MEC 3102 – PRODUCTION ENGINEERING I AND ELECTRICITY & ELECTRONICS II

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2nd Series Lecture 2[4]

Review of Measuring Requirements

II. Dynamic characteristics: The set of criteria defined for the instruments, which are changes rapidly with time, is called ‘dynamic characteristics’.

The various dynamic characteristics are:

i) Speed of response
ii) Measuring lag
iii) Fidelity
iv) Dynamic error

- Speed of response: It is defined as the rapidity with which a measurement system responds to changes in the measured quantity.
- Measuring lag: It is the retardation or delay in the response of a measurement system to changes in the measured quantity. The measuring lags are of two types:
  a) Retardation type: In this case the response of the measurement system begins immediately after the change in measured quantity has occurred.
  b) Time delay lag: In this case the response of the measurement system begins after a dead time after the application of the input.

- **Fidelity**: It is defined as the degree to which a measurement system indicates changes in the measurand quantity without dynamic error.
- **Dynamic error**: It is the difference between the true value of the quantity changing with time & the value indicated by the measurement system if no static error is assumed. It is also called measurement error.

Error

Errors in measurement systems can be divided into those that arise during the measurement process and those that arise due to later corruption of the measurement signal by induced noise during transfer of the signal from the point of measurement to some other point.

- Static Error is the difference between the result of measurement and the true value of the quantity being measured:

  Error = measured value – true value

- Thus if the measurement system gives voltage of 21 volts when the actual voltage is 20 volts then error is

  Error = 21V – 20V = 1V

TYPES OF STATIC ERROR

- Types of error in measurement:
  1) Gross error/human error
  2) Systematic Error
  3) Random Error

1. Gross Error

- caused by human mistakes in reading and using instruments
- cannot be eliminated but can be minimized

2. Systematic Error

- is due to shortcomings of the instrument such as defective or worn out parts
- there are 3 types of systematic error :-

(i) Instrumental error
(ii) Environmental error
(iii) Observational error

i. Instrumental error

- Inherent in the measuring instrument because of their mechanical structure (bearing friction, irregular spring tension, stretching of spring, etc)

- ✓ error can be avoided by:
  - a. Selecting a suitable instrument for the particular measurement application
  - b. Apply correction factor by determining instrumental error
  - c. Calibrate the instrument against standard

ii. Environmental error
  - ▪ Due to external condition affecting the measurement, including surrounding area condition such as change in temperature, humidity,pressure, etc
    - ✓ to avoid the error :-
      - (a) use air conditioner
      - (b) sealing certain component in the instruments
      - (c) use magnetic shields

iii. Observational error
  - ▪ Introduced by the observer
  - ✓ most common : parallax error and estimation error (while reading the scale)

3. **Random error**

- Due to unknown causes, occur when all systematic error has accounted
- Accumulation of small effect, required at high degree of accuracy
  - ✓ Can be avoided by
  - ➢ Increasing number of reading
  - ➢ Use statistical means to obtain best approximation of true value

Digital Instruments

- ❖ All types of digital meter are basically modified forms of the digital voltmeter (DVM), irrespective of the quantity that they are designed to measure.
- Digital meters designed to measure quantities other than voltage are in fact digital voltmeters that contain appropriate electrical circuits to convert current or resistance measurement signals into voltage signals.
- Digital meters have been developed to satisfy a need for higher measurement accuracies and a faster speed of response to voltage changes than can be achieved with analogue instruments.
  - ✓ They are technically superior to analogue meters in almost every respect. However, they have a greater cost due to the higher manufacturing costs compared with analogue meters.

- The major part of a digital voltmeter is the circuitry that converts the analogue voltage being measured into a digital quantity.
- Digital voltmeters differ mainly in the technique used to effect the analogue-to-digital conversion between the measured analogue voltage and the output digital reading.
- As a general rule, the more expensive and complicated conversion methods achieve a faster conversion speed.

Some common types of DVM are discussed below.

1. Voltage-to-time conversion digital voltmeter
2. Potentiometric digital voltmeter
3. Dual-slope integration digital voltmeter
4. Voltage-to-frequency conversion digital voltmeter

Digital Multimeter

- ❖ This is an extension of the DVM. It can measure both a.c. and d.c. voltages over a number of ranges through inclusion within it of a set of switchable amplifiers and attenuators.
- ✓ It is widely used in circuit test applications as an alternative to the analogue multimeter, and includes protection circuits that prevent damage if high voltages are applied to the wrong range.

Analogue Intruments

- An analog instrument is one in which the operation and output are continuously changing and bear a fixed relationship to the input

1. MOVING-IRON INSTRUMENTS

- Moving-iron instruments are commonly used in laboratories and switch boards at commercial frequencies because they are very cheap and can be manufactured with required accuracy. There are two types of moving iron instruments viz:

- Attraction type moving iron meter
- Repulsion type moving iron meter

➢ The Attraction type Moving Iron Instrument

- ✓Moving iron meter consists of solenoid (or coil) C and a shaft or spindles to which an indicating pointer P and oval shaped soft-iron disc D is attached in such a way that it can move in and out of the solenoid. The front and end view of the Attraction type moving iron meter is as shown in figure 5.4.
- ✓When the current to be measured is passed through the solenoid, a magnetic field is set up inside the solenoid, which in turn magnetizes the iron. Thus the soft-iron disc is attracted into the solenoid/coil, causing the spindle and the pointer to rotate. Damping is provided by vane V attached to the spindle and moving in an air chamber and the control is by the hair spring.

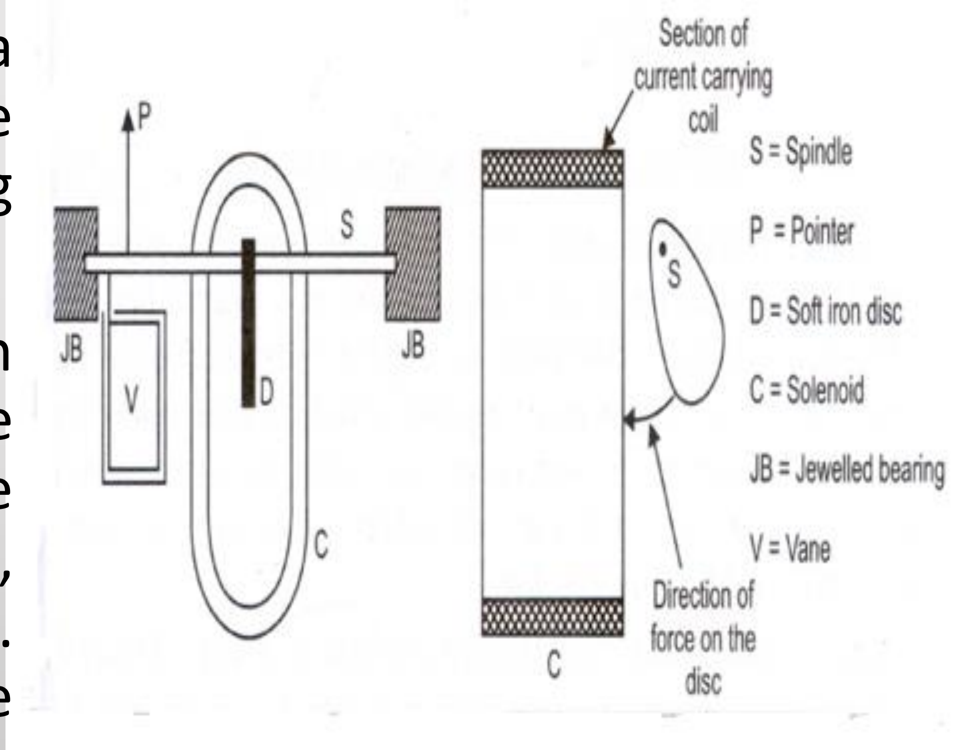


Fig. 5.4 Moving iron meter (attraction type)

Deflection Torque of a moving iron Instrument

- An expression for the torque of a moving iron instrument is derived by considering the energy relations when there is a small increment in current supplied to the instrument.
- When this happens there will be a small deflection of the pointer and work will be done.

Work done = deflecting torque*small deflection

$$= T_d \times d\theta$$

Where, T_d is the deflecting torque of the instrument

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

Let, I = Initial Current

L = Inductance of the instrument, and

θ = Deflection

dI = increase in current

dL = change in inductance

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

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

- The electrical energy supplied is,

$$eIdt = I^2 dL + ILdI$$

- The stored energy changes from

$$\frac{1}{2}I^2L \quad \text{to} \quad \frac{1}{2}(I+dI)^2(L+dL)$$

- Hence the change in stored energy is

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

- Neglecting higher-order terms in small quantities, this reduces to

$$ILdI+\frac{1}{2}I^2dL$$

- Invoking the principle of conservation of energy, we have:

Electrical energy supplied = increase in stored energy + mechanical work done.

$$I^2dL+ILdI=ILdI+\frac{1}{2}I^2dL+T_d.d\theta$$

- Simplifying yields,

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

Or

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

Where, T_d is in [N-m], I in [A], L in [H], θ in [rad].

- The moving system is provided with control springs and in turn the deflecting torque T_d is balanced by controlling torque, $T_c = K\theta$

Where, K [Nm/rad] = control spring constant

θ [rad] = deflection

At steady deflection states:

$$T_c = T_d$$

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

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

- It is evident from the above equation that the deflection is proportional to square of the rms value of the operating current.
- The deflecting torque is therefore, unidirectional whatever may be the polarity of the current.

Repulsion-type Moving-Iron Instrument

- This instrument has two iron discs, one fixed and the other mounted on a short arm fixed to the spindle. A is the fixed iron-disc and B is the movable iron-disc.
- The two iron-discs lie in the magnetic field due to a solenoid/coil C. When there is no current in the coil the two iron pieces are almost touching each other and the pointer rests on zero position.
- When the current to be measured is passed through the solenoid, a magnetic field is set up inside the solenoid and the two iron pieces are magnetized in the same direction.
- This sets up a repulsive force, so moving iron piece is repelled by fixed iron piece, thereby resulting in the motion of the moving iron piece, carrying the pointer.

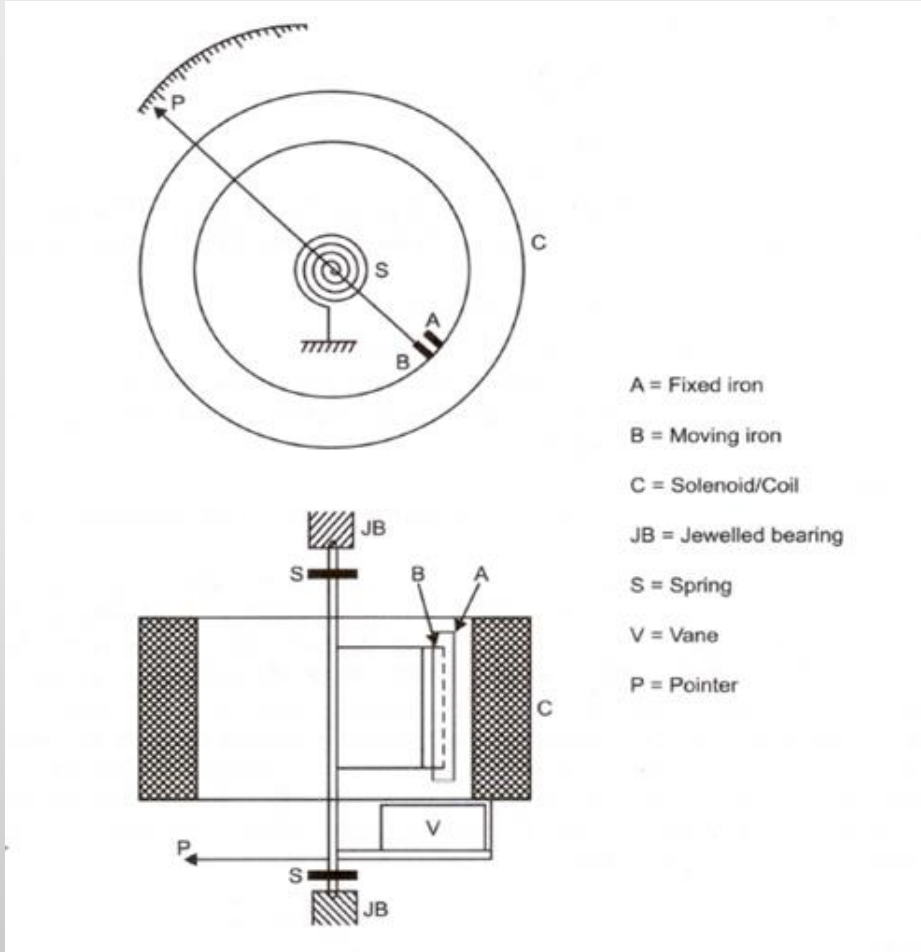


Fig. 5.5 Repulsive-type meter

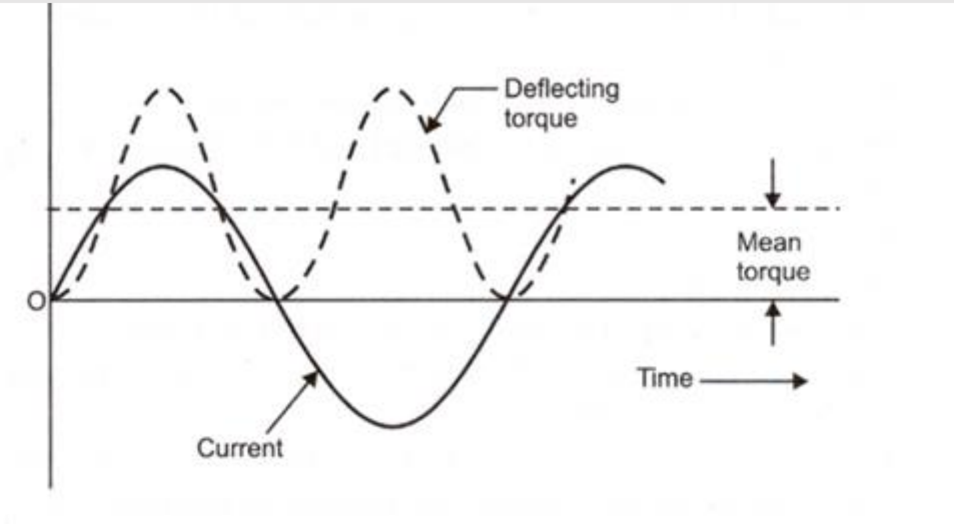
Deflecting Torque in moving-iron instruments

- In moving iron instruments deflecting torque is proportional to the square of the current, so long as the iron is working below saturation.

$$T_d \propto I^2$$

$$\Rightarrow \quad T_d = k\, I^2$$

Where k is a constant for a given instrument, I is the r.m.s value of current.



- Thus the moving-iron instrument can be used to measure both direct current and alternating current, and in the latter case, the instrument gives the r.m.s value of the current.

- Owing to the deflecting torque being proportional to the square of the current, the scale divisions are not uniform, being cramped at the beginning and open at the upper end of the scale.

Comparison between attracting and repulsion types of instruments

- In general, it may be said that both types of these instruments have the same advantages and are subject to same limitations, yet they differ as follows:-
- An attraction type instrument will usually have low inductance than the corresponding repulsion type instrument therefore, voltmeters will be accurate over a wider range of frequency and there is greater possibility of using shunts.
- Repulsion instruments, however, are more suitable for economical production in manufacture, and a nearly uniform scale is more easily obtained. These are more common than attraction type.

Advantages

1. Can be used both in D.C. as well as in A.C. circuits
2. Robust and simple in construction.
3. Posses high operating torque.
4. Can work with stand overload momentarily.
5. Cheap
6. Suitable for low frequency and high power circuits.
7. Less friction errors

Disadvantages

1. Scales not uniform
2. For low voltage range power consumption is high.
3. The errors are caused due to hysteresis in the iron of the operating system and due to stray magnetic field.
4. In case of A.C. measurements change in frequency causes serious error.
5. The stiffness of spring varies with changes in temperature.

Applications

- ❖ These are used as ammeters and voltmeters for D.C. and A.C.
- ❖ These instruments can easily be constructed for rangers of 0.1A to 30A without the use of shunts.

2. Moving-coil instrument

- A moving coil meter is s very commonly used form of analogue voltmeter because of its sensitivity, accuracy and linear scale, although it only responds to dc signals.
- It consists of a rectangular coil wound around a soft iron core that is suspended in the field of permanent magnet. The signal being measured is applied to the coil and this produces a radial magnetic field.
- Interaction between the two magnetic fields causes a torque which results in rotation of the coil.

➢There are two (2) types of moving-coil instruments viz

i. Permanent magnet type – can be used for D.C. only

1. Dynamometer type – can be used for both A.C. and D.C.

1. Permanent magnet type

Construction

The Permanent Magnet Moving Coil Instrument is the most accurate type of D.C. measurement.

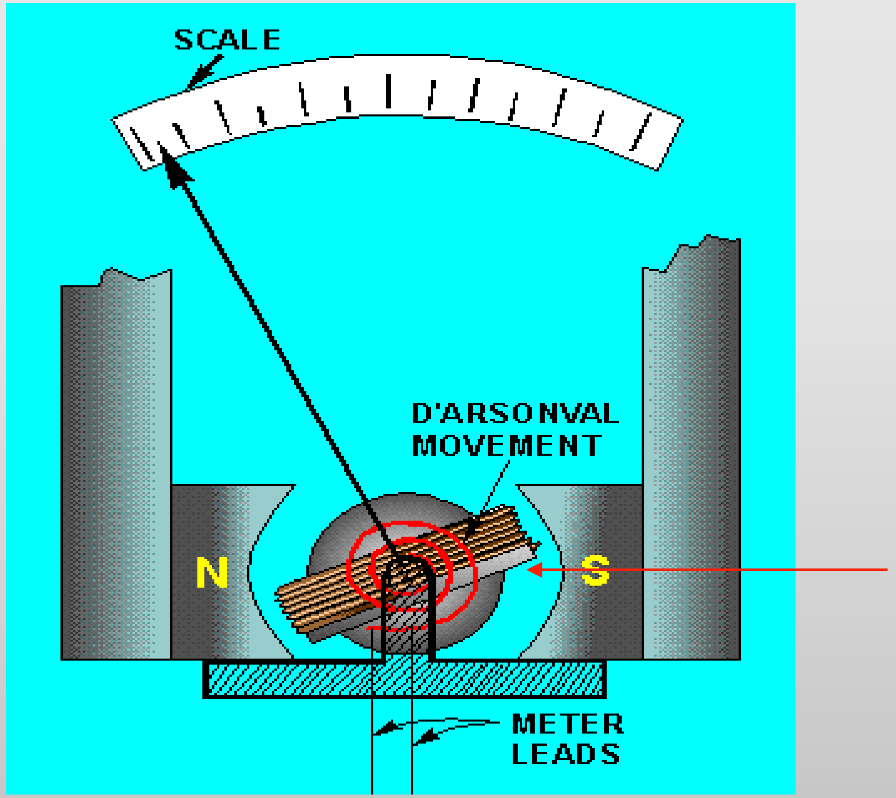
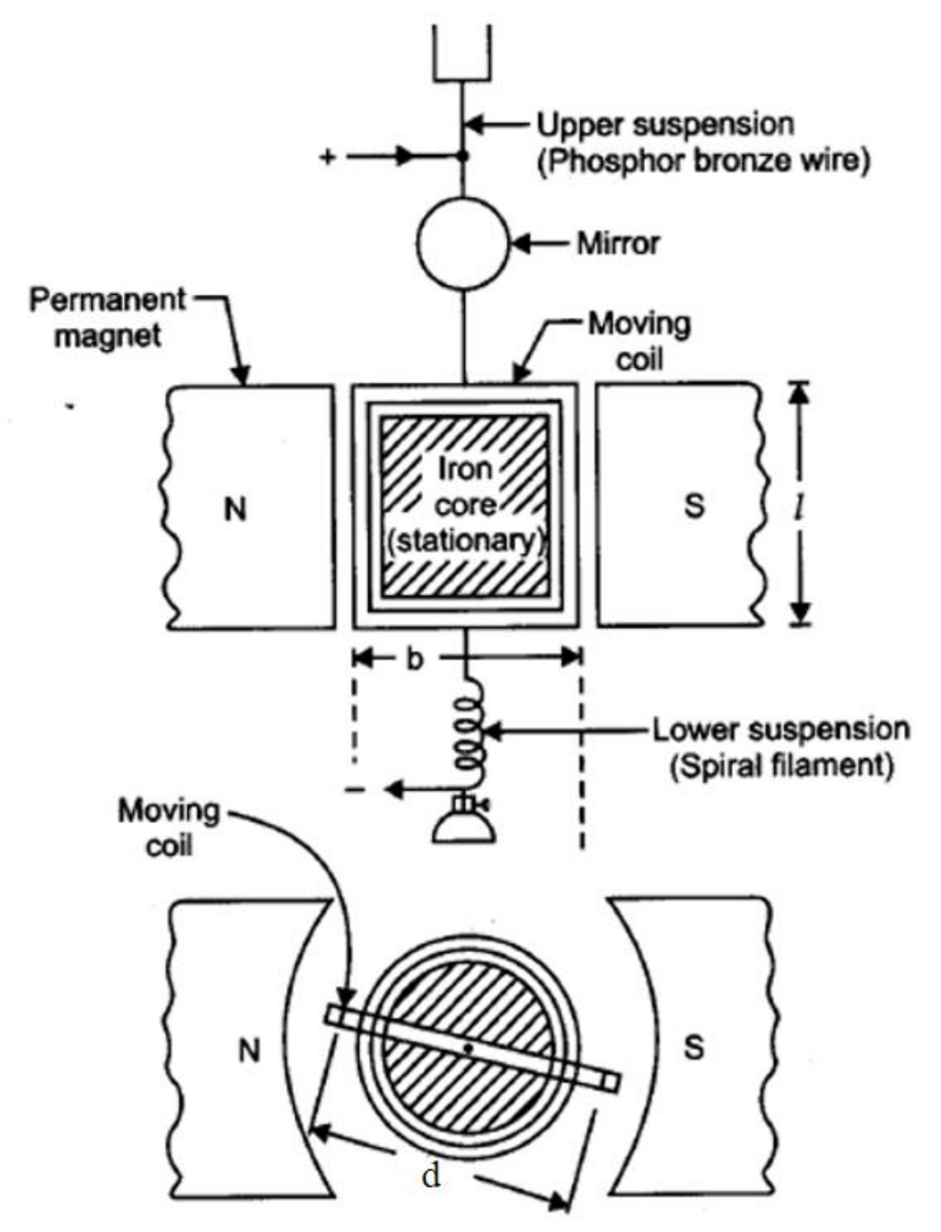


Fig. 5.6 D’arsonval Meter



- When current flows through the coil, the core will rotate.
- Amount of rotation is proportional to the amount of current flowing through the coil.
- The meter requires low current (~50uA) for a full scale deflection, thus consumes very low power (25-200 Uw).
- Its accuracy is about 2% -5% of full scale deflection

Moving Coil:

- It is the current carrying element. It is either rectangular or circular in shape and consists of number of turns of fine wire. This coil is suspended so that it is free to turn about its vertical axis of symmetry.
- It is arranged in a uniform, radial, horizontal magnetic field in the air gap between pole pieces of a permanent magnet and iron core.
- The iron core is spherical in shape if the coil is circular but is cylindrical if the coil is rectangular.
- The iron core is used to provide a flux path of low reluctance and therefore to provide strong magnetic field for the coil to move in this increases the deflecting torque and hence the sensitivity of the galvanometer.

Damping:

- There is a damping torque present owing to production of eddy currents in the metal former on which the coil is mounted.
- Damping is also obtained by connecting a low resistance across the galvanometer terminals. Damping torque depends upon the resistance and we can obtain critical damping by adjusting the value of resistance.

Suspension:

- The coil is supported by a flat ribbon suspension which also carries current to the coil. The other current connection in a sensitive galvanometer is a coiled wire. This is called the lower suspension and has a negligible torque effect.
- The upper suspension consists of gold or copper wire of nearly 0.012-5 or 0.02-5 mm diameter rolled into the form of a ribbon. This is not very strong mechanically; so that the galvanometers must he handled carefully without jerks.
- Sensitive galvanometers are provided with coil clamps to the strain from suspension, while the galvanometer is being moved.

Indication:

- The suspension carries a small mirror upon which a beam of light is cast. The beam of light is reflected on a scale upon which the deflection is measured.
- This scale is usually about 1 meter away from the instrument, although ½ meter may be used for greater compactness.

Zero Setting:

- A torsion head is provided for adjusting the position of the coil and also for zero setting.

Deflecting Torgue

- Deflection torque

$$T_d = NBldI = GI$$

Where, G is a constant $= NBld$

The spring control provides a restoring torque

$$T_c = K\theta$$

For the final stedy deflection, $T_c = Td$ or $GI = K\theta$

$\therefore$ Final steady deflection

$$\theta = \frac{G}{K} I$$

Or current: $$I = \frac{K}{G}\theta$$

Moving coil meter

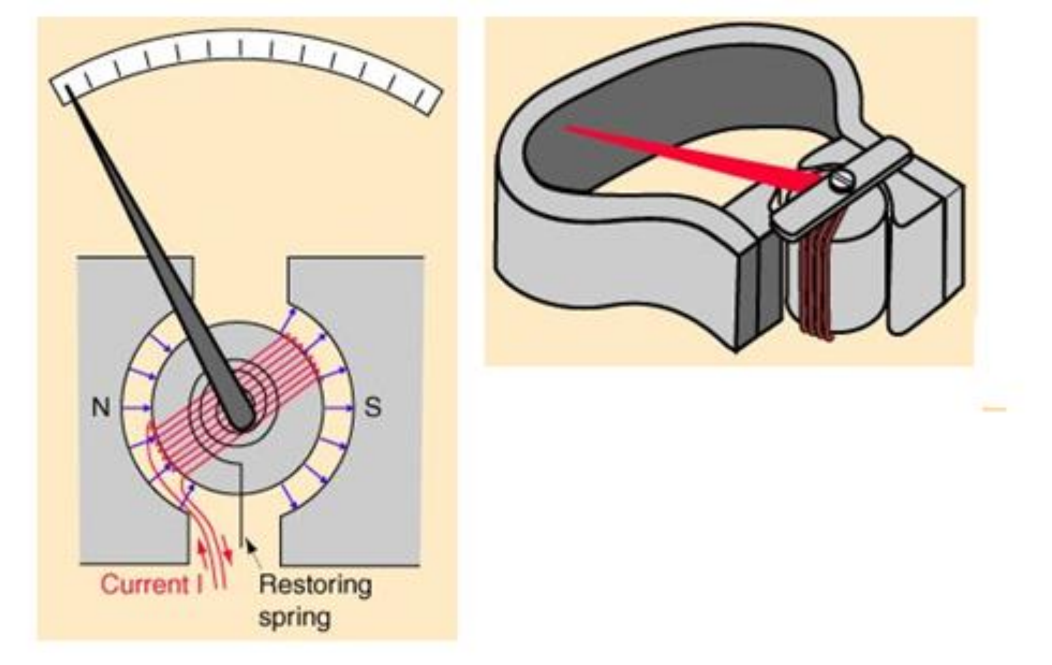


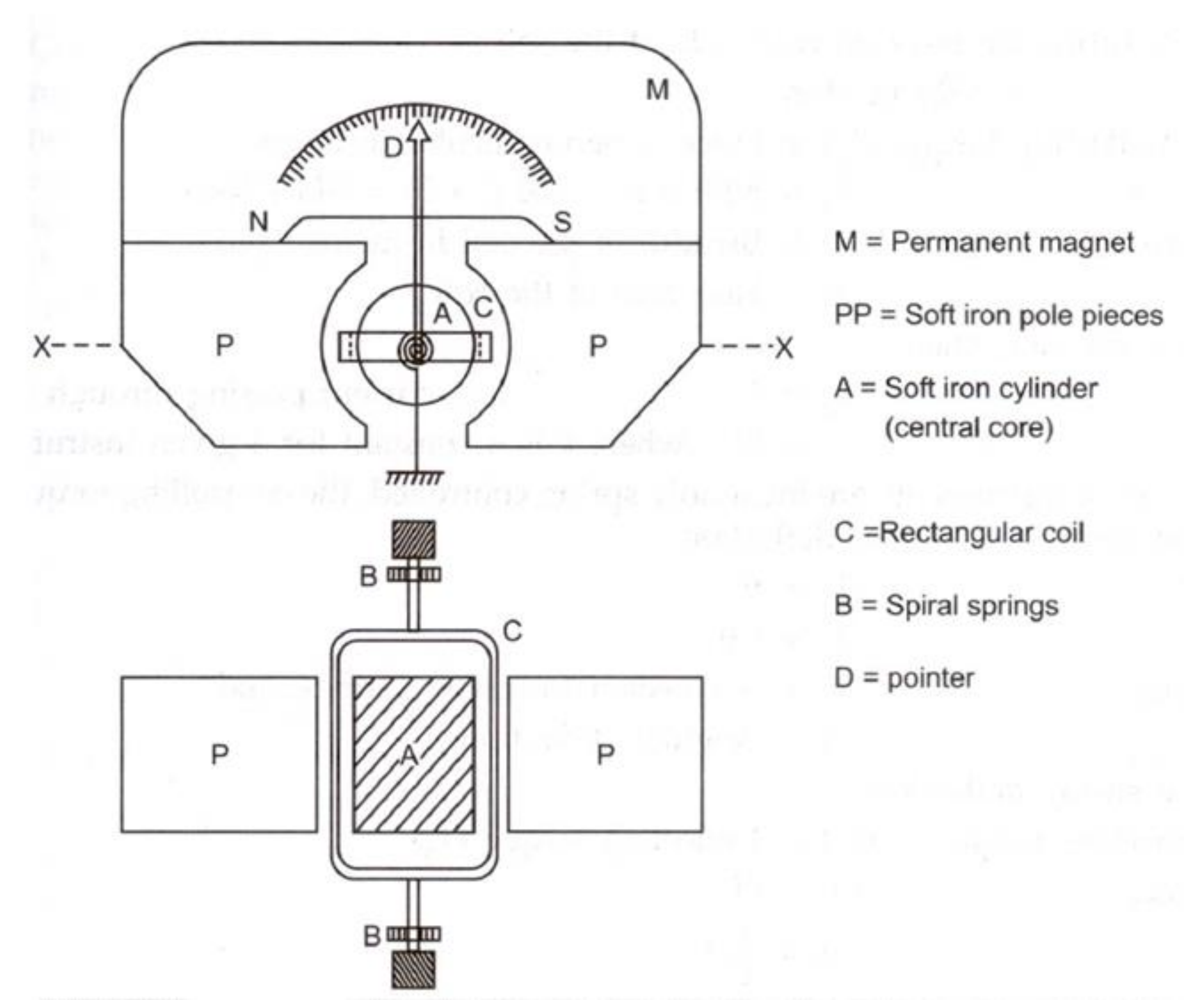
Fig. 5.7 Moving coil meter

Principle of Operation

- A permanent-magnet moving coil-type instrument works on the principle that when the current, I is passed through the movable coil the pointer deflects by an angle, θ proportional to the current.
- Thus I = kθ; Where k is the constant.

Construction

- The instrument consists of a permanent magnet M and a rectangular coil C which consists of insulated copper wire wound on a light aluminium frame fitted with polished steel pivots resting in jevel bearing.
- The magnet is made of Alnico and has soft-iron pole-pieces PP which are bossed out cylindrically.
- The rectangular coil C is free to move in air gaps between the soft-iron pole pieces and a soft-iron cylinder A, supported by a brass plate (not shown).



The functions of the central core A are:

- To intensify the magnetic field by reducing the length of the air gap across which magnetic flux has to pass.
- To give a radial magnetic flux of uniform density, thereby enabling the scale to be uniformly divided.

➢The movement of the coil is controlled by two phosphor bronze hair springs BB, which also serve the purpose of leading the current in and out of the coil.

➢The two springs are spiraled in opposite directions for neutralizing the effects of changes in temperature.

➢The aluminium frame not only provides support for the coil but also provides damping by eddy currents induced in it.

Deflection Torque

- When current is passed through the coil, forces are set up on both sides of the coil producing deflecting torque T_d. If I, amperes is the current passing through the coil, the magnitude of the force, F experienced by each of its sides is given by:

$$F = B\,Ll\ [N]$$

Where,

B = flux density in, Wb/m^2

L = length or depth of the coil in metres.

For N turns, the force on each side of the coil is

➢ $$F = N\,B\,L\,l\ [N]$$

Deflecting torque (T_d) = Force * perpendicular distance

$$T_d = N\,B\,IL * b$$
$$= N\,B\,I(L * b)$$
$$= N\,B\,I\,A\ [N - m]$$

Where,

b = breadth of the coil in metres, and A = area of the coil

- ❑If B is constant, then

$$T_d\ \alpha\ I = kI$$

Where, k = constant for a given instrument

- ❖Since such instruments are invariably spring controlled, the controlling torque T_c of the spiral springs ∝ angular deflection.

i.e., $T_c \propto \theta$

Or $T_c = C\theta$

Where, C is a constant for a given spring θ is angular deflection.

- For steady deflection,

Controlling torque

$$T_c = Td$$

$$C\theta = kI$$

$$\theta = (\frac{K}{C})I$$

➢ The deflection is proportional to the current and the scale is therefore uniformly divided.

- PMMC instrument is unsuitable for A.C. measurements unless the current is rectified.
- The PMMC system can be converted into an instrument to measure D.C. as well as A.C. quantities like current, voltage and resistance etc. It carries maximum current of I_m, without any modification and can withstand a maximum D.C. voltage, $V = I_m R_m$.

❖The various modifications of PMMC meter movement may be summed up as follows:-

1. D.C. instruments:
   (i) D.C. ammeter – By using a shunt resistor
   (ii) D.C. voltmeter – By using series multiplier
   (iii) Ohmmeter – By using battery and series resistor
2. A.C. instruments:
   i. Audio-frequency (AF) A.C. ammeter or voltmeter by using a rectifier.
   ii. Radio-Frequency (RF) ammeter or voltmeter – By using a thermocouple.

Characteristics of PMMC meter movement

1. Full-Scale deflection current (I):

   Varies from 2mA to 30mA

   For 2mA, N turns should be more for 30mA should be less.

2. Internal resistance (R_m)

   R_m ranges from 1 – 2 ohms for a 30mA movement.

3. Sensitivity (S)

   It is also known as current-sensitivity or sensitivity factor. It is given by the reciprocal of full scale deflection current I_m

$$S = \frac{1}{I_m} \text{ [ohm/volt]}$$

❖ The sensitivity of a meter movement depends on the strength of the permanent magnet and number of turns in the coil. The larger the number of turns, the smaller the amount of current required to produce full-scale deflection and hence, the higher the sensitivity.

Advantages

(i) Low power consumption

(ii) Their scales are uniform

(iii) No hysteresis

(iv) High torque/weight ratio

(v) They have very effective and efficient eddy current damping

(vi) Range can be extended by shunts and multipliers

(vii) No effect of stray magnetic field as intense polarized or unidirectional field is employed

Disadvantages

(i) Cannot be used for A.C. measurements

(ii) Friction and temperature can cause errors

(iii) Problem of errors due to ageing of control springs and permanent magnets

(iv) They are too costly

Application

(i) Ammeters – By using low resistance shunts

(ii) Voltmeters – By using high resistance multipliers

(iii) Flux meters – By eliminating the control spring

(iv) Ballistic galvanometers – By making control springs of large moment of Inertia

Dynomometer type moving Coil Meter

- In this type of instrument the operating field is produced by another fixed coil and not by permanent magnet.
- These instruments are employed as A.C. voltmeters and ammeters both in the range of power frequencies and lower part of audio frequency range. They are also used as watt-meters, var-meters and with some modifications as power factor meters and frequency meters.

Construction and Operation

The main components of the instrument are:

Field system (fixed coil).
Moving system (moving coil).
Control system (hair spring)
Damping system (air friction damping)
Shielding
Cases and scales

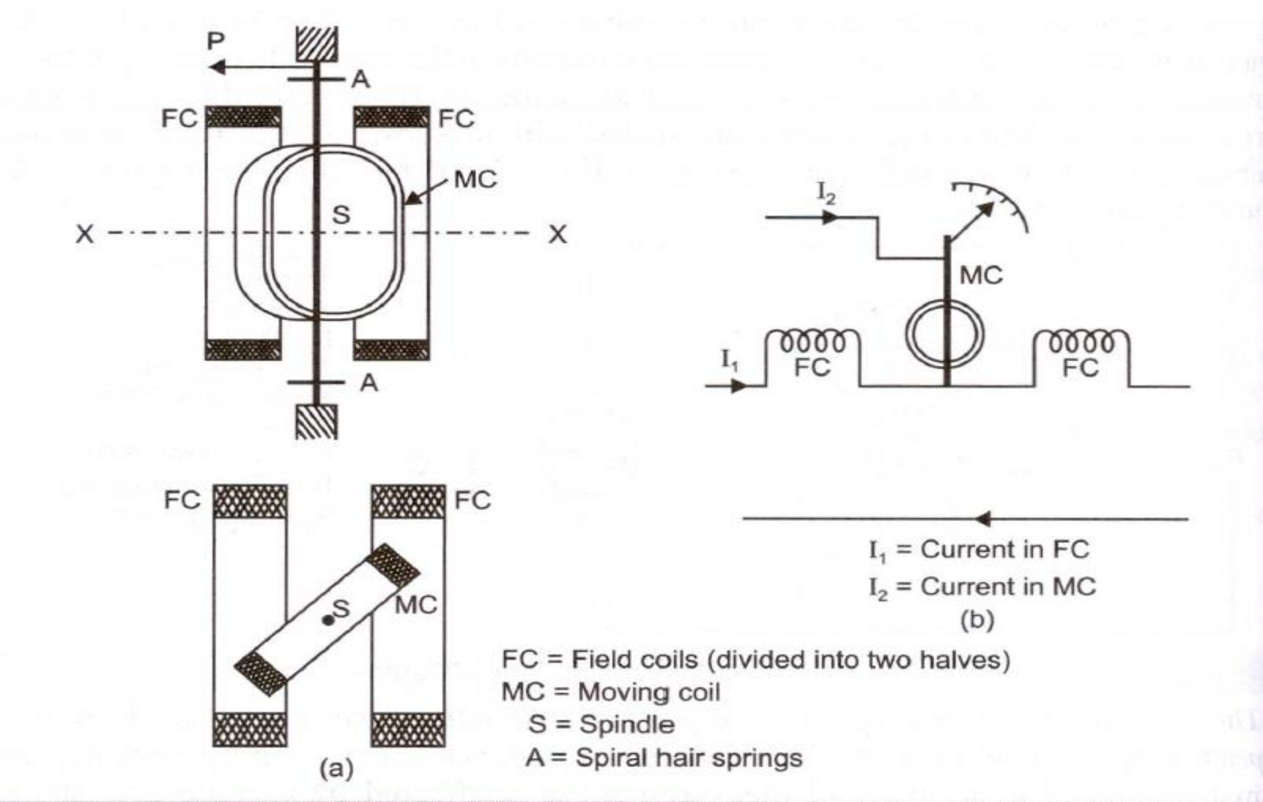


Fig. 5.8 Dynamometer

- These instruments **essentially** consist of fine wire moving coil placed in the magnetic field produced by another fine wire fixed coil when carrying currents.
- The coils are usually air cored to avoid hysteresis, eddy currents and other errors when the instrument is used on A.C.
- The fixed coil, FC is divided into two halves placed close together and parallel to each other in order to provide a fairly uniform field, within the range of the movement of the moving coil.
- The diagram in fig 5.8 shows a section elevation through fixed coil FC and the lower diagram represents a sectional plan on XX. The moving coil MC is carried by a spindle S and the controlling torque is exerted by spiral hair spring A, which may also serve to lead the current into and out of the MC.
- In these instruments, air damping is used which may be either piston type or vane type.
- Eddy current damping cannot be used as introduction of permanent magnet for the purpose would distort the working magnetic field of the instrument.
- The complete assembly is surrounded by a laminated steel shield to protect the instrument from external magnetic field which may affect the operation of the instrument.

Deflecting Torque

- The deflecting torque is due to interaction of magnetic fields produced by currents in the fixed and moving coils

Deflection torque,

$$T_d \alpha I_1 \times I_2$$

$$T_d = kI_1 I_2$$

Where, k is a constant.

- Since the instrument is spring controlled, the restoring or control torque (T_c) is proportional to the angular deflection θ.

$$T_c\ \alpha\ \theta \text{ or } Tc = k'\theta$$

$$T_d = Tc$$

$$kI_1 I_2 = k'\theta$$

$$=> \quad \theta\ \alpha\ I^2,$$ since, I_1 α I and I_2 α I

Expression for torque in terms of mutual inductance (M) between fixed and moving coils:

- The total energy stored in the magnetic field of the fixed coil,

$$E = \frac{1}{2} L_1 I_1^2 + \frac{1}{2} L_2 I_2^2 + I_1 I_2 M$$

Where, L_1 and L_2 are the self inductances of the fixed coil and moving coil respectively.

- The interaction of these currents give rise to a deflecting torque, T_d that sets the moving coil in a position for which the energy in the magnetic field attains maximum value. Hence, Deflecting torque,

$$T_d = \frac{dE}{d\theta} = \frac{1}{2} \frac{dL_1}{d\theta} I_1^2 + \frac{1}{2} \frac{dL_2}{d\theta} I_2^2 + I_1 I_2 \frac{dM}{d\theta}$$

Where, dθ is the increase in angular deflection at which the field energy increases by dE.

Since coil inductances L_1 and L_2 are constant, therefore dL_1 and dL_2 each is equal to zero and T_d is given by:

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

Where, I_1 and I_2 are currents in fixed coils and moving coil respectively.

- The above expression shows that the deflecting torque depends in general both on currents and position of the moving coil with respect to the fixed one.
- The dependence of the rate of change of mutual inductance on the angular deflection of the moving coil,

$$\frac{dM}{d\theta} = f(\theta)$$

is determined by the shape of coils and their relative positions.

- Deflecting torque rotates the moving coil through an angle θ, at which restoring torque of springs is equal to T_d

$\therefore \quad T_d = T_c = C\theta$ where, C is spring constant in (Nm/rad.)

Or $$I_1 I_2 \frac{dM}{d\theta} = C\theta$$

or, Deflection, $$\theta = \frac{I_1 I_2}{C} \cdot \frac{dM}{d\theta}$$

For alternating current:

- When the coils carry alternating currents and the instantaneous deflecting torque,

$$\left(T_d\right)=i_1 i_2 \frac{dM}{d\theta}$$

- The average deflecting torque over a complete cycle,

$$\left(T_d\right)_{av.}=\frac{1}{T}\int_o^T T_d dt$$

Or,

$$\left(T_d\right)_{av.}=\frac{dM}{d\theta}\frac{1}{T}\int_o^T i_1 i_2 dt$$

  - Here, T = Time period for one complete cycle.

- If currents are sinusoidal and are displaced by a phase angle , i.e.,

$i_1 = I_{max.1} \sin \omega t$ and $i_2 = I_{max.2} \sin(\omega t - \varphi)$

- the average deflecting torque,

$$\left(T_d\right)_{av.} = \frac{dM}{d\theta}\frac{1}{T}\int_o^T i_1 i_2 dt$$

$$= \frac{dM}{d\theta}\frac{1}{2\pi}\int_o^{2\pi} I_{max.1}\sin\omega t.I_{max.2}\sin(\omega t - \varphi)d(\omega t)$$

$$= \frac{I_{max.1}.I_{max.1}}{2}\cos\varphi\frac{dM}{d\theta}$$

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

Where, I_1 and I_2 are r.m.s values of current flowing in the coils.

- At steady deflection state,

$$T_d = T_c$$

- Thus, the deflection,

$$\theta = \frac{I_1 I_2}{C} \cos\varphi . \frac{dM}{d\theta}$$

- ❖From the above discussion it is obvious that for sinusoidal alternating currents, the deflecting torque and the deflection are determined by the product of r.m.s. values of coil currents and the cosine of the phase angle between them.
- ❖It is clear that the dynomometer type of instruments can be used on both D.C. and A.C.