DSE 4A CLASS

Lecture-7

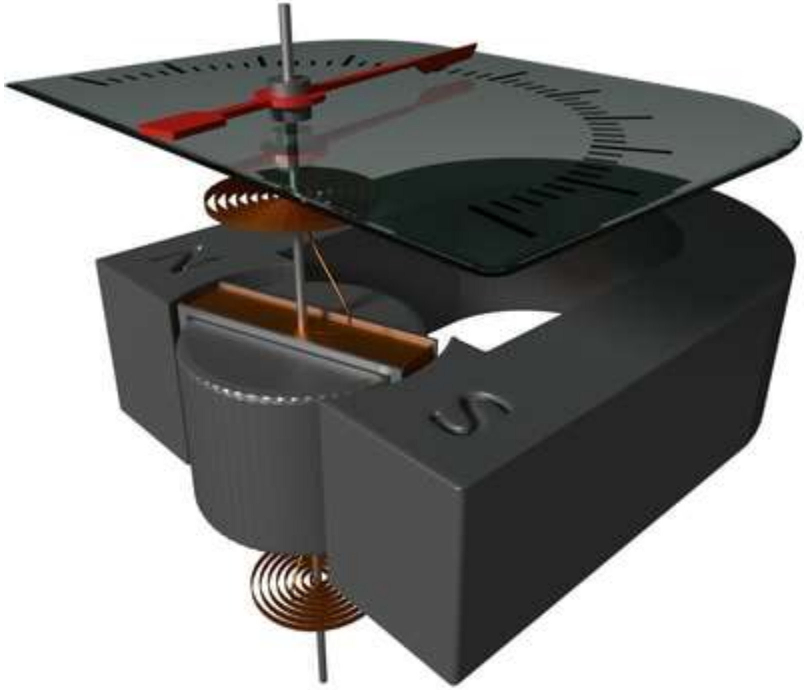
10/06/2021

Moving Coil Instrument

There are two types of moving coil instrument.
One is
permanent magnet moving coil instrument
and another is
dynamometer type instrument.

Permanent Magnet Moving Coil Instrument (PMMC)

A coil is allowed to move inside a magnetic field.
Whenever current flows inside the coil mechanical force act on it.
This mechanical force acts as the deflecting force of the instrument.

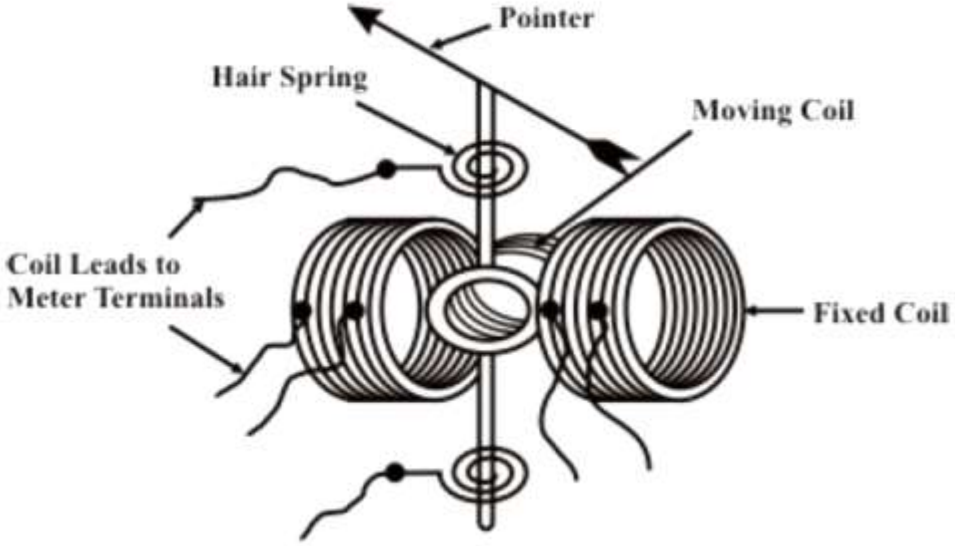


Dynamometer type instruments:

The basic working principle similar to that of a permanent magnet moving coil instrument.

Here instead of using permanent magnet current carrying coil used for producing the operating magnetic field. The fixed coil has two halves and a moving coil is placed in between them. A pointer is attached with the moving system

The **Dynamometer type instrument** is normally spring controlled.



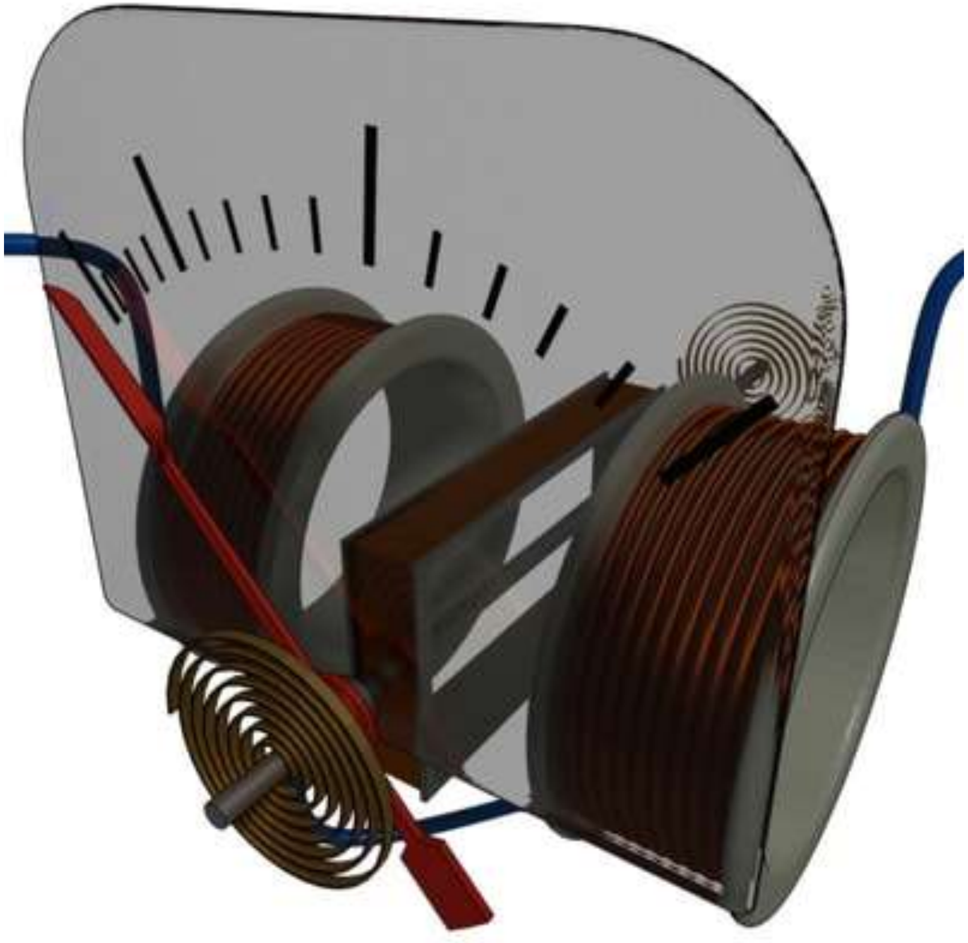
Fixed coil

Moving coil:

Springs: controlling torque is provided by two control springs

Dampers: Air friction damping is employed by a pair of Al-vanes attached to the spindle at the bottom.

Shielding: by enclosing the mechanism in a laminated iron hollow cylinder with closed ends



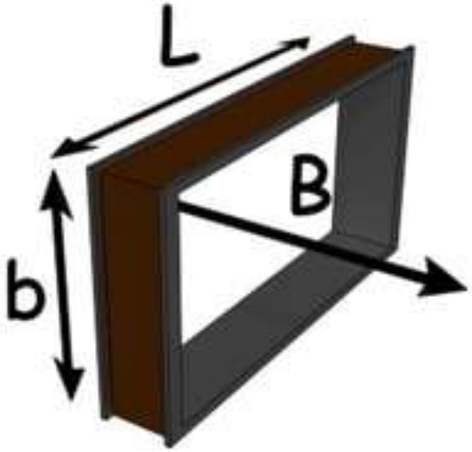
Torque in Dynamometer Type Instrument

The flux density of the magnetic field (B) produced by the fixed coil is proportional to the current through it. If the current through the field coil is I_1, then we can write,

$$B \propto I_1 \Rightarrow B = K_1 I_1$$

Let us consider, the noving coil is L×b, as shown below,

Here, L is the length and b is the breath of the coil.



If the current flowing through the moving coil is I_2, we can write the force acting on each side of the moving coil as

$$F = NLBI_2$$

Here, N is the number of conductors per coil side.

Hence, we can write the deflecting torque acting the moving coil as,

$$T_d = Fb = NLBI_2b = NLK_1I_1I_2b \quad [\because B = K_1I_1]$$

$$T_d = KI_1I_2 \quad [Considering,\ K = NLK_1b = constant]$$

As a dynamometer type instrument is spring controlled, controlling torque is directly proportional to the angle of deflection of the moving system. We can write,

$$T_c = K_2\theta$$

The deflecting torque equals the controlling torque at the steady position of the pointer. Hence,

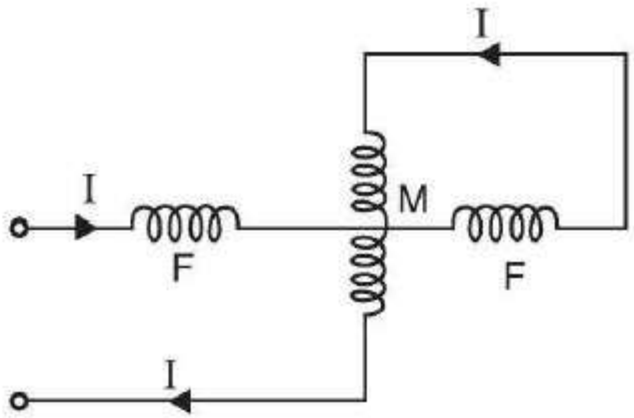
$$T_d = T_c \Rightarrow KI_1I_2 = K_2\theta \Rightarrow I_1I_2 \propto \theta$$

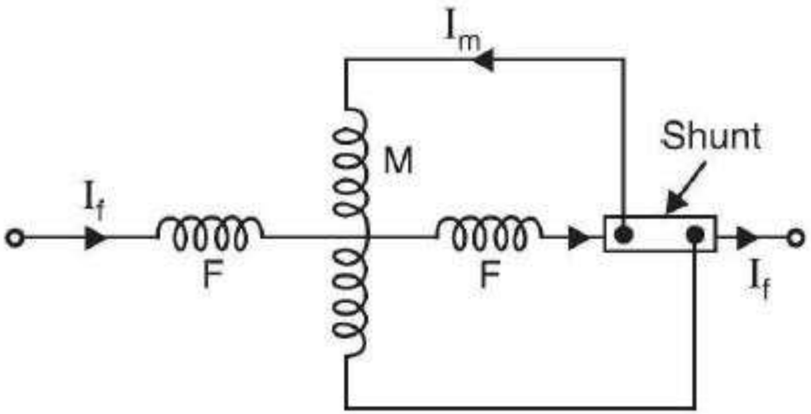
So, it is seen that the deflection angle is directly proportional to the product of the currents through the field coil and the moving coil.

Dynamometer Type Ammeter

If we use the instrument as an ammeter, the same current I (say) flows through the field coil and moving coil, and the: $I^2 \propto \theta$

$$\theta \propto I^2$$



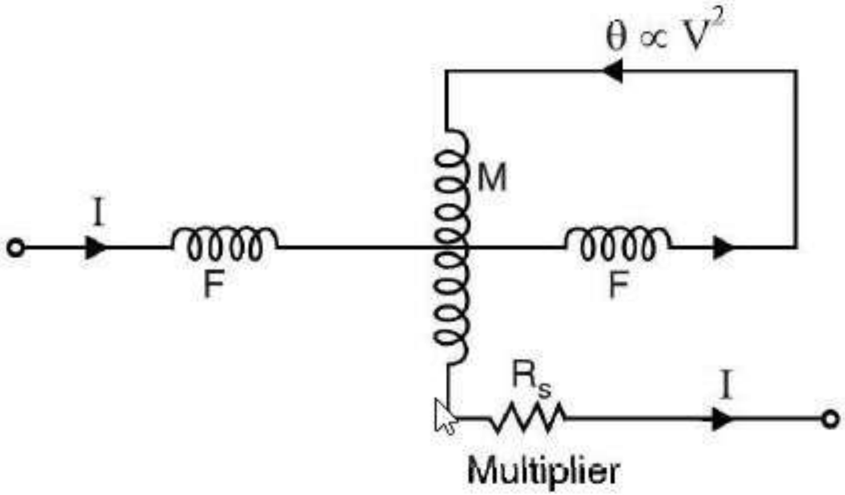


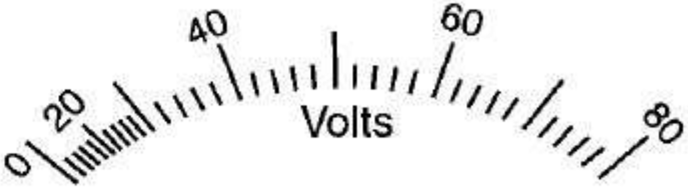
For measuring large currents, moving coil is shunted; the shunt being in series with the fixed coils.

Dynamomometer Type Voltmeter

Both fixed coils and the moving coil are connected in series together with a high resistance R_s, (called multiplier).

The current flowing through the field coil and moving coil is proportional to the voltage being measured. Ultimately the angle of deflection is also proportional to the square of the voltage to be measured. $V^2 \propto \theta$





Dynamometer Type Wattmeter

We mostly use the dynamometer type instrument as wattmeter. In dynamometer type wattmeter, we use the **field coil** as the **current coil** and the **moving coil** as the **voltage coil**. The angle of deflection of the pointer is directly proportional to the product of current and voltage. The product of current and voltage is nothing but the power or wattage.

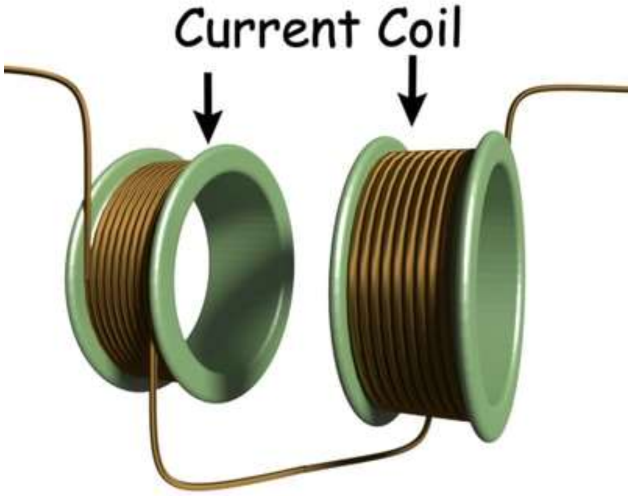
$$IV \propto \theta$$

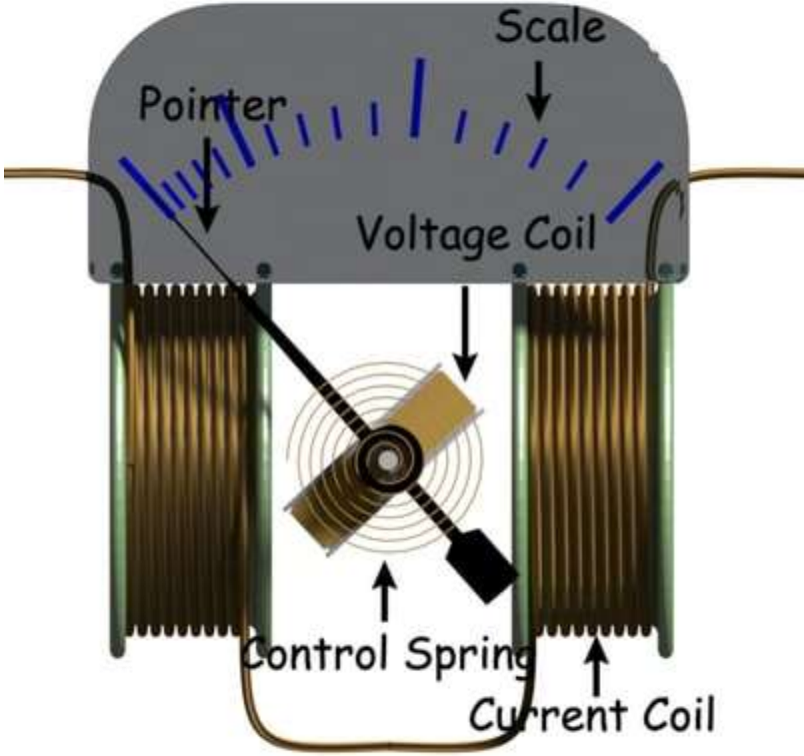
Current Coil

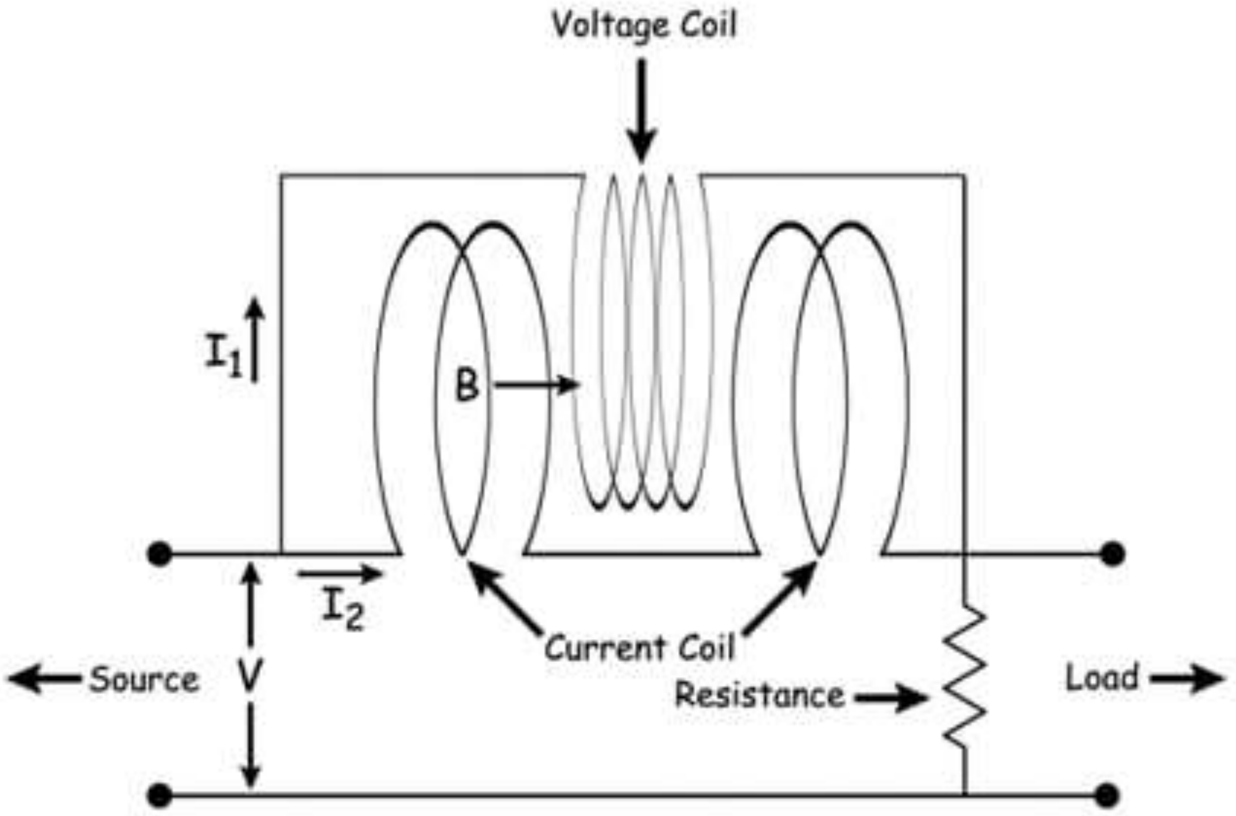
The current coil is connected in series with the circuit. So, the main current can flow through this coil.

Voltage Coil

It as also called pressure coil. This coil is connected across the source. One high resistance in series with the voltage coil limits the current through the coil. Also it minimize the inductive effect of the voltage







The current flows through the current coil from the source to the load. Let us consider this current is I_1. Here this current I_1 creates a magnetic field. Hence, the density of the magnetic field is proportional to the curren $B \propto I_1$

The current I_2 flows through the voltage coil. The interaction of the magnetic field of density (B) with current I_2 produces deflecting torqu $T_d \propto BI_2$

Again the current I_2 is directly proportional to the voltage V of the source.

$$I_2 \propto V$$

So, ultimately we can write the deflecting torque is directly proportional to the product of current and voltage of the source.

$$\Rightarrow T_d \propto I_1 V$$

The deflecting torque is proportional to the power delivered to the load

AC Power Measurement

Here the instantaneous torque acting on the moving system is directly proportional to the product of instantaneous current and instantaneous voltage.

$$T_{ins} \propto v\, i$$

$$v = V_m \sin\theta \qquad\qquad i = I_m \sin(\theta - \phi)$$

$$T_{ins} \propto V_m \sin\theta\; I_m \sin(\theta - \phi)$$

The mean torque causes the deflection of the pointer due to the inertia of the moving system.

$$T_{ins} = KV_m \sin\theta \, I_m \sin(\theta - \phi)$$
$$[K \ is \ the \ constant \ of \ proportionality]$$

$$\therefore \quad T_m = K\frac{1}{2\pi}\int_0^{2\pi} V_m \sin\theta \, I_m \sin(\theta - \phi) d\theta$$
$$= \frac{KV_m I_m}{4\pi}\int_0^{2\pi} 2\sin\theta \sin(\theta - \phi) d\theta$$
$$= \frac{KV_m I_m}{4\pi}\int_0^{2\pi} [\cos\phi - \cos(2\theta - \phi)]\, d\theta$$

$$= \frac{KV_m I_m}{4\pi}\left[\theta \cos\phi - \sin(2\theta - \phi)\right]_0^{2\pi}$$

$$= \frac{KV_m I_m}{4\pi}\left[2\pi \cos\phi - \sin(4\pi - \phi) - 0\cos\phi + \sin(0 - \phi)\right]$$

$$= K\frac{V_m I_m}{2}\cos\phi = K\frac{V_m}{\sqrt{2}}\frac{I_m}{\sqrt{2}}\cos\phi = KVI\cos\phi$$

$$T_m \propto VI\cos\phi$$

This is the deflecting torque of the dynamometer type wattmeter.

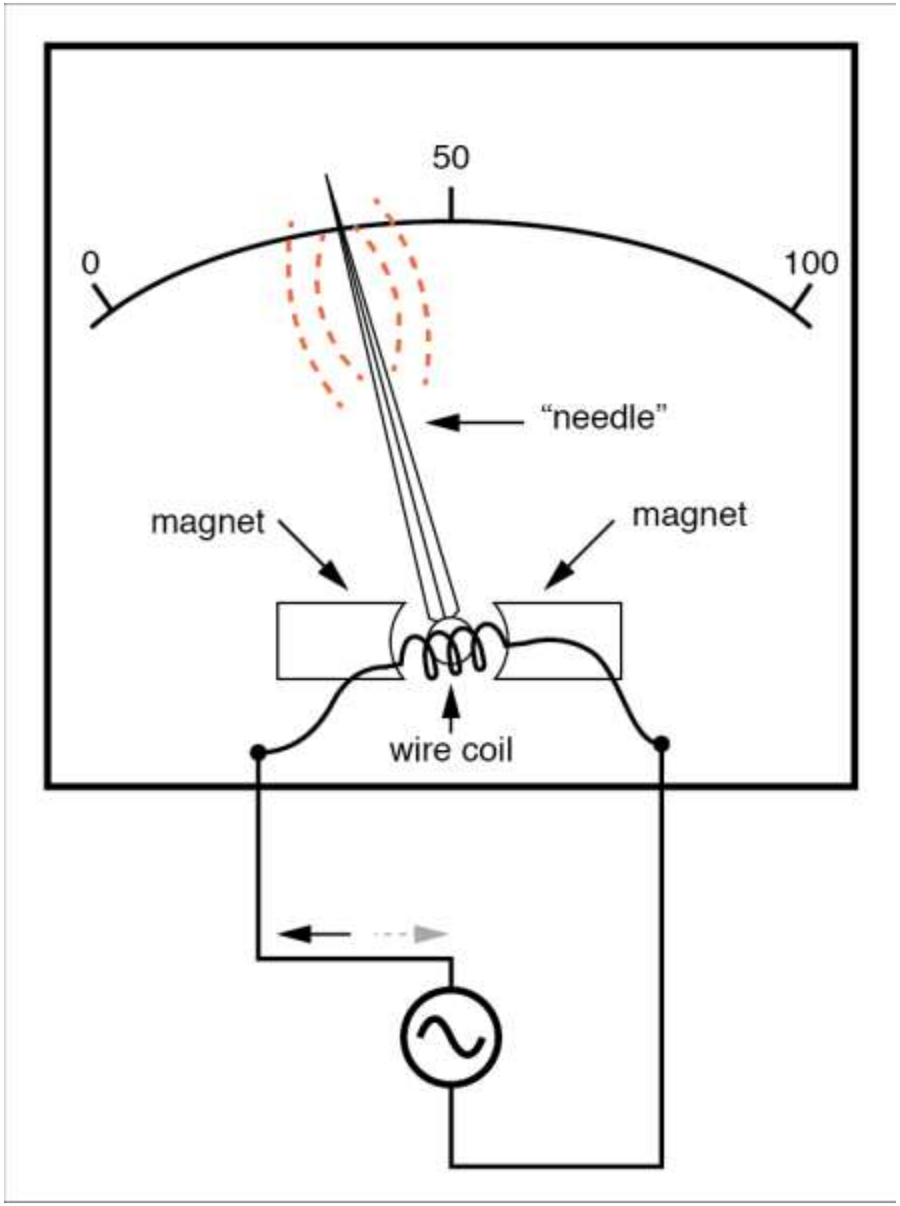
AC Voltmeters and Ammeters

AC electromechanical meter movements come in two basic arrangements:

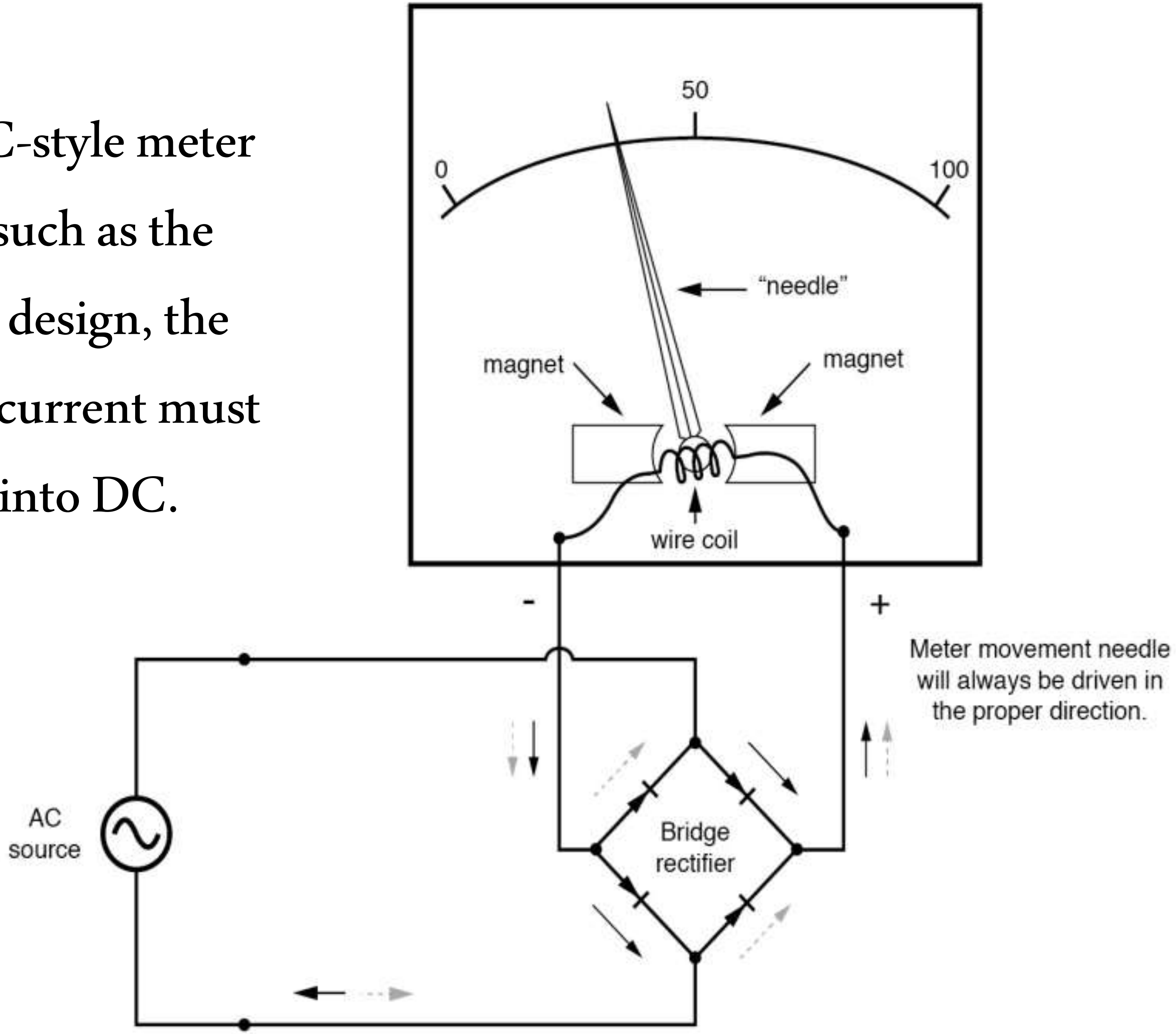
those based on **DC movement designs**, and

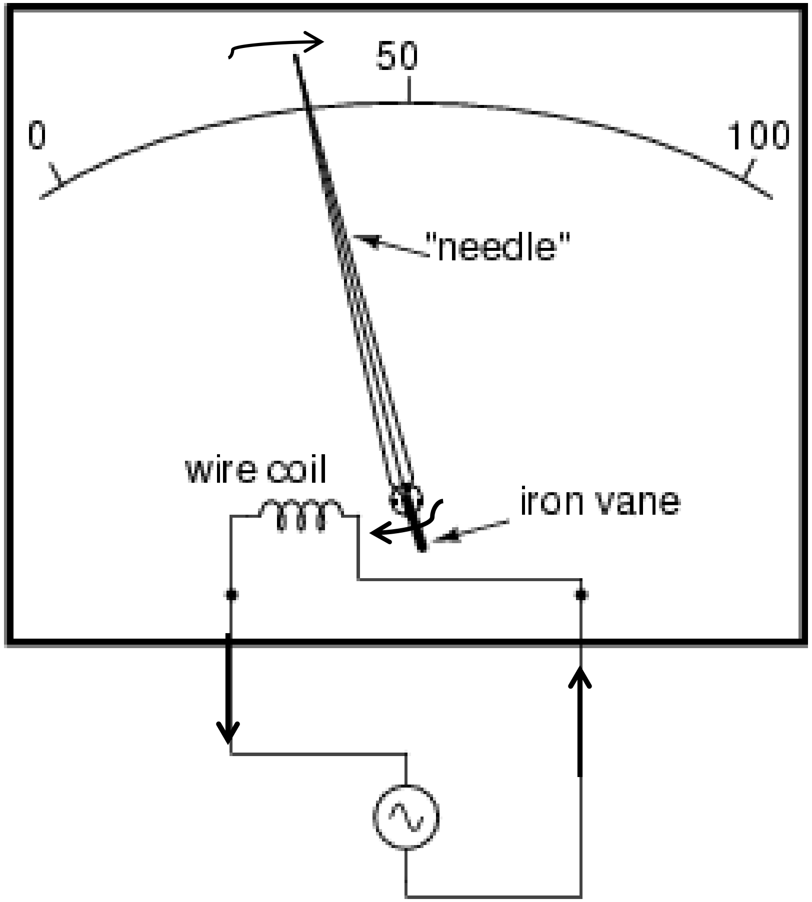
those **engineered specifically for AC** use.

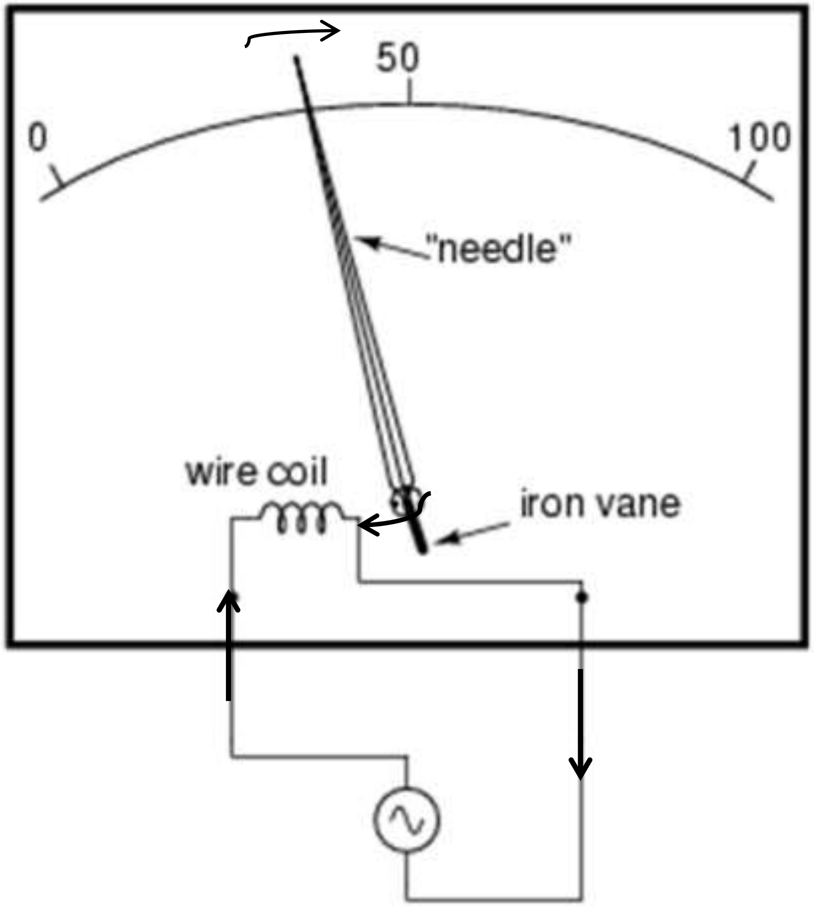
PMMC) meter movements will not work correctly if directly connected to alternating current, because the direction of needle movement will change with each half-cycle of the AC.



To use a DC-style meter movement such as the D'Arsonval design, the alternating current must be *rectified* into DC.







A nonmagnetized soft iron vane attracted toward a stationary coil connected with the AC quantity to be measured.

This moves the needle against spring tension over the calibrated scale.

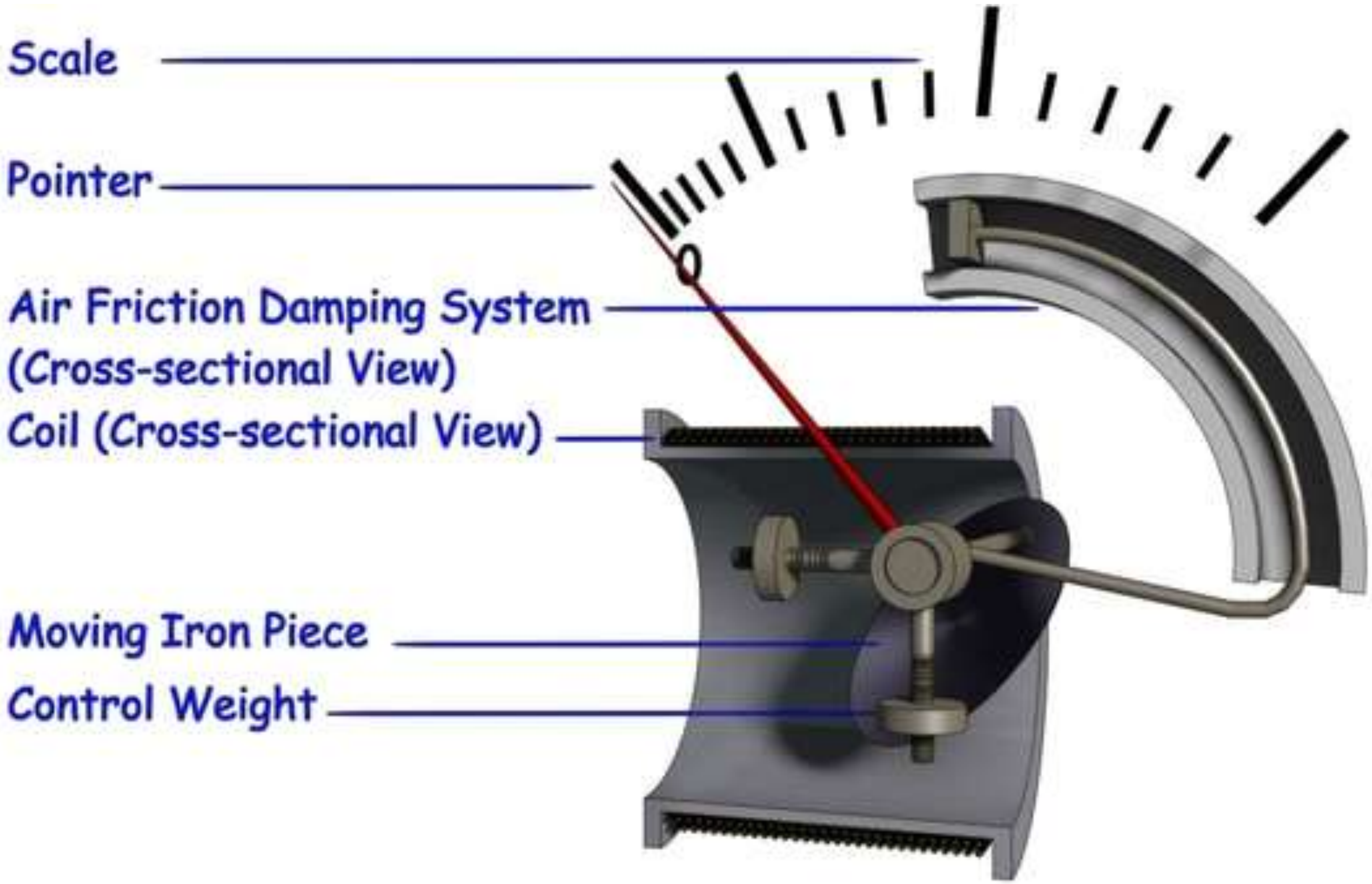
Moving iron instruments

Attractive type

Repulsive type

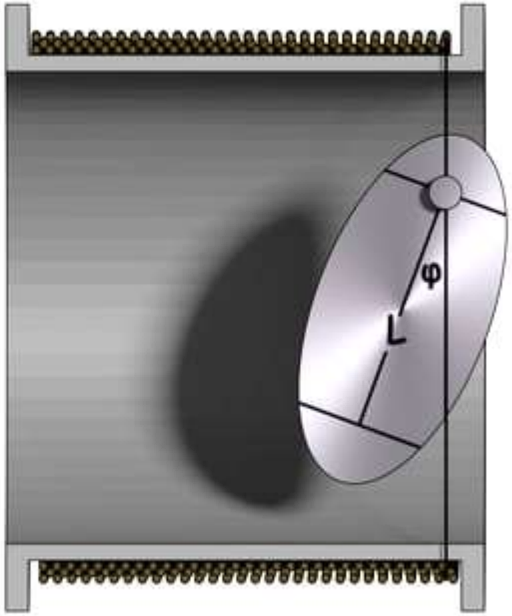
avoid use of permanent magnets

Attraction Type Moving Iron Instrument

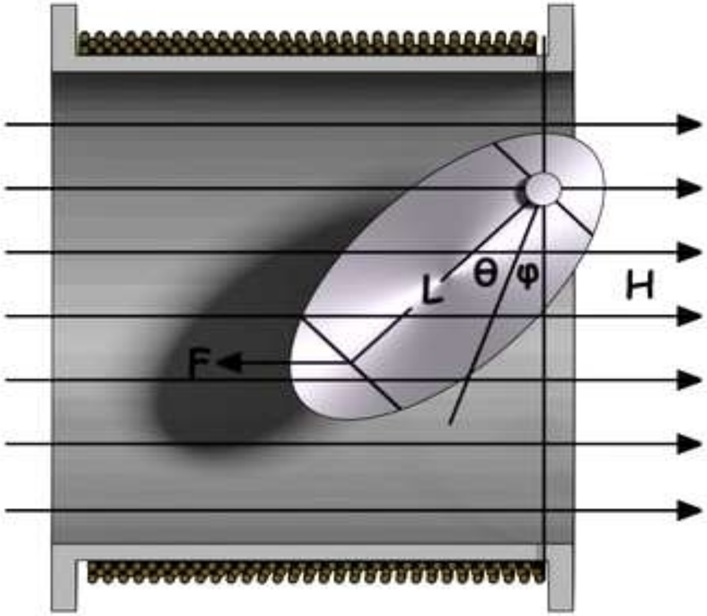


There is a **coil**, an oval-shaped lightweight **iron disc** pivoted along the axis of the coil, a **pointer**, **control weight**, **balance weight**, and the **damping system** with this iron disc.

Let the axis of the iron disc create an angle φ with the imaginary vertical axis initially when there is no current flowing through the coil.



Due to a current I through the coil, the angle of deflection of the disc is θ. The total angle between the axis of the disc and the imaginary vertical axis is (φ + θ).



The magnetization of the iron disc is proportional to the component of the magnetic field acting along the axis of the disc. That means, the magnetization M is proportional to H.sin(φ + θ).

$$M \propto H\sin(\theta+\phi)$$

The inward force (F) acting the disc is proportional to the product of M and H.

$$F \propto MH$$

$$F \propto H^2\sin(\theta+\phi) \;\Rightarrow\; F \propto I^2\sin(\theta+\phi) \;\; [\because H \propto I\,]$$

The expression of deflecting torque is $T_d = FL\cos(\theta + \phi)$

$$T_d \propto I^2 \sin(\theta + \phi) L \cos(\theta + \phi)$$

$$T_d \propto I^2 \frac{L}{2} \sin 2(\theta + \phi) \Rightarrow T_d = K_1 I^2 \sin 2(\theta + \phi)$$

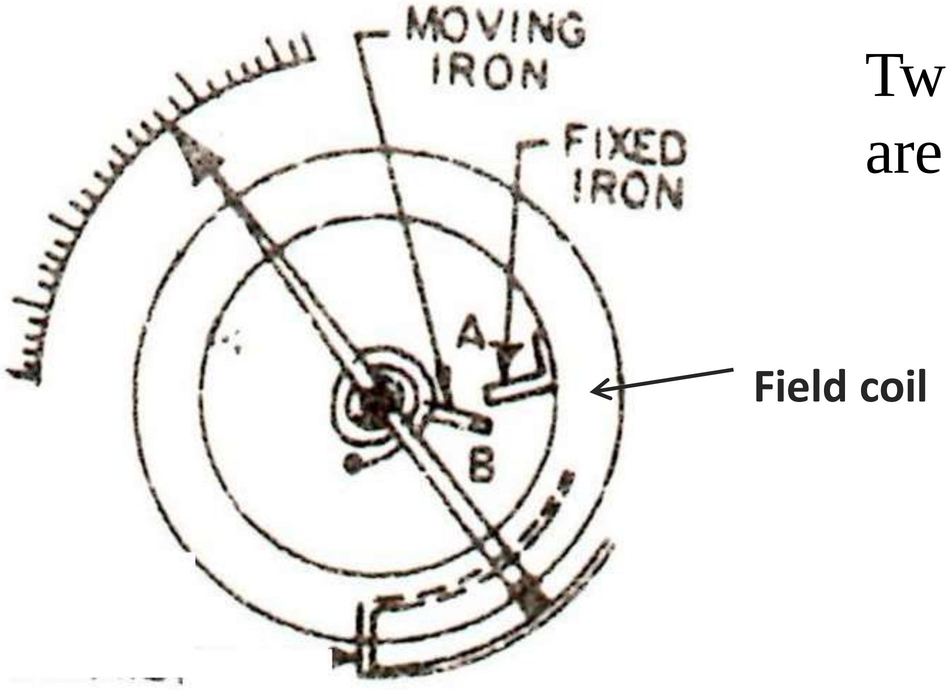
Controlling torque $T_c = K_2 \theta$

When the pointer comes to its steady position

$$T_d = T_c \qquad \Rightarrow I^2 \sin 2(\theta + \phi) \propto \theta$$

Repulsive type:

A stationary coil of many turns which carries the current to be measured



Two vanes of iron strips (vanes) are placed inside the coil.

One vane is rigidly attached to the coil frame, while the other is connected to the instrument shaft which rotates freely.

The current through the coil magnetizes both the vanes with same polarity.

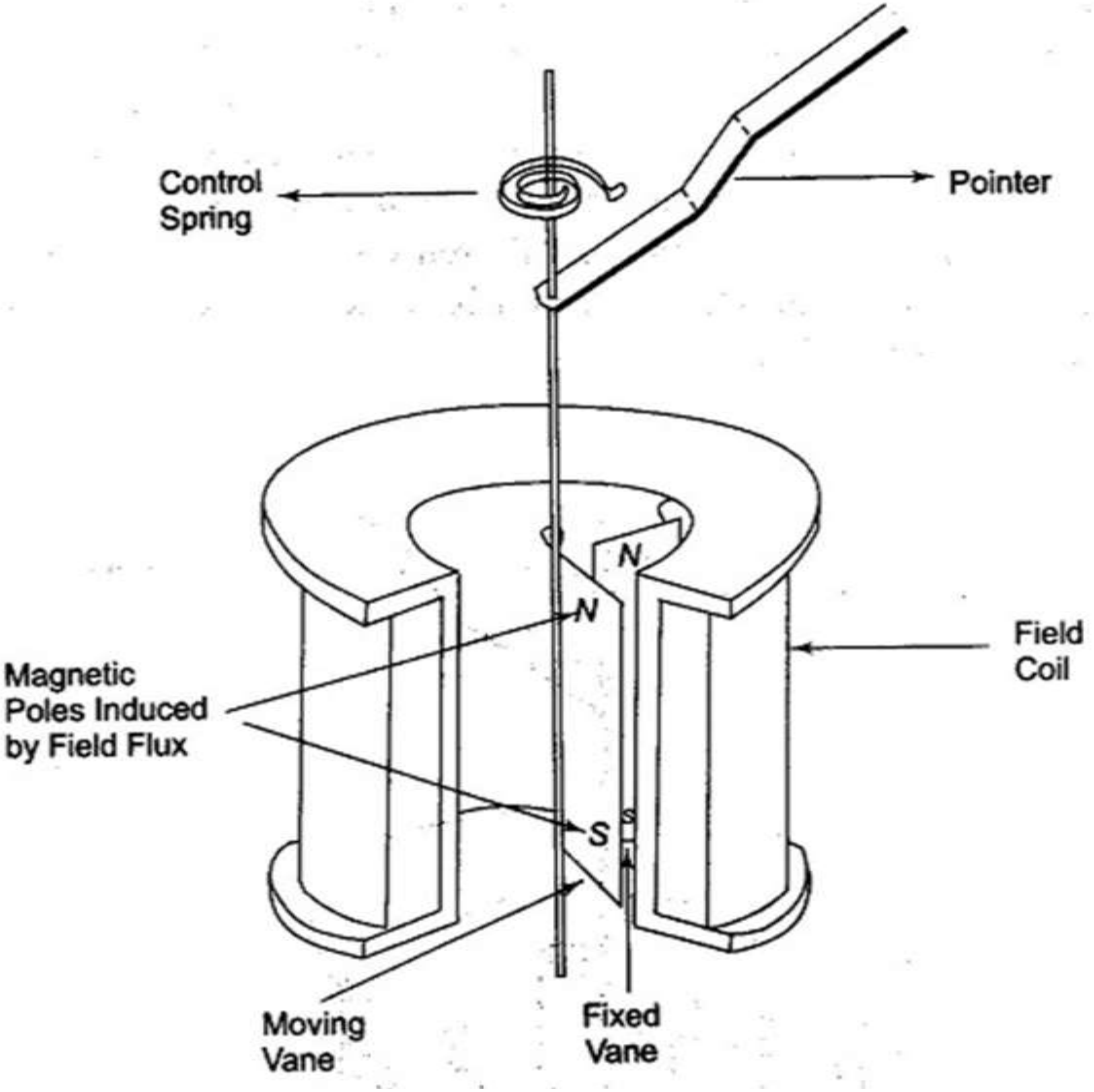
- The two magnetized vanes repel each other.
- The repelling force is proportional to square of the current.
- Moving vane displaces depending on the magnitude of the coil current.

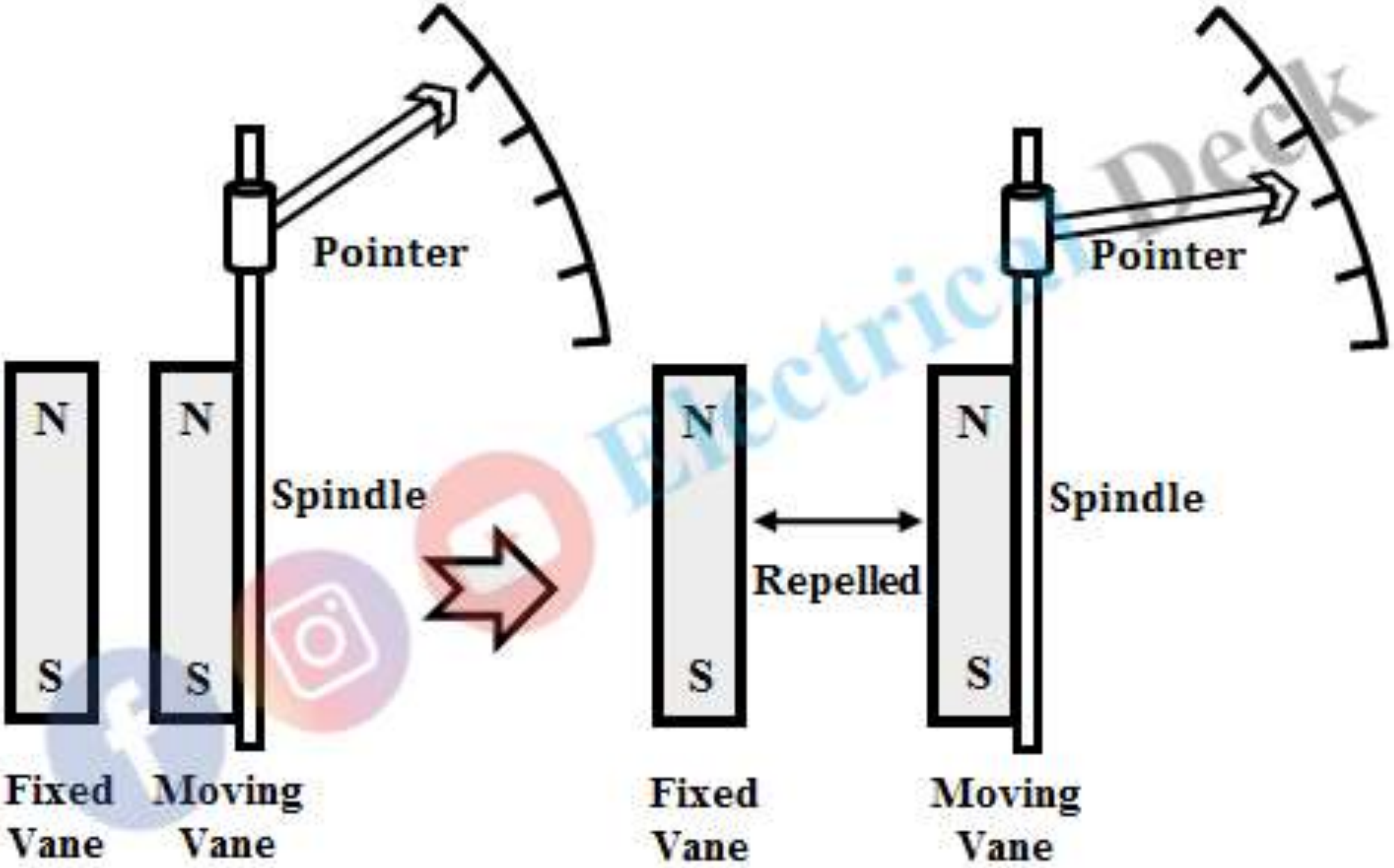
Depending on the design of construction, there are two types of repulsion type instruments:

- **radial vane type**
- **Co-axial or concentric vane type**

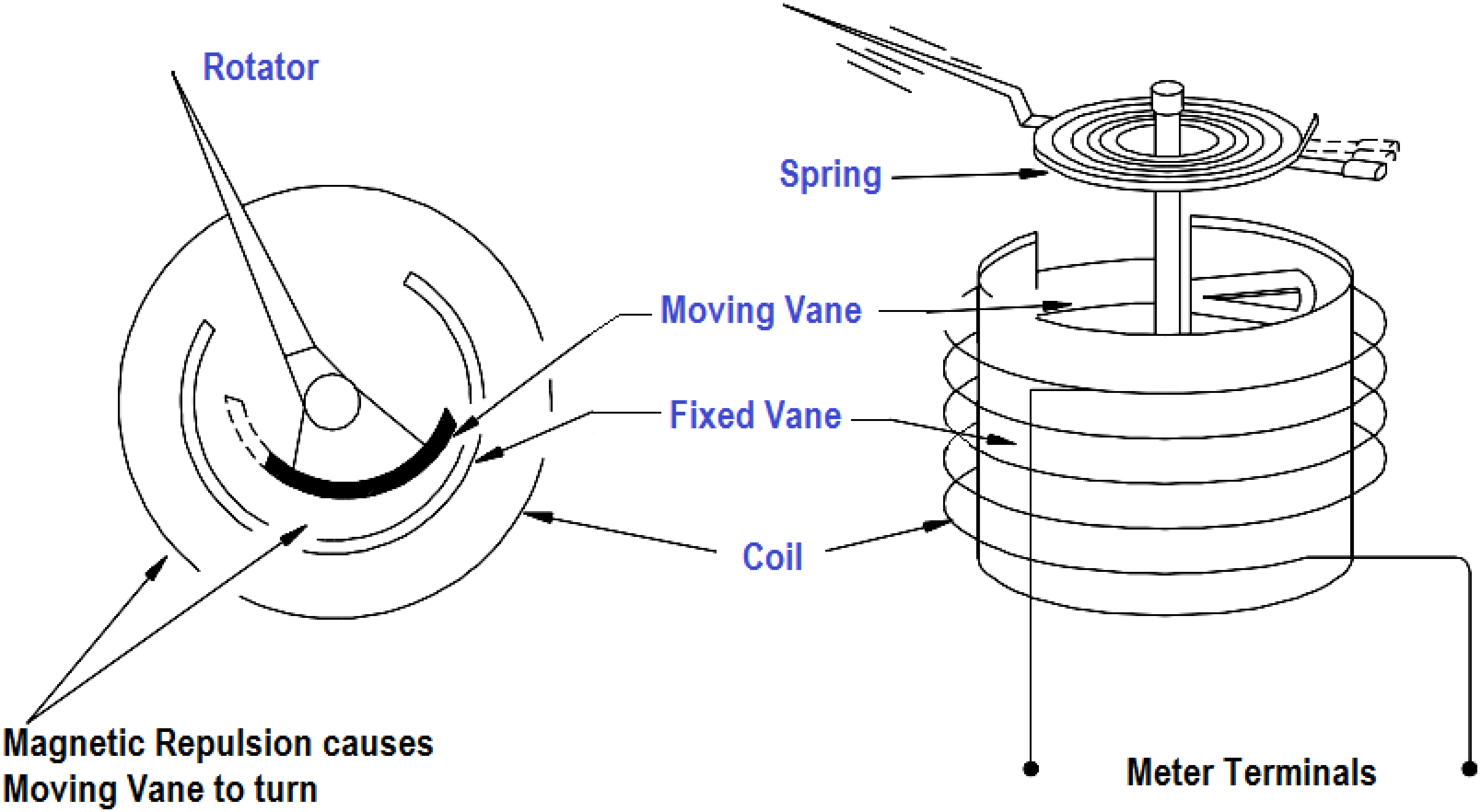
Radial Vane Repulsion Type Instrument :

It consists of two iron strips (vanes) are placed radially




Pointer
N
S
N
S
Spindle
Fixed Vane
Moving Vane
Pointer
N
S
N
S
Spindle
Repelled
Fixed Vane
Moving Vane

Concentric vane type



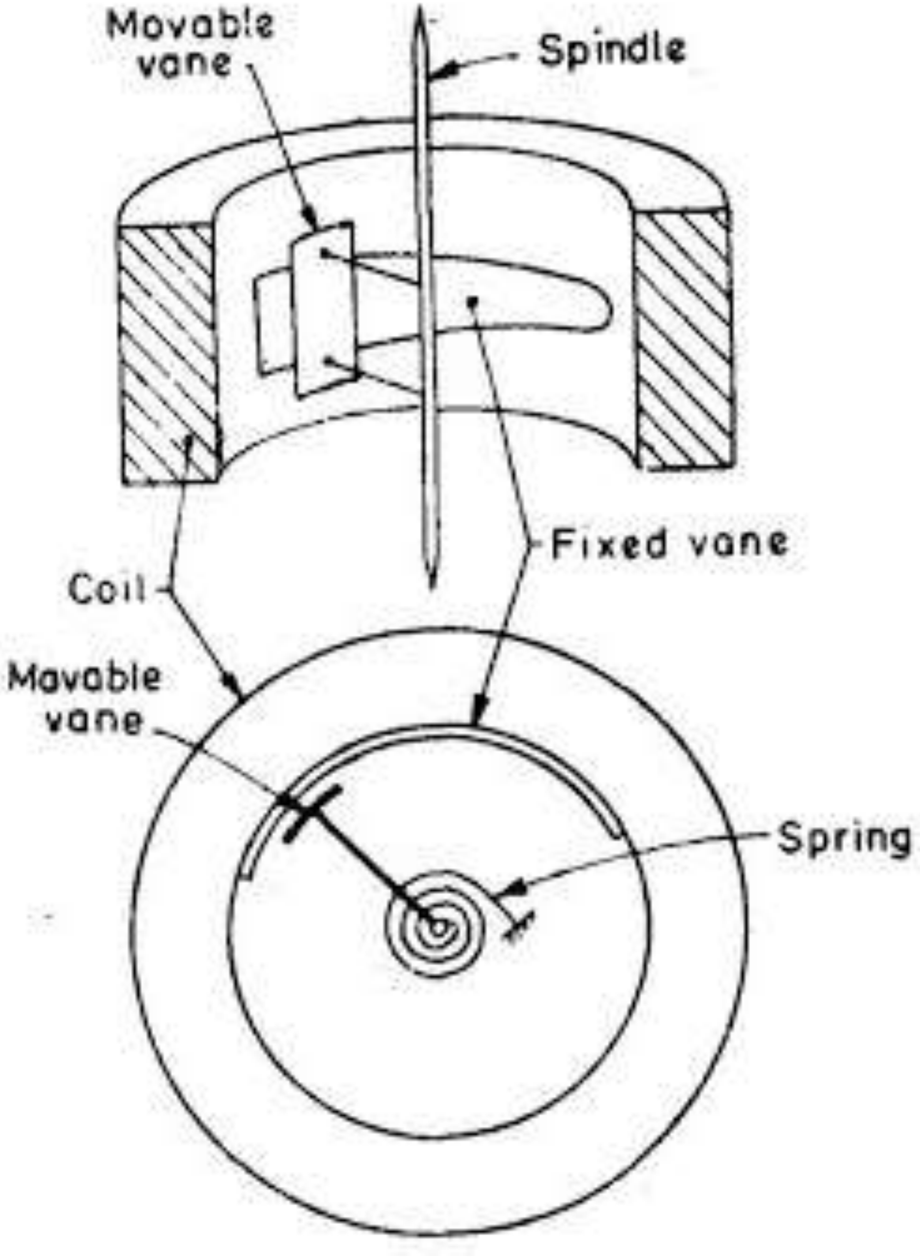
The vanes are the sections of coaxial cylinders

One vane is rigidly attached to the coil frame while the other can rotate coaxially inside the stationary vane.

The moving vane is attached to a pivoted shaft

The vanes slip laterally under repulsion.

This results in a rotational force that is a function of the current in the coil.



Torque equation of Moving Iron Instruments

Let I = initial current

L = instrument inductance

θ = deflection

dI = increase in current

$d\theta$ = change in deflection

dL = change in inductance

To cause an increment in current the increase in applied voltage is given by

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

$$= I\frac{dL}{dt} + L\frac{dI}{dt}$$

as both I and L are changing.

The electrical energy supplied

is given by

$$eIdt = \left(I \frac{dL}{dt} + L \frac{dI}{dt} \right) Idt = I^2 \; dL + IL \; dI$$

Stored energy increases from

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

Thus change in stored energy is given by

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

Thus energy supplied is used up for increase in stored energy and energy required for mechanical work

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

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

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

Controlling torque is

$$T_c = K\,\theta$$

Under equilibrium

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

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

The deflection is proportional to square of the current.

Advantages of the Moving Iron Instruments

- ✓ The instrument is independent of the direction of current and hence used for both AC and DC.

- ✓ The friction error is very less in the moving iron instrument because their torque weight ratio is high. The torque weight ratio is high because their current carrying part is stationary and the moving parts are lighter in weight.

- ✓ The instruments require less number of turns as compared to PMMC instrument

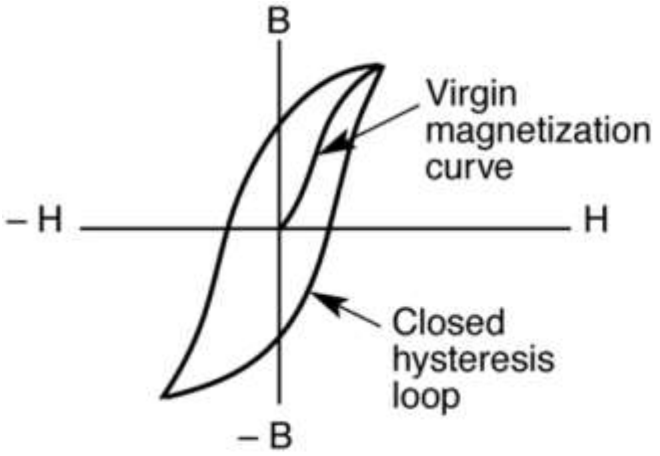
- ✓ The instrument is robust because of their simple construction and because their current carrying part is stationary.

Disadvantages of Moving Iron Instruments.

- The scale is not uniform, and hence the accurate result is not possible.
- Serious error occurs in the instruments because of the hysteresis, frequency and stray magnetic field.
- The increase in temperature increases the resistance of coil, decreases stiffness of the springs, decreases the permeability.
- Due to the non linearity of B-H curve, the deflecting torque is not exactly proportional to the square of the current.
- The calibration of the AC and DC are different due to effect of inductance of meter and eddy current in AC. The AC is calibrated on the frequency at which they use.
- Iron instrument may be used within its specified accuracy from 25 to 125 Hz frequency range.

Hysteresis error:

Due to hysteresis effect, the flux density for the same current while ascending and descending values is different. So meter reads higher for descending values of current or voltage. Remedy for this is to 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 spring. Errors can cause due to self heating of the coil and due to which change in resistance of the coil. So coil and series resistance must have low temperature coefficient.

Stray magnetic Field Error:

The operating magnetic field is very low. Hence effect of external i.e. stray magnetic field can cause error.

Frequency Error:

The change in frequency affects the reactance of the working coil and also affects the magnitude of the eddy currents.

Eddy Current Error:

The eddy currents in the iron parts affects the instrument current causing the change in the deflection torque. This produces the error in the meter reading. As eddy current are frequency dependent, frequency changes cause eddy current errors

The accuracy of the instrument is limited by several factors:

The magnetization curve of the iron vane is non-linear.

At low current values, the peak to peak of the ac produces a greater displacement per unit current than the average value, resulting in an ac reading that may be appreciably higher than the equivalent dc reading at the lower end of the scale.

Similarly, at the higher end of the scale, the knee of the magnetization curve is approached and the peak value of the ac produces less deflection per unit current than the average value, so that the ac reading is lower than the equivalent dc value.