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BTECH NOTES SERIES

Electrical Measurements and Instrumentation
(Electrical and Electronic Measurements)

(As Per AICTE/Technical Universities Syllabus)

CONTENT

(Use bookmarks to navigate)

MEASUREMENT OF VOLTAGE AND CURRENT

TORQUES

Deflecting Torque

The deflecting torque acts on the moving system of the instrument to give the required deflection and indicates the corresponding electrical quantity to be measured on a graduated scale. It exists as long as the instrument is connected to the supply. It is produced by any one of the following effects:

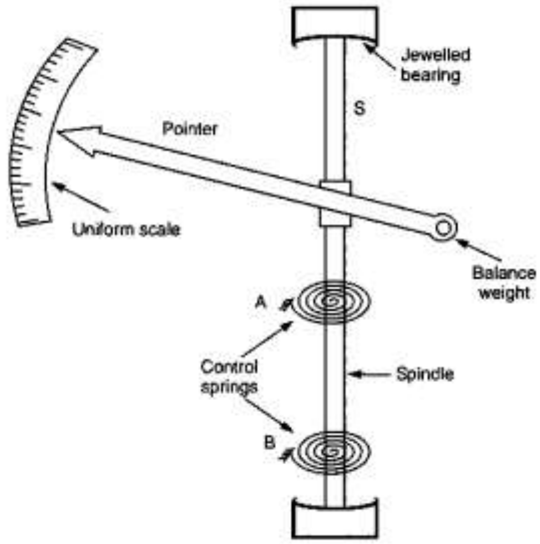
- **Magnetic effect:** When a current-carrying conductor is placed in a uniform magnetic field, it experiences a force, which causes the conductor to move. Example: moving-iron attraction and repulsion type, permanent-magnet moving-coil instrument.
- **Thermal effect:** When the current to be measured is allowed to flow through a small element, heat gets generated, which causes rise in temperature and it is then converted to an emf. Example: hot-wire instrument, thermocouple instrument.
- **Electrostatic effect:** When two charged plates are placed together, a force is exerted between them, which makes any one plate to move.
- **Induction effect:** When a non-magnetic conducting disc is placed in a magnetic field produced by an electromagnet, an emf gets induced in it.
- **Hall effect:** If a current-carrying bar of semiconducting material is placed in a uniform magnetic field, an emf is produced between the two edges of conductor.

Controlling Torque

The controlling torque is produced by a spring or gravity, which opposes the deflecting torque. The pointer comes to rest at a particular position corresponding to the electrical quantity to be measured, when these two torques are equal. The control torque can be produced using spring or gravity.

Spring Control

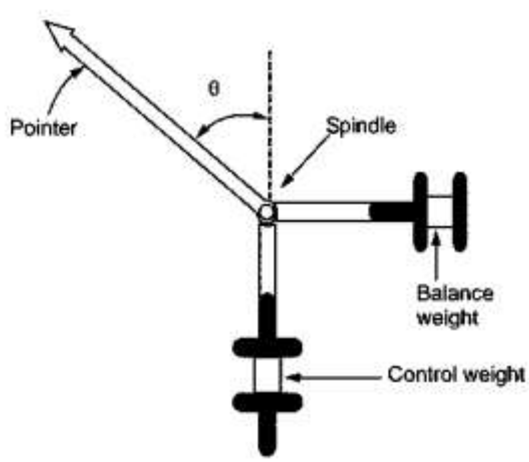
Two helical springs of rectangular cross-sections are connected to the spindle of the moving system, as shown in following figure. With the movement of the pointer, the springs get twisted in the opposite direction, which affects the moving system.



The inner end of the spring is attached to the spindle while the outer end is attached to a lever or arm which is actuated by a set of screw mounted at the front of the instrument. So zero setting can be easily done. The controlling torque provided by the instrument is directly proportional to the angular deflection of the pointer.

Gravity Control

In this method, small weights which can be adjusted are added to the moving system as shown in following figure.

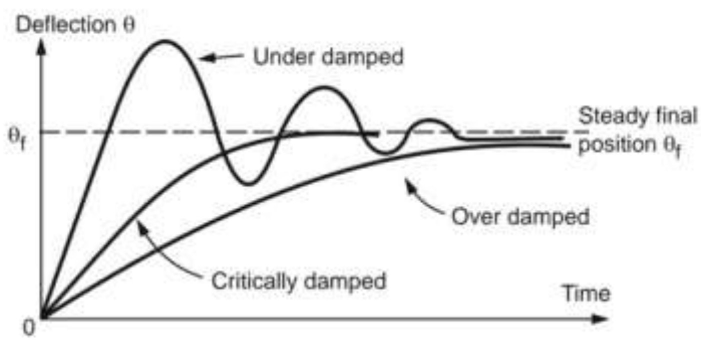


When the pointer deflects, this weight also takes a deflected position. The required controlling torque is produced by the gravitational force, which is acting on the moving weight.

Damping Torque

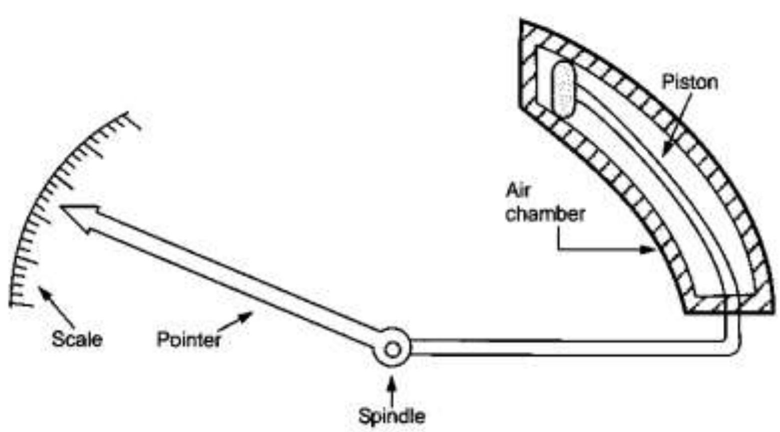
The torque that is used to reduce the oscillations of the pointer and to bring it to the final deflected position is known as damping torque. It acts on the pointer only when the instrument is in operation.

- **Under damped instrument:** If sufficient damping torque is not produced, the pointer makes under-damped oscillations before reaching the steady deflection.
- **Over damped instrument:** If the damping torque is more than the required value, the pointer becomes sluggish and it takes longer than the required time to reach the final deflection.
- **Critically damped instrument:** Critical damping or dead beat is the condition where the magnitude of damping torque is sufficient enough to make the pointer to read the correct reading without passing or oscillating about it.



Air-Friction Damping

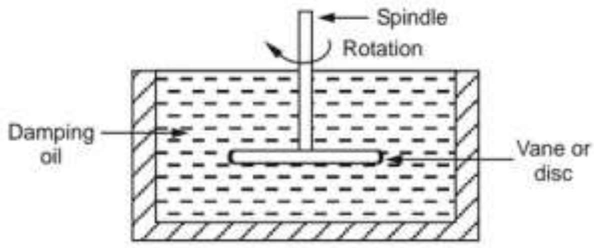
Following figure shows the arrangement where a piston, attached to the spindle of the moving system, moves inside the air chamber provided with a very small clearance between the piston and the chamber.



When the deflecting torque acts on the moving system, the suction and compression actions on the air inside the air chamber produce the necessary damping torque.

Fluid Friction Damping

It is like air friction damping with fluid instead of air.

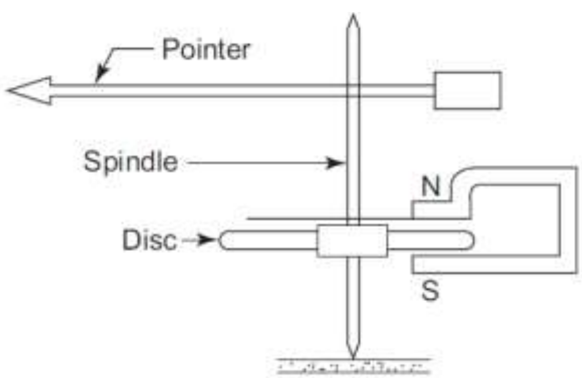


The arrangement is shown in the given figure. It consists of a vane attached to the spindle which is completely dipped in the oil. The frictional force between oil and the vane is used to produce the damping torque, which opposes the oscillating behaviour of the pointer.

Eddy Current Damping

This is the most effective way of providing damping. It is based on the Faraday's law and Lenz's law. When a conductor moves in a magnetic field cutting the flux, e.m.f. gets induced in it. And direction of this e.m.f. is so as to oppose the cause producing it.

In this method, an aluminium disc is connected to the spindle. The arrangement of disc is such that when it rotates, it cuts the magnetic flux lines of a permanent magnet. The arrangement is shown below.



Difference between gravity control and spring control

Gravity Control	Spring Control
Adjustable small weight is used which produces the controlling torque.	Two hair springs are used which exert controlling torque.
The performance is not temperature dependent.	The performance is temperature dependent.
Non uniform scale.	Uniform scale.

Controlling torque ∝ sinθ	Controlling torque ∝ θ
Variable controlling torque.	Fixed controlling torque.
Cheap.	Costly.
Not so accurate readings.	Accurate readings.

MOVING IRON INSTRUMENTS

Moving-iron instruments are generally used to measure the flow of alternating voltage and current with the help of moving iron.

There are two distinct types of moving-iron instruments. They differ according to whether deflection is produced by **attraction** or **repulsion**. The former makes use of the attraction of iron in the electromagnetic field of a current-carrying solenoid. The latter depends on the mutual repulsion of two similarly magnetized pieces of iron within an energized solenoid, one being fixed and the other movable.

Torque and deflection equations in moving iron Instrument

At any instant of time, let I be the current flowing through the coil, which has a self-inductance L and produces a deflection θ in the needle. The deflection θ, can also be known as the angular position of the soft-iron piece. Therefore, the initial energy stored in the coil in the form of magnetic field is given by

$$E_i = \frac{1}{2}LI^2 \quad (1)$$

Let dθ be the increment in the deflection indicated in the instrument using the deflecting torque, T_d, when a small increment in current, dI is supplied to the coil. Therefore, the mechanical work done due to such deflection is given by

$$W_m = T_d \times d\theta \quad (2)$$

Also, due to this change in current dI, there will be a change in inductance dL. Therefore, the final energy stored in the coil is given by

$$E_f = \frac{1}{2}(L + dL)(I + dI)^2 \quad (3)$$

Change in energy

$$dE = E_f - E_i$$

From (3) and (1)

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

This equation leads to

$$dE = LIdI + \frac{1}{2} I^2 dL \quad (4)$$

Due to change in current, emf increases.

$$e = \frac{d(LI)}{dt} = I\frac{dL}{dt} + L\frac{dI}{dt} \quad (5)$$

Therefore, the electrical energy supplied by the source is given by

$$E_s = eIdt$$

Substituting Eqn. (5) in the above equation, we get

$$E_s = I^2dL + LIdI \quad (6)$$

According to the law of conservation of energy, the electrical energy supplied by the source is converted into stored energy in the coil and the mechanical work done for deflection of needle in the instruments.

∴ $$E_s = dE + W_m$$

Substituting Eqn. (4) and Eqn. (2) in the above equation and solving, we get

$$\boxed{T_d = \frac{1}{2} I^2 \frac{dL}{d\theta}} \quad (7)$$

From the above equation, it is clear that the deflecting torque depends on the rate of change of inductance with the angular position of the soft-iron piece and the square of the RMS current flowing through the coil.

The controlling torque, T_c, provided by the spring arrangement in the instrument is given by

$$T_c = k_s\theta \quad (8)$$

where k_s is the spring constant.

In equilibrium state, the deflecting and controlling torques are equal, as given by

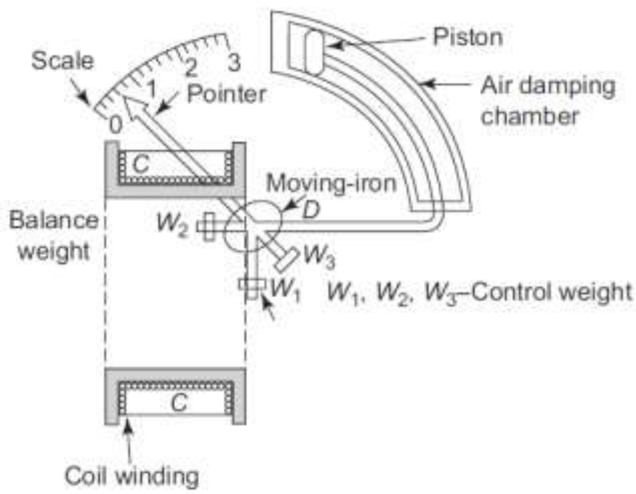
$$T_d = T_c$$

Substituting Eqn. (7) and Eqn. (8) in the above equation, we get the deflection of the needle or the angular position of the soft-iron piece as

$$\boxed{\theta = \frac{1}{2k_s} I^2 \frac{dL}{d\theta}}$$

Moving-Iron Instrument-Attraction Type

The basic working principle of attraction type of moving-iron instrument is that, when a soft-iron piece is brought near to the magnet, the magnet attracts it. The schematic diagram of the attraction type moving-iron instrument is shown in figure.



Construction

- 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 is eccentrically mounted on the spindle.
- The spindle is supported between the jewel bearings. The spindle carries a pointer which moves over a graduated scale.
- The controlling torque is provided by the springs.
- The damping torque is provided by the air friction.

Working

- When the measuring instrument is connected to the circuit, the current starts flowing through the coil and generates a magnetic field. Now, the coil behaves like a magnet, thereby attracting the soft-iron piece towards the centre of the coil, where the flux density is maximum. As a result, the spindle and the pointer attached to the spindle move from their initial positions and give a proportional deflection due to deflecting torque.
- If the current flowing through the coil is *reversed*, then the direction of the magnetic field, and hence the polarity formed in the soft-iron piece, get reversed. Hence, there will be no change in the direction of deflecting torque. Therefore, *this instrument can be used to measure both DC and AC quantities.*

Moving-Iron Instrument-Repulsion Type

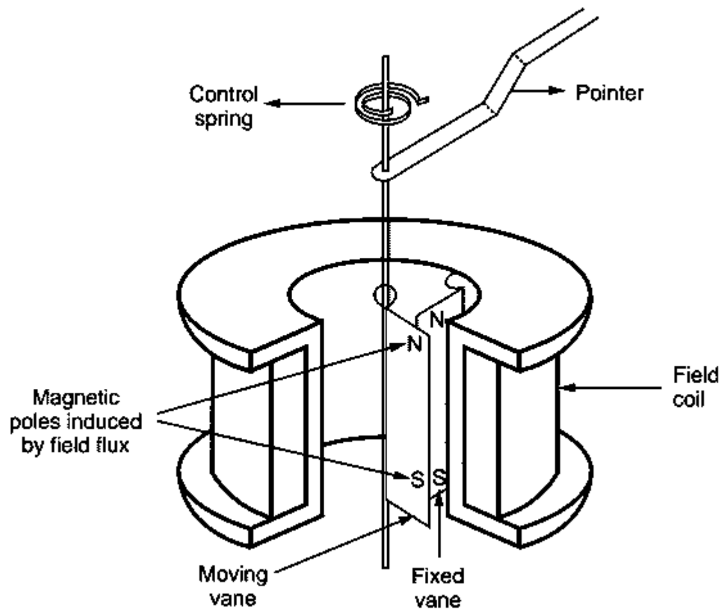
The basic working principle of a repulsion type moving-iron instrument is that, when two soft-iron pieces are magnetised to the same polarity, a force of repulsion exists between them, which cause the movement. In this instrument, there are two pieces of soft-iron inside the coil: one is fixed and the other is movable.

The two different designs of repulsion type instruments are:

1. Radial vane type
2. Co-axial or concentric vane type

Radial Type

The schematic diagram of a radial vane type repulsive moving-iron instrument is shown in Figure below.



Construction

- 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.

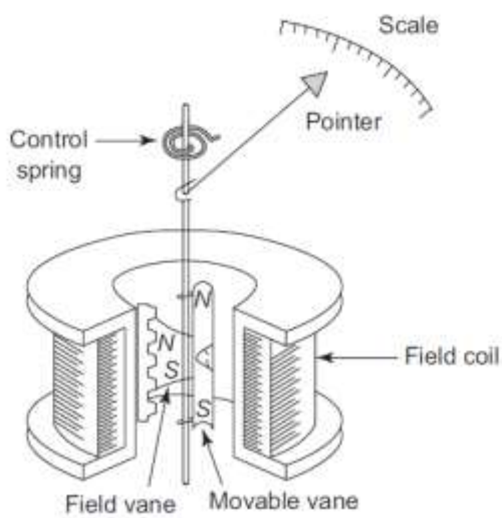
Working

- The magnetic field, which magnetises both the soft-iron pieces, is produced when the current starts flowing through the operating coil. Hence, a *repulsive force* exists between these two soft-iron pieces.

- This repulsive force, when acting on the moving iron, pushes away from its initial position. Thus, the spindle attached to the moving-iron moves and hence the pointer gives a proportional deflection. Now, even when the alternating current flows through the coil, a repulsive force *always* exists between the two soft-iron pieces. Therefore, the deflection of the pointer is always in the same direction and is directly proportional to the actual current. Hence, *this instrument can be used to measure both AC and DC quantities.*

Coaxial or Concentric Vane Type

The schematic diagram of a concentric vane type repulsive moving-iron instrument is shown in the given figure.



Construction

- The instrument has two concentric vanes or soft-irons. One is fixed to the coil frame rigidly while the other rotates coaxially inside the fixed vane.
- The shaft, which holds the pointer, is attached to the coaxial moving vane.
- The controlling torque is provided by the spring or gravity arrangement, and pneumatic or air-damping arrangement provides the damping torque.

Working

- Both the vanes are magnetized 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 square of the current through coil.

Advantages of moving iron instruments

- The instruments can be used for both a.c. and d.c. measurements.
- It can be used in low frequency and high-power circuits.
- Errors due to the friction are very less.
- A single type of moving element can cover the wide range.
- There are no current carrying parts in the moving system hence reliable.
- Give good accuracy.
- These can withstand large loads and are not damaged even under severe overload conditions.
- The range of instruments can be extended.

Disadvantages of moving iron instruments

- Because of pneumatic damping, the scale of the instrument is not uniform, which results in *less accurate* readings.
- The instrument is *not very sensitive*.
- Errors exist due to hysteresis, frequency and stray magnetic field.
- There exists difference in calibrating AC and DC instruments.
- High power consumption
- Increase in temperature increases the resistance of coil and decreases the stiffness of the spring, and permeability of soft-iron, which affects the reading.

Applications of moving iron instruments

- Heavy-current moving-iron ammeter
- Moving-iron voltmeter
- Moving-iron power factor meter
- Moving-iron synchroscope

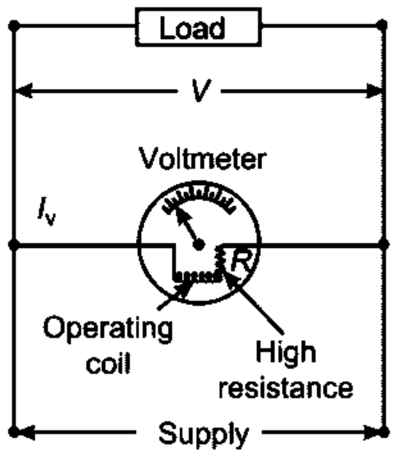
Errors in Moving Iron Instruments

- **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. We should use smaller iron parts which can demagnetize quickly or to work with lower flux densities.
- **Temperature error:** The temperature error arises due to the effect of temperature on the temperature coefficient of the spring. The coil and series resistance must have low temperature coefficient.

- **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.
- **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.
- **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 deflecting torque. This produces the error in the meter reading. As eddy currents are frequency dependent.

Moving iron voltmeter

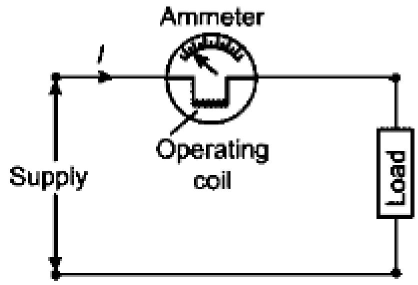
An instrument that is used to measure potential difference (or voltage) across the load or between two points in a circuit is called a voltmeter. A voltmeter is always connected in parallel with the load or portion of the circuit whose voltage is to be measured.



The deflection of the meter depends upon the current (I) flowing through the operating coil that is proportional to the voltage across the meter ($I \propto V$). Since a voltmeter is connected in parallel, it should have high resistance to keep the circuit conditions to be the same. Hence, the operating coil of a voltmeter should have a large number of turns of thin wire. However, it is not sufficient, and therefore, a high resistance is connected in series with the operating coil.

Moving iron ammeter

An instrument that is used to measure electric current in an electric circuit is called an ammeter. An ammeter is connected in series with the circuit or load whose current is to be measured. The operating coil of the instrument is to carry the whole of the current to be measured or fraction of it. When current flows through the operating coil, the desired deflecting torque is produced.



Since an ammeter is connected in series, it should have low resistance to keep the circuit conditions to be the same. Hence, the operating coil of an ammeter should have a few turns of thick wire.

Example (AU 2024, JNTUK 2020, AKTU 2021, 13 marks)

The inductance of a moving iron ammeter. With a full scale deflection of 90° at 1.5 A, is given by the expression L= $(200 + 40\theta - 40\theta^2 - \theta^3)\ \mu H$, where θ is the deflection in radian from the zero position. Estimate the angular deflection of the pointer for a current of 1.0 A.

Solution

Rate of change of deflection with respect to deflection is

$$\frac{dL}{d\theta} = (40 - 8\theta - 3\theta^2)\mu H / rad$$

For $\theta = \pi/2$

$$\frac{dL}{d\theta} = 40 - 8x\frac{\pi}{2} - 3\left(\frac{\pi}{2}\right)^2 = 20\mu H / rad$$

Now, the formula for deflection is

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

Putting various values

$$\frac{\pi}{2} = \frac{1}{2}.\frac{1.5^2}{K}x(20x10^{-6})$$

which gives value of spring constant K = 14.32×10^{-6} Nm/rad

For I = 1 A $\qquad \theta = \frac{1}{2}x\frac{1^2}{14.32x10^{-6}}(40 - 8\theta - 3\theta^2)x10^{-6}$

From this, θ = 1.008 radian = 1.008 x 180/π degree = 57.8^0

Problem

The inductance of a moving iron instrument is given by

$$L = (12 + 6\theta - \theta^2)\ \mu H$$

where θ is the deflection in radians from zero position. The spring constant is 12 x 10^{-6} Nm/radians. Calculate the deflection for a current of 8 A.

Answer: 144.74^0

Example (BPUT 2022, 6 marks)

The coil of 300 V moving iron voltmeter has a resistance of 500 Ω and an inductance of 0.8 H. The instrument reads correctly at 50 Hz a.c. supply and takes 100 mA at full scale deflection. What is the percentage error in the instrument reading when it is connected to 200 d.c. supply?

Solution

V_{ac} = 300 V; V_{dc} = 200 V; I_{ac} = 100 mA

Instrument reactance X = 2πfL = 2 x 3.14 x 50 x 0.8 = 251.32 Ω

Impedance $Z = V_{ac}/I_{ac} = 300/(100 \times 10^{-3}) = 3000\ \Omega$

Resistance $R^2 = Z^2 - X^2 = 3000^2 - 251.32^2$

∴ R = 2989.45 Ω

∴ $I_{dc} = V/R = 200/2989.45 = 0.06690$ A

Reading of instrument when connected to 200 V dc supply,

$= 0.0669 \times 300/(100 \times 10^{-3}) = 200.7$ V

Example (JNTUH 2023, 5 marks)

A 100 V moving iron voltmeter is intended for 50 Hz, has a resistance of 3 KΩ. Find the series resistance required to the extent of the range of the instrument to 200 V. If the 200 V instrument is used to measure a dc voltage of 150 V. Find the voltage across the meter?

Solution

R_m = 3 kΩ; V_m = 100 V; V = 200 V

Case 1

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

$$200 = 100\left(1 + \frac{R_{se}}{3}\right)$$

Giving $R_{se} = 3\ k\Omega$

Case 2

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

$$200 = V_m\left(1 + \frac{3}{3}\right)$$

Giving $V_m = 100\ V$

MOVING COIL INSTRUMENTS

Moving-coil instruments are mainly used in measuring DC quantities. When fed through appropriate rectifiers, this instrument can be used in measuring AC quantities. The basic principle of moving-coil instruments is that, when a current-carrying coil is placed in a magnetic field, a force or torque is exerted on it, which moves the coil away from the magnetic field. This movement of the coil helps in measuring current or voltage. The different types of moving-coil instruments are:

- Permanent magnet moving-coil instrument (PMMC): used for DC
- Dynamometer type moving-coil instrument: used for both AC and DC

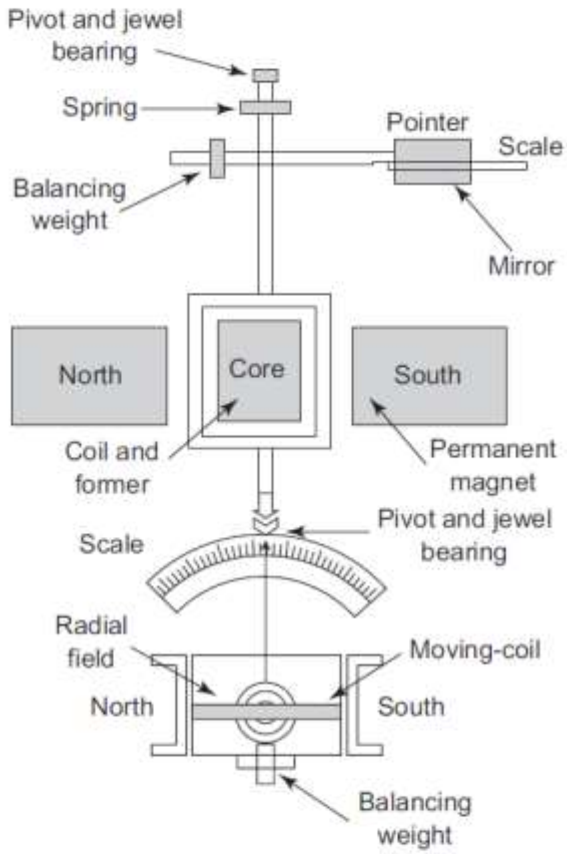
PMMC TYPE MOVING COIL INSTRUMENT

Constructional details

Main component of a PMMC instrument are moving coil, permanent magnet, spring control mechanism, damping system, scale and pointer etc.

Moving coil is wound with many turns of enamelled wire on a rectangular aluminium former which is pivoted on jewelled bearings coil moves freely in the field of permanent magnet. Voltmeter coils are wound on metal frames to provide the required electromagnetic damping.

Magnetic system consists of long U shaped **permanent magnet** having soft iron pole pieces. When the coil is supported between two jewel bearings, the control torque is provided by two phosphor bronze **hair springs**. Damping torque is provided by movement of the **aluminium former** moving in the magnetic field of permanent magnet. The **pointer** is carried by the **spindle** and moves over a **graduated scale**. The weight of the instrument is counter balanced by **weight** situated diametrically opposite and rigidly connected to it.

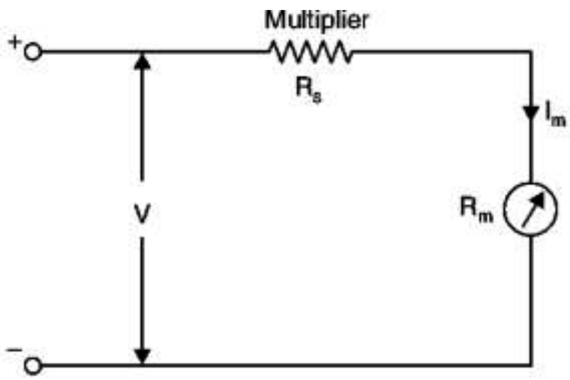


Working Principle

- When the current starts flowing through the moving-coil, a magnetic field gets generated, which is proportional to the current.
- Based on the electromagnetic action between the current-carrying coil and the permanent magnetic field, a deflecting torque is developed.
- When the controlling torque provided by the two springs matches with the deflecting torque or at balanced condition, the moving-coil gets stopped.
- The pointer attached to the moving-coil measures the amount of electrical quantity passing through the coil, by determining the angular displacement of the coil against a fixed reference, called a scale.
- The damping torque prevents further oscillation of the coil i.e., after the balanced condition.

Basic voltmeter based on PMMC

Following figure gives the *basic voltmeter* based on PMMC.



Let V is the max. voltage to be measured.

I_m = full scale deflection current of meter.

R_m = internal resistance of meter

R_s = series resistance

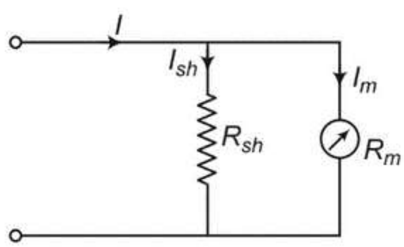
Then $V = I_m(R_m + R_s)$

∴ $R_s = \dfrac{V}{I_m} - R_m$

Thus, if a resistance of value R_s given by above equation is connected in series write PMMC, it gets converted into a voltmeter of range 0 volts.

Basic ammeter based on PMMC

Current $I = \left(1 + \dfrac{R_m}{R_{sh}}\right) I_m = I_{sh} + I_m$



Shunt resistance

$$R_{sh} = \frac{R_m}{m-1}$$

where m = I/I_m

Here R_m = internal resistance of the movement (Ω)

I_m = Full scale deflection current of the movement (A)

I = Full scale current of the ammeter including the shunt

Advantages

- Scale is uniformly divided.
- Very low power consumption (25μw to 200μw).
- Torque weight ratio is high giving high frequency.
- Voltage range can be changed merely by connecting suitable series multiplier.
- Errors due to stray magnetic fields are small.
- Useful in aircraft and aerospace applications due to self shielding magnets.

Disadvantages

- They can be used on ac only. If connected to ac, readings are zero due to finite inertia of pointer.
- These instruments are costlier than moving iron instruments.

Deflecting current is proportional to current

Deflection torque

$$T_d = BINA$$

Controlling torque

$$T_c = k\theta$$

where B = magnetic flux density

I = current

N = coil turns

A = area of coil

Provided by the spring

At equilibrium $T_d = T_c$

$$k\theta = BINA$$

Or $\theta \propto I$

Derivation for deflection of a PMMC

Let l = length of vertical side of the coil,(m)

d = length of horizontal side of the coil(m)

N = No of turns of the coil

B = Flux density in the air gap(wb/m^2)

i = Current in the coil(Amp)

K = Spring constant

θ_F = Final steady deflection(rad.)

Force on each side of the coil

$= NBil\sin\alpha$ (Lorentz force)

where α = angle between direction of magnetic field and the conductor.

Since the field is radial

$\therefore \quad \alpha = 90^0$

Hence force on each side

$= NBil$

Deflecting torque, T_d = force x distance

$T_d = NBild$

$T_d = NBiA$

where A is the area of the coil = l.d

Controlling torque exerted by the suspension at deflection θ_F is;

$T_c = K.\theta_F$

For final steady state deflection

$T_c = T_d$

$\therefore \quad K.\theta_F = NiBA$

Or $\quad \theta_F = \dfrac{NBiA}{K}$ radians.

Difference between ammeter and voltmeter

- In an ammeter, the deflecting torque is produced by current to be measured or by a definite fraction of it, whereas in a voltmeter, torque is produced by the current proportional to the voltage to be measured.
- Thus, the real difference between the two instruments is in the magnitude of the current producing the deflecting torque.
- An ammeter is connected in series with the circuit whose current is to be measured. Therefore, it should have a low resistance.
- On the other hand, a voltmeter is connected in parallel with the circuit whose voltage is to be measured, and therefore, it must have high resistance.

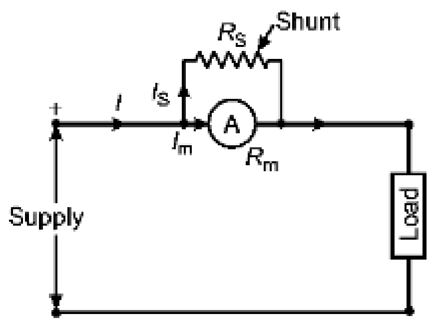
- So we see that the difference is only in the resistance of the instrument; in fact, an ammeter can be converted into voltmeter by connecting a high resistance in series with it. Similarly, a voltmeter can be converted into an ammeter by connecting a shunt across the voltmeter.

Extension of range of ammeters using shunt

The moving coil instruments can carry maximum current of about 50 mA safely and the potential drop across the moving coil is about 50 mV. However, in practice, heavy currents and voltages are required to be measured. Therefore, it becomes necessary that the current and voltage being measured be reduced and brought within the range of instrument.

Shunts are used for the extension of range of ammeters. Shunt is a resistance of small value, just like a strip having minimum temperature co-efficient. It is always connected in parallel with the ammeter whose range is to be extended. The combination is connected in series with the circuit whose current is to be measured.

The current range of a DC moving coil ammeter is extended by connecting a **shunt** R_S (low resistance) across the coil, circuit is shown in the figure.



Let I = current to be measured.

I_m = full-scale deflection current of ammeter;

I_s = shunt current;

R_m = resistance of ammeter;

R_s = shunt resistance,

Analysing the circuit,

$$\frac{I}{I_m} = \frac{R_m + R_s}{R_s} = 1 + \frac{R_m}{R_s}$$

The ratio of the total current I to be measured to the full-scale deflection current I_m is known as the **multiplying power** of the shunt or instrument constant. It may be denoted by N.

So, we can write

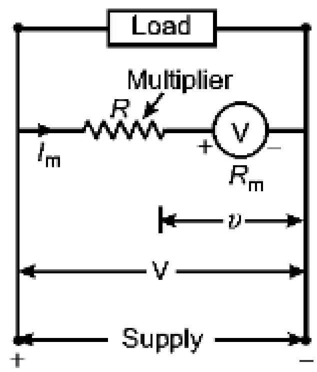
$$N = 1 + \frac{R_m}{R_s}$$

$$\therefore \qquad R_s = \frac{R_m}{N-1}$$

Hence, for measurement of current N times, the current range of instrument, the shunt resistance should be **1/(N -1) times** the meter resistance.

Extension of Voltmeter Range

The voltage range of a DC moving coil voltmeter (instrument) is extended by connecting a **multiplier** R (high resistance) in series with the coil. The circuit is shown in following figure.



Let V = voltage to be measured;

v = voltage across the meter;

I_m = full-scale deflection current of voltmeter;

R = resistance in series with the coil to extend the range;

R_m = voltmeter resistance.

Using circuit analysis

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

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

Again from given figure

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

∴ $$R = \frac{\left(\frac{V}{v} - 1\right)}{I_m}$$

The ratio of voltage to be measured to the voltage across the voltmeter for which it is actually designed (i.e., V/v) is known as **multiplying factor** (m).

∴ $$R = \frac{v(m-1)}{I_m} \Rightarrow R = (m-1)R_m$$

Hence, for the measurement of voltage, m times the voltage range of the instrument the series multiplying resistance R should be **(m − 1) times** the meter resistance R_m.

Errors in PMMC Instrument

- **Frictional errors:** To reduce these errors, ratio of torque to weight is made very high.
- **Error due to change in temperature:** This changes the resistance of the working coil, causing large errors. In case of voltmeters, a large series resistance of very low temperature coefficient is used. This reduces the temperature errors.
- **Errors due to aging:** The aging of permanent magnet and control springs also cause errors. The weakening of magnet and springs cause opposite errors. The weakening of magnet cause less deflection while weakening of the control springs cause large deflection, for a particular value of current. The proper use of material may eliminate these errors.

Loading effect and sensitivity of voltmeters

The voltmeter is always connected in parallel with the points in a circuit at which the voltage is to be measured. It must possess a very high value of resistance because a low resistance may result in changing of voltage of the circuit under test. This is known as **loading effect** of the voltmeter.

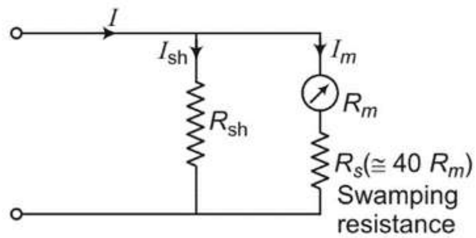
When selecting a meter for certain voltage measurement, the **sensitivity** of DC voltmeter is an important factor. It is defined as the total resistance of the instrument per unit volt. The total resistance of the voltmeter is the sum of multiplier resistance and coil resistance.

Effect of Temperature Changes in Voltmeters

The multiplier resistance used in series with the moving-coil is usually made of manganin having a negligible resistance temperature coefficient. Since the series resistance of the multiplier is very much greater than the coil resistance (which is of copper), the variations of resistance of R_m due to temperature changes are *'swamped'* by the resistance R_s of multiplier. This is illustrated by the following example.

Effect of Temperature changes in Ammeters

As temperature increases the resistance of copper increases and this result into change of reading of the instrument. To reduce the effect of temperature a resistance having very small temperature coefficient made up of manganin is connected in series with the coil and this is known as **swamping resistance**.



COMPARISON BETWEEN MOVING-COIL AND MOVING-IRON INSTRUMENTS

Moving-Coil Instrument	Moving-Iron Instrument
Costly	Cheaper
Uniformly distributed reading scale	Absence of uniformity in the scale
Power consumption is low	Power consumption is high
Uses eddy current damping	Uses air-friction damping
Deflection is directly proportional to current, $\theta \propto I$	Deflection is directly proportional to square of the current, $\theta \propto I^2$
Errors are set due to ageing of control springs, permanent magnet	Errors are set due to hysteresis and stray fields

Example (JNTUK 2021, 8 marks)

A PMMC instrument has a coil of dimensions 15 mm x 12 mm. The flux density in the air gap is 1.8 x10^{-3} Wb/m^2 and the spring constant is 0.14 x10^{-6} Nm/rad. Determine the number of turns required to produce an angular deflection of 90 degrees. When a current of 5 mA is flowing through the coil.

Solution

Total deflecting torque exerted on the coil,

$$T_d = BILNW$$

$$= 1.8 \times 10^{-3} \times 5 \times 10^{-3} \times 15 \times 10^{-3} \times 12 \times 10^{-3} \times N$$

$$= 1620 \times 10^{-12}\ N\ Nm$$

The control torque of the springs is

$$T_c = K\theta = 0.14 \times 10^{-6} \times 90 \times \pi/180 = 0.2198 \times 10^{-6}\ Nm$$

At equilibrium, $T_d = T_c$

$$1620 \times 10^{-12}\ N = 0.2198 \times 10^{-6}\ Nm$$

This gives $N = 136$

Example (BPUT 2022, 2 marks)

A PMMC meter has an internal resistance 200 Ω and the current required for its full scale deflection is 50 µA. What will be the maximum measuring voltage of the meter.

Solution

Current sensitivity is given by

$$S = \frac{1}{I_f} = \frac{R_{int}}{V_m}$$

Where

S = Sensitivity of ammeter.

I_f = Full scale deflection of an ammeter.

R_{int} = Internal resistance of an ammeter

V_m = Full range voltage.

Given $R_{int} = 200\ \Omega$, $I_f = 50\ \mu A$

$$S = \frac{1}{50x10^{-6}} = 20,000\Omega / V$$

Now $$V_m = \frac{R_{int}}{S} = \frac{200}{20,000} = 10mV$$

Example (UTU 2023, 5 marks)

Calculate the value of multiplier resistance on the 50 V range of a DC voltmeter that uses a 500 mA meter movement with an internal resistance of 1KΩ?

Solution

$$S = \frac{1}{I_f} = \frac{1}{500mA} = 2k\Omega / V$$

R_s = S x range – R_m

$$= \frac{2k\Omega}{V} x50V - 1k\Omega = 99k\Omega$$

Example (JNTUH 2021, 8 marks)

A moving coil voltmeter having an internal resistance of 20 Ω gives a full scale deflection with a voltage of 20 mV. The instrument is to be used with a multiplier of manganin to extend the range to 10 V. Calculate the error caused by 18^{0}C rise in temperature. The temperature coefficient of Copper is 0.004/^{0}C and that of Manganin is 0.00015/^{0}C.

Solution

Meter current for FSD

$$I_m = \frac{V}{R_m} = \frac{20x10^{-3}}{20} = 1mA$$

Multiplying factor

$$M = \frac{V}{v} = \frac{18}{20x10^{-3}} = 900$$

Multiplier resistance = R_{se} = (M - 1)R_m = (900 - 1) x 20 = 17980 Ω

Total resistance of voltmeter circuit = 17980 + 20 = 18000 Ω

Resistance of the meter with 18° rise in temperature $R_{m,15}$

= 20 (1 + 0.004 x 18) = 21.44 Ω

Resistance of the multiplier with 18° rise in temperature $R_{se,15}$

= 17980 (1 + 0.00015 x 18) = 18028.55

Total resistance of the voltmeter circuit with 18° rise in temperature

= 21.44 + 18028.55 = 18050

Reading of the voltmeter at 18^0 rise in temperature

$$= \frac{18000}{18050} x18 = 17.95$$

Percentage error

$$= \frac{14.965 - 15}{15} = 0.232\%$$

Example (JNTUH 2023, 4 marks)

The pointer of a moving coil instrument gives full scale deflection of 20 mA. The potential difference across the meter when carrying 20 mA is 400 mV. Determine (i) the shunt resistance *required to design 0 – 200 A range ammeter. (ii) the series resistance required to design 0 – 1000 V range voltmeter.*

Solution

Case 1

V_m = 400m V

I_m = 20 mA

I = 200 A

$$R_m = \frac{V_m}{I_m} = \frac{400}{20} = 20\Omega$$

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

$$200 = 20x10^{-3}\left[1 + \frac{20}{R_{sh}}\right]$$

Giving $R_{sh} = 2 \times 10^{-3}\ \Omega$

Case 2

V = 1000 V

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

$$4000 = 400x10^{-3}\left(1 + \frac{R_{se}}{20}\right)$$

Giving R_{se} = 49.98 kΩ

Example (JNTUK 2022, 7 marks)

A moving coil instrument gives a full-scale deflection of 10 mA when the potential difference across its terminals is 100 mV. Calculate (i) the shunt resistance for a full-scale deflection corresponding to 100 A, (ii) the series resistance for full scale reading with 1000 V. Calculate the power dissipation in each case.

Solution

Given data

I_m = 10 mA; V_m = 100 mV

∴ $$R_m = \frac{V_m}{I_m} = \frac{100}{10} = 10\Omega$$

For a full-scale deflection corresponding to 100 A

Shunt resistance

$$R_{sh} = \frac{I_m R_m}{I - I_m} = \frac{10x10^{-3}x10}{100 - 10x10^{-3}} = 1.0001 m\Omega$$

Power dissipated

$$P = I^2 R_{sh} = 100^2 \text{ x } 1.0001 \text{ x } 10^{-3} = 10.001 \text{ W}$$

For full scale reading with 1000 V

Series resistance

$$R_s = \frac{V}{I_m} - R_m = \frac{1000}{10x10^{-3}} - 10 = 99990\Omega$$

Power dissipated

$$P = \frac{V^2}{R_s} = \frac{1000^2}{99990} = 10.001 W$$

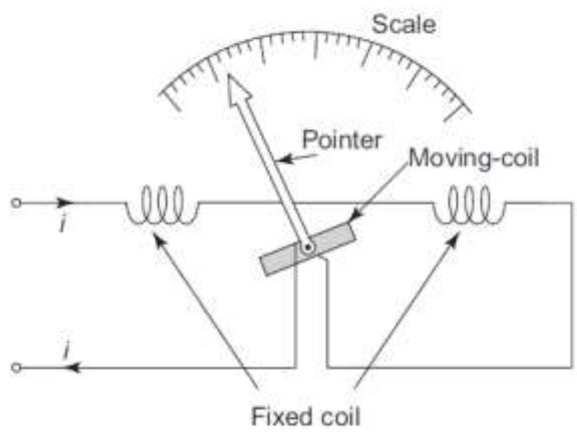
ELECTRODYNAMOMETER TYPE MOVING COIL INSTRUMENT

An electrodynamometer-type instrument is used for the measurement of AC and DC quantities, unlike a PMMC instrument, which can only be used for the measurement of DC quantities.

The electrodynamometer-type instrument, which is similar to a PMMC type instrument except for the permanent magnet used in PMMC-type instrument, is replaced with another fixed coil that generates the necessary magnetic field.

Constructional details

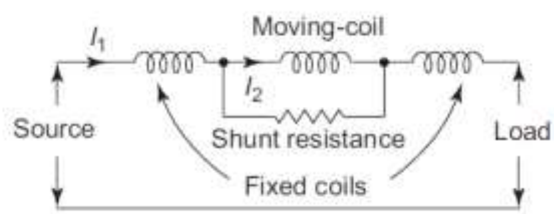
- In these instruments two kinds of coils are used viz. fixed coil and moving coil.
- The **fixed coils** are connected in series with the load and carry the current in the circuit. They are also called current coils.



- The **moving coil** is connected across voltage.
- A high non inductive resistance is connected in series with the moving coil to limit the current through it. This coil is also called **voltage coil** or pressure coil of wattmeter.
- Fixed coils are divided in **two halves**. They are wound with a standard heavy wire to avoid eddy current losses.
- Moving coil is mounted on a **pivoted spindle** and is entirely embraced by the fixed current coils. A **series resister** is used to limit the current to a small valve between 10 to 50 mA
- **Spring control** is used for the instrument together with **air friction damping**. Latter is provided by a **light aluminium vane** carried by the moving system.
- **Minor type scale** is used with knife edge pointers to remove parallel error.

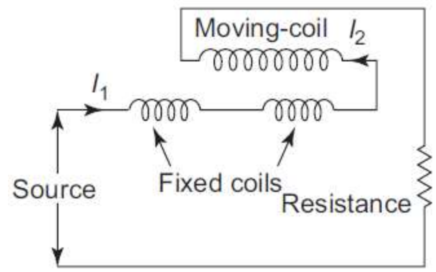
Working Principle

- When the electrodynamometer instrument is used as an **ammeter**, both the fixed and moving-coils are connected in series to carry the same current. To limit the current that is flowing through these coils, a suitable shunt-resistance is connected to these coils.



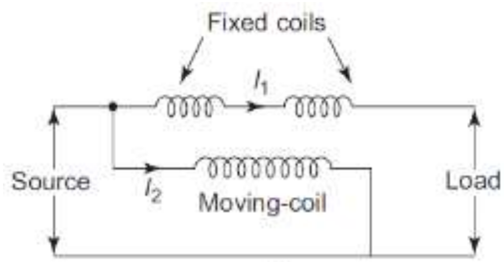
electrodynamometer as ammeter

- But, when the electrodynamometer instrument is used as a **voltmeter**, the fixed and moving-coils are connected in series with high non-inductive resistance.



electrodynamometer as voltmeter

- When it is used to **measure the power**, the fixed coil and moving-coil act as the current and voltage coils, connected in series with the load and across the supply terminals respectively.



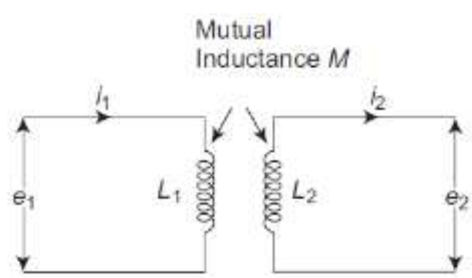
electrodynamometer as wattmeter

- When the current starts flowing through both the coils, a **magnetic field** is produced.
- The **magnetic field** produced by the fixed coil is proportional to the load current and the magnetic field produced by the moving coil is proportional to the voltage.
- Now, the **deflecting torque** is produced due to the interaction of these two fields, and the deflection indicated by the pointer is proportional to the power supplied to the load.

Torque equation

Let i_1 and i_2 be the instantaneous currents flowing through the fixed and moving-coils respectively; L_1 and L_2 be the self-inductances of the fixed and moving-coils respectively and M be the mutual inductance existing between the fixed and moving-coils.

The equivalent circuit of an electrodynamometer instrument is shown below.



The flux linkages of coil 1 and coil 2 are given by

$$\phi_1 = L_1 i_1 + M i_2 \text{ and } \phi_2 = L_2 i_2 + M i_1 \quad (1)$$

Now, the induced emfs in the fixed and moving-coils are given by

$$e_1 = \frac{d\phi_1}{dt}; e_2 = \frac{d\phi_2}{dt} \quad (2)$$

Electrical input energy

$$e_i = e_1 i_1 dt + e_2 i_2 dt$$

Using equation 2,

$$e_i = i_1 d\phi_1 + i_2 d\phi_2$$

Substituting Eqn. 1 in the above equation, we get

$$e_i = i_1 d(L_1 i_1 + M i_2) + i_2 d(L_2 i_2 + M i_1)$$

$$= i_1 L_1 di_1 + i_1^2 dL_1 + i_1 i_2 dM + i_1 M di_2 + i_2 L_2 di_2 + i_2^2 dL_2 + i_1 i_2 dM + i_2 M di_1 \quad (3)$$

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

$$e_s = \frac{1}{2} L_1 i_1^2 + \frac{1}{2} L_2 i_2^2 + i_1 i_2 M$$

The change in stored energy is given by

$$de_s = d\left[\frac{1}{2} L_1 i_1^2 + \frac{1}{2} L_2 i_2^2 + i_1 i_2 M\right]$$

$$= i_1 L_1 di_1 + \frac{1}{2} i_1^2 dL_1 + i_1 i_2 dM + i_1 M di_2 + i_2 L_2 di_2 + \frac{1}{2} i_2^2 dL_2 + i_1 i_2 dM + i_2 M di_1 \quad (4)$$

According to the principle of conservation of energy, we get

Input energy = Energy stored + Mechanical energy

Therefore, Mechanical energy = Input energy – Energy stored

Substituting Eqn. (3) and Eqn. (4) in the above equation, we get

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-inductances L_1 and L_2 are constant, $dL_1 = dL_2 = 0$.

Therefore, the mechanical energy = $i_1 i_2 dM$ (5)

Mechanical work is also given by $T_d d\theta$ (6)

From (5) and (6)

$$i_1 i_2 dM = T_d d\theta$$

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

Case 1: DC operation

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

Case 2: AC operation

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

ELECTROSTATIC VOLTMETERS

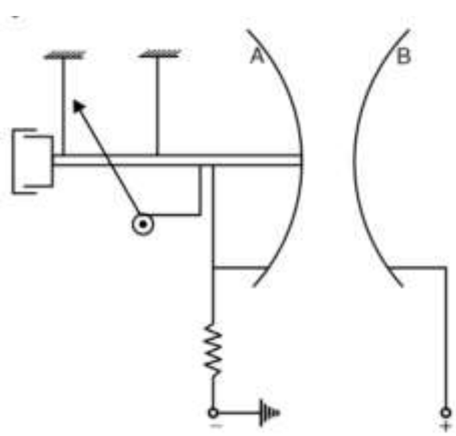
These instruments are based on the fact that an electric force (attraction or repulsion) exists between charged plates or objects. An electrostatic voltmeter is essentially an air condenser; one plate is fixed while the other, which is coupled to the pointer, is free to rotate on jewelled bearings. When p.d. to be measured is applied across the plates, the electric force between the plates gives rise to a deflecting torque. Under the action of deflecting torque, the movable plate moves and causes the deflection of the pointer to indicate the voltage being measured. Such instruments can be used to measure direct as well as alternating voltages.

There are three types of electrostatic voltmeters viz.:

- Attracted disc type (usual range from 500 V to 500 kV)
- Quadrant type (usual range from 250 V to 10 kV)
- Multicellular type (usual range from 30 V to 300 V)

Attracted disc type voltmeter

Following figure shows the simplified diagram of an attracted disc electrostatic voltmeter.



It consists of two mushroom-shaped plates A and B, each mounted on insulated pedestal. The plate B is fixed while the plate A (negative, for direct voltage) has a movable central portion-the attracted disc. The movable plate A is attached to a horizontal rod which is suspended by two phosphor bronze strips. When p.d. to be measured is applied across the plates, the plate A moves towards the fixed plate B and actuates the pointer via a pulley or link mechanism.

The control force is provided by gravity and damping force by air dash pot. If the plates are too close together or if the applied voltage is too high, a spark discharge may occur. In order to prevent such a possibility, a ballast resistor is included in the circuit. The function of this resistor is to limit the current if any sparking-over occurs.

If the applied voltage reverses in polarity, there is a simultaneous change in the sign of charge on the plates so that the direction of deflecting force remains unchanged. Hence such instruments can be used for both d.c. and a.c. measurements.

Force of attraction is given by

$$F = \frac{1}{2}\frac{dC}{dx}V^2$$

Where x = distance between the plates

C = capacitance between the plates

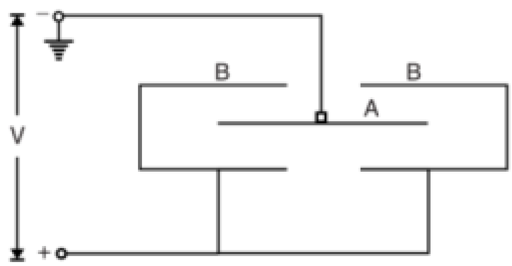
V = applied voltage

$\therefore \quad F \propto V^2$

Obviously, the scale of the instrument will be non-uniform.

Quadrant type voltmeter

Following figure shows the simplified diagram of a quadrant electrostatic voltmeter.



It consists of a light aluminium vane A suspended by a phosphor-bronze string mid-way between two inter-connected quadrant shaped brass plates BB. One terminal is joined to fixed plates BB (positive for direct voltage) and the other to the movable plate A (negative for direct voltage). The controlling torque is provided by the torsion of the suspension string. Damping is provided by air friction due to the motion of another vane in a partially closed box.

Working

When the instrument is connected in the circuit to measure the p.d., an electric force exists between the plates. Consequently, the movable vane A moves in between the fixed plates and causes the deflection of the pointer. The pointer comes to rest at a position where deflecting torque is equal to the controlling torque. Since the force of attraction between the movable plate A and the fixed plates BB is directly proportional to $(p.d.)^2$, the instrument can be used to measure either direct or alternating voltages. When used in an a.c. circuit, it reads the r.m.s. values.

Average deflecting torque

$$T_d = \frac{1}{2}\frac{dC}{d\theta}V^2$$

Example

An electrostatic voltmeter consists of two parallel plates, one movable and one fixed. With 11 kV applied between the plates, it is found that the pull is 10 × 10^{-3} N on the movable plate. Determine the change in capacitance produced for a movement of movable plate by 1 mm. Diameter of movable plate is 150 mm.

Solution

Area of plate $A = \frac{\pi}{4}(150\,x10^{-3})^2 = 17.6\,x10^{-3}\,m^2$

Force of attraction

$$F = \frac{1}{2}\varepsilon_0\frac{U_{rms}{}^2}{d^2}A$$

$$\therefore \qquad d = \sqrt{\frac{\varepsilon_0 A}{2F}}U_{\max} = \sqrt{\frac{8.854x10^{-12}\,x17.6x10^{-3}}{2x10x10^{-3}}}(11x10^3) = 30.7 \text{ mm}$$

The position of movable plate changes by 1 mm.

Hence, d changes from 30.7 to (30.7 - 1) = 29.7 mm, that is, d_1 = 30.7 mm and d_2 = 29.7 mm.

Now, for a parallel-plate capacitor

$$C = \varepsilon_0\varepsilon_r A/d$$

So, the change in capacitance is

$$\Delta C = \varepsilon_0\varepsilon_r A\left(\frac{1}{d_2} - \frac{1}{d_1}\right)$$

$$= 8.854x10^{-12}x17.6x10^{-3}\left(\frac{1}{29.7x10^{-3}}-\frac{1}{30.7x10^{-3}}\right)$$

= 0.17 pF

ASSIGNMENT

Q.1. (RGPV 2023, 7 marks): Give the detailed classification of analog instruments along with their operating principle.

Q.2. (BPUT 2022, 2 marks): What is the difference between gravity control and spring control?

Answer: Described in this module.

Q.3. (JNTUK 2021, 8 marks): Explain the following control mechanisms used in indicating instruments: (i) Gravity control (ii) Spring control

Answer: Described in this module.

Q.4. (JNTUH 2023, GTU 2022, 3 marks): Which methods are used for producing deflecting, controlling and damping torques in a Moving Iron instruments?

Answer: Described in this module.

Q.5. (AU 2024, 2 marks): Distinguish between air friction damping and fluid friction damping.

Answer: Described in this module.

Q.6. (RGPV 2020, 7 marks): What are the various operating forces and damping techniques used in analog instruments?

Answer: Described in this module.

Q.7. (JNTUK 2022, 8 marks): Explain the following damping systems used in indicating instruments:

(i) Air friction damping

(ii) Fluid friction damping

(iii) Eddy current damping

(iv) Electromagnetic damping

Answer: Described in this module.

Q.8. (AKTU 2022, 2 marks): Differentiate between null type and deflection type of measuring instruments along with suitable example.

Q.9. (AKTU 2023, RGPV 2020, 10 marks): Describe the construction and working principle of electro dynamometric type instrument with suitable diagram.

Q.10. (AU 2023, 2 marks): Give the importance of iron loss measurement.

Q.11. (AU 2024, 2 marks): How the iron loss is measured?

Q.12. (HPTU 2021, 7.5 marks): Explain three electromechanical forces in indicating instruments.

Q.13. (JNTUH 2020, 2021, 5 marks): How to extend the range of the instrument using shunts?

Q.14. (JNTUH 2021, PTU 2019, 8 marks): Compare moving coil and moving iron type instruments.

Q.15. (JNTUK 2022, 8 marks): Explain the working of Electrostatic instruments and derive the force and torque equations of Electrostatic instruments.

Q.16. (RTU 2017, 8 marks): Explain the errors in wattmeter and energy meter and their compensation techniques.

Q.17. (UTU 2023, 5 marks): Explain different types of torques present in indicating type instrument?

MOVING IRON INSTRUMENTS

Q.18. (HPTU 2021, 7.5 marks): Explain moving iron type instruments.

Answer: Described in this module.

Q.19. (JNTUH 2023, 2 marks): What are the advantages of M. I instrument?

Answer: Described in this module.

Q.20. (AU 2024, AKTU 2022, GTU 2021, RGPV 2020, 2023, RTU 2016, 10 marks): Illustrate the construction and operation of moving iron type of instruments. Also derive the expression of deflecting torque. Enlist the advantages, disadvantages of these instruments. Prove that its scaling is non-uniform.

Answer: Described in this module.

Q.21. (HPTU 2021, 7.5 marks): Explain comparison of damping methods.

Answer: Described in this module.

Q.22. (BPUT 2020, 2 marks): Can Moving Iron instruments be used for measurement of DC currents? Justify it.

Answer: Described in this module.

Q.23. (AU 2023, 2 marks): List the possible causes of errors in moving iron instruments.

Answer: Described in this module.

Q.24. (AKTU 2021, 10 marks): Explain the principle construction and operation of Attraction type moving iron instruments with neat diagram.

Answer: Described in this module.

Q.25. (JNTUH 2020, JNTUK 2021, 7 marks): Explain the working principle of repulsion type moving iron instrument.

Answer: Described in this module.

Q.26. (AU 2024, JNTUK 2020, AKTU 2021, 13 marks): The inductance of a moving iron ammeter. With a full scale deflection of 90° at 1.5 A, is given by the expression $L = (200 + 40\theta - 40\theta^2 - \theta^3)$ μH, where θ is the deflection in radian from the zero position. Estimate the angular deflection of the pointer for a current of 1.0 A

Answer: Solved in this module.

Q.27. (BPUT 2022, 6 marks): The coil of 300 V moving iron voltmeter has a resistance of 500 Ω and an inductance of 0.8 H. The instrument reads correctly at 50 Hz a.c. supply and takes 100 mA at full scale deflection. What is the percentage error in the instrument reading when it is connected to 200 d.c. supply?

Answer: Solved in this module.

Q.28. (JNTUH 2023, 5 marks): A 100 V moving iron voltmeter is intended for 50 Hz, has a resistance of 3 KΩ. Find the series resistance required to the extent of the range of the instrument to 200 V. If the 200 V instrument is used to measure a dc voltage of 150 V. Find the voltage across the meter?

Answer: Solved in this module.

MOVING COIL INSTRUMENTS

Q.29. (GTU 2021, 3 marks): Why PMMC instrument cannot be used for ac measurement?

Answer: 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.

Q.30. (RTU 2017, 8 marks): Explain why PMMC instruments are the most widely used instruments. Discuss their advantage and disadvantage.

Answer: Described in this module.

Q.31. (HPTU 2016, 2 marks): State the advantages of PMMC instruments.

Answer: Described in this module.

Q.32. (GTU 2021, 4 marks): How the current range of PMMC instrument extended with the help of shunts?

Answer: Described in this module.

Q.33. (GTU 2023, 4 marks): How the range of dc voltmeter can be extended? Derive the expression to calculate multiplier resistance.

Answer: Described in this module.

Q.34. (JNTUH 2022, 7 marks): Explain with neat diagrams for the extension of ranges of volt meters and ammeters using series and shunt resistors.

Answer: Described in this module.

Q.35. (UTU 2023, 5 marks): Derive the deflecting torque developed in the PMMC?

Answer: Described in this module.

Q.36. (AKTU 2023, AU 2023, GTU 2022, 2023, JNTUH 2020, 2022, BPUT 2022, 13 marks): Describe the construction and working of permanent magnet moving coil instrument. Also derive the expression for deflection.

Answer: Described in this module.

Q.37. (JNTUH 2023, RTU 2016,10 marks): Explain the working of PMMC instrument. State the errors present in them.

Answer: Described in this module.

Q.38. (JNTUH 2023, 5 marks): Briefly discuss the operation of DC Voltmeter with help of neat diagram.

Answer: Described in this module (PMMC instrument).

Q.39. (AKTU 2020, 2 marks): Define sensitivity of voltmeter.

Answer: Described in this module.

Q.40. (AKTU 2021, 2 marks): What is the difference between an ammeter and a voltmeter?

Answer: Described in this module.

Q.41. (BPUT 2020, 2 marks): Why a voltmeter should have a high resistance value?

Answer: Described in this module.

Q.42. (BPUT 2022, 2 marks): A PMMC meter has an internal resistance 200 Ω and the current required for its full scale deflection is 50 μA. What will be the maximum measuring voltage of the meter.

Answer: Solved in this module.

Q.43. (JNTUH 2021, 8 marks): A moving coil voltmeter having an internal resistance of 20 Ω gives a full scale deflection with a voltage of 20 mV. The instrument is to be used with a multiplier of manganin to extend the range to 10 V. Calculate the error caused by 18^0C rise in temperature. The temp coefficient of Copper is $0.004/^0$C and that of Manganin is $0.00015/^0$C.

Answer: Solved in this module.

Q.44. (JNTUH 2023, 4 marks): The pointer of a moving coil instrument gives full scale deflection of 20 mA. The potential difference across the meter when carrying 20 mA is 400 mV. Determine (i) the shunt resistance required to design 0 – 200 A range ammeter. (ii) the series resistance required to design 0 – 1000 V range voltmeter.

Answer: Solved in this module.

Q.45. (JNTUK 2021, 8 marks): A PMMC instrument has a coil of dimensions 15 mm x 12 mm. The flux density in the air gap is 1.8 $\times 10^{-3}$ wb/m^2 and the spring constant is 0.14 $\times 10^{-6}$ Nm/rad. Determine the number of turns required to produce an angular deflection of 90 degrees. When a current of 5 mA is flowing through the coil.

Answer: Solved in this module.

Q.46. (JNTUK 2022, 7 marks): A moving coil instrument gives a full-scale deflection of 10 mA when the potential difference across its terminals is 100 mV. Calculate (i) the shunt resistance for a full-scale deflection corresponding to 100 A, (ii) the series resistance for full scale reading with 1000 V. Calculate the power dissipation in each case.

Answer: Solved in this module.

Q.47. (JNTUK 2023, 7 marks): A moving coil meter gives full scale deflection with a current of 5 mA, if the coil of the instrument has a resistance of 10 Ω. Show how it can be adopted to work (i) as an ammeter with a range of 0 to 10 A (ii) as Voltmeter with a range of 0 to 100 V.

Answer: Similar problem is solved in this module.

Q.48. (UTU 2023, 5 marks): Calculate the value of multiplier resistance on the 50 V range of a DC voltmeter that uses a 500 mA meter movement with an internal resistance of 1KΩ?

Answer: Solved in this module.

ELECTRODYNAMOMETER-TYPE INSTRUMENT

Q.49. (HPTU 2016, RGPV 2023, 6 marks): Explain the operating principle of Electrodynamometer type instrument and also derive torque equation of Electrodynamometer instrument.

Answer: Described in this module.

Q.50. (GTU 2022, RTU 2017, 5 marks): Explain why electrodynamometer type of instruments can be used both on ac and dc?

Answer: They work on the principle of magnetic effects of electric current, which is applicable to both DC and AC. The moving iron is attracted towards the fixed coil when current flows through it, regardless of the direction of the current. Therefore, these instruments can measure both DC and AC quantities.

Q.51. (JNTUK 2021, 8 marks): List and explain the various sources of errors in Electrodynamometer instruments and how to mitigate them.

Answer:

- Eddy current error: it reduces the reading.
- Frequency error: As frequency increases, the value of Z also increases. Now in the case of voltmeter the reading is reduced as $\theta \propto 1/Z^2$.

ELECTROSTATIC VOLTMETER

Q.52. (JNTUH 2022, 2023, 8 marks): Describe the principle and working of attractive disc type electrostatic volt meters with a neat sketch.

Answer: Described in this module.

Q.53. (JNTUH 2022, 7 marks): An electrostatic voltmeter consists of two attracted plates (movable and fixed provided with guard rings). When a potential difference of 10 KV is applied between the plates, there is a pull of 5×10^{-3} N on the movable plate. Find the change in capacitance produced due to the change in the position of the movable plate by 1mm. Diameter of the movable plate is 100 mm.

Answer: 0.014 pC. A similar problem is solved in this module.