INSTRUMENTS

Instrument :-

A tool (or) a device used for measuring is called an instrument. The instruments used to measure electrical quantities are called electrical instruments.

- The instrument used to measure current, voltage, power and energy are called ammeter, voltmeter, wattmeter and energy meter.
- The construction, working and applications of ~~the~~ some electrical instruments is studied.

~~Types~~ Classification of Electrical Instruments :-

Instruments are been classified based on the type of work which they are used. They are

(a) absolute instruments (b) secondary instruments

1. Absolute Instruments (or) Primary instruments :-

These are rarely used. The quantity to be measured will be given in terms of the deflection and the constant of the instrument. No calibration is needed in these instruments. Divisions on the graduated scale will not have any value marked on it. Examples of these instruments are (i) Tangent galvanometer (ii) Rayleigh current balance.

2) Secondary Instruments :-

These instruments are most commonly used. The quantity to be measured will be indicated in terms of the deflection of the pointer which indicates the value on the calibrated dial. Examples :- ammeter and voltmeter.

- Measuring instruments are also classified on the basis of the type of i/p provided such as

(iii) Analogy instruments (iv) Digital Instrument

Analog instruments :-

In these type of instruments, a mechanical representation is used as the analogue of an electrical quantity to indicate the magnitude of the electrical quantity.

) Digital Instruments :-

In these instruments, the electrical quantity or any other signal constitutes the i/p signal. This analog i/p is converted to the Binary coded decimal (BCD) i/p representation, which is then decoded and displayed as digits on a screen.

Secondary instruments are also called as electrical Instruments. They are further classified according to their functions as.

(i) indicating instruments
(ii) integrating instruments
(iii) recording instruments

i) Indicating Instruments :-

The instruments which directly indicate the value of the electrical quantity at the time when it is being measured are called indicating instruments. (eg). ammeters, voltmeters and wattmeters.

- In these instruments, a pointer moving over a graduated scale directly gives the value of the electrical ~~instruments~~ quantity being measured.
- For example, when an ammeter is connected in the circuit, the pointer of the meter directly indicates the value of current flowing in the circuit at that time.

2) **Integrating instruments :-**

The instruments which measure the total quantity of electricity (in ampere-hours) or electrical energy (in watt-hours) in a given time are called integrating instruments.

Eg :- ampere-hour meter and watt hour meter.

In such instruments, there are sets of dials and pointers which register the total quantity of electricity (or) electrical energy supplied to the load.

for eg, in an energy meter, the electrical energy consumed during a particular period is summed up and indicated on a display. (2) water meter used by the municipal corporations for recording the ~~display~~ quantity of water consumed by the individual consumers in a month is another example of an integrating instrument.

3) **Recording instruments :-**

· The instruments which gives a continous record of the variations of the electrical quantity to be measured are called recording instruments.

· Recording voltmeters are used in supply stations to ~~the~~ record the voltage of the supply mains during the day. Recording ammeters are employed in supply stations for registering the current taken from the batteries.

Eg :- demand meter, aneroid barometer.

Principle of Operation of Electrical Intruments :-

· An electrical instrument essentially consists of a movable element and a scale to indicate or register the electrical quantity being measured. The movable element is supported on jewelled bearings and carries a pointer or sets of dials. The movement of the movable element is caused by the effects of current or voltage.

For example :- When current flows through a circuit, it

produces a number of effects.
When current flows through a wire, it produces a magnetic field as well as heating effect. When it flows through a battery it produces a chemical effect in the electrolyte solution. In a similar way, it produces an electrostatic field and can also induce emf in a nearby ~~cird~~ circuit due to electromagnetic induction. In any secondary instrument, one of the above effects is used to produce the deflecting torque. For example:-

1) magnetic effect is used in ammeter, voltmeter, wattmeter and energy meters.
2) heating effect is used in ammeter and voltmeter
3) chemical effect is used in dc ampere-hour meter
4) electrostatic effect is used in voltmeter
5) electromagnetic induction effect is used in ac ammeters, voltmeters, wattmeters.

(classification based on various effects of electric current)

Type	Effect	Suitable for	Instruments
1) Moving iron	magnetic effect	dc and ac	Ammeter, voltmeter
2) Permanent magnet moving coil	Electrodynamic effect	dc only	Ammeter, voltmeter
3) Dynamometer type	Electrodynamic effect	dc and ac	Ammeter, voltmeter wattmeter
4) Induction type	Electromagnetic induction type	ac only	Ammeter, voltmeter wattmeter, Energymeter
5) Hot wire	Thermal effect	dc & ac	Ammeter, voltmeter
6) Electrolyticmeter	Chemical effect	dc only	Ammeter-hour meter
7) Electrostatic type	Electrostatic effect	dc & ac	Voltmeter only

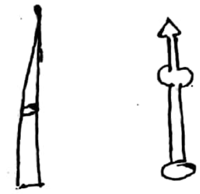
Essential features of measuring instruments :-

The general requirements of an indicating instrument are

(i) Pointer and scale
(ii) Deflecting torque (Td)
(iii) Controlling torque (Tc)
(iv) Damping torque

Pointer and scale :-

Pointer is essential for an indicating instrument to
indicate the value of the quantity to be measured.
The pointer must be lighter in weight to reduce the
bearing friction and damping ~~torque~~ force. Pointers are
available in different shapes. Alluminium is generally
preffered as the material from which pointers are made.
For accurate reading the pointer must be thin



Types of pointers used in indicating instruments

Scale :-

A stiff card-board mounted on a metal sheet is used
for making scales as shown. To avoid parallel error,
a small strip of mirror is fixed with the card board.

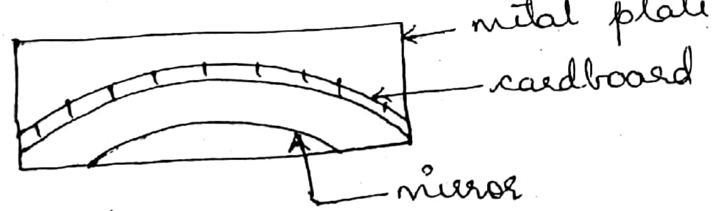


Fig:- Scale.

(ii) Deflecting torque (Td) :-

There must be some agency which can detect the quantity
to be measured. This agency is known as the deflecting
torque which acts on the moving system of the instrument
so that the pointer is deflected on the scale, when an
unknown quantity is being measured.
... a coil carrying a current ; when placed in

a magnetic field will experience a torque. This torque is used to drive the pointer in moving coil permanent magnet type instruments. Deflecting torque can be produced using one of the following effects:
(a) magnetic effect (b) heating effect (c) chemical effect
(d) electrostatic effect (e) electromagnetic induction.

Controlling Torque (T_c):-

Controlling torque is essential in an indicating instrument in order to get a steady deflection of the pointer. If this is not present, the pointer will continue to move forever since there is no force to oppose the deflecting torque. When deflecting torque (T_d) is equal to the controlling torque (T_c), the pointer will indicate the steady deflection. Controlling torque (T_c) can be produced in two ways. They are
(a) by spring control (b) by gravity control.

Spring control:-

Control Torque (T_c) can be produced using a spring control as shown in fig.

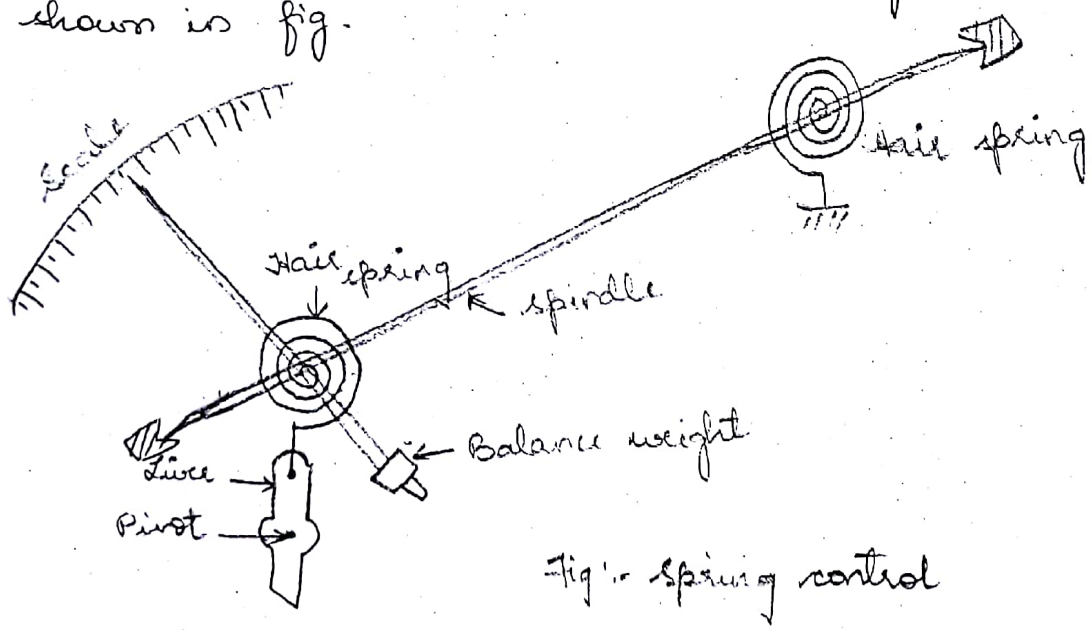


Fig:- Spring control

When this pointer moves under the influence of a deflecting torque (T_d), the spring will be completely wound and would exert a relative force in a direction opposite to

to that of Td. If θ is the angle of twist in the spring, (4)
then the control torque (Tc) will be given as

$$T_c = K_c \cdot \theta$$

where K_c is a constant which depends upon the material of spring
The controlling torque (T_c) is always proportional to the angle of twist (θ) provided there is no permanent set in the spring. To avoid this, the springs are usually made large.
The requirements of the material used for spring are
(i) They should be non-magnetic
(ii) They should not be subjected to fatigue.
(iii) Control springs are also used sometimes as leads for the passage of current through the moving coil and hence when used for carrying current, the electrical resistance of the spring material should be low and it should also have a low temperature coefficient of resistance.

- The following are some of the materials commonly used for the control springs.

(a) German silver (ii) silicon bronze (iii) platinum silver
(iv) Platinum-iridium (v) Phosphor bronze.
Phosphor bronze satisfies all the requirements.

- The deflecting torque (Td) which depends on the current I in the moving coil can also be written as

$$T_d = K_D \cdot I \quad [K_D \text{ is a constant}]$$

Thus, under steady state conditions, $T_D = T_c$

$$K_D \cdot I = K_c \, \theta \text{ (or) } I \propto \theta$$

when spring control is used, $I \propto \theta$ and hence it is possible to get a uniformly graduated scale for reading the current.

Gravity control :-

In a gravity controlled instrument, the moving system is attached with a weight (w) known as the control weight as shown in fig. to produce the controlling torque when the moving system is deflected due to the deflecting torque.

• A small balance weight (w_b) is also added so that the centre of gravity of the moving system coincides with the spindle carrying the moving system. If the system is deflected by an angle θ, then the component w. sin θ produces the controlling torque.

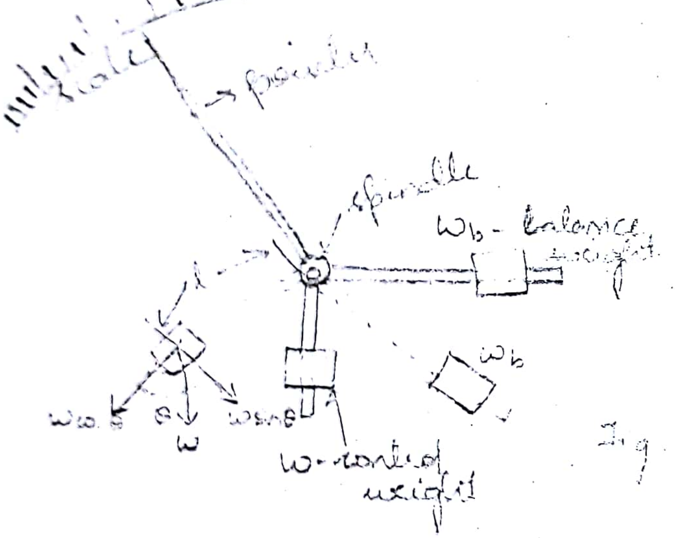


Fig. gravity control

$T = F \times d$

Thus, $T_c = w \cdot \sin\theta \cdot l$

where w is the control weight and l is its distance from the axis of rotation.

Under steady conditions,

$$T_d = T_c$$

$$K_D \cdot I = W \cdot \sin\theta \cdot l$$

$$I = \left[\frac{Wl}{K_D}\right] \sin\theta = K \sin\theta$$

$$I \propto \sin\theta$$

Since I is proportional to the sine of angle of deflection, gravity controlled instruments have non-uniform scales,

Advantages:-

1) It is cheap
- control torque is independent of the temperature
- The controlling torque can be changed easily.

Disadvantages:-

1) The instrument has to be kept in vertical position
2) The control weight increases the weight of moving system
3) They have non uniform scale.

Differences b/w Spring control and Gravity control:-

Spring control	Gravity control
1) Control torque is proportional to angle of twist (θ)	1) $T_c \propto \sin\theta$
2) Provides uniform scale	2) scale is not uniform.
3) Affected by temperature	3) Not affected by temperature
4) It can be used in any position	4) It must be used only in vertical position.

Damping Torque:-

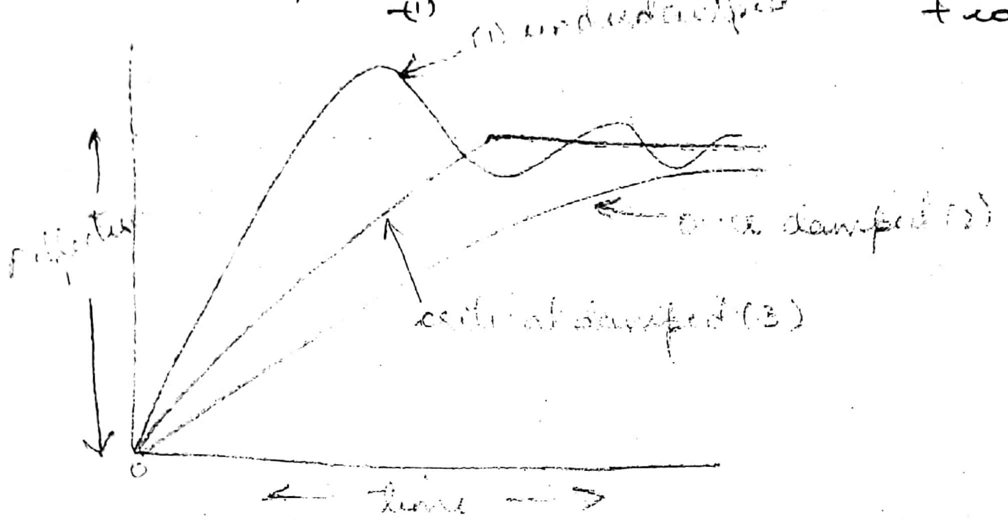
In a measuring instrument, the damping torque is necessary to bring the moving system to rest to indicate steady deflection in a short time. The damping torque must exist only as long as the pointer is in motion. If the damping torque is not employed, owing to the inertia of the moving system, the pointer will oscillate about the mean position for a short interval of time before it comes to rest as shown by curve 1. It is called under damping.

- If the damping force is too large, then the pointer will come to rest very slowly as shown by curve 2 and is called overdamping.
- Under the conditions of critical damping, the pointer

comes to rest in a small time without any oscillations as shown in curve 3.

If T_P is the damping torque on the moving system, then the equation of motion of the moving system will be given by

$$T_D = T_P + T_C \quad \text{---(1)}$$ [i.e deflecting torque = damping torque + control torque]



The damping torque should not exists when the pointer is steady, ∴ under steady conditions, eq(1) reduces to

$$T_D = T_C \quad \text{--- (2)}$$

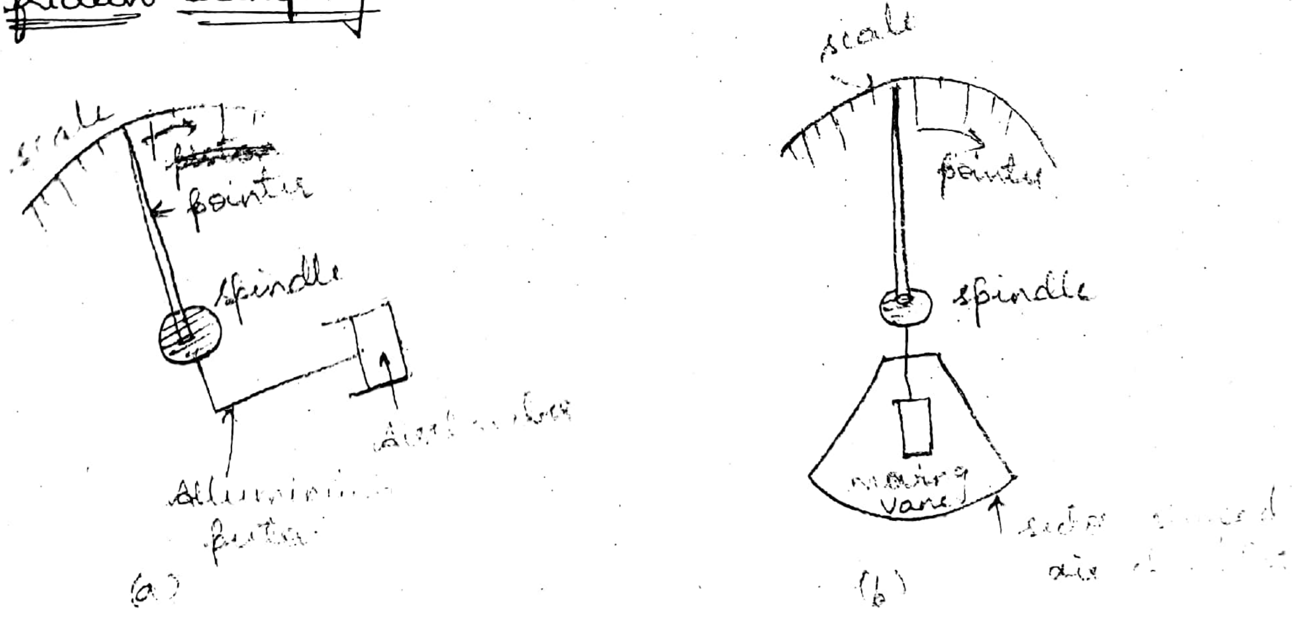
The most common types of dampings employed are

(i) air friction damping (ii) fluid friction damping

(iii) eddy current damping.

Eddy current damping is found to be most efficient method of damping.

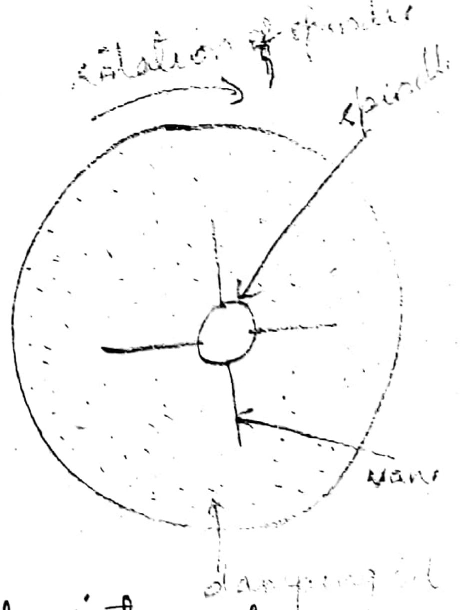
i) <u>**Air friction damping**</u> :-



An arrangement for providing air friction damping is shown in fig (a). An alluminium piston which moves in an air chamber is attached to the pointer. A damping force is provided by the movement of an alluminium piston in the air chambre. (6)

- When the pointer deflects in the clockwise direction, the piston moves out of the chamber, and the pressure inside the chamber falls below the external value.
- The difference between these two pressures acts on the piston and tries to arrest its movement. Again when the piston moves into the chamber, the air inside it will be compressed, and this compression opposes the movement of the piston and damping occurs.
- It should be noted that the damping force comes into action only when the motion of the piston exists.
- An alternate method of air friction damping utilises a vane mounted on a spindle of the moving system. The principle of operation is the same as above. The vane is usually made of thin alluminium sheet and moves inside a closed sector shaped box as in (b)

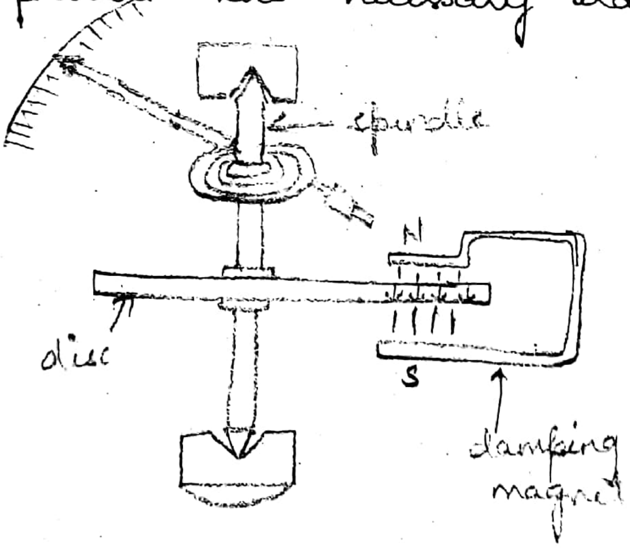
<u>Fluid friction damping</u> :-



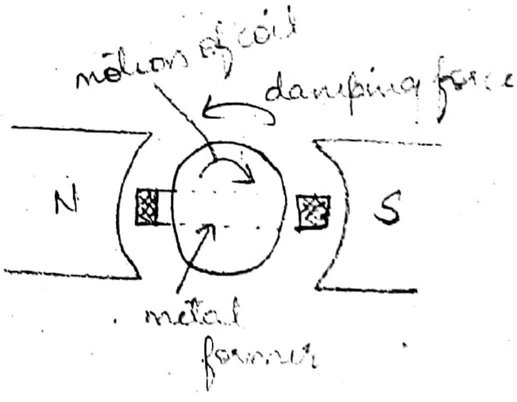
- In this method, discs or vanes attached to the spindle of the moving system are kept immersed in a pot containing oil of high viscosity. As the pointer moves, the friction between the oil and vanes opposes the motion of the pointer and thus necessary damping is provided.
- This method is not suitable for portable instruments because of the oil contained in the instrument.

i) <u>Eddy current damping</u> :-

Two methods of eddy current damping are shown in fig. In fig(a), a thin alluminium or copper disc attached to the moving system is allowed to pass between the poles of a permanent magnet.
As the pointer moves, the disc cuts across the magnetic field and eddy currents are induced in the disc. These eddy currents react with field of the magnet to produce a force which opposes the motion (Lenz law). In this way, eddy currents provide the damping torque to reduce the oscillations of the pointer.
In fig (b) the operating coil (i.e the coil which produces the deflecting torque) is wound on the alluminium former. As the coil moves in the field of the instrument, eddy currents are induced in the alluminium former to provide the necessary damping torque.



(a)



∴ The damping torque (T_D) will depend on induced current and flux i.e

$$T_D \propto I_e \cdot \phi$$ [I_e = induced current] [ϕ = flux in the air gap of magnet.]

$$I_e \propto emf \propto N\phi$$ [N is the speed of rotation of disc]

$$T_D \propto N \cdot \phi \cdot \phi$$

$$T_D = K_D N \cdot \phi^2$$

... damping torque exists only when disc is in ...

Permanent magnet moving coil instruments (PMMC) :-

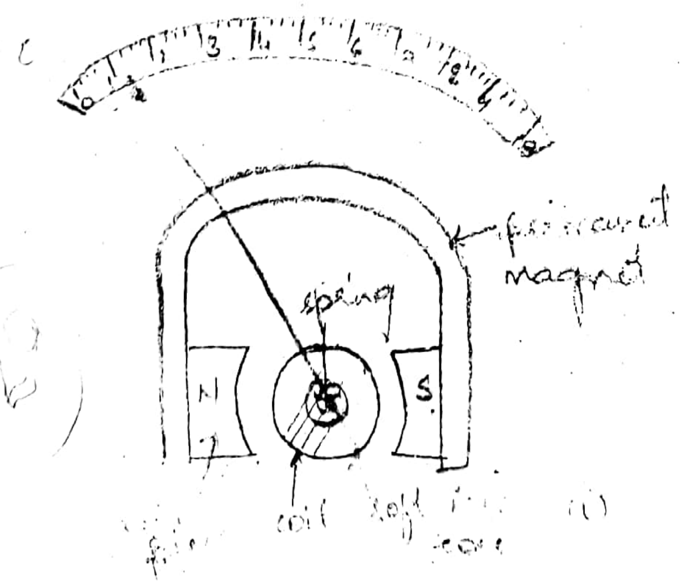
These instruments are used either as ammeters or voltmeters and are suitable for dc work only.

This type of instrument is based on the principle that when a current carrying conductor is placed in a magnetic field, mechanical force acts on a conductor.

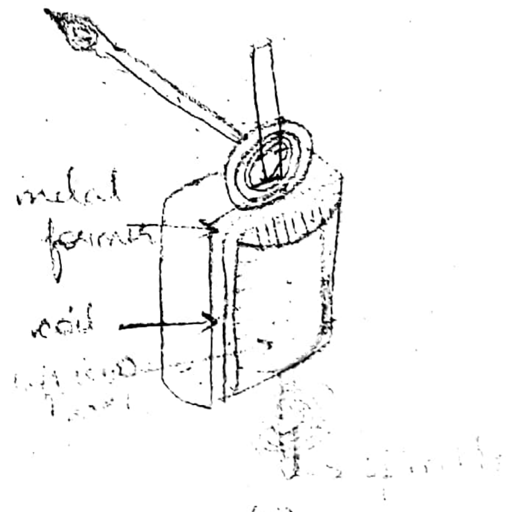
Construction :-

Fig. shows various parts of a permanent-magnet moving coil instrument. It consists of a light rectangular coil of many turns of fine wire wound on an aluminium former inside which is an iron core as shown in fig(i).

- The coil is pivoted upon jewel bearings and is mounted between the poles of a permanent horse-shoe magnet.
  Two soft iron pole pieces are attached to these poles which concentrate the magnetic field.
- The current is led into and out of the coil by means of two control hair springs, one above and below the coil in fig(ii). These springs also provide the controlling torque.
- The damping torque is provided by eddy currents induced in the aluminium former as coil moves from one position to another.



(i)



(ii)

Working :-

When the instrument is connected in the circuit to measure current or voltage, the operating current flows through the coil. Since the coil is carrying current and is placed in the magnetic field of the permanent magnet, a mechanical force acts on it.

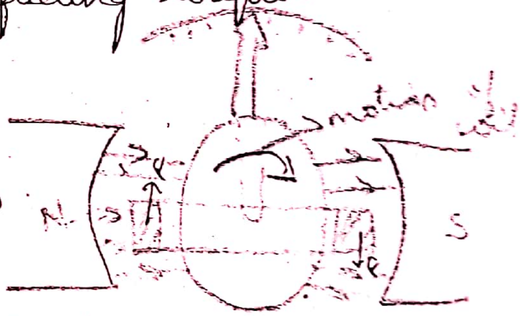
As a result, the pointer attached to the moving system moves in a clockwise direction over the graduated scale to indicate the value of current or voltage being measured.

- If the current in the coil is reversed, the deflecting torque will also be reversed since the direction of the field of the permanent magnet is the same.
- ∴ the pointer will try to deflect below zero. Deflection in this direction is prevented by a spring.
- Since deflecting torque reverses with the reversal of current in the coil, such instruments can be used to measure direct current and voltage only.

Deflecting torque :-

- when current is passed through the coil, forces act on its both sides which produce the deflecting torque.

Referring to fig.



B = flux density in Wb/m^2

l = length (or) depth of coil in m

b = breadth of coil

N = no. of turns in a coil.

If a current of I amperes flows in the coil, then force acting on each coil side is given by

$F = BIl$ newtons ⇒ Force acting on the coil of N conductors is $F = BIlN$ newtons.

Deflecting torque, T_d = Force × distance

$= BIlN \times b$ $\quad [l \times b = A]$

$T_d = BINA$ newton-meters

Since the value of B, N, A are constant

$\therefore T_d \propto I$; The instrument is spring controlled $T_c \propto \theta$

The pointer shows the steady deflection ~~when~~ when

$$T_d = T_c$$

$$\therefore \theta \propto I$$

Thus, the deflection is directly proportional to the operating current. Hence, such instruments have uniform scale.

<u>Advantages</u> :-

1) Uniform scale

2. Very effective eddy current damping [as aluminium former moves in an mag. field of permanent magnet]

3). Less power required for its operation

4) Very accurate and reliable.

<u>Disadvantages</u> :-

1. These cannot be used for ac measurements

2. More expensive

3. Errors are caused due to variations with time & temperature in the control springs.

<u>Applications</u> :-

- These are very sensitive and maintain a high degree of accuracy over long periods. Applications are

(i) In the measurement of direct current and voltages

(ii) In dc galvanometers to detect small currents.

(iii) In ballistic galvanometers for measuring changes of magnetic flux linkages.

Types of Ammeters and voltmeters :-

(a) Moving coil type
  (i) permanent magnet type (used with dc)
  (ii) dynamometer type (used with both dc and ac)

(b) moving iron type (used with both dc and ac)

(c) Hot wire type (used with both ac and dc)

(d) electrostatic type (used with both dc and ac)

(e) Induction type (used with ac)

Moving iron ammeter and voltmeter :-

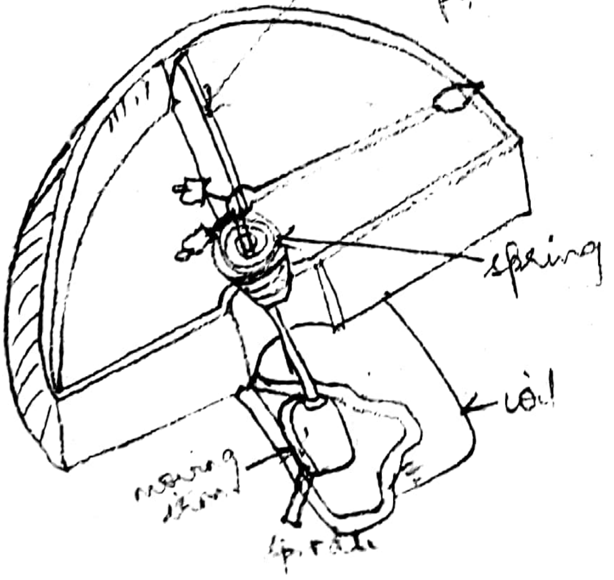
- This type of instruments is principally used for the measurement of alternating currents and voltages, it can also be used for dc measurements. There are two types of moving iron instruments.

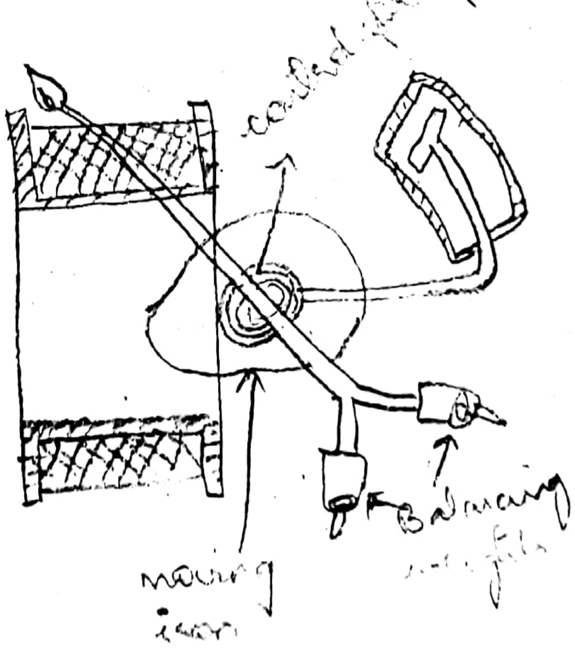
(i) Attractive type in which a single soft iron vane (or moving iron) is mounted on the spindle and is attracted towards the coil when operating current flows through it.

(ii) Repulsive type in which two soft iron vanes are used, one fixed and attached to the stationary coil while the other is movable (i.e moving iron) and mounted on the spindle of the instrument. When operating current flows through the coil, the two vanes are magnetised, developing similar property at the same ends. Consequently repulsion takes place between the vanes and the movable vane causes the pointer to move over the scale.

Attraction type :-

- It consists of a cylindrical coil which is kept fixed. An oval-shaped soft iron is attached to the spindle in such a way that it can move in and out of the coil. A pointer is attached to the spindle so that it is deflected with the motion of the soft-iron piece. The controlling torque is provided by one spiral spring arranged at the top of the moving element.
- The damping device is an alluminium vane attached to the spindle, which moves in a closed air chamber.
- In some instruments damping is provided by the movement of a piston inside the curved chamber, the piston being attached to the spindle.





Working :-

When the instrument is connected in the circuit to measure current or voltage, the operating current flowing through the coil sets up a magnetic field. ∴ The coil behaves like a magnet and it attracts the soft iron piece towards it. ∴ pointer attached to the moving system moves. The pointer will come to rest at a position where deflecting torque is equal to controlling torque.

If the current in the coil is reversed, the direction of the magnetic field also reverses and so does the magnetism produced in the soft-iron piece.

Hence, the direction of the deflecting torque remains unchanged. ∴ Such instruments can be used for both ac and dc measurements.

Deflecting torque :-

The force F pulling the soft iron piece towards the coil is directly proportional to

(i) field strength H produced by the coil.

(ii) pole strength m developed in the iron piece

$$F \propto mH$$

$$F \propto H^2 \quad [\because m \propto H]$$

Deflecting torque $T_d = F \times d$.

$$T_d \propto F$$

$$T_d \propto H^2$$

If permeability of iron is assumed constant (conductivity of magnetic flux)

$$T_d \propto i^2$$

$$T_d \propto i_{rms}^2$$

$\because T_c \propto \theta$ [spring controlled]

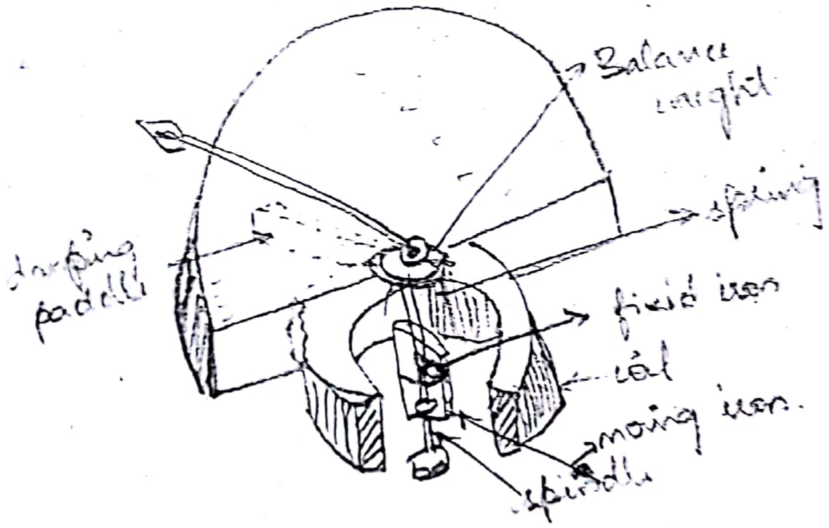
In the steady position of deflection, $T_d = T_c$

$$\theta \propto I^2_{rms}.$$

Since deflecting is proportional to the square of coil currents, the scale of such instruments is non-uniform

<u>Repulsion type</u> :-

- It consists of two soft-iron pieces or vanes surrounded by fixed cylindrical hollow coil which carries the operating current. One of these vanes is fixed and other is free to rotate
- The movable vane is of cylindrical shape and is mounted axially on a spindle to which a pointer is attached.
- The fixed vane, which is wedge-shaped and has a larger radius, is attached to the stationary coil.
- The controlling torque is provided by one spiral at the top of the instrument.
- Damping is provided by the air friction due to the motion of a piston in an air chamber.



Working :-

When current to be measured or current proportional to voltage to be measured flows through the coil, a magnetic field is set up by the coil.

The magnetic field magnetises the two vanes in the same direction i.e, similar polarities are developed at the same ends of the vanes.

Since the adjacent edges of the vanes are of same polarity, the two vanes repel each other. As the fixed vane cannot move, the movable vane deflects and causes the pointer to move from zero position.

The pointer will come to rest at a position where deflecting torque is equal to the controlling torque provided by spring.

- If the current in the coil is reversed, the direction of the deflecting torque remains unchanged.
- Such instruments can be used for both dc and ac applications.

Deflecting torque :-

The deflecting torque results due to the repulsion between the similarly magnetised soft iron pieces or vanes. If the two pieces develop pole strengths of m_1 and m_2 resp, then

$$\text{deflecting torque} \propto m_1 m_2 \propto H^2$$

If the permeability of iron is assumed constant,

$$H \propto i$$

$$\text{deflecting torque} \propto i^2$$

∴ Average deflecting torque, $T_d \propto$ mean of i^2 over a cycle.

$$T_d \propto i^2_{rms}$$

$$T_c \propto \theta \text{ [spring controlled]}$$

At steady deflection, $T_d = T_c$

$$\theta \propto I^2_{rms}$$

(11)

Thus, deflection is proportional to the square of coil current, the scale of such instruments is also non uniform

Advantages:-

1. These are less expensive, robust and simple in construction
2. can be used for both dc and ac measurements.
3. These instruments are accurate.
4. High operating torque.

Disadvantages:-

1. These instruments have non-linear scales.
2. Errors are introduced due to change in frequency in case of ac measurements.