Chapter 6

Electrical measuring instruments

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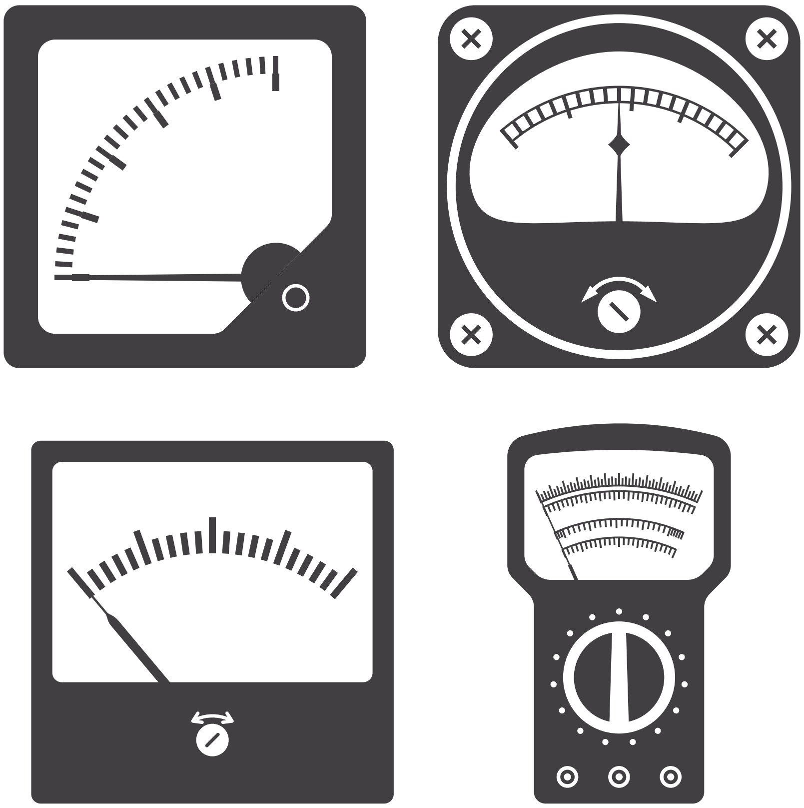

There is no lack of courage or no other virtues
— **Mahatma Gandhi**

Learning Objectives

Measuring instruments are used in electrical engineering to measure the electrical quantities like current, voltage, energy, resistance and frequency. Electrical measuring instruments are used to measure electrical quantities of any value and range.

The main objectives of this chapter is to learn the basic types of electrical measuring instruments, torques acting on indicating instruments, construction and operation of various types of electrical measuring instruments.

Table of Content

6.1 Introduction

Measurement is the act or the result of a quantitative comparison between a given quantity of same kind chosen as a standard. A device or mechanism used for comparing the unknown quantity with the unit of measurement or a standard quantity is called a measuring instrument.

Instruments which measure electrical quantities like voltage, current, power, energy etc. are called electrical instruments. These instruments are generally named after the electrical quantity to be measured. The instruments which measure voltage, current, electrical power and energy are called voltmeter, ammeter, wattmeter and energy meter respectively.

6.2 Classification of electrical measuring instruments

The various electrical measuring instruments may broadly classified into two groups, namely

1. Absolute instruments
2. Secondary instruments

6.2.1 Absolute instruments

Those instruments which indicate the quantity to be measured in terms of the instruments constants and its deflection are known as absolute instruments. It requires no previous calibration or comparison.

Example: Tangent galvanometer

6.2.2 Secondary instruments

Those instruments in which the value of electrical quantity to be measured can be measured from the deflection of instruments only are called secondary instruments. These instruments are calibrated by comparison with an absolute instrument or another secondary instrument which has already been calibrated against an absolute instrument.

Example: Voltmeters, ammeters and watt meters.

Secondary instruments are classified as:

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

i. Indicating instruments

An instrument which indicates the magnitude of the electrical quantity being measured at the time at which it is being measured is called as an indicating instrument. It has a pointer which moves over a calibrated scale and indicates the magnitude of electrical quantity.

Example: Ammeter, voltmeter and wattmeter.

ii. Integrating instruments

The instruments which measure the total quantity of electricity delivered over a specified time are called as integrating instruments.

Example: Energy meters (KWH meters) and ampere-hour meters

iii. Recording instruments

Instruments which give a continuous record of the variations of an electrical quantity over a period of time are called as recording instruments. The variations of the quantity being measured are recorded by a pen on a sheet of paper put over a moving drum.

Example: Electrocardiogram machine, pressure and temperature recorders.

6.2.3 Classification of measuring instruments according to the quantity being measured

Sl. No.	Name of the instrument	Quantity being measured
1	Voltmeter	Voltage
2	Ammeter	Current
3	Ohm meter	Resistance
4	Wattmeter	Power
5	Watt-hour meter	Energy
6	Power factor meter	Power Factor
7	Frequency meter	Frequency

6.3 Torques in indicating instruments

The following three types of torques are essential for the satisfactory operation of indicating instruments.

i. Deflecting torque
ii. Controlling torque and
iii. Damping torque

6.3.1 Deflecting torque

This torque is required in an indicating instrument for moving the pointer from its zero position. Deflecting torque is produced by utilizing the effects of electric current.

6.3.2 Controlling torque

This torque is required in an indicating instrument to ensure that the deflection is proportional to the magnitude of the quantity being measured. The controlling system produces a torque equal and opposite to the deflecting torque in order to make the deflection of pointer at a definite magnitude. The controlling system brings the moving system back to zero when the torque causing the deflection is removed.

(A) Controlling devices

There are two types of controlling devices.

i. Spring control
ii. Gravity control

i. Spring control

Figure 6.1 shows a commonly used spring control arrangement. Two hair springs made of phosphor bronze are attached to the moving system which exerts controlling torque. The two coils are coiled in opposite directions.

The inner ends of both the hair springs are attached to the spindle. The outer end of spring A is attached to lever which is actuated by a set screw mounted at the front of the instrument. So zero setting can be easily done without removing the cover. The outer end of spring B is fixed.

When the pointer moves under the influence of deflecting torque, one of the spring unwind itself while the other gets twisted. The twist produces the controlling torque which is directly proportional to the angular deflection of the pointer.

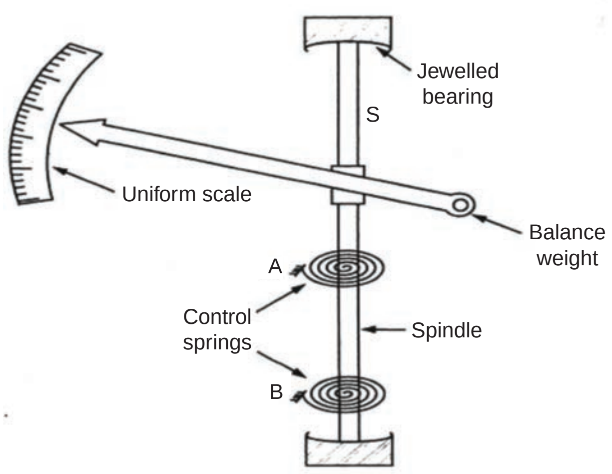

Fig. 6.1 Spring control

ii. Gravity control

The arrangement of gravity control system is shown in figure 6.2, in which two adjustable weights, control weight and balance weight are attached to the spindle. The control weight provides a controlling torque due to gravity while the balance weight is used for balancing the weight of the moving system.

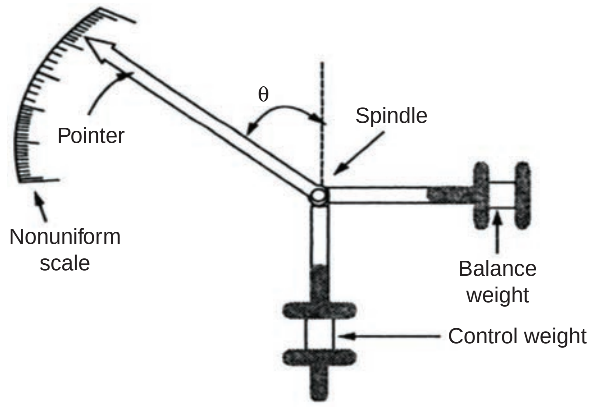

Fig. 6.2 Gravity control

6.3.3 Damping torque

The deflecting torque provides some deflection and controlling torque acts in the opposite direction to that of deflecting torque. So before coming to the rest, pointer always oscillates due to inertia, about the equilibrium position. So to bring the pointer to rest within short time, damping torque is required.

If the moving system reaches to its final position rapidly but smoothly without oscillations, the instrument is said to be critically damped. If the damping torque is more than what is required for critical damping, the instrument is said to be over damped. In over damped case the response of the system is very slow and lethargic.

If the instrument is under damped, the moving system will oscillate about the final steady position with decreasing amplitude and will take some time before it comes to rest.

The following three methods are used for producing damping torque.

i. Air friction damping
ii. Fluid friction damping
iii. Eddy current damping

i. Air friction damping

Figure 6.3 shows an arrangement for obtaining air friction damping. This arrangement consists of a light aluminium piston which is attached to the moving system. The piston moves in a fixed air chamber which is closed at one end. The clearance between piston and wall chamber is uniform and small.

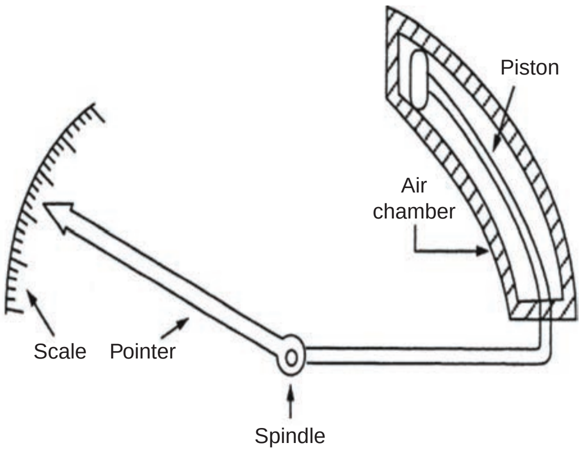

Fig. 6.3 Air friction damping

When the piston moves into the chamber, air inside the chamber is compressed and thus the pressure inside the chamber opposes the motion of the piston and hence whole of the moving system. When the piston moves out of the chamber, the pressure inside the chamber falls and the pressure on open side becomes greater than on the other side and thus there is again an opposition to motion of the piston.

ii. Fluid friction damping

This method is similar to air friction damping. In this only air is replaced by damping oil. The damping oil employed must have the following properties:

i. Must be a good insulator.
ii. Viscosity of oil should not change with temperature.
iii. Should be non-evaporating.
iv. Should be non-corrosive.

In this method, a disc attached to the spindle of moving system is immersed in damping oil as shown in figure 6.4. When the moving system moves, the disc moves in oil and a frictional drag is produced which opposes the motion of the moving system. Damping force due to fluid is greater than that of air due to more viscosity.

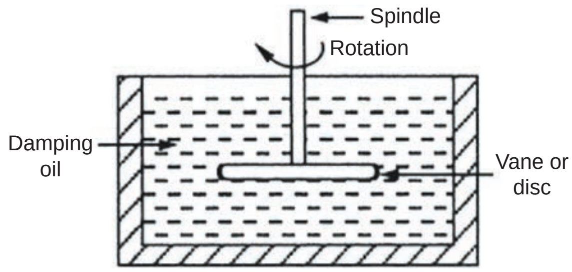

Fig. 6.4 Fluid friction damping

iii. Eddy current damping

In this method, an aluminium or copper disc is connected to the spindle. The disc is positioned between the poles of a permanent magnet as shown in figure 6.5. If the disc moves, it cuts the flux which causes an induced e.m.f. in the disc. As the disc is a closed path, induced emf circulates eddy currents in the disc.

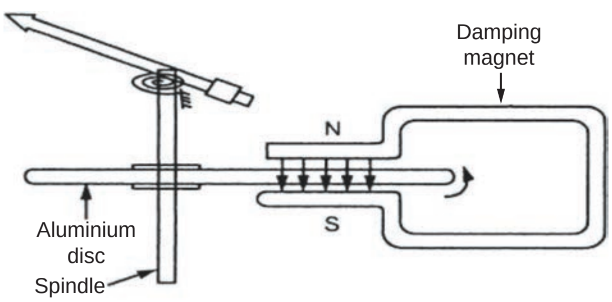

Fig. 6.5 Eddy current damping

The direction of such eddy currents is so as to oppose the cause producing it which is the relative motion between disc and field. Thus it produces an opposing torque so as to reduce the oscillations of pointer. This is the most efficient method of damping.

6.4 Types of electrical measuring instruments based on principle of operation

1. Moving coil type
   (a) Permanent magnet moving coil instruments
   (b) Dynamometer type instruments
2. Moving iron type
   (a) Attraction type
   (b) Repulsion type

6.4.1 Permanent Magnet Moving Coil (PMMC) instruments

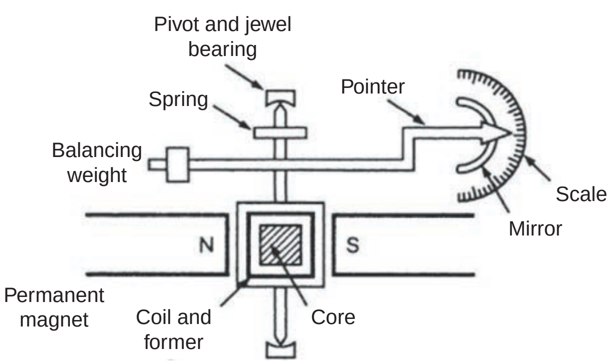

Fig. 6.6 Permanent magnet moving coil instrument

The permanent magnet moving coil instrument is shown in the figure 6.6. It is the most accurate type of instrument and is used for DC measurements.

The moving coil is wound with many turns of fine enameled or silk covered copper wire. The coil is mounted on rectangular aluminium former which is pivoted on jeweled bearings. The coil is placed in the magnetic field of a permanent magnet in the shape of a horse-shoe. Two spiral shaped phosphor bronze hair springs are fixed. They are used to carry the coil current and give the controlling torque to the coil. The damping torque is provided by eddy current damping. It is obtained by movement of the aluminium former, moving in the magnetic field of the permanent magnet.

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It works on the principle that when a current carrying coil (or conductor) is placed in the magnetic field, the coil (or conductor) experiences a force and moves. The amount of force experienced by the coil is proportional to the magnitude of current through the coil.

Thus deflecting torque is directly proportional to the current passing through the coil and hence the scale is uniform. The direction of deflection is according to the direction of current through the coil.

(A) Advantages

i. The scale is uniform
ii. No hysteresis loss
iii. Low power consumption
iv. No effect of stray magnetic field
v. High torque-weight ratio
vi. Effective and efficient eddy current damping
vii. Range can be extended by using shunts and multipliers

(B) Disadvantages

i. Can be used for DC measurements only.
ii. Cost is higher than that of moving iron instruments.

6.4.2 Extension of range

a) DC voltmeters

A DC milli ammeter may be converted as a voltmeter by connecting a high resistance called multiplier in series with the instrument. The multiplier limits the current through the meter so that the current through it not exceed the value of full scale deflection current. A voltmeter measures the voltage across two points and hence connected in parallel to the terminals.

Let,

R_s = multiplier resistance

I_m = full scale deflection current of the instrument

R_m = resistance of the moving coil of the instrument

V = voltage of the circuit to be measured

$$V = I_m R_m + I_m R_s$$

$$I_m R_s = V - I_m R_m$$

$$\therefore R_s = \frac{V - I_m R_m}{I_m}$$

Do you Know?

Ammeters must always be connected in series in a circuit and have a very low internal resistance. Voltmeters must always be connected in parallel in a circuit and have a very high internal resistance

b) DC ammeters

The moving coil of PMMC instrument is light and small and hence can carry very small current. The galvanometer may be converted as an ammeter by connecting a very low value of resistance called shunt in parallel with the instrument. The shunt is used to bypass major part of current so that the current through the moving coil not exceed the value of full scale deflection current. An ammeter measures the current through the circuit and hence connected in series to the load.

Let,

R_{sh} = the value of shunt resistance

I_{sh} = current through the shunt

I_m = full scale deflection current of the instrument

R_m = resistance of the moving coil of the instrument

I = current of the circuit to be measured

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

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

$$R_{sh} = \frac{I_m R_m}{I - I_m}$$

6.4.3 Moving iron type instruments

The moving iron instruments are used to measure both AC and DC voltages and currents. They are classified into two types:

(i) Attraction type

(ii) Repulsion type

(i) Attraction type moving iron instruments

The construction of the attraction type instrument is shown in the figure 6.7. Attraction type moving iron instrument consists of a fixed coil and moving iron piece. The fixed coil is wounded on a former. The fixed coil carries the current proportional to the voltage to be measured or the current to be measured. The moving iron is a flat disc which is eccentrically mounted on the spindle. The spindle is supported between the jewel bearings. A pointer is also attached to the spindle which moves over a graduated scale.

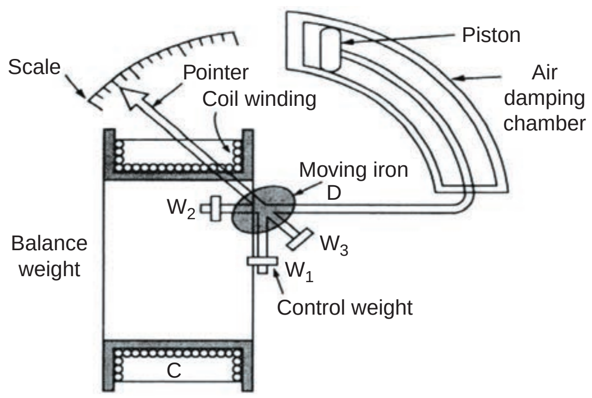

Fig. 6.7 Attraction type moving iron instrument

The basic principle of these instruments is that when a soft iron piece is brought near the magnet gets attracted by the magnet. When the current flows through the coil, a magnetic field is produced. Thus the moving iron gets attracted and moves into the coil, causing the spindle and the pointer to rotate.

The controlling torque is provided by the springs but gravity control may be used for vertically mounted panel type instruments. Damping torque is provided by air friction. A light aluminium piston is attached to the moving system. It moves in a fixed air chamber which is closed at one end. The movement of piston provides the required damping torque.

(ii) Repulsion type moving iron instruments

Repulsion type moving iron instrument is shown in figure 6.8. It has two vanes inside the coil, one fixed and the other movable. The vanes are radial stripes of iron. The fixed vane is attached to the coil and the movable vane to the spindle of the instrument.

The fixed coil carries the current or the current proportional to the voltage to be measured. When the current flows through the coil, the two vanes are magnetized in the same direction and there is a force of repulsion between the two vanes resulting in the motion of moving vane. As the moving iron is fixed with the spindle, the pointer moves on the scale when the spindle moves. The controlling torque is provided by springs and the damping torque is produced by Air friction. Whatever may be the direction of current in the coil, the two vanes are magnetized in the same direction. So the spindle always moves in one direction. Therefore, these instruments can be used on both AC and DC.

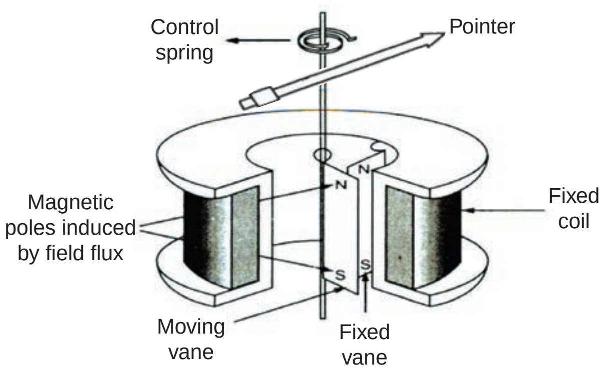

Fig. 6.8 Repulsion type moving iron instrument

a) Advantages

i. It can be used for both AC and DC measurements.
ii. Robust and simple in construction.
iii. The cost is low.
iv. Possess high operating torque.
v. Less friction errors.
vi. These can withstand over loads momentarily.
vii. The range of instruments can be extended.

b) Disadvantages

i. This Scale is not uniform and is cramped at the lower end.
ii. There are serious errors due to hysteresis, frequency changes and stray magnetic fields.
iii. Power consumption is higher for low voltage range.
iv. There is a difference between AC and DC calibrations on account of the effect of inductance of the meter and eddy currents on AC.

6.5 Dynamometer type wattmeter

Dynamometer type watt meters are generally used for the measurement of power. It has two coils, one is a fixed coil and other is a moving coil. Both the fixed and moving coils are air cored. The fixed coil is divided into two equal portions in order to provide uniform field. The fixed coil is used as current coil and is connected in series with the load. The moving coil is used as pressure coil and is connected in parallel with the load. A high non-inductive resistance is connected in series with the moving coil to limit the current through it.

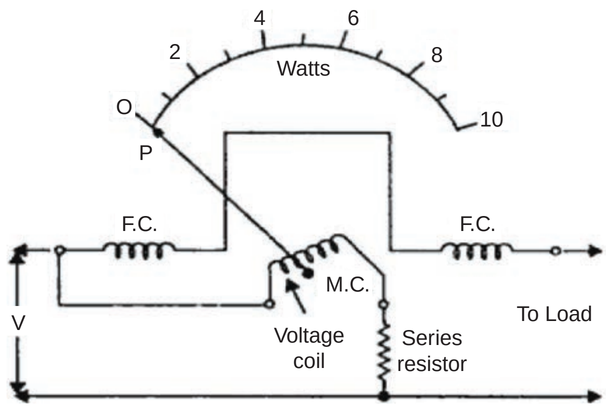

Fig. 6.9 Connection diagram of dynamometer type wattmeter

In this meter, the current coil carries the load current and the pressure coil carries the current proportional to the voltage across the circuit. The interaction of two magnetic fields produced by the current flowing through the fixed coils and moving coil causes the moving coil to turn about its axis. It is directly proportional to the product of voltage and current. The controlling torque is provided by the hair springs. These hair springs also lead the current into and out of the moving element. Air friction damping is used. Dynamometer type watt meters are suitable for both DC and AC power measurements.

a) Advantages

1. The scale is uniform.
2. High degree of accuracy can be obtained by careful design.
3. It is used both in AC and DC.

b) Disadvantages

1. The error due to the inductance of the pressure coil at low power factor is very serious.
2. Stray field may affect the reading of the instrument.

6.6 Induction type wattmeter

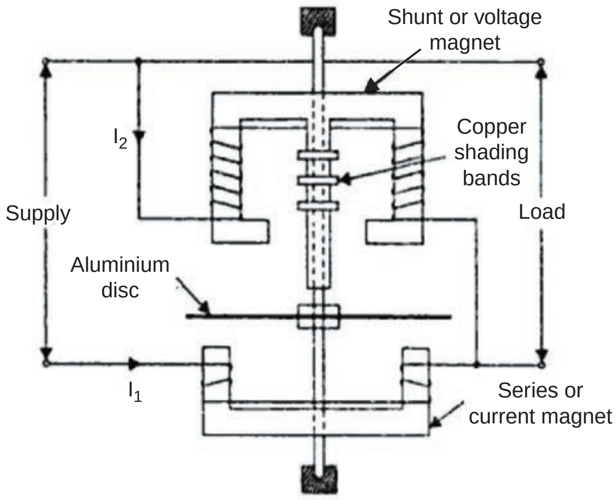

Fig. 6.10 Induction type wattmeter

Figure 6.10 shows an induction type wattmeter. It has two laminated electromagnets, namely shunt magnet and series magnet. The shunt magnet is excited by pressure coil and carries current which is proportional to the voltage of the circuit. Its pressure coil is connected in parallel with the circuit. The series magnet is excited by current coil which is connected in series with the load. A thin aluminium or copper disc is mounted in such a way that it cuts the fluxes of both the magnets.

Hence two eddy currents are produced in the disc. The deflection torque is produced due to the interaction of these eddy currents and the inducing fluxes. Two or three copper rings, called shadings rings are fitted on the central limb of the shunt magnet and can be so adjusted as to make the resultant flux in the shunt magnet lag behind the applied voltage by exactly 90°.

This instrument is provided with spiral springs to provide controlling torque. The spring being fitted to the spindle of the moving system and carries a pointer. The scale is quite uniform and extends over 300°. Induction watt meters can be used on AC circuit only.

a) Advantages

i. Fairly long scale. (extending over 300°)
ii. Free from the effects of stray fields.
iii. Good damping.
iv. Practically free from frequency errors.

b) Disadvantages

i. Sometimes subject to serious temperature errors.
ii. Power consumption is comparatively higher.
iii. Heavy moving system.

6.7 Multimeter

A multimeter is used to measure the following quantities.

i. AC voltage and current of different ranges
ii. DC voltage and current of different ranges
iii. Resistance of different ranges

As multi meter is used for measuring current (A), voltage (V) and resistance (Ohm), it is also called AVO meter. There are two types of multimeters, namely analog multimeter and digital multimeter.

An analog multimeter is basically a permanent magnet moving coil galvanometer. The scale is calibrated for each range and type of measurement. The range and the particular type of measurement are selected by a selector switch.

To measure the resistance of an external resistor, the test leads are connected across the external resistor. The pointer moves on the scale and shows the value of resistor. Different electrical quantities can be measured by inserting the test leads in different jacks for each quantity and range.

Fig. 6.11 Multi meter

6.8 Megger

An instrument used for the measurement of high resistance or the insulation resistance is called as megger or insulation tester. The simplified connection diagram of megger is shown in figure 6.12. It has three terminals, namely, the line (L), the earth (E), and the guard.

The moving system consists of three coils known as, the pressure (or control) coil and the current (or deflecting) coil and compensating coil which are mounted rigidly to a pivoted central shaft. The compensating coil is connected in series with the pressure coil in order to provide better scale proportions and to make the arrangement a static. The moving system is free to rotate over a C-shaped iron core. The magnetic field is produced by a pair of permanent magnets for both generator and the moving system.

a. Working principle

Now when the resistance under measurement is connected to the test terminals L and E, the deflecting torque and the controlling torque are produced which oppose each other. At balance, the pointer rests at some intermediate point on the scale. The scale is calibrated in mega ohm and kilo ohm and therefore the value of the resistance under test is indicated by the position of the pointer on the scale.

The required test voltage is generated by a small handle operated permanent magnet DC generator. The generator armature is rotated by hand using the handle at a constant speed which induces the required voltage for testing.

The resistance under test is connected between the terminals L and E and the hand driven generator is rotated at a uniform speed until the pointer shows a stead deflection. In order to maintain constant voltage, a centrifugal clutch is usually provided in the generator drive mechanism which slips at predetermined speed. The test voltages of hand driven megger are 250V, 500V and 1000V.

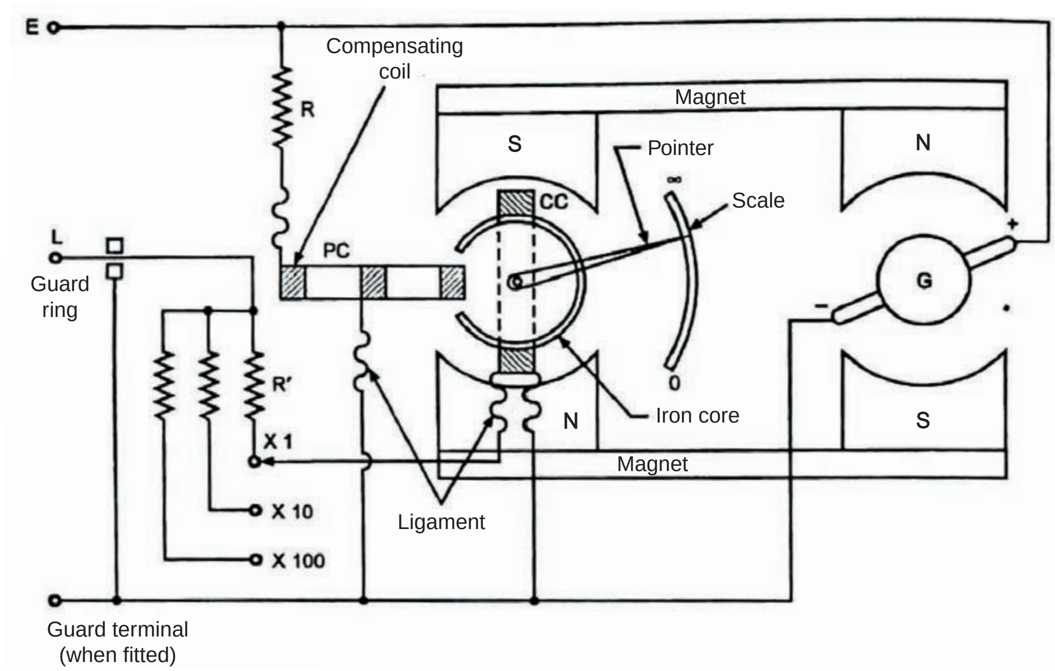

Fig. 6.12 **Megger**

6.9 Tong Tester

A tong tester is shown in figure 6.13. Ammeters cannot be used directly to measure the current flowing through lines. Because, to connect the ammeter along the path of the current, the line has to be opened at that point and then the ammeter has to be connected in series in the line. Once the testing is over the line has to be rewired. This is not an efficient or feasible method.

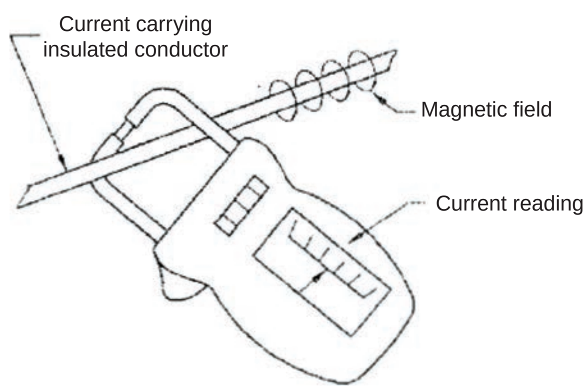

Fig. 6.13 **Tong tester**

Tong tester is helpful in measuring the alternating current without interrupting the circuit. It consists of a current transformer in its jaw, usually a bar CT. When the instrument is clamped on a conductor, the conductor itself acts as primary and the magnetic flux due to current flowing through the conductor cuts the secondary of CT. With the help of ammeter connected to the handle of the tong tester, the current flowing through the circuit can be measured. It is also called as clamp-on meter. This is also used to measure high voltage across any two points.

Handling procedure

i. Open the jaws of the tong tester and place them around the conductor.
ii. To avoid any harm in the circuit, select a higher scale-value first.
iii. Slowly decrease the scale value using selector switch if current is less.
iv. Measure the current of each line one by one.

Glossary

Deflecting torque	-	விலக்க சுழற்றுமை
Controlling torque	-	கட்டுப்படுத்தும் சுழற்றுமை
Damping torque	-	ஒடுக்கல் சுழற்றுமை
Moving iron	-	இயங்கு இரும்பு
Absolute instruments	-	தனிநிலைக் கருவிகள்
Spring control	-	வில் கட்டுப்பாடு
Gravity control	-	ஈர்ப்பு விசைக் கட்டுப்பாடு
Piston	-	உந்துத் தண்டு
Multiplier	-	பெருக்கி
Shunt	-	இணைத்தடம்
Analog multimeter	-	குறிமுள் பல்நோக்கு அளவுமானி
Digital multimeter	-	எண்ணிலக்க பல்நோக்கு அளவுமானி
Eddy current	-	சுழல் மின்னோட்டம்
Range	-	நெடுக்கம்
Galvano meter	-	மின்னோட்ட அளவி

Evaluation

PART-A

Choose the correct answer **(1 Marks)**

1. Which of the following are integrating instruments?
   a) Ammeters
   b) Voltmeters
   c) Watt meters
   d) Ampere-hour and energy meters

2. Which of the following essential feature is possessed by an indicating instrument?
   a) deflecting system
   b) controlling system
   c) damping system
   d) recording system

3. Damping of deflecting type instrument is done to
   a) reduce the angle of deflection of the pointer
   b) reduce the oscillations of the pointer in the final deflected position
   c) make the moving system go slow
   d) make the moving system move fast on the graduated scale

4. The permanent magnet moving coil type instruments are best suited for
   a) DC Measurement
   b) AC measurement
   c) DC/AC measurement
   d) frequency measurement

5. For measurement of direct current, we may use
   a) a galvanometer
   b) a hot-wire-type ammeter
   c) a moving-iron-type ammeter
   d) a permanent magnet moving coil type ammeter

6. The moving iron type instruments are suitable for
   a) DC measurements only
   b) AC measurements only
   c) DC/AC measurement
   d) resistance measurement

7. When a permanent magnet moving coil (PMMC) instrument is connected to AC voltage
   a) the instrument will get damaged.
   b) the pointer will not move at all.
   c) the pointer will oscillate to and fro.
   d) the instrument will indicate zero.

8. The extension of range of an ammeter and a volt meter can be made respectively by

a) reducing the spring tension of the deflecting system
b) using series capacitor and a series inductor
c) using multiplier and shunt
d) using shunt and multiplier

9. Ammeter is connected with load in
a) series
b) parallel
c) series and parallel
d) opposite to each other

10. Voltmeter is connected in a circuit in
a) series
b) parallel
c) series and parallel
d) opposite to each other

11. The dynamometer wattmeter can be used to measure
a) DC power only
b) AC power only
c) AC or DC power
d) milli values only

12. Induction wattmeter can be used to measure
a) AC power only
b) DC power only
c) AC or DC power
d) milli values only

13. In induction-type wattmeter,
a) voltage coil is the moving coil
b) current coil is the moving coil
c) both are moving coils
d) none are moving coils

14. A megger is used for the measurement of
a) low valued resistances.
b) medium valued resistances.
c) high valued resistances, particularly insulation resistance.
d) power only.

15. The electrical power to a megger is provided by
a) battery
b) permanent magnet DC generator
c) AC Generator
d) DC motor

16. Multi meter is called as
a) watt meter
b) tong tester
c) AVO meter
d) energy meter

17. Tong testers are used because
a) it is possible to measure current flowing in a line without breaking the circuit.
b) for accurate measurement of electrical quantities.
c) for accurate measurement of energy.
d) for accurate measurement of resistance.

PART-B

Answer the questions in brief **(3 Marks)**

1. How are secondary instruments classified?
2. Describe the various operating forces needed for proper operation of an analog indicating instrument.
3. What is multimeter?
4. What is the use of tong tester?
5. How is watt meter connected in a circuit?
6. How will you convert a moving coil instrument into a voltmeter?
7. How will you convert a moving coil instrument into an ammeter?
8. What will happen if a voltmeter is connected in series with the load and ammeter in parallel with the supply?
9. What are the advantages of induction type watt meters?
10. How will you connect an ammeter and a voltmeter in an electric circuit?

PART-C

Answer the questions in one page **(5 Marks)**

1. Write short notes on (i) air friction damping (ii) eddy current damping.
2. Explain the working principle of moving iron instruments?
3. Explain the construction and operation of dynamometer type wattmeter.
4. Describe with a neat sketch the construction and working of tong tester.

PART-D

Answer the questions in two page **(10 Marks)**

1. Explain the constructional details and principle of working of a permanent magnet moving coil instrument.
2. Explain with the help of a neat sketch the construction and working of megger.

Reference Book

1. A text book of ‘Electrical Technology’ Volume-I B.L.Theraja and A.K.Theraja, S.Chand & Company Ltd.
2. A course in Electronics and Electrical Measurements and Instrumentation- J.B.Gupta, S.K.Kataria & Sons
3. Electrical Measurements and Measuring Instruments-R.K.Rajput, S.Chand & Company Ltd.

Reference Internet Source

1. http://www.wikipedia.org
2. https://www.electrical4u.com