EMI: UNIT – I

Measuring Instruments

Objectives:

- To familiarize the students with the basic construction of PMMC and MI instruments and explain their operation
- To familiarize the students with different type of errors and compensations in measuring instruments
- To familiarize the students with the extension of range of meters using shunts and multipliers.

Syllabus:

Classification, Error Analysis– deflecting, controlling and damping torques – Ammeters and Voltmeters – PMMC, Moving iron type instruments – expression for the deflecting torque and control torque – Errors And compensations. Extension of range using shunts and series resistance

Learning Outcomes:

After the completion of this unit, students will be to

1. Describe the principle of operation of various measuring instruments
2. Extend the range of voltmeter and ammeter.
3. Select an instrument to measure AC and DC quantities.

Unit-I

MEASURING INSTRUMENTS

Measurements are the basic means of acquiring knowledge about the parameters and variables involved in the operation of a physical system. Measurement, generally involves using an instrument as a physical means of determining a quantity or variable. An instrument or a measuring instrument is, therefore, defined as a device for determining the value or magnitude of a quantity or variable. The electrical measuring instrument, as its name implies, is based on electrical principles for its measurement function.

These days a number of measuring instruments, both analog as well as digital ones, are available for the measurement of electrical quantities like voltage, current, power energy, frequency, power factor, etc. First Analog devices are worth concerning.

Analog instruments may be divided into three groups:

(a) Electromechanical instruments;

(b) Electronic instruments which are often constructed by the addition of electronic circuits to electromechanical indicators thus increasing their sensitivity and input impedances; and

(c) Graphical instruments which are electromechanical and electronic instruments having a modified display arrangement so that a graphical trace, that is, a display of instantaneous values against time is obtained.

Measurement:- The measurement of a given quantity is an act or the of comparison between the quantity whose magnitude is unknown and a predefined standard. Since two quantities are compared the result is expressed in the form of numerical values.There are two methods of measurement

(i) Direct method

(ii) Indirect method.

Direct Measurement:- In direct method the unknown quantity is measured directly such as measurement of current by an ammeter, voltage by voltmeter, resistance by ohm meter, power by wattmeter etc.

Indirect Measurement:- In the indirect method of measurement the unknown quantity is determined by measuring other functionally related quantities and calculating the desired quantity rather than measuring it directly with an instrument. For example resistance of a conductor may be determined by measuring voltage across the conductor V, and current flowing through the conductor I, and then calculating it by R=V/I

Important definitions relevant to instruments will be discussed first. Measurement work employs a number of terms which are defined below:

Measurand: The quantity or variable being measured is called measurand or measurement variable.

Accuracy: It is defined in terms of the closeness with which an instrument reading approaches the true or expected (desired) value of the variable being measured.

Precision: It is measure of the consistency of reproducibility (repeatability) of the measurement (i.e., the successive reading do not differ). For a given fixed value of an input variable, precision is a measure of the degree to which successive measurement differ from one another.

Sensitivity: It is defined by the change in the output or response of the instrument for a unit change of input or measured variable.

Resolution: Resolution is the smallest change in a measured variable (or measurand) to which the instrument will respond.

True or Expected Value:

The true or expected value of a quantity to be measured may be defined as the average of an infinite number of measured values when the average deviation due to the various contributing factors tends to zero. It also refers to a value of the quantity under consideration that would be obtained by a method (known as exemplar method) agreed upon by experts. In other words, it is the most probable value that calculations indicate and one should expect to measure. Note that the value of the unknown obtained by making use of primary standards and measuring instruments is considered to be its ture value.

Error:

It is the deviation of the measured (or indicated) value from the true (or expected) value of a quantity. In other words, error is the difference between the measured value and the true value of the unknown quantity. It is also called absolute error are maximum possible error. Then error of measurements is given by

$$\in A = Am - At \text{ ---------(1)}$$

where Am = measured value of the quantity

At = true value of the quantity

Absolute error, ∈0, is the limit of error in measurement. In other words, ∈A must not be higher than ∈0.

Thus, $|\in 0| = \max |Am - At|$ --------(2)

Note that the absolute error does not give any information about accuracy. For example, an error of (–1) volt in measurement of 1000 volt is negligible, but the same error in measurement of 10 volts is never acceptable. Thus, error is expressed in terms of another term called the relative error which is the ratio of absolute error of the true value of the quantity being measured

$$\in_R = \frac{\text{Absolute error}}{\text{True value}} = \frac{\in_0}{A_t}$$

$$= (A_m - A_t)/ A_t \quad \text{....}$$

The percentage relative error % $\in_R = \in_R \times 100$.

Also, from Eqn. (12.3), we have

$$(1 + \in_r)\, A_t = A_m$$

or

$$A_t = \frac{A_m}{1 + [\in_R]} \quad \text{....}$$

If the absolute error $\in_A$ is sufficiently small, then Eqn. (12.1) shows that

$$\in_A = A_m - A_t \approx 0$$

or

$$A_t \cong A_m \quad \text{....}$$

That is, A_m may be substituted for A_t in Eqn. (12.3) for practical purpose. Now in view Eqn. becomes

Therefore, the relative error, ∈R is given by

$$\in_R = \frac{\in_0}{A_m}$$

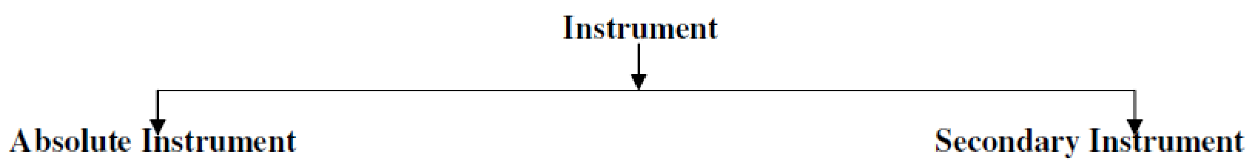
Correction:

The difference between the true value and the measured value of the sought quantity is defined as the reading correction or simply correction. That is, correction is negative or error. Thus,

$$\delta C = -\in_A$$
$$= A_t - A_m$$
$$A_t = \text{expected value} = A_m + \delta C$$

Therefore addition of correction in measured value gives the true (or accurate or expected) value.

Classification of instruments



Absolute instruments or Primary Instruments:- These instruments gives the magnitude of quantity under measurement in terms of physical constants of the instrument e.g. Tangent Galvanometer. These instruments do not require comparison with any other standard instrument

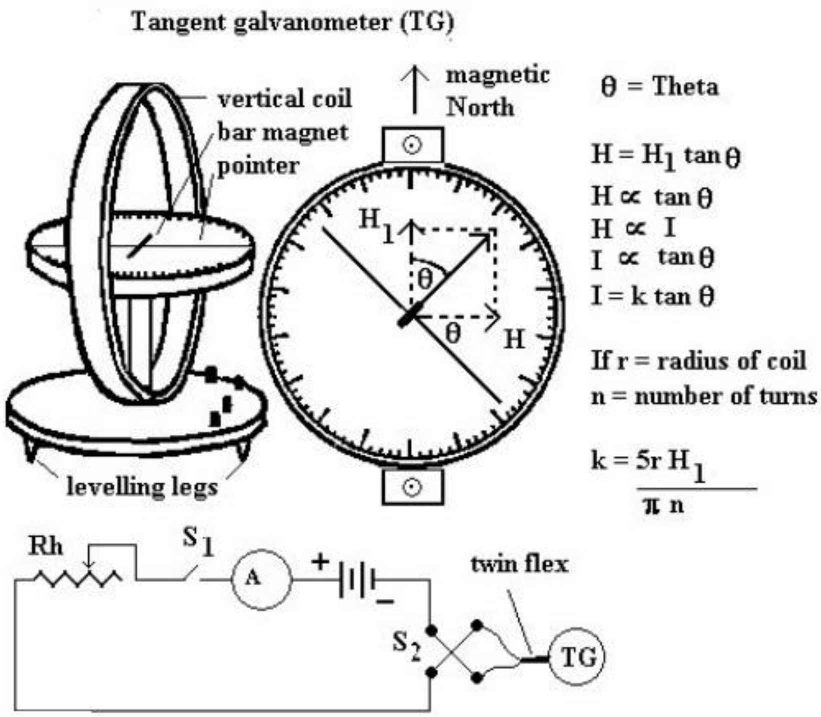
These instruments give the value of the electrical quantity in terms of absolute quantities (or some constants) of the instruments and their deflections. In this type of instruments no calibration or comparison with other instruments is necessary. They are generally not used in laboratories and are seldom used in practice by electricians and engineers. They are mostly used as means of standard measurements and are maintained lay national laboratories and similar institutions.

Some of the examples of absolute instruments are:

Tangent galvanometer

Raleigh current balance

Absolute electrometer



Secondary instruments:-

These instruments are so constructed that the quantity being measured can only be determined by the output indicated by the instrument. These instruments are calibrated by comparison with an absolute instrument or another secondary instrument, which has already been calibrated against an absolute instrument.

Working with absolute instruments for routine work is time consuming since every time a measurement is made, it takes a lot of time to compute the magnitude of quantity under measurement. Therefore secondary instruments are most commonly used.

• They are direct reading instruments. The quantity to be measured by these instruments can be determined from the deflection of the instruments.

• They are often calibrated by comparing them with either some absolute instruments or with those which have already been calibrated.

• The deflections obtained with secondary instruments will be meaningless until it is not calibrated.

•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.

Classification of Secondary Instruments:

(a) Classification based on the various effects of electric current (or voltage) upon which their operation depend.

They are:

• Magnetic effect: Used in ammeters, voltmeters, watt-meters, integrating meters etc.

• Heating effect: Used in ammeters and voltmeters.

• Chemical effect: Used in dc ampere hour meters.

• Electrostatic effect: Used in voltmeters.

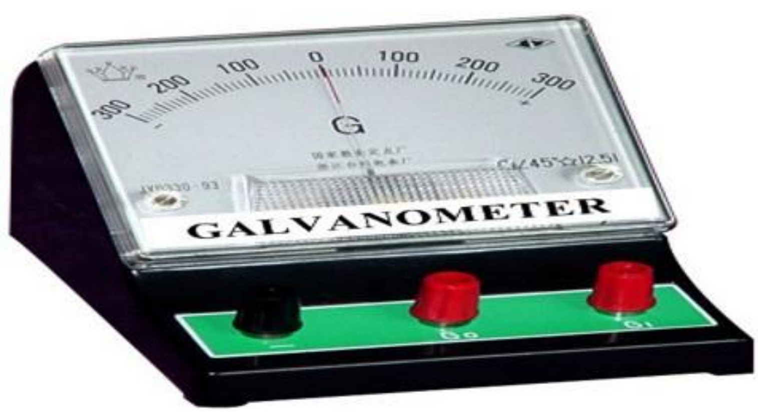
• Electromagnetic induction effect: Used in ac ammeters, voltmeters, watt meters and integrating meters.

Generally the magnetic effect and the electromagnetic induction effect are utilized for the construction of the commercial instruments. Some of the instruments are also named based on the above effect such as electrostatic voltmeter, induction instruments, etc.

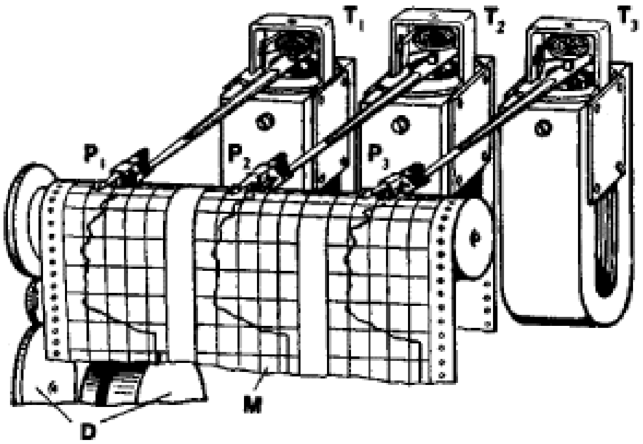
(b) Classification based on the Nature of their Operations:

We have the following instruments.

• **Indicating instruments**: Indicating instruments indicate, generally the quantity to be measured by means of a pointer which moves on a scale. Examples are ammeter, voltmeter, wattmeter etc.



• Recording instruments: These instruments record continuously the variation of any electrical quantity with respect to time. In principle, these are indicating instruments but so arranged that a permanent continuous record of the indication is made on a chart or dial. The recording is generally made by a pen on a graph paper which is rotated on a dice or drum at a uniform speed. The amount of the quantity at any time (instant) may be read from the traced chart. Any variation in the quantity with time is recorded by these instruments. Any electrical quantity like current, voltage, power etc., (which may be measured lay the indicating instruments) may be arranged to be recorded by a suitable recording mechanism.



• **Integrating instruments:** These instruments record the consumption of the total quantity of electricity, energy etc., during a particular period of time. That is, these instruments totalize events over a specified period of time. No indication of the rate or variation or the amount at a particular instant are available from them. Some widely used integrating instruments are: Ampere-hour meter: kilowatt-hour (kWh) meter, kilovolt-ampere-hour (kVARh) meter.

Fig. Energy meter

(c) Classification based on the Kind of Current that can be Measurand:

Under this heading, we have:

- Direct current (dc) instruments
- Alternating current (ac) instruments
- Both direct current and alternating current instruments (dc/ac instruments).

(d) Classification based on the method used.

Under this category, we have:

- **Direct measuring instruments:** These instruments converts the energy of the measured quantity directly into energy that actuates the instrument and the value of the unknown quantity is measured or displayed or recorded directly. These instruments are most widely used in engineering practice because they are simple and inexpensive. Also, time involved in the measurement is shortest. Examples are Ammeter, Voltmeter, Watt meter etc.
- **Comparison instruments:** These instruments measure the unknown quantity by comparison with a standard. Examples are dc and ac bridges and potentiometers. They are used when a higher accuracy of measurements is desired.

1.3.4 Electromechanical indicating instrument:

For satisfactory operation electromechanical indicating instrument, three forces are necessary. They are

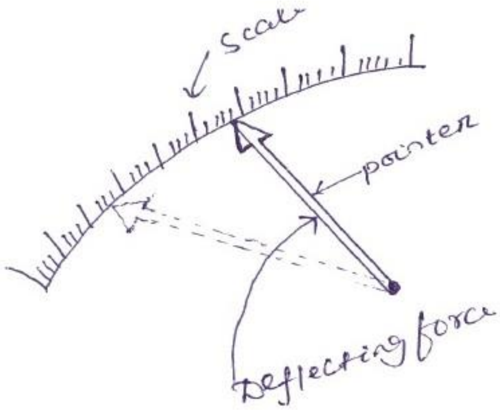
(a) Deflecting force

(b) Controlling force

(c)Damping force

1.4 Deflecting force:

When there is no input signal to the instrument, the pointer will be at its zero position. To deflect the pointer from its zero position, a force is necessary which is known as deflecting force. A system which produces the deflecting force is known as a deflecting system. Generally a deflecting system converts an electrical signal to a mechanical force.



1.5 Controlling force:

To make the measurement indicated by the pointer definite (constant) a force is necessary which will be acting in the opposite direction to the deflecting force. This force is known as controlling force. A system which produces this force is known as a controlled system. When the external signal to be measured by the instrument is removed, the pointer should return back to the zero position. This is possibly due to the controlling force and the pointer will be indicating a steady value when the deflecting torque is equal to controlling torque.

$$T_d = T_c$$

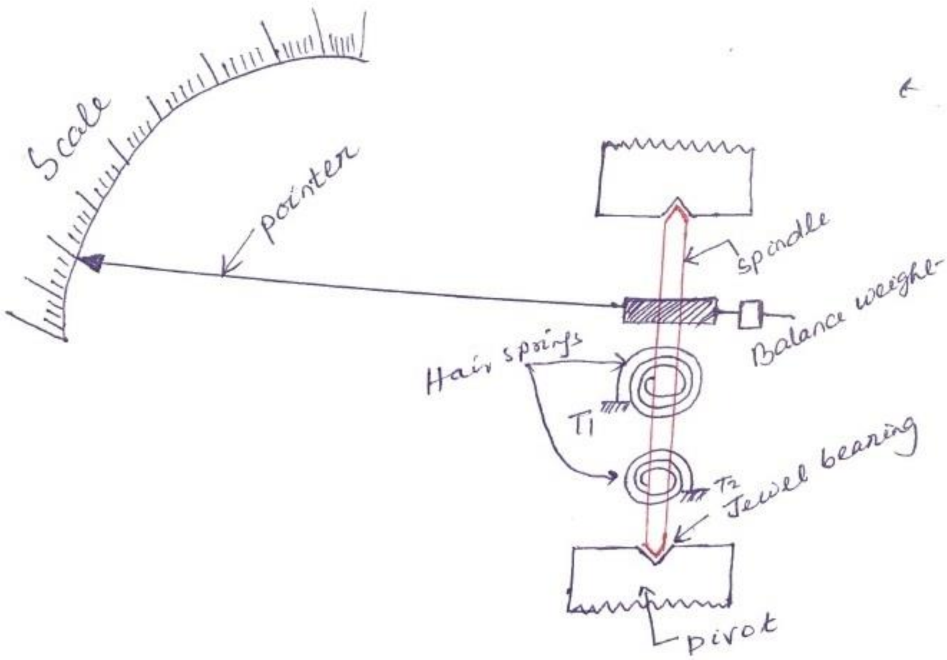
1.5.1 Spring control:

Two springs are attached on either end of spindle (Fig. 1.5).The spindle is placed in jeweled bearing, so that the frictional force between the pivot and spindle will be minimum. Two springs are provided in opposite direction to compensate the temperature error. The spring is made of phosphorous bronze.

$$T_C \propto \theta$$

The deflecting torque produced Td proportional to ‘I’. When T_C = Td the pointer will come to a steady position. Therefore

$$\theta \propto I$$



Since, θ and I are directly proportional to the scale of such instrument which uses spring controlled is uniform

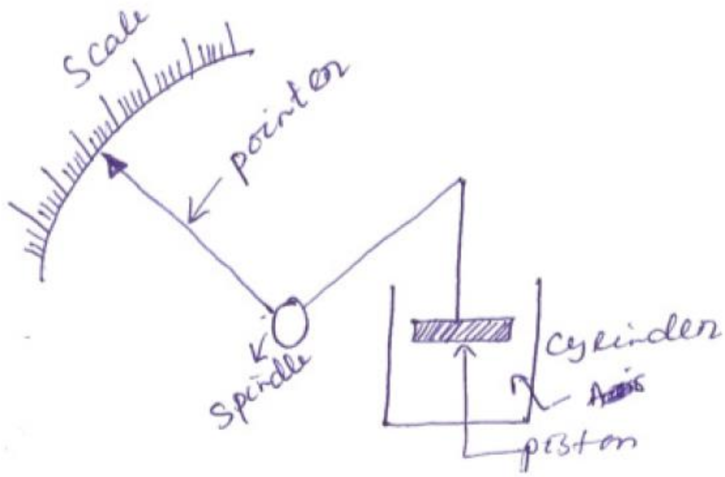
1.6 Damping force:

The deflection torque and controlling torque produced by systems are electro mechanical. Due to inertia produced by this system, the pointer oscillates about it final steady position before coming to rest. The time required to take the measurement is more. To damp out the oscillations quickly, a damping force is necessary. This force is produced by different systems.

(a) Air friction damping
(b) Fluid friction damping
(c) Eddy current damping

1.6.1 Air friction damping:

The piston is mechanically connected to a spindle through the connecting rod (Fig. 1.6). The pointer is fixed to the spindle moves over a calibrated dial. When the pointer oscillates in clockwise direction, the piston goes inside and the cylinder gets compressed. The air pushes the piston upwards and the pointer tends to move in anticlockwise direction



If the pointer oscillates in anticlockwise direction the piston moves away and the pressure of the air inside cylinder gets reduced. The external pressure is more than that of the internal pressure. Therefore the piston moves down wards. The pointer tends to move in clock wise direction.

1.6.2 Eddy current damping:

An aluminum circular disc is fixed to the spindle (Fig. 1.6). This disc is made to move in the magnetic field produced by a permanent magnet.

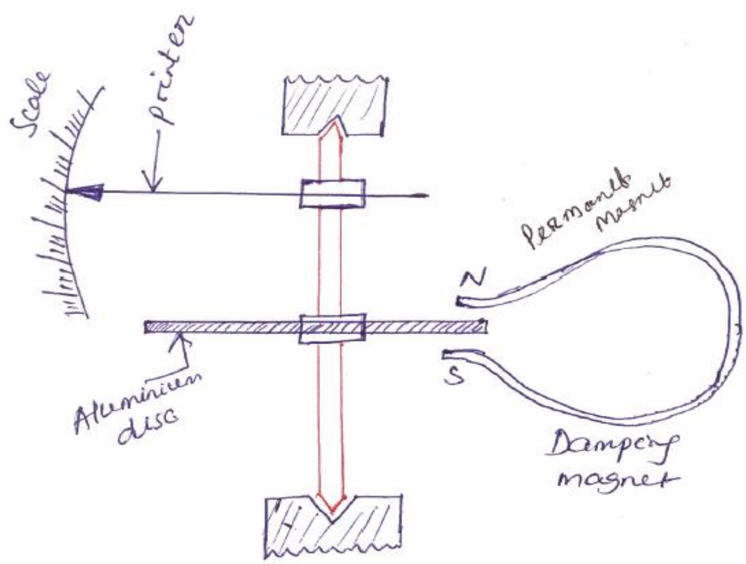


Fig. 1.6 Disc type

When the disc oscillates it cuts the magnetic flux produced by damping magnet. An emf is induced in the circular disc by faradays law. Eddy currents are established in the disc since it has several closed paths. By Lenz's law, the current carrying disc produced a force in a direction opposite to oscillating force. The damping force can be varied by varying the projection of the magnet over the circular disc.

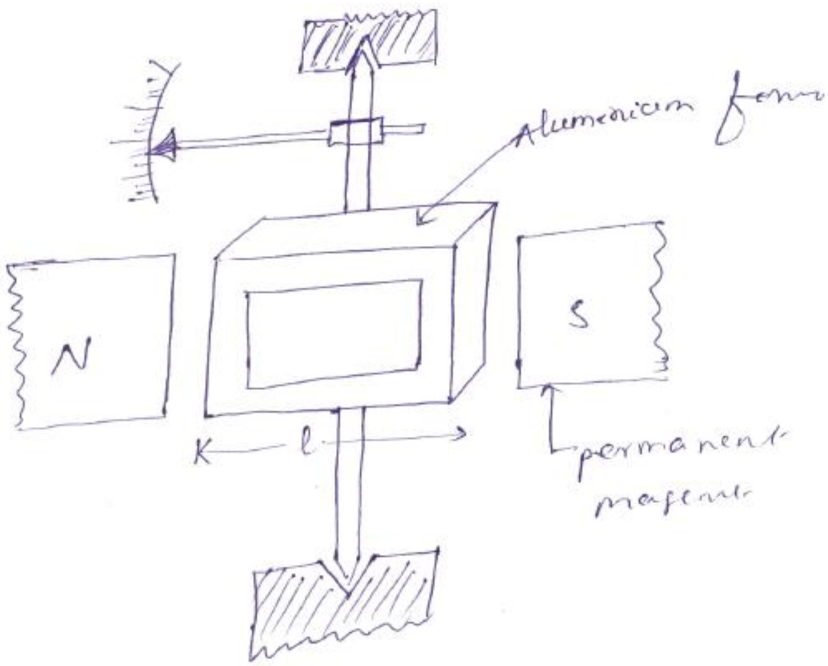


Fig. 1.6 Rectangular type

1.7 Permanent Magnet Moving Coil (PMMC) instrument:

One of the most accurate type of instrument used for D.C. measurements is PMMC instrument.

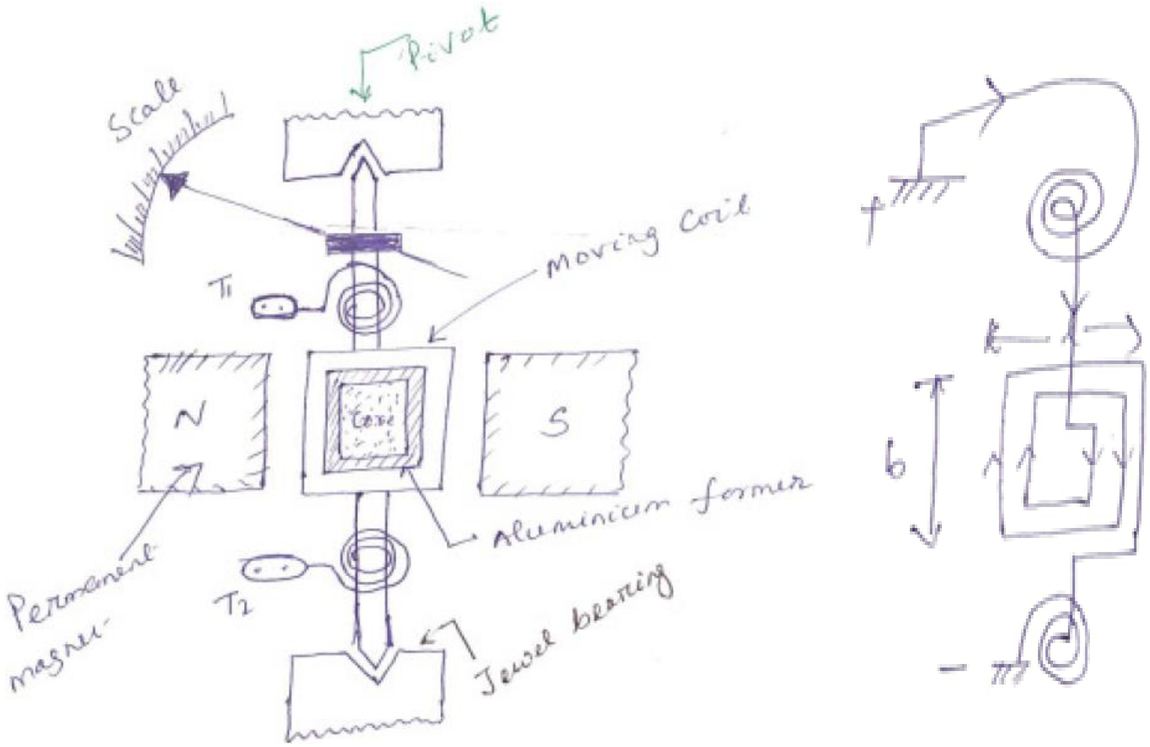
Construction: A permanent magnet is used in this type instrument. Aluminum former is provided in the cylindrical in between two poles of the permanent magnet (Fig. 1.7). Coils are wound on the aluminum former which is connected with the spindle. This spindle is supported with jeweled bearing. Two springs are attached on either end of the spindle. The terminals of the moving coils are connected to the spring. Therefore the current flows through spring 1, moving coil and spring 2.

Damping: Eddy current damping is used. This is produced by aluminum former.

Control: Spring control is used.

Principle of operation:

When D.C. supply is given to the moving coil, D.C. current flows through it. When the current carrying coil is kept in the magnetic field, it experiences a force. This force produces a torque and the former rotates. The pointer is attached with the spindle. When the former rotates, the pointer moves over the calibrated scale. When the polarity is reversed a torque is produced in the opposite direction. The mechanical stopper does not allow the deflection in the opposite direction. Therefore the polarity should be maintained with PMMC instrument.



If A.C. is supplied, a reversing torque is produced. This cannot produce a continuous deflection. Therefore this instrument cannot be used in A.C.

Torque developed by PMMC:

Let Td =deflecting torque

TC = controlling torque

θ = angle of deflection

K=spring constant

b=width of the coil

l=height of the coil or length of coil

N=No. of turns

I=current

B=Flux density

A=area of the coil

The force produced in the coil is given by $F = BIL \sin\theta$

When $\theta = 90^{\circ}$

For N turns, $F = NBIL$

Torque produced T_d = F* perpendicular distance

T_d =NBIL* b

= BINA

T_d =BANI

$T_d \alpha I$

Advantages:

- Torque/weight is high
- Power consumption is less
- Scale is uniform
- Damping is very effective
- Since operating field is very strong, the effect of stray field is negligible
- Range of instrument can be extended

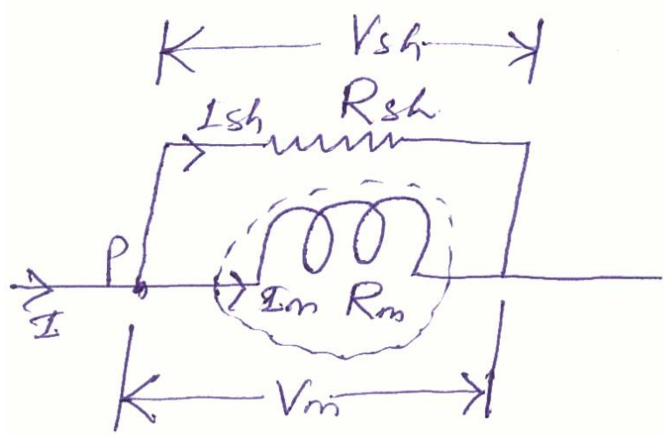
Disadvantages:

- Use only for D.C.
- Cost is high
- Error is produced due to ageing effect of PMMC
- Friction and temperature error are present

1.7.1 Extension of range of PMMC instrument:

Case-I: Shunt:

A low shunt resistance connected in parallel with the ammeter to extent the range of current. Large current can be measured using low current rated ammeter by using a shunt.



Let R_m =Resistance of meter

R_{sh} =Resistance of shunt

I_m = Current through meter

I_{sh} =current through shunt

I = current to be measure

$$\therefore V_m = V_{sh}$$

$$I_m R_m = I_{sh} R_{sh}$$

$$\frac{I_m}{I_{sh}} = \frac{R_{sh}}{R_m}$$

Apply KCL at 'P' $I = I_m + I_{sh}$

Eq^n (1.12) $\div$ by I_m

$$\frac{I}{I_m} = 1 + \frac{I_{sh}}{I_m}$$

$$\frac{I}{I_m} = 1 + \frac{R_m}{R_{sh}}$$

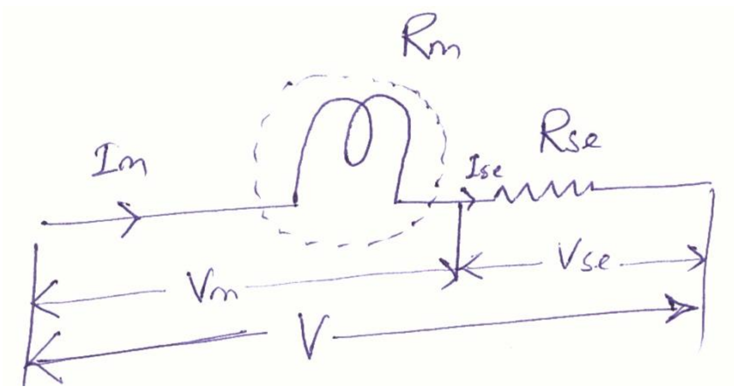
$$\therefore I = I_m \left(1 + \frac{R_m}{R_{sh}}\right)$$

$\left(1 + \frac{R_m}{R_{sh}}\right)$ is called multiplication factor

Shunt resistance is made of manganin. This has least thermo electric emf. The change is resistance, due to change in temperature is negligible

Case (II): Multiplier:

A large resistance is connected in series with voltmeter is called multiplier (Fig. 1.9). A large voltage can be measured using a voltmeter o f small rating with a multiplier.



(Fig. 1.9)

Let R = resistance of meter

R_{se} = resistance of multiplier

V_m = Voltage across meter

V_{se} = Voltage across series resistance

V = voltage to be measured

$$I_m = I_{se}$$

$$\frac{V_m}{R_m} = \frac{V_{se}}{R_{se}}$$

$$\therefore \frac{V_{se}}{V_m} = \frac{R_{se}}{R_m}$$

Apply KVL, $V = V_m + V_{se}$

Eq^n (1.19) $\div V_m$

$$\frac{V}{V_m} = 1 + \frac{V_{se}}{V_m} = \left(1 + \frac{R_{se}}{R_m}\right)$$

$$\therefore V = V_m\left(1 + \frac{R_{se}}{R_m}\right)$$

$$\left(1 + \frac{R_{se}}{R_m}\right) \rightarrow \text{Multiplication factor}$$

Errors in PMMC:

Temperature effect: Error in the reading of the PMMC may cause due to change in the temperature which will effect the resistance of the moving coil. The temperature coefficients of the value of coefficient of copper wire in moving coil is 0.04 per degree celsius rise in temperature. Since the coil has a lower temperature coefficient, it will have a faster rate of temperature rises which will result in increase in the resistance causing an error

Spring material and age: The other factor which may lead to error in the PMMC reading is the quality and contortion of the spring. Old ageing spring will not allow the pointer to show the correct reading making an error.

Ageing of Magnet: Along with the age, the effect of heat and vibration will reduce the magnetic effect of the permanent magnet which will produce an error in the reading.

Moving Iron (MI) instruments:

One of the most accurate instruments used for both AC and DC measurement is moving iron instrument.

The moving iron instruments are classified as:

1. Moving iron attraction type instruments and
2. Moving iron repulsion type instruments

Moving iron attraction type instruments

The basic working principle of these instruments is very simple that a soft iron piece if brought near the magnet gets attracted by the magnet.

The construction of the attraction type instrument is shown in the Fig.1.

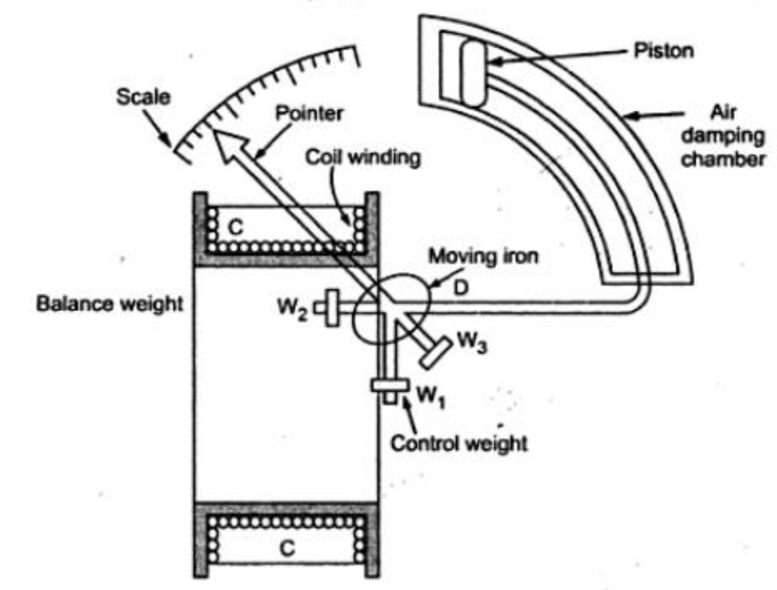


Fig. 1 Moving iron attraction type instruments

It consists of a fixed coil C and moving iron piece D. The coil is flat and has a narrow slot like opening. The moving iron is a flat disc which eccentrically mounted. on the spindle. The spindle is supported between the jewel bearings. The spindle caries a pointer which moves over a graduated scale. The number f turns of the fixed coil are dependent on the range of the instrument. For passing current through the coil only few turns are required.

The controlling torque is provided by the springs but gravity control may also ne used for vertically mounted panel type instruments.

The damping torque is provided by the air friction. A light aluminium piston is attached to the moving system. It moves in a fixed chamber. The chamber is closed at one end. It can also provided with the help of van attached to the moving system.

The operating magnetic field in moving iron instruments is very weak. Hence eddy current damping is not used since it require a permanent magnet which would affect or distort the operating field.

1.2 Moving Iron Repulsion Type Instrument

These instruments have two vanes inside the coil, the one is fixed and other is movable. When the current flows in the coil, both the vanes are magnetized with like polarities induced on the same side. Hence due to repulsion of like polarities, there is a force of repulsion between the two vanes causing the movement of the moving van. The repulsion type instruments are the most commonly used instruments.

The two different designs of repulsion type instruments are:

i) Radial vane type and

ii) Co-axial vane type

1.2.1 Radial Van Repulsion Type Instrument

The Fig. 2 shows the radial vane repulsion type instrument. Out of the other moving iron mechanism, this is the most sensitive and has most linear scale.

The two vanes are radial strips of iron. The fixed vane is attached to the coil. The movable vane is attached to the spindle and suspended in the induction field of the coil. The needle of the instrument is attached to this vane.

Eventhough the current through the coil is alternating, there is always repulsion between the like poles of the fixed and the movable vane. Hence the deflection of the pointer is always in the same direction. The deflection is effectively proportional to the actual current and hence the scale is calibrated directly to rad amperes or volts. The calibration is accurate only for the frequency for which it is designed because the impedance is different for different frequencies.

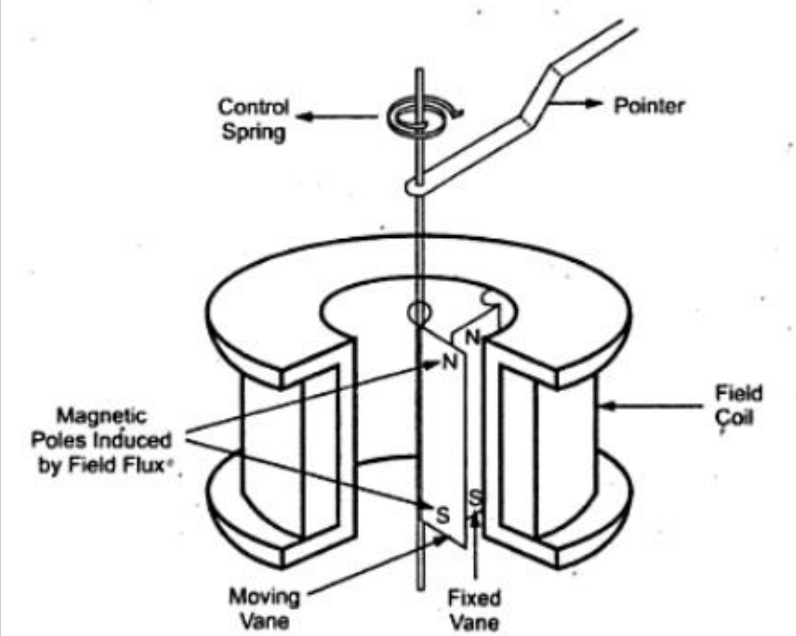


Fig. 2 Radial Van Repulsion Type Instrument

Concentric Vane Repulsion Type Instrument

Fig. 3 shows the concentric vane repulsion type instrument. The instrument has two concentric vanes. One is attached to the coil frame rigidly while the other can rotate coaxially inside the stationary vane.

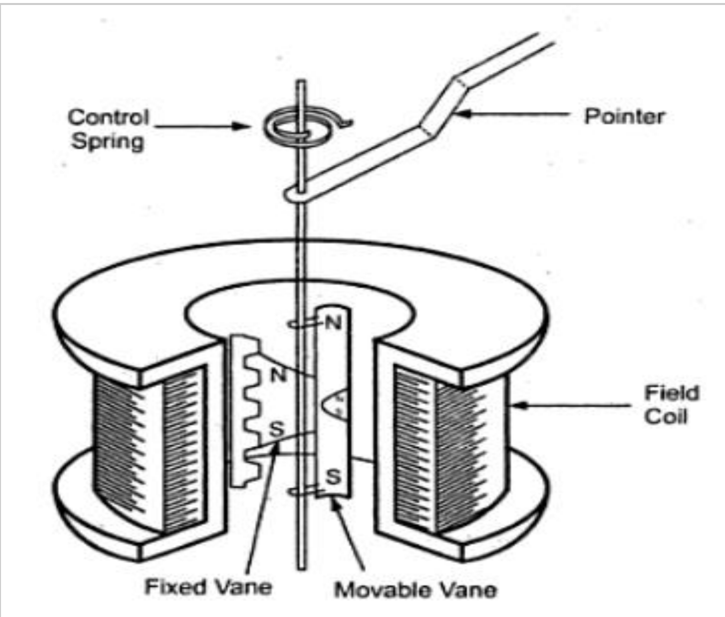


Fig. 3 Concentric Vane Repulsion Type Instrument

Both the vanes are magnetised to the same polarity due to the current in the coil. Thus the movable vane rotates under the repulsive force. As the movable vane is attached to the pivoted shaft, the repulsion results in a rotation of the shaft. The pointer deflection is proportional to the current in the coil. The concentric vane type instrument is moderately sensitive and the deflection is proportional to the square of the current through coil. Thus the instrument said to have square low response. Thus the scale of the instrument is non-uniform in nature. Thus whatever may be the direction of the current in the coil, the deflection in the moving iron instruments is in the same direction. Hence moving iron instruments can be used for both a.c. and d.c. measurements. Due to square low response, the scale of the moving iron instrument is non-uniform.

Torque Equation of moving iron instruments

Consider a small increment in current supplied to the coil of the instrument. due to this current let $d\theta$ be the deflection under the deflecting torque T_d. Due to such deflection, some mechanical work will be done.

$\therefore$ Mechanical Work = $T_d \; d\theta$

There will be a change in the energy stored i the magnetic field due to the change in inductance. This is because the vane tries to occupy the position of minimum reluctance. The inductance is inversely proportional to the reluctance of the magnetic circuit of coil.

Let I = initial current

L=instrument inductance

θ = deflection

dI = increase in current

$d\theta$ = change in deflection

dL = change in inductance

In order to effect an increment dL in the current, there must be an increase in the applied voltage given by,

$$e = \frac{d(LI)}{dt}$$

$$= I\frac{dL}{dt} + L\frac{dI}{dt} \qquad \text{as both I and L are changing.}$$

The electrical energy supplied is given by,

$$e I dt = \left(I \frac{dL}{dt} + L \frac{dI}{dt} \right) I dt$$

$$= I^2 \, dL + IL \, dI$$

The stored energy increases from $\frac{1}{2} L I^2$ to $\frac{1}{2}(L + dL)(I + dI)^2$

Hence the change in stored energy is given by,

$$= \frac{1}{2}(L + dL)(I + dI)^2 - \frac{1}{2} L I^2$$

Neglecting higher order terms, this becomes, $IL \, dI + \frac{1}{2} I^2 \, dL$

The energy supplied in nothing but increase in stored energy plus the energy required for mechanical work done.

$$\therefore \quad I^2 dL + IL \, dI = IL \, dI + \frac{1}{2} I^2 \, dL + T_d \cdot d\theta$$

$$\therefore \quad T_d \cdot d\theta = \frac{1}{2} I^2 \, dL$$

$$\therefore \quad \boxed{T_d = \frac{1}{2} I^2 \frac{dL}{d\theta}}$$

While the controlling torque is given by,

$$T_c = K \theta$$

where K = spring constant

$$\therefore \quad K \theta = \frac{1}{2} I^2 \frac{dL}{d\theta} \qquad \text{under equilibrium}$$

$$\therefore \quad \theta = \frac{1}{2} \frac{I^2}{K} \frac{dL}{d\theta}$$

Thus the deflection is proportional to the square of the current through the coil. And the instrument gives square law response.

Advantages

The various advantages of moving iron instruments are,

1) The instruments can be used for both a.c. and d.c. measurements.

2)As the torque to weight ratio is high, errors due to the friction are very less.

3) A single type of moving element can cover the wide range hence these instruments are cheaper than other types of if instruments.

4) There are no current carrying parts in the moving system hence these meters are extremely rugged and reliable.

5) These are capable of giving good accuracy. Modern moving iron instruments have a d.c. error of 2% or less.

6) These can withstand large loads and are not damaged even under sever overload conditions.

7) The range of instruments can be extended.

Disadvantages

The various disadvantages of moving iron instruments are,

1. The scale of moving iron instruments is not uniform and is cramped at the lower end. Hence accurate readings are not possible at this end.
2. There are serious errors due to hysteresis, frequency changes and stray magnetic fields.
3. The increase in temperature increases the resistance of coil, decreases stiffness of the springs, decreases the permeability and hence affect the reading severely.
4. Due to the non linearity of B-H curve, the deflecting torque is not exactly proportional to the square of the current.
5. There is a difference between a.c. and d.c. calibration on account of the effect of inductance of the meter. Hence these meters must always be calibrated at the frequency at which they are to be used. The usual commercial moving iron instrument may be used within its specified accuracy from 25 to 125 HZ frequency range.
6. Power consumption is on higher side.

1.6 Errors in moving iron instruments

The various errors in the moving iron instruments are,

1) Hysteresis error: Due to hysteresis effect, the flux density for the same current while ascending and descending values is different. While descending, the flux density is higher and while ascending it is lesser. So meter reads higher for descending values of current or voltage. So remedy for this is to use smaller iron parts which can demagnetise quickly or to work with lower flux densities.

2) Temperature error : The temperature error arises due to the effect of temperature on the temperature coefficient of the spring. This error is of the order of 0.02 % per ^{o}C change in temperature. Errors can cause due to self heating of the coil and due to which change in resistance of the coil. So coil and series resistance must have low temperature coefficient. Hence mangnin is generally used for the series resistance.

3) Stray magnetic Field Error: The operating magnetic field in case of moving iron instruments is very low. Hence effect of external i.e. stray magnetic field can cause error. This effect depends on the direction of the stray magnetic field with respect to the operating field of the instrument.

4) Frequency Error : These are related to a.c. operation of the instrument. The change in frequency affects the reactance of the working coil and also affects the magnitude of the eddy currents. This cause error in the instrument.

5) Eddy Current Error : When instrument is used for a.c. measurements the eddy currents are produced in the iron parts of the instrument. The eddy current affects the instrument current causing the change in the deflection torque. This produce the error in the meter reading. As eddy current are frequency dependent, frequency changes cause eddy current error.

EMI: UNIT-II

MEASUREMENT OF POWER AND ENERGY

Objectives:

1. To familiarize the students with the constructional details and working principle of Electro-dynamometer type instruments
2. To familiarize the students with LPF & UPF. Extension of range of watt meters with CT & PT
3. To familiarize the students with the Induction type Energy meters and its testing.

Syllabus:

Single phase and three phase dynamometer wattmeter, LPF and UPF, expression for Deflecting and control torques – Extension of range of wattmeter using instrument transformers. Single Phase induction type energy meter – driving and braking torques – errors and compensations –Testing of Energy meter

Learning Outcomes:

After the completion of this unit, students will be to

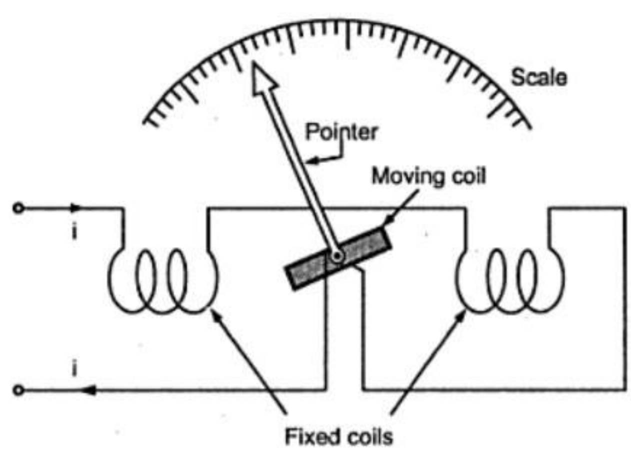
1. Describe the constructional details and working principle of Electro-dynamometer type instruments
2. Describe the LPF & UPF. Extension of range of watt meters with CT & PT
3. Describe the constructional details and working principle of Single Phase induction type energy meter with its driving and braking torques and errors with compensations.

The electrodynamometer type instrument is a transfer instrument. A transfer instrument is one which is calibrated with a d.c. source and used without any modifications for a.c. measurements. Such a transfer instrument has same accuracy for a.c. and d.c. measurements. The electrodynamometer type instruments are often used in accurate a.c. voltmeters and ammeters, not only at the power line frequency but also in the lower audiofrequency range. With some little modifications, it can be used as a wattmeter for the power measurements.

Why PMMC Instruments cannot be used for a.c. measurements ?

The PMMC instrument cannot be sued on a.c. currents or voltages. If a.c. supply is given to these instruments, an alternating torque will be developed. Due to moment of inertia of moving system, the pointer will not follow rapidly changing alternating torque and will fail to show any reading. In order that the instrument should be able to read a.c. quantities, the magnetic field in the air gap must change along with the change in current. This principle is used in the electrodynamometer type instrument. Instead of a permanent magnet, the electrodynamometer type instrument uses the current under measurement to produce the necessary field flux.

The Fig. 1 shows the construction of electrodynamometer type instrument.



Construction

The various type of the electrodynamometer type instrument are:

Fixed Coils : The necessary field required for the operation of the instrument is produced by the fixed coils. A uniform field is obtained near the center of coil due to division of coil in two sections. These coils are air cored. Fixed coils are wound with fine wire for using as voltmeter, while for ammeters and wattmeters it is wound with heavy wire. The coils are usually varnished. They are clamped in place against the coil supports. This makes the construction rigid.

Ceramic is usually used for mounting supports. If metal parts would have been used then it would weaken the field of the fixed coil.

Moving Coil : The moving coil is wound either as a self-sustaining coil or else on a non-metallic former. If metallic former is used, then it would induce eddy currents in it. The construction of moving coil is made light as well as rigid. It is air cored.

Controlling : The controlling torque is provided by springs. These springs act as leads to the moving coil.

Moving System : The moving coil is mounted on an aluminium spindle. It consists of counter weights and pointer. Sometimes a suspension may be used, in case a high accuracy is desired.

Damping : The damping torque is provided by air friction, by a pair of aluminium vanes which are attached to the spindle at the bottom. They move in sector shaped chambers. As operating field would be distorted by eddy current damping, it is not employed.

Shielding : The field produced by these instruments is very weak. Even earth's magnetic field considerably affects the reading. So shielding is done to protect it from stray magnetic fields. It is done by enclosing in a casing high permeability alloy.

Cases and Scales : Laboratory standard instruments are usually contained in polished wooden or metal cases which are rigid. The case is supported by adjustable levelling screws.

A spirit level may be provided to ensure proper levelling.

For using electrodynamometer instrument as ammeter, fixed and moving coils are connected in series and carry the same current. A suitable shunt is connected to these coils to limit current through them upto desired limit.

The electrodynamometer instruments can be used as a voltmeter by connecting the fixed and moving coils in series with a high non-inductive resistance. It is most accurate type of voltmeter.

For using electrodynamometer instrument as a wattmeter to measure the power, the fixed coils acts as a current coil and must be connected in series with the load. The moving coils acts as a voltage coil or pressure oil and must be connected across the supply terminals. The wattmeter indicates the supply power. When current passes through the fixed and moving coils, both coils produce the magnetic fields. The field produced by fixed coil is proportional to the load current while the field produced by the moving coil is proportional to the voltage. As the deflecting torque is produced due to the interaction of these two fields, the deflection is proportional to the power supplied to the load.

Torque Equation

Let i_1 = Instantaneous value of current in fixed coil

i_2 = Instantaneous value of current in moving coil

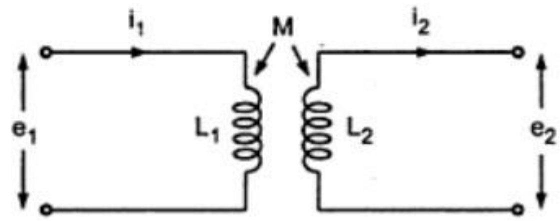
L_1 = Self inductance of fixed coil

L_2 = self inductance of moving coil

M = Mutual inductance between fixed and moving coils

The electrodynamometer instrument can be represented by an equivalent circuit as shown in the

Fig.2.



The flux linkages of coil 1 are,

$$\phi_1 = L_1 i_1 + M i_2$$

The flux linkages of coil 2 are,

$$\phi_2 = L_2 i_2 + M i_1$$

Now $$e_1 = \frac{d\phi_1}{dt}$$

and $$e_2 = \frac{d\phi_2}{dt}$$

$$\text{Electrical input energy} = e_1 i_1 dt + e_2 i_2\, dt$$
$$= i_1\, d\phi_1 + i_2\, d\phi_2$$
$$= i_1\, d(L_1 i_1 + M i_2) + i_2\, d(L_2 i_2 + M i_1)$$
$$= i_1 L_1\, di_1 + i_1^2\, dL_1 + i_1 i_2\, dM + i_1 M\, di_2 +$$
$$i_2 L_2\, di_2 + i_2^2\, dL_2 + i_1 i_2\, dM + i_2 M\, di_1 \qquad \dots(1)$$

The energy stored in the magnetic field due to L_1, L_2 and M is given by,

$$\text{Energy stored} = \frac{1}{2} L_1 i_1^2 + \frac{1}{2} L_2 i_2^2 + i_1 i_2 M$$

$$\text{Change in stored energy} = d\left[\frac{1}{2} L_1 i_1^2 + \frac{1}{2} L_2 i_2^2 + i_1 i_2 M\right]$$

$$= i_1 L_1\, di_1 + \frac{1}{2} i_1^2\, dL_1 + i_2 L_2\, di_2 + \frac{1}{2} i_2^2\, dL_2 +$$
$$i_1 M\, di_2 + i_2 M\, di_1 + i_1 i_2\, dM \qquad \dots(2)$$

From the principle of conversation of energy, Energy input = Energy stored + Mechanical energy

∴ Mechanical energy = Energy input - Energy stored

Substraction (2) from equation (1),

$$\text{Mechanical energy} = \frac{1}{2} i_1^2 \, dL_1 + \frac{1}{2} i_2^2 \, dL_2 + i_1 \, i_2 \, dM$$

The self inductance L_1 and L_2 are constant and hence dL_1 and dL_2 are zero. Mechanical energy = i1 i2 dM

If Ti is the instantaneous deflecting torque and dθ is the change in the deflection then

Mechanical energy = Mechanical workdone

$= T_i \; d\theta$

$i_1 \; i_2 \, d M = T_i \; d\theta$

$$\boxed{T_i = i_1 i_2 \frac{dM}{d\theta}}$$

This is the expression for the instantaneous deflection torque. Let us see its operation on a.c. and

$$T_d = I_1 I_2 \frac{dM}{d\theta}$$

D.C. operation : For d.c current of I_1 and I_2,

The controlling torque is provided by springs hence

$$T_c = K\theta$$

In steady state, $T_d = T_c$

∴ $$I_1 I_2 \frac{dM}{d\theta} = K\theta$$

∴ $$\boxed{\theta = \frac{I_1 I_2}{K} \cdot \frac{dM}{d\theta}}$$

Thus the deflection is proportional to the product of the two currents and the rate of change of mutual inductance.

A.c. operation : In a.c. operation, the total deflecting torque over a cycle must be obtained by integrating T_i over one period.

Average deflecting torque over one cycle is,

$$T_d = \frac{1}{T}\int_0^T T_i \, dt$$

$$T = \text{Time period of one cycle}$$

$$T_d = \frac{dM}{d\theta} \cdot \frac{1}{T}\int_0^T i_1 \, i_2 \, dt$$

Now if two currents are sinusoidal and displaced by a phase angle then

$$i_1 = I_{m1} \sin \omega t$$

and

$$i_2 = I_{m2} \sin (\omega t - \phi)$$

$$\therefore \quad T_d = \frac{dM}{d\theta} \cdot \frac{1}{T}\int_0^T I_{m1} \sin \omega t \cdot I_{m2} \sin(\omega t - \phi) d(\omega t)$$

$$= \left(\frac{I_{m1} \, I_{m2}}{2}\right) \cos\phi \frac{dM}{d\theta}$$

$$= I_1 \, I_2 \cos\phi \frac{dM}{d\theta}$$

where i_1, i_2 are the r.m.s. values of the two currents as,

$$I_1 = \frac{I_{m1}}{\sqrt{2}} \quad \text{and} \quad I_2 = \frac{I_{m2}}{\sqrt{2}}$$

As $\quad T_c = K \theta$

Hence in steady state, $\quad T_c = T_d$

$$\therefore \quad I_1 \, I_2 \cos\phi \frac{dM}{d\theta} = K \theta$$

$$\therefore \quad \boxed{\theta = \frac{I_1 I_2}{K} \cos\phi \frac{dM}{d\theta}}$$

$$I_1 = \frac{I_{m1}}{\sqrt{2}} \quad \text{and} \quad I_2 = \frac{I_{m2}}{\sqrt{2}}$$

As $T_c = K\,\theta$

Hence in steady state, $T_c = T_d$

$\therefore$ $$I_1\, I_2 \cos\phi \frac{dM}{d\theta} = K\,\theta$$

$\therefore$ $$\boxed{\theta = \frac{I_1\, I_2}{K} \cos\phi \frac{d\,M}{d\theta}}$$

Thus the deflection is decided by the product of r.m.s. values of two currents, cosine of the phase angle (power factor) and rate of change of mutual inductance.

For d.c. use, the deflection is proportional to square of current and the scale is nonuniform and crowded at the ends. For a.c. use the instantaneous torque is proportional to the square of the instantaneous current. The i^2 is positive and as current varies, the deflecting torque also varies.

But moving system, due to inertia cannot follow rapid variations and thus finally meter shows theaverage torque.

Thus the deflection is the function of the mean of the squared current. The scale is thus calibrated in terms of the square root of the average current squared i.e. r.m.s value of the a.c. quantity to be measured.

If an electrodynamometer instrument is calibrated with a d.v. current if 1 A and pointer indicates 1 A

d.c. on scale then on a.c., the pointer will deflect upto the same mark but 1A in this case will indicate r.m.s value.

Thus as it is a transfer instrument, there is direct connection between a.c. and d.c. Hence the instrument is often used as a calibration instrument.

The instrument can be used as an ammeter to measure currents upto 20 A while using as a voltmeter it can have low sensitivity of about 10 to 30 Ω/v

The Fig. 3(a), (b) and (c) shows the connections of the electrodynamometer instrument as ammeter, voltmeter and the wattmeter

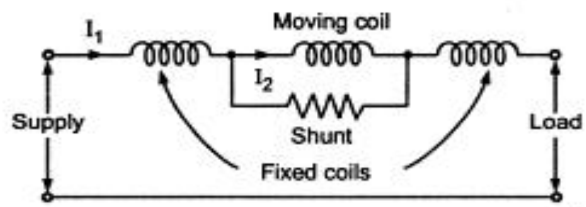


Fig. 3 (a) Electrodynamometer ammeter upto 100 mA

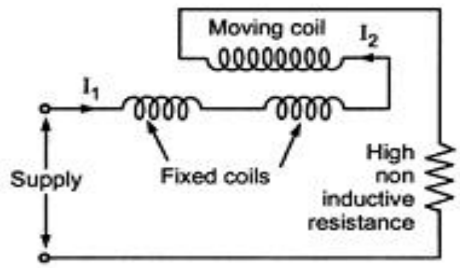


Fig. 3 (b) Electrodynamometer voltmeter

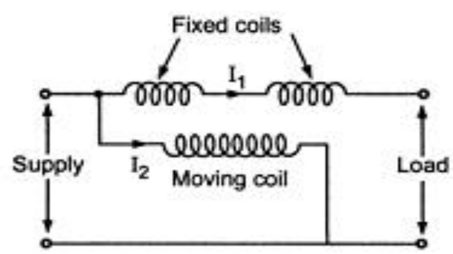


Fig. 3 (c) Electrodynamometer wattmeter

Single phase dynamometer wattmeter:

An electro dynamo meter type wattmeter is used to measure power. It has two coils, fixed coil which is current coil and moving coil which is pressure coil or voltage coil. The current coil carries the current of the circuit while pressure coil carries current proportional to the voltage in the circuit. This is achieved by connecting a series resistance in voltage circuit. The connections of an electrodynamometer wattmeter in the circuit are shown in fig

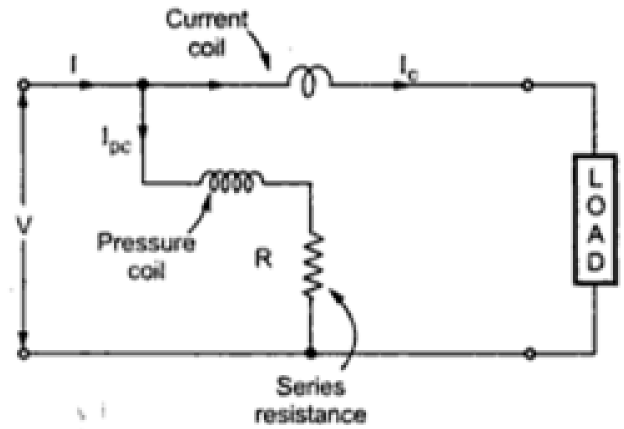


Fig: electro dynamometer wattmeter

I_C = current through current coil

I_{PC}= current through pressure coil

R = series resistance.

V= R.M.S. value of supply voltage

I= R.M.S. value of current.

Torque equation:

According to theory of electrodynamics instruments

$T_i = i_1 i_2 \frac{dM}{d\theta}$

Let v = instantaneous voltage = $V_m \sin\omega t = \sqrt{2}V \sin\omega t$

Due to the high resistance, pressure coil is treated to be purely resistive.

I_{PC}= instantaneous value = $\frac{V}{R_P}$

Where $R_P = r_{Pc} + R$

$I_{PC} = \frac{\sqrt{2}\,V}{R_P} \sin \omega t$

If current coil lags the voltage by angle $\emptyset$ then its instantaneous value is

$i_c = \sqrt{2}\, I_C \sin(\omega t - \emptyset)$

Now $i_1 = i_c$ and $i_2 = i_{pc}$ hence

$T_i = [\sqrt{2}\mathrm{I_{PC}}\sin \omega t][\sqrt{2}\, I_C \sin(\omega t - \emptyset)] \frac{dM}{d\theta}$

$= 2\mathrm{I_{PC}} I_C \sin(\omega t)\sin(\omega t - \emptyset)\frac{dM}{d\theta}$

$T_i = \mathrm{I_{PC}} I_C [\cos\emptyset - \cos(2\omega t - \emptyset)\frac{dM}{d\theta}$

$T_d =$ average deflecting torque $= \frac{1}{T}\int_0^T T_i \mathrm{d}\,(\omega t)$

$= \frac{1}{T}\int_0^T \mathrm{I_{PC}} I_C [\cos\emptyset - \cos(2\omega t - \emptyset)\frac{dM}{d\theta}\mathrm{d}\,(\omega t)$

$T_d = \mathrm{I_{PC}} I_C \cos\emptyset \frac{dM}{d\theta}$

Where $\mathrm{I_{PC}} = \frac{V}{R_P}$

For a spring controlled wattmeter

$T_c = \mathrm{k}\,\theta$ But $T_d = T_c$

$\mathrm{I_{PC}} I_C \cos\emptyset \frac{dM}{d\theta} = \mathrm{k}\,\theta$

$\theta = \frac{1}{K}\mathrm{I_{PC}} I_C \cos\emptyset \frac{dM}{d\theta} = K_1 \mathrm{I_{PC}} I_C \cos\emptyset$

Where $K_1 = \frac{1}{K}\frac{dM}{d\theta}$

$\theta = K_1 I_C \frac{V}{R_P}\cos\emptyset = K_2 \mathrm{P}$

$K_2 = \frac{K_1}{R_P}$ and $\mathrm{P} = \mathrm{V} I_C \cos\emptyset$ = power

$\theta \propto \mathrm{P}$

Extension of range of wattmeter using instrument transformer:

For very high voltage circuits, the high rating wattmeters are not available to measure the power. The range of wattmeter can be extended using instrument transformers, in such high voltage circuits. The connections are as shown in fig.

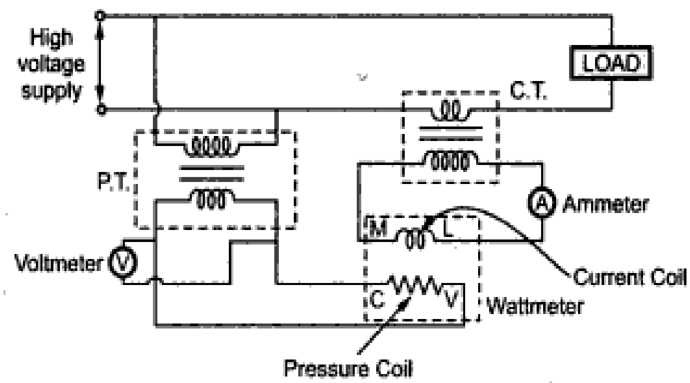


Fig: power measurement using C.T and P.T

The primary winding of C.T is connected in series with the load and secondary is connected in series with an ammeter and the current coil of a wattmeter.

The primary winding of P.T is connected across the supply and secondary is connected across voltmeter and the pressure coil of the wattmeter. One secondary terminal of each transformer and the casings are grounded.

Now both C.T and P.T have errors like ratio and phase angle error. For precise measurements, these errors must be considered. If not considered, these errors may cause inaccurate measurements. The correction must be applied to such errors to get the accurate results.

Low Power Factor Electro-Dynamometer Type Wattmeters

Ordinary **electro-dynamometer wattmeter** is not suitable for measurement of power in low power factor circuits owing to

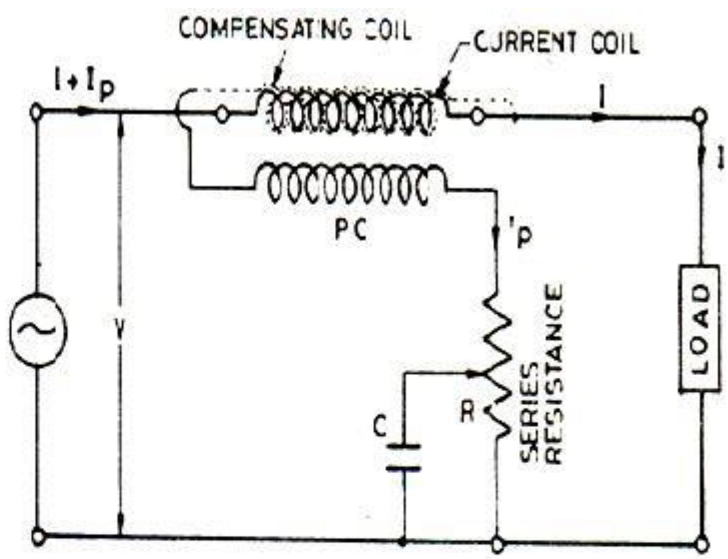
Small deflecting torque on the moving system even when the current and pressure coils are fully excited and

Introduction of large error due to inductance of pressure coil at low power factor

Pressure coil Circuit. The pressure coil circuit is made of low resistance in order to make the pressure coil current large resulting in increased operating torque. The pressure coil current in a low pf wattmeter may be as much as 10 times the value used for ordinary wattmeters.

Compensation For Pressure Coil current

Compensation For Inductance of Pressure Coil. The error caused by pressure coil inductance is (sinΘ)/cos Ø + sinΘ times the actual reading of wattmeter. Now with low pf, the value of Ø is large and, therefore, the error is large. The error caused by inductance of pressure coil is compensated by connecting a capacitor across a part of series resistance in the pressure coil circuit, as shown in fig



REACTIVE POWER MEASUREMENTS

A single wattmeter can also be used for three phase reactive power measurements. For example, the connection of a single wattmeter for 3-phase reactive power measurement in a balanced three phase circuit is as shown in figure 4.6.The current coil of the wattmeter is inserted in one line and the potential coil is connected across the other two lines. Thus, the voltage applied to the voltage coil is $V_{RB}=V_R-V_B$, where V_R and V_B are the phase voltage values of lines R and B respectively, as illustrated by the phasor diagram of figure

The reading of the wattmeter, W3ph for the connection shown in figure 3.6 can be obtained based on the phasor diagram of figure, as follows:

Wattmeter reading, **Wph** = Iy VRB

$= I_y V_L \cos(90+Ø)$

$= - \sqrt{3} V_{ph} I_{ph} \sin Ø$

$= - \sqrt{3}$ (Reactive power per phase)

Thus, the three phase power, $\mathbf{W_{3ph}}$ is given by,

W3ph = (VArs/phase)

$= 3 [W_{ph}/-\sqrt{3}]$

$= - \sqrt{3}$ (wattmeter reading)

THREE PHASE REAL POWER MEASUREMENTS

The three phase real power is given by,

$P_{3ph} = 3 V_{ph} I_{ph} \cos Ø$ or

$P_{3ph} = \sqrt{3} V_L I_L \cos Ø$

The three phase power can be measured by using one wattmeter, two wattmeters or three wattmeters in the measuring circuit. Of these, the two wattmeter method is widely used for the obvious advantages of measurements involved in it as discussed below.

1. Single Wattmeter Method

Here only one wattmeter is used for measurement of three phase power. For circuits with the balanced loads, we have: W_{3ph}=3(*wattmeter reading).* For circuits with the unbalanced loads, we have: W_{3ph}=sum of the three readings obtained separately by connecting wattmeter in each of the three phases. If the neutral point is not available (3 phase 3 wire circuits) then an artificial neutral is created for wattmeter connection purposes. Instead three wattmeters can be connected simultaneously to measure the three phase power. However, this involves more number of meters to be used for measurements and hence is not preferred in practice. Instead, the three phase power can be easily measured by using only two wattmeters, as discussed next.

2. Two Wattmeter Method

The circuit diagram for two wattmeter method of measurement of three phase real power is as shown in the figure 34.7. The current coil of the wattmeters W_1 and W_2 are inserted respectively in R and Y phases. The potential coils of the two wattmeters are joined together to phase B, the third phase. Thus, the voltage applied to the voltage coil of the meter, W_1 is $V_{RB}= V_R-V_B$, while the voltage applied to the voltage coil of the meter, W_2 is $V_{YB}=V_Y-V_B$, where, V_R, V_B and V_C are the phase voltage values of lines R, Y and B respectively, as illustrated by the phasor diagram of figure 3.8. Thus, the reading of the two wattmeters can be obtained based on the phasor diagram of figure 4.8, as follows:

$$W_1 = IR\ VRB$$

$$= I_L\ V_L \cos (30 - Ø)$$

$$W_2 = IY\ VYB$$

$$= I_L\ V_L \cos (30 + Ø)$$

Hence, $W_1+W_2 = \sqrt{3}\ V_L\ I_L \cos Ø = P_{3ph}$

And $W_1-W_2 = V_L\ I_L \sin Ø$

So that then,

$$\textbf{Tan } Ø = \sqrt{3}\ [W_1-W_2]/\ [W_1+W_2]$$

<u>Types of power factor meters:</u>

The power in single phase A.C circuit is given by

$$P = VI \cos Ø$$

$\cos Ø$ = power factor of the circuit.

Thus by using precise voltmeter, ammeter and wattmeter in the circuit, the readings of V, I and P can be obtained. Then power factor can be calculated as

$$\cos\emptyset = \frac{P}{VI}$$

Single phase induction type energy meter

It works on the principle of induction i.e. on the production of eddy currents in the moving system by the alternating fluxes. These eddy currents induced in the moving system interact with each other to produce a driving torque due to which disc rotates to record the energy.

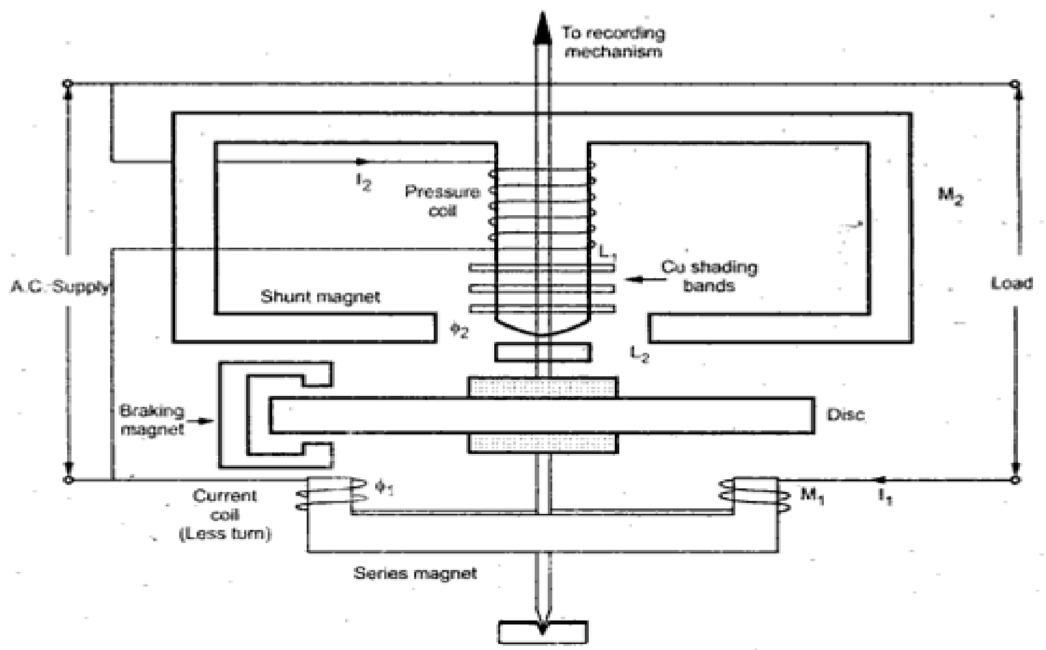


Fig. 4.1 Induction type single phase energymeter

In the energy meter there is no controlling torque and thus due to driving torque only, a continuous rotation of the disc is produced. To have constant speed of rotation braking magnet is provided.

Construction:

There are four main parts of operating mechanism

1) Driving system

2) Moving room

3) Braking system

4) Registering system.

1) Driving system: It consists of two electromagnets whose core is made up of silicon steel laminations. The coil of one of the electromagnets, called current coil, is excited by load current which produces flux further. The coil of another electromagnetic is connected across the supply and it carries current proportional to supply voltage. This is called pressure coil. These two electromagnets are called as series and shunt magnets respectively.

The flux produced by shunt magnet is brought in exact quadrature with supply voltage with the help of copper shading bands whose position is adjustable.

2) Moving system: Light aluminum disc mounted in a light alloy shaft is the main part of moving system. This disc is positioned in between series and shunt magnets. It is supported between jewel bearings. The moving system runs on hardened steel pivot. A pinion engages the shaft with the counting mechanism. There are no springs and no controlling torque.

3) Braking system: a permanent magnet is placed near the aluminum disc for barking mechanism. This magnet reproduced its own field. The disc moves in the field of this magnet and a braking torque is obtained. The position of this magnet is adjustable and hence braking torque is adjusted by shifting this magnet to different radial positions. This magnet is called braking magnet.

4) Registering mechanism: It records continuously a number which is proportional to the revolutions made by the aluminum disc. By a suitable system, a train of reduction gears, the pinion on the shaft drives a series of pointers. These pointers rotate on round dials which an equally marked with equal division.

Working: since the pressure coil is carried by shunt magnet M2 which is connected across the supply, it carries current proportional to the voltage. Series magnet M1 carries current coil which carries the load current. Both these coils produced alternating fluxes $\emptyset 1$ and $\emptyset 2$ respectively. These fluxes are proportional to currents in their coils. Parts of each of these fluxes link the disc and induce e.m.f. in it. Due to these e.m.f.s eddy currents are induced in the disc. The eddy current induced by the electromagnet M_2 react with magnetic field produced by M_1 react with magnetic field produced by M_2. Thus each portion of the disc experiences a mechanical force and due to

Motor action, disc rotates. The speed of disc is controlled by the C shaped magnet called braking magnet. When disc rotates in the air gap, eddy currents are induced in disc which opposes the cause producing them i.e. relative motion of disc with respect to magnet. Hence braking torque Tb is generated. This is proportional to speed N of disc. By adjusting position of this magnet, desired speed of disc is obtained. Spindle is connected for recording mechanism through gears which record the energy supplied.

Driving and braking torques:

The phasor diagram is shown in below

V= supply voltage.

I= load current

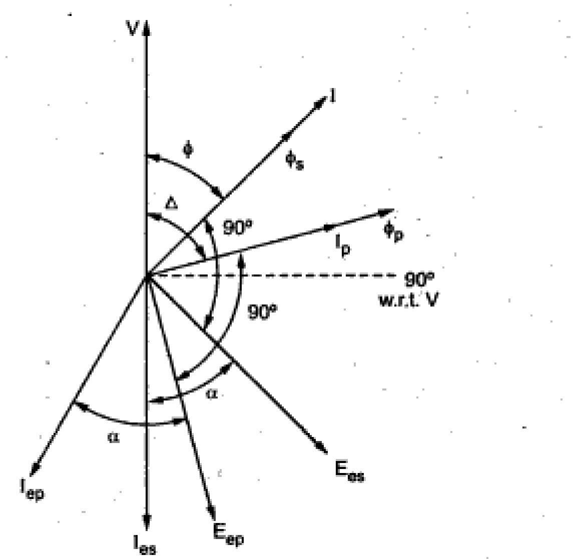


Fig: phasor diagram of single phase induction type energy meter

I_P= pressure coil current.

Δ= phase angle between v and I_P

Δ=90^0

E_{ep}= eddy e.m.f induced due to $\emptyset_p$

E_{es}= eddy e.m.f induced due to $\emptyset_s$

α= phase angle of eddy currents.

I_{ep}= eddy current due to E_{ep}

I_{es}= eddy current due to E_{es}

The current $I_p$lags V by Δ and Δ is made 90^0 using copper shading bands. The current I lags by $\emptyset$ which is depends on the load. The flux $\emptyset_s$ and I are in phase. The E_{ep} lags $\emptyset_p$ by 90^0 while E_{es} lags $\emptyset_s$ by 90^0. The eddy currents $I_{ep}$and I_{es} lags E_{ep} and E_{es} respectively by angle α.

The interaction between $\emptyset_p$ and I_{es} produces torque T1.

The interaction between ϕ_s and I_{ep} produces torque T2.

$T1 \propto \phi_p I_{es} \cos(\phi_p \wedge I_{es})$ and $T2 \propto \phi_s I_{ep} \cos(\phi_s \wedge I_{ep})$

$\phi_p \wedge I_{es} = \alpha + \phi$ and $\phi_s \wedge I_{ep} = 180 - \phi + \alpha$

$T_d \propto t1 - t2 \propto \{[\phi_p I_{es} \cos(\alpha + \phi)] - [\phi_s I_{ep} \cos(180 - \phi + \alpha)]\}$

Now $\phi_p \propto V$, $\phi_s \propto I$, $I_{es} \propto \phi_s \propto I$, $I_{ep} \propto \phi_p \propto V$

$T_d \propto VI[\cos(\alpha + \phi) - \cos(180 - \phi + \alpha)]$

$\propto VI[\cos\alpha\cos\phi - \sin\alpha\sin\phi - (\cos(180 - \phi)\cos\alpha - \sin(180 - \phi)\sin\alpha]$

$\propto VI \cos\alpha\cos\phi$

$T_d = K_3 VI\cos\phi$

If Δ is considered

$T_d \propto VI[\sin(\Delta - \phi)$

The breaking torque is due to eddy currents induced in the aluminum disc. Magnitude of eddy currents is proportional to the speed N of the disc. Hence the braking torque T_b is also proportional to the speed N.

$$T_b \propto N$$

$T_b = K_4 N.$

ERRORS AND COMPENSATION:

Speed error: Due to the incorrect position of the brake magnet, the braking torque is not correctly developed. This can be tested when meter runs at its full load current alternatively on loads of unity power factor and a low lagging power factor. The speed can be adjusted to the correct value by varying the position of the braking magnet towards the centre of the disc or away from the centre and the shielding loop. If the meter runs fast on inductive load and correctly on non-inductive load, the shielding loop must be moved towards the disc. On the other hand, if the meter runs slow on non-inductive load, the brake magnet must be moved towards the center of the disc.

Meter phase error: An error due to incorrect adjustment of the position of shading band results an incorrect phase displacement between the magnetic flux and the supply voltage (not in quadrature). This is tested with 0.5 p.f. load at the rated load condition. By adjusting the position of the copper shading band in the central limb of the shunt magnet this error can be eliminated.

Friction error: An additional amount of driving torque is required to compensate this error. The two shading bands on the limbs are adjusted to create this extra torque. This adjustment is done at low load (at about 1/4th of full load at unity p.f.).

v) Creeping: In some meters a slow but continuous rotation is seen when pressure coil is excited but with no load current flowing. This slow revolution records some energy. This is called the creep error. This slow motion may be due to (a) incorrect friction compensation, (b) to stray magnetic field (c) for over voltage across the voltage coil. This can be eliminated by drilling two holes or slots in the disc on opposite side of the spindle. When one of the holes comes under the poles of shunt magnet, the rotation being thus limited to a maximum of 180^0. In some cases, a small piece of iron tongue or vane is fitted to the edge of the disc. When the position of the vane is adjacent to the brake magnet, the attractive force between the iron tongue or vane and brake magnet is just sufficient to stop slow motion of the disc with full shunt excitation and under no load condition.

(v) Temperature effect: Energy meters are almost inherently free from errors due to temperature variations. Temperature affects both driving and braking torques equally (with the increase in temperature the resistance of the induced-current path in the disc is also increases) and so produces negligible error. A flux level in the brake magnet decreases with increase in temperature and introduces a small error in the meter readings. This error is frequently taken as negligible, but in modern energy meters compensation is adopted in the form of flux divider on the break magnet.

Energy meter constant K is defined as K = No. of revolutions/ kwh

In commercial meters the speed of the disc is of the order of 1800 revolutions per hour at full load.

Testing by phantom loading using R.S.S. meter:

This test is conducted for short period of time hence called short period test. A rotating substandard meter (R.S.S) is used along with the meter under test. The current coils of two meters are connected in series while pressure coils in parallel. The two meters are started and stopped simultaneously for short period of time.

When the predetermined load is adjusted, then the meter under test is allowed to make certain number of revolutions. At the same time, the numbers of revolutions made by rotating substandard meter, in the same time are observed.

If the constants of meters are same then error can be directly obtained. But if meter constants are different then error is required to be calculated.

Let K_X= Meter constant in number of revolutions per Kwh for meter under test.

K_s=meter constant in number of revolutions per kwh for substandard meter.

N_X= number of revolutions made by meter under test.

N_s = number of revolutions made by substandard meter

E_r= energy recorded by meter under test = $\frac{N_X}{K_X}$

E_t= energy recorded by substandard meter = $\frac{N_s}{K_s}$

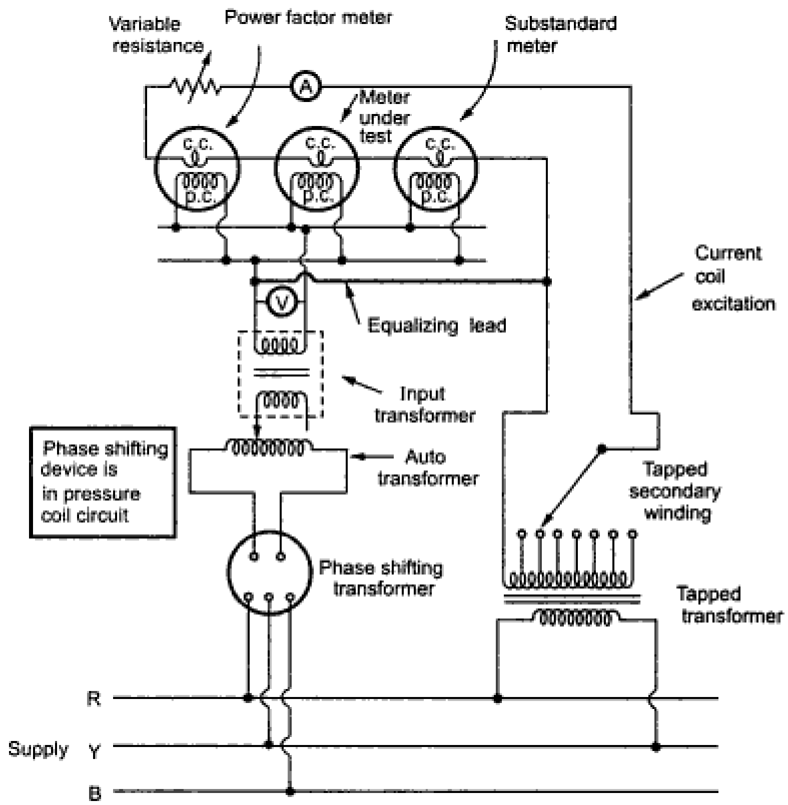


Fig. 4.19 Phantom loading of a.c. meter using rotating substandard meter

$$\%\text{error} = \frac{\frac{N_X}{K_X} - \frac{N_S}{K_S}}{\frac{N_S}{K_S}} * 100$$

Before conducting the test, the meters are allowed to rue for 15 to 30 minutes with full load, to attain steady state temperature.

EMI: UNIT – III

Potentiometers

Objectives:

1. To familiarize the students with the principle and operation of DC Crompton's potentiometer Standardization.
2. To familiarize the students with calibration of Ammeter, Voltmeter, wattmeter using DC Crompton's potentiometer.
3. To familiarize the students with designing of volt-ratio box

Syllabus:

Basic slide wire Potentiometer: Principle and operation of DC Crompton's potentiometer. Standardization – Volt Ratio Box, Measurement of Unknown resistance, Calibration of ammeter, volt meter and watt meter.

Learning Outcomes:

After the completion of this unit, students will be to

1. Describe the principle and operation of DC Crompton's potentiometer Standardization.
2. Design a volt-ratio box for DC Crompton's potentiometer
3. Calibrate Ammeter, Voltmeter, and wattmeter using DC Crompton's potentiometer.

UNIT – III

Potentiometers

Basic slide wire Potentiometer: Principle and operation of DC Crompton's potentiometer. Standardization – Volt Ratio Box, Measurement of Unknown resistance, Calibration of ammeter, volt meter and watt meter.

Construction and Working of basic (slide wire) dc Potentiometers

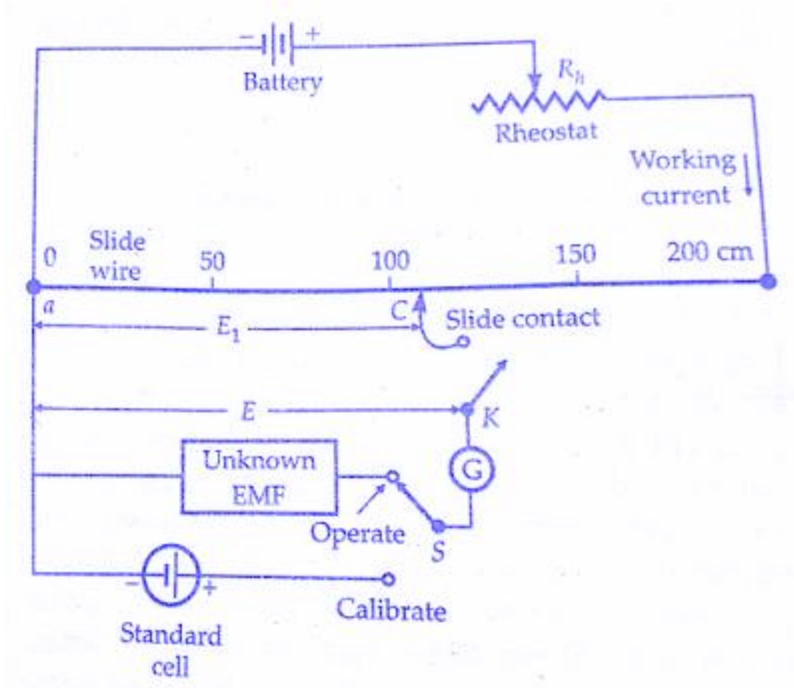
A potentiometer is an instrument used to measure the potential in a circuit. A potentiometer is an instrument designed to measure an unknown voltage by comparing it with a known voltage. The known voltage may be supplied by a standard cell or any other known voltage reference source.Measurements using comparison methods are capable of a high degree of accuracy because the result obtained does not depend upon the actual deflection of a pointer, as is the case in deflectional methods, but only upon the accuracy with which the voltage of the reference source is known.

Another advantage of the potentiometers is that since a potentiometer makes use of a balance or null condition, no current flows and hence no power is consumed in the circuit containing the unknown emf when the instrument is balanced. Thus, the determination of voltage by a potentiometer is quite independent of the source resistance.

Since a potentiometer measures voltage, it can also be used to determine current simply by measuring the voltage drop produced by the unknown current piling through a known standard resistance. The potentiometer is extensively used for a calibration of voltmeters and ammeters and has, in fact, become the standard for the calibration of these instruments. For the above mentioned advantages the potentiometer has become very important in the field ofelectrical measurements and calibration.

Basic Circuit diagram of D.C Potentiometer:

The principle of operation of all potentiometers is based on the figure shown below, which shows the circuit diagram of the basic slide wire potentiometer.



Construction and Working of basic dc Potentiometer:

With switch 'S' in the "operate" position and the galvanometer key K open, the battery supplies the "working current" through the rheostat R and the slide wire.The working current through the slide wire may be varied by changing the rheostat setting.The method of measuring the unknown voltage, E, depends upon finding a position for the sliding contact such the galvanometer shows zero deflection, i.e., indicates a null condition, when the galvanometer key, K. is closed. Zero galvanometer deflection or a null means that the unknown voltage, E, is equal to the voltage drop E1, across portion ac of the slide wire. Thus, the determination of the value of unknown voltage now becomes a matter of evaluating the voltage drop E1 along the portion ac of the slide wire.

The slide wire has a uniform cross-section and hence uniform resistance along its entire length. A calibrated scale in cm and fractions of cm is placed along the slide wire so that the sliding contact can be placed accurately at any desired position along the slide wire. Since the resistance of slide wire is known accurately, the voltage drop along the slide wire can be controlled by adjusting the value of working current. The process of adjusting the workingcurrent so as to match the voltage drop across a portion of sliding wire against a standard reference source is known as "Standardisation".

All the resistors in a potentiometer, with the exception of slide wires, are made of manganin. This is because manganin has a high stability, a low temperature co-efficient and has freedom from thermo-electric effects against copper.The slide wire is usually made of platinum-silver alloy and the sliding contact is of a copper—gold-silver alloy. This combination of materials for slide wire and sliding contacts results in a good contact, freedom from thermo-electric EMFs and minimum wear of slide wire.The current controlling rheostat is usually a combination of a stud dial and a multi-turn slide wire.

It is very important that internal thermoelectric EMFs in a **potentiometer** are minimum. The use of manganin resistors helps in this direction. It is desirable that all the parts work at the same temperature. Therefore, all the parts are covered in a single case. This has the added advantage of protecting the contacts from fumes and dust which may cause corrosion and appearance of volatic EMFs at the joints.**Potentiometers** designed especially for thermocouple measurements have copper terminals. In order to prevent leakage, all the parts must be enclosed, so as to protect them from moisture. The **working** parts are normally mounted on ebonite or Keramot panels

Standardisation of the potentiometer:

The procedure for **standardisation of the potentiometer** is illustrated by the following example:

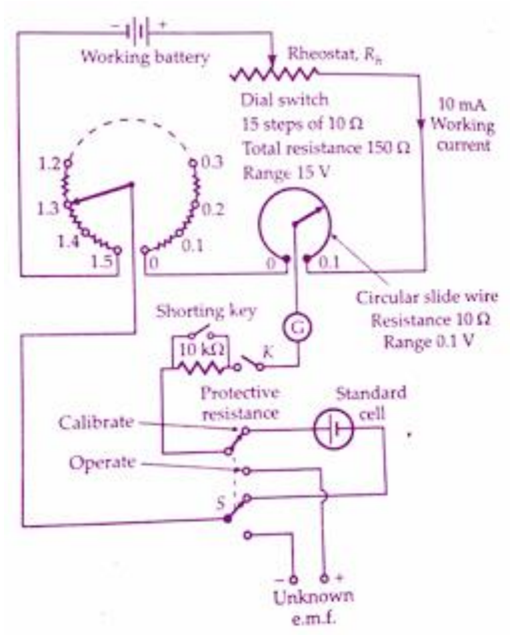
The slide wire present in above figure has a total length of 200 cm and a resistance of 200 Ω. The emf of the standard cell is 1.0186 V. Switch 'S' is thrown to "calibrate" position and the sliding contact is placed at 101.86 cm mark on the **slide wire** scale. The rheostat Rh is now adjusted so as to vary the working current. This adjustment is carried on till the galvanometer shows no deflection when key 'K' is pressed. Under these conditions, the voltage drop, along the 101.86 cm portion of the slide wire is equal to standard cell voltage of 101.86 V. Since the 101.86 cm portion of the slide wire has a resistance of 101.86 Ω, the working current, in fact, has been adjusted to a value

$$(1.0186/101.86) \times 1000 = 10 \text{ mA}$$

The voltage at any point along the slide wire is proportional to the length of **slide wire**. This voltage is obtained by converting the calibrated length into the corresponding voltage, simply by placing the decimal point in the proper position e.g. 153.6 cm =1.536 V. If the **potentiomete**r has been calibrated once, its working current is never changed.

Crompton's DC Potentiometer:

Modern **laboratory type potentiometers** use calibrated dial resistors and a small circular wire of one or more turns, thereby reducing the size of the instrument. The circuit of a simple laboratory type potentiometer is shown in the below figure. There is one dial switch with fifteen steps, each having a precision resistor. There is also a single turn circular slide wire. For the case shown, the resistance of slide wire is 10 Ω and the dial resistors have a value of 10 Ω each. Thus, the dial has a total resistance of 150 Ω and in addition, the slide wire has a resistance of 10 Ω. The working current of the potentiometer is 10 mA and therefore each step of dial switch corresponds to 0.1 V. The slide wire is provided with 200 scale divisions and since the total resistance of slide wire corresponds to a voltage drop of 0.1 V, each division of slide wire corresponds to 0.1/200 = 0.0005 V. It is quite comfortable to interpolate readings upto 1/5 of a scale division and therefore with this potentiometer it is possible to estimate the readings upto 0.0001 V.



This potentiometer is provided with a double throw switch which allows the connection of either the standard cell or the unknown emf to be applied to the working circuit. A key and a protective resistance (usually about 10 KΩ) is used in the galvanometer circuit. In order to operate the galvanometer at its maximum sensitivity provision is made to short the protective resistance when near the balance conditions.

The following steps are used when making measurements with the above potentiometer:

1. The combination of dial resistors and the slide wire is set to the standard cellvoltage.Supposing the value of emf of the standard cell is 1.0186 V, the dial resistors put at 1.0 V and the slide wire is put at 0.0186 setting.

2. The switch S is thrown to the calibrate position and the galvanometer key is tapped while the rheostat is adjusted for zero deflection on the galvanometer. The protective resistance is kept in the circuit in the initial stages so as to protect the galvanometer from being getting damaged.

3. As the balance or null point is approached, the protective resistance is shorted so as to increase the sensitivity of the galvanometer. Final adjustments are made for zero deflection with the help of the rheostat. This completes the **standardisation** process for the potentiometer.

4. After completion of standardisation, the switch 'S' is thrown to operate position thereby connecting the unknown emf into the potentiometer circuit. With the protective resistance in the circuit, the potentiometer is balanced by means of the main dial and the slide wire.

5. As the balance is approached, the protective resistance is shorted, and final adjustments are made to obtain true balance.

6. The value of unknown emf is read off directly from the settings of the dial adjust slide wire.

7.The standardisation of the potentiometer is checked again by returning the switch S to the calibrate position. The dial settings arc kept exactly the same as in the original standardisation process. If the new reading does not agree with the old one, the second measurement of unknown emf must be made. The standardisation should be again checked after the completion of the measurement. This potentiometer is a form of **Crompton's Potentiometer.**

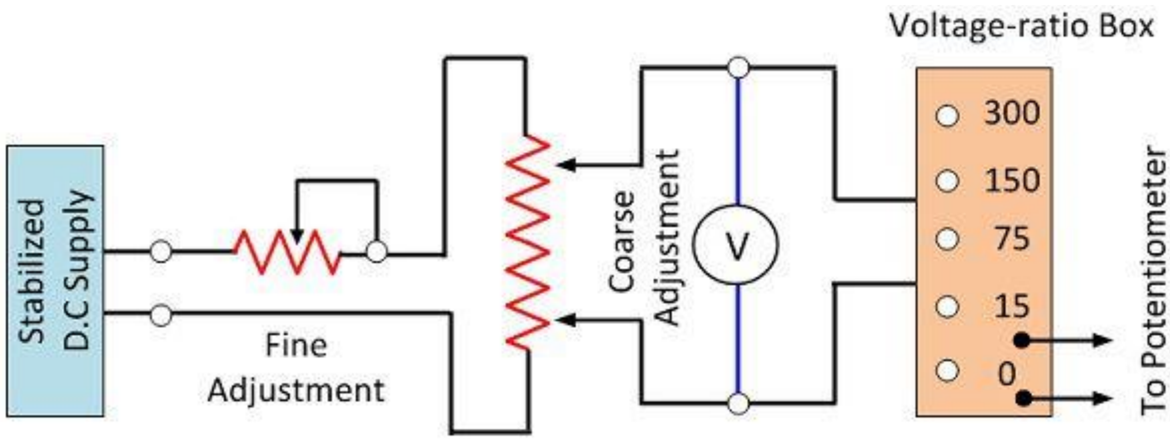
Applications of DC Potentiometer:

- Calibration of Ammeter
- Calibration of voltmeter
- Measurement of Power
- Measurement of Resistance
- Calibration of Wattmeter

The calibration is the process of checking the accuracy of the result by comparing it with the standard value. In other words, calibration checks the correctness of the instrument by comparing it with the reference standard. It helps us in determining the error occurs in the reading and adjusts the voltages for getting the ideal reading.

Calibration of Voltmeter

The circuit for the calibration of the voltmeter is shown in the figure below.



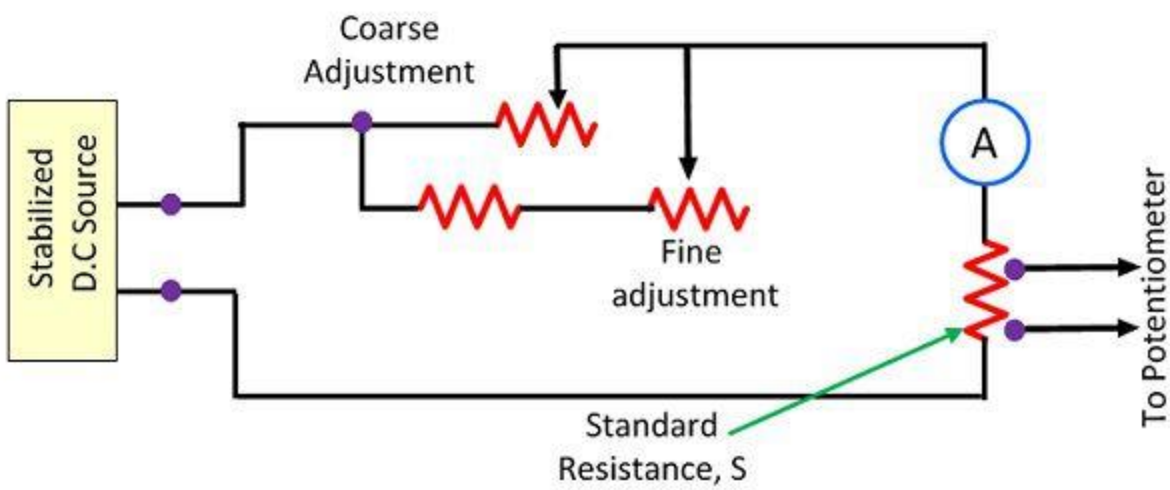
Calibration of Voltmeter with Potentiometer

The circuit requires two rheostats, one for controlling the voltage and another for adjustment. The voltage ratio box is used to step-down the voltage to a suitable value. The accurate value of the voltmeter is determined by measuring the value of the voltage to the maximum possible range of the potentiometer.

The potentiometer measures the maximum possible value of voltages. The negative and positive error occurs in the readings of the voltmeter if the readings of the potentiometer and the voltmeter are not equal.

Calibration of Ammeter

The figure below shows the circuit for the calibration of the ammeter.



Calibration of an ammeter with Potentiometer

The standard resistance is connected in series with the ammeter which is to be calibrated. The potentiometer is used for measuring the voltage across the standard resistor.

$$I = \frac{V_s}{S}$$

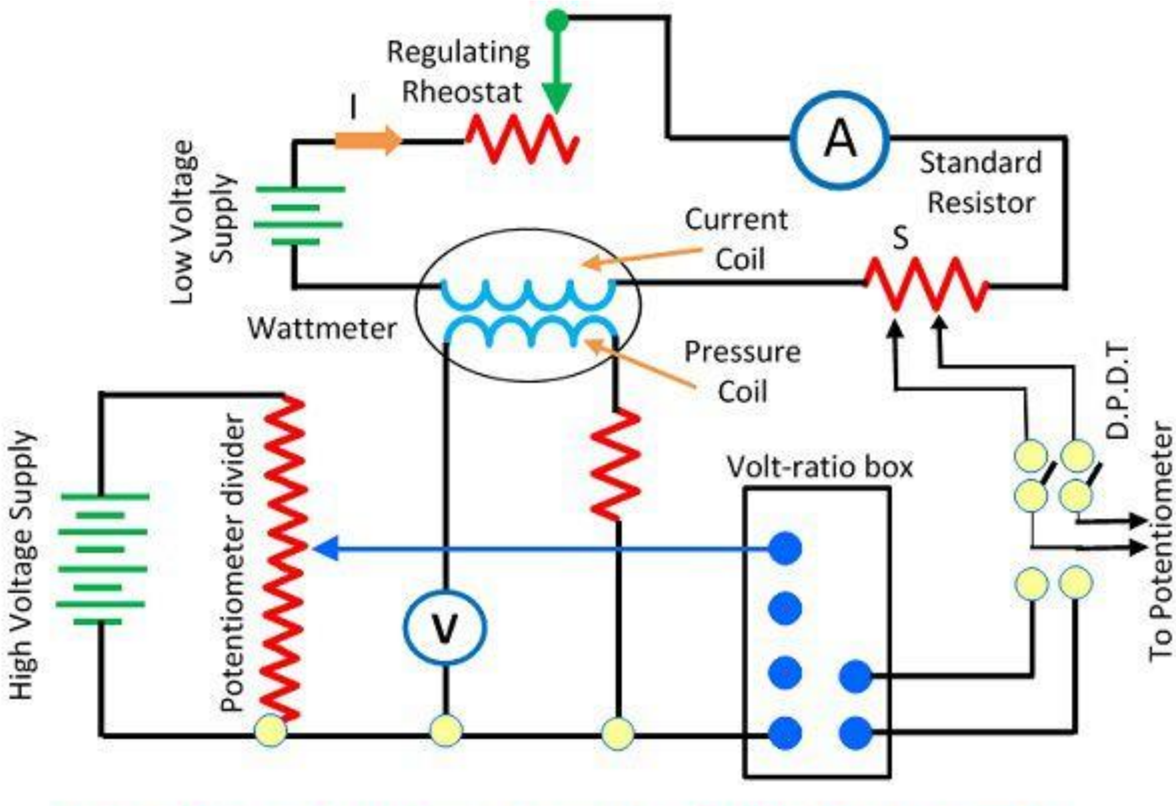
The above mention formula determines the current through the standard resistance.

Where,
V_s – voltage across the standard resistor as indicated by the potentiometer.
S – resistance of standard resistor

This method of calibration of the ammeter is very accurate because in this method the value of standard resistance and the voltage across the potentiometer is exactly known by the instrument.

Calibrating of Wattmeter

The figure below shows the circuit used for calibrating the Wattmeter.



Calibration of Wattmeter with a DC Pontentioemter

The standard resistance is connected in series with the Wattmeter which is to be calibrated. The low voltage supply is given to the current coil of the Wattmeter. The rheostat is connected in series with the coil for adjusting the value of current.

The potential circuit is supplied from the supply. The volt-ratio box is used to step-down the voltage so that the potentiometer can easily read the voltage. The actual value of the actual value of voltage and current is measured by using a double pole double throw switch. The accurate value VI and the value of Wattmeter are compared.

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.

Let understand this with the help of the circuit diagram. The R is the unknown resistance whose value is needed 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.

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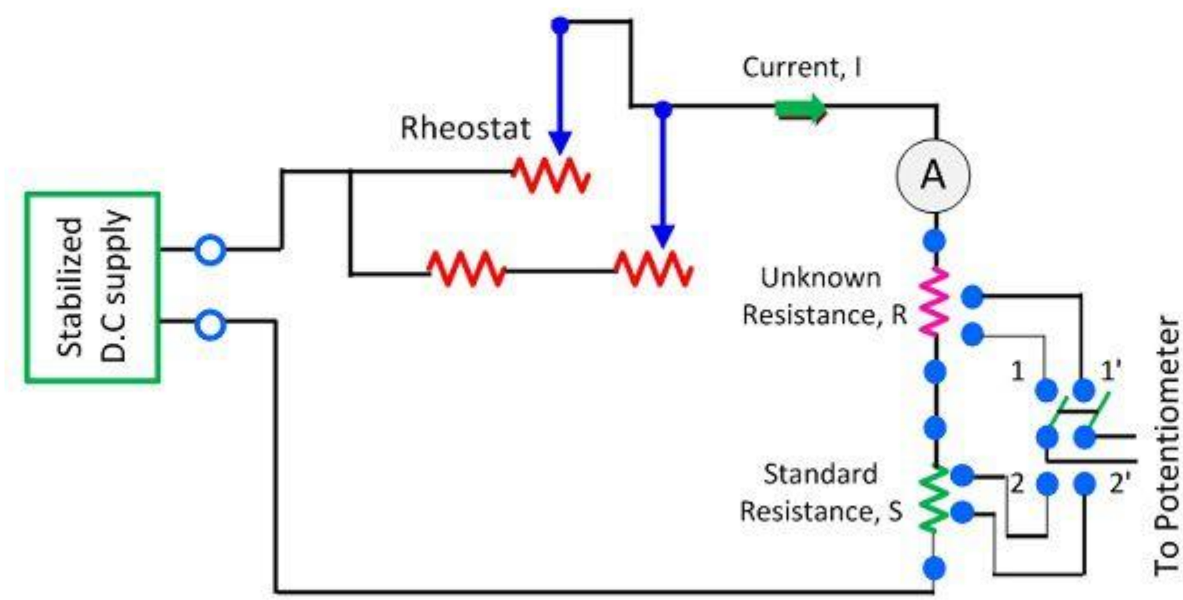

Measurement of Resistance with Potentiometer

The double pole double throw switch is used in the circuit. The switch, when moves 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 V_r

$$V_R = IR \quad \text{.........(1)}$$

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

$$V_S = IS \quad \text{.........(2)}$$

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 same, the circuit gives the accurate result. The ammeter is used in the circuit for determining the magnitude of current passing through resistor during the reading.

EMI: UNIT – IV

Bridges

Objectives:

1. To familiarize the students with measurement of low, medium and high resistances.
2. To familiarize the students with measurement of Inductance.
3. To familiarize the students with measurement of Capacitance.

Syllabus:

Methods of measuring low, medium and high resistance – Kelvin's double bridge, Wheat stone's bridge – loss of charge Method –Methods of measuring Inductance and Capacitance-Maxwell's bridges, Anderson's bridge-Schering bridge

Learning Outcomes:

After the completion of this unit, students will be to

i. Describe the principle and operation of various methods for measurement of low, medium and high resistance.
ii. Describe the operation of Maxwell's bridges, Anderson's bridge and Schering bridge for measurement of Inductance and Capacitance.

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UNIT – IV

Bridges

Kelvin Double Bridge

Before we introduce Kelvin Bridge, it is very essential to know what is the need of this bridge, though we have Wheatstone bridge which is capable of measuring electrical resistance accurately as it gives accuracy of 0.1 %. To understand the need of Kelvin bridge, let us categorize the **Electrical resistances on the basis of view point of measurement**:

Electrical resistances are classified as follows:

1. **High Resistance**: under this category resistance is greater than 0.1 Mega-ohm.
2. **Medium Resistance**: under this category resistance is ranging from 1 ohm to 0.1 Mega-ohm.
3. **Low Resistance**: under this category resistance value is lower than 1 ohm

Now the logic of doing this classification is that if we want to measure electrical resistance, we have to use different devices for different categories. It means if the device is used in measuring the high resistance gives high accuracy, it may or may not give such high accuracy in measuring the low value of resistance. So, we have to apply our brain to judge what device must be used to measure a particular value of electrical resistance. However there are other kind of methods also like ammeter-voltmeter method, substitution method etc but they give large error as compared to bridge method and are avoided in most of the industries. Now let us again recall our classification done above, as we move from top to bottom the value of resistance decreases hence, we require more accurate and precise device to measure the low value of resistance. One of the major drawback of the Wheatstone bridge is that, it can measure the resistance from few ohm to several mega ohm but to measure low resistance it gives significant error. So, we need some modification in Wheatstone bridge itself, and the modified bridge so obtained is Kelvin bridge, which is not only suitable for measuring low value of resistance but has wide range of applications in the industrial world.

Let us discuss few terms that will be very helpful to us in studying the Kelvin Bridge. Bridge:

They are usually consisting of four arms, balance detector and source. They work on the concept of null point technique. They are very useful in practical applications because there is no need of making the meter precise linear with an accurate scale. There is no requirement of measuring the voltage and current, the only need is to check the presence or absence of current or voltage. However, the main concern is that during the null point meter must be able to pick up fairly small current. A bridge can be defined as the voltage dividers in parallel and the difference between the two dividers is our output. It is highly useful in measuring components like electrical resistance, capacitance, inductor and other parameter of circuit. Accuracy of any bridge is directly related to bridge components.

Null point: It can be defined as the point at which the null measurement occurs when the reading of ammeter or voltmeter is zero.

Kelvin Bridge Circuit

As we have discussed that Kelvin Bridge is a modified Wheatstone bridge and provides high accuracy especially in the measurement of low resistance. Now the question that must be arise in our mind that where do we need the modification. The answer to this question is very simple, it is the portion of leads and contacts where we must do modification because of these there is an increment in net resistance. Let us consider the modified Wheatstone bridge or Kelvin bridge circuit given below:

Here, t is the resistance of the lead.

C is the unknown resistance.

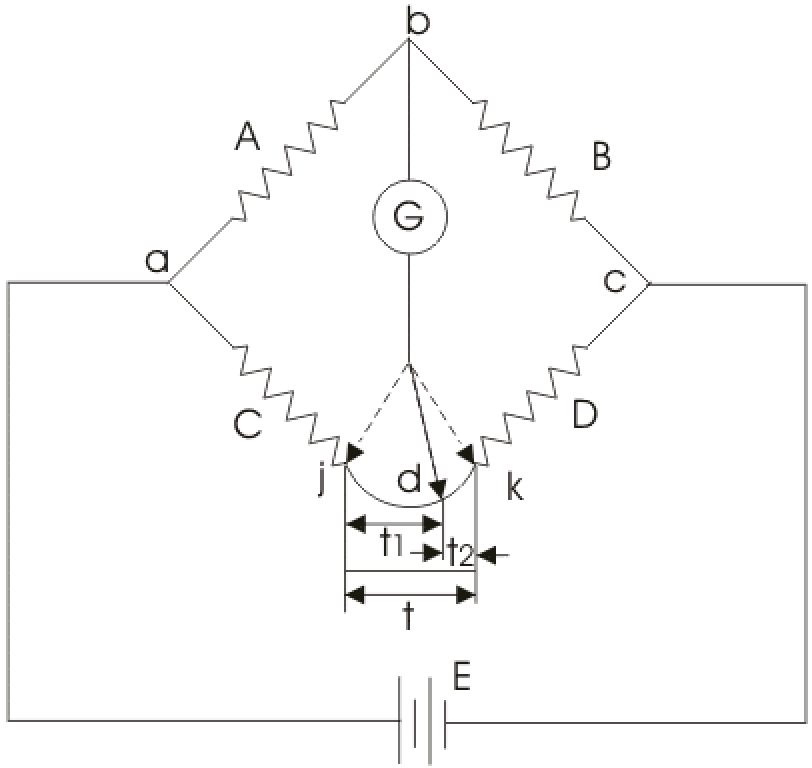
D is the standard resistance (whose value is known).

Let us mark the two points j and k. If the galvanometer is connected to j point the resistance t is added to D which

results in too low value of C. Now we connect galvanometer to k point it would result in high value of unknown resistance C.

Let us connect the galvanometer to point d which is lying in between j and k such that d divides t into ratio t1 and t2, now from the above figure it can be seen that

$$\frac{t_1}{t_2} = \frac{A}{B}$$



Then also the presence of t_1 causes no error, we can write.

$$C + t_1 = \frac{A}{B}(D + t_2)$$

$$Also\ we\ have\ \frac{t_1}{t_2} = \frac{A}{B} \cdots\cdots\cdots\cdots\cdots\cdots (1)$$

$$So,\ \frac{t_1}{t_1 + t_2} = \frac{A}{A + B} \Rightarrow t_1 = \frac{A}{A + B} \times t$$

$$As\ t_1 + t_2 = t\ and\ t_2 = \frac{B}{A + B} \times t$$

We can write equation (1) as

$$C + \frac{A}{A + B} \times t = \frac{A}{B} \times \left(D + \frac{B}{A + B} \times t\right)$$

$$It\ implies\ that\ C = \frac{A}{B} \times D$$

Thus we can conclude that there is no effect of t (i.e. resistance of leads). Practically it is impossible to have such situation however the above simple modification suggests that the galvanometer can be connected between these points j and k so as to obtain the null point.

Kelvin Double Bridge Circuit for Measurement of Low Resistance

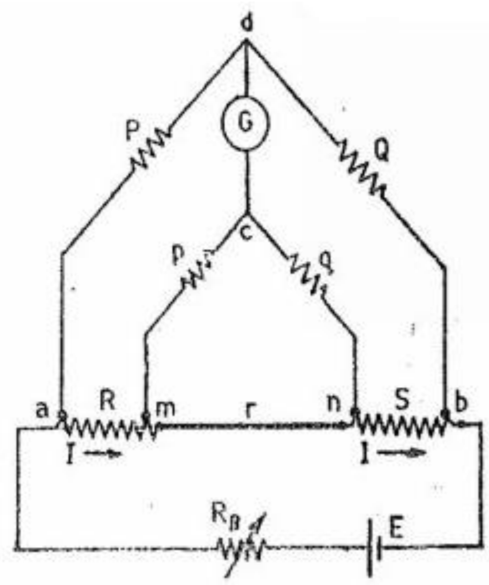
It is used for the measurement of low resistances. The Kelvin double bridge is the modification of the Wheatstone bridge and provides greatly increased accuracy in measurement of low value resistance.

An understanding of the Kelvin bridge arrangement may be obtained by the study of the difficulties that arise in a Wheatstone bridge on account of the resistance of the leads and the contact resistances while measuring low valued resistance.

The Kelvin double bridge incorporates the idea of a second set of ratio arms-hence the name double bridge-and the use of four terminal resistors for the low resistance arms.

Figure shows the schematic diagram of the Kelvin bridge. The first of ratio arms is P and Q. the second set of ratio arms, p and q is used to connect the galvanometer to a point d at the appropriate potential between points m and n to eliminate effect of connecting lead of resistance r between the unknown resistance, R, and the standard resistance, S.

The ratio p/q is made equal to P/Q. under balance conditions there is no current through the galvanometer, which means that the voltage drop between a and b, Eab is equal to the voltage drop Eamd.



Kelvin Double Bridge

Now the voltage drop between a and b is given by

$$E_{ab} = \frac{P}{P+Q} E_{ac}$$

Since,

$$E_{ac} = I\left[R + S + \frac{(p+q)r}{p+q+r}\right]$$

Put above value of E_{ac} in E_{ab}, we get,

$$E_{ab} = \frac{P}{P+Q} I\left[R + S + \frac{(p+q)r}{p+q+r}\right]$$

$$E_{amd} = I\left\{R + \frac{p}{p+q}\frac{(p+q)r}{p+q+r}\right\}$$

$$= I\left[R + \frac{pr}{p+q+r}\right]$$

$$E_{ab} = E_{amd}$$

$$\frac{P}{P+Q} I\left[R + S + \frac{(p+q)r}{p+q+r}\right] = I\left[R + \frac{pr}{p+q+r}\right]$$

$$R = \frac{P}{Q}S + \frac{qr}{p+q+r}\left[\frac{P}{Q} - \frac{p}{q}\right]$$

If

$$\frac{P}{Q} = \frac{p}{q}$$

$$R = \frac{P}{Q}S$$

Above equation is the usual working equation for the Kelvin Double Bridge. It indicates that the resistance of connecting lead, r, has no effect on the measurement, provided that the two sets of ratio arms have equal ratio. The former equation is useful, however, as it shows the error that is introduced in case the ratios are not exactly equal. It indicates that it is desirable to keep r as small as possible in order to minimize the errors in case there is a difference between ratios P/Q and p/q.

Measurement of Medium Resistance by Wheatstone Bridge Method &Sensitivity of Wheatstone bridge

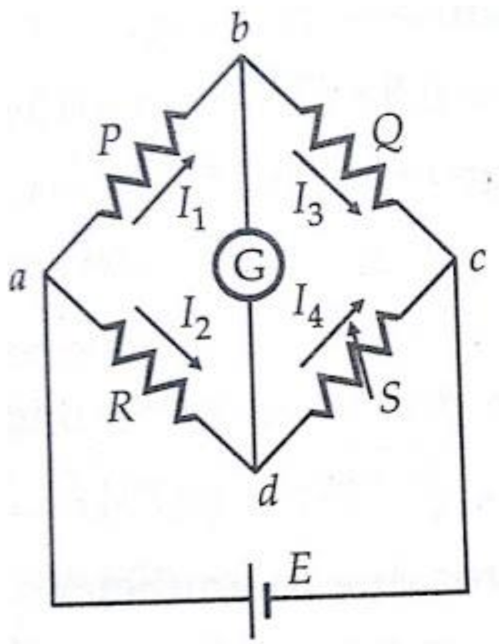
Wheatstone bridge is a very important device used in the measurement of mediumresistances .A Wheatstone bridge has been in use longer than almost, any electrical measuring instrument.It is still an accurate and reliable instrument and is extensively used in industry.Wheatstone bridge is an instrument for making comparison measurements and operates upon a null indication principle. This means the indication is independent of the calibration of the null indicating instrument or any of its characteristics.For this reason, very high degrees of accuracy can be achieved using Wheatstone bridge.The accuracy of 0.1% is quite common with a Wheatstone bridge as opposed to accuracies of 3% to 5% with the ordinary ohmmeter for measurement of medium resistances.

The figure below shows the basic circuit of a **Wheatstone bridge**. It has four resistive arms, consisting of resistances P, Q R and S together with a source of emf (a battery) and a null detector, usually a galvanometer G or other sensitive current meter. The current through the galvanometer depends on the potential difference between points c and d. The bridge is said to be balanced when there is no current through the galvanometer or when the potential difference across galvanometer is zero. This occurs when the voltage from point b to point a equals the voltage from point d to point b or by referring to the other battery terminal, when the voltage from point d to point c equals the voltage from point b to point c.

For balanced condition, we can write,

$$I_1 P = I_2 R$$

The figure below shows the circuit for Wheatstone bridge for the **measurement of medium resistance.**



For the galvanometer current to be zero,the following conditions also exist:

$$I_1 = I_3 = \frac{E}{P+Q}$$

$$I_2 = I_4 = \frac{E}{R+S}$$

Where E=emf of the battery

Combining above three equations we get ,

$$\frac{P}{P+Q} = \frac{R}{R+S}$$

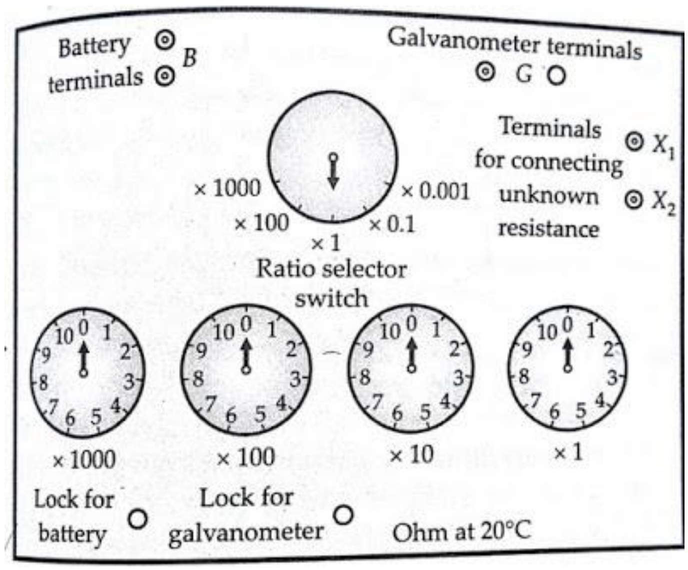
from which **Q.R = P.S --->(4)**

Equation-4 is the well-known expression for the balance of **Wheatstone bridge**. If three of theresistances are known, the fourth may be determined from equation-4 and we obtain

R = S*(P/Q)

where R is the unknown resistance, S is called the 'standard arm' of the bridge and P and Q are called the 'ratio arms'.

In the industrial and laboratory form of the bridge, the resistors which make up P, Q and S are mounted together in a box, the appropriate values being selected by dial switches.Battery and galvanometer switches are included together with a galvanometer and dry battery in the portable sets. P and Q normally consist of four resistors each, the values being 10,100,100 and 10,000Ω respectively S that decade arrangement of resistors.The below figure shows the commercial form of Wheatstone bridge for the **measurement of medium resistance.**



Sensitivity of Wheatstone Bridge:

It is frequently desirable to know the galvanometer response to be expected in a bridge which is slightly unbalanced so that a current flows in the galvanometer branch of the bridge network.This may be used for

(i)selecting a galvanometer with which a given unbalance may be observed in a specified bridge arrangement,

(ii) determining the minimum unbalance which can be observed with a given galvanometer in the specified bridge arrangement, and

(iii) Determining the deflection to be expected for a given unbalance.

The sensitivity to unbalance can be computed by solving the bridge circuit for a small unbalance.The solution is approached by converting the **Wheatstone bridge** of figure above to its "Thevenin Equivalent" circuit.Assume that the bridge is balanced when the branch resistancesare P, Q, R, S so that P / Q = R / S. Suppose the resistance R is changed to

R+ΔR creating an unbalance. This will cause an emf 'e' to appear across the galvanometer branch. With galvanometer branch open, the voltage drop between points a and b is :

$$E_{ab} = I_1 P = \frac{EP}{P+Q}$$

Similarly, $E_{ad} = I_2(R+\Delta R) = \dfrac{E(R+\Delta R)}{R+\Delta R+S}$

Therefore voltage difference between points *d* and *b* is :

$$e = E_{ad} - E_{ab} = E\left[\frac{R+\Delta R}{R+\Delta R+S} - \frac{P}{P+Q}\right]$$

and since $\dfrac{P}{P+Q} = \dfrac{R}{R+S}$

$$\therefore \qquad e = E\left[\frac{R+\Delta R}{R+\Delta R+S} - \frac{P}{P+S}\right]$$

$$= \frac{ES\Delta R}{(R+S)^2 + \Delta R(R+S)}$$

$$\approx \frac{ES\Delta R}{(R+S)^2}$$

as $\quad \Delta R(R+S) << (R+S)^2$

Let S_v be the voltage sensitivity of galvanometer.

Therefore, deflection of galvanometer is

$$\theta = S_v e = S_v \frac{ES\Delta R}{(R+S)^2}$$

The bridge sensitivity is defined as the deflection of the galvanometer per unitfractional change in unknown resistance.

Sensitivity of Wheatstone bridge

$$S_B = \frac{\theta}{\Delta R / R}$$

$$= \frac{S_v ESR}{(R+S)^2}$$

From the above equation, it is clear that the sensitivity of Wheatstone bridge is dependent upon bridge voltage, bridge parameters and the voltage sensitivity of the galvanometer.Rearranging the terms in the expression for sensitivity**,**

$$S_B = \frac{S_v E}{(R+S)^2/SR} = \frac{S_v E}{\frac{R}{S}+2+\frac{S}{R}}$$
$$= \frac{S_v E}{\frac{P}{Q}+2+\frac{Q}{P}}$$

From the above equation, it is apparent that maximum sensitivity occurs where R / S = 1.As the ratio becomes either larger or smaller, the sensitivity decreases. Since the accuracy of measurement is dependent upon sensitivity a limit can be seen to the usefulness for a given bridge, battery and galvanometer combination.

For a bridge with equal arms, R=S=P=Q**.**

Bridge sensitivity, SB = (SV. E)/4

As explained above the **sensitivity of Wheatstone bridge** is maximum when the ratio is unity. The sensitivity with ratio P/Q = R/S = 1000 would be about 1/250 of that for unity ratio. The sensitivity with P/Q=R/S=1000 would similarly be about 1/250 of that for unity ratio.

Thus the sensitivity decreases considerably if the ratio P / Q = R / S is greater or smaller than unity. This reduction in sensitivity is accompanied by a reduction in accuracy with which a bridge can be balanced.

Galvanometer Current :

The current through the galvanometer can be found out by finding the Thevenin equivalent circuit.The Thevenin or open circuit voltage appearing between terminals b and d with galvanometer circuit open circuited is,

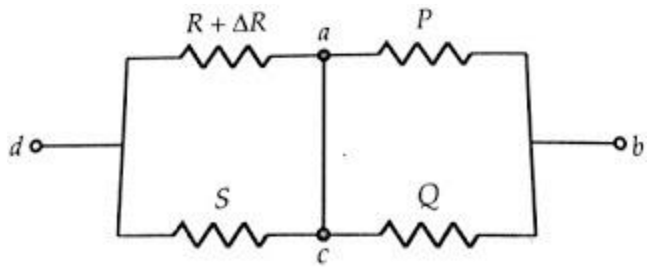
$$E_0 = E_{ad} - E_{ac} = I_2(R+\Delta R) - I_1 P$$
$$= \frac{E(R+\Delta R)}{R+\Delta R+S} - \frac{EP}{P+Q}$$
$$= E\left[\frac{R+\Delta R}{R+\Delta R+S} - \frac{P}{P+Q}\right]$$

$$E_0 = E\left[\frac{R+\Delta R}{R+\Delta R+R} - \frac{R}{R+R}\right]$$

$$= E\left[\frac{R+\Delta R}{2R+\Delta R} - \frac{1}{2}\right]$$

$$\approx E\left(\frac{AR}{4R}\right) \text{ as } \Delta R << R.$$

The resistance of the Thevenin equivalent circuit is found by looking back into terminal c and d and replacing the battery by its internal resistance. In most cases, however, the extremely lowresistance of the battery can be neglected and this simplifies the solution as we can assume that terminals a and b are shorted. The Thevenin equivalent resistance can be calculated by referring to the below figure.



Thevenin equivalent resistance of bridge ,

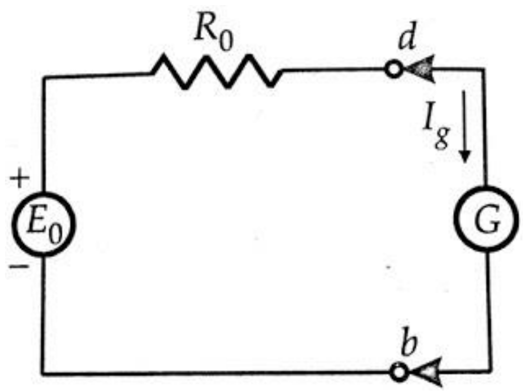
$$R_0 = \frac{R.S}{R+S} + \frac{P.Q}{P+Q}$$

For a bridge with equal arms,

P = Q = S = R

R0 =R

The Thevenin equivalent of the bridge circuit, therefore, reduces to a Thevenin generator with an emf E0 and an internal resistance R0.Thevenin equivalent circuit of Wheatstone Bridge is shown below.



The current in the galvanometer circuit ,

Ig = E0/(R0 + G)

Where G = resistance of the galvanometer circuit,

For a bridge with equal arms,

$$I_g = \frac{E(\Delta R / 4R)}{(R + G)}$$

The deflection of the galvanometer for a small change in resistance in the unknown arm is,

$$\theta = \frac{S_v \, E S \Delta R}{(R + S)^2}$$

But $\qquad S_v = \dfrac{S_i}{R_0 + G}$

where S_i = current sensitivity of the galvanometer.

$$\therefore \qquad \theta = \frac{S_i \, E S \Delta R}{(R_0 + G)(R + S)^2}$$

For a bridge with equal arms,

$$\theta = \frac{S_i \, E \Delta R}{4R(R + G)}$$

Also bridge sensitivity,

$$S_B = \frac{\theta}{\Delta R / R} = \frac{S_i \, E S R}{(R_0 + G)(R + S)^2}$$

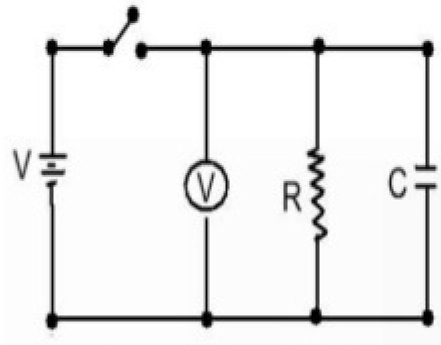
For a bridge with equal arms,

Bridge sensitivity,

$$S_B = \frac{S_i E}{4(R + G)}$$

Measurement of high resistance by Loss of charge method

In '**Loss of charge method**', the insulationresistance 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

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

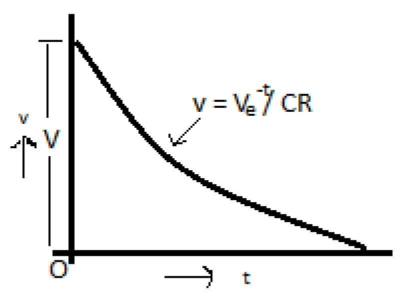
or $V/ v = \exp(-t/ CR)$

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:



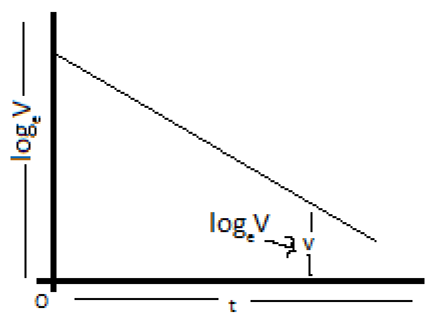
From the equation above , it follows that if V,v,C and t are known then value of R can be computed.

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 voltages 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

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

This change in voltage may be measured by a galvanometer.

However, from the experimental point of view, it may be advisable to determine the time t from the discharge curve of the capacitor by plotting a curve of log v against time t .This curve is linear as shown in the figure below and thus the determination of time t from this curve for the voltage to fall from V to v yields more accurate results.



This measurement of resistance by loss of charge method is applicable to some high resistances, but it requires a capacitor of a very high leakage resistance as high as the resistance being measured.The method is very attractive if the resistance being measured is the leakage resistance of a capacitor as in this case auxiliary R and C units are not required.

Actually, in this loss of charge method, we do not measure the true value of resistance since we assume here that the value of resistance of electrostatic voltmeter and the leakage resistance of the capacitor have infinite value. But in practice corrections must be applied to take into consideration the above two resistances.The figure below shows the actual circuit of loss of charge method measuring high resistance where R1 represents the leakage resistance of the capacitor. Then if R' is the resistance of R1 and R in parallel the discharge equation for capacitance gives

$$R' = \frac{0.4343\ t}{C\ log_{10}\frac{V}{v}}$$

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.

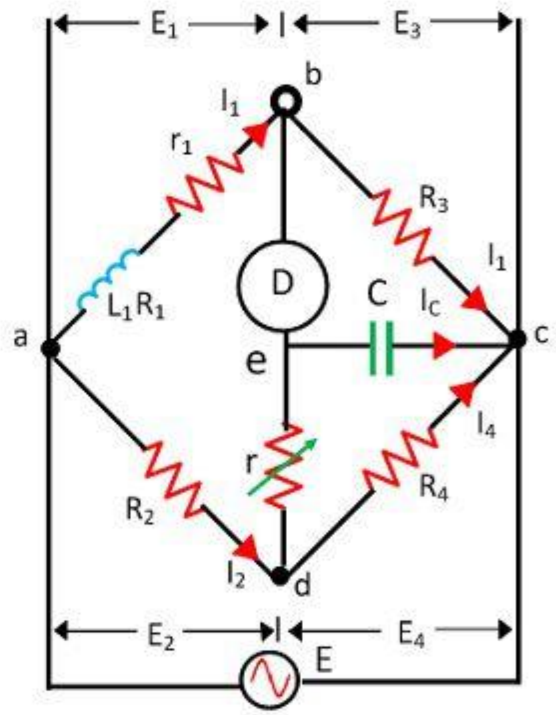
The leakage resistance of the voltmeter, unless very high should also be taken into consideration.

Anderson's Bridge

The Anderson's bridge gives the accurate measurement of self-inductance of the circuit. The bridge is the advanced form of Maxwell's inductance capacitance bridge. In Anderson bridge, the unknown inductance is compared with the standard fixed capacitance which is connected between the two arms of the bridge.

Constructions of Anderson's Bridge

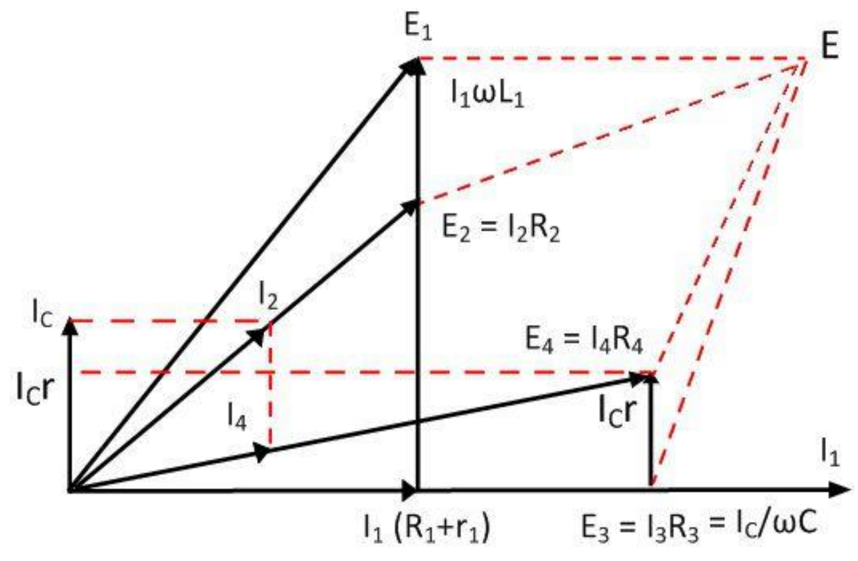
The bridge has fours arms **ab, bc, cd,** and **ad.** The arm **ab** consists unknown inductance along with the resistance. And the other three arms consist the purely resistive arms connected in series with the circuit. The static capacitor and the variable resistor are connected in series and placed in parallel with the **cd** arm. The voltage source is applied to the terminal a and c.



Anderson's Bridge

Phasor Diagram of Anderson's Bridge

The phasor diagram of the Anderson bridge is shown in the figure below. The current $\mathbf{I_1}$ and the $\mathbf{E_3}$ are in phase and represented on the horizontal axis. When the bridge is in balance condition the voltage across the arm **bc** and **ec** are equal.



Anderson's Bridge

The current enters into the bridge is divided into the two parts $\mathbf{I_1}$ and $\mathbf{I_2}$. The $\mathbf{I_1}$ is entered into the arm **ab** and causes the voltage drop $\mathbf{I_1(R_1+R)}$ which is in phase with the $\mathbf{I_1}$. As the bridge is in the balanced condition, the same current is passed through the arms bc and **ec.**

The voltage drop $\mathbf{E_4}$ is equal to the sum of the $\mathbf{I_C/\omega C}$ and the $\mathbf{I_C\,r}$. The current $\mathbf{I_4}$ and the voltage $\mathbf{E_4}$ are in the same phase and representing on the same line of the phasor diagram. The sum of the current $\mathbf{I_C}$ and $\mathbf{I_4}$ will give rise to the current $\mathbf{I_2}$ in the arm **ad.**

When the bridge is at balance condition the emf across the arm **ab** and the point **a, d** and **e** are equal. The phasor sum of the voltage across the arms **ac** and **de** will give rise the voltage drops across the arm **ab**.

The $\mathbf{V_1}$ is also obtained by adding the $\mathbf{I_1(R_1+r_1)}$ with the voltage drop $\mathbf{\omega I_1 L_1}$ in the arm **AB**. The phasor sum of the $\mathbf{E_1}$ and $\mathbf{E_3}$ or $\mathbf{E_2}$ and $\mathbf{E_4}$ will give the supply voltage.

Theory of Anderson Bridge

Let, L_1 – unknown inductance having a resistance R_1.

R_2, R_3, R_4 – known non-inductive resistance

C_4 – standard capacitor

At balance Condition, $I_1 = I_3 \; and \; I_2 = I_C + I_4$

$$I_1 R_3 = I_C \times \frac{1}{j\omega C}$$

Now, $I_C = I_1 \omega C R_3$

The other balance condition equation is expressed as

$$I_1(r_1 + R_1 + j\omega L_1) = I_2 R_2 + I_C r$$

$$I_c\left(r + \frac{1}{j\omega C}\right) = (I_2 - I_C)R_4$$

By substituting the value of I_c in the above equation we get,

$$I_1(r_1 + R_1 + j\omega L_1) = I_2 R_2 + I_1 j\omega C R_3 r$$

$$I_1(r_1 + R_1 + j\omega L_1 - j\omega C R_3 r) = I_2 R_2$$

and $I_1(R_3 + j\omega R_3 R_4 + j\omega C R_3 r) = I_2 R_4$

on equating the equation, we get

$$I_1(r_1 + R_1 + j\omega L_1 - j\omega C R_3 r) = I_1(\frac{R_1 R_2}{R_3} + \frac{j\omega C R_3 r R_2}{R_4} + j\omega C R_3 R_2)$$

Equating the real and the imaginary part, we get

$$R_1 = \frac{R_1 R_3}{R_4} - r_1$$

$$L_1 = C\frac{R_3}{R_4}[4(R_4 + R_2) + R_2 R_4]$$

Advantages of Anderson Bridge

The following are the advantages of the Anderson's Bridge.

1. The balance point is easily obtained on the Anderson bridge as compared to Maxwell's inductance capacitance bridge.
2. The bridge uses fixed capacitor because of which accurate reading is obtained.
3. The bridge measures the accurate capacitances in terms of inductances.

Disadvantages of Anderson Bridge

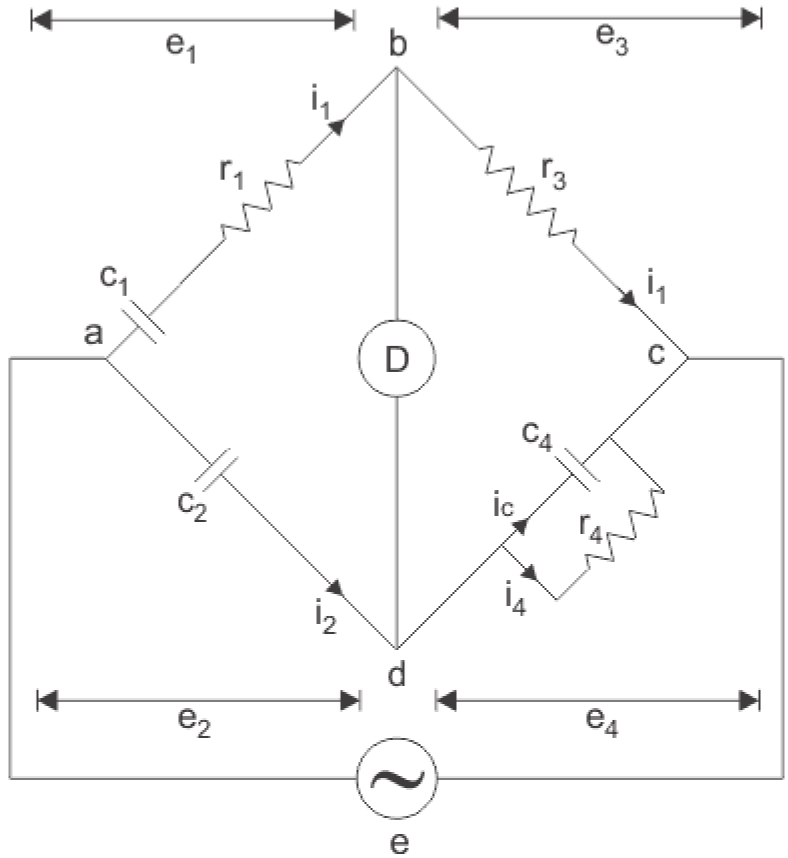
The main disadvantages of Anderson's bridge are as follow.

1. The circuit has more arms which make it more complex as compared to Maxwell's bridge. The equation of the bridge is also more complex.
2. The bridge has an additional junction which arises the difficulty in shielding the bridge.

Because of the above-mentioned disadvantages, Maxwell's inductance capacitance bridge is used in the circuit.

Schering Bridge

This bridge is used to measure to the capacitance of the capacitor, dissipation factor and measurement of relative permittivity. Let us consider the circuit of **Schering bridge** as shown below:



Here, c_1 is the unknown capacitance whose value is to be determined with series electrical resistance r_1.

c_2 is a standard capacitor.

c_4 is a variable capacitor.

r_3 is a pure resistor (i.e. non inductive in nature).

And r_4 is a variable non inductive resistor connected in parallel with variable capacitor c_4.

Now the supply is given to the bridge between the points a and c. The detector is connected between b and d. From the theory of ac bridges we have at balance condition,

$$z_1 * z_4 = z_2 * z_3$$

Substituting the values of z_1, z_2, z_3 and z_4 in the above equation, we get

$$\left(r_1 + \frac{1}{j\omega c_1}\right)\left(\frac{r_4}{1 + j\omega c_4 r_4}\right) = \frac{r_3}{j\omega c_2}$$

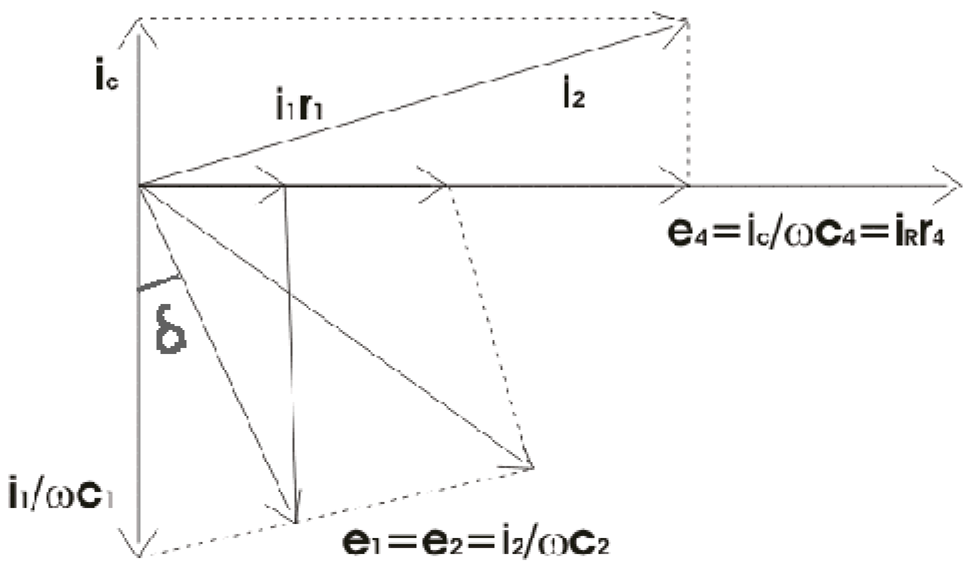
$$(r_1 + \frac{1}{j\omega c_1})r_4 = \frac{r_3}{j\omega c_2}(1 + j\omega c_4 r_4)$$

$$r_1 r_4 - \frac{jr_4}{\omega c_1} = -\frac{jr_3}{\omega c_2} + \frac{r_3 r_4 c_4}{c_2}$$

Equating the real and imaginary parts and the separating we get,

$$r_1 = \frac{r_3 c_4}{c_2}$$

$$c_1 = c_2 \frac{r_4}{r_3}$$



Let us consider the phasor diagram of the above Shearing bridge circuit and mark the voltage drops across ab,bc,cd and ad as e_1, e_3,e_4 and e_2 respectively. From the above Schering bridge phasor diagram, we can calculate the value of tanδ which is also called the dissipation factor.

$$tan\delta = \omega c_1 r_1 = \omega \frac{c_2 r_4}{r3} \times \frac{r_3 c_4}{c_2} = \omega c_4 r_4$$

Maxwell's Bridge

The bridge used for the measurement of self-inductance of the circuit is known as the Maxwell bridge. It is the advanced form of the Wheatstone bridge. The Maxwell bridge works on the principle of the comparison, i.e., the value of unknown inductance is determined by comparing it with the known value or standard value.

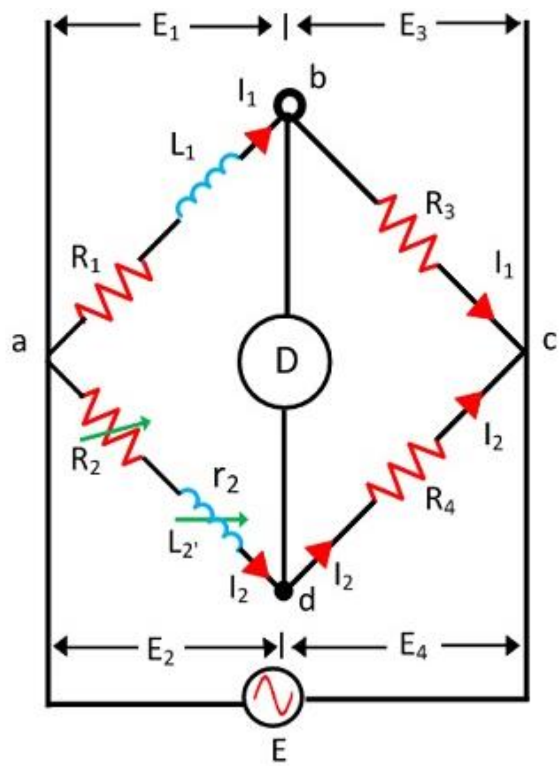
Types of Maxwell's Bridge

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

In such type of bridges, the value of unknown resistance is determined by comparing it with the known value of the standard self-inductance. The connection diagram for the balance Maxwell bridge is shown in the figure below.



Maxwell's Inductance Bridge

Let, L_1 – unknown inductance of resistance R_1.

L_2 – Variable inductance of fixed resistance r_1.

R_2 – variable resistance connected in series with inductor L_2.

R_3, R_4 – known non-inductance resistance

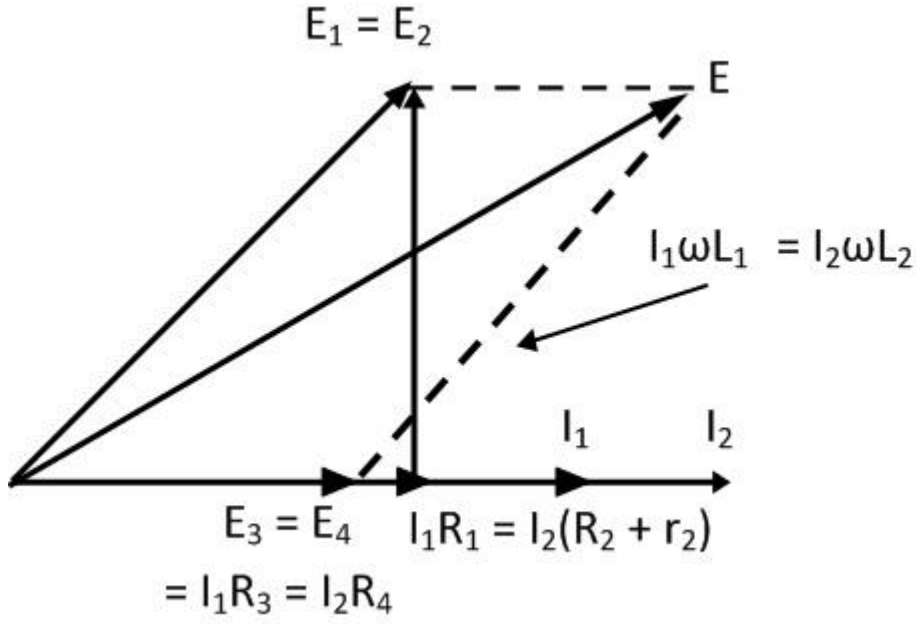
At balance,

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

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

The value of the R_3 and the R_4 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.

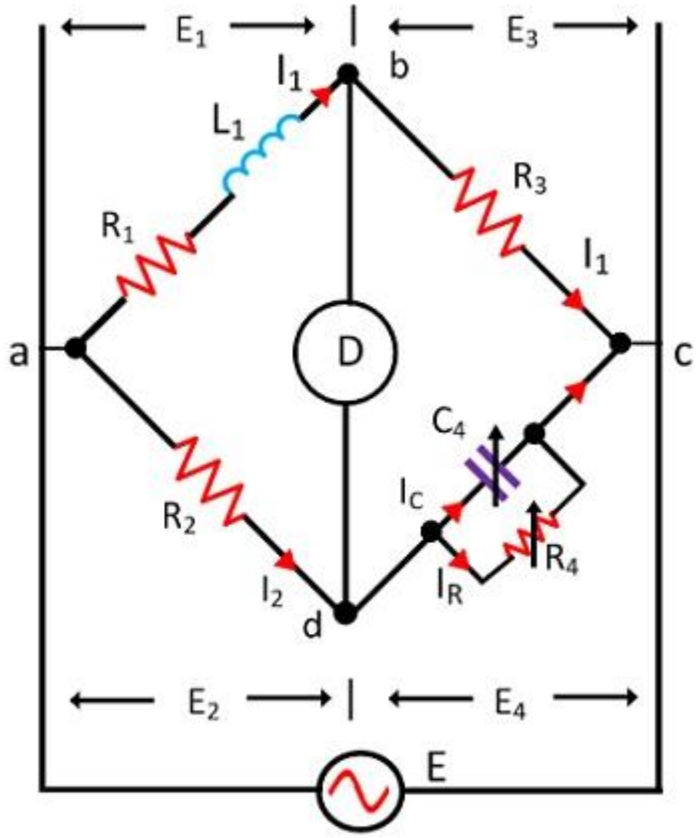
The phasor diagram of Maxwell's inductance bridge is shown in the figure below.



Phasor Diagram of Maxewell Inductance Bridge

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.



Maxewell's Inductance Capacitance Bridge

Let, L_1 – unknown inductance of resistance R_1.

R_1 – Variable inductance of fixed resistance r_1.

R_2, R_3, R_4 – variable resistance connected in series with inductor L_2.

C_4 – known non-inductance resistance

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

$$R_1 R_4 = j\omega L_1 R_4 = R_2 R_3 + j\omega C_4 R_4 R_2 R_3$$

For balance condition,

By separating the real and imaginary equation we get,

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

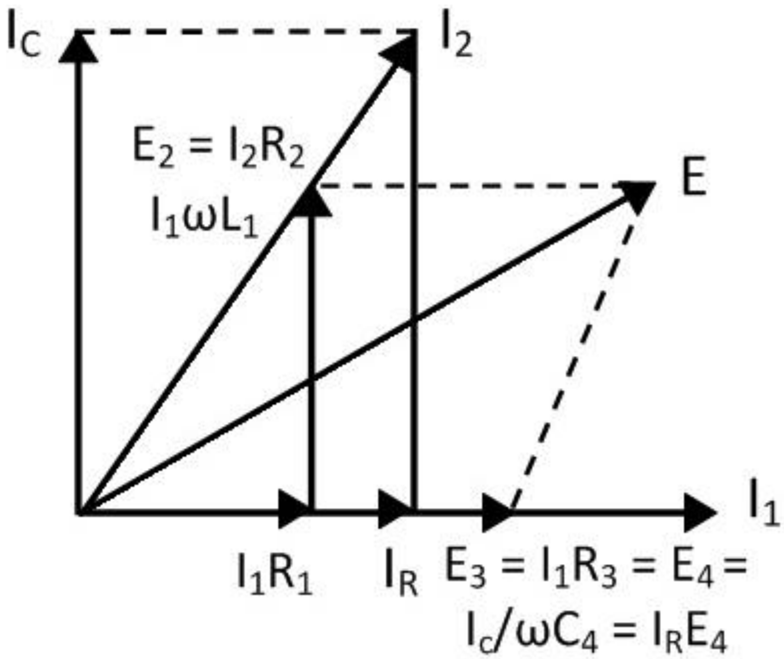
$$L_1 = R_2 R_3 C_4$$

The above equation shows that the bridges have two variables R_4 and C_4 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 of Inductance Capacitance Bridge

Advantages of the Maxwell's Bridges

The following are the advantages of the Maxwell bridges

1. The balance equation of the circuit is free from frequency.
2. Both the balance equations are independent of each other.
3. The Maxwell's inductor capacitance bridge is used for the measurement of the high range inductance.

Disadvantages of the Maxwell's Bridge

The main disadvantages of the bridges are

1. The Maxwell inductor capacitance bridge requires a variable capacitor which is very expensive. Thus, sometimes the standard variable capacitor is used in the bridges.
2. The bridge is only used for the measurement of medium quality coils.

A. Questions testing the remembering / understanding level of students

I) Objective Questions

1. A potentiometer may be used for [ ]

a) Measurement of resistance b) Measurement of current

c) Calibration of ammeter & calibration of voltmeter d) All of the above

2. __________is an instrument which measures the insulation resistance of an electric circuit relative to earth and one another, [ ]

a) Tangent galvanometer b) Meggar

c) Current transformer d) none of the above

3. Measurement of an unknown voltage with a dc potentiometer loses its advantage of open circuit measurement when [ ]

(A) The primary circuit battery is changed

(B) Standardization has to be done again to compensate for drifts

(C) Voltage is larger than the range of the potentiometer

(D) Range reduction by a factor of 10 is employed

4. Match List-I (Properties of Standard Resistance Materials) with ListII (Resistance Quality) and select the correct answer using the codes given below the lists:

List-I List-II

a. High resistivity	1. Low measuring error
b. Small temperature coefficient	2. Small change of resistance due to ageing
c. Permanence with time	3. Resists oxidation and corrosion
d. Low thermo-electric e.m.f with copper	4. Low resistance change with temperature
	5. Small size of resistor

Codes:	a	b	c	d
(A)	2	4	3	1
(B)	2	1	3	4
(C)	5	1	2	4
(D)	5	4	2	1

5. For low resistance (from few micro ohms to one ohm) measurement, which bridge is used?

(A) Wheatstone bridge (B) Kelvin bridge [ ]

(C) Guarded Wheatstone bridge (D) Maxwell bridge

6. The materials to be used in the manufacture of a standard resistance should be of [ ]

(A) High resistivity and low temperature coefficient (B) low resistivity

(C) High temperature coefficient (D) low resistivity and high temperature coefficient

7. Which one of the following is measured by the loss of charge method ? [ ]

(A) Low R (B) High R (C) Low L (D) High L

8. A potentiometer is basically a [ ]

a) deflection type instrument b) null type instrument

c) deflection as well as null type instrument d) a digital instrument

II) Descriptive Questions

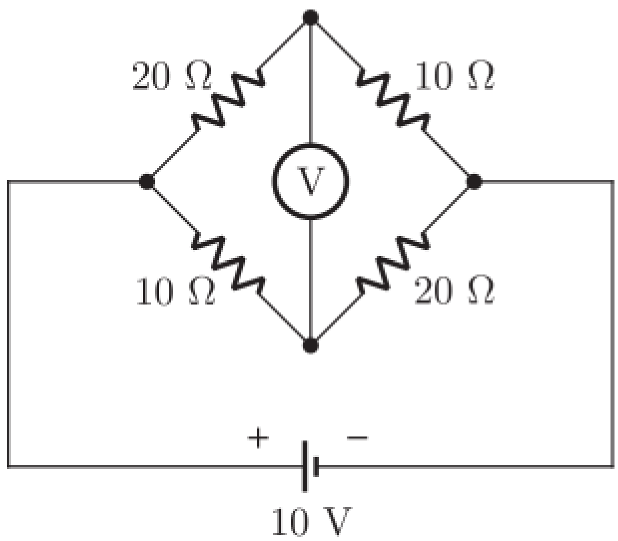
1. Draw the connection diagram of Crompton potentiometer? How it is standardized?
2. Describe the loss of charge method for measurement of high resistance.
3. Explain how the Crompton's potentiometer can be used for the measurement ofunknown resistance and current
4. Explain the working of Kelvin's double bridge and derive the equation for its balance condition.
5. Derive the expression for bridge sensitivity for a wheat stone bridge with equal arms. Find also expression for current through the galvanometer for a small unbalance

6. Describe the salient features of Crompton's d.c. potentiometer. How the d.c. ammeter is calibrated using direct reading of this d.c. potentiometer
7. what are the limitations of wheat stone's bridge?
8. Write a short note on the following Calibration of wattmeter using potentiometer.

B. Question testing the ability of students in applying the concepts.

I) Multiple Choice Questions:

1. The reading of high impedance voltmeter V in the bridge circuit shown in the given figure is
(A) zero (B) 3.33 V (C) 4.20 V (D) 6.66 V [ ]



2. A single slide wire is used for the measurement of current in a circuit. The voltage drop across a standard resistance of 1.0 Ω is balanced at 70 cm. What is the magnitude of the current, if the standard cell having an e.m.f of 1.45 volts is balanced at 50 cm? [ ]
(A) 3.09 A (B) 2.65 A (C) 2.03 A (D) 1.45 A

3. A Wheatstone bridge has ratio arms of 1000 Ω and 100 Ω resistances, the standard resistance arms consists 4decade resistance boxes of 1000,100,10,1 Ω steps. The maximum and minimum values of unknown resistance which can be determined with this set up is [ ]
a) 111100 Ω, 1 Ω b) 11110 Ω, 10 Ω c) 111100 Ω, 10 Ω d) 111000 Ω, 1 Ω

4. A Crompton's potentiometeris provided with a dial resistor having 15steps of10Ω each and a slide wire of 10Ω resistance. The slidewire is divided into 100divisions and one fifth of a division can be read with certainly. The working current of potentiometer is 10mA. The range and resolution of the potentiometer are respectively [ ]
a) 1.6V,0.2mV b) 1.6V,0.5mV c) 1.5V,0.1mV d) 1.6V,0.1mV

5. Match List-I (Bridges) with List-II (Parameters) and select the correct answer using the codes given below the lists: [ ]

List-I **List-II**

a. Anderson bridge	1. Low Resistance
b. Kelvin Bridge	2. Medium Resistance
c. Schering Bridge	3. Inductance
d. Wheatstone Bridge	4. Capacitance

Codes:	a	b	c	d
(A)	4	2	3	1
(B)	3	2	4	1
(C)	3	1	4	2
(D)	4	1	3	2

6. When a potentiometer is used for measurement of voltage of unknown source, the power consumed in the circuit of the unknown source under null conditions [ ]

a) is very High b) is High c) is Small d) is ideally Zero

7. To measure a resistance with the help of a potentiometer it is [ ]

A) Necessary to standardize the potentiometer

B) Not necessary to standardize the potentiometer

C) Necessary to use a volt ratio box in conjunction with the potentiometer

D) None of the above

II) Problems:

1. The four arms of Wheatstone bride are as follows: AB = 100Ω, BC = 1000 Ω, CD =4000 Ω and DA = 400 Ω. The galvanometer has resistance of 100 Ω at sensitivity of 100mm/μA and connected across AC. A source of 4V d.c. is connected across BD. Calculatethe current through the galvanometer and its deflection, if the resistance of arm DA ischanged from 400 to 401.

2.A Kelvin's double bridge having the ratio arm P = Q = p = q = 1000 Ω. The emf ofbattery is 100 V and resistance of 5 Ω including battery circuit. The galvanometer hasresistance of 500 Ω and the resistance of the link connecting the unknown resistance tostandard resistance may be neglected, the bridge is balanced when the standardresistance S = 0.001 Ω. Determine the value of unknown resistance.

3. A 4-terminal resistance of approximately 50 μΩ is measured using Kelvin's doublebridge with component resistances as given below:

Standard resistor = 100.03 μΩ

Inner ratio arms = 100.31 Ω and 200 Ω

Outer ratio arms = 100.24 Ω and 200 Ω

Value of low resistance link = 700 μΩ

Find the unknown resistance to the nearest of 0.01 μΩ.

4. The following results were obtained by loss of charge method of testing a cable:

Discharged immediately after charging, the deflection = 200 divisions

i) Discharged 30 seconds after charging, the deflection = 125 divisions

ii) Discharged 30 seconds after charging, When in parallel with resistance of 10 MΩ, the deflection = 100 divisions. Calculateinsulation resistance of the cable

5. In a Kelvin double bridge, there is error due to mismatch between the ratios of outer and inner arm resistances. The following data relate to this bridge:

Standard resistance = 100.03μΩ; inner ratio arms = 100.31Ω and 200Ω; outer ratio arms = 100.24Ω and 200Ω; the resistance of connecting leads from standard to unknown resistor is 680 μΩ. Calculate the unknown resistance.

6. The value of a high resistance is measured by Loss of Charge method. A capacitor having a capacitance of 2.5 µF is charged to a potential of 500V D.C. and is discharged through the high resistance. An electrostatic voltmeter, kept across the high resistance, reads the voltage of 300V at the end of 60seconds. Calculate the value of high resistance.

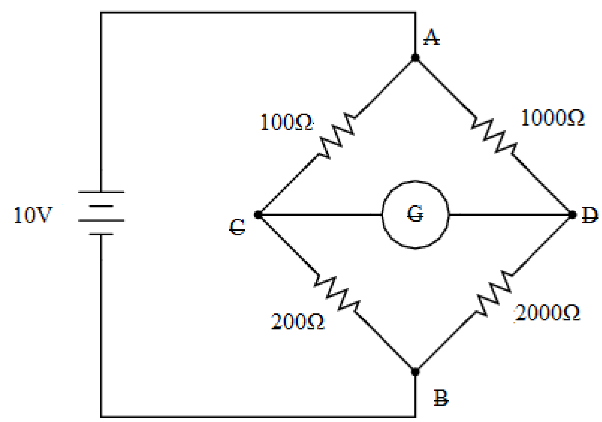
7. A 2.5 µF capacitor is charged to a potential of 450V. The capacitor is disconnected from the supply and the reading on an electrostatic voltmeter in parallel with the capacitor is observed to fall to 280V in 15.2minutes. The test is repeated with a resistor R in parallel with the capacitor and voltmeter. the voltmeter’s reading is now found to fall from 450V to 280V in 10.8minutes. Calculate the value of high resistance

C. Questions testing the analyzing / evaluating ability of students

1. A basic slide wire potentiometer has a working battery voltage of 3V with negligible internal resistance. The resistance of slide wire is 400Ω & its length is 200cm. A 200cm scale is placed along the slide wire. The slide wire has 1mm scale division and it is possible to read up to 1/5 of division. The instrument is standardized with 1.018 standard cell with sliding contact at the 101.8cm mark on scale. Calculate
   (i) Working current
   (ii) The resistance of series rheostat
   (iii)The measurement range
   (iv)The resolution of instrument

2. A d.c Crompton type potentiometer is used to find an unknown resistance. The resistance is connected a series with 100 ohms standard resistor fed by a separate D.C supply. Voltage across the standard resistor as measured by potentiometer is 1 volt from a volt-ratio box of 50:1 .The voltage across the unknown resistance is 3volts. Find the unknown resistance?

3. In a wheatstone bridge the galvanometer has acurrent sensitivity of 12mm/µA. the internal resistance of galvanometer is 200Ω. Calculate the deflection of the galvanometer caused due to 5Ω unbalance in the arm BD.



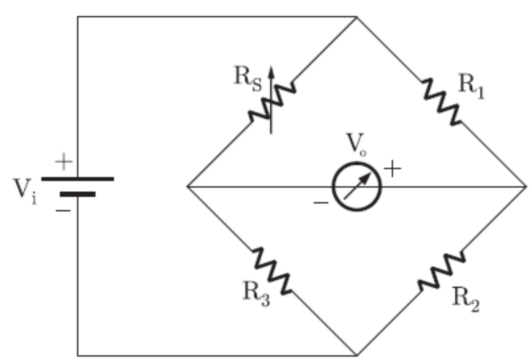
D. GATE/IES EXAM QUESTIONS

1. Suppose that resistors *R*1 and *R*2 are connected in parallel to give an equivalentresistor *R*. If resistors *R*1 and *R*2 have tolerance of 1% each, the equivalentresistor *R* for resistors *R*1 = 300 W and *R*2 = 200 W will have tolerance of

(A) 0.5% (B) 1% (C) 1.2% (D) 2% **GATE-2014**

2. A strain gauge forms one arm of the bridge shown in the figure below and hasa nominalresistance without any load as *Rs* = 300Ω. Other bridge resistancesare *R*1 = *R*2 = *R*3 = 300 Ω. The maximum permissible current through the straingauge is 20 mA. During certainmeasurement when the bridge is excited bymaximum permissible voltage and the strain gauge resistance is increased by 1%over the nominal value, the output voltage *V*0 in mV is

(A) 56.02 (B) 40.83 (C) 29.85 (D) 10.02 **GATE-2013**



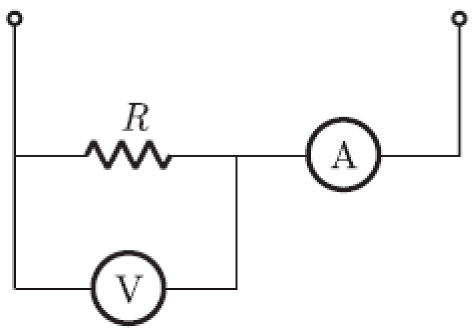
3. $R1$ and $R4$ are the opposite arms of a Wheatstone bridge as are $R3$ and $R2$. Thesource voltage is applied across $R1$ and $R3$. Under balanced conditions which oneof the following is true

(A) $R1 = R3R4/R2$ (B) $R1 = R2R3/R4$

(C) $R1 = R2R4/R3$ (D) $R1 = R2+ R3+ R4$ **GATE-2006**

4. The set-up in the figure is used to measure resistance R .The ammeter andvoltmeter resistances are 0.01W and 2000 W, respectively. Their readings are 2 Aand 180 V, respectively, giving a measured resistances of 90 W The percentageerror in the measurement is

(A) 2.25% (B) 2.35% (C) 4.5% (D) 4.71% **GATE-2005**



5. A dc potentiometer is designed to measure up to about 2 V with a slide wire of800 mm. A standard cell of emf 1.18 V obtains balance at 600 mm. A test cell isseen to obtain balance at 680 mm. The emf of the test cell is [ ] **GATE-2004**

(A) 1.00 V (B) 1.34 V (C) 1.50 V (D) 1.70 V

6. The items in Group-I represent the various types of measurements to be madewith a reasonable accuracy using a suitable bridge. The items in Group-IIrepresent the various bridges available for this purpose. Select the correct choiceof the item in Group-II for the corresponding item in Group-I from the following [ ] **GATE-2003**

List-I	**List-II**
P. Resistance in the milli-ohm range	**1.** Wheatstone bridge
Q. Low values of Capacitance	**2.** Kelvin Double Bridge
R. Comparison of resistance which are nearly equal	**3.** Schering Bridge
S. Inductance of a coil with a large time-constant	**4.** Wien’s Bridge
	5. Hay’s Bridge
	6. Carey-Foster Bridge

Codes :

(A) P=2, Q=3, R=6, S=5

(B) P=2, Q=6, R=4, S=5

(C) P=2, Q= 3, R=5, S=4

(D) P=1, Q=3, R=2, S=6

CHAPTER V

DIGITAL VOLTMETERS

Objectives:

1. To familiarize the students with the working of Digital Voltmeter-Successive approximation.
2. To familiarize the students with working of ramp and dual slope integrating type continuous balance type.
3. To familiarize the students with the working of Micro processor based ramp type.
4. To familiarize the students with the working of Extension Digits Digital frequency Meter, phase angle meter and LCR Q-meter.

Syllabus:

Digital meters

Digital Voltmeter-Successive approximation, ramp and dual slope integrating type continuous balance type-Micro processor based ramp type. Extension Digits Digital frequency Meter, phase angle meter, LCR Q-meter.

Learning Outcomes:

After the completion of this unit, students will be to

1. Describe the working of Digital Voltmeter-Successive approximation.

2. Describe the working of ramp and dual slope integrating type continuous balance type.

3. Describe the working of Micro processor based ramp type.

4. Describe the working Extension Digits Digital frequency Meter, phase angle meter and LCR Q-meter.

Digital Voltmeter-Successive approximation, ramp and dual slope integrating type continuous balance type-Micro processor based ramp type. Extension Digits Digital frequency Meter, phase angle meter, LCR Q-meter

A digital voltmeter, or DVM, is used to take highly accurate voltage measurements. These instruments measure the electrical potential difference between two conductors in a circuit. DV Ms are electric voltmeters, and the preferred standard, as they offer several benefits over t heir analog counterparts. Voltmeters are use d to measure the gain or loss of voltage between two points in a circuit. The leads are connected in parallel on each side of the circuit being tested.

Comparison of analog & digital instruments:

Parameter	Analog	Digital
Accuracy	Less than ±0.1% of FSD	Very high, up to ± 0.005% of reading
Resolution	Limited, upto 1 part of several hundreds	High, upto 1 part of several thousands
Power	Power requirement is high hence can cause loading.	Negligible, hence no loading effect.
Frictional errors	Errors due to moving parts are present	No moving part, hence no errors.
Speed	Reading speed is low	Reading speed is high
Observational errors	Errors such as parallax errors or approximation errors are present	Due to digital display the observational errors are absent.
Cost	Low in cost	High compared to analog
Compatibility	Not compatible with modern digital instruments	The digital output can be directly fed into memory of modern digital instruments.

Basic Block Diagram of DVM:

Any digital instrument requires analog to digital converter at its input. Hence first block in a general DVM is ADC as shown in fig.1

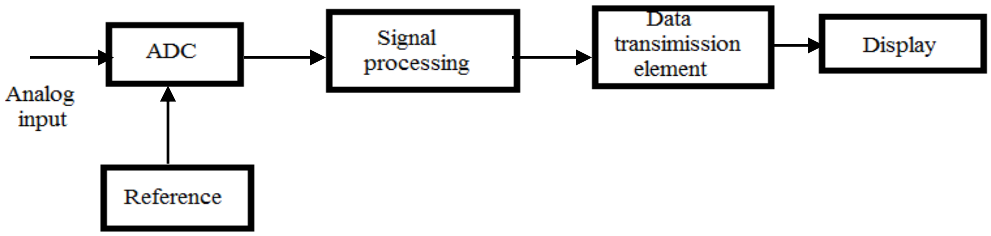


Fig.1 Basic block diagram of DVM

Every ADC requires a reference. The reference **is** generated internally and reference generator circuitry depends on the type of ADC technique used. The output of ADC is decoded and signal is processed in the decoding stage. Such a decoding is necessary to drive the seven segment display. The data from decoder is then transmitted to the display. The data transmission element may be a latches, counters etc, as per the requirement. A digital display shows the necessary digital result of the measurement.

Classification of digital voltmeters:

The DVMs are classified mainly based on the technique use for the analog to digital conversion

Ramp type DVM

It uses a linear ramp technique or staircase ramp technique. The stair case ramp technique is simpler than the linear ramp technique.

<u>LINEAR RAMP TECHNIQUE:</u>

The basic principle of such measurement is based on the measurement of the time taken by linear ramp to rise from 0 V to the level of the input voltage or to decrease from the level of the input voltage to zero. The time measured with the help of electronic time interval counter and the count is displayed in the numeric form with the help of digital display.

Block Diagram

- Properly attenuated input signal is applied as one input to the input comparator
- The ramp generator generates the proper linear ramp signal which is applied to both the comparators.
- The input comparator is used to send the start pulse while the ground comparator is used to send the stop pulse.

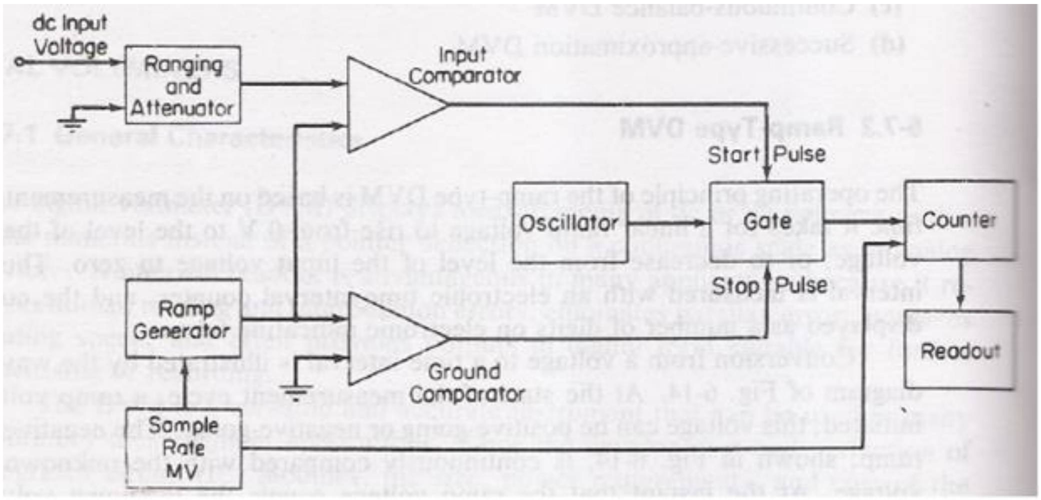


Fig Block diagram of a ramp-type digital voltmeter

- When the input ramp are applied to the input comparator and at the point when negative going ramp becomes equal to input voltages the comparator
- The oscillator drives the counter. The counter starts counting the pulses received from the oscillator.
- Now the input ramp is applied to the ground comparator and it is decreasing.
- Thus when ramp becomes zero, both the inputs of ground comparator becomes zero and send it the stop pulse due to which gate closed.
- The sample rate multivibartor determines the rate at which the measurement cycles are initiated.

Advantages:

i) The ramp technique circuit is easy to design.

ii) Its cost is low.

iii) The output pulse can transmitted over long feeder liner.

Disadvantages:

i) Single ramp requires excellent characteristics regarding linearity of ramp & time measurement.

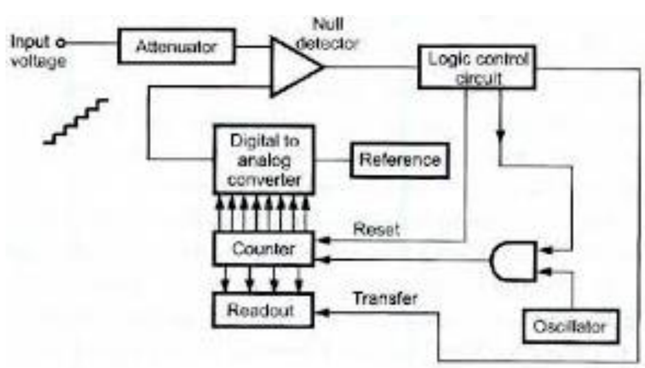
ii) Large errors are possible when noise is super imposed on the input signal.

STAIRCASE RAMP TECHNIQUE:

In this type of DVM, instead of linear ramp, the staircase ramp is used. The staircase ramp is generated by the digital to analog converter. The technique of using staircase ramp is also called null balance technique.

Block Diagram

- The input voltage is properly attenuated and is applied to a null detector. The input to null detector is the staircase ramp generated by the digital to analog converter. The ramp is continuously compared with the input signal.
- The logical control circuit sends a rest signal. This signal resets the counter.
- The digital to analog converter is also resetted by same signal.
- The output counter is given to the digital to analog converter which generates the ramp signal.
- At every count there is an incremental change in the ramp generated. Thus the staircase ramp is generated at the output of the digital to analog converter.

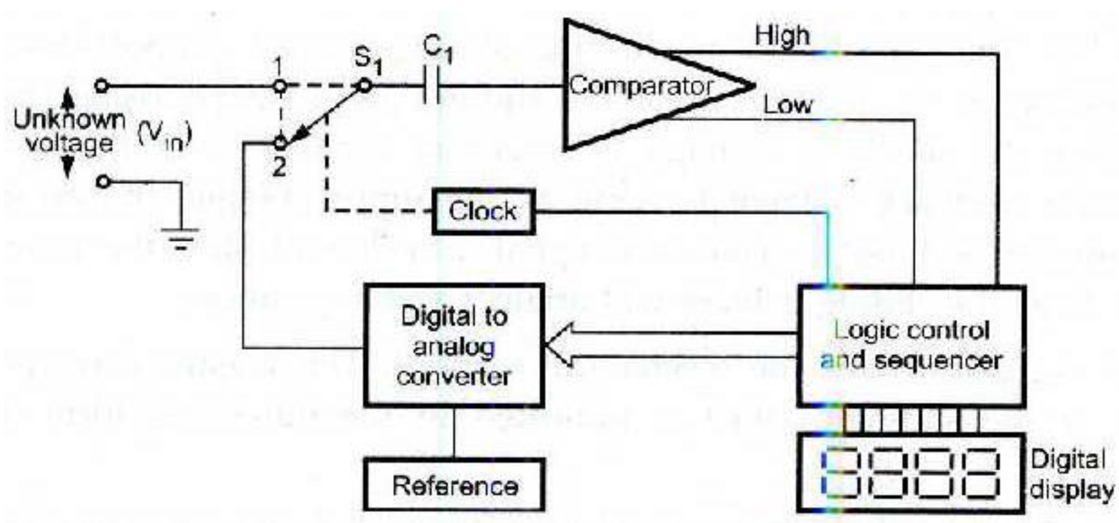


- This is given as the second input of the null detector.

- The increase in ramp continues till it achieves the voltage equal to input voltage. When the two voltages are equal, the null detector generates a signal which in turn initiates the logic control circuit.

Successive Approximation Type Digital Voltmeter

- The potentiometric used in the servo balancing type DVM is a linear divider but in successive approximation type a digital divider is used.
- The digital divider is a Digital to analog (D/A) converter.
- The servo motor replaced by an electronic logic.



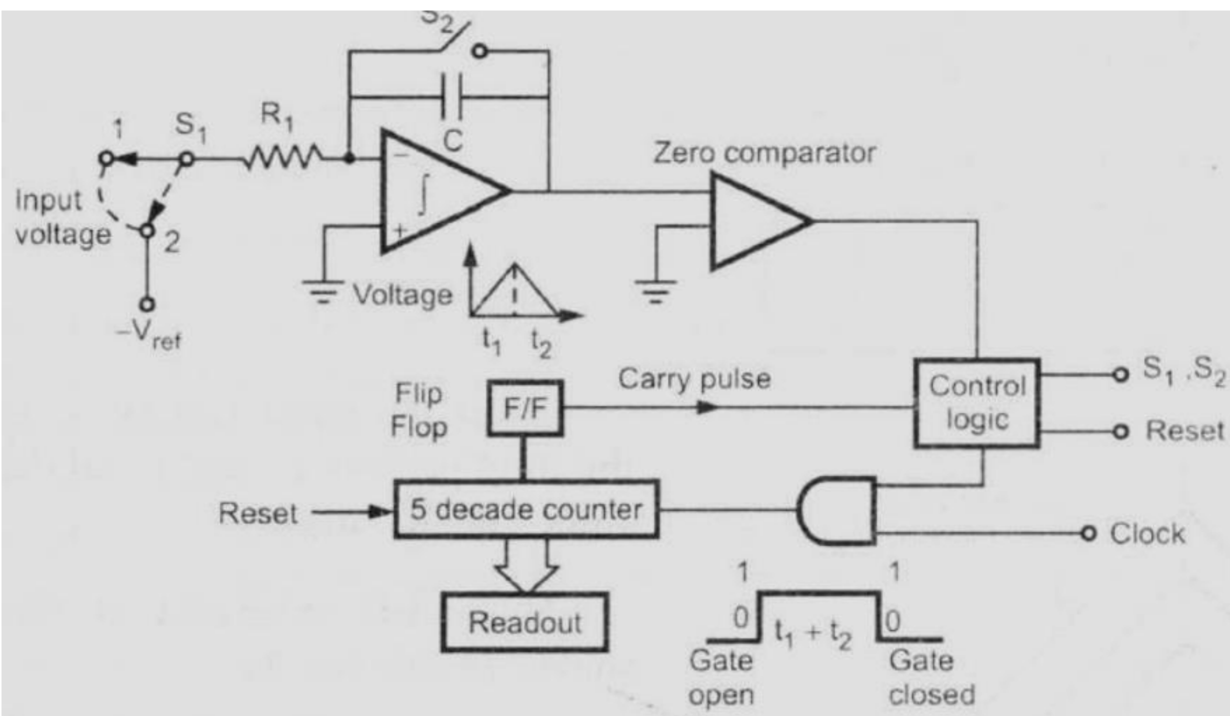
- The basic principle of measurement by this method is similar to the simple example of determination of weight of the object.
- The object is placed on one side of the balance and the approximate weight is placed on the other side.
- If this weight is smaller than the object, another small weight is added weight is removed and smaller weight is added.
- Thus by such successive procedure of adding and removing, the weight of the object is determined.

- The successive approximation type DVM works exactly on the same principle.
- In successive approximation type DVM, the comparator compares the output of digital to analog converter with the unknown voltage.
- Accordingly, the comparator provides logic high or low signals.
- The digital to analog converter successively generates the set pattern of signals.
- The procedure continues till the output of the digital to analog converter becomes equal to the unknown voltage.

DUAL SLOPE INTEGRATING TYPE DIGITAL VOLTMETER

Block Diagram

This is the most popular method of analog to digital conversion. In the ramp techniques, the noise can cause large errors but in dual slope method the noise is averaged out by the positive and negative ramps using the process of integration. The basic principle of this method is that the input signal is integrated for a fixed interval of time. And then the same integrator is used to integrate the reference voltage with reverse slope. Hence the name given to the technique is dual slope integration technique. The block diagram of dual slope integrating type DVM is shown in the Fig. It consists of five blocks, an op-amp used as an integrator, a zero comparator, clock pulse generator, a set of decimal counters and a block of control logic.



When the switch Sl is in position 1, the capacitor C starts charging from zero level. The rate of charging is proportional to the input voltage level. The output of the op-amp is given by,

$$V_{out} = -(1/R_1 C) \int_0^{t1} V_{in}\, dt$$

$$V_{out} = -(V_{in} t_1 / R_1 C) \qquad \text{.........(1)}$$

Where, t_1 = Time for which capacitor is charged

V_{in} = Input voltage

R_1 = Series resistance

C = Capacitor in feedback path

After the interval t I, the input voltage is disconnected and a negative voltage -Vref is connected by throwing the switch S1 in position 2. In this position, the output of the op-ilmp is given by,

$$V_{out} = -(1/R_1 C) \int_0^{t2} -V_{ref}\, dt$$

Therefore

$$\boxed{V_{out} = -(V_{ref}\ t_2) / (R_1 C} \qquad \text{.........(2)}$$

Subtracting equation (1) from (2),

$$V_{out} - V_{out} = 0 = [-(V_{ref}\ t_2) / (R_1 C)] - [-(V_{in}\ t_{1)} / (R_1 C)]$$

$$(V_{ref}\ t_2) / (R_1 C) = (V_{in}\ t_{1)} / (R_1 C)$$

$$V_{ref}\ t_2 = V_{in}\ t_1$$

$$V_{in} = V_{ref}\ (t_2/t_1) \qquad \text{.........(3)}$$

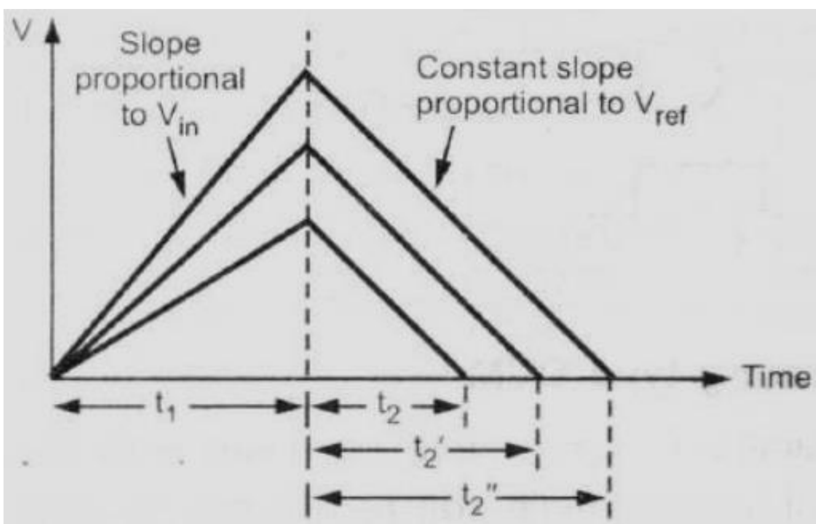
Subtracting (1) from (2),

$$V_{out} - V_{out} = 0 = \frac{-V_{ref}\ t_2}{R_1\ C} - \left(\frac{-V_{in}\ t_1}{R_1\ C}\right)$$

$$\therefore \quad \frac{V_{ref}\ t_2}{R_1\ C} = \frac{V_{in}\ t_1}{R_1\ C}$$

$$\therefore \quad V_{ref}\ t_2 = V_{in}\ t_1$$

$$\therefore \quad \boxed{V_{in} = V_{ref} \cdot \frac{t_2}{t_1}}$$



Thus the input voltage is dependent on the time periods t] and t2 and not on the values of R] and C. This basic principle of this method is shown in the Fig.

At the start of the measurement, the counter is reset to zero. The output of the flip-flop is also zero. This is given to the control logic. This control sends a signal so as to close an electronic switch to position 1 and integration of the input voltage starts. It continues till the time period t.

As the output of the integrator changes from its zero value, the zero comparator output changes its state. This provides a signal to control logic which in turn opens the gate and the counting of the clock pulses starts.

The counter counts the pulses and when it reaches to 9999, it generates a carry pulse and all digits go to zero. The flip flop output gets activated to the logic level T. This activates the control logic. This sends a signal which changes the switch S1 position from 1 to 2 Thus -Vref gets connected to op-amp. As Vref polarity is opposite, the capacitor starts discharging. The integrator output will have constant negative slope as shown in th Fig. The output decreases linearly and after the interval t2, attains zero value, when the capacitor C gets fully discharged.

From equation (3) we can write,

$$V_{in} = V_{ref} \cdot \frac{t_2}{t_1}$$

Let time period of clock oscillator be T and digital counter has counted the counts n1 and n2 during the period t] and t2 respectively.

$$V_{in} = V_{ref} \cdot \frac{n_2 T}{n_1 T} = V_{ref} \cdot \frac{n_2}{n_1}$$

Thus the unknown voltage measurement is not dependent on the clock frequency, but dependent on the counts measured by the counter.

The advantages of this technique are:

i) Excellent noise rejection as noise and superimposed a.c are averaged out during the process of integration.

ii) The RC time constant does not affect the input voltage measurement.

iii) The capacitor is connected via an electronic switch. This capacitor is an auto zero capacitor and avoids the effects of offset voltage.

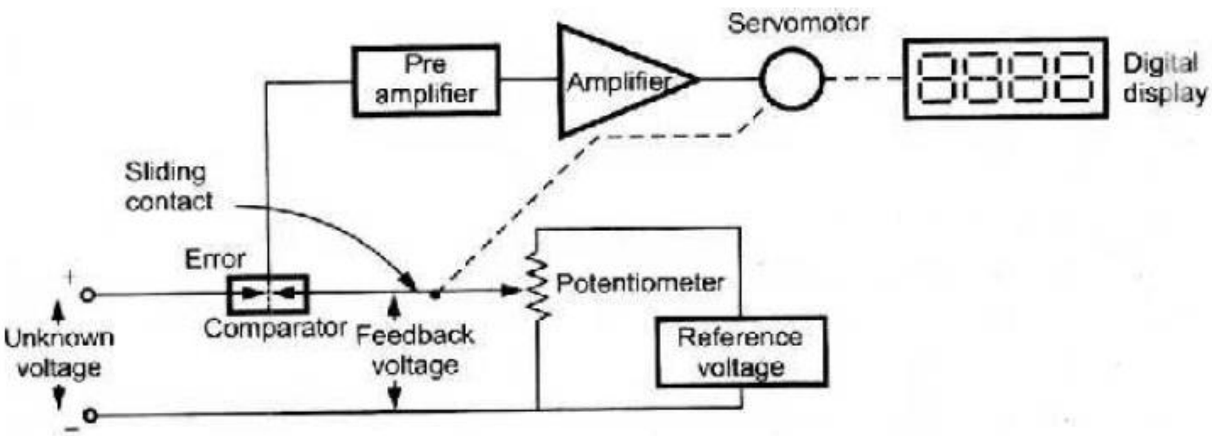
iv) The integrator responds to the average value of the input hence sample and hold circuit is not necessary.

v) The accuracy is high and can be readily varied according to the specific requirements.

The only disadvantage of this method is Slow speed.

SERVO POTENTIOMETRIC TYPE DIGITAL VOLTMETER

Block Diagram



- In this potentiometric type voltmeters internal reference voltage is provided.
- A voltage comparison technique is used to measure the input voltage.
- The unknown voltage is compared with the reference voltage with the help of the setting of the calibrated potentiometer i.e. potential divider.
- The arm of the potentiometer is varied to obtain the null condition i.e. balance condition.
- The internal reference voltage is present at the two terminals of the potentiometer. When the null condition is obtained, the value of the unknown voltage is indicated by the dial setting of the potentiometer.
- Practically, the null balancing is not obtained manually but is obtained automatically.
- Such a voltmeter is called self balancing potentiometric type DVM.
- The servomotor is used to vary the arm of the potentiometer hence it is also called servo balancing potentiometer type DVM.

DIGITAL FREQUENCY METER

The input signal whose frequency is to measures it first converted into a pulse train such that each cycle possesses one pulse. Then the number of pulses, so generated, is counted with help of circuit called electronic counter the number being displayed upon the display unit is direct representation of the frequency of the signal fed to the measurement device because of the pulses being in a fixed interval of time. It is because of the fast action of the electronic counter that makes it possible to **measure very high frequency**

Here the signal under test is fed to the Schmitt trigger where it may also be the case that it is first amplified before feeding it to the Schmitt trigger. Whereas, after application of the amplified or direct signal to the Schmitt trigger it is changed into a square wave having very fast rising as well as falling time. After formation of this square wave it is further performed upon by many functions like:

•Differentiation

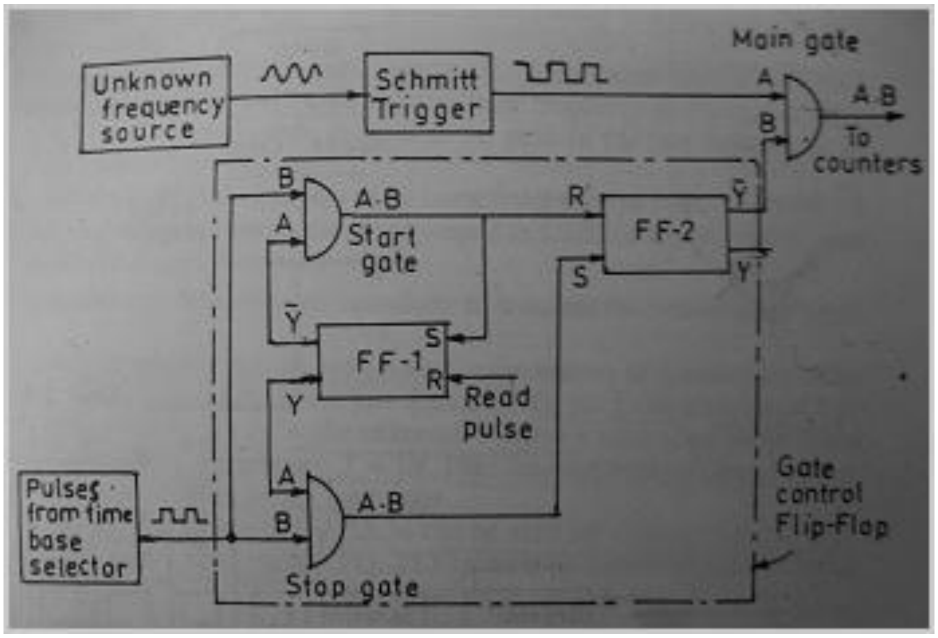
• Clipping

The outcome of this stage results into a pulse train where one pulse is representative of one cycle of the input signal. After getting output from Schmitt trigger it is applied to the star stop gate. Now, there are two stages or phases regarding this gate i.e. start stage and stop stage in which when the gate is in open state it is called start state when pulse passes through it and is fed to an electronic counter that actually performed functioning of maintain a record of input pulses. On the other hand in stop state the gate turns off and no more pulses are allowed to pass through the gate and as a result no recording of pulses takes place. Now display comes into picture that actually shows that how many pulses have passed through gate during the time interval from starting and stopping of gate. With applied condition that we know this time interval it becomes possible to know the frequency of applied signal with help of display unit. For example let us take a condition when we are given with a input signal whose frequency is 'f' and the display shows a reading 'n' where the initially fixed interval is 'T' then these terms can be related as below

$$f=n/T$$

The complete block diagram of actual circuitry is shown is the figure blow.

Here point A is getting the unknown frequency which are called counted signal point A is called main gate where point B gets positive pulse from base selector. Point B is situated at start gate. The flip flop FF1 that is shown in the figure is initially in its 1 state. Upon application of resultant +Ve pulse voltage coming from Y to the stop gate at point A due to which it is shifted to open state. Now on the other hand upon application of zero voltage from the same flip flop FF1 to the point A causes to close the gate. In the state when the stop gate remains in its open state the input terminal of flip flop. As soon the stop gate comes in open state the positive pulse coming from the base will be able to reach to the input of flip-flop named as FF2 this makes it to remain in 1 state. As a result the zero voltage coming from the output of y bar of the flip flop that is made to be supplied to B terminal of main gate which make it closed. Consequently, now, no other pulse is capable of passing through the main gate and ultimately no pulse will be reaching to the register of counter circuit.



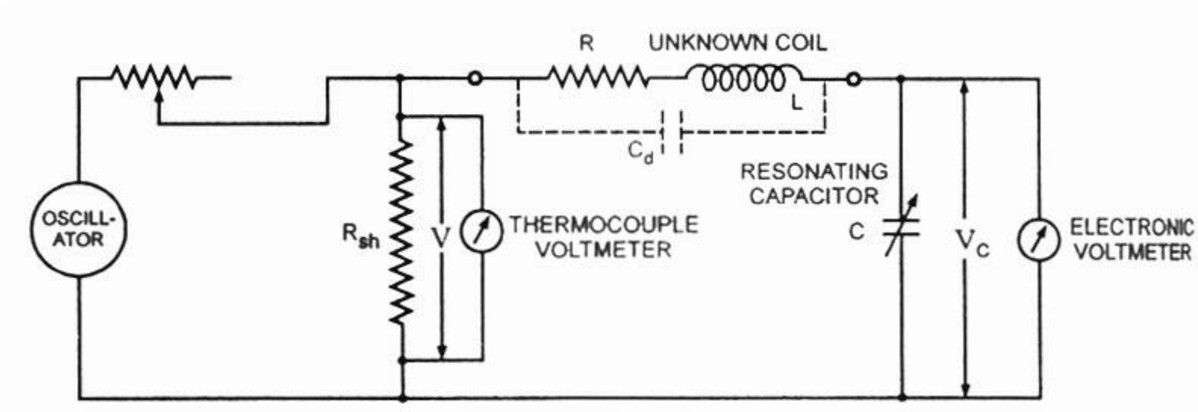
Now when we proceed onwards to make the **operation of the digital meter** system to start a read pulse which is a positive pulse is made to be supplied to the reset terminal of flip flop FF1 this action results in inversion of state of the flip-flop i.e. it becomes 0 from its previous state which was 1. Now y bar being a positive voltage becomes the output and y becomes 0. This results in closing of stop gate and opening of the start gate. At the same time the same read pulse is applied to the decades of the counter making them all to zero and to facilitate the starting of count.

With the arrival of next pulse from time base section it becomes able to pass through the start gate and is applied to the reset of flip-flop FF2 which changes its state from 1 to 0. And thus the resulting output is supplied to terminal B of main gate that make it open. Now the source of the outer signal is capable of passing through gate and on the same time that is also get registered at the counter circuit the pulse that is passed to the start gate is also applied to the flip flop FF1 due to which its state changes from 0 to 1. As a result the start gate is closed and at the same time opens the stop gate. Now as main gate is still open that allows the signal of outer source to passed through it and keeping the process going on in the same way.

After this much of the process when the next pulse coming form time base selector made to pass open stop gate and then to input terminal of flip flop FF2 at its point S. This action changes its state back to 1. As a result of this the output from this terminal which is Y bar comes to zero. At this time the main gate become closed and counting also stops.

This way in the time elapsed between two successive pulsed from the base selector the counter circuit performs the function of recording that how many pulse have passed through the main gate and them through it. thus the frequency of the input signal can be obtained directly from the display placed over the system when we initially fix the time between two pulse from base selector to be 1 second them display will directly show that how many pulse have passed through the main gate in one second. The unit of this frequency will in Hz. Here the assembly or a collection of two AND gates and two flip flops FF1 and FF2 gives rise to a gate control flip flop.

Q-Meter



Circuit Diagram of a Q-meter

We know that every inductor coil has a certain amount of resistance and the coil should have lowest possible resistance. The ratio of the inductive reactance to the effective resistance of the coil is called the quality factor or Q-factor of the coil.

So $Q = X_L / R = \omega L / R$

A high value of Q is always desirable as it means high inductive reactance and low resistance. A low value of Q indicates that the resistance component is relatively high and so there is a comparatively large loss of power.

The effective resistance of the coil differs from its dc resistance because of eddy current and skin effects and varies in a highly complex manner with the frequency. For this reason Q is rarely computed by determination of R and L.

One possible way for determination of Q is by using the inductance bridge but such bridge circuits are rarely capable of giving accurate measurements, when Q is high. So special meters are used for determination of Q accurately.

The Q-meter is an instrument designed for the measurement of Q-factor of the coil as well as for the measurement of electrical properties of coils and capacitors. -This instrument operates on the principle of series resonance i.e. at resonate condition of an ac series circuit voltage across the capacitor is equal to the applied voltage times of Q of the circuit. If the voltage applied across the circuit is kept-constant then voltmeter connected across the capacitor can be calibrated to indicate Q directly.

Circuit diagram of a Q-meter is shown is figure. A wide-range oscillator with frequency range from 50 kHz to 50 MHz is used as a power supply to the circuit. The output of the oscillator is shorted by a low-value resistance, R_{sh} usually of the order of 0.02 ohm. So it in-troduces almost no resistance into the oscillatory circuit and represents a voltage source with a very small or of almost negligible internal resistance. The voltage across the low-value shunt resistance R_{sh}, V is measured by a thermo-couple meter and the voltage across the capacitor, V_c is measured by an electronic voltmeter.

For carrying out the measurement, the unknown coil is connected to the test terminals of the instrument, and the circuit is tuned to resonance either by varying the frequency of the oscillator or by varying the resonating capacitor C. Readings of voltages across capacitor C and shunt resistance R_{sh} are obtained and Q-factor of the coil is determined as follows :
By definition Q-factor of the coil,

Q = XL / R

And when the circuit is under resonance condition

XL = XC

Or IXL = IXC = VC

And the voltage applied to the circuit.

V = IR

So, **Q = XL / R = IXL / R = VC / V**

This Q-factor is called the circuit Q because this measurement includes the losses of the resonating capacitor, voltmeter and the shunt resistor R_{sh}. So, the actual Q-factor of the coil will be somewhat greater than the calculated Q-factor. This difference is usually very small and maybe neglected., except when the resistance of the coil under test is relatively small in comparison to the shunt resistance R_{sh}.
The inductance of the coil can also be computed from the known values of frequency f and resonating capacitor C as follows.

At resonance, **XL= XC or 2∏fL = 1/2∏fC or L = 1/ (2∏f)2** Henry.

CHAPTER VI

TRANSDUCERS

Objectives:

1. To familiarize the students with Classification of transducers and advantages of Electrical transducers.
2. To familiarize the students with Principle operation of resistor and inductor
3. To familiarize the students with the principle and operation of LVDT and capacitor transducers
4. To familiarize the students with the Strain gauge and its principle of operation of guage –factor
5. To familiarize the students with the Thermistors, Piezo- electric transducers and Hall sensors.

Syllabus:

Definition of transducer, Classification of transducers, Advantages of Electrical transducers, Characteristics and choice of transducers; Principle operation of resistor, inductor, LVDT and capacitor transducers, Strain gauge and its principle of operation- guage factor, Thermistors, Piezo- electric transducers, Hall sensors.

Learning Outcomes:

After the completion of this unit, students will be to

1. Describe the Classification of transducers and advantages of Electrical transducers.
2. Describe the principle and operation of resistor and inductor.
3. Describe the principle and operation of LVDT and capacitor transducers.
4. Describe the principle and operation of the Strain gauge and its principle of operation of guage –factor.
5. Describe the principle and operation of the Thermistors, Piezo- electric transducers and Hall sensors.

6.1 INTRODUCTION

A transducer is a device that is used to convert a physical quantity into its corresponding electrical signal.

In most of the electrical systems, the input signal will not be an electrical signal, but a non-electrical signal. This will have to be converted into its corresponding electrical signal if its value is to be measured using electrical methods.

The block diagram of a transducer is given below.

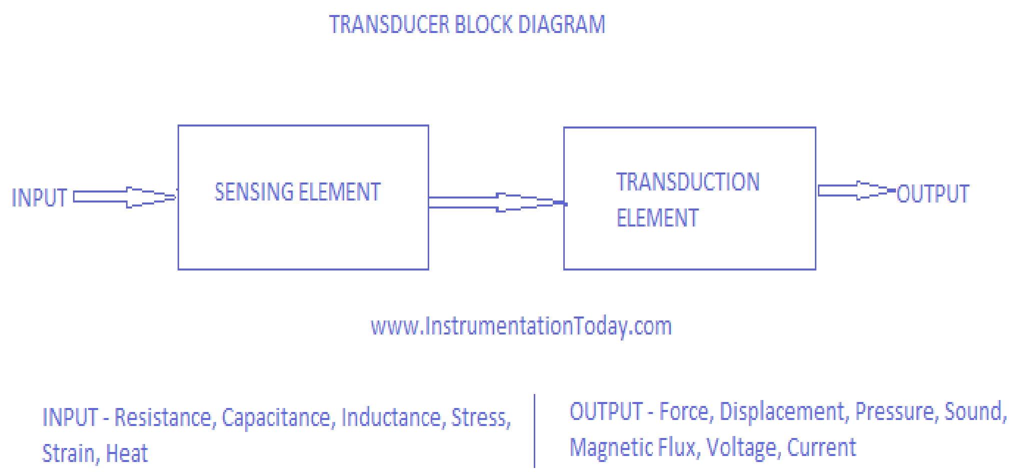


Fig 1.Transducer Block Diagram

A transducer will have basically two main components. They are

1. Sensing Element

The physical quantity or its rate of change is sensed and responded to by this part of the transistor.

2. Transduction Element

The output of the sensing element is passed on to the transduction element. This element is responsible for converting the non-electrical signal into its proportional electrical signal.

There may be cases when the transduction element performs the action of both transduction and sensing. The best example of such a transducer is a thermocouple. A thermocouple is used to generate a voltage corresponding to the heat that is generated at the junction of two dissimilar metals.

Selection of Transducer

Selection of a transducer is one of the most important factors which help in obtaining accurate results. Some of the main parameters are given below.

- Selection depends on the physical quantity to be measured.
- Depends on the best transducer principle for the given physical input.
- Depends on the order of accuracy to be obtained.

Transducer Classification

Some of the common methods of classifying transducers are given below.

- Based on their application.
- Based on the method of converting the non-electric signal into electric signal.
- Based on the output electrical quantity to be produced.
- Based on the electrical phenomenon or parameter that may be changed due to the whole process. Some of the most commonly electrical quantities in a transducer are resistance, capacitance, voltage, current or inductance. Thus, during transduction, there may be changes in resistance, capacitance and induction, which in turn change the output voltage or current.
- Based on whether the transducer is active or passive.

Transducer Applications

The applications of transducers based on the electric parameter used and the principle involved is given below.

6.2 Passive Type Transducers

a. **Resistance Variation Type**

- **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.
- **Resistance Thermometer** – The change in resistance of metal wire due to the change in temperature known by the measurement of temperature.
- 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.
- 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.
- **Photoconductive Cell** – The change in resistance of a cell due to a corresponding change in light flux is known by its corresponding light intensity.
- **Thermistor** – The change in resistance of a semi-conductor that has a negative co-efficient of resistance is known by its corresponding measure of temperature.
- **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.

b. Capacitance Variation Type

- **Variable Capacitance Pressure Gauge** – The change in capacitance due to the change of distance between two parallel plates caused by an external force is known by its corresponding displacement or pressure.
- Dielectric Gauge – The change in capacitance due to a change in the dielectric is known by its corresponding liquid level or thickness.
- Capacitor Microphone – The change in capacitance due to the variation in sound pressure on a movable diagram is known by its corresponding sound.

c. Inductance Variation Type

- **Eddy Current Transducer** – The change in inductance of a coil due to the proximity of an eddy current plate is known by its corresponding displacement or thickness.
- **Variable Reluctance Type** – The variation in reluctance of a magnetic circuit that occurs due to the change in position of the iron core or coil is known by its corresponding displacement or pressure.
- **Proximity Inductance Type** – The inductance change of an alternating current excited coil due to the change in the magnetic circuit is known by its corresponding pressure or displacement.
- **Differential Transformer** – The change in differential voltage of 2 secondary windings of a transformer because of the change in position of the magnetic core is known by its corresponding force, pressure or displacement.
- **Magnetostrictive Transducer** – The change in magnetic properties due to change in pressure and stress is known by its corresponding sound value, pressure or force.

d. Voltage and Current Type

- **Photo-emissive Cell** – Electron emission due to light incidence on photo-emissive surface is known by its corresponding light flux value.
- **Hall Effect** – The voltage generated due to magnetic flux across a semi-conductor plate with a movement of current through it is known by its corresponding value of magnetic flux or current.
- **Ionisation Chamber** – The electron flow variation due to the ionisation of gas caused by radio-active radiation is known by its corresponding radiation value.

6.3. Active Type

- Photo-voltaic Cell – The voltage change that occurs across the p-n junction due to light radiation is known by its corresponding solar cell value or light intensity.
- **Thermocouple** – The voltage change developed across a junction of two dissimilar metals is known by its corresponding value of temperature, heat or flow.
- **Piezoelectric Type** – When an external force is applied on to a quartz crystal, there will be a change in the voltage generated across the surface. This change is measured by its corresponding value of sound or vibration.

- Moving Coil Type – The change in voltage generated in a magnetic field can be measured using its corresponding value of vibration or velocity.

6.4 Resistive transducer:

In general, the resistance of a metal conductor is given by,

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

Where ρ = Resistivity of conductor (Ω)

L = length of conductor in meters.

A = area of cross section of conductor m^2

Principle:-

A change in resistance of a circuit due to the displacement of an object is themeasure 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.

The electrical resistive transducers are designed on the basis of the methods of "arintioll of anyone of the quantities in above equation; such as change in length, change in iueil of cross-section and change in resistivity. The sensing element which is resistive in nature, may be in different forms depending upon the mechanical arrangement. The change in pressure can be sensed by Llsing ~nsitive resistive elements. The resistance pressure transducers may use Bellow, Diaphragm or Bourdon tube.

6.5 Resistance Position Transducer:

In many industrial measurements and control applications, it is necessary to sense position of the object or the distance that object travels. For such applications, simple resi~tanceposition transducer is very useful. It works on the principle that resistance of the sensing element changes due to the wiations in physical quantity being measured. A simple resistance position transducer is as shown in the Fig.

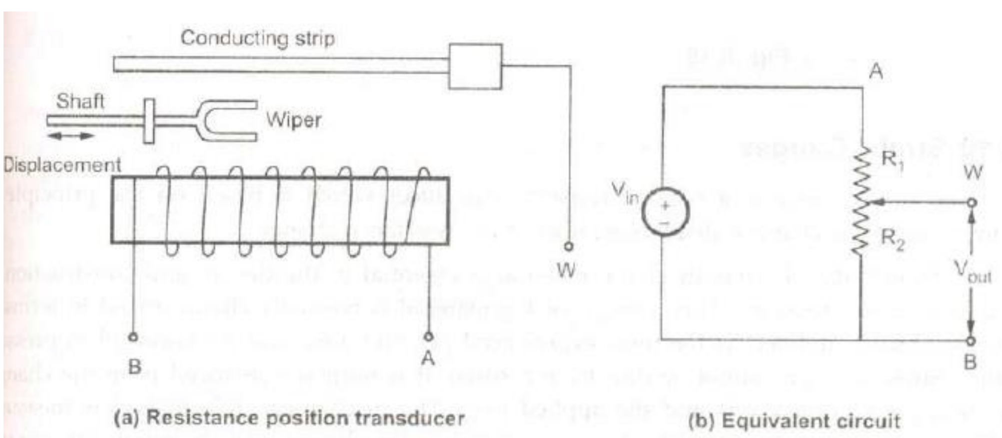


Fig 2. Resistance Position Transducer

The transducer consists a sliding contact or wiper. A resistive element is mounted with the sliding contact which is linked with the object whose position is to be monitored. Depending upon the position of the object, the resistance between slider and the one end of resistive element varies. The equivalent circuit is as shown in the Fig. 8.18 (b). *The* output voltage Vout depends on the position of the wiper. Thus depending upon position of the wiper, the output voltage is given by,

$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$$

6.6 Capacitive Transducers:

To learn about a capacitive transducer, it is important to know the basics of a parallel plate capacitor. Being the simplest form of a capacitor, it has two parallel conducting plates that are separated to each other by a dielectric or insulator with a permittivity of E (for air). Other than paper, vacuum, and semi-conductor depletion region, the most commonly used dielectric is air.

Due to a potential difference across the conductors, an electric field develops across the insulator. This causes the positive charges to accumulate on one plate and the negative charges to accumulate on the other. The capacitor value is usually denoted by its capacitance, which is measured in Farads. It can be defined as the ratio of the electric charge on each conductor to the voltage difference between them.

The capacitance is denoted by C. In a parallel plate capacitor,

$$C = \frac{A * \varepsilon_r * \varepsilon_0}{d}$$

A – Area of each plate (m)

d – Distance between both the plates (m)

ε_r – Relative Dielectric Constant

The value $9.85*10^{12}$ F/M is a constant denoted by $\varepsilon_0$and is called the dielectric constant of free space.From the equation it is clear that the value of capacitance C and the distance between the parallel plates,d are inversely proportional to each other. An increase of distance between the parallel plates will decrease the capacitance value correspondingly. The same theory is used in a capacitive transducer. This **transducer** is used to convert the value of displacement or change in pressure in terms of frequency.

As shown in the figure below, a capacitive transducer has a static plate and a deflected flexible diaphragm with a dielectric in between. When a force is exerted to the outer side of the diaphragm the distance between the diaphragm and the static plate changes. This produces a capacitance which is measured using an alternating current bridge or a tank circuit.

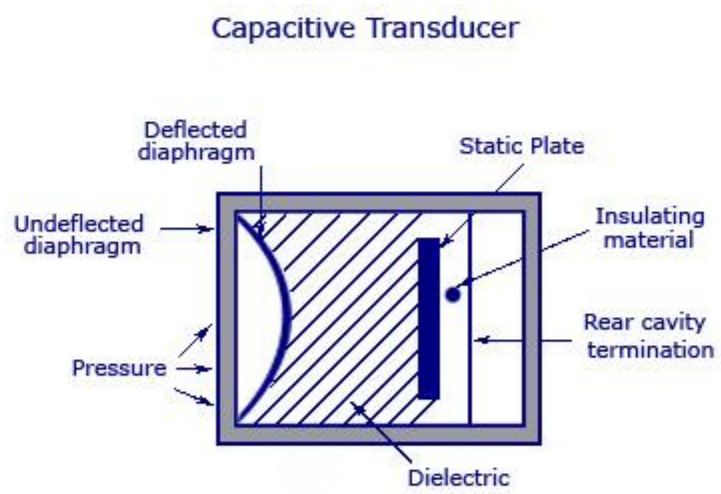


Fig 3. Capacitive Transducer

A tank circuit is more preferred because it produces a change in frequency according to the change in capacitance. This value of frequency will be corresponding to the displacement or force given to the input.

Advantages

- It produces an accurate frequency response to both static and dynamic measurements.

Disadvantages

- An increase or decrease in temperature to a high level will change the accuracy of the device.
- As the lead is lengthy it can cause errors or distortion in signals.

Inductive Transducer:

An **proximity(inductive) sensor** is an electronic proximity sensor, which detects metallic objects without touching them.

The sensor consists of an induction loop. Electric current generates amagnetic field, which collapses generating a current that falls toward zero from its initial trans when the input electricity ceases. The inductance of the loop changes according to the material inside it and since metals are much more effective inductors than other materials the presence of metal increases the current flowing through the loop. This change can be detected by sensing circuitry, which can signal to some other device whenever metal is detected.

Common applications of inductive sensors include metal detectors, traffic lights, car washes, and a host of automated industrial processes. Because the sensor does not require physical contact it is particularly useful for applications where access presents challenges or where dirt is prevalent.

6.8 Linear Variable Displacement Transducer (LVDT):

A very basic transducer which is always useful in the field of instrumentation, I have studied about this in my college days. Now let me explain about the LVDT with its Principle of Operation and I will explain how it is constructed for its well known operation and you can understand the working of LVDT.

Principle of LVDT:

LVDT works under the principle of mutual induction, and the displacement which is a non-electrical energy is converted into an electrical energy. And the way how the energy is getting converted is described in working of LVDT in a detailed manner

Construction of LVDT:

LVDT consists of a cylindrical former where it is surrounded by one primary winding in the centre of the former and the two secondary windings at the sides. The number of turns in both the secondary windings are equal, but they are opposite to each other, i.e., if the left secondary windings is in the clockwise direction, the right secondary windings will be in the anti-clockwise

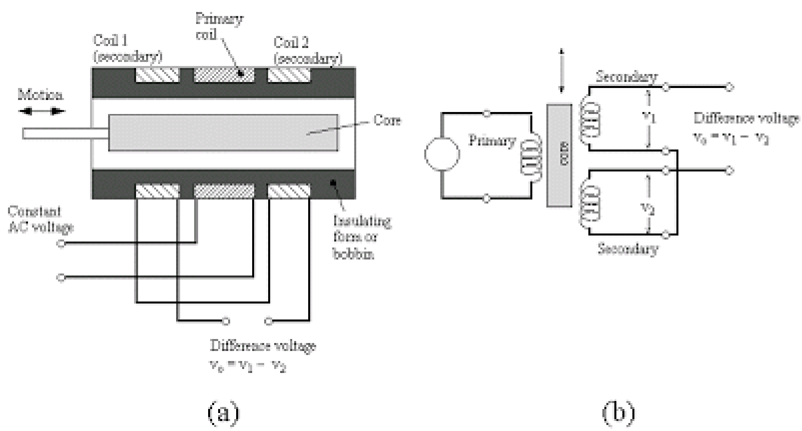


Fig 4. Linear Variable Displacement Transducer (LVDT)

direction, hence the net output voltages will be the difference in voltages between the two secondary coil. The two secondary coil is represented as S1 and S2. Esteem iron core is placed in the centre of the cylindrical former which can move in to and fro motion as shown in the figure. The AC excitation voltage is 5 to 12V and the operating frequency is given by 50 to 400 HZ.

Working ofLVDT:

Let's study the working of LVDT by splitting the cases into 3 based on the iron core position inside the insulated former.

Case 1:

On applying an external force which is the displacement, if the core reminds in the null position itself without providing any movement then the voltage induced in both the secondary windings are equal which results in net output is equal to zeroi.e., Esec1-Esec2=0

Case 2:

When an external force is appilied and if the steel iron core tends to move in the left hand side direction then the emf voltage induced in the secondary coil is greater when compared to the emf induced in the secondary coil 2. Therefore the net output will be Esec1-Esec2

Case 3:

When an external force is applied and if the steel iron core moves in the right hand side direction then the emf induced in the secondary coil 2 is greater when compared to the emf voltage induced in the secondary coil 1. therefore the net output voltage will be Esec2-Esec1

Advantages of LVDT:

* Infinite resolution is present in LVDT
* High output
* LVDT gives High sensitivity
* Very good linearity
* Ruggedness
* LVDT Provides Less friction
* Low hysteresis
* LVDT gives Low power consumption.

Disadvantages of LVDT:

* Very high displacement is required for generating high voltages.
* Shielding is required since it is sensitive to magnetic field.
* The performance of the transducer gets affected by vibrations
* Its is greatly affected by temperature changes.

Applications of LVDT:

LVDT is used to measure displacement ranging from fraction millimeter to centimeter. Acting as a secondary transducer, LVDT can be used as a device to measure force, weight and pressure, etc.

6.9. Strain Gauge Transducer:

Strain Gauge is a passive **transducer** that converts a mechanical elongation or displacement produced due to a force into its corresponding change in resistance R, inductance L, or capacitance C. A strain gauge is basically used to measure the strain in a work piece. If a metal piece is subjected to a tensile stress, the metal length will increase and thus will increase the electrical resistance of the material. Similarly, if the metal is subjected to compressive stress, the length will decrease, but the breadth will increase. This will also change the electrical resistance of the conductor. If both these stresses are limited within its elastic limit (the maximum limit beyond which the body fails to regain its elasticity), the metal conductor can be used to measure the amount of force given to produce the stress, through its change in resistance.

Strain Gauge Transducer

The device finds its wide application as a strain gauge transducer/sensor as it is very accurate in measuring the change in displacement occurred and converting it into its corresponding value of resistance, inductance or capacitance. It must be noted that the metal conductor which is subjected to an unknown force should be of finite length.

Types

Strain gauge transducers are broadly classified into two. They are

1. **Electrical Resistance Type Strain Gauge**

In an electrical resistance strain gauge, the device consists of a thin wire placed on a flexible paper tissue and is attached to a variety of materials to measure the strain of the material. In application, the strain gauge will be attached to a structural member with the help of special cement. The gauge position will be in such a manner that the gauge wires are aligned across the direction of the strain to be measured. The wire used for the purpose will have a diameter between 0.009 to 0.0025 centimeters. When a force is applied on the wire, there occurs a strain (consider tensile, within the elastic limit) that increases the length and decreases its area. Thus, the resistance of the wire changes. This change in resistance is proportional to the strain and is measured using a Wheatstone bridge.

A simple Wheatstone bridge circuit is shown in the figure below. It can be set in three different ways such as – full bridge, half bridge or quarter bridge. A full bridge will have all four of its gauges active. The half bridge will have two of its gauges active and thus uses two precise value resistors. The quarter bridge will have only one gauge and the rest of the resistors will be precise in value.

A full bridge circuit is used in applications where complimentary pair of strain gauges is to be bounded to the test specimen. In practice, a half bridge and full bridge circuit has more sensitivity than the quarter bridge circuit. But since, the bonding is difficult,a quarter bridge circuits are mostly used for strain gauge measurements. A full bridge circuit is said to be more linear than other circuits.

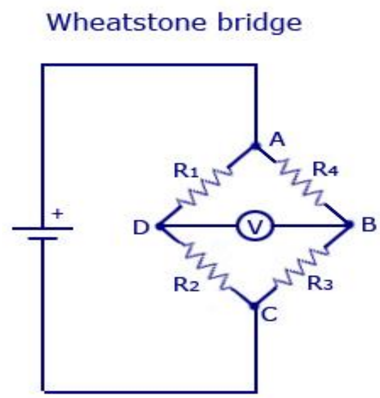


Fig 5.Wheatstone Bridge

An external supply is given to the bridge as shown in the diagram. Initially, when there is no application of strain, the output measurement will be zero. Thus, the bridge is said to be balanced. With the application of a stress to the device, the bridge will become unbalanced and produces an output voltage that is proportional to the input stress.

The application of a full bridge and quarter bridge strain gauge circuit is shown in the figure below.

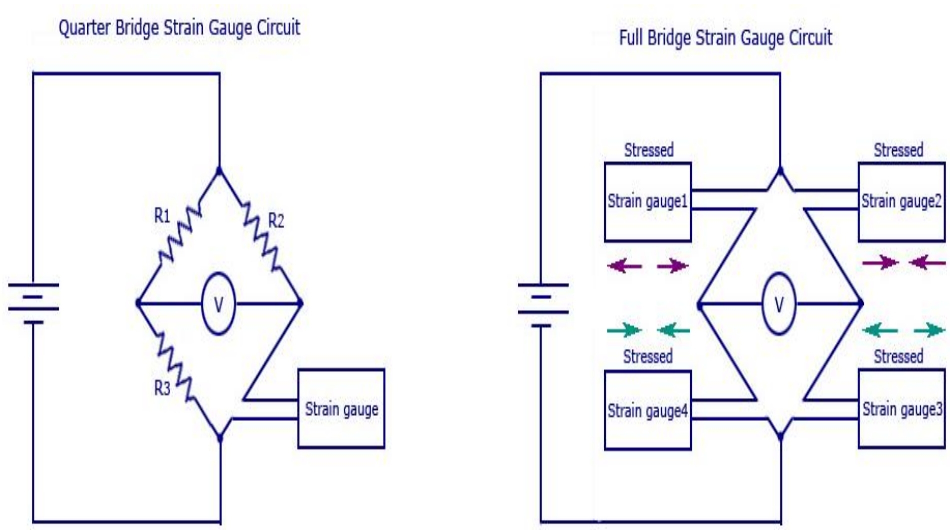


Fig 6.Quarter And Full Bridge Strain Gauge Circuit

A quarter bridge output corresponding to the application of a force is shown below. Initially, the circuit will be balanced without the application of any force. When a downward force is applied, the length of the strain gauge increases and thus a change in resistance occurs. Thus an output is produced in the bridge corresponding to the strain.

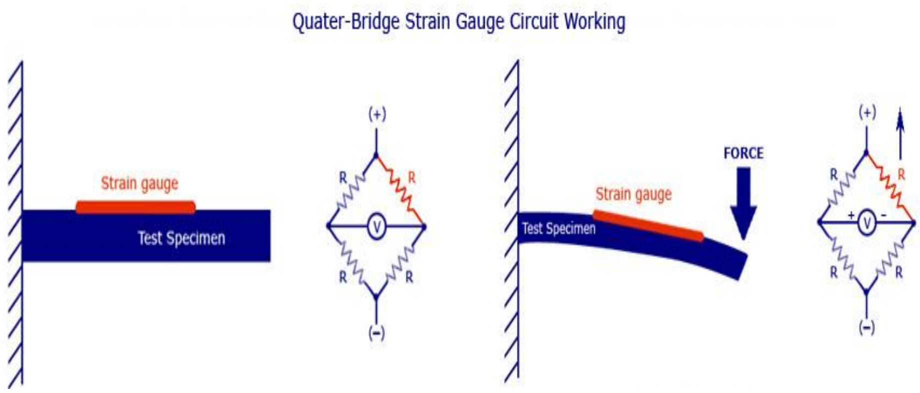


Fig 7.Quarter Bridge Strain Gauge Circuit-Working

Errors in Strain Gauge

Some of the main causes for errors and inaccuracy in the device reading are given below.

- Temperature Variation – This can be one of the major causes of error in a strain gauge. It can easily change the gauge resistance and cause differential expansion between the gauge and the test piece, causing variation in the measurable strain.
- Humidity – Humidity can affect the accuracy by the breakdown of insulation between the gauge and the ground point. It also causes electro-chemical corrosion of gauge wire due to electrolysis.
- Small errors could be caused due to thermoelectric effect.
- The gauge will be erroneous even due to small factors like zero drift, hysteresis effect and so on.
- Magnetostrictive effect can also cause errors in strain gauges of ferromagnetic materials. It produces a small voltage fluctuation of almost 2 mill volts.

Strain Gauge Applications

1. **Pressure Measurement**
2. **Acceleration Measurement**
3. **Temperature Measurement**

Piezoelectric Transducer

A piezoelectric crystal transducer/sensor is an active sensor and it does not need the help of an external power as it is self-generating. It is important to know the basics of a piezoelectric quartz crystal and piezoelectric effect before going into details about the **transducer**.

Piezoelectric Quartz Crystal

A quartz crystal is a piezoelectric material that can generate a voltage proportional to the stress applied upon it. For the application, a natural quartz crystal has to be cut in the shape of a thin plate of rectangular or oval shape of uniform thickness. Each crystal has three sets of axes – Optical axes, three electrical axes OX1, OX2, and OX3 with 120 degree with each other, and three mechanical axes OY1,OY2 and OY3 also at 120 degree with each other. The mechanical axes will be at right angles to the electrical axes. Some of the parameters that decide the nature of the crystal for the application are

- Angle at which the wafer is cut from natural quartz crystal
- Plate thickness
- Dimension of the plate
- Means of mounting

Piezoelectric Effect

The X-Y axis of a piezoelectric crystal and its cutting technique is shown in the figure below.

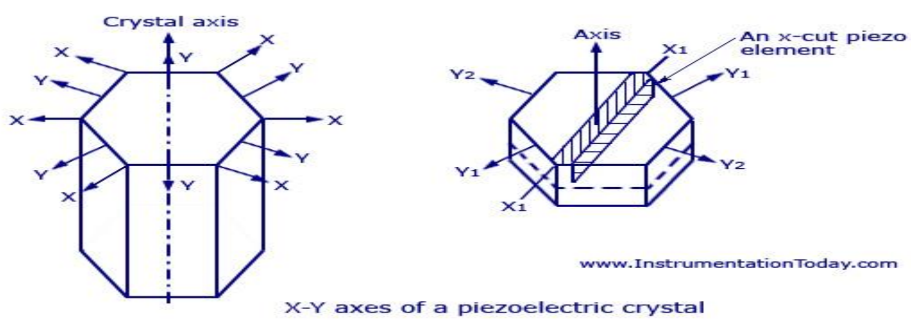


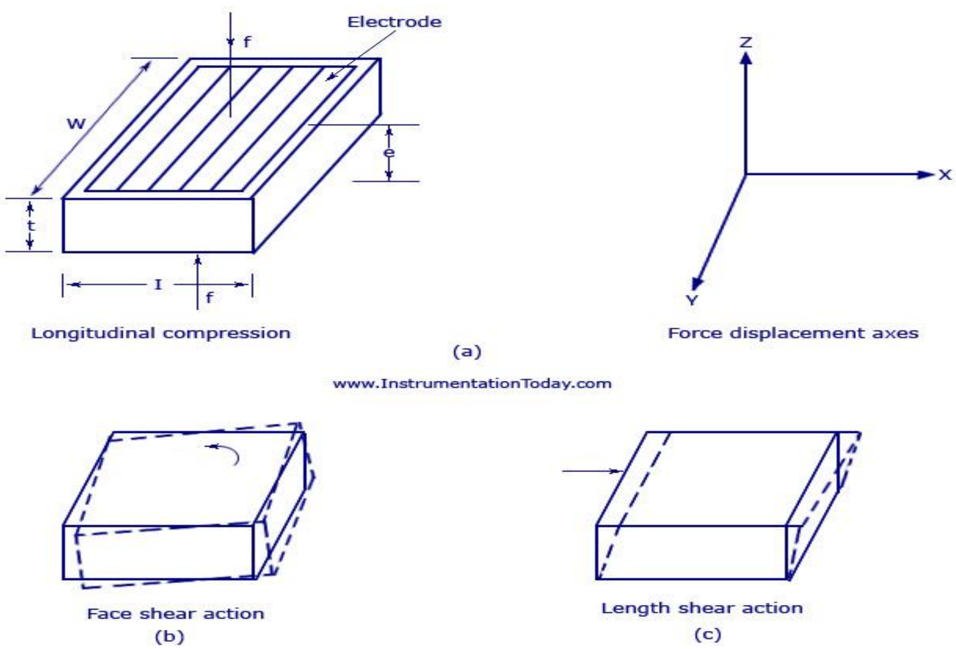
Fig 12.X-Y Axes of a Piezoelectric Crystal

The direction, perpendicular to the largest face, is the cut axis referred to.

If an electric stress is applied in the directions of an electric axis (X-axis), a mechanical strain is produced in the direction of the Y-axis, which is perpendicular to the relevant X-axis. Similarly, if a mechanical strain is given along the Y-axis, electrical charges will be produced on the faces of the crystal, perpendicular to the X-axis which is at right angles to the Y-axis.

Some of the materials that inherit piezo-electric effect are quartz crystal, Rochelle salt, barium titanate, and so on. The main advantages of these crystals are that they have high mechanical and thermal state capability, capability of withstanding high order of strain, low leakage, and good frequency response, and so on.

A piezoelectric transducer may be operated in one of the several modes as shown in the figure below.

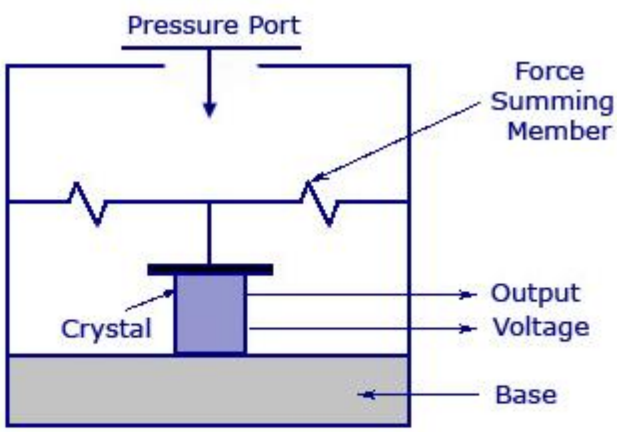


5.13 Piezoelectric Crystal

Piezoelectric Transducer

The main principle of a piezoelectric transducer is that a force, when applied on the quartz crystal, produces electric charges on the crystal surface. The charge thus produced can be called as piezoelectricity. Piezo electricity can be defined as the electrical polarization produced by mechanical strain on certain class of crystals. The rate of charge produced will be proportional to the rate of change of force applied as input. As the charge produced is very small, a charge amplifier is needed so as to produce an output voltage big enough to be measured. The device is also known to be mechanically stiff. For example, if a force of 15 kiloN is given to the transducer, it may only deflect to a maximum of 0.002mm. But the output response may be as high as 100KiloHz.This proves that the device is best applicable for dynamic measurement.

The figure shows a conventional piezoelectric transducer with a piezoelectric crystal inserted between a solid base and the force summing member. If a force is applied on the pressure port, the same force will fall on the force summing member. Thus a potential difference will be generated on the crystal due to its property. The voltage produced will be proportional to the magnitude of the applied force.



Piezo-Electric Transducer

Piezoelectric Transducer

Piezoelectric Transducer can measure **pressure** in the same way a **force**or an **acceleration** can be measured. For low pressure measurement, possible vibration of the amount should be compensated for. The pressure measuring quartz disc stack faces the pressure through a**diaphragm** and on the other side of this stack, the compensating mass followed by a compensating quartz.

Applications

1. Due to its excellent frequency response, it is normally used as an accelerometer, where the output is in the order of (1-30) mV per gravity of acceleration.
2. The device is usually designed for use as a pre-tensional bolt so that both tensional and compression force measurements can be made.
3. Can be used for measuring force, pressure and **displacement** in terms of voltage.

Advantages

1. Very high frequency response.
2. Self generating, so no need of external source.
3. Simple to use as they have small dimensions and large measuring range.
4. Barium titanate and quartz can be made in any desired shape and form. It also has a large dielectric constant. The crystal axis is selectable by orienting the direction of orientation.

Disadvantages

1. It is not suitable for measurement in static condition.
2. Since the device operates with the small electric charge, they need high impedance cable for electrical interface.
3. The output may vary according to the temperature variation of the crystal.
4. The relative humidity rises above 85% or falls below 35%, its output will be affected. If so, it has to be coated with wax or polymer material.

Hall Effect Sensor

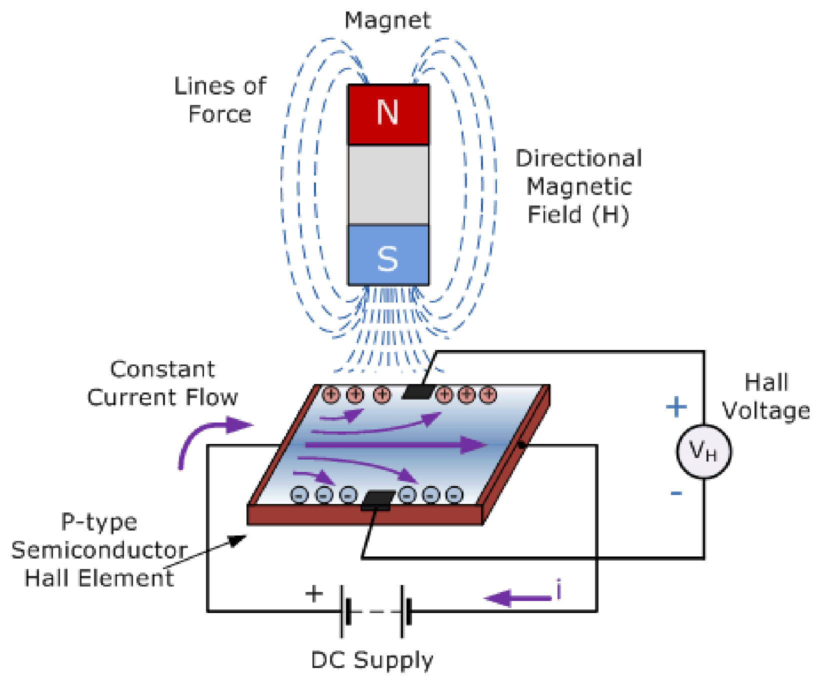
Magnetic sensors are solid state devices that are becoming more and more popular because they can be used in many different types of application such as sensing position, velocity or directional movement. They are also a popular choice of sensor for the electronics designer due to their non-contact wear free operation, their low maintenance, robust design and as sealed hall effect devices are immune to vibration, dust and water.

One of the main uses of magnetic sensors is in automotive systems for the sensing of position, distance and speed. For example, the angular position of the crank shaft for the firing angle of the spark plugs, the position of the car seats and seat belts for air-bag control or wheel speed detection for the anti-lock braking system, (ABS).

Magnetic sensors are designed to respond to a wide range of positive and negative magnetic fields in a variety of different applications and one type of magnet sensor whose output signal is a function of magnetic field density around it is called the **Hall Effect Sensor**.

Hall Effect Sensors are devices which are activated by an external magnetic field. We know that a magnetic field has two important characteristics flux density, (B) and polarity (North and South Poles). The output signal from a Hall effect sensor is the function of magnetic field density around the device. When the magnetic flux density around the sensor exceeds a certain pre-set threshold, the sensor detects it and generates an output voltage called the **Hall Voltage, V_H**. Consider the diagram below.

Hall Effect Sensors consist basically of a thin piece of rectangular p-type semiconductor material such as gallium arsenide (GaAs), indium antimonide (InSb) or indium arsenide (InAs) passing a continuous current through itself. When the device is placed within a magnetic field, the magnetic flux lines exert a force on the semiconductor material which deflects the charge carriers, electrons and holes, to either side of the semiconductor slab. This movement of charge carriers is a result of the magnetic force they experience passing through the semiconductor material.



As these electrons and holes move side wards a potential difference is produced between the two sides of the semiconductor material by the build-up of these charge carriers. Then the movement of electrons through the semiconductor material is affected by the presence of an external magnetic field which is at right angles to it and this effect is greater in a flat rectangular shaped material.

The effect of generating a measurable voltage by using a magnetic field is called the **Hall Effect**after Edwin Hall who discovered it back in the 1870's with the basic physical principle underlying the Hall effect being Lorentz force. To generate a potential difference across the device the magnetic flux lines must be perpendicular, (90°) to the flow of current and be of the correct polarity, generally a south pole.

The Hall effect provides information regarding the type of magnetic pole and magnitude of the magnetic field. For example, a south pole would cause the device to produce a voltage output while a north pole would have no effect. Generally, Hall Effect sensors and switches are designed to be in the “OFF”, (open circuit condition) when there is no magnetic field present. They only turn “ON”, (closed circuit condition) when subjected to a magnetic field of sufficient strength and polarity.

THEMISTORS

Thermistor is a temperature sensitive device. If the temperature varies, then the resistance of thethermistor either increases or decreases. By using this property, we can use it as a temperature sensor.Thermistor Thermometer is a resistor type thermometers. But, it differs from RTD or resistanceTemperature Detector. In Thermistors, thesebi-conductor materials are used, while RTD has pure metals.

The semiconductor materials are prepared from the oxides of chromium, cobalt, nickel, manganese, and sulphides of iron, aluminium or copper. Because of semiconductor, resistance of the thermistor varies significantly with temperature, more than the normal resistance. Thermistor thermometers have high sensitivity but it has nonlinear characteristics. This can be understood from the following example; for a typical 2000 Ω thermistor, the change in temperature at 25°C is 80Ω/°C, whereas for a 2000Ω platinum RTD, the change in temperature at 25°C is 7Ω/°C.

Thermistors are classified into two types. They are, Negative Temperature Co-efficient Thermistors, Positive Temperature Co-efficient Thermistors.The characteristics of NTC thermistor is more common, which is shown in below figure. In NTC thermistor, the resistance decreases as the temperature increases, according to the following expression

$$R_T = R_0 e^{\beta\left(\frac{1}{T}-\frac{1}{T_0}\right)} \quad (1)$$