# Chapter 2

# Electrical Measuring Instruments

**LEARNING OBJECTIVES**

*After reading this chapter, you will be able to understand:*

- Indicating instruments
- Types of torques
- Moving coil instruments
- Errors in PMMC instruments
- Electrodynamometer type
- Instruments
- Deflecting torque
- Moving iron instruments
- Deflecting torque
- Classification of instruments

## Indicating Instruments

- They consist of a pointer moving over a calibrated scale attached to the moving system pivoted in jewel bearings.
- The following torques are needed for proper operation.

## Types of Torques

### Deflecting Torque ($T_d$)

- When the instrument is connected in the electrical circuit to measure given electrical quantity, there must be an arrangement for providing operating or deflecting torque.
- Deflecting torque causes the moving system to move from zero position. When the instrument is connected in the circuit.

### Controlling Torque ($T_c$)

Under the action of deflecting torque, the pointer will continue to move indefinitely and shall be independent of the value of electrical quantity to be measured.

- Here, a controlling torque is introduced which should oppose $T_d$ and should increase with deflection of moving system so that the pointer is brought to rest at a position when two opposing torques are equal.
- Controlling torque limits the movement of the pointer so that the magnitude of deflection is always the same for given value of electrical quantity to be measured.
- It brings the pointer back to zero position when $T_d$ is removed. If it was not provided the pointer once deflected would not return to zero position on removing the deflecting torque.
- $T_c$ (or) restoring (or) balancing torque is provided either by a spring or by gravity. A hair spring is attached to the moving system the spring is twisted in opposite direction, which produces a restoring torque. Gravity control is obtained by attaching a small adjustable weight to the moving system.

### Damping Torque

- If the moving system is acted upon by a $T_D$ and $T_c$, then the pointer, due to its inertia will oscillate about final position before coming to rest.
- In order to avoid these oscillations of the pointer and bring it to its deflected position, damping torque is provided which opposes the movement of the pointer and operates 'only when the system is moving'.
- If the instrument is underdamped the pointer will oscillated about the final position before coming to rest.
- For overdamped instrument the pointer is slow and lethargic.
- For dead beat system, the degree of damping is adjusted such that pointer moves and quickly comes to its final position.
- Damping force is produced by air friction, eddy currents and fluid friction.
- In air friction damping, an aluminium piston attached to the moving system is arranged to travel in a fixed air chamber closed

at one end. The necessary damping effect is produced by movement of piston in the chamber.

- Fluid friction is similar in action to the air friction. Damping is produced by movement of piston in oil.
- The most efficient type of damping is obtained by eddy current damping. A non-magnetic metallic disc is attached to the moving system, cuts the magnetic flux. Hence eddy currents are produced in the disc, which produces a damping force in such a direction to oppose the cause producing them.

## Types of Indicating Instruments

1. Moving coil instruments
2. Moving iron instruments
3. Dynamometer type instruments
4. Electrostatic instruments
5. Hot wire type instruments
6. Induction type instruments

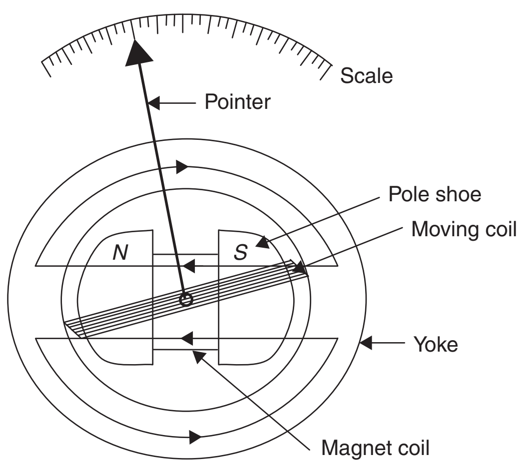
# Moving Coil Instruments

They are again classified into the following two types:

1. Permanent magnet moving coil instruments
2. Dynamometer type instruments

## Permanent Magnet Moving Coil Instruments

- It is a DC-indicating instrument.
- It is employed either as ammeter or voltmeter and can be used for DC work only.




### Principle

This type of instrument is based on the principle of Permanent Magnet Moving Coil (PMMC), i.e. when a current-carrying conductor is placed in a magnetic field, mechanical force acts on the conductor. The coil placed in the magnetic field and carrying operating current is attached to the moving system. With the movement of the coil the pointer moves over the scale.

### Construction

It consists of a powerful permanent magnet with soft iron pieces and light rectangular coil of many turns of fine wire wound on aluminium former inside which is an iron core.

- The purpose of the coil is to make field uniform. The coil is mounted on the spindle and acts as the moving element.
- The current is led into and out of the coil by means of the two control hair springs, one above and the others below the coil.
- The springs also provide controlling torques. Eddy current damping is provided by aluminium former.

### Working

- When the instrument is connected in the circuit, operating current flows through the coil. This current carrying coil is placed in the magnetic field produced by the permanent magnet and therefore mechanical force acts on the coil. As the coil is attached to the moving system the pointer moves over the scale.
- These instruments work for DC circuits only, since negative current leads to opposite side deflection of the pointer (below zero).

### Deflecting Torque

When current is passed through the coil, a deflection torque due to the reaction between permanent magnet field and magnetic field of the coil.

$$F = BIN\,L$$

where $B$ = Flux density in Wb/m$^2$
$L$ = Active length of the coil side in meters
$N$ = Number of turns of coil
$I$ = Current flowing through the coil
$F$ = Force acting on each coil side

Deflecting torque $T_d\,\omega$ = Force × perpendicular distance

$$T_d\,\omega = F \times 2r \text{ Nm}$$

$r$ = distance of the coil side from the axis of rotation in meters

$$T_d = NBI\,l \times 2r \text{ Nm}$$

If $A = l \cdot 2r$ is the surface area of the coil

$$T_d = NBIA \text{ Nm}$$

$N$, $B$ and $A$ are constants

$$\Rightarrow \qquad T_d \propto \text{I} \qquad (1)$$

Since control is by springs

$$T_c \propto \theta \qquad (2)$$

The pointer will come to rest at $T_d = T_c$

From (1) and (2) $\theta \propto I$

Therefore, such instruments have uniform scale.

**Note:** PMMC reads average values.

## Errors in PMMC Instruments

The main sources of error in moving coil instruments are due to

1. Weakening of permanent magnets due to ageing and temperature effects.
2. Change of resistance of moving coil with temperature.

### Advantages

1. Uniform scale.
2. Very effective eddy current damping.
3. Power consumption is low.
4. No hysteresis loss.
5. As working field is very strong, such instruments are not affected by stray fields.
6. Such instruments require small operating current.
7. Very accurate and reliable.

### Disadvantages

1. Such instruments cannot be used for AC.
2. Costlier as compared to moving iron instruments.
3. Errors are caused due to the ageing of control springs and the permanent magnet.

## Solved Examples

**Example 1:** The cross-sectional area of the coil of a P.M.M.C instrument with a spring constant of $0.28 \times 10^{-6}$ Nm/rad is $7.2 \times 10^{-4}$ m$^2$. The air gap flux density is 3.6 m Wb/m$^2$. The number of turns required to produce a deflection of 60° when a current of 10 mA flows through the coil would be

(A) 136 (B) 44 (C) 22 (D) 11

**Solution:** (D)

For P.M.M.C. $T_d = NBAI$ $T_c = K\theta$

At the instance when reading is taken

$$T_d = T_c$$

$$NBIA = K\theta$$

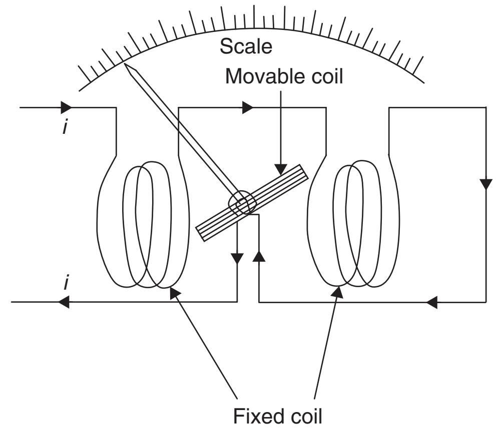
$$N = \frac{K\theta}{BIA}$$

$$= \frac{0.28\times10^{-6}\times\frac{\pi}{3}}{3.6\times10^{-3}\times7.2\times10^{-4}\times10\times10^{-3}}$$

= 11 turns.

## Electrodynamometer Type Instruments

- It is a modified form of PMMC.
- Here, operating field is produced not by a permanent magnet but by another fixed coil. The moving system and control system are similar to those of permanent magnet type.
- They can be used as ammeters and voltmeters but are generally used as wattmeters.




### Principle

These instruments are based on the principle that the mechanical force exists between the current-carrying conductors.

### Construction

- It consists of a fixed coil and moving coil.
- Fixed coil is split into two equal parts which are placed close together and parallel to each other. The moving coil is pivoted between two fixed coils.
- The fixed and moving coils may be exited separately or they may be connected in series depending upon the use to which the measurement is put. The moving coil is attached to the moving system such that under the action of deflecting torque the pointer moves over the scale.
- The controlling torque is provided by two springs which also serves the additional purpose of leading the current into and out of the moving coil. Air friction damping is provided in such instruments.

### Working

- When instrument is connected in the circuit, operating current flows through the coils, due to which mechanical force exist between the coils.
- The result is that the moving coil moves the pointer over the scale. The pointer comes to rest at a position where deflecting torque is equal to controlling torque.
- By reversing the current, the field due to fixed coils as well as the current in the moving coil is reversed, so that the direction of deflection remains unchanged.
- These instruments can be used for both AC and DC.

### Deflecting Torque

$$T_d \propto I_f I_m$$

$I_f$ = Current through fixed coil

$I_m$ = Current through moving coil

$I_f = I_m$ [since it is a series connection]

$$T_d \propto I^2$$

Since the control is by springs $T_c \propto \theta$

The pointer will come to rest at

$$T_d = T_c$$
$$\theta \propto I^2$$

Hence the scale of these instruments is non-uniform being crowded in their lower parts and spread out at the top.

Electrodynamometer type Ammeter $\theta = \frac{I^2}{K}\left(\frac{dM}{d\theta}\right)$

Electrodynamometer type Voltmeter $\theta = \frac{V^2}{KZ^2}\left(\frac{dM}{d\theta}\right)$

where $K$ is the spring constant in Nm/rad
$M$ is mutual inductance of the coil

### Errors

1. **Torque/Weight ratio:** A low torque/weight ratio indicates a heavy moving system and therefore the friction losses in electrodynamometer type of instrument are larger than in other types. Frictional errors are high.
2. **Frequency:** Frequency error is large as a result of variation of self-reactance of the coils, with frequency.
3. **Eddy currents:** The effect of eddy current is to produce a torque as a result of coupling between moving coil and adjacent metal parts. The metal present in coil supports, in the shields, etc. produces a frequency error in the instrument.
4. **External magnetic fields:** Since the operating field in electrodynamometer instruments is weak, therefore these instruments must be protected from external magnetic fields.
5. **Temperature changes:** High currents are carried by coils which produce heat. Self-heating of coils produce errors.

### Advantages

- These instruments can be used for both AC and DC measurements.
- They are free from hysteresis and eddy current errors.

### Disadvantages

- Since torque/weight ratio is small therefore such instruments have frictional errors which reduce sensitivity.
- Scale is not uniform.
- A good amount of screening of the instruments is required to avoid the effect of stray fields.
- These instruments are costlier and so they are rarely used.

**Example 2:** The variation of mutual inductance $M$ with deflection $\theta$ for a certain dynamometer type ammeter is given as $M = [-3\cos(\theta + 60°)]$ mH. If the pointer deflects 30° for a direct current of 25 mA.The magnitude of deflecting torque produced would be.

(A) 1.875 μN
(B) 3.6 μN
(C) 15 μN
(D) 18.75 μN

**Solution:** (A)

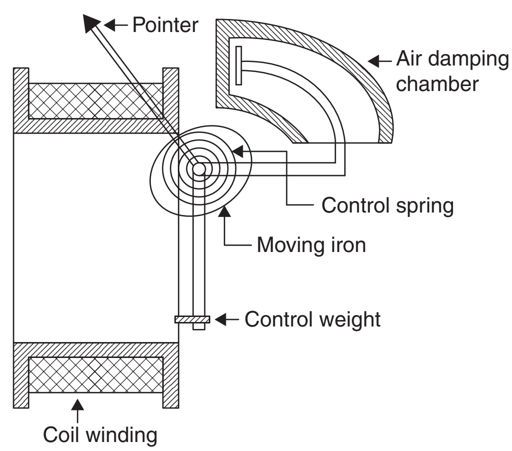
$$M = -3\cos(\theta + 60°)$$
$$\left(\frac{dM}{d\theta}\right) = 3\sin(\theta + 60°)$$
$$\left(\frac{dM}{d\theta}\right)_{\theta = 30°} = 3\sin(30 + 60) = 3 \text{ mH/degrees}$$
$$T_d = I^2\left(\frac{dM}{d\theta}\right) = (25 \times 10^{-3})^2 \times 3 \times 10^{-3}$$
$$T_d = 1.875 \text{ μN.}$$

## Moving Iron Instruments

Classification of moving iron Instruments

1. Attraction type
2. Repulsion type

### Attraction Type Moving Iron Instrument




### Principle

- When an unmagnetized soft iron piece is placed in the magnetic field of a coil, then piece is attracted towards coil.
- The moving system is attached to a soft iron piece and operating current is passed through a coil placed near it.
- The operating current sets up the magnetic field which attracts the iron piece and moves the pointer over the scale.

### Construction

- It consists of a hollow cylindrical coil or solenoid which is kept fixed.
- An oval-shaped iron piece is attached to the spindle in such a way that it can move in or out of the coil.

- The pointer is attached to the spindle so that it is deflected with the motion of soft iron piece.
- The controlling torque on the moving system is provided by spring control method while damping is provided by air friction.

### Working

- When instrument is connected in the circuit, the operating current flows through the coil which sets up magnetic field in the coil.
- In other words coil behaves like a magnet and therefore it attracts the soft iron piece towards it, which makes the pointer attached to move from 0 position.
- If the current in the coil is reversed the direction of magnetic field also reverses and so does the magnetism produced in the soft iron piece.
- Therefore the direction of the deflecting torque unchanged.

### Deflecting Torque

- The force pulling the soft iron piece towards the coil depends upon
  1. Field strength $H$ produced by the coil
  2. Pole strength m developed by the piece

$$F = mH$$

$$T_d \propto F \propto H^2$$

If permeability of iron is assumed constant, then

$$H \propto I$$

$$T_d \propto I^2$$

$$T_d = \frac{1}{2} I^2 \left(\frac{dL}{d\theta}\right)$$

If the controlling torque provided by springs

$$T_c \propto \theta$$

$$T_c = K\theta$$

In steady position, $T_d = T_c$

$$\theta = I^2 \text{ for DC}$$

$$\theta = I_{RMS} \text{ for AC}$$

$$\theta = \frac{I^2}{2k}\left(\frac{dL}{d\theta}\right)$$

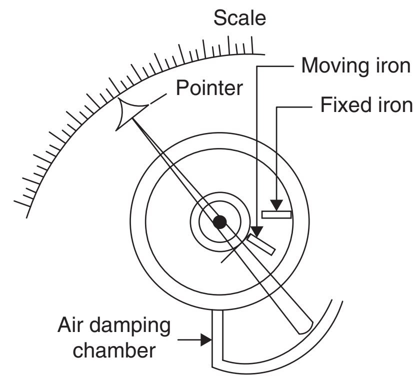
Since $\theta \propto I^2$, scale of such instrument is non-uniform.

In order to make the scale, uniform, tongue-shaped iron piece is used.

## Repulsion Type Moving Iron Instruments

### Principle

It is based on the principle of repulsion between the two iron pieces similarly magnetized.




### Construction

It consists of a fixed cylindrical hollow coil which carries operating current. Inside the coil there are two soft iron pieces or vanes, one of which is fixed and other is movable.

- The fixed iron piece is attached to the coil whereas the movable iron piece is attached to the pointer shaft.
- Under the action of deflecting torque, the pointer attached to the moving system moves over the scale.
- The controlling torque is produced by spring control and damping torque is provided by air friction damping.

### Working

- When the instrument is connected in the circuit, current flows through the coil, which sets up magnetic field in the coil.
- The magnetic field magnetizes both iron pieces in the same direction, i.e. both become similar magnets and hence they repel each other.
- Due to this movable iron piece moves as the other piece is fixed and cannot move, hence the pointer moves from zero position.

### Deflecting Torque

- The deflecting torque results due to the repulsion between the similarly magnetized iron pieces.

If two pieces develop pole strengths $m_1$, and $m_2$, respectively, then

Instantaneous deflecting torque $\propto$ repulsive force $\propto m_1 m_2$

Assuming constant permeability $H \propto$ current through the coil,

Deflecting torque $T_d \propto I^2$

Controlling torque $T_c \propto \theta$

In the steady position of deflection

$$T_d = T_c$$

$$\theta \propto I^2$$

$$\theta \propto I^2 \text{ (for DC)}$$

$$\theta \propto I_{RMS} \text{ (for AC)}$$

Since $\theta \propto I^2$, the scale of such instruments are non-uniform being crowded in the beginning.

## Comparison between Attraction and Repulsion Types of Instruments

- An attraction type instrument will have a lower inductance than corresponding repulsion type instrument.
- Repulsion instruments are suitable for more economical production in manufacture and a nearly uniform scale is more easily obtained they are therefore much more common than attraction type.

### *Errors*

1. **Errors with both DC and AC**
   (a) **Hysteresis error:** This error occurs as the value of flux density is different for the same current for ascending and descending values.
   The value of flux density is higher for descending values of current and therefore instrument tends to read higher for descending values of current, than for ascending values.
   (b) **Temperature error:** this occurs due to the temperature coefficient of spring. As temperature increases, (due to self-heating and series resistance), resistance increases causing decrease in current for a given voltage. This produces a decreased deflection.
   (c) **Stray magnetic fields:** Such errors may be appreciable as the operating magnetic field is weak and hence can be easily distorted.
2. **Errors with AC only**
   (a) **Frequency error:** Changes in frequency may cause errors due to changes of reactance of the working coil and also due to changes of magnitude of eddy currents set up in metal parts of the instrument.
   (b) **Eddy current:** At low frequencies the eddy current error increases with square of frequency while at high frequencies the error is practically constant.

For these reasons moving iron instruments are unsuitable for frequencies above 125 Hz.

### *Advantages*

1. These are cheap, robust and simple in construction.
2. They can be used for both AC and DC.
3. They have high operating torque.
4. They are reasonably accurate.

### *Disadvantages*

1. Such instruments have non-uniform scale.
2. They are not very sensitive.
3. Errors are introduced due to changes in frequency in case of AC measurements.
4. Higher power consumption.

**Note:** Moving Iron Instruments indicate RMS values.

**Example 3:** In the measurement of voltage or current using moving iron instruments it indicates

(A) High values of the measuring quantity for ascending values.
(B) High values of the measuring quantity for descending values.
(C) Same values of measurement for both ascending and descending values.
(D) None of the above.

**Solution:** (B).

## Induction Type Instruments

These instruments are based on the principle of inductor motor.

### *Principle*

When a drum or disc of a non-magnetic conducting material is placed in a rotating magnetic field, eddy currents are induced in it.

- The reaction between the rotating flux and eddy current produced by it creates a torque which rotates the disc or drum.
- The rotating flux is produced by the current or voltage to be measured.
  The eddy current is proportional to flux

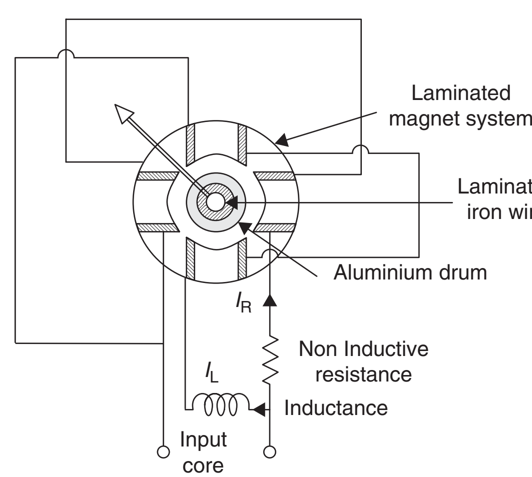
$$R \propto \phi_1 \propto I^2.$$

- A single-phase supply is converted into two phases in the instrument; this is done by split phase or shaded pole arrangement.

## Classification of Instruments

1. Split-phase type
2. Shaded-pole type

## Split-phase Type Instruments



### Construction

- It is also called Ferraris type instrument.
- It consists of a laminated magnet with the pairs of poles at right angles to each other.
- Coils are wound on the poles, the opposite poles being connected in series.
- The coils on two pairs of poles are connected in parallel. One set of coil is connected through an inductance and another with a high resistance to create a phase difference of 90°.
- The input to both the coils is the current to be measured. In the centre of the yoke and coil is an aluminium drum. Inside the drum there is a cylindrical laminated iron core to strengthen the magnetic field.

### Working

- When the instrument is connected in the circuit and current flows through the coil, a rotating magnetic field is produced.
- This field induces eddy current in the drum and a torque is produced by the reaction of magnetic field and current. This torque deflects the pointer attached to the drum. Controlling torque is produced by the spring.

### Deflecting Torque

Deflecting torque produced is given by

$$T \propto \frac{I_R\ I_L\ f}{z} \cos\theta \sin\alpha$$

For an ammeter $T \propto \dfrac{I_R}{z} \cos\theta \sin\alpha$

For a voltmeter $T \propto \dfrac{V^2}{Z} \cos\theta \sin\alpha$

where $I_R$ = Current through resistor
$I_L$ = Current through inductor
$F$ = Supply frequency
$Z$ = Impedance of eddy current path
$\theta$ = Phase angle between voltage and current in resistor
$\alpha$ = Phase angle between currents in resistor and inductor

$\theta$ = Almost zero and $R$ is very much larger than reactive part of eddy paths

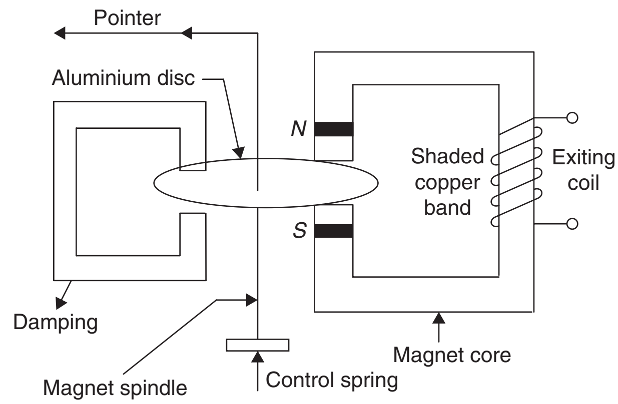
$$T \propto \frac{I^2}{R} \sin\alpha$$

Obviously $\alpha$ should be as high as possible for high torque.

## Shaded-pole Type Instruments

### Construction

- A band of copper is placed in pole faces, this makes the two fluxes of the shaded and unshaded portions differ in phase by 90°. A metallic disc rotates between the pole faces.
- Damping is provided by another magnet.




### Working

- The current flowing through the exiting coil sets up flux.
- Eddy currents are induced in the copper band.
- Flux of the eddy current opposes the flux in the magnetic core and a two-way flux, same as Ferraris type instruments is induced.

## Measurement of Electric Voltage and Current

Moving iron instruments are used as ammeter and voltmeter is only. They work on both AC and DC systems.

### Ammeter

- An instrument which is used to measure electric current in a circuit is called an ammeter.
- It is always connected in series with the circuit and carries current to be measured. This current flows through the operating coil to produce the desired deflecting torque.
- Since it is to be connected in series it should have low resistance. Hence when a moving iron instrument is used as ammeter, the operating coil is provided with a few turns of thick wire so that it has low resistance.

### Shunts

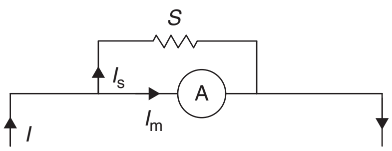
- A resistance placed in parallel with an instrument to control the current passing through it, when placed in a circuit carrying a fairly large current.
- A length of wire with resistance of constant temperature within the box of the instrument can be used as shunt. Or there may be an external shunt having very low resistance.

### General Requirements of a Shunt

1. The temperature coefficient of shunt and instrument should be low and nearly identical.
2. The resistance of shunt should not vary with time.
3. It should carry the current without excessive temperature rise.
4. It should have a low thermal emf.

- Shunts for low current are enclosed in meter casing but for currents above 200 A they are mounted separately.
- Constantan is very useful material for AC circuit since its comparatively high thermal emf being unidirectional is ineffective on these circuits.
- Manganin is usually used as a shunt for DC instruments since it gives a low value of thermal emf with copper.

### Shunt with Ammeter




Low resistance of shunt is connected across the coil of ammeter.

Let $I$ be the circuit current to be measured.

$R_m$ = Ammeter resistance

$S$ = Shunt resistance

$I_m$ = Full-scale deflection of ammeter

$I_s$ = Shunt current

$I = I_s + I_m$

$I_s = I - I_m$.

Since voltage across shunt and ammeter is same

$$I_m R_m = (I - I_m)R_s$$

$$I_m (R_m + R_s) = IR_s$$

$$I = \frac{I_m(R_m + R_s)}{R_s}$$

$$\text{Circuit current} = \text{Full-scale deflection} \times \left(\frac{R_m + R_s}{R_s}\right)$$

### Instrument Constant

It is the ratio of current to be measured to the full-scale deflection.

$$M = \frac{I}{I_m} = \frac{R_m + R_s}{R_s}$$

- With different shunts the same instrument will have different instrument constants.

### Shunts for AC Instruments

In order to maintain the current division between shunt and instrument, constant for all frequencies, the ratio of impedances of the instrument and leads to the shunt must remain constant.

$L_m$ = Inductance of the instrument

$L_s$ = Inductance of the shunt

Then $\dfrac{\sqrt{R_m^2 + \omega^2 L_m^2}}{\sqrt{R_s^2 + \omega^2 L_s^2}}$ should be constant.

This is possible only if time constant of the shunt and instruments are the same.

$$\text{i.e., } \frac{L_m}{R_m} = \frac{L_s}{R_s} = K$$

$$\text{Multiplying factor } N = \frac{I}{I_m} = \frac{I_m + I_s}{I_m}$$

$$N = \frac{R_m}{R_m} + 1$$

where
$$I_m = \frac{V}{\sqrt{R_m^2 + \omega^2 L_m^2}}$$

$$I_s = \frac{V}{\sqrt{R_s^2 + \omega^2 L_s^2}}$$

## Voltmeter

An instrument which is used to measure voltage between two points in a circuit is called voltmeter.

- It is always connected in parallel with the portion whose voltage is to be measured.
- The current flowing through the operating coil of the meter produces a deflecting torque.
- Since voltmeter is connected in parallel and in order that its connection does not disturb the circuit condition therefore the resistance of the voltmeter should be very high.
- To do so a high resistance is connected in series with the coil of the instrument.
  Let $R_0$ be the total resistance (resistance of the operating coil + high series resistance) of the instrument current flowing through instrument

$$I_v = \frac{V}{R_v}$$

$$\theta \propto I_v \propto \frac{V}{R_v}$$

$$\theta \propto V$$

Deflection is proportional to voltage and hence measures voltage.

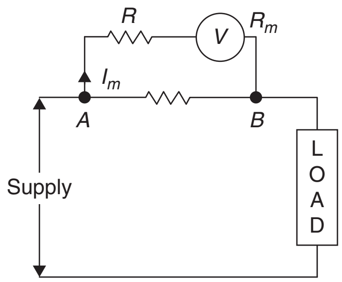
## Multipliers

- A high resistance in series with a galvanometer is connected to limit the current flowing through the meter, so that it does not exceed the value for full-scale deflection and thus prevent the instrument from being damaged. Such a resistance is called multiplier.

### Multiplier with Voltmeter

High resistance is connected with a voltmeter coil

$$V = I_m (R + R_m) \tag{3}$$




From given figure

$V_{AB}$ = Voltage across voltmeter
$V$ = Voltage across voltmeter
$R$ = High resistance in series with voltmeter coil
$R_m$ = Voltmeter resistance
$I_m$ = Full-scale deflection current for voltmeter

Equation (3) can also be written as $R + R_m = \frac{V}{I_m}$

$$R = \frac{V}{I_m} - R_m$$

Multiplier constant $m = \frac{I_m(R_m + R_s)}{I_m R_m}$

$$m = 1 + \frac{R}{R_m}$$

Required high resistance

$$R = \frac{\text{Maximum voltage to be measured}}{f.s.d.\text{ Voltmeter current}} - \text{Voltmeter resistance}$$

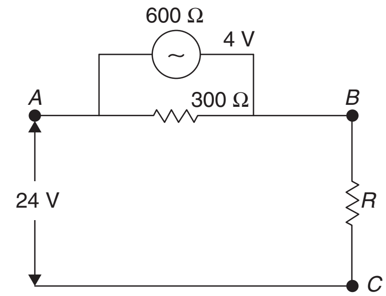
**Example 4:** Determine the current through the voltmeter if it reads half of full-scale deflection of 200 V and sensitivity of voltmeter is 500 Ω/V.

**Solution:** Half of f.s.d 200 V = 100 V
Resistance of the voltmeter

$$R_v = S_v \times V$$
$$= 500 \times 100$$
$$= 50 \text{ k}\Omega$$
$$I = \frac{V}{R} = \frac{100\text{ V}}{50\text{ k}\Omega} = 2\text{ mA}.$$

**Example 5:** A voltmeter having internal resistance 600 Ω is connected across 300 Ω resistor reads 4 V, when the above combination is connected in series with a resistance and is given a supply voltage of 24 V the resistance $R$ will be
(A) 150 Ω
(B) 500 Ω
(C) 1.0 kΩ
(D) 2.0 kΩ

**Solution:** (C)




$R_{eq}$ of parallel combination

$$\frac{600 \times 300}{600 + 300} = 200\ \Omega$$
$$V_{AC} = V_{AB} + V_{BC}$$
$$V_{BC} = V_{AC} - V_{AB}$$
$$= 24 - 4 = 20\text{ V}$$
$$\frac{V_{BC}}{R_{BC}} = \frac{V_{AB}}{R_{AB}}$$
$$\frac{20}{R} = \frac{4}{200}$$
$$R = \frac{200 \times 20}{4} = 1000\ \Omega$$
$$R = 1\text{ k}\Omega$$

**Example 6:** A meter has a full-scale deflection of 120° at a current of 2 A. The response of the meter is square law. Assuming spring control, the current for deflection at 60° will be

(A) 1.414 A (B) 0.707 A
(C) 2 A (D) 1 A

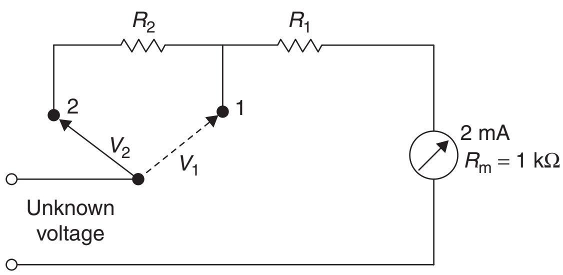
**Solution:** (A)
We know that deflecting torque

$$T_d = K I^2$$
$$T_c = C\,\theta$$
$$I^2 = \left(\frac{C}{K}\right)\theta$$

Suppose $(C/K)$ is a constant

$$\frac{I_1^2}{I_2^2} = \frac{\theta_1}{\theta_2} \quad I_2^2 = \frac{I_1^2 \times \theta_2}{\theta_1}$$
$$= 2^2 \times \left(\frac{60}{120}\right)$$
$$I_2 = \sqrt{2} = 1.414\text{ A}.$$

**Example 7:** For the voltmeter circuit shown in the given figure, it has a f.s.d. of 2 mA and an internal resistance of 1 kΩ. The values of series resistance required for a range of $V_1 = 12$ V and $V_2 = 60$ V will be, respectively.




(A) 9.9 kΩ and 40 kΩ (B) 8 kΩ and 30 kΩ
(C) 20 kΩ and 30 kΩ (D) 5 kΩ and 29 kΩ

**Solution:** (D)
For 12 V, the f.s.d can be calculated as

$$2 \times 10^{-3} = \frac{12}{(1000 + R_1)}$$

$$R_1 \times 2 \times 10^{-3} = 12 - 2$$

$$R_1 = 5\ \text{k}\Omega$$

For 60 V, the f.s.d can be calculated as

$$2 \times 10^{-3} = \frac{60}{(1000 + R_1 + R_2)}$$

$$(R_1 + R_2) \times 2 \times 10^{-3} = 60 - 2$$

$$R_2 = 29\ \text{k}\Omega$$

**Example 8:** What will happen if a voltmeter is connected like an ammeter in series to the load

**Solution:** There will be almost no current in the circuit.

## Instrument Transformers

- Instrument transformers are used in AC systems for measurement of current, voltage, power and energy.
- They are also used in connection with measurement of power factor, frequency and indication of synchronism.
- They also have a wide application in protection circuit of power systems for operation of various relays.

### *Advantages*

1. These enable single instruments to cover a large current or voltage range.
2. Minimal power loss.
3. Measuring instruments can be located far from the high voltage circuit by using long loads connecting the instrument transformer to the instrument. Hence the instrument is isolated from high voltages and stray fields providing safety in use to both instrument and the observer.
4. By using a C.T. with a suitably split and hinged core upon which the secondary winding is wound, the current in a heavy bus bar is measured without breaking the circuit.
5. Due to the inductance of the instrument winding being in parallel with the non-inductive shunt, shunt on AC does not give a linear relation between instrument current and bypassed current. On the other hand, in case of C.T, the whole current passes through primary a proportional voltage is induced in the secondary which sends a current in direction proportion around the secondary circuit.

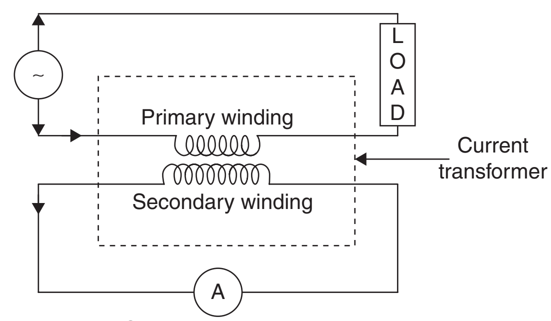
### *Disadvantages*

They cannot be used for DC.

### *Types of Instrument Transformers*

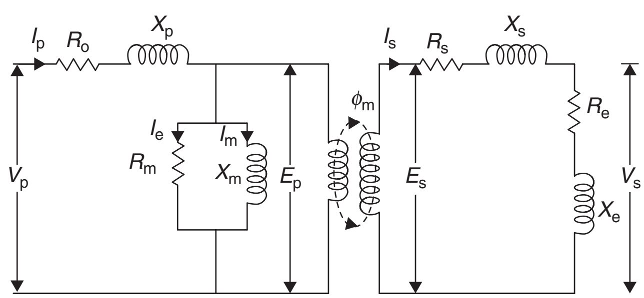
1. Current transformer (Series)
2. Potential transformer (Parallel)

## Current Transformer (C.T.)




Connection diagram

- The primary winding of the C.T. is connected in series with the load, and carries the load current to be measured. It consist of a very few turns.
- Secondary winding is directly connected across the load and has more turns.
- The amount of power C.T. can handle is small. The product of voltage and current on secondary side of C.T. when it is supplying the instrument with its maximum rated value of current is called rated burden and is measured in V.A. Its secondary is kept short circuited always.




Equivalent circuit of C.T.

## Ratio of Current Transformers

Transformation ratio

$$R = \frac{\text{Primary winding current}}{\text{Secondary winding current}}$$

$$\text{Nominal ratio } K_n = \frac{\text{Rated primary current}}{\text{Rated secondary current}}$$

$$\text{Turns ratio} = \frac{\text{Number of turns in secondary}}{\text{Number of turns in primary}}$$

**For the phasor diagram**

$E_p$ = Primary induced voltage
$E_s$ = Secondary induced voltage
$n$ = Turns ratio
$I_p$ = Primary current
$I_s$ = Secondary current
$I_o$ = Exciting current
$I_m$ = Magnetizing component of exciting current
$I_c$ = Loss component of exciting current
$\phi$ = Working flux of C.T.
$\alpha$ = Angle between $I_o$ and $\phi$
$\delta = \tan^{-1}\left(\frac{X_s + X_e}{R_s + R_e}\right)$ = angle between $E_s$ and $I_s$
$\Delta = \tan^{-1}\left(\frac{X_e}{R_e}\right)$ = phase angle of secondary burden
$\theta$ = Phase angle of transformers

From the phasor diagram, transformation ratio can

$$R \approx \frac{nI_s + I_o \sin(\delta + \alpha)}{I_s} \qquad \left[\because \begin{array}{l} I_m = I_o \cos\alpha \\ I_e = I_o \sin\alpha \end{array}\right]$$

$$R \approx \frac{nI_s + I_m \sin\delta + I_e \cos\delta}{I_s}$$

$$\text{Phase angle } \theta \approx \frac{180}{\pi}\left(\frac{I_m \cos\delta - I_e \sin\delta}{nI_s}\right)$$

### Errors

1. **Ratio angle error:** It is mainly on account of magnetizing component of excitation current

$$\text{Ratio error} = \frac{\text{Nominal ratio} - \text{Actual ratio}}{\text{Actual ratio}}$$

$$\text{Ratio error} = \frac{K_n - R}{R}$$

2. **Phase angle error:** It is mainly on account of magnetizing component of excitation current

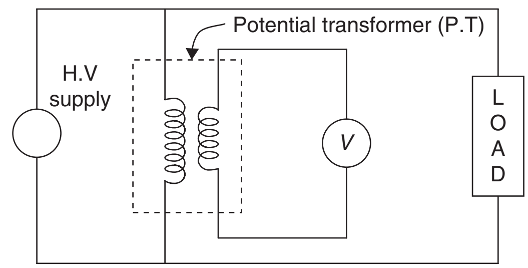
$$\theta = \frac{180}{\pi}\left(\frac{I_m \cos\delta - I_e \sin\delta}{nI_s}\right)\text{degree}$$

$$\theta = \frac{180}{\pi}\left(\frac{I_m}{I_p}\right)\text{degree}$$

### Design Features

- The coils are wound close together to reduce the secondary leakage reactance. They are separately wound and insulated by tape and varnish for lower voltages.
- The number of exciting ampere turns are kept very small when compared to the total primary ampere turns, to reduce the current ratio and phase angle errors.
- $I_m$ and $I_e$ are kept small by using core of high permeability and low magnetic materials.
- The core reluctance is reduced by reducing the length of magnetic path in the core and increasing the area of the magnetic path in the core. The transformer has a rectangular or ring shaped core.

## Potential Transformers




Connection diagram

- They are used for measurement of high voltages by means of low range voltmeters or for energizing the potential coils of wattmeters, energy meters.
- The primary winding is connected across the line carrying the voltage to be measured that the voltage circuit is connected across the secondary winding.
- In the phasor diagram,
  $\theta$ = Angle between $V_p$ and $V_s$ reversed
  $\theta$ = Phase angle of the transformer
  $\beta$ = Phase angle between $I_p$ and $V_s$ reversed
  $\Delta$ = Phase angle of secondary load circuit

### Design Features

- The ratio error produced is compensated by increasing the turn on the secondary winding by an appropriate small amount. The increased secondary turns compensate the voltage drop in potential transformers.
- By minimizing the no load current errors of potential transformers are controlled to a great extent.
- The reluctance of the core and flux density in the core is kept low.
- High-quality core material is used to reduce core loss.
- The windings are wound one over the other to reduce leakage to minimum.

### Ratios

1. $\text{Transformation ratio } R = \frac{\text{Primary winding voltage}}{\text{Secondary winding voltage}}$

2. Nominal ratio $K_n = \dfrac{\text{Rated primary voltage}}{\text{Rated secondary voltage}}$

3. Turns ratio

$$n = \frac{\text{Number of turns of primary winding}}{\text{Number of turns of secondary winding}}$$

Transformation ratio from phasor diagrams

$$R = \frac{V_p}{V_s}$$
$$= n + \frac{nI_s(R_s\cos\Delta + X_s\sin\Delta) + I_sR_p + I_mX_p}{V_s}$$

$$\theta = \frac{I_s}{V_s}\left(X_s\cos\Delta - R_s\sin\Delta\right) + \frac{I_eX_p - I_mR_p}{nV_s}$$

## Errors

1. Ratio error $= \dfrac{K_n - R}{R} \times 100$

2. Phase angle error

$$\theta = \frac{I_s}{V_s}\left(X_s\cos\Delta - R_s\sin\Delta\right) + \frac{I_eX_p - I_mR_p}{n\,V_s}$$

**Example 9:** When the primary winding of a current transformer is energized with the secondary winding open circuited.

(A) A large value of flux is produced in the core due to the whole of the primary winding current producing a large voltage on the secondary side.
(B) When large magnetization force is taken off, it leaves behind a huge residual magnetism.
(C) Large secondary voltage may damage the insulation.
(D) All of the above.

**Solution:** (D)

**Example 10:** The size of the potential transformers

(A) Is much greater than that of power transformers of same VA rating.
(B) Is the same as that of power transformers of the same VA rating.
(C) Is smaller than that of power transformer of same VA rating.
(D) Cannot be determined.

**Solution:** (A)

The size of potential transformers would be much greater than that of power transformers of the same VA rating since they are designed for low ratio and phase angle errors which requires large sized cores and winding conductors.

**Example 11:** Calculate the transformation ratio of a current transformer rate 60/6 A. Its secondary side being purely resistive has magnetizing and loss component of exciting current as 20 A and 1.2 A, respectively.

(A) 10.02 (B) 10.20
(C) 10.002 (D) 100.2

**Solution:** (B)

Transformation ratio

$$R = n + \frac{I_e\cos\delta + I_m\sin\delta}{I_s}$$

$n = 60/6 = 10$

$I_e = 1.2$

$I_m = 20$ A

$\cos\delta = \dfrac{R_s}{Z_{eq}}$ $\sin\delta = \dfrac{X_s}{Z_{eq}}$

$[Z_{eq} = R$ since $X_s = 0]$

$\cos\delta = 1$ $\sin\delta = 0$

$$R = 10 + \frac{(1.2\times1) + (20\times0)}{6} = 10.2.$$

**Example 12:** The magnetizing and loss component of exciting current of a current transformer rated 1000/5 A, are 15 A and 9 A, respectively. The phase angle between secondary winding induced voltage and current is 40°. The phase angle error of the transformer is

(A) 0.657 (B) 0.125
(C) 0.457 (D) 0.327

**Solution:** (D)

$$n = \frac{1000}{5} = 200$$

$I_m = 15$ A

$I_p = 1000$ A

$\delta = 40°$

$I_e = 9$ A

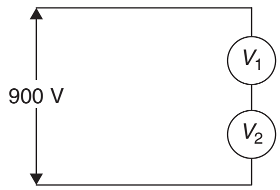
$I_s = 5$ A

$$\theta = \frac{180}{\pi}\left(\frac{I_m\cos\delta - I_e\sin\delta}{nI_s}\right)$$
$$= \frac{180}{\pi}\left(\frac{15\cos40 - 9\sin40}{200\times5}\right)$$
$$= \frac{180}{\pi}\left(\frac{11.5 - 5.78}{1000}\right) = 0.327°$$

## EXERCISES

### Practice Problems 1

1. Two 500 V full-scale voltmeters $V_1$ and $V_2$ having resistances 200 kΩ/V and 250 kΩ/V, respectively, are connected in series to measure 900 V. Then




(A) $V_1$ and $V_2$ reads 400 V each
(B) $V_1$ reads 400 V and $V_2$ reads 500 V
(C) $V_1$ reads 500 V and $V_2$ reads 400 V
(D) $V_1$ and $V_2$ reads 0 V

2. Which of the following is an indicating type instrument?
(A) Tachometer (B) C.R.O.
(C) Energymeter (D) E.C.G.

3. A moving coil milli ammeter with a resistance of 1.6 Ω is connected with a shunt of 0.52 Ω. What will be the current flowing through the instrument if it is connected in a circuit in which a current of 400 mA is flowing?
(A) 97.98 mA (B) 97.02 mA
(C) 98.28 mA (D) 99 mA

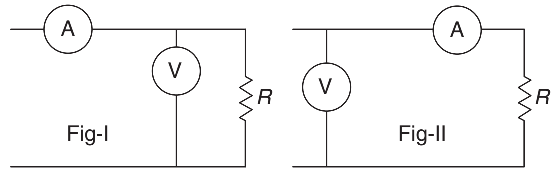
4. In ammeter, the shunt and the moving coil are made of the same material because
(A) Temperature error can be eliminated
(B) Temperature error cannot be eliminated
(C) Both A and B
(D) None of these

5. The error occurring in current transformer is due to
(1) The magnetic leakage in secondary winding
(2) Power consumption in the metering circuit
(3) The exiting mmf required by the primary winding to produce flux
(4) The non-linear relation between flux density in the core and magnetizing force Of these statements which are correct?
(A) 1 and 4 (B) 1, 2 and 3
(B) 1, 3, 4 (D) 2 and 3

6. The error produced due to the inductance in voltage coil of an electrodynamometer type wattmeter.
(A) Increases as P.F. decreases
(B) Decreases as P.F. decreases
(C) Constant irrespective of P.F. of the circuit
(D) No relation between P.F. and inductance of the coil

7. What is the correct sequence of the following types of ammeter and voltmeter with increasing accuracy?
(1) Moving iron
(2) P.M.M.C.
(3) Induction
(A) 1, 3, 2 (B) 1, 2, 3
(C) 3, 1, 2 (D) 2, 1, 3

8. Ammeter voltmeter method is employed to measure the resistance of resistor R. From among the circuits shown below the least erroneous results are obtained by adopting




(A) Circuit I for low resistance and circuit II for high resistance
(B) Circuit I for high resistance and circuit II for low resistance
(C) Circuit I should not be employed for resistance measurement
(D) Circuit II should not be employed for resistance measurement

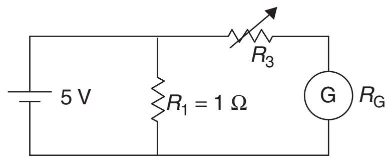
9. The coil of a PMMC instrument has 20 turns on a rectangular former of 3.5 cm × 1.5 cm swings in a uniform field of 0.05 Wb/m$^2$. If a steady current of 40 mA is flowing through the coil, the deflecting torque is
(A) $210 \times 10^{7}$ Nm (B) $210 \times 10^{-6}$ Nm
(C) $210 \times 10^{-7}$ Nm (D) $210 \times 10^{-5}$ Nm

10. A sinusoidal voltage of 230 V RMS 50 Hz is connected to a rectifier type ammeter which do not allow the flow of current in one direction and offers a resistance of 30 Ω to flow of current in other direction. The current recorded by ammeter is
(A) 2.95 A (B) 10.35 A
(C) 7.67 A (D) 3.45 A

11. A 10 mA ammeter has a resistance of 50 Ω. It has to be converted to a 1 A ammeter. The value of shunt resistance is
(A) 5 Ω (B) 0.05 Ω
(C) 0.5 Ω (D) 50 Ω

12. A current transformer has a rating of 200/5 A. The magnetizing and loss component of exciting current are 2 A and 1 A, respectively, and secondary has a burden of pure resistance. The transformation ratio of rated current is
(A) 40 (B) 40.1
(C) 40.2 (D) 41

13. A galvanometer is tested in the circuit where $E$ = 5 V, $R_1$ = 1.0 Ω and $R_2$ = 4500 Ω with $R_3$ set as 600 Ω, the deflection in galvanometer is 160 mm. When $R_3$ is changed to 1280 Ω the deflection is changed to 80 mm. The resistance of the galvanometer is




(A) 80 Ω (B) 79 Ω (C) 100 Ω (D) 99 Ω

**14.** A 1000 A/5 A, 50 Hz current transformer has a bar primary. The secondary burden is a pure resistance of 0.5 Ω and it is drawing a current of 5 A. If the core of the C.T requires 400 AT for magnetization, then the percentage ratio error is

(A) –10.8% (B) +7.1%
(C) +10.8% (D) –7.1%

**15.** A simple slide wire is used for measurement of current in a circuit. The voltage drop across a standard resistor of 0.1 Ω is balanced at 60 cm. Find the magnitude of current if the standard cell emf of 1.45 V is balanced at 50 cm

(A) 14.5 A
(B) 14.7 A
(C) 17.4 A
(D) 24.5 A

## Practice Problems 2

**1.** Rectifier moving coil instruments respond to
(A) Average value irrespective of nature of waveform
(B) RMS value irrespective of nature of waveform
(C) Peak value irrespective of nature of waveform
(D) RMS value for symmetrical square waveform

**2.** A certain measuring instrument has a resistivity of 20,000 Ω/V. The current required to deflect the meter to full scale is
(A) 20 μA (B) 50 μA (C) 20 mA (D) 50 mA

**3.** A (0–5) A PMMC ammeter reads 3 A when connected in a certain circuit. If the bottom control spring snaps, the reading will be
(A) 3 mA (B) 6 mA (C) 1.5 mA (D) Zero

**4.** A (0–5) A PMMC ammeter does not have any controlling mechanism. Now, if a current of 2 A (DC) is passed through the coil, the reading shown by the Meter would be (frictional opposition is overcome by torque produced
(A) 2 A
(B) 5 A
(C) Pointer rotates continuously.
(D) Pointer does not rotate.

**5.** In moving coil meters, damping is provided by
(A) Damping vane in the airtight chamber
(B) Coil spring attached to the moving coil
(C) Aluminium frame of the coil
(D) Eddy current disk

**6.** A PMMC instrument has a 50 turn coil and carries a current of 5 mA. The flux density in the air gap is 0.5 Wb/m$^2$. The coil dimensions are: length = 2 cm, and Diameter = 1 cm. The torque will be
(A) 25 μNm (B) 25 Nm
(C) 25 mNm (D) None of the above

**7.** The inductance of a certain MI ammeter is $L = 30 + 2\theta - \frac{\theta^2}{18}$ μH. The control spring torque is 35 μNm/radian. The deflection of the pointer in radian when it carries a current of 6 A is
(A) $\pi^c$ (B) $1^c$ (C) $\frac{\pi^c}{3}$ (D) $2^c$

**8.** A PMMC voltmeter is connected across a series combination of a DC source of 4 V and AC source of 4sin$\omega t$. The meter reads
(A) $\sqrt{6}$ V (B) 2 V
(C) 4 V (D) $2\sqrt{2}$ V

**9.** A moving iron voltmeter reads correctly on 230 V DC. If 230 V, 50 Hz AC is applied to it, the reading of the voltmeter is
(Coil has a resistance of 800 Ω and an inductance of 1 H and a series non inductive resistance of 1500 Ω)
(A) 225.78 V (B) 227.88 V
(C) 230 V (D) 232.12 V

**10.** An unshielded moving iron voltmeter is used to measure the voltage in an AC circuit. If a stray DC magnetic field having a component along the axis of the meter coil appears, the meter reading would be
(A) Unaffected
(B) Decreased
(C) Increased
(D) Either increased or decreased depending on the direction of the field

**11.** A moving iron type ammeter and a PMMC type ammeter are connected in series in a resistive circuit supplied from a half-wave rectified voltage source. If the moving iron type meter reads 8 A, the reading of PMMC instrument is likely to be
(A) 5.09 A (B) Zero
(C) 8 A (D) 6.18 A

**12.** Two voltmeter of range (0–500) V are connected in series. The internal resistances of the voltmeter are 5000 Ω and 15,000 Ω respectively. A voltage of 400 V is applied across them. The voltage shown by two meter are
(A) 150 V, 250 V (B) 200 V, 200V
(C) 100 V, 300 V (D) None of these

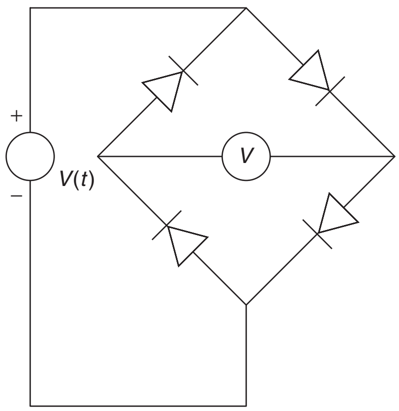
**13.** The mutual inductance of a dynamometer ammeter varies with deflection $\theta$ as

$M = 10 \sin(\theta + 30)$ mH

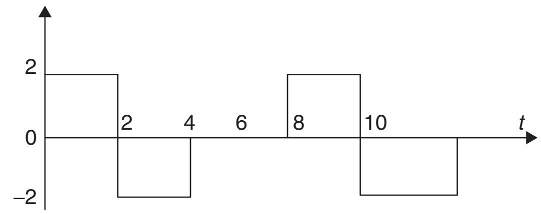
The deflecting torque produced by a DC current of 0.5 A corresponding to a deflection of 30° is

(A) 1.25 m Nm (B) 1.5 m Nm
(C) 1 m Nm (D) 0.75 m Nm

**Common Data for Questions 14 and 15:**




$V(t)$ is as shown below.




**14.** The voltmeter is PMMC. The reading shown is
(A) 2 V (B) 1 V
(C) $\sqrt{2}$ V (D) 0 V

**15.** If the voltmeter is M.I, then reading shown is
(A) 2 V (B) 1 V
(C) $\sqrt{2}$ V (D) 0 V

## PREVIOUS YEARS' QUESTIONS

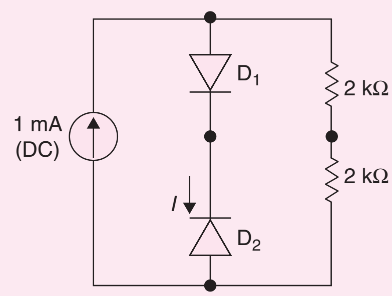
**1.** A moving iron ammeter produces a full-scale torque of 240 μNm with a deflection of 120° at a current of 10 A. The rate of change of self-inductance (μH/radian) of the instrument at full scale is **[2004]**
(A) 2.0 μH/radian (B) 4.8 μH/radian
(C) 12.0 μH/radian (D) 114.6 μH/radian

**2.** A 50 Hz, bar primary CT has a secondary with 500 turns. The secondary supplies 5 A current into a purely resistive burden of 1 Ω. The magnetizing ampere-turns is 200. The phase angle between the primary and secondary current is **[2004]**
(A) 4.6° (B) 85.4°
(C) 94.6° (D) 175.4°

**3.** The core flux in the CT of problem 83, under the given operating condition is **[2004]**
(A) 0 (B) 45.0 μWb
(C) 22.5 mWb (D) 100.0 mWb

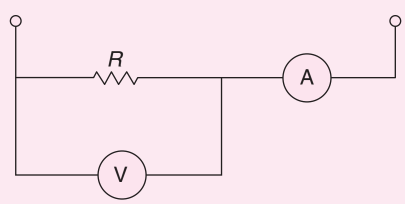
**4.** A PMMC voltmeter is connected across a series combination of a DC voltage source $V_1 = 2$ V and an AC voltage source $V_2(t) = 3\sin(4t)$ V. The meter reads **[2005]**
(A) 2 V (B) 5 V
(C) $\left(2+\frac{\sqrt{3}}{2}\right)$ V (D) $\left(\frac{\sqrt{17}}{2}\right)$ V

**5.** Assume that $D_1$ and $D_2$ in Fig. Q23 are ideal diodes. The value of current $I$ is: **[2005]**



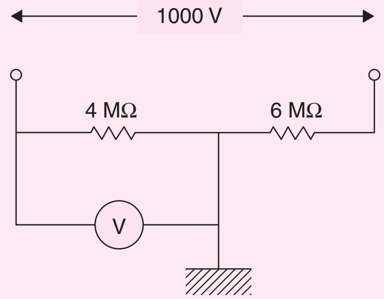

(A) 0 mA (B) 0.5 mA
(C) 1 mA (D) 2 mA

**6.** The set-up in Fig. Q.66 is used to measure resistance $R$. The ammeter and voltmeter resistances are 0.01 Ω and 2000 Ω, respectively. Their readings are 2 A and 180 V, respectively, giving a measured resistance of 90 Ω. The percentage error in the measurement is: **[2005]**




(A) 2.25% (B) 2.35%
(C) 4.5% (D) 4.71%

**7.** A 1000 V DC supply has two 1-core cables as its positive and negative leads; their insulation resistances to earth are 4 MΩ and 6 MΩ, respectively, as shown in Fig. Q67. A voltmeter with resistance 50 kΩ is used to measure the insulation of the cable. When connected between the positive core and earth, the voltmeter reads **[2005]**




(A) 8 V (B) 16 V (C) 24 V (D) 40 V

**8.** A current of $-8 + 6\sqrt{2}$ (sin $\omega t$ + 30°) A is passed through three meters. They are a centre zero PMMC meter, a true RMS meter and a moving iron instrument. The respective readings (in A) will be **[2006]**

(A) 8, 6, 10 (B) 8, 6, 8
(C) –8, 10, 10 (D) –8, 2, 2

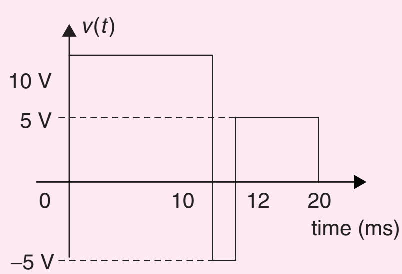
**9.** A 200/1 current transformer (CT) is wound with 200 turns on the secondary on a toroidal core. When it carries a current of 160 A on the primary, the ratio and phase errors of the CT are found to be –0.5% and 30 minutes, respectively. If the number of secondary turns is reduced by 1 the new ratio error (%) and phase error (min) will be, respectively, **[2006]**

(A) 0.0, 30 (B) –0.5, 35
(C) –1.0, 30 (D) –1.0, 25

**10.** An ammeter has a current range of 0–5 A, and its internal resistance is 0.2 Ω. In order to change the range to 0–25 A, we need to add a resistance of **[2010]**

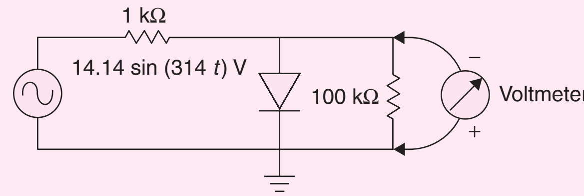
(A) 0.8 Ω in series with the meter
(B) 1.0 Ω in series with the meter
(C) 0.04 Ω in parallel with the meter
(D) 0.05 Ω in parallel with the meter

**11.** A periodic voltage waveform observed on an oscilloscope across a load is shown. A permanent magnet moving coil (PMMC) meter connected across the same load reads. **[2012]**



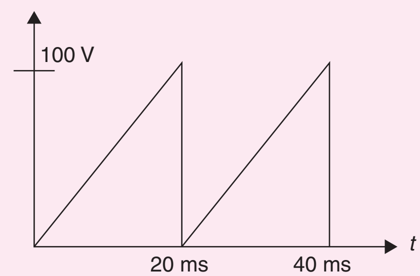

(A) 4 V (B) 5 V (C) 8 V (D) 10 V

**12.** The input impedance of the permanent magnet moving coil (PMMC) voltmeter is infinite. Assuming that the diode shown in the figure below is ideal, the reading of the voltmeter in volts is **[2013]**




(A) 4.46 (B) 3.15 (C) 2.23 (D) 0

**13.** The saw-tooth voltage waveform shown in the figure is fed to a moving iron voltmeter. Its reading would be close to ________ **[2014]**




**14.** Two ammeters $X$ and $Y$ have resistances of 1.2 Ω and 1.5 Ω, respectively, and they give full-scale deflection with 150 mA and 250 mA, respectively. The ranges have been extended by connecting shunts so as to given full-scale deflection with 15 A. The ammeters along with shunts are connected in parallel and then placed in a circuit in which the total current flowing is 15 A. The current in amperes indicated in ammeter $X$ is ___________. **[2014]**

**15.** A dc voltage with ripple is given by $v(t) = [100 + 10 \sin \omega (t) - 5 \sin (3\omega (t))]$ volts.

Measurements of this voltage $v(t)$, made by moving-coil and moving-iron voltmeters, show readings of $V_1$ and $V_2$ respectively. The value of $V_1 - V_2$, in volts, is _______. **[2015]**

**16.** A(0 – 50 A) moving coil ammeter has a voltage drop of 0.1 V across its terminals at full scale deflection. The external shunt resistance (in milliohms) needed to extend its range to (0 – 500 A) is ________.

**17.** Match the following. **[2015]**

| Instrument Type | Used for |
|---|---|
| P. Permanent magnet moving coil | 1. DC only |
| Q. Moving iron connected through current transformer | 2. AC only |
| R. Rectifier | 3. AC and DC |
| S. Electrodynamometer | |

(A) P–1 Q–2 R–1 S–3
(B) P–1 Q–3 R–1 S–2
(C) P–1 Q–2 R–3 S–3
(D) P–3 Q–1 R–2 S–1

## Answer Keys

## Exercises

### Practice Problems 1

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **1.** B | **2.** C | **3.** C | **4.** A | **5.** B | **6.** D | **7.** C | **8.** A | **9.** C | **10.** D |
| **11.** C | **12.** C | **13.** B | **14.** D | **15.** C | | | | | |

### Practice Problems 2

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **1.** A | **2.** B | **3.** D | **4.** C | **5.** C | **6.** A | **7.** B | **8.** C | **9.** B | **10.** D |
| **11.** A | **12.** C | **13.** A | **14.** B | **15.** C | | | | | |

### Previous Years' Questions

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **1.** B | **2.** A | **3.** B | **4.** A | **5.** A | **6.** C | **7.** A | **8.** C | **9.** A | **10.** D |
| **11.** A | **12.** A | **13.** 57.73 | **14.** 10.13 | **15.** 0.312 | **16.** 0.22 to 0.23 | | **17.** C | | |