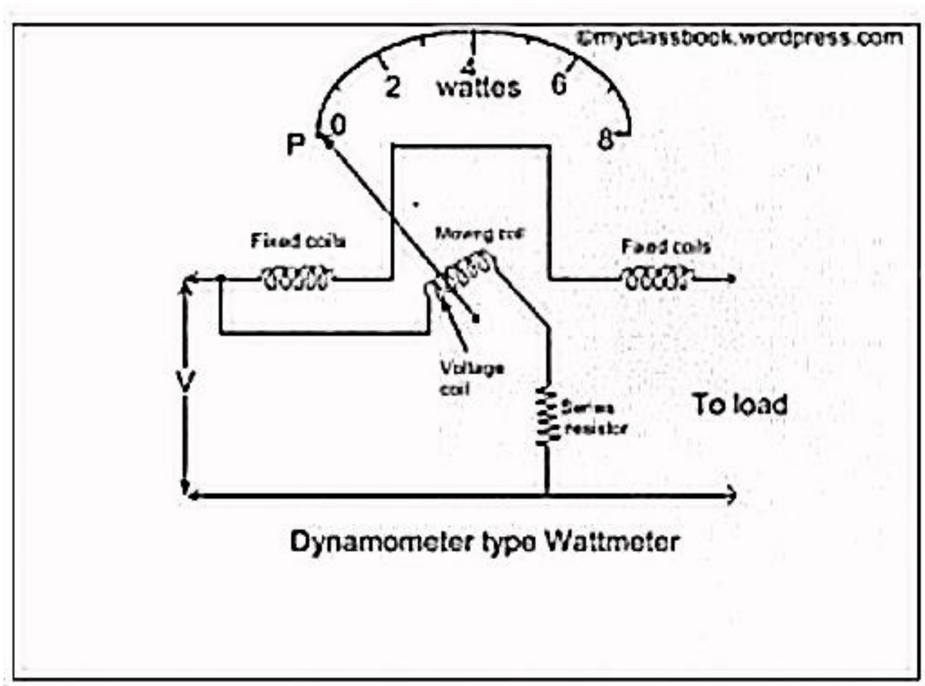
Fixed coil - The fixed coil is divided into two equal parts and these are connected in series with the load, therefore the load current will flow through these coils. Now the reason is very obvious by using two fixed coils instead of one, so that it can be constructed to carry a considerable amount of electric current. These coils are called the current coils of electrodynamometer type wattmeter. Earlier these fixed coils were designed to carry the current of about 100 amperes but now the modern wattmeter are designed to carry current of about 20 amperes in order to save power.

Control system - Out of two controlling systems i.e. gravity control and spring control, only spring controlled systems are used in these types of wattmeter. Gravity controlled system cannot be employed because they will contain an appreciable amount of errors.

Damping system - Air friction damping is used, as eddy current damping will distort the weak operating magnetic field and thus it may lead to error.

Scale - There is a uniform scale used in these types of instrument as a moving coil moves linearly over a range of 40 degrees to 50 degrees on either side.

Working of Dynamometer type wattmeter: When power is to be measured in a circuit, the instrument is suitably connected in the circuit. The current coil is connected in series with load so that it carries the circuit current. The potential coil is connected across the load so that it carries current proportional to the voltage. Due to the current in the coils, mechanical force exists between them. The result is that the moving coil moves the pointer over the scale. The pointer comes to rest at a position where deflecting torque is equal to the controlling torque. Reversing the current, reverses the field due to the fixed coil as well as the current in the moving coil so that the direction of the deflection torque remains unchanged. Therefore, such instruments can be used for the measurement of a.c as well as d.c power.



Dynamometer type Wattmeter

Merits :

1.Scale is uniform up to a certain limit.

2.They can be used for both to measure ac as well dc quantities as scale is calibrated for both.

Errors/Demerits :

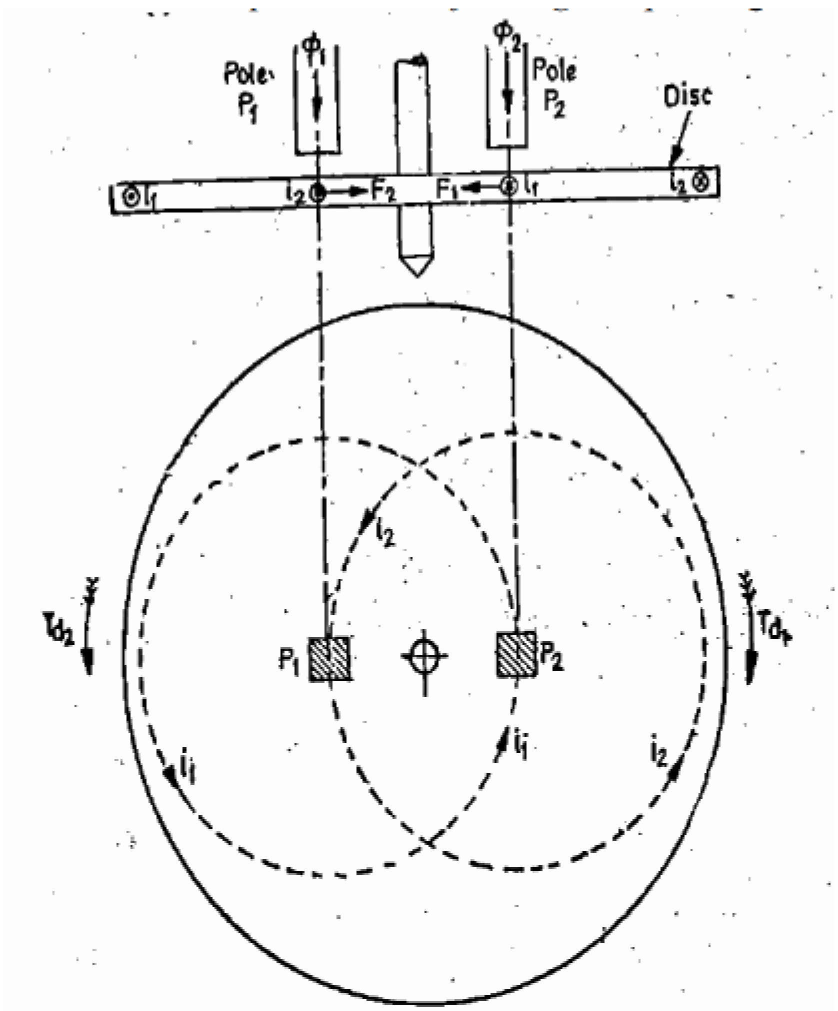
1. Errors in the pressure coil inductance
2.Errors may be due to pressure coil capacitance
3.Errors may be due to mutual inductance effects
4. Errors may be due connections (i.e. pressure coil is connected after current coil)
5.Error due to Eddy currents

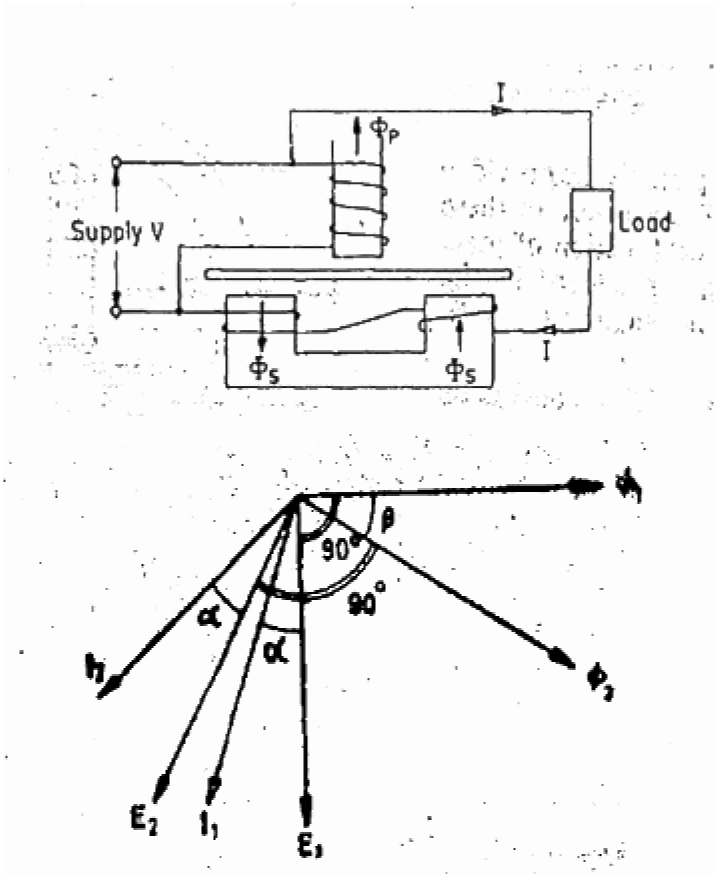
1. Pressure coil inductance: In an ideal dynamo-meter type wattmeter the current in the pressure coil is in phase with the applied voltage. But practically the pressure coil of wattmeter has an inductance and current in it will lag behind the applied voltage. If there is no inductance the current in pressure coil will be in phase with the applied voltage. In the absence of inductance in pressure coil of wattmeter, it will read correctly in all power factors and frequency. The wattmeter will read high when the load power factor is lagging ,as in that case the effect of pressure coil inductance is to reduce the phase angle between load current and pressure coil current . Hence the wattmeter will read high. This is very serious error. The wattmeter will read low when the load power factor is leading as in that case the effect of pressure coil inductance is to increase the phase angle between load current and pressure coil current. Hence the wattmeter will read low. Compensation for inductance of pressure coil. Inductance of pressure coil can be reduced by means of capacitor connected in parallel with a portion of multiplier (series resistance).

SINGLE PHASE ENERGY METER :

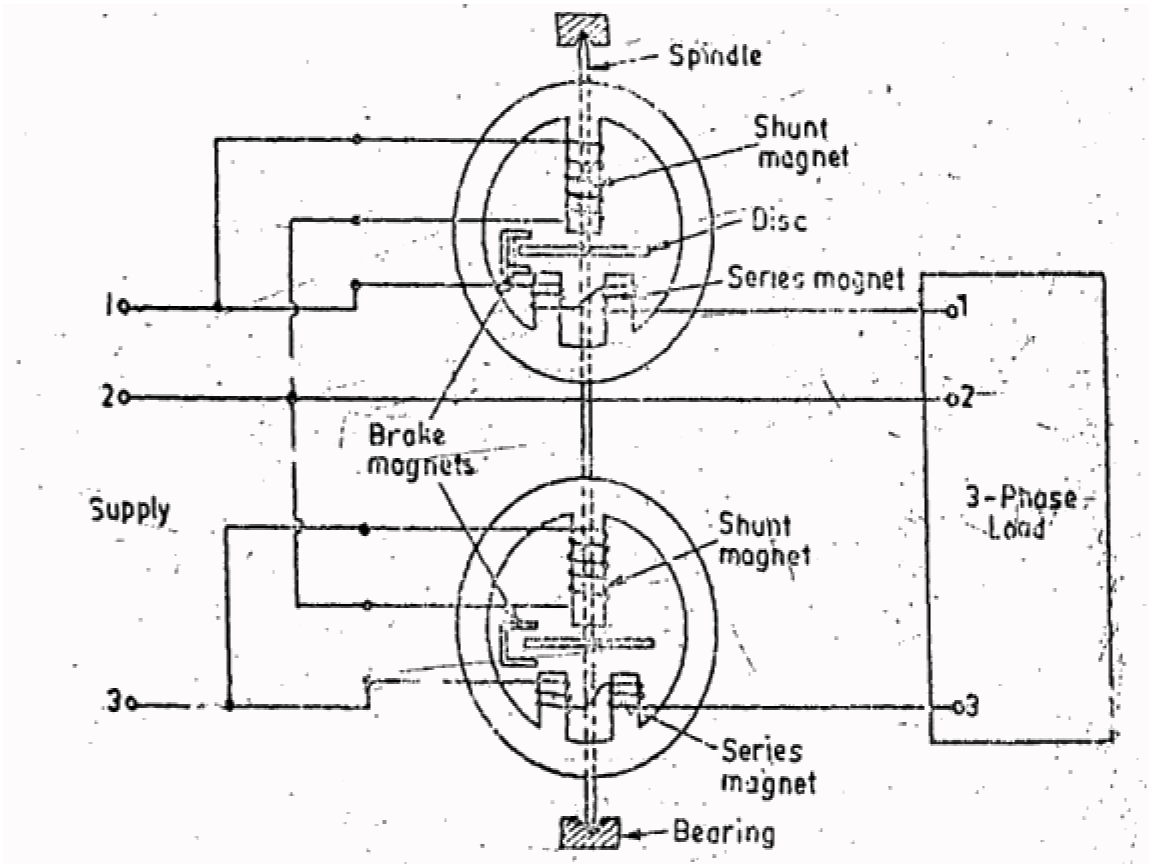
Operating Principle of Single Phase Energy Meter:

In the construction part, we discussed the different parts of the single phase energy meter. We also saw that we have two currents flowing in the system, one of the current is proportional to the Voltage of the supply and flowing in the pressure coil, the second one is flowing in the current coil and is proportional to the supply current (Refer to the figure under the heading “Single Phase Induction Type Watt-Hour Meter”). Since both the currents are alternating in nature so the flux produced by both the currents is also alternating in nature. When these alternating flux pass through the Aluminium disc, which is placed between two coils, an emf is generated in the disc, this emf causes the eddy currents to flow in the disc. These eddy currents flow in a small circular path and produces torque of their own. Thus we have two eddy currents causing two torques. The resultant of these two torques is the Deflecting Torque. Fig. below depicts this operation. The two type of fluxes Φ1 and Φ2 are the same as Φp and Φs as shown in the figure. They produce i1 and i2 eddy currents which in turn produce Td1 and Td2 deflecting torques. These torques produce F1 and F2 force on the disc which in turn rotate the disc. Since the two torques are proportional to the two alternating fluxes, which are proportional to the voltage and current of the supply respectively, we have the rotation of the disc proportional to the power. The registering system measures the number of rotation of the disc in a particular amount of time and converts the Power into Energy by multiplying with time. The scale is calibrated to show the energy consumed.


Pole P1
φ1
φ2
Pole P2
Disc
i1
i2
F2
F1
i1
i2
i2
Td2
P1
P2
Td1
i1
i1
i2



2. Three Phase Energy Measurement Just like 3- Φ power measurement, here also we can use 3 energy meters for 3- Φ 4-wire system and 2 energy meters for 3- Φ 3 wire system. The assembly with 2 energy meters is most common because of the ease of operation and also because of the wide use of the 3 wire system. Figure below shows the two energy meter method for the measurement of 3- Φ energy.The meter shown above is provided with 2 discs, one for each element. It is essential that the driving torque of the two elements be exactly equal for equal amounts of power passing through each phase. Thus in addition to normal compensating devices attached to each element, an adjustable magnetic shunt is provided on one or both the elements to balance the torques of the two. The pressure coils are connected in parallel and the current coils in series in such a manner that the torques produced by the two elements oppose each other. The magnetic shunt is adjusted to a position where the two torques are exactly equal and opposite and therefore there is no rotation of disc. This way the two elements are rendered exactly similar.



3. Errors in the Energy Meter:

The errors in an energy meter are predominantly due the driving system. Some of the important errors due to driving system are:

i. Incorrect magnitude of fluxes: This may be due to abnormal values of current or voltage. The shunt magnet flux may be in error due to changes in resistance of coil or due to abnormal frequencies.

ii. Incorrect phase angles: There may not be proper relationship between the various phasors, this may be due to improper lag adjustment, abnormal frequencies, change in resistance with temperature, etc.

iii. Lack of Symmetry in magnetic circuit: In case the magnetic circuit is not symmetrical, a driving torque is produced which makes the meter creep.

The errors due to the braking system are:

(i) Changes in strength of brake magnet

(ii) Changes in disc resistance

(iii) Self-braking effects of series magnet flux

(iv) Abnormal friction of moving parts

4. Adjustment of Errors:

The adjustments required to rectify the errors which are described above are:

i. Preliminary light load adjustment: The disc is placed in such a manner that the holes are not underneath the electromagnets. Rated voltage is applied to the potential coil with no current through the current coil. The lightload device is adjusted until the disc just fails to start.

ii. Full load Unity Factor Adjustment: The pressure coil is connected across the supply voltage and rated full load current at unity power factor is passed through the current coils. The position of the brake magnet is adjusted to vary the braking torque so that the meter revolves at the required speed within required limits or error.

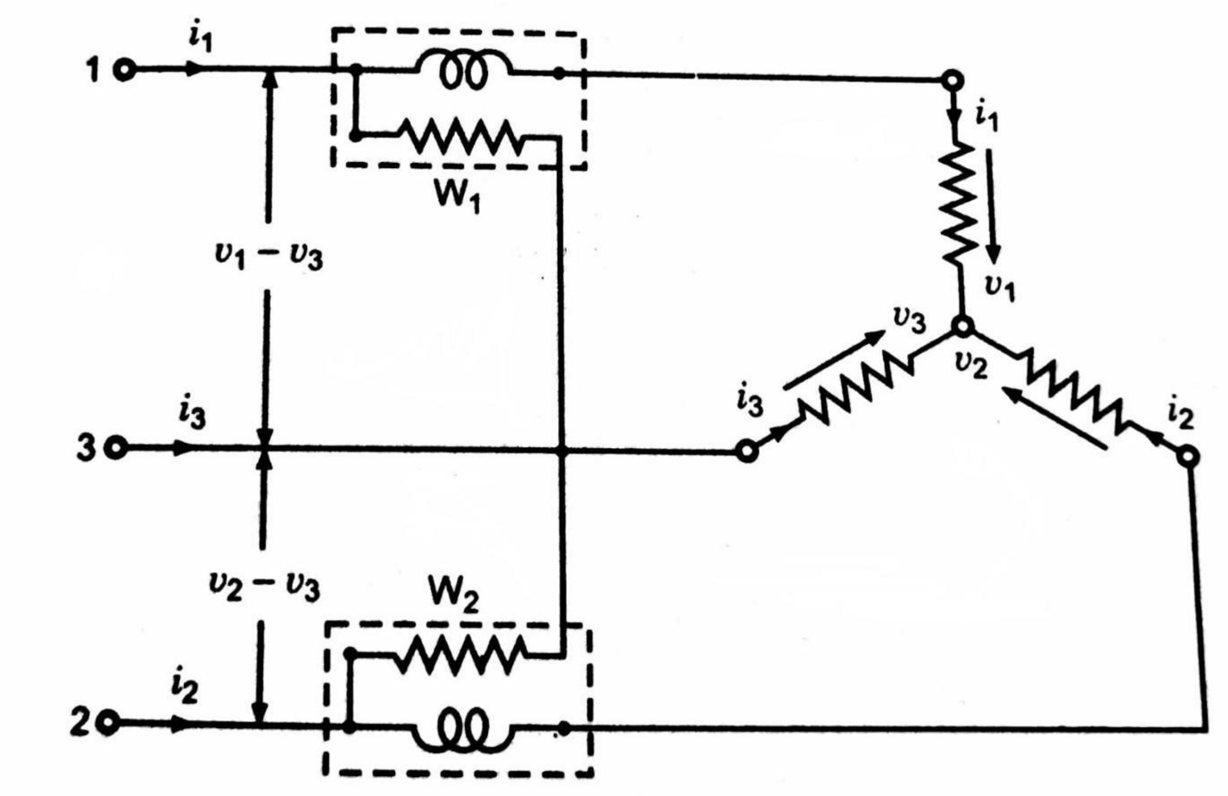
iii. Lag Adjustment (Low power factor adjustment): The pressure coil is connected across rated supply voltage and rated full load current is passed through the current coil at 0.5 p.f. lagging. The lag device is adjusted, till the meter runs at correct speed.

iv. Light Load Adjustment: Rated supply voltage is applied across the pressure coil and a very low current (about 5 percent of full load) is passed through the meter at unity power factor. The Light load adjustment is done so that the meter runs at the correct speed.

v. Creep Adjustment: As a final check on light load adjustment, the pressure coil is excited by 110 percent of rated voltage with zero load current. If the light load adjustment is correct, the meter should not creep under these conditions.

Two Wattmeter Method: Two wattmeter method is generally used for measurement of power in 3-phase,3 wire load circuits. The current coils of two wattmeters are inserted in any two lines and pressure coil is connected from its own current coil to the line without a current coil.Let V1,V2,V3 and I1,I2,I3 be the voltages and currents of the three loads connected across three different phases at particular instant. Thus the power at the instant under consideration is equal to the sum of their products regardless of power factor.

Measurement of Power by Two Wattmeter Method in Star Connection system

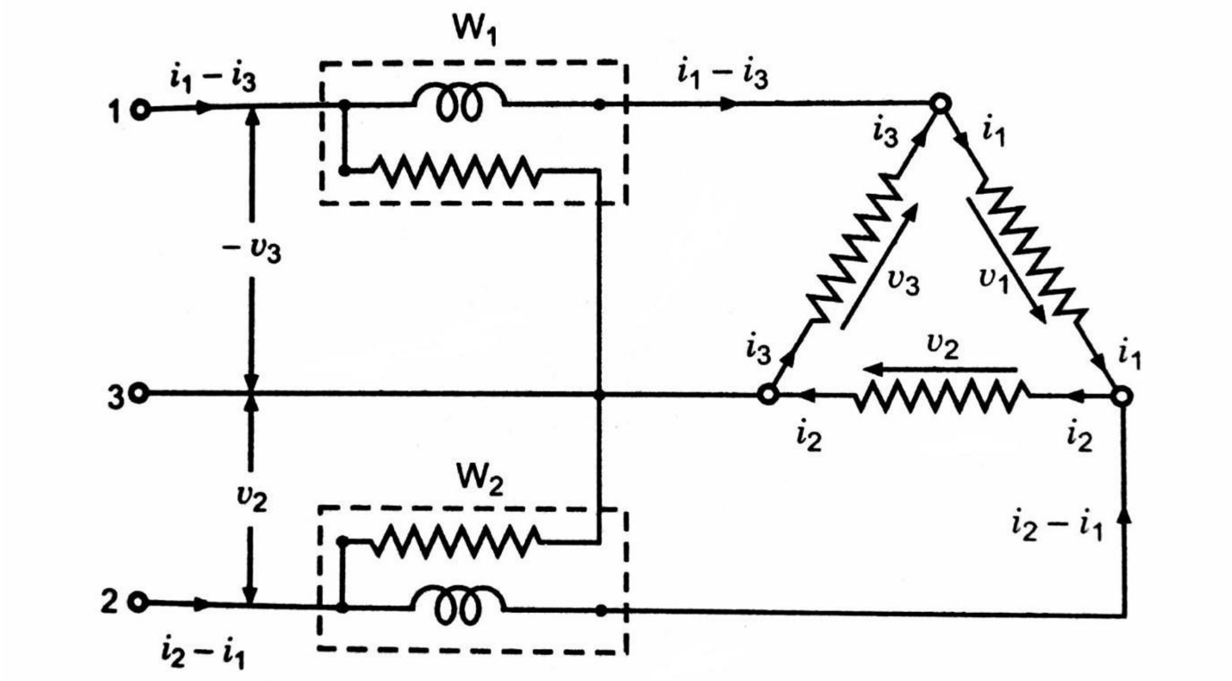


Two-wattmeter method of measuring 3-phase 3-wire power in Star connected system

According to the Kirchhoff's first law,the algebraic sum of three instantaneous current is Zero as all three phases meet at a star point is the instantaneous power measured by wattmeter W1.since i2 is the instantaneous current flowing through the current coil and (v2-v3) is the instantaneous potential difference across pressure coil of wattmeter W2, is the instantaneous power measured by wattmeter W2.

P=W1+W2

Measurement of Power by Two Wattmeter Method in Delta Connection system



Two-wattmeter method of measuring 3-phase 3-wire power in Delta- connected system

In delta connected system the three phases form a closed loop,according to Krichhoff`s second law ,

v1+v2+v3=0

Instantaneous Power(P)=V1I1+V2I2+V3I3

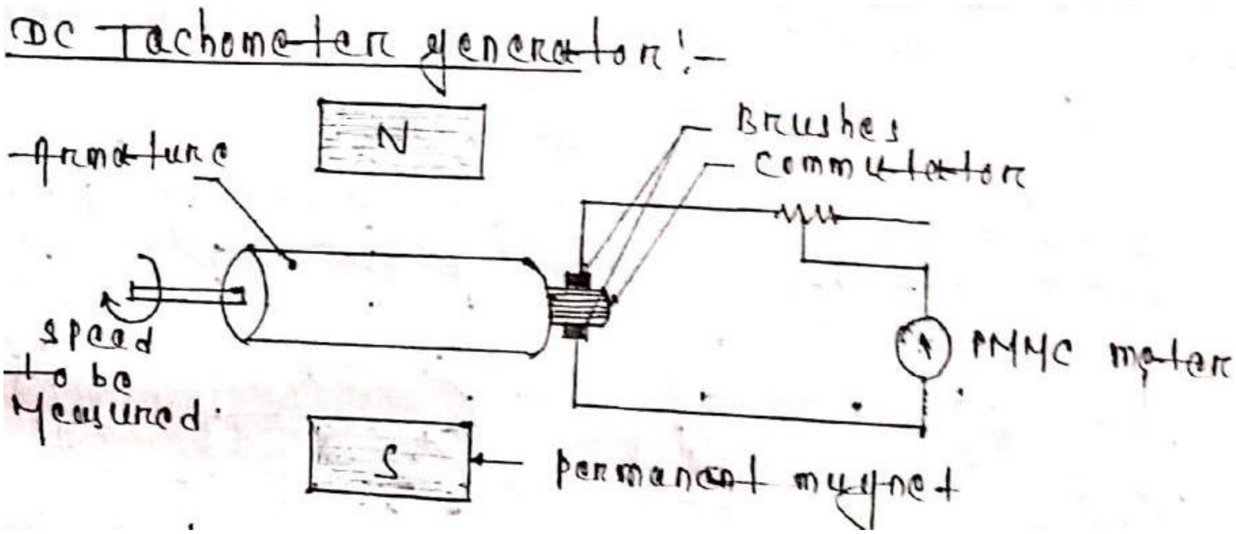
since -v3 is the instantaneous potential difference across pressure coil and (i1-i3) is the instantaneous current flowing through current coil of wattmeter W1,

since v2 is the instantaneous potential difference across pressure coil and (i2-i1) is the instantaneous current flowing through current coil of wattmeter W2,

W2=V2(I2-I1)

UNIT 4 TACHOMETER

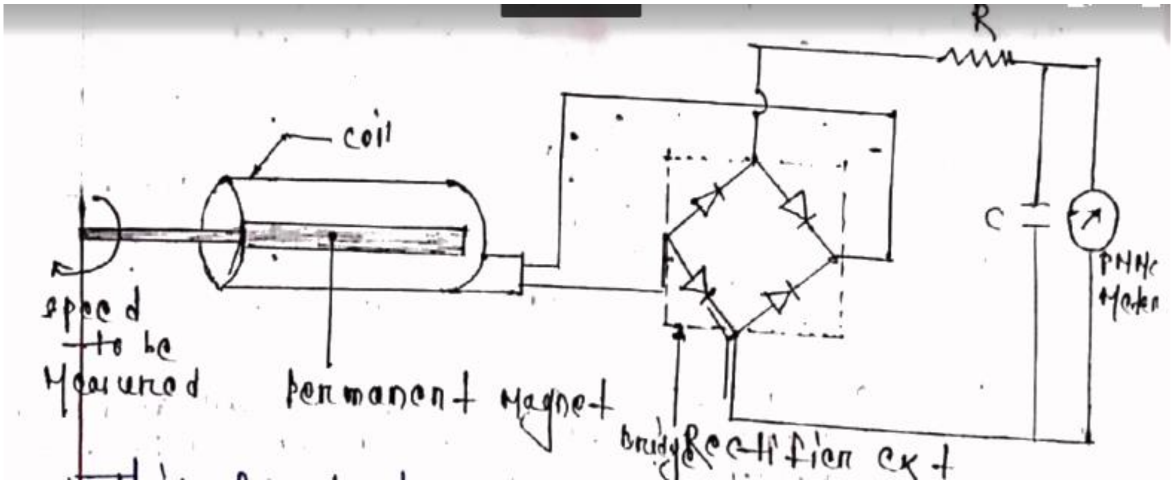
Tachometer is a device which is used for measuring the speed of any device.
It is classified as:
1)DC Tachometer
2)AC Tachometer



DC Tachogenerator consists of a small armature which is connected to the machine whose speed is to be measured.This armature coil revolves within the permanent magnetic field.Due to the rotation of armature within the magnetic field an EMF is induced in the armature coil this used EMFis proportional to flux and speed of rotation since the permanent magnetic field flux is constant,so the generator voltage is proportional to speed of rotation So the induced EMF can be collected with the help of commutator and brushes arrangements This voltage can be measured by using a PMMC type of meter which can be calibrated with the speed.

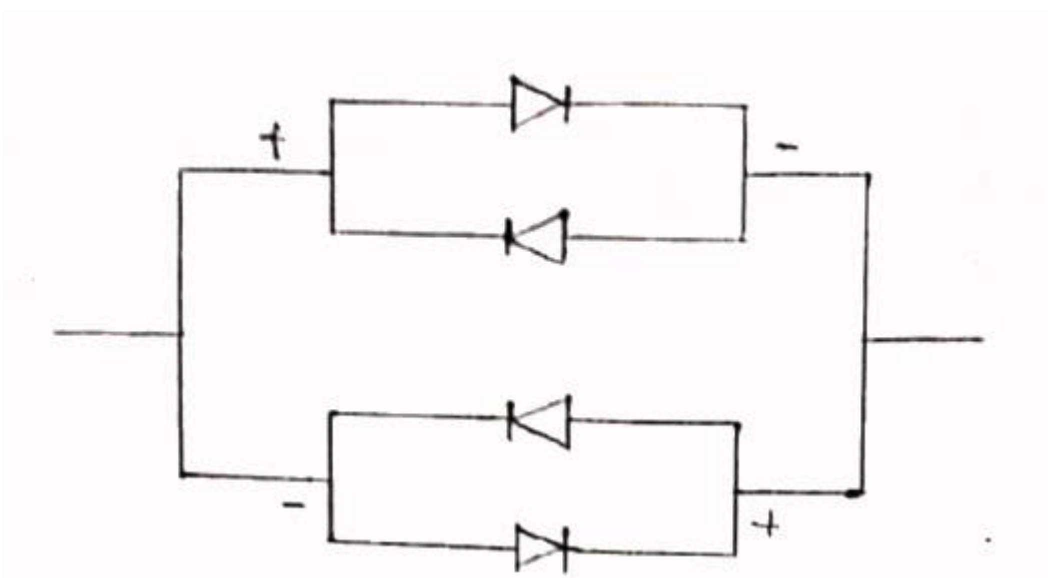
AC Tachometer Generator:

The Ac Tachometer generator contain rotating magnet which can be either an permanent magnet and electromagnet The AC Tachometer generally generate AC voltage with respect to the measured speed The diagram of AC Tachometer is shown below



This Ac tachometer generator generates output AC voltage which can be converted into DC voltage with the help of rectifier circuit.An PMMC type meter can be used to indicate the generated voltage which can be calibrated with respect to measured speed.

Fig: AC Tachometer Generator:



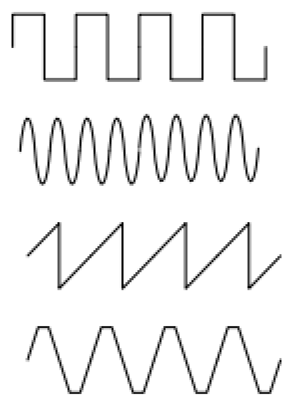
So we can easily identify the direction of speed using DC Tachometer.It requires regular maintenance as the carbon brushes used in it, easily gets damaged.AC tachometer generator requires very less maintenance as compared to DC Tachometer generator.

Frequency Meter:

frequency meter, a device for measuring multiplication by each unit of time (traditionally, seconds) of the full electric wave form. Different types of frequency meters are used. Many are deviation-type instruments, commonly used to measure low waves but can be used for up to 900 Hz waves. These work by measuring two opposing forces. Changes in the frequency to be measured cause a change in the balance that can be measured by the deviation of the indicator on the scale. Deflection type meters are of two types, output power circuits and ratios.

An example of a simple resonant electrical circuit is a moving coil meter. In one version, this device has two coils connected at different frequencies and connected at right angles to each other in such a way that everything, with the attached sensor, can move. Medium-width frequencies cause the waves on the two coils to be approximately equal and the indicator indicates the center point of the scale. The frequency change causes the imbalance of the currents in the two coils, which in turn, in turn, cause the signal to move.

Frequency of a periodic signal is defined as: the number of occurrences of a repeating event per unit time = Number of signal’s cycles per one second.



Principle of Working:To measure the frequency of a certain periodic signal, the waveform of that signal is used to toggle a counter for a certain fixed time. The number of counted cycles per unit time indicates the signal frequency.

The basic DFM consists of:

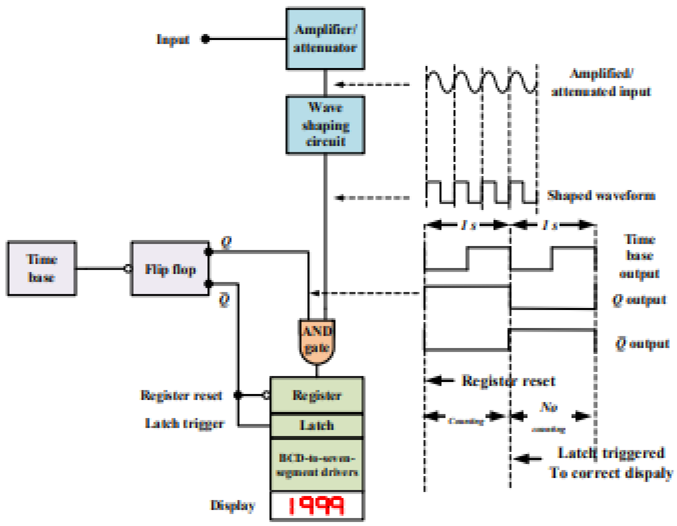
1) Accurate timing source (time base) with frequency of 1 Hz.

2)Digital counting circuit to count the input waveform cycles.

3) Amplifier/Attenuation circuit to amplify or attenuate the input signal.

4)Waveform shaping circuit to convert the input signal to square wave.

Basic Digital Frequency Meters (DFM):



Basic Digital Frequency Meters (DFM):

The operation of basic DFM:

1 The input signal is amplified or attenuated as necessary.

2 The input signal is converted to a square wave and is fed to one terminal of the AND gate.

3 The time base signal with 1 Hz. freq. is fed to a flip-flop.

4 The flip-flop changes its state at each falling-edge of the time base. It divides the frequency by 2 giving a **high** on the Q terminal for 1 s and a **low** for another 1 s. The terminal Q¯ is an inverted version of Q.

5 One terminal of the AND gate is fed from the flip-flop Q output and the other terminal is fed from the shaped input signal. So, the counter circuit will count the input pulses for the duration of 1 s. (Frequency).

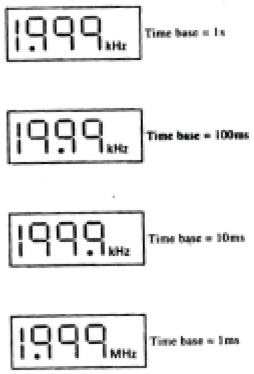
6 The counter will reset to zero at each negative (falling) edge of the Q .

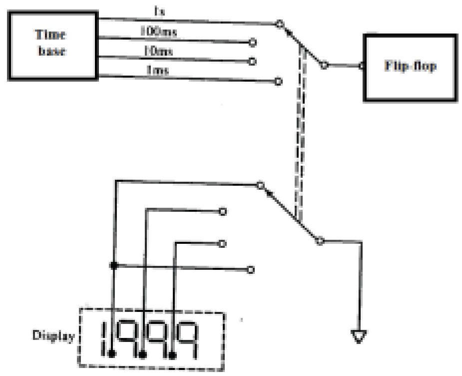
7 The latch will isolate the counting from the display during the first 1 s and will update the display on the rising edge of Q .

Frequency Range Changing:

Different time-base frequencies could be used to give several range of frequency measurements.

The different time base could be achieved by connecting a series decade counter. Each decade counter divides the frequency by 10





Frequency Range Changing

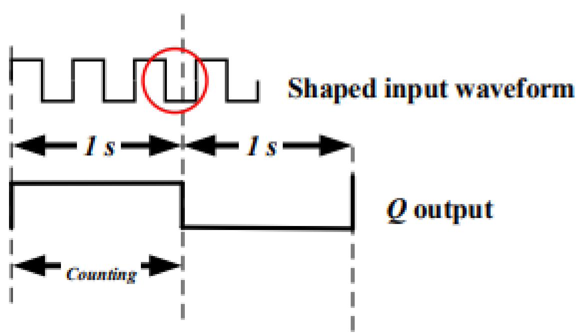
Frequency Meter Accuracy:

Range Selection Error

The lowest possible frequency range should be used for the greatest measurement accuracy.

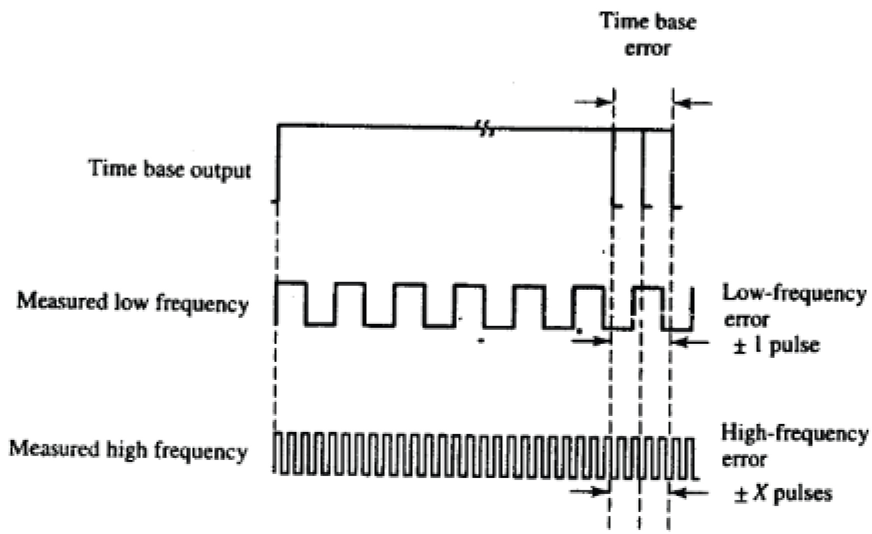
Frequency Meter Accuracy:

Accuracy Specification There is always a possible error of ±1 cycle in the measured frequency due to the partial input pulse that may or may not succeed in triggering the counting circuit. This one cycle is defined as least significant digit (LSD).



Frequency Meter Accuracy: Accuracy Specification Also, the time base error Etb due to freq. variation will give a reading error in the measured frequency fi as:

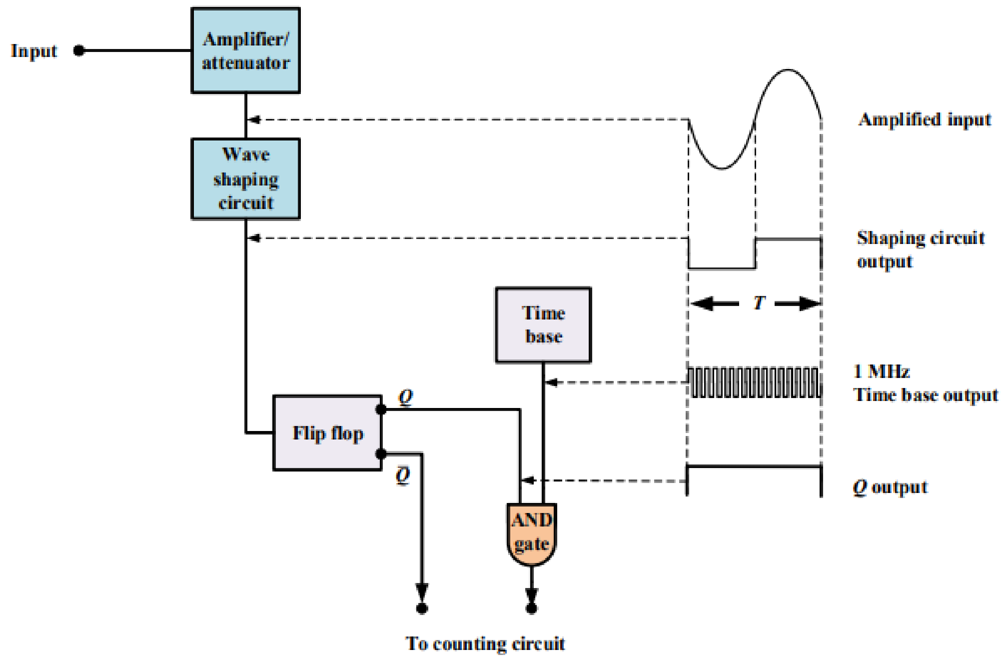
time base error = fi x Etb



So, the total accuracy of digital frequency meter is specified as:

±1 LSD ± time base error

Reciprocal Digital Frequency Meters (DFM):

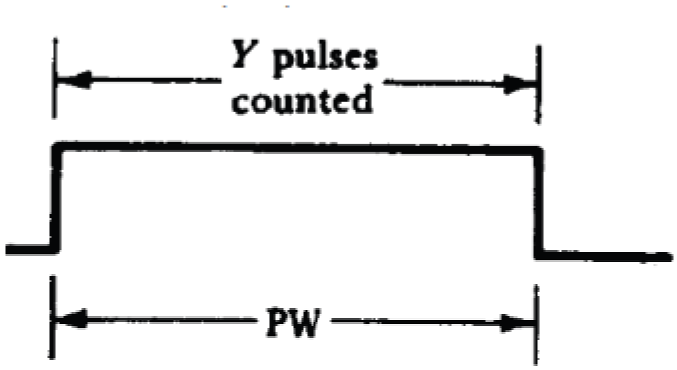


The time base signal with 1 MHz. is applied directly to the AND gate.
The reshaped input signal is employed to toggle the flip-flop circuit.
It is better for measuring low frequencies than the direct frequency meters.
The measure frequency fin is:

fin = ftime base/n

Time and Ratio Measurements:

Frequency Ratio Measurement If the flip-flop in Reciprocal FM is made to toggle on +ve and -ve edges, we can measure the input pulse width.



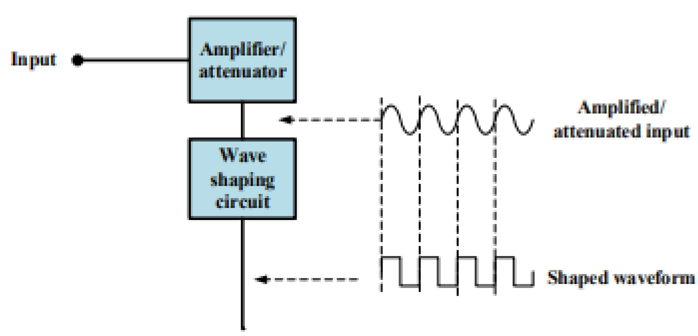
Digital measurement of pulse width
PW = Y μs

Frequency Ratio Measurement :

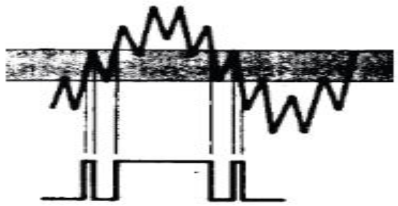
To find the ratio between two frequencies f1 and f2, the higher frequency signal is fed to the AND while the lower frequency is applies to the flip-flop.

Digital Frequency Input Stage:

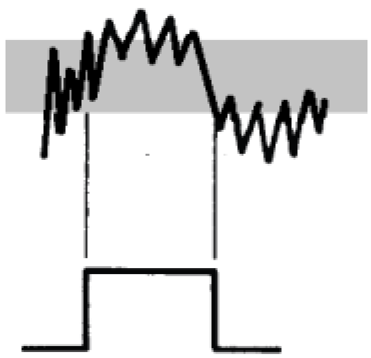
Why we use the attenuator/amplifier in input ?

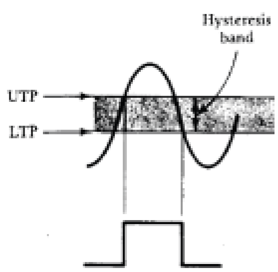


In the case of noisy input signal, an error is exist due to the amplified signal and the amplified noise.



To reduce the effect of noise, the input signal should be attenuated to attenuate the input noise.



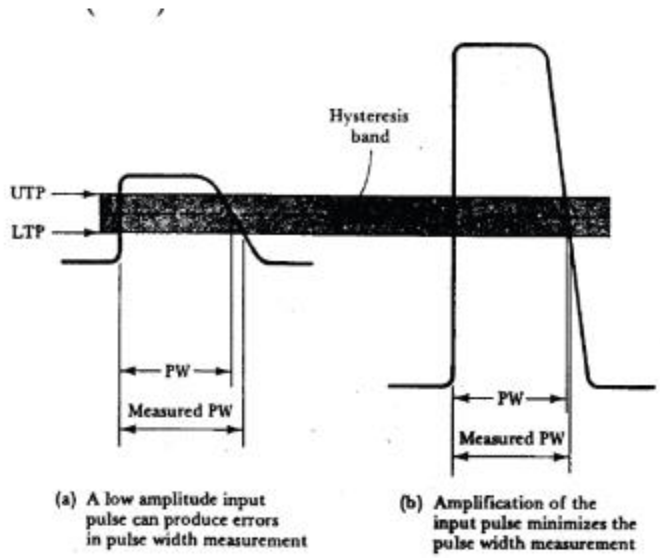


UTP: Upper Triggering Point.
LTP: Lower Triggering Point.

The small input signal could be amplified to make it suitable to be triggered by UTP and LTP.

Digital Frequency Input Stage:

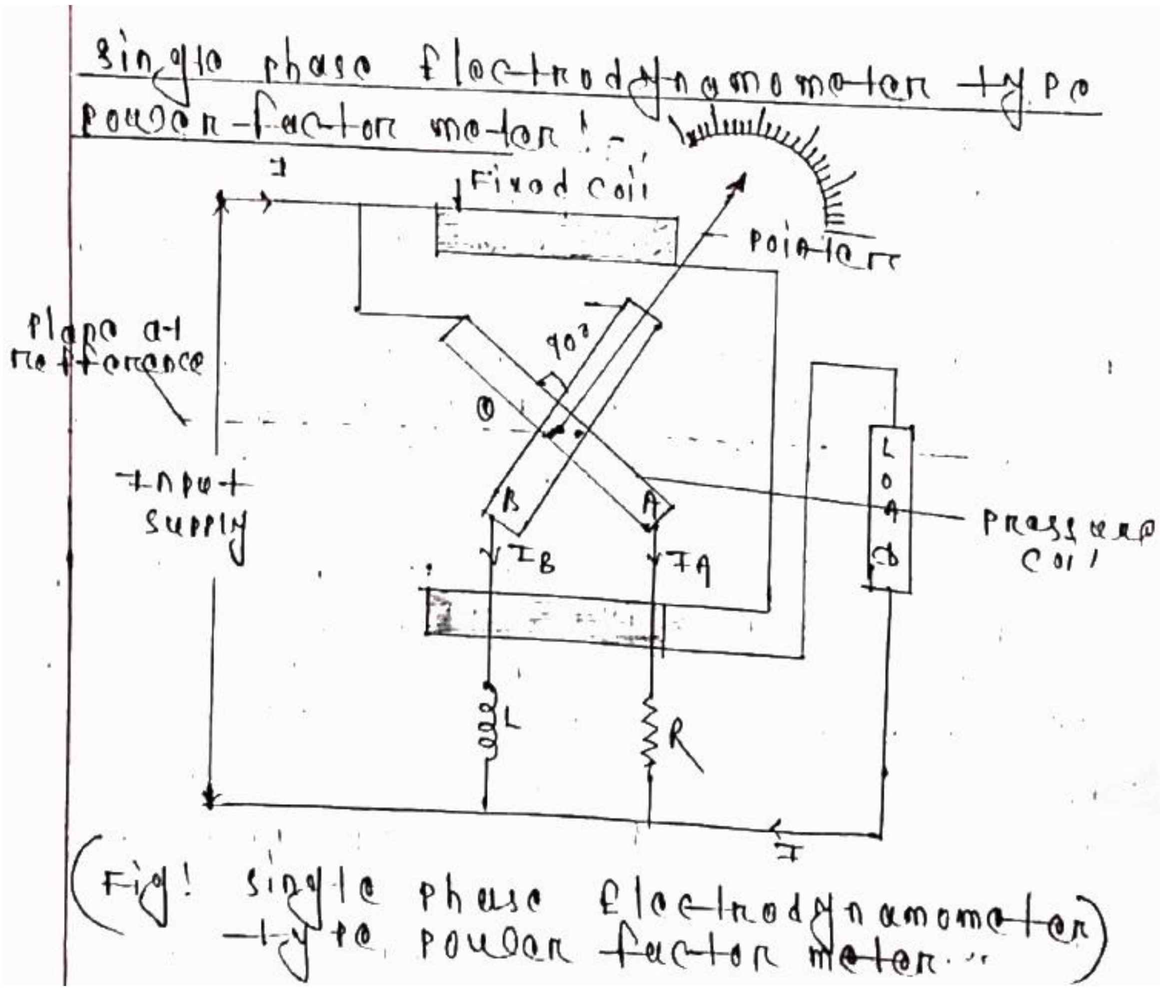
Also, amplification could help in reducing the measurement error due to hysteresis when measuring the Pulse Width (PW)



POWER FACTOR METER:

Definition: The power factor meter measures the power factor of a transmission system. The power factor is the cosine of the angle between the voltage and current. The power factor meter determines the types of load using on the line, and it also calculates the losses occur on it.

Construction : The construction of single phase electrodynamometer Power Factor Meter is shown in figure It consists of a fixed coil which acts as the current coil.This coil is split up into two parts and carriers the current of the circuit under test.Therefore,the magnetic field produced by this coil is proportional to the main current.



The single phase electrodynamometer type power factor consists of fixed coil and pressure coil. the fixed coil and splits into two parts and carries the currents of the circuit which is supplied to the load.The pressure coil also consists of two coils that is coil A and coil B.These two pressure coil pivoted on spindle which constitute the moving system.Pressurencoil ‘n’ is connected in series with inductance ‘L’.The current proportional to the voltage drop across the load flows through the pressure coil.The value of R & Lare so adjusted that

$$R = \omega L.$$

The angle between the plane of the coil is made equal to 90° The current Ib legs behind the voltage by 90° Current Ia is in phase with Voltage

Working/Operation:In this case to deflecting Torque produced which acts on coil a and coil b the coils are so designed that the torque acting on it are equal and opposite in direction so the pointer takes a position where the two torquess are equal .

Deflecting torque acting on coil A is:

$T_A = KVI\,M_{max}\cos\Phi\sin\theta$

where, θ = angular deflection from the plane of reference

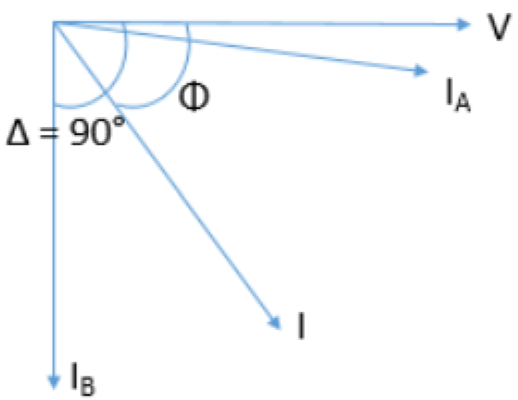
M_{max} = maximum value of mutual inductance between the two coils.

Deflecting torque acting on coil B is:

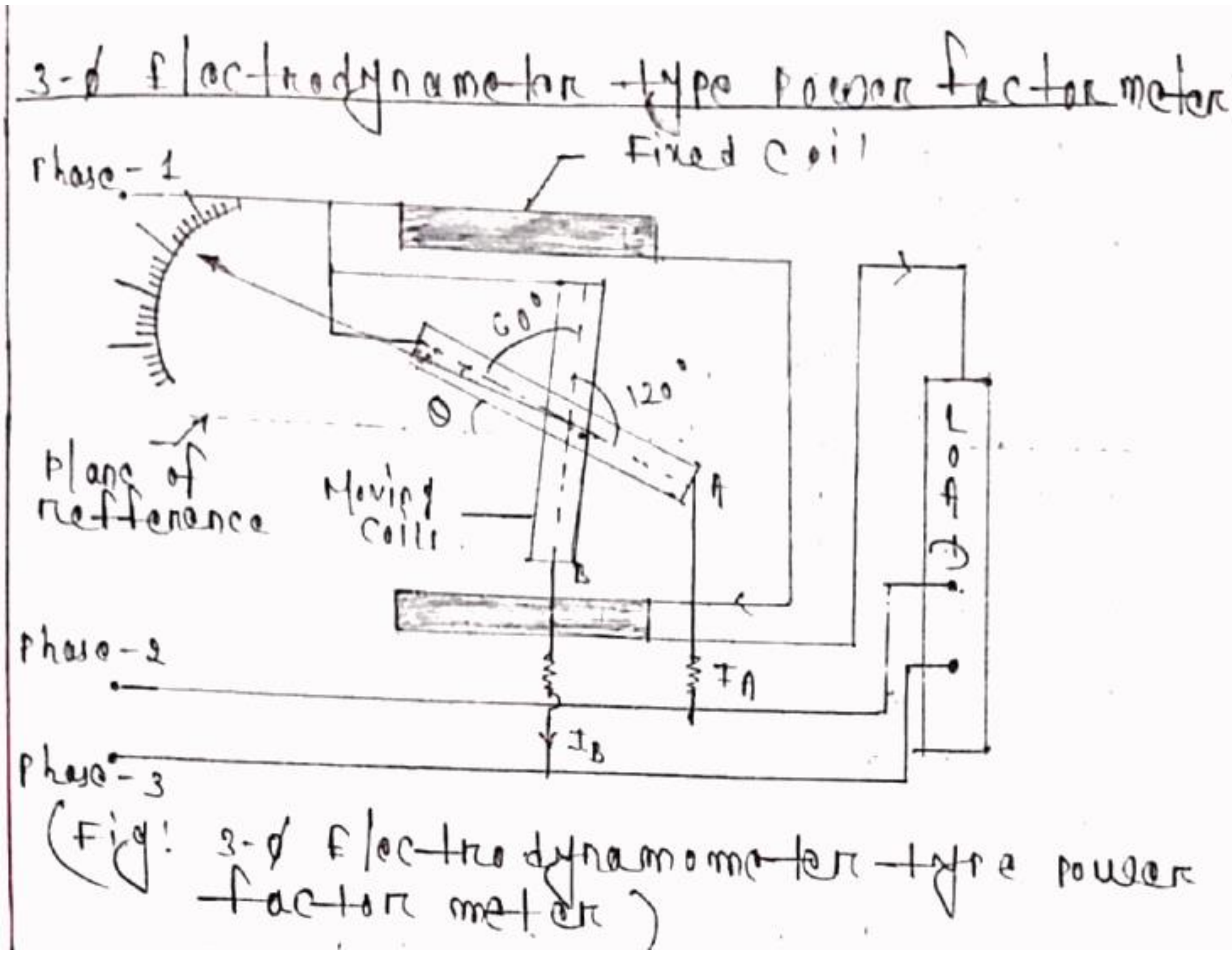
$\Rightarrow KVI\,M_{max}\cos\Phi\sin\theta = KVI\,M_{max}\sin\Phi\cos\theta$

$\Rightarrow \boldsymbol{\theta = \Phi}$

Therefore the deflection of the Instrument is the measure of phase angleOf the circuit The scale of the instrument can be calibrated Indirectly in the terms of power factor
The phasor diagram is also shown For the circuit such that the cu
rrent In the coil a is approximately At an angle of 90° To the current in the coil B



Three Phase Electro Dynamo type Power Factor Meter:



Construction:- The above figure shows the construction and connection of a 3 phase electrodynamometer type power factor the two moving coils of the meter are shown and so placed that the angle between their place is is 120 degrees this two calls are connected across 2 different phases of the supply circuit each of these two coils are has series resistance through which it is connected to the phase angle the voltage applied across coil a is V12 and the current flowing in it is I a the voltage applied across coilB isV13 and the current flowing through it is Ib these two moving coils are placed between segments of fixed coils

Working Principle:

The basic working principle of power factor meter is similar to that of dynamometer type wattmeter that is when the field produced by a moving system tries to come in line with the field produced by the fixed coil deflecting torque is exerted on the moving system which deflects the pointer attached to it. Power factor meter is an indicating instrument and no controlling torque is provided in this instrument the currents are being led into the moving coil A and B by fine ligaments where exert no control.

When the instrument is connected to the load circuit current flows through the fixed coil and moving coils A and B, flux is set by the fixed coil and moving coils.

By the alignment of two fields ,torque is developed that is the resultant field produced by the moving coil tries to come in line with the field produced by the fixed coil and the torque is developed still both of them come in line with each other there are three extreme conditions in which these instruments is connected in the circuit .

1) When power factor of the circuit is unity.
2) When power factor of the circuit is zero lagging
3) When power factor of the circuit is zero leading

Condition 1: when the power factor of the circuit is unity:

In this case current is in phase with the circuit voltage the current flowing through potential coil A is in phase with the voltage which is also in phase with the current flowing through current coil FF at the same time the current flowing through the potential coil B lags behind the voltage as well as the current flowing through current coil FF be 90°.Thus pressure coil a will experience the turning moment so its plane will come in position a parallel to the plane of the current coil FF the torque acting on the pressure coil B is zero does the pointer indicates Unity power factor on the scale.

Condition 2: when the power factor of the circuit is zero lagging:

In this case current lags behind the circuit voltage by 90° therefore the current flowing through pressure coil B will be in phase with the current in the circuit coil FF both being

Lagging behind the circuit voltage by 90° .The current flowing through pressure coil A will lead the current in the current coil FF by 90° .Thus a turning moment acts on the pressure will be B and bring its plane parallel to the plane of current coil FF and the pointer indicates zero power factor lagging

Condition 3: Power factor of the circuit is zero leading:

In this case current leads the circuit voltage by 90° therefore the current flowing through the pressure coil A lags the current in the current coil FF by 90° and current flowing through the pressure will B lags behind the current in the current coil FF by 180 degrees. Thus the field produced by the moving system is just reversed to that in the case(2).Thus an opposite turning moment acts on the pressure coil B and brings its plane parallel to the plane of the current coil asFF and the pointer indicates zero power factor leading.

Power Factor Meter Types:

The power factor meter is of two types they are

1)Electrodynamometer:

a)Single Phase Electrodynamometer

b) Three Phase Electrodynamometer

2) Moving Iron Type Meter

a)Rotating Iiron magnetic field

b)Number of alternating field

Unit 6 Measurement of Resistance

Classification of resistances:

1) Low resistances: All the resistances from 1ohm and under are classified as low resistances.

2) Medium resistances: The resistance from 1Ohms upward To about 0.1 M ohms are included.

3) High resistances: Resistance of the order of 0.1Mohms and upward are classified as high resistances .

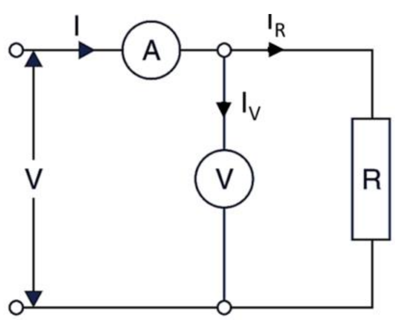
Methods For measurement of low resistances:

1) Ammeter voltmeter method

2) Kelvin's double bridge method

3) Potentiometer method

1)Ammeter Voltmeter method :



It is a simple method of measuring the lower value resistances as shown in figure the connections are made and both the current and voltage drop across the resistance simultaneously measured find the ammeter and voltmeter the accuracy mainly depends upon the accuracy and range of the instruments employed for the measurement of current and voltage.

here are current through ammeter(I) is the sum of the currents in voltmeter (Iv)And resistance(Ir), so

I=Iv+Ir

or

Ir=I-Iv

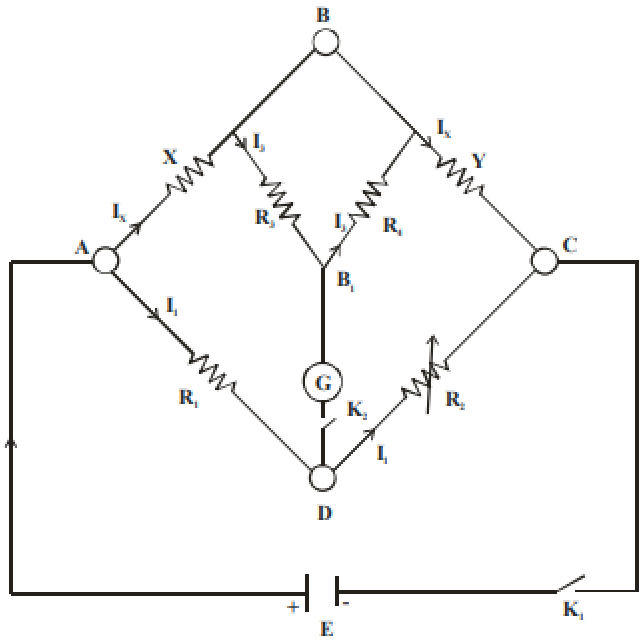
True value of of the resistance

$$= \frac{\text{Voltage across the resistance}}{\text{current in the resistance}}$$

$$= \frac{V}{I-Iv} \text{Ohms}$$

2) Kelvin Double Bridge Circuit –

The Kelvin Double Bridge is one of the best devices available for the precise measurement of low resistances. It is the modification of wheatstone bridge by which the errors due to contact resistance and lead resistances are eliminated. This bridge is named double bridge because it contains a second set of ratio arms. An interesting variation of the Wheatstone bridge is the Kelvin Double Bridge, used for measuring very low resistances (typically less than 1/10 of an ohm)



Let Y be the unknown and X standard known resistance of the same order.

R1, R2, R3, R4 are non inductive resistances of higher values as compared to X, Y.

The Balance is obtained when the points B and D are at the same potential.

The current at A divides into I1 and Ix in arms R1 and X respectively and I3 passes through R3, Potential drop on AD arm = I1R1.

The sum of potential drops across X and R3 = Ix X + I3R3 But potential at B and D are the same for no deflection in galvanometer, which implies that –

I1R1 = Ix X + I3R3 ………………….. (1)

Similarly,

P.D. across R2 = P.D. across R4 + P.D. across Y

or

I1R2 = I3R4 + Ix Y ………………… (2)

From (1) and (2)

we get Ix = I1R1 – I3R3 Ix y = I1R2 – I3R4 Dividing

$$\frac{Y}{X} = \frac{I_1R_2 - I_3R_4}{I_1R_1 - I_3R_3}$$

or $$\frac{X}{Y} = \frac{R_2\left[I_1 - I_3\frac{R_4}{R_2}\right]}{R_1\left[I_1 - I_3\frac{R_3}{R_1}\right]}$$

But $$\frac{R_1}{R_2} = \frac{R_3}{R_4} \text{ or } \frac{R_4}{R_2} = \frac{R_3}{R_1} = K$$

$$\therefore \frac{Y}{X} = \frac{R_2\left[I_1 - I_3K\right]}{R_1\left[I_1 - I_3K\right]}$$

or $$\frac{Y}{X} = \frac{R_2}{R_1}$$

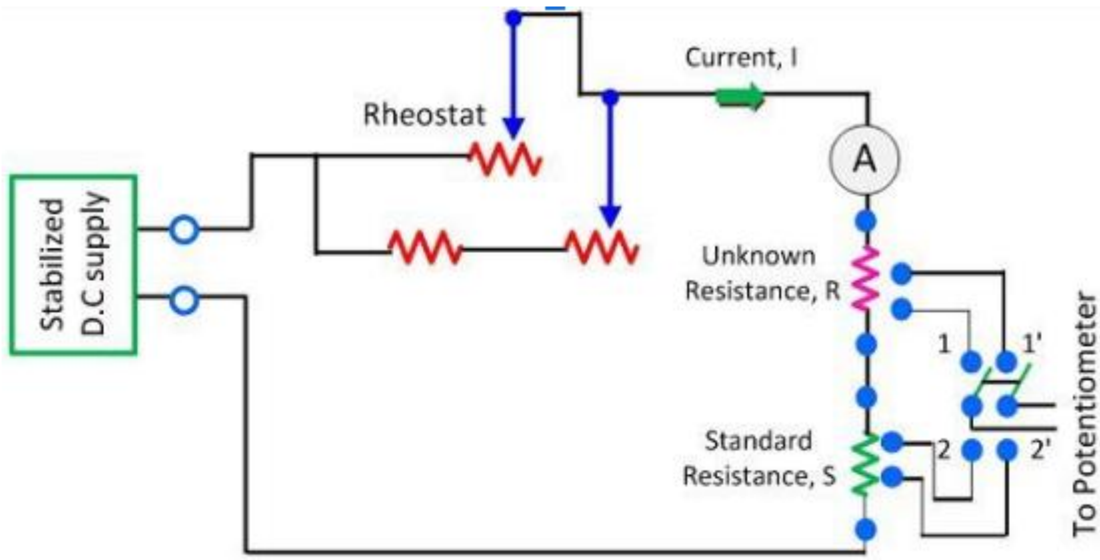
or $$\boxed{Y = X\frac{R_2}{R_1}} \quad \text{.........................} \quad (3)$$

This equation gives the value of Y in terms of known X1R1, R2 resistances.

Measurement of Resistance using Potentiometer:

The DC potentiometer method of measurement of resistance is used for measuring the unknown resistance of low value. This can be done by comparing the unknown resistance with the standard resistance. The voltage drop across the known and unknown resistance is measured and by comparison the value of known resistance is determined.

Following is the circuit diagram of potentiometer where R is the unknown resistance whose value needs to be measured. The S is the standard resistance from which the value of unknown resistance is compared. The rheostat is used for controlling the magnitude of current into the circuit.



Measurement of Resistance

The double pole double throw switch is used in the circuit. The switch, when moved to position 1, 1 the unknown resistance connects to the circuit, and when it moves to position 2, 2 the standard resistance connects to the circuit.

Consider that when the switch is in position 1,1 the voltage drop across the unknown resistance is Vr

$$V_r = IR \qquad (1)$$

and when it is in 2, 2 the voltage drop across the resistance is Vs

$$V_s = IS \qquad (2)$$

On equating the equation (1) and (2), we get

$$\frac{V_R}{V_S} = \frac{IR}{IS}$$

$$\frac{V_R}{V_S} = \frac{R}{S}$$

$$R = \frac{V_R}{V_S}.S$$

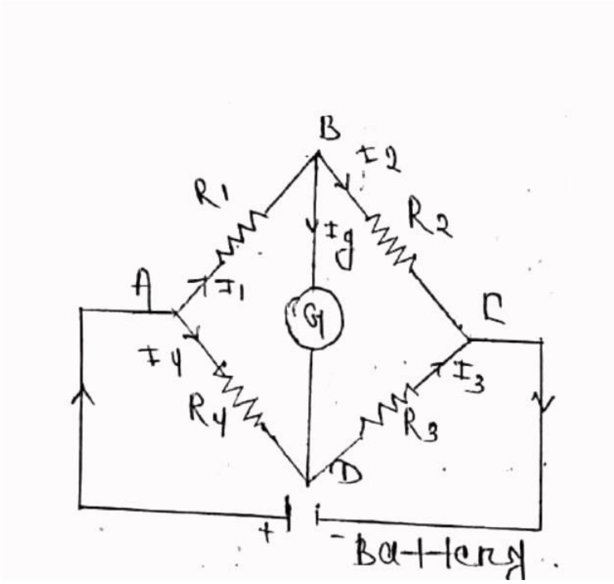
The accuracy of unknown resistance depends on the value of standard resistance.The accuracy of the unknown resistance also depends on the magnitude of the current at the time of the readings. If the magnitude of current remains the same, the circuit gives the accurate result. The ammeter is used in the circuit for determining the magnitude of current passing through the resistor during the reading.The magnitude of the current is adjusted in such a way that the voltage drop across the resistance is equal to 1 volt.

Measurement of Medium Resistances:

WheatStone Bridge Method:

The Wheatstone Bridge is one of the most common and simplest bridge networks / circuits, which can be used to measure resistance very precisely. But often the Wheatstone Bridge is used with Transducers to measure physical quantities like Temperature, Pressure, Strain etc.

Wheatstone Bridge is used in applications where small changes in resistance are to be measured in sensors. This is used to convert a change in resistance to a change in voltage of a transducer. The combination of this bridge with the operational amplifier is used extensively in industries for various transducers and sensors.For example, the resistance of a Thermistor changes when it is subjected to change in temperature. Likewise, a strain gauge, when subjected to pressure, force or displacement, its resistance changes. Depending on the type of application, the Wheatstone Bridge can be operated either in a Balanced condition or an Unbalanced condition.A Wheatstone bridge consists of four resistors (R1, R2, R3 and R4) that are connected in the shape of a diamond with the DC supply source connected across the top and bottom points (C and D in the circuit) of the diamond and the output is taken across the other two ends (A and B in the circuit).



This bridge is used to find the unknown resistance very precisely by comparing it with a known value of resistances. In this bridge, a Null or Balanced condition is used to find the unknown resistance.For this bridge to be in a Balanced Condition, the output voltage at points A and B must be equal to 0. From the above circuit:

The Bridge is in Balanced Condition if:

$$VOUT = 0\ V$$

Now, for Balanced Condition, the voltage across the resistors R1 and R2 is equal. If V1 is the voltage across R1 and V2 is the voltage across R2, then:

$$V1 = V2$$

Similarly, the voltage across resistors R3 (let us call it V3) and R4 (let us call it V4) are also equal. So,

$$V3 = V4$$

The ratios of the voltage can be written as:

$$V1 / V3 = V2 / V4$$

From Ohm's law, we get:

$$I1\ R1 / I3\ R3 = I2\ R2 / I4\ R4$$

Since $I1 = I3$ and $I2 = I4$, we get:

$$R1 / R3 = R2 / R4$$

From the above equation, if we know the values of three resistors, we can easily calculate the resistance of the fourth resistor.

Find Unknown Resistance using Balanced Wheatstone Bridge:

In the above circuit, let us assume that R1 is an unknown resistor. So, let us call it RX. The resistors R2 and R4 have a fixed value. Which means, the ratio R2 / R4 is also fixed. Now, from the above calculation, to create a balanced condition, the ratio of resistors must be equal i.e.,

$$RX / R3 = R2 / R4$$

Since the ratio R2 / R4 is fixed, we can easily adjust the other known resistor (R3) to achieve the above condition. Hence, it is important that R3 is a variable resistor, which we call RV.

By placing the Galvanometer between the points A and B, we can detect the Balanced Condition.With RX placed in the circuit, adjust the RV until the Galvanometer points to 0. At this point, note down the value of RV. By using the following formula, we can calculate the unknown resistor RX.

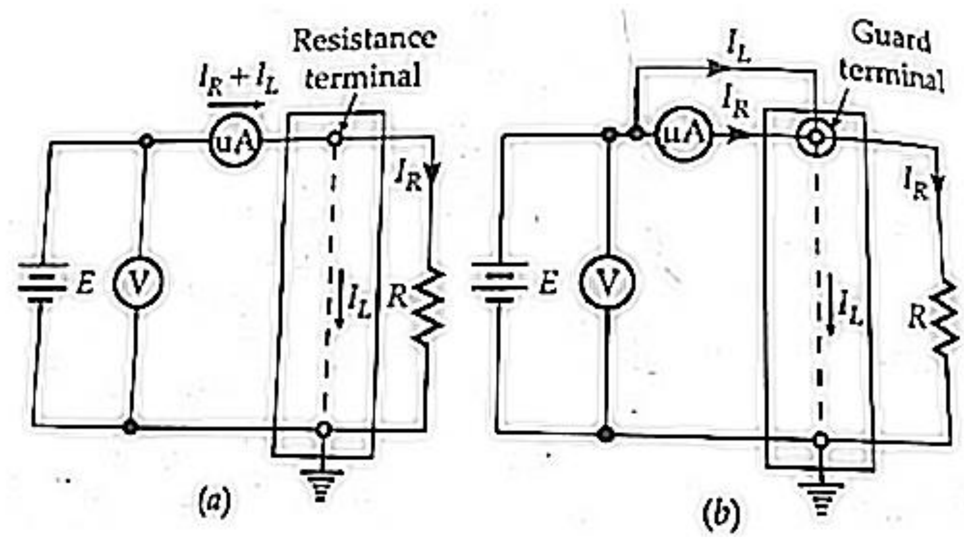
$$RX = RV\ (R2 / R4)$$

Measurements of High Resistances:

1) Direct Deflection Method
2) Loss of Charge Method

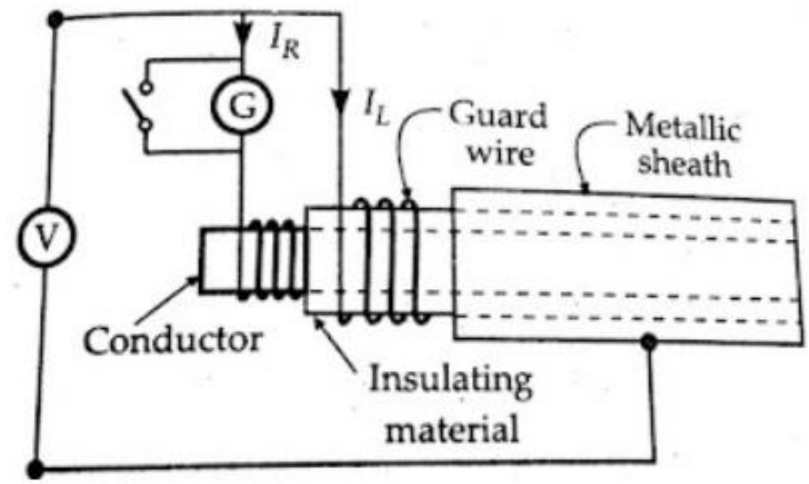
3) Megohm Bridge
4) Megger

1)Direct Deflection Method:



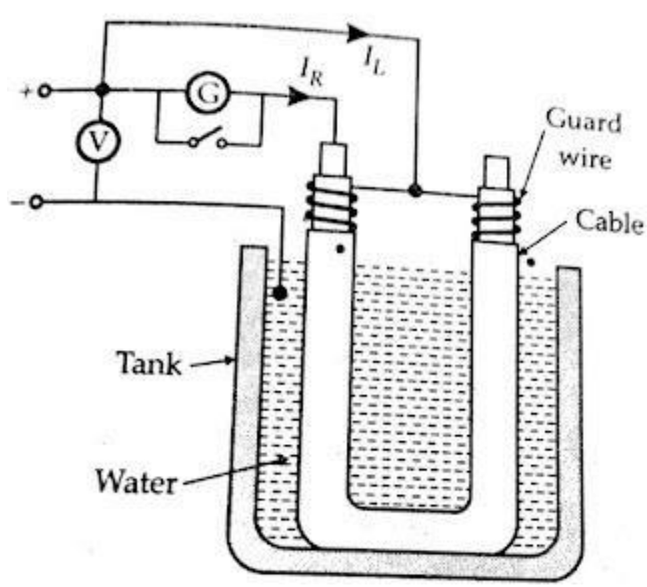
The direct deflection method is that of the figure-(b) above. For high resistance, such as insulation resistance of cables, a sensitive galvanometer of d'Arsonval type (usually having a current sensitivity of at 1000 mm/µA at a scale distance of 1 meter) is used in place of the microammeter. In fact, many sensitive types of galvanometers can detect currents from 0.1 - 1 nA. Therefore, with an applied voltage of 1 kV, resistances as high as 10^12 to 10*10^12 can be measured.

An illustration of the direct deflection method used for measuring the insulation resistance of a cable is shown in the figure below. The galvanometer G measures the current IR between the conductor and the metal Sheath. The leakage current IL, over the insulating material, is carried by the guard wire wound on the insulation and therefore does not flow through the galvanometer.



Cables without metal sheaths can be tested in a similar way if cable, except the end or ends on which corrections are made, is immersed in water in a tank. The water and the tank then form the return path for the current. The cable is immersed in slightly saline water for about 24 hours, and the temperature is kept constant (at about 20°C) and then the measurement is taken as in the figure below.

The insulation resistance of the cable R = V / IR .



In some cases, the deflection of the galvanometer is observed, and its scale is afterwards calibrated by replacing the insulation by a standard high resistance (usually 1 M**Ω**), the galvanometer shunt being varied, as required to give a deflection of the same order as before.

In tests on cables, the galvanometer should be short-circuited before applying the voltage. The short-circuited connection is removed only after sufficient time has elapsed so that charging and absorption currents cease to flow. The galvanometer should be well shunted during the early stages of measurement, and it is normally desirable to include a protective series resistance (of several M**Ω**) in the galvanometer circuit.The value of this resistance should be subtracted from the observed resistance value to determine the true resistance. A high voltage battery of 500 V emf is required and its emf should remain constant throughout the test.

Measurement of volume and surface resistivity:

The **direct deflection method** is often used for measurement of insulation resistance of insulating material samples available in sheet form. In such cases, we are interested in the measurement of volume resistivity and the surface resistivity of the material.

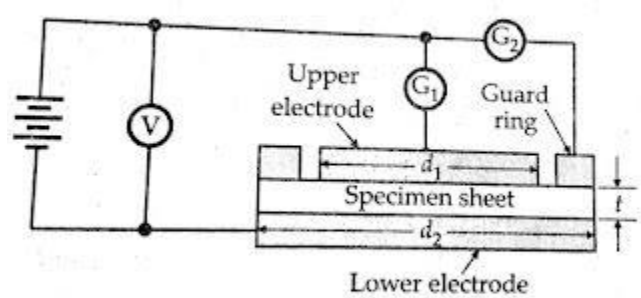
The figure below shows the schematic diagram for measurement of volume and surface resistivities of a specimen of insulating material. The specimen is provided with tin foil or colloidal graphite electrodes; the upper electrode having a guard ring. For measurement of volume resistivity (which in fact is the specific resistance), readings of the voltage applied and the current through the galvanometer are taken. Leakage currents over the edge of the specimen will flow between the guard ring and the lower electrode and hence will not introduce error into the measurement. The volume resistivity, p, can be calculated as follows:

Let d1 = diameter of the upper electrode d1,

r= thickness of the specimen sheet,

V1 = reading of voltmeter,

and I = current through galvanometer G1.



$\therefore$ Resistance of specimen

$$R = V_1 / I_1. \quad \text{But } R = \rho t / \pi d_1^2$$

$\therefore$ Volume resistivity of specimen,

$$\rho = \frac{\pi d_1^2}{t} = \frac{\pi d_1^2 V_1}{t I_1}$$

The resistivity of a thin layer of dielectric materials is different from volume resistivity, not only because of an adherent humidity layer but also because of contamination, chemical alterations, absorption of gasses, or structural modification.The resistance Rt between two electrodes embedded in or attached to a dielectric medium is composed of volume resistance Rv and surface resistance Rs with (1 / Rt) =(1/ Rv) +(1 /Rs)

The volume resistance, Rv, can be measured separately from surface resistance Rs with the help of guard rings as shown in the figure above. If we want to measure surface resistivity, the galvanometer is placed in position G2. In this position, the galvanometer measures the leakage current, and the current flowing between upper and lower electrodes will be eliminated from the measurement. Let

d2 = diameter of lower electrode disc,

V2 = reading of voltmeter

And I2 = current through galvanometer G2.

Surface resistance, Rs = V2/I2

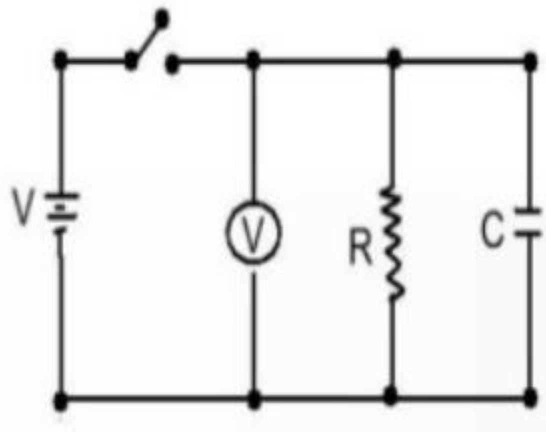
The leakage current flows along a path of length t and width πd2 and therefore, surface resistivity,

$$\rho_s = \frac{R_s \times \pi d_2}{t} = \frac{\pi d_2}{t} \cdot \frac{V_2}{I_2}$$

Other forms of specimen and electrodes are also used. For example, the electrodes and guard ring may be mercury, either placed in specially machined recesses, in moulded insulating materials or retained by metal rings on the surface of sheet materials.

2) Loss of charge Method:

In 'Loss of charge method' the insulation resistance R to be measured is connected in parallel with a capacitor C and an electrostatic voltmeter. The capacitor is charged to some suitable voltage, by means of a battery having voltage V and is then allowed to discharge through the resistance. The terminal voltage is observed over a considerable period of time during discharge.



Loss of charge method

The voltage across the capacitor at any instant t after the application of voltage is

$$V = V \exp(-t/ CR)$$

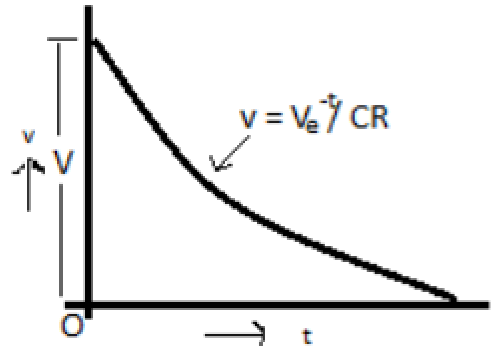
or $V/ v = \exp(-t/ CR)$

or Insulation resistance

$$R = t / \{C \log V/v\}$$

$$= 0.4343t /\{C \log V/v\}$$

The variation of voltage v with time shown in below figure:



From the equation above, it follows that if V,v, C and t are known the value of R can be computed. If the resistance R is very large the time for an appreciable fall in voltage is very large and thus this process may become time-consuming. Also the voltage-time curve will thus be very flat and unless great care is taken in measuring voltage at the beginning and end of the time 'r', a serious error may be made in the ratio V / v causing a considerable corresponding error in the measured value of R. More accurate results may be obtained by change in the voltage V-v directly and calling this change as e, the expression for R becomes

$$R = \frac{0.4343\ t}{C\ log_{10} \frac{V}{V - e}}$$

The test is then repeated with the unknown resistance R, disconnected and the capacitor discharging through R1. The value of R1 obtained from this second test and substituted into the expression

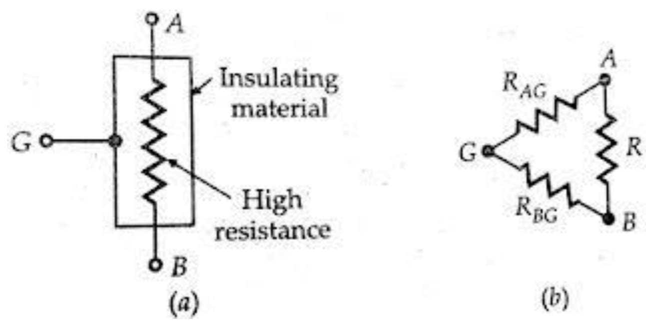
$$R' = \frac{R\ R_1}{R + R_1}$$

in order to get the value of R.

The leakage resistance of the voltmeter, unless very high, should also be taken into consideration.

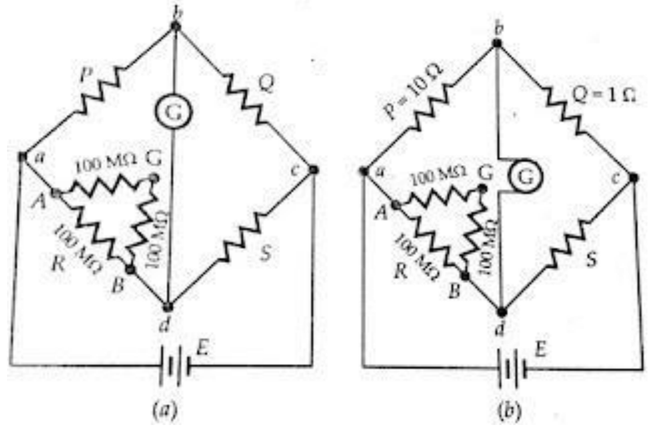
3) Megohm Bridge Method:

The below figure(a) shows a very high resistance R with its two main terminals A and B, and a guard terminal, which is put on the insulation. This high resistance may be diagrammatically represented as in figure(b). The resistance R is between main terminals A and B and the leakage resistances RAG and RBG between the main terminals A and B of from a "Three-terminal resistance".

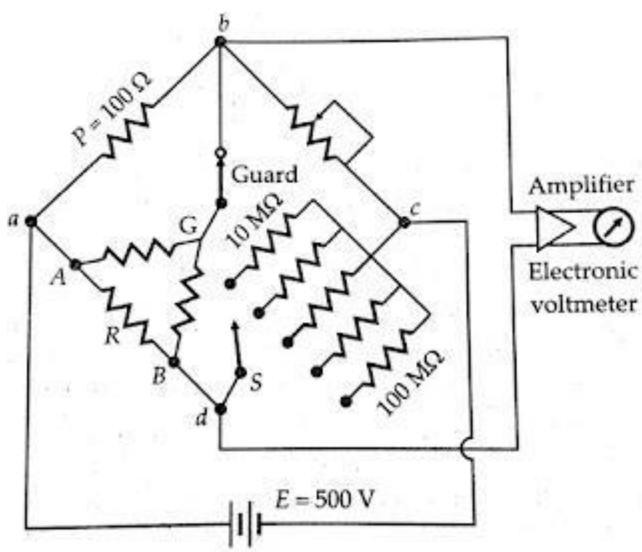


Let us consider the hypothetical case of a 100 MΩ resistance. We assume that each of the leakage resistances is 100 MΩ, i.e., RAG = RBG =100 MΩ. Let this resistance be measured by an ordinary Wheatstone bridge as shown in the figure(a) below. It is clear that the wheatstone bridge will measure a resistance of $\frac{100*100}{100+200} = 67M\Omega$ instead of 100 MΩ thus giving an error of 33 percent.

Megohm Bridge Circuit:



However if the same resistance is measured by a modified Wheatstone bridge as shown in the figure(b) above with the guard connection G connected as indicated, the error in measurement is considerably reduced. For the arrangement shown in figure(b) above resistance, RBG is put in parallel with the galvanometer and thus it has no effect on the balance and only affects the sensitivity of the galvanometer slightly.The resistance RAG =100 MΩ is put in parallel with a resistance P =100 kΩ and therefore for the arrangement shown the measured value has an error of only 0.01 percent and this error is entirely negligible for measurements of this type. The arrangement of the below figure illustrates the operation of a Megohm bridge.The below figure shows the circuit of a completely self-contained Megohm bridge which includes power supplies, bridge a members, amplifiers, and indicating instrument.It has a range from 0.1 MΩ to 10^6 MΩ. The accuracy is within 3% for the lower part of the range to possibly 10% above 10,000 MΩ.



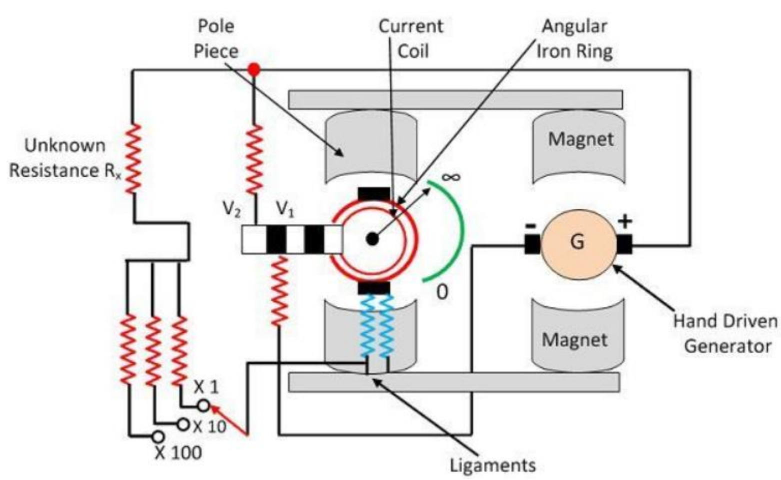
Sensitivity for balancing against high resistance is obtained by use of adjustable high voltage supplies of 500 V or 1000 V and the use of a sensitive null indicating arrangement such as a high gain amplifier with an electronic voltmeter or a CRO.The dial on Q is calibrated 1 - 10 - 100 - 1000 MΩ, with main decade 1 - 10 occupying the greater part of the dial space. Since unknown resistance R= P.S/Q the arm Q is made, tapered, so that the dial calibration is approximately logarithmic in the main decade, 1 - 10. Arm S gives five multipliers, 0.1, 1, 10, 100 and 1000.The junction of ratio arms P and Q is brought on the main panel and is designated as 'Guard' terminal.

4) Megger:

Definition: The Megger is the instrument used for measuring the resistance of the insulation. It works on the principle of comparison, i.eThe resistance of the insulation is compared with the known value of resistance. If the resistance of the insulation is high, the pointer of the moving coil deflects towards the infinity, and if it is low, then the pointer indicates zero resistance. The accuracy of the Megger is high as compared to other instruments.

Construction of Megger

The construction of the Megger is shown in the figure below. The Megger has one current coil and the two voltage coils V1 and V2. The voltage coil V1 is passed over the magnet connected to the generator. When the pointer of the PMMC instrument deflects towards infinity, it means that the voltage coil remains in the weak magnetic field and thus experiences very little torque.



The torque experienced by the coil increases when it moves inside the strong magnetic field. The coil experiences the maximum torque under the pole faces and the pointer set at the zero end of the resistance scale.For improving the torque, the voltage coil V2 is used. The coil V2 is so allocated that when the pointer deflects from infinity to zero the coil moves into a stronger magnetic field.

In Megger, the combined action of both the voltage coils V1 and V2 are considered. The coil comprises a spring of variable stiffness. It is stiff near the zero end of the coil and becomes very weak near the infinity end of the spring.The spring compresses the low resistance portion and opens the high resistance of the spring, which is the great advantage of the Megger because it is used for measuring the insulation of the resistance which is usually very high.The instrument has voltage selector switch which is used for selecting the voltage range of the instrument. The voltage range is controlled by selecting the varying resistance R connected in series with the current coil. The voltage is generated by connecting the hand driven generator.

Working of Megger:

The testing voltage is usually 500, 1000 or 2500 V which is generated by the hand driven generator. The generator has a centrifugal clutch due to which the generator supplied the constant for the insulation test. The constant voltage is used for testing the insulation having low resistance.The Megger has three coils, two pressure coils and one current coil. The pressure coil rotates the moving coil in the anticlockwise direction, whereas the current coil rotates it in the clockwise direction.When the unknown resistance is connected in the circuit, the pointer of the moving coil becomes stable. The pressure coil and the current coil balance the pointer and set it in the middle of the scale.The deflection of the pointer is directly proportional to the voltage applied to the external circuit. When the testing circuit is applied across the Megger, and if there is no shorting throughout the insulation then the pointer deflects towards the infinity. Which shows that the resistance has high insulation. For low resistance, the pointer moves towards zero.

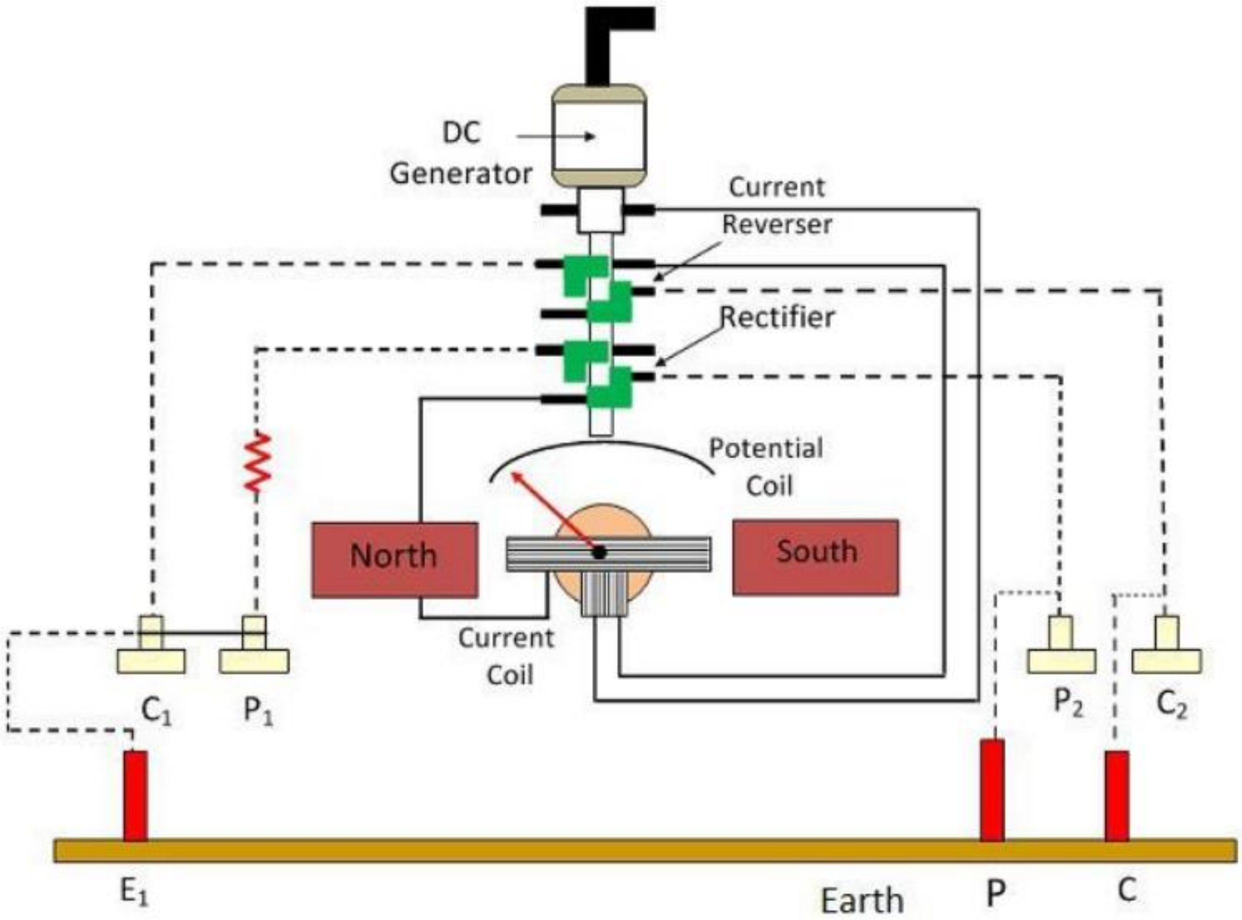
Earth Tester:

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 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 **r**otational 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 the pressure coil to the current of the current coil.The short circuit current passing 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 occurs because of chemical action or because of the production of back emf.

Inductance Measurement:

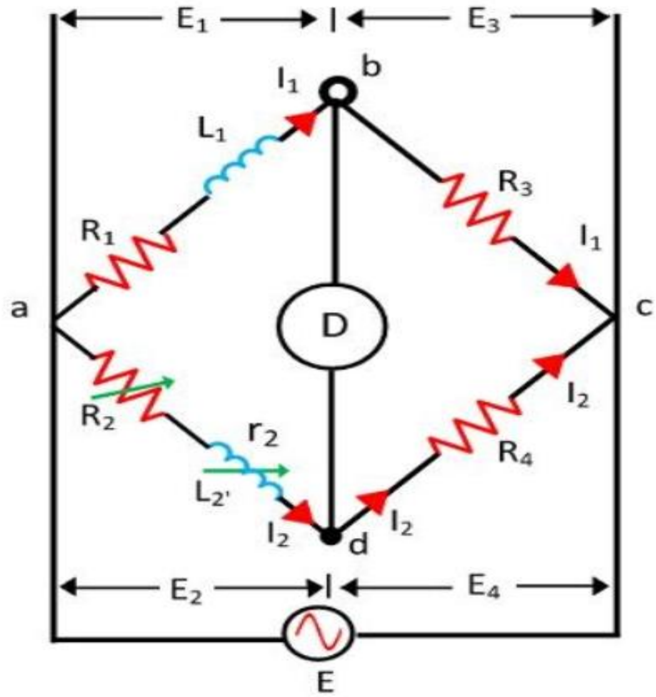
Two methods are used for determining the self-inductance of the circuit. They are

1. Maxwell's Inductance Bridge
2. Maxwell's inductance Capacitance Bridge

Maxwell's Inductance Bridge:A Maxwell bridge is a modification to a wheatstone bridge used to measure an unknown inductance(usually of low Q value) in terms of calibrated resistance and inductance or resistance and capacitance. When the calibrated components are a parallel resistor and capacitor, the bridge is known as a Maxwell-Wien bridge.

It uses the principle that the positive phase angle of an inductive impedance can be compensated by the negative phase angle of a capacitive impedance when put in the opposite arm and the circuit is at resonance; i.e., no potential difference across the detector and hence no current flowing through it. The unknown inductance then becomes known in terms of this capacitance.

With reference to the picture,



Let, L1 – unknown inductance of resistance R1.

L2 – Variable inductance of fixed resistance r1.

R2 – variable resistance connected in series with inductor L2.

R3, R4 – known non-inductance resistance

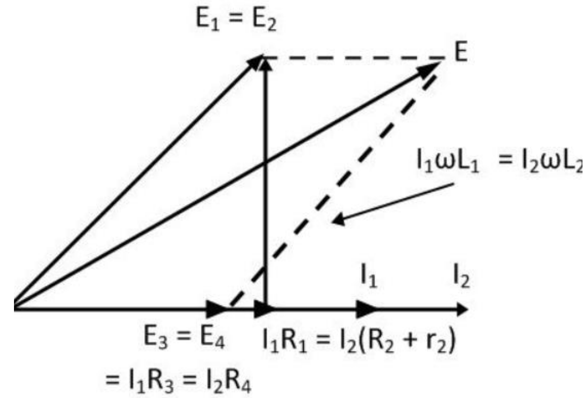
At balance,

$$L_1 = \frac{R_3}{R_4} L_2$$

$$R_1 = \frac{R_3}{R_4}(R_2 + r_2)$$

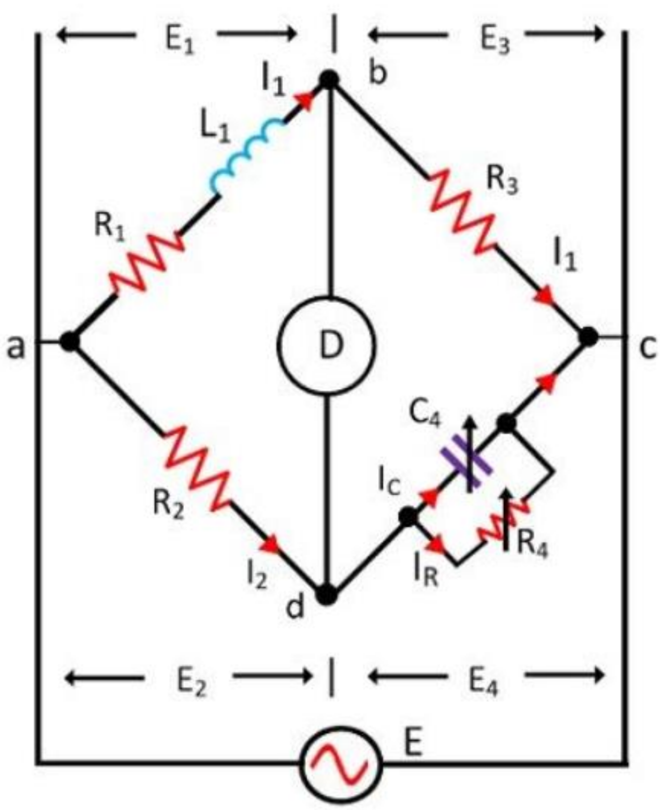
The value of the R3 and the R4 resistance varies from 10 to 1000 ohms with the help of the resistance box. Sometimes for balancing the bridge, the additional resistance is also inserted into the circuit.

The phasor diagram of Maxwell's inductance bridge is shown in the figure below.



Maxwell's Inductance Capacitance Bridge

In this type of bridges, the unknown resistance is measured with the help of the standard variable capacitance. The connection diagram of the Maxwell Bridge is shown in the figure below.



Let, L1 – unknown inductance of resistance R1.

R1 – Variable inductance of fixed resistance r1.

R2, R3, R4 – variable resistance connected in series with inductor L2.

C4 – known non-inductance resistance

$$(R_1 + j\omega L_1)\left(\frac{R_4}{1 + j\omega C_4 R_4}\right) = R_2 R_3$$

For balance condition, $R_1 R_4 = j\omega L_1 R_4 = R_2 R_3 + j\omega C_4 R_4 R_2 R_3$

By separating the real and imaginary equation we get,

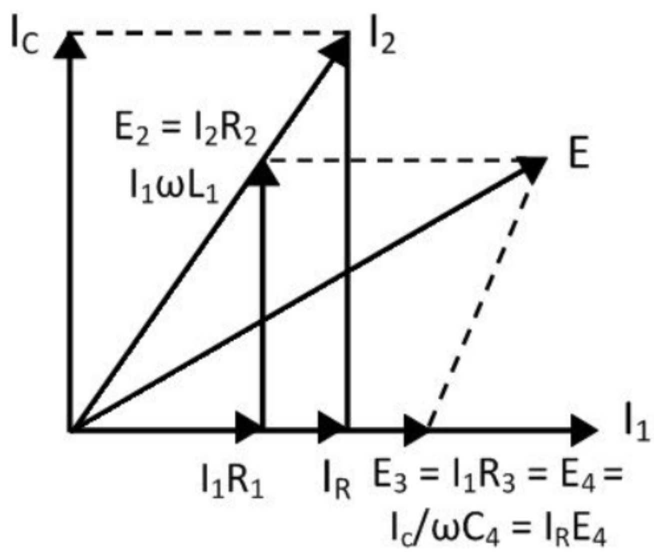
$$R_1 = \frac{R_2 R_3}{R_4}$$

$$L_1 = R_2 R_3 C_4$$

The above equation shows that the bridges have two variables R4 and C4 which appear in one of the two equations and hence both the equations are independent.

The circuit quality factor is expressed as $Q = \frac{\omega L_1}{R_1} = \omega C_4 R_4$

Phasor diagram of Maxwell's inductance capacitance bridge is shown in the figure below.



Phasor Diagram

Schering Bridge

The Schering bridge use for measuring the capacitance of the capacitor, dissipation factor, properties of an insulator, capacitor bushing, insulating oil and other insulating materials. It is one of the most commonly used AC bridge. The Schering bridge works on the principle of balancing the load on its arm.

Let, C1 – capacitor whose capacitance is to be determined,

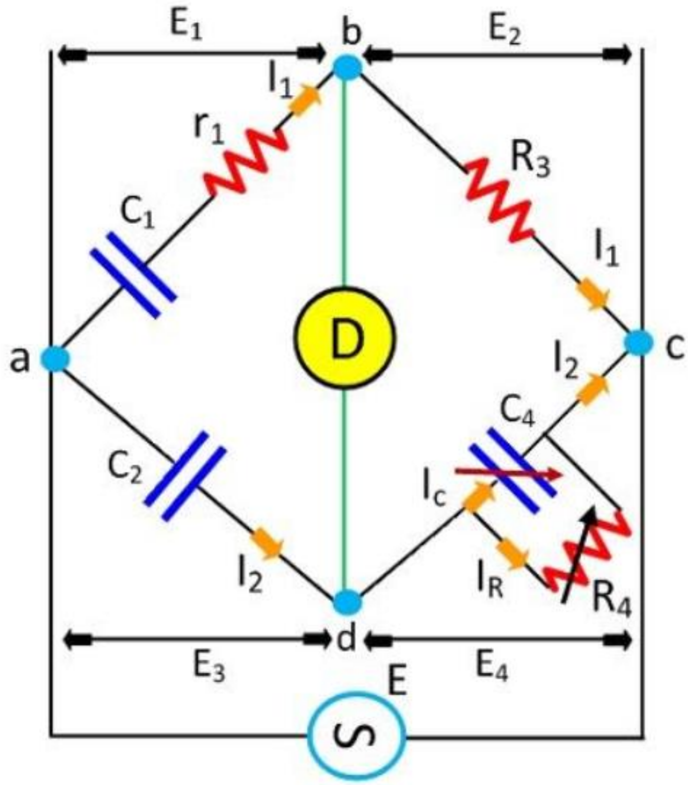
r1 – a series resistance, representing the loss of the capacitor C1.

C2 – a standard capacitor (The term standard capacitor means the capacitor is free from loss)

R3 – a non-inductive resistance

C4 – a variable capacitor.

R4 – a variable non-inductive resistance parallel with variable capacitor C4.



When the bridge is in the balanced condition, zero current passes through the detector, which shows that the potential across the detector is zero. At balance condition

$Z_1/Z_2 = Z_3/Z_4$

$Z_1Z_4 = Z_2Z_3$

$$\left(r_1 + \frac{1}{jwC_1}\right)\left(\frac{R_4}{1 + j\omega C_4 R_4}\right) = \frac{1}{j\omega C_2}.R_3$$

$$\left(r_1 + \frac{1}{jwC_1}\right)R_4 = \frac{R_3}{jwC_2}(1 + j\omega C_4 R_4)$$

So,

$$r_1 R_4 - \frac{jR_4}{\omega C_1} = -j\frac{R_3}{\omega C_1} + \frac{R_3 R_4 C_4}{C_2}$$

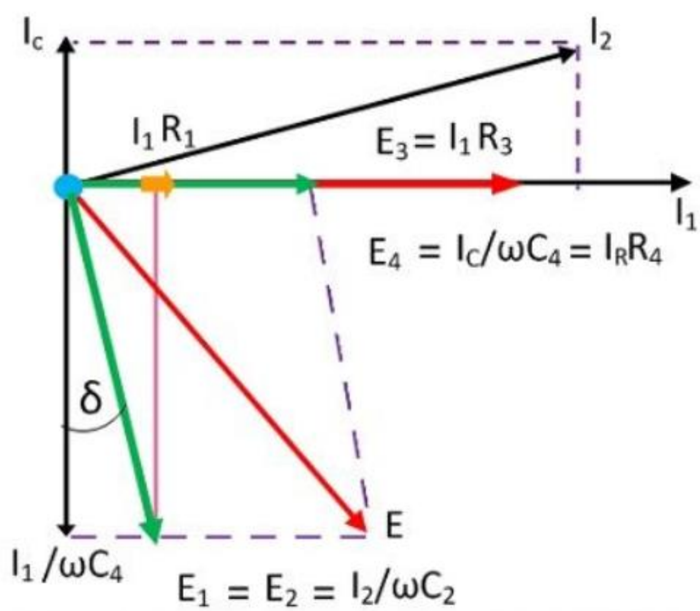
Equating the real and imaginary equations, we get

$$r_1 = \frac{R_3 C_4}{C_2} \ldots\ldots\ldots. equ(1)$$

$$C_1 = C_2\left({}^{R_4}/_{R_3}\right) \ldots\ldots\ldots equ(2)$$

The equation (1) and (2) are the balanced equation, and it is free from the frequency.

The dissipation factor obtains with the help of the phasor diagram. The dissipation factor determines the rate of loss of energy that occurs because of the oscillations of the electrical and mechanical instrument.



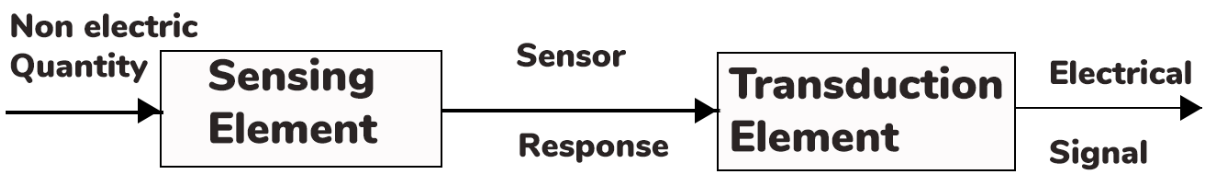
$$D_1 = tan\delta = \omega C_1 r_1 = \omega(C_1 r_1) = \omega(C_2 R_4/R_3) \times (R_3 C_4/C_2)$$

$$D_1 = \omega C_4 R_4$$

By the help of the above equation, we can calculate the value of tanδ which is the dissipation factor of the Schering bridge.

Unit 7:Sensors and Transducers:

Introduction: A device which converts a physical quantity into the proportional electrical signal is called a transducer. The electrical signal produced may be a voltage, current or frequency. A transducer uses many effects to produce such conversion. The process of transforming signal from one form to other is called transduction. A transducer is also called pick up. The transduction element transforms the output of the sensor to an electrical output, as shown in the Fig



The input in any instrumentation system makes its first contact with a primary detection element this includes process variables like temperature, pressure and the flow rate which are widely employed in the process and production plants .The measurand also includes electrical quantity like current ,voltage, resistance, inductance, capacitance ,frequency ,phase angle, power and magnetic quantity like flux, flux density, reluctance all this quantity required a primary detection element or a transducer to be converted into analogous format which is the acceptable by the later stages of the measurement system .The measurand or input signal is called as information of the measurement system and it is in the form of physical phenomena or it could be the electrical signal this energy may be extracted from the measurand but it also loads error the efforts should be made two supplies energy required for conversion from outside sources so that the measure and is not distorted during the process of conversion in order that ate be faithfully reproduced in its analogous form .

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Mechanical devices as primary detectors: In order to get the information from the mechanical systems only mechanical displacement or velocity can be used some of the commonly used mechanical sensing elements are Springs which converts the force or torque into a displacement a diaphragm, capsule ,or Bourdon tube which converts pressure into displacement a bimetallic strip converts temperature into displacement mass damper system is used for measurement of acceleration velocity and displacement some input devices may involve more than one mechanical conversion for example fluid flow measurements may involve conversion of fluid rate into pressure differential using an orifice Venturi tube or pitot tube and then in turn this pressure is converted into displacement for the purpose of measurement.

Mechanical spring devices:

1. cantilever

2 helical spring

3. spiral spring

4. Torsion bars and shafts

5. Proving rings

6.Load cells

7. spring fixture pivotes

pressure sensitive primary devices:

1.Bourdain tubes

2.Spiral type

3. bellows type

4.Diaph ragms

Transducers: an electronic instrumentation system consists of a number of of components to perform the measurement and record its result the measurement system consists of three major components.

1. An input device

2. A signal conditioning or processing device

3. Output device

The input device receives the measure and or the quantity under measurement and delivers to a proportional or analogue signal to the signal conditioning device the signal is amplified 10 activated then filtered then modulated in the format acceptable to the output device the input quantity for most instrumentation systems is a non electrical quantity in order to use electrical methods and techniques for measurements the non electrical quantity is generally converted into electrical for by a device called a transducer which can define a transducer as a device which when activated transforms energy from one form to another.

Electrical transducers: In order to measure non electrical quantities a detector is used which usually convert the physical quantity into a displacement this displacement actuates and electrical transducer which acting as a secondary transducer give Sar output that is electrical in nature the electrical quantities produced is measured in standard methods used for electrical measurements the electrical signal may be current or voltage or frequency and production of the signals is based on the electrical effects which maybe resistive capacitive in the safe in nature the first stage of measurement system is called as Is called as transducer stage

Advantages of electrical transducers:

1. Electrical amplification and detonation can be done easily and that too with the static devices.

2. The effects of friction are minimized.

3. The electrical or electronic system can be controlled with a very small power level

4. Battery is used in almost all sophisticated measurement systems

5. There has been an explosive development in the field of Electronics components and devices. This development is on account of the fact that electronic devices are very amenable to miniaturization .

Classifications of transducer

1. On the basis of transduction form used

2. Primary and secondary transducers

3. As passive and active transducers

4. As analogue and digital transducers

5. Transducers and Inverse transducers

Classification based on the principle of the transducer:

It can be classified on the basis of the principle of transaction as resistive inductive capacitive depending upon how they convert the input quantity in to resistance inductance of capacitance respectively they can be classified as piso electric thermoelectric Magneto restrictive electro Kinetic and optical.

Resistive Transducers

1. Resistance Strain Gauge – The change in value of resistance of metal semi-conductor due to elongation or compression is known by the measurement of torque, displacement or force.

2. Resistance Thermometer – The change in resistance of metal wire due to the change in temperature known by the measurement of temperature.

3. Resistance Hygrometer – The change in the resistance of conductive strip due to the change of moisture content is known by the value of its corresponding humidity.

4. Hot Wire Meter – The change in resistance of a heating element due to convection cooling of a flow of gas is known by its corresponding gas flow or pressure.

5. Photoconductive Cell – The change in resistance of a cell due to a corresponding change in light flux is known by its corresponding light intensity.

6. Thermistor – The change in resistance of a semiconductor that has a negative coefficient of resistance is known by its corresponding measure of temperature.

7. Potentiometer Type – The change in resistance of a potentiometer reading due to the movement of the slider as a part of an external force applied is known by its corresponding pressure or displacement.

Capacitance Transducers

1. Variable capacitance pressure gauge - Principle of operation: Distance between two parallel plates is varied by an externally applied force Applications: Measurement of Displacement, pressure

2. Capacitor microphone Principle of operation: Sound pressure varies the capacitance between a fixed plate and a movable diaphragm. Applications: Speech, music, noise

3. Dielectric gauge Principle of operation: Variation in capacitance by changes in the dielectric. Applications: Liquid level, thickness

Inductance Transducers :

1. Magnetic circuit transducer :

Principle of operation: Self inductance or mutual inductance of ac-excited coil is varied by changes in the magnetic circuit. Applications: Pressure, displacement

2. Reluctance pickup:

Principle of operation: Reluctance of the magnetic circuit is varied by changing the position of the iron core of a coil. Applications: Pressure, displacement, vibration, position

3. Differential transformer :

Principle of operation: The differential voltage of two secondary windings of a transformer is varied by positioning the magnetic core through an externally applied force. Applications: Pressure, force, displacement, position

4. Eddy current gauge:

Principle of operation: Inductance of a coil is varied by the proximity of an eddy current plate. Applications: Displacement, thickness

5. Magnetostriction gauge:

Principle of operation: Magnetic properties are varied by pressure and stress.

Applications: Force, pressure, sound

Voltage and current Transducers:

1. Hall effect pickup:

Principle of operation: A potential difference is generated across a semiconductor plate (germanium) when magnetic flux interacts with an applied current.

Applications: Magnetic flux, current

2. Ionization chamber :

Principle of operation: Electron flow induced by ionization of gas due to radioactive radiation. Applications: Particle counting, radiation

3. Photoemissive cell:

Principle of operation: Electron emission due to incident radiation on photoemissive surface. Applications: Light and radiation

4. Photomultiplier tube :

Principle of operation: Secondary electron emission due to incident radiation on photosensitive cathode.

Applications: Light and radiation, photo-sensitive relays .

Self-Generating Transducers (No External Power) –

Active Transducers They do not require an external power, and produce an analog voltage or current when stimulated by some physical form of energy.

1. Thermocouple and thermopile:

Principle of operation: An emf is generated across the junction of two dissimilar metals or semiconductors when that junction is heated.

Applications: Temperature, heat flow, radiation.

2. Moving-coil generator

Principle of operation: Motion of a coil in a magnetic field generates a voltage.

Applications: Velocity. Vibration

3. Piezoelectric pickup :An emf is generated when an external force is applied to certain crystalline materials, such as quartz Sound, vibration. acceleration, pressure changes

4. Photovoltaic cell :

Principle of operation: A voltage is generated in a semi-conductor junction device when radiant energy stimulates the cell.

Applications: Light meter, solar cell

Primary Transducers and Secondary Transducers- Bourden tube acting as a primary detecter senses the pressure and converts the pressure into a displacement of its free end.The displacement of the free end moves the core of a linear variable differential transformer(LVDT) which produces an output voltage.

Analog Transducers-These transducers convert the input quantity into an analog output which is a continuous function of time. Strain Gauge , LVDT, Thermocouple . Thermistor

Digital Transducers-These transducers convert the input quantity into an electrical output which is in the form of pulses. Glass Scale can be read optically by means of a light source,an optical system and photocells .

Transducers and Inverse Transducers- -A Transducer can be broadly defined as a device which converts a non-electrical quantity into an electrical quantity. Ex:-Resistive,inductive and capacitive transducers -An inverse transducer is defined as a device which converts an electrical quantity into a non-electrical quantity. Ex:-Piezoelectric crystals.

Advantages of Electrical transducers :Mostly quantities to be measured are non-electrical such as temperature, pressure, displacement, humidity, fluid flow, speed etc., but these quantities cannot be measured directly. Hence such quantities are required to be sensed and changed into some other form for easy measurement. Electrical quantities such as current, voltage, resistance, inductance and capacitance etc. can be conveniently measured, transferred and stored, and, therefore, for measurement of the non-electrical quantities these are to be converted into electrical quantities first and ten measured. The function of converting non-electrical quantity into electrical one is accomplished by a device called the electrical transducer. Basically an electrical transducer is a sensing device by which a physical, mechanical or optical quantity to be measured is transformed directly, with a suitable mechanism, into an electrical signal (current, voltage and frequency). The production of these signals is based upon electrical effects which may be resistive, inductive, capacitive etc. in nature. The input versus output energy relationship takes a definite reproducible function. The output to input and the output to time behavior is predictable to a known degree of accuracy, sensitivity and response, within the specified environmental conditions. Electrical transducers have numerous advantages. Modern digital computers have made use of electrical transducers absolutely essential.

Electrical transducers suffer due to some draw-backs too, such as low reliability in comparison to that of mechanical transducers due to the ageing and drift of the active components and comparative high cost of electrical transducers and associated signal conditioners. In some cases the accuracy and resolution attainable are not as high as in mechanical transducers.

Some of the advantages are:

1. Electrical amplification and attenuation can be done easily and that to with a static device. 2. The effect of friction is minimized.

3. The electric or electronic system can be controlled with a very small electric power.

4. The electric power can be easily used, transmitted and process for the purpose of measurement.

Factor to be considered while selecting transducer:

It should have high input impedance and low output impedance, to avoid loading effect.

It should have good resolution over is entire selected range.

It must be highly sensitive to desired signal and insensitive to unwanted signal.

Preferably small in size.

It should be able to work in corrosive environment.

It should be able to withstand pressure, shocks, vibrations etc..

It must have high degree of accuracy and repeatability.

Selected transducer must be free from errors.

The transducer circuit should have overload protection so that it will withstand overloads.

Requirements of a good transducers

• Smaller in size and weight.

• High sensitivity.

• Ability to withstand environmental conditions.

• Low cost.

RESISTIVE TRANSDUSERS

Resistance of an electrical conductor is given by, R=ρl/A Where ,

R = Resistance in „Ω"

P = Resistivity of the conductor (Ω - cm)

l = Length of the conductor in cm.

A = Cross-sectional area of the metal conductor in cm2

It is clear from the equation that, the electrical resistance can be varied by varying,

(i) Length (ii) Cross-sectional area and (iii) Resistivity or combination of these.

Principle:- A change in resistance of a circuit due to the displacement of an object is the measure of displacement of that object ,method of changing the resistance and the resulting devices are summarized in the following

Method of changing resistance

Length - Resistance can be changed varying the length of the conductor,(linear and rotary). Dimensions - When a metal conductor is subjected to mechanical strain, change in dimensions of the conductor occurs, that changes the resistance of the conductor.

Resistivity - When a metal conductor is subjected to a change in temperature and change in resistivity occurs which changes resistance of the conductor.

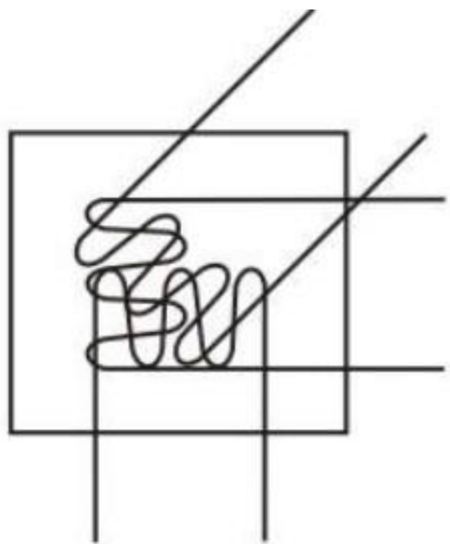
Resulting device:- Resistance potentiometers or sliding contact devices displacements ,Electrical resistance strain gauges.Thermistor and RTD

Use:- the resistive transducer used for the measurement of linear and angular, and used for the temperature mechanical strain measurement.

Strain Gauge: Strain gauge is one of the most popular types of transducer. It has got a wide range of applications. It can be used for measurement of force, torque, pressure, acceleration and many other parameters. The basic principle of operation of a strain gage is simple: when strain is applied to a thin metallic wire, its dimension changes, thus changing the resistance of the wire. Let us first investigate what are the factors, responsible for the change in resistance.

Metallic Strain Gage Most of the strain gages are metallic type. They can be of two types: unbonded and bonded. The unbonded strain gauge is normally used for measuring strain (or displacement) between a fixed and a moving structure by fixing four metallic wires in such a way, so that two are in compression and two are in tension, as shown in fig. (a). On the other hand, in the bonded strain gauge, the element is fixed on a backing material, which is permanently fixed over a structure, whose strain has to be measured, with adhesive. Most commonly used bonded strain gauges are metal foil type. The construction of such a strain gauge is shown in fig. (b). The metal foil type strain gauge is manufactured by photo-etching technique. Here the thin strips of the foil are the active elements of the strain gauge, while the thick ones are for providing electrical connections. Because of the large area of the thick portion, their resistance is small and they do not contribute to any change in resistance due to strain, but increase the heat dissipation area. Also it is easier to connect the lead wires with the strain gauge.

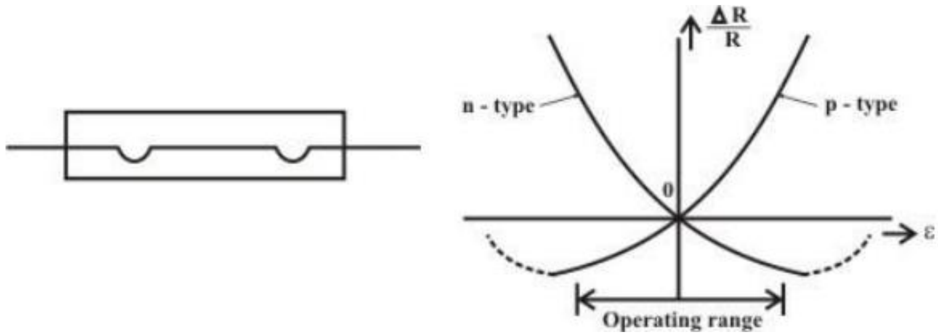
The strain gauge in fig.(b) can measure strain in one direction only. But if we want to measure the strain in two or more directions at the same point, strain gage rosette, which is manufactured by stacking multiple strain gauges in different directions, is used. Fig. shows a three element strain gage rosette stacked at 45 Degree .



Three Element Strain Gauge Rosette-45 Degree Stacked

The backing material, over which the strain gage is fabricated and which is fixed with the strain measuring structure has to satisfy several important properties. Firstly, it should have high mechanical strength; it should also have high dielectric strength. But the most important it should have is that it should be non-hygroscopic, otherwise, absorption of moisture will cause bulging and generate local strain. The backing materials normally used are impregnated paper, fiberglass, etc. The bonding material used for fixing the strain gauge permanently to the structure should also be non hygroscopic. Epoxy and Cellulose are the bonding materials normally used.

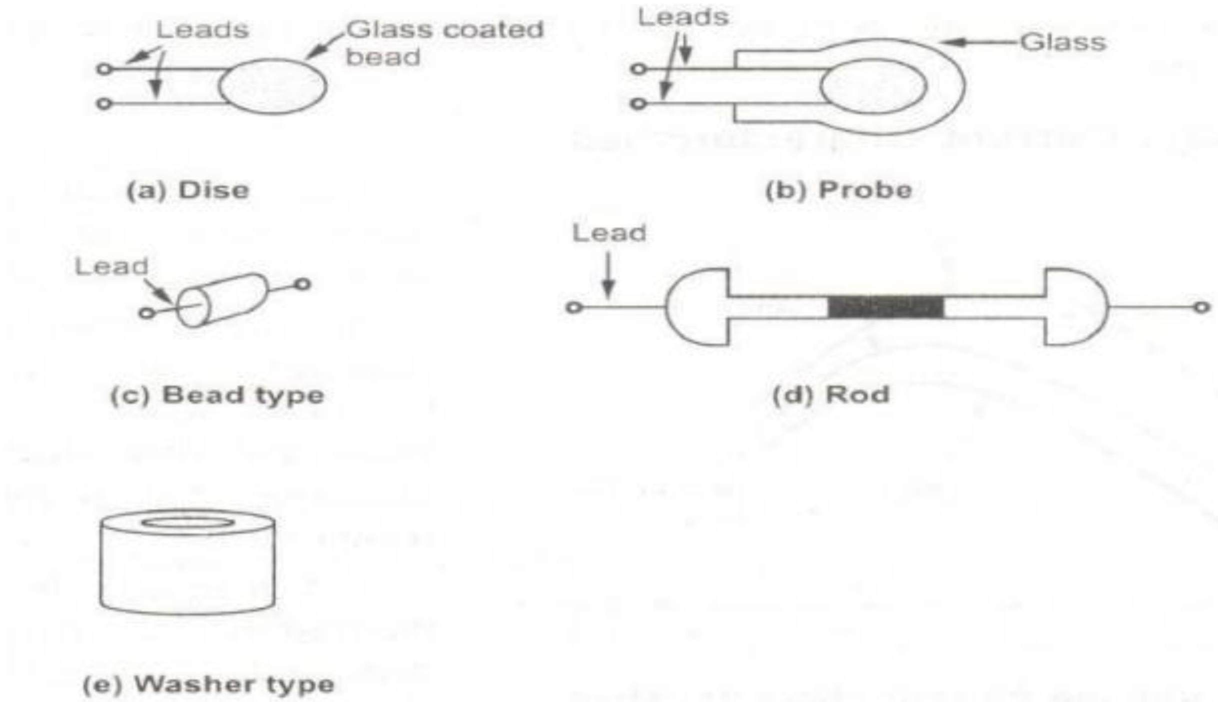
Semiconductor type Strain Gage :Semiconductor type strain gauge is made of a thin wire of silicon, typically 0.005 inch to 0.0005 inch, and length 0.05 inch to 0.5 inch. They can be of two types: p-type and n-type. In the former the resistance increases with positive strain, while, in the later the resistance decreases with temperature. The construction and the typical characteristics of a semiconductor strain gauge are shown in fig. MEMS pressure sensors are nowadays becoming increasingly popular for measurement of pressure. It is made of a small silicon diagram with four piezo-resistive strain gages mounted on it. It has an inbuilt signal conditioning circuits and delivers measurable output voltage corresponding to the pressure applied. Low weight and small size of the sensor make it suitable for measurement of pressure in specific applications.



a) Construction b)Characteristic of semiconductor strain gauge

Thermistors: Basically thermistor is a contraction of the word 'thermal resistors', The resistors depending on temperature are thermal resistors. Thus resistance thermometers are also thermistors having positive -temperature coefficients. But generally the resistors having negative temperature coefficients (NTC) are called thermistors. The resistance of a thermistor decreases as temperature increases. The NTC of thermistors can be as large as a few percent per degree celsius change in temperature. Thus the thermistors are very sensitive and can detect very small changes in temperature too.

Construction of thermistor: Thermistors are composed of a sintered mixture of metallic oxides, such as manganese, nickel, cobalt, copper, iron, and uranium. Their resistances at ambient temperature may range from 100 n to 100 ill. Thermistors are available in a wide variety of shapes and sizes as shown in the Fig. Smallest in size are the beads with a diameter of 0.15 mm to 1.25 mm. Beads may be sealed in the tips of solid glass rods to form probes. Disks and washers are made by pressing thermistor material under high pressure into Hat cylindrical shapes. Washers can be placed in series or in parallel to increase power dissipation rating.



Thermistors are well suited for precision temperature measurement, temperature control, and temperature compensation, because of their. very large change in resistance with temperature. They are widely used for measurements in the temperature range -1000 C to +2000 C. The measurement of the change in resistance with temperature is carried out with a Wheatstone bridge.

Inductive Transducer

Inductive transducers work on the principle of inductance change due to any appreciable change in the quantity to be measured i.e. measured. For example, LVDT, a kind of inductive transducers, measures displacement in terms of voltage difference between its two secondary voltages. Secondary voltages are nothing but the result of induction due to the flux change in the secondary coil with the displacement of the iron bar. Anyway LVDT is discussed here briefly to explain the principle of inductive transducer. LVDT will be explained in other article in more detail. For the time being let‟s focus on basic introduction of inductive transducers. Now first our motive is to find how the inductive transducers can be made to work. This can be done by changing the flux with the help of measured and this changing flux obviously changes the inductance and this inductance change can be calibrated in terms of measured. Hence inductive transducers use one of the following principles for its working.

1. Change of self inductance

2. Change of mutual inductance

3. Production of eddy current

Change of Self Inductance of Inductive Transducer

We know very well that self inductance of a coil is given by $L = \frac{N^2}{R}$

Where, N = number of turns. R = reluctance of the magnetic circuit.

Also we know that reluctance R is given by $R = \frac{l}{\mu A}$

$L = \frac{N^2 \mu A}{l}$ where μ = effective permeability of the medium in and around the coil.

$L = N^2 \mu G$ Where, G = A/l and called geometric form factor. A = area of cross-section of coil. l = length of the coil. So, we can vary self inductance by

1)Change in number of turns, N,

2) Changing geometric configuration, G,

3)Changing permeability

For the sake of understanding we can say that if the displacement is to be measured by the inductive transducers, it should change any of the above parameter for causing in the change in self inductance

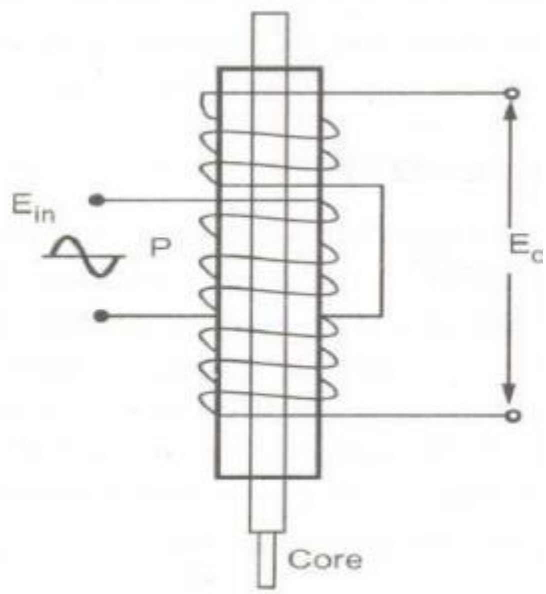
Change of Mutual Inductance of Inductive Transducer Here transducers, which work on change of mutual inductance principle, use multiple coils. We use two coils here for the sake of understanding. Both coils have their self inductance as well. So let‟s denote their self inductance by L1 and L2. Mutual inductance between these two coils is given by $M = K\sqrt{L_1 L_2}$

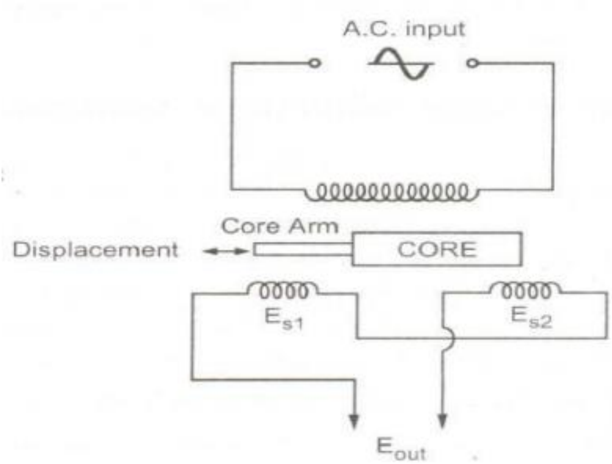
Thus mutual inductance can be changed by varying self inductance or by varying coefficient of coupling, K. The methods of changing self inductance we already discussed. Now the coefficient of coupling depends on the distance and orientation between two coils. Thus for the measurement of displacement we can fix one coil and make other movable which moves with the source whose displacement is to be measured. With the change in distance in displacement coefficient of coupling changes and it causes the change in mutual inductance. This change in mutual inductance can be calibrated with the displacement and measurement can be done.

Production of Eddy Current of Inductive Transducer

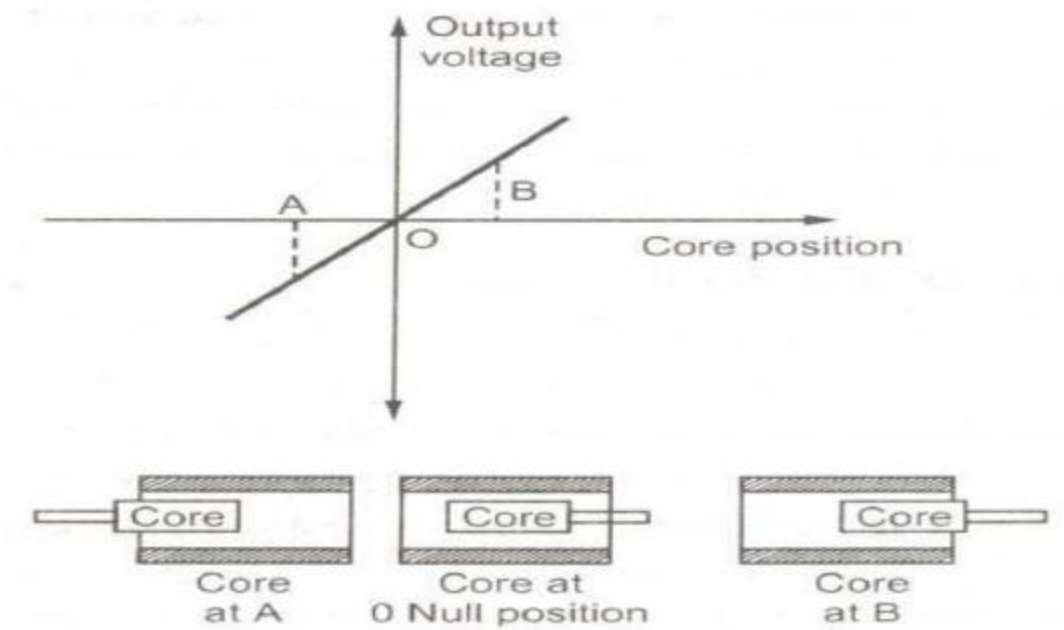
We know that when a conducting plate is placed near a coil carrying alternating current, a circulating current is induced in the plate called "EDDY CURRENT". This principle is used in such type of inductive transducers. Actually what happens? When a coil is placed near to coil carrying alternating current, a circulating current is induced in it which in turn produces its own flux which try to reduce the flux of the coil carrying the current and hence inductance of the coil changes. Nearer the plate is to the coil, higher will be eddy current and higher is the reduction in inductance and vice versa. Thus inductance of coil varied with the variation of distance between coil and plate. Thus the movement of the plate can be calibrated in terms of inductance change to measure the quantity like displacement.

Linear variable differential transformer (LVDT):





When an externally applied force moves the core to the left-hand position, more magnetic flux links the left-hand coil than the right hand coil. The emf induced in the left-hand coil, ES], is therefore larger than the induced emf of the right-hand [oil, Es2' The magnitude of the output voltage is then equal to the difference between the two secondary voltages and it is in phase with the voltage of the left-hand coil.



Construction of LVDT:

Main Features of Construction are as,

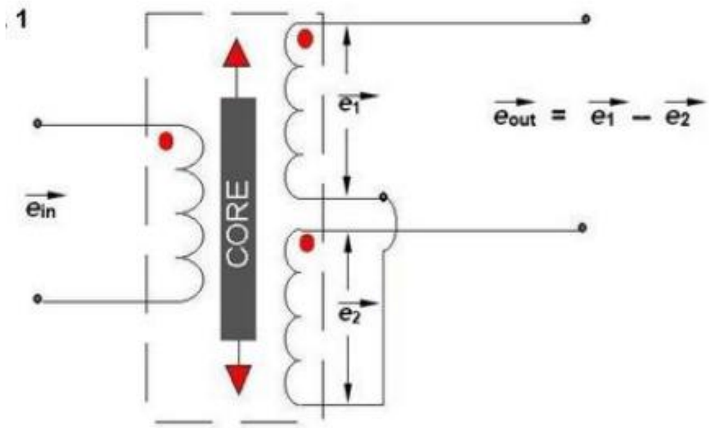
The transformer consists of a primary winding P and two secondary winding S1 and S2 wound on a cylindrical former(which is hollow in nature and will contain core).

Both the secondary windings have equal number of turns and are identically placed on the either side of primary winding .The primary winding is connected to an AC source which produces a flux in the air gap and voltages are induced in secondary windings. A movable soft iron core is placed inside the former and displacement to be measured is connected to the iron core.

The iron core is generally of high permeability which helps in reducing harmonics and high sensitivity of LVDT. The LVDT is placed inside a stainless steel housing because it will provide electrostatic and electromagnetic shielding. Both the secondary windings are connected in such a way that the resulting output is the difference of the voltages of two windings.

Principle of Operation and Working :

As the primary is connected to an AC source so alternating current and voltages are produced in the secondary of the LVDT. The output in secondary S1 is e1 and in the secondary S2 is e2. So the differential output is, eout = e1 - e2 This equation explains the principle of Operation of LVDT.



Now three cases arise according to the locations of core which explains the working of LVDT are discussed below as,

CASE I :When the core is at null position (for no displacement) When the core is at null position then the flux linking with both the secondary windings is equal so the induced emf is equal in both the windings. So for no displacement the value of output eout is zero as e1 and e2 both are equal. So it shows that no displacement took place.

CASE II :When the core is moved to the upward of null position (For displacement to the upward of reference point) In this case the flux linking with secondary winding S1 is more as compared to flux linking with S2. Due to this e1 will be more as that of e2. Due to this output voltage eout is positive.

CASE III: When the core is moved to the downward of Null position (for displacement to the downward of reference point) In this case magnitude of e2 will be more as that of e1. Due to this output eout will be negative and shows the output to downward of reference point

Output VS Core Displacement A linear curve shows that output voltage varies linearly with displacement of core.

Some important points about magnitude and sign of voltage induced in LVDT

1) The amount of change in voltage either negative or positive is proportional to the amount of movement of the core and indicates the amount of linear motion.

2) By noting the output voltage increasing or decreasing the direction of motion can be determined

3)The output voltage of an LVDT is a linear function of core displacement .

Advantages of LVDT

High Range - The LVDTs have a very high range for measurement of displacement.they can used for measurement of displacements ranging from 1.25mm to 250mm

No Frictional Losses - As the core moves inside a hollow former so there is no loss of displacement input as frictional loss so it makes LVDT as very accurate device. High Input and **High Sensitivity** - The output of LVDT is so high that it doesn‟t need any amplification.the transducer possesses a high sensitivity which is typically about 40V/mm.

Low Hysteresis - LVDTs show a low hysteresis and hence repeatability is excellent under all conditions

Low Power Consumption - The power is about 1W which is very low as compared to other transducers.

Direct Conversion to Electrical Signals - They convert the linear displacement to electrical voltage which are easy to process

Disadvantages of LVDT

LVDT is sensitive to stray magnetic fields so they always require a setup to protect them from stray magnetic fields. They are affected by vibrations and temperature. It is concluded that they are advantageous as compared than any other inductive transducers.

Applications of LVDT

1. They are used in applications where displacements ranging from fraction of mm to few cm are to be measured. The LVDT acting as a primary Transducer converts the displacement to electrical signal directly.

2. They can also acts as the secondary transducers. E.g. the Bourbon tube which acts as a primary transducer and converts pressure into linear displacement.then LVDT converts this displacement into electrical signal which after calibration gives the ideas of the pressure of fluid.

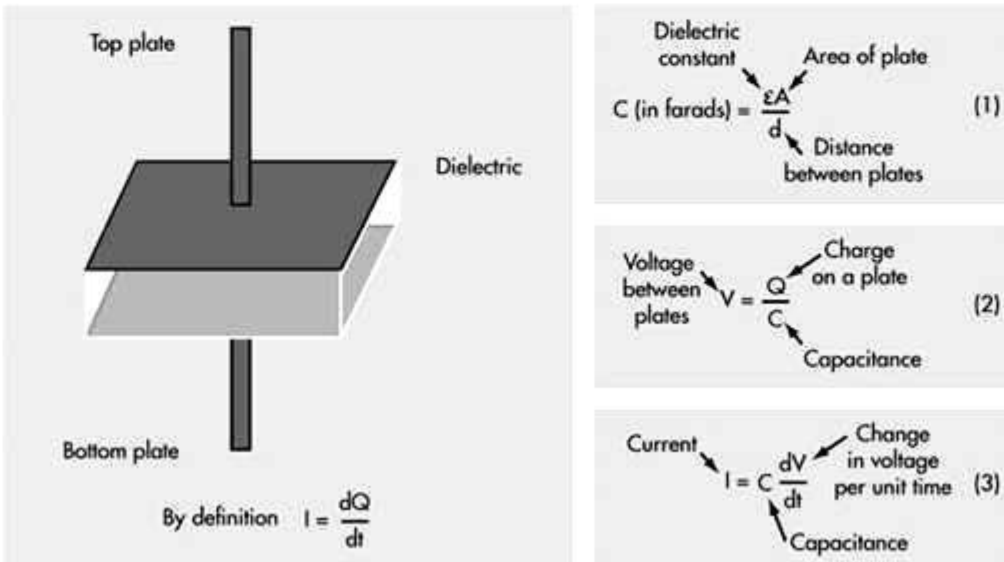
Capacitive Transducers:

A capacitor consists of two conductors (plates) that are electrically isolated from one another by a nonconductor (dielectric). When the two conductors are at different potentials (voltages), the system is capable of storing an electric charge. The storage capability of a capacitor is measured in farads.The principle of operation of capacitive transducers is based upon the equation for capacitance of a parallel plate capacitor as shown in Fig.

$$Capacitance \qquad C = \frac{\varepsilon A}{D}$$

Where, A = Overlapping area of plates;m2 ,

d = Distance between two plates; m, = Permittivity (dielectric constant); F/m.



Parallel Plate Capacitor

The capacitance is measured with a bridge circuit. The output impedance Z of a capacitive transducer is:

Z = 1/2πfC

Where: Z = Impedance

f = frequency, 50 Hz.

C = capacitance

In general, the output impedance of a capacitive transducer is high. This fact calls for a careful design of the output circuitry. The capacitive transducers work on the principle of change in capacitance of the capacitor. This change in capacitance could be caused by change in overlapping area A of the plates, change in the distance d between the plates and change in dielectric constant

In most of the cases the above changes are caused by the physical variables, such as, displacement, force or pressure. Variation in capacitance is also there when the dielectric medium between the plates changes, as in the case of measurement of liquid or gas levels.Therefore, the capacitive transducers are commonly used for measurement of linear displacement, by employing the following effects as shown in Fig a and fig b.

i) Change in capacitance due to change in overlapping area of plates.

ii) Change in capacitance due to change in distance between the two plates.

iii) Change in capacitance due to change in dielectric between the two plates

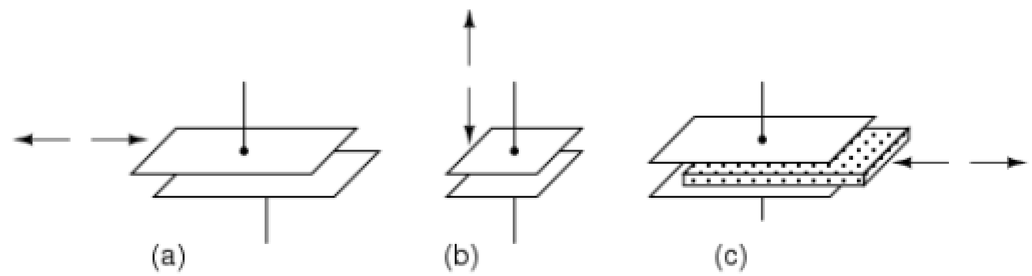


Fig.a Variable capacitive transducer varies; (a) area of overlap, (b) distance between plates, (c) amount of dielectric between plates

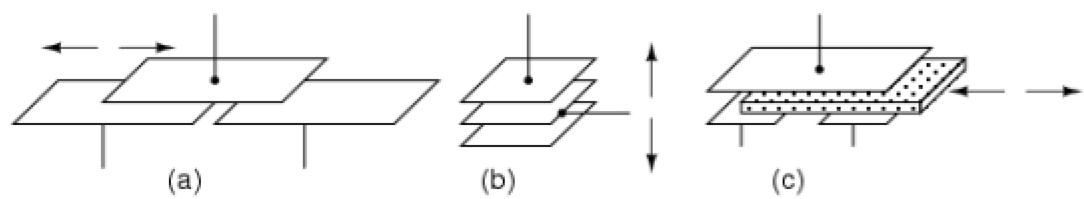


Fig.b Differential capacitive transducer varies capacitance ratio by changing: (a) area of overlap, (b) distance between plates, (c) dielectric between plates

As may be seen in Fig b, all of the differential devices have three wire connections rather than two: one wire for each of the end plates and one for the common plate. As the capacitance between one of the endplates and the common plate changes, the capacitance between the other end plate and the common plate also changes in the opposite direction.

a) Transducers Using Change in Area of Plates

Examining the equation for capacitance, it is found that the capacitance is directly proportional to the area, A of the plates. Thus, the capacitance changes linearly with change in area of plates. Hence this type of capacitive transducer is useful for measurement of moderate to large displacements, say from 1 mm to several cm. The area changes linearly with displacement and also the capacitance.For a parallel plate capacitor, the capacitance is:

$$C = \frac{\varepsilon A}{d} = \frac{\varepsilon l w}{d} F$$

Where, l = length of overlapping part of plates; m, and

w = width of overlapping part of plates; m.

$$Sensitivity \qquad S = \frac{\partial C}{\partial l} = \varepsilon \frac{w}{d} F/m$$

The sensitivity is constant and therefore there is a linear relationship between capacitance and displacement.This type of a capacitive transducer is suitable for measurement of linear displacement ranging from 1 to 10 cm. The accuracy is as high as 0.005%.

b) Transducers Using Change in Distance between Plates

Fig. shows the basic form of a capacitive transducer employing change in distance between the two plates to cause the change in capacitance. One plate is fixed and the displacement to be measured is applied to the other plate which is movable. Since, the capacitance, C, varies inversely as the distance d, between the plates the response of this transducer is not linear. Thus this transducer is useful only for measurement of extremely small displacements.

$$Sensitivity \qquad S = \frac{\partial C}{\partial l} = -\frac{\varepsilon A}{d^2}$$

Thus the sensitivity of this type of transducer is not constant but varies over the range of the transducer. The relationship between variations of capacitance with variation of distance between plates is hyperbolic and is only approximately linear over a small range of displacement. The linearity can be closely approximated by use of a piece of dielectric material like mica having a high dielectric constant, such as, a thin piece of mica.

c) Transducers Using Change in dielectric constant between Plates:

If the area (A) of and the distance (d) between the plates of a capacitor remain constant, capacitance will vary only as a function of the dielectric constant of the substance filling the gap between the plates. If the space between the plates of a capacitor is filled with an insulator, the capacitance of the capacitor will change compared to the situation in which there is vacuum between the plates. The change in the capacitance is caused by a change in the electric field between the plates.

The value of dielectric constant is initially set by design in the choice of dielectric material used to make the capacitor. Many factors will cause the to change, and this change in will vary for different materials. The major factors that will cause a change in are moisture, voltage, frequency, and temperature. The dielectric constant of a process material can change due to variations in temperature, moisture, humidity, material bulk density, and particle size etc. The in the basic formula is the effective dielectric constant of the total space between the electrodes. This space may consist of the dielectric material, air, and even moisture, if present. The figure shows how in a capacitor the position of the dielectric is varied to vary the capacitance. Physical variables, such as displacement, force or pressure can cause the movement of dielectric material in the capacitor plates, resulting in changes in the effective dielectric constant, which in turn will change the capacitance.

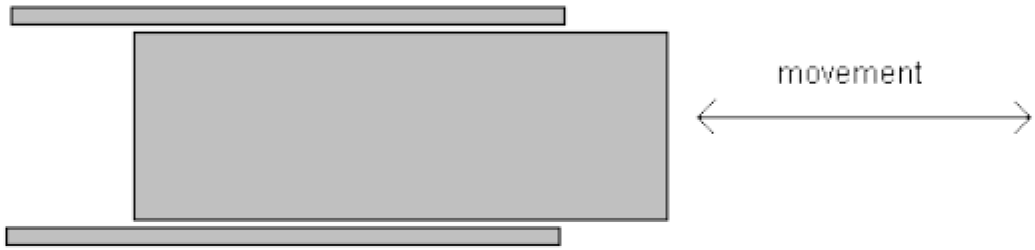
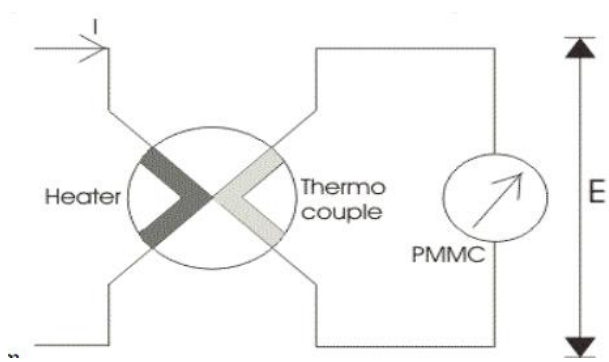


Fig. Change in capacitance due to movement of dielectric between plates

The major advantages of capacitive transducers are that they require extremely small forces to operate them and hence are very useful for use in small systems. They are extremely sensitive and require small power to operate them. Owing to their good frequency response they are very useful for dynamic studies.The disadvantages of capacitive transducers include their non-linear behavior on account of edge effects and the effects of stray capacitances especially when the transducers have a low value of capacitance. Therefore guard rings must be used to eliminate this effect. The metallic parts of the capacitive transducers must be insulated from each other. In order to reduce the effects of stray capacitances, the frames must be earthed.Capacitive transducers can be used for measurement of both linear and angular displacements.The capacitive transducers are highly sensitive and can be used for measurement of extremely hand, they can be used for measurement of large displacements up to about 30 m as in aeroplane altimeters. The change in area method is used for measurement of displacements ranging from 10 to 100 mm. Capacitive transducers can be used for the measurement of force and pressure. The force and pressure to be measured are first converted to displacement which causes a change of capacitance. Capacitive transducers can also be used directly as pressure transducers in all those cases where the dielectric constant of a medium changes with pressure. They can be used for measurement of humidity in gases and moisture content in soil / food products etc.

Thermocouples

Basically thermocouple consists of two different metals which are placed in contact with each other as



shown in the diagram.First part is called the heater element because when the current will flow through this, a heat is produced and thus the temperature will increase at the junction. At this junction an emf is produced which is approximately proportional to the temperature difference of hot and cold junctions.

The emf produced is a DC voltage which is directly proportional to the root mean square value of electric current. A permanent magnet moving coil instrument is connected with the second part to read the current passing through the heater. One question must arise in our mind that **why we have used only a permanent magnet coil instrument?** Answer to this question is very easy because PMMC instrument has greater accuracy and sensitivity towards the measurement of DC value. The thermocouple type instruments employ thermocouple in their construction. Thermocouple type instruments can be used for both ac and DC applications. Also thermocouple type of instruments has greater accuracy in measuring the current and voltages at very high frequency accurately.

Now we will look how the temperature difference is mathematically related to generated emf at the junction in thermocouple type of instruments. Let us consider the temperature of the heater element be Ta and the temperature of cold metal be Tb. Now it is found that the generated emf at the junction is related to temperature difference as:

$$e = a(T_a - T_b) + b(T_a - T_b)^2$$

Where a and b are constant whose values completely depends upon the type of metal we are using. The

above equation represents parabolic function. The approximated value of a is from 40 to 50 micro volts or

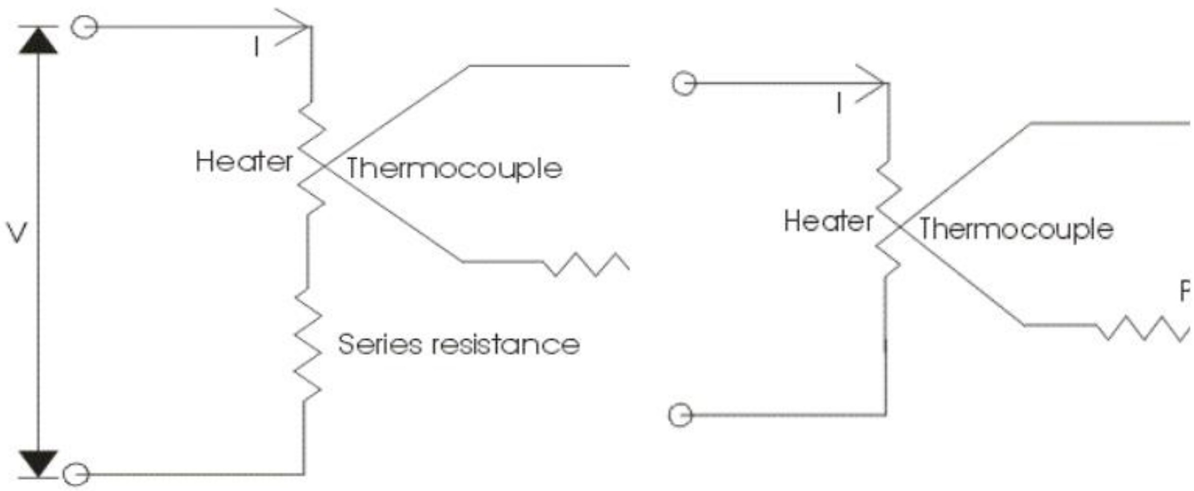
more per degree Celsius rise in temperature and value of constant b is very small and can be neglected if the air gap field of permanent magnet moving coil is uniform. Thus we can approximate the above temperature emf relation as e = a(Ta - Tb), here we have assume b = 0. The current flowing through the heater coil produces heat as I2R where I is the root mean square value of current, if we assume the temperature of the cold junction is maintained at room temperature then the rise in the temperature of the hot junction will be equal to temperature rise at the junction. Hence we can write (Ta-Tb)is directly proportional to I2R or we can say (Ta - Tb) = kI2R. Now the deflection angle x in moving coil instrument is equal to; x = Ke or x = K[a(Ta - Tb)] hence we can write k.K.a.I2R = k1I2, where k1 is some constant.From the above equation we see that the instrument shows the square law response.

Construction of Thermocouple Type Instrument:

Now let us look at the construction of Thermocouple type Instruments. Broadly speaking the thermocouple type of instruments consists of two major parts which are written below:

(a) Thermoelectric elements: The thermocouple type of instruments consists of thermoelectric elements which can be of four types:

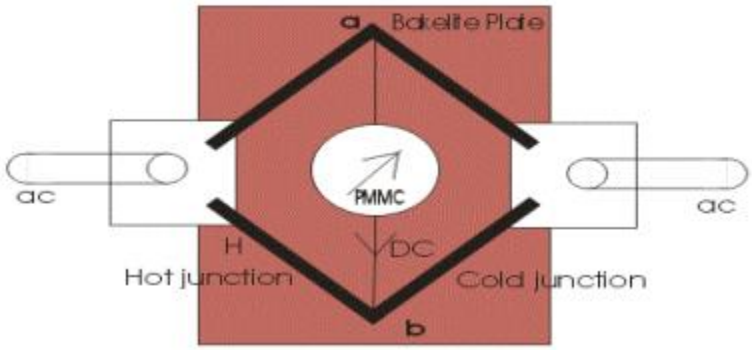
1. **Contact Type: It has a separate heater which is shown in the diagram.**



The action of thermocouple type instruments can be explained briefly as,

- At the junction the electrical energy is being converted to thermal energy in the heater element. A portion of the heat is transferred to the hot junction while most of the heat energy is dissipated away.
- The heat energy which is transferred to the hot junction is again converted to electrical due to Seebeck effect. Only a portion of electrical energy is converted into mechanical energy which is used to produce a deflecting torque. The overall efficiency of the system is low thus the instrument consumes high power. So there is a requirement for a highly accurate and sensitive DC instrument.

2. **Non Contact Type**: In non contact type there is insulation between the heating element and the thermocouple i.e. there is no direct contact between two. Due to this these instruments are not as sensitive as the contact type.
3. **Vacuum Thermo-elements**: These types of instruments are mostly employed for the measurement of electric current at very high frequency of the order of 100 Mega hertz or more as these instruments retain their accuracy even at such high frequency.
4. **Bridge Type**: These bridges are manufactured on the ac ratings usually from 100 mili amperes to 1 amperes. In this two thermocouple are connected to form a bridge which is shown in the figure given



below:

5. There is no requirement of heating element, the electric current which directly passes through the thermocouple raises the temperature which is directly proportional to the I2R losses. The bridge works in a balanced condition at which there will be no current in the arm ab. The connected meter will show the potential difference between the junctions a and b.

Advantages of Thermocouple Type Instruments

Following are advantages of Thermocouple type of instruments,

1. The thermocouple type of instruments accurately indicates the root mean square value of current and voltages irrespective of the waveform. There is a wide variety of thermocouple instruments available in the market.

2. Thermocouple types of instruments give very accurate reading even at high frequency, thus these types of instruments are completely free from frequency errors.

3. The measurement of quantity under these instruments is not affected by stray magnetic fields.

4. These instruments are known for their high sensitivity.

5. Usually for measuring the low value of current bridge type of arrangement is used i.e. ranging from 0.5 Amperes to 20 Amperes while for measuring the higher value of current heater element is required to retain accuracy.

Disadvantages of Thermocouple Type Instruments

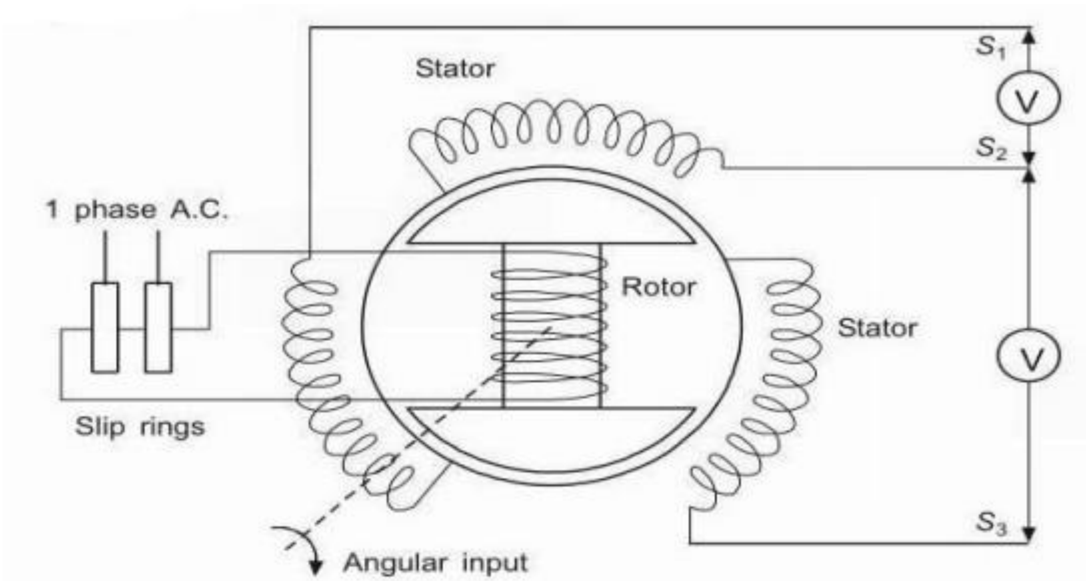
Instead of many advantages these types of instruments possess one disadvantage, The over load capacity of thermocouple type of instrument is small, even fuse is not able to the heater wire because heater wire may burn out before the fuse blows out.

Synchro Position Transducer Working Principle

We know that Syncro is an inductive device which works on the principle of rotating transformers. Here the term rotating transformer means the primary to secondary coupling can be changed by physically changing the relative orientation of the winding. So based on this working principle of synchro we can use it as a position transducer.

Construction Of Position Transducer:

Position transducer is one of the basic applications of the Synchro. It uses dumb-bell shaped rotor. Single phase ac supply is given to the rotor of the Synchro. This rotor is mechanically coupled with the shaft of rotating element whose angular position is to be determined.



Position Transducer Working Principle:

We know that the stator of the synchro has three windings. These three winding of the stator are connected in star connection. Remaining ends of each winding are taken out to connect them with the voltmeter as shown in the figure. When the angle of the rotor changes the output voltage i.e. the stator voltages of each winding is given by,

E1 = Eom cosθ sin wt = instantaneous voltage for stator windings S1.

E1 = Eom cos(θ+120) sin wt = instantaneous voltage for stator windings S2.

E1 = Eom cos(θ+240) sin wt = instantaneous voltage for stator windings S3.

Where

θ= angular position of the rotor

Eom = peak value of voltage of each winding

w= 2πf

f= frequency of the rotor

t = time in seconds.

All instantaneous voltages are sinusoidal in nature. But they give different values of voltages at different positions of the rotor.Thus using these three values of stator voltages we can easily measure the position of the rotor. Hence Synchro can be used as a position transducer.

Applications Of Position Transducer:

1) For measuring the angle of the rotating machine-like antenna platform.

2) Position transducer can be used as rotary position sensor for aircraft control surfaces