Basic Instruments

- Introduction
- Classification of instruments
- Operating principles
- Essential features of measuring instruments
- PMMC Instruments
- Moving Iron instruments

Introduction

- Electrical instruments are broadly classified into TWO types
- 1. ABSOLUTE Instruments
- 2. Secondary Instruments

- ABSOLUTE Instruments:
- Gives the value of the quantity to be measured in terms of the constants of the instruments and their deflection
- Ex: Tangent Galvano meter
- No previous calibration or comparison required
- They are mainly used in labs as standard measuring instruments

- Secondary Instruments:
- The value of the electrical quantity to be measured can be determined from the deflection of the instrument only when they have been pre-calibrated by comparison with an absolute instrument

- Calibration is essential.
- These instruments are used in day-to-day maeasurements.

- Secondary instruments are classified into
- 1.Indicating instruments
- 2.recording instruments
- 3.integrating instruments.

- Indicating instruments
- Indicates the instantaneous value of the electrical quantity being measured at that time at which it is being measured.
- Indications is given by a pointer moving on a calibrated dial or scale.
- Ex:- Ordinary Ammeters, Voltmeters and Wattmeters.

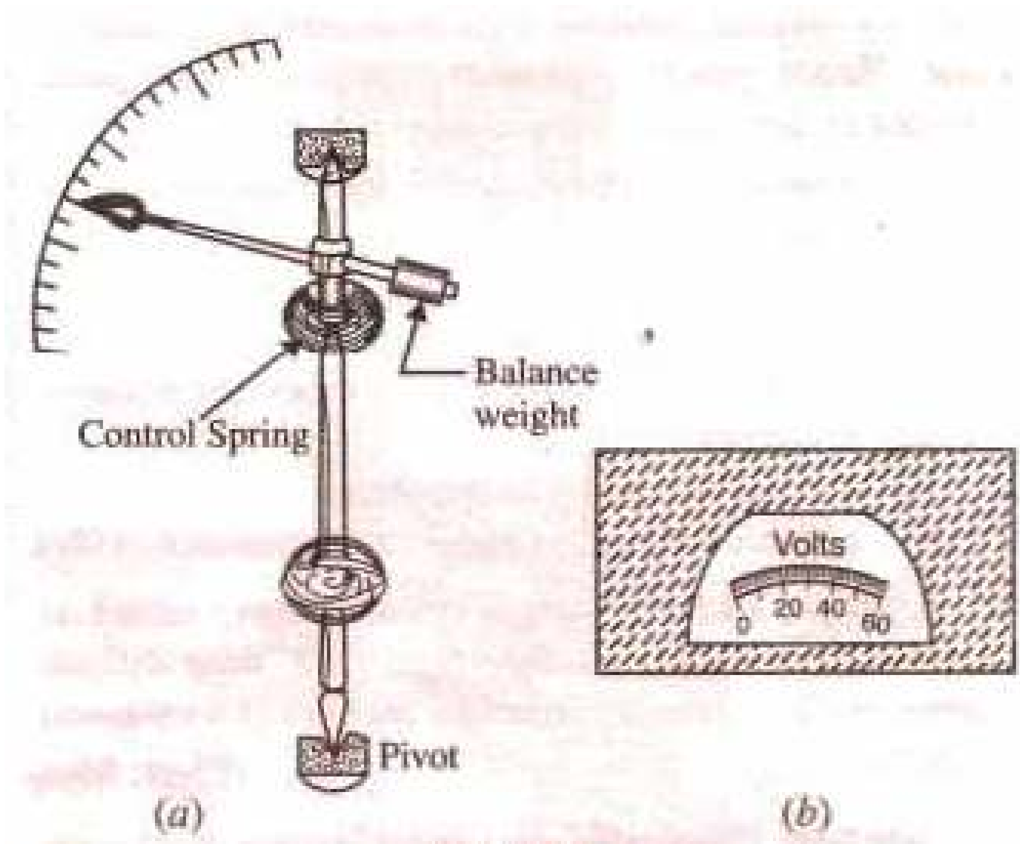
- Recording Instruments.
- Gives the continuous record or variation of the quantity to be measured over a selected period of time.
- The moving system of the instrument carries a marked pen which rests lightly on a chart or graph.
- The chart or graph is moved at uniform low speed at perpendicular to the movement of the pen.
- This gives a continuous record
- Ex:sesimographs etc

- Integrating Instruments:
- Measures and register by a set of dials and pointers.
- Usually measures the total quantity of electricity (in Amp-Hours) or the total amount of electrical energy (in KWH)
- Their reading gives the product of time and the electrical quantity
- EX:- energy meter, amp-hour meters.

All electrical measuring instruments depend for their action on one of the many physical effects of an electric current or potential and are generally classified according to which of these effects is utilized in their operation. The effects generally utilized are :

1. Magnetic effect - for ammeters and voltmeters usually.
2. Electrodynamic effect - for ammeters and voltmeters usually.
3. Electromagnetic effect - for ammeters, voltmeters, wattmeters and watthour meters.
4. Thermal effect - for ammeters and voltmeters.
5. Chemical effect - for d.c. ampere-hour meters.
6. Electrostatic effect - for voltmeters only.

- Essential of indicating instruments:



- An indicating instrument is generally subjected to THREE Types of TORQUEs

1. Deflecting Torque

2. Controlling Torque

3. Damping Torque

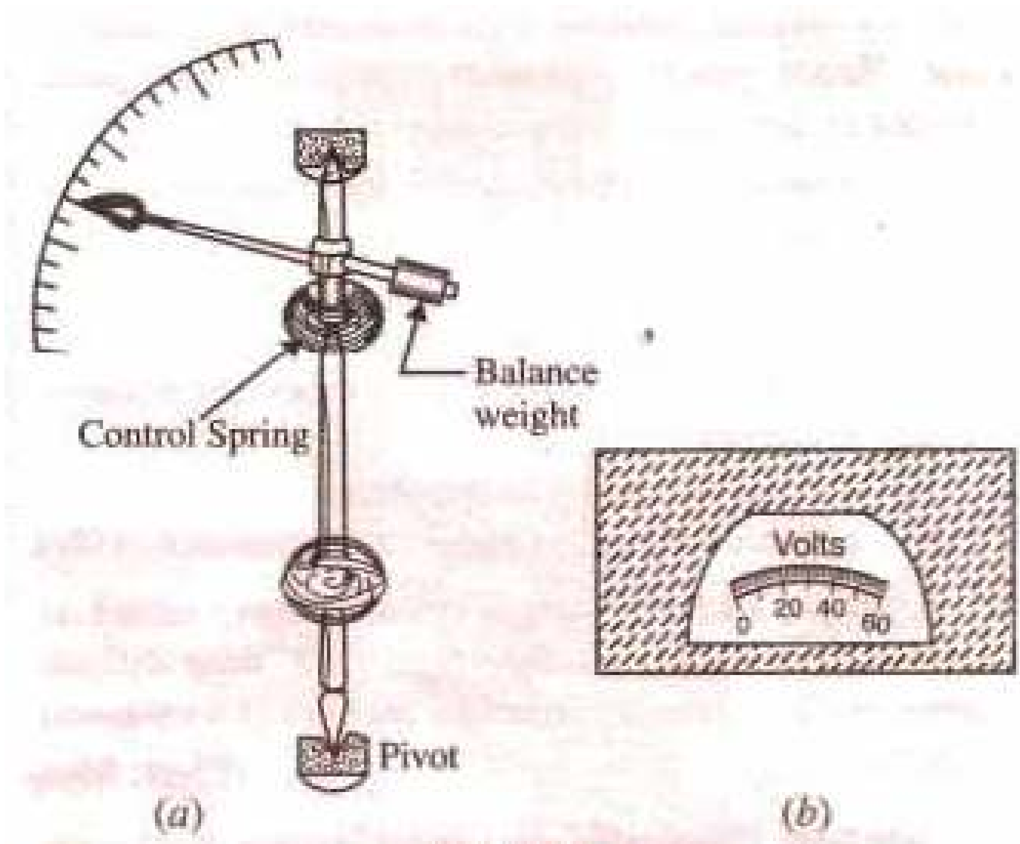
Deflecting Torque or Operating Torque.

- It is produced by utilizing one of the electrical effects.
- Deflection torque causes the moving system to move from ‘zero’ position.

Controlling Torque or Restoring torque:

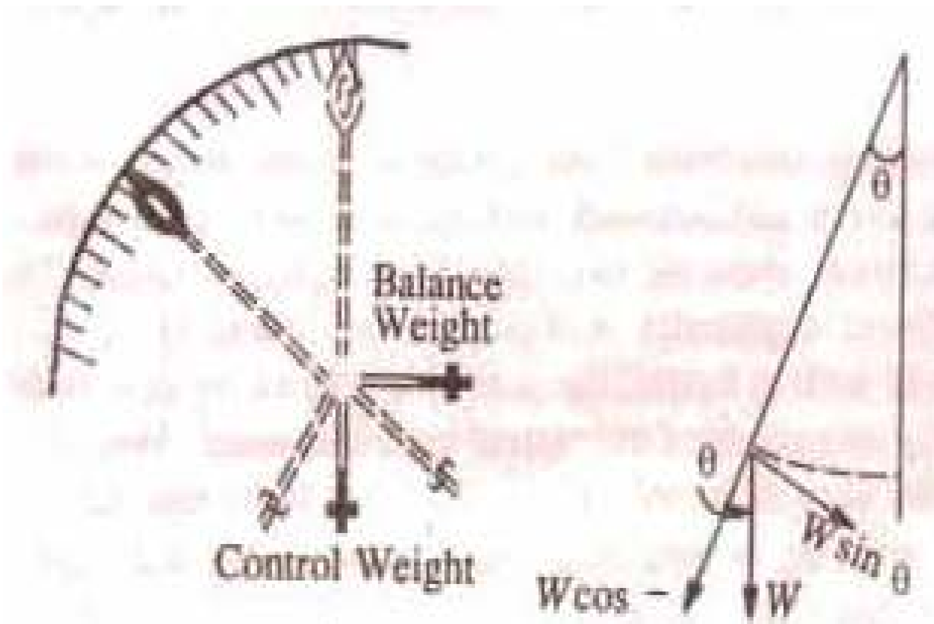
- The deflection of the moving system is indefinite if there is no controlling torque.
- This torque opposes the deflecting torque and increases with the deflection of the moving system.
- The pointer is brought to rest when these two torques are equal.
- Controlling torque is obtained in indicating instrument by TWO ways
- 1.Spring Control 2. Gravity control.

- Spring control:



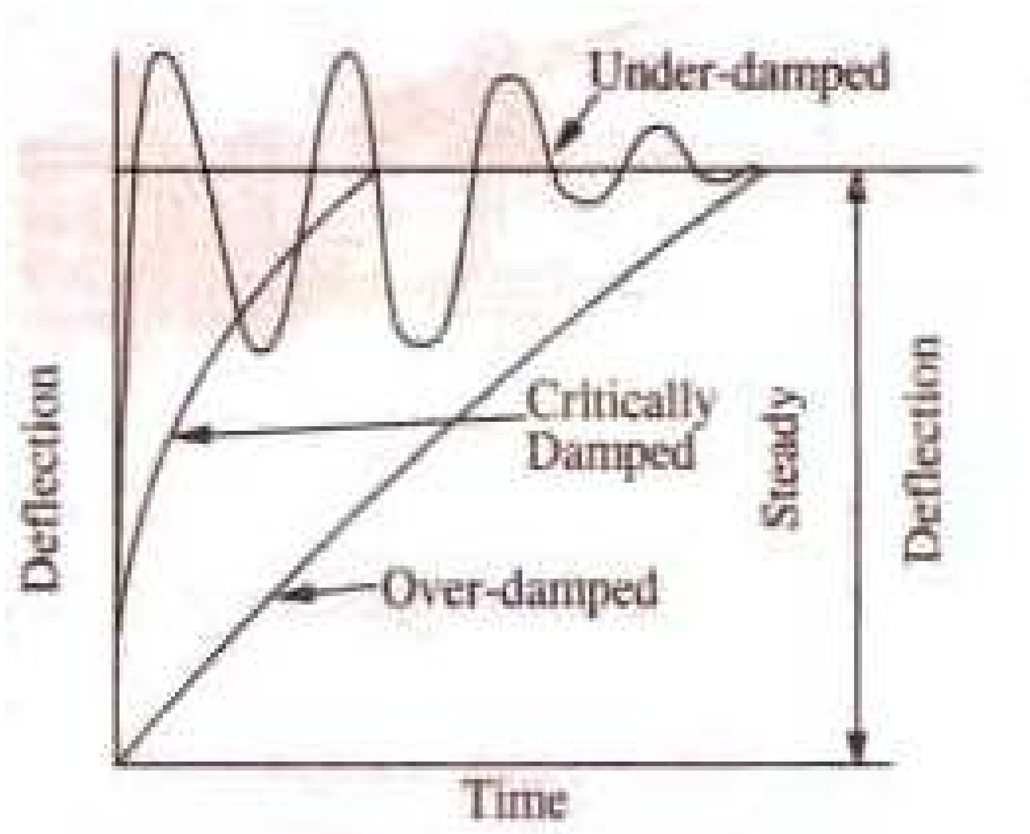
- A hair-spring, usually Phosphor bronze, is used to provide the controlling torque.
- With the deflection of the pointer, the spring is twisted in the opposite direction
- The twist in the spring produces the restoration torque which is directly proportional to the angle of deflection
- Since the deflection is proportional to current , the scale on the spring controlled meter is uniform or equally-spaced scale over the whole of their range

- Gravity Control:



- Gravity control is obtained by attaching small adjustable weights to some part of the moving system such that the two exert torques in the opposite directions.
- In Gravity control, controlling torque is proportional to the sine of the angle of deflection.
- The degree of control is adjusted by screwing the weight up or down the carrying system.
- At equilibrium point, the current is proportional to sine of the angle of deflection
- Gravity controlled instruments have scales cramped or crowded at their lower region.

Damping Torque:



- A damping force is one which acts on the moving system of the instrument only when it is moving and always opposes its motion.
- Such stabilizing or damping force is necessary to bring the pointer to rest quickly.
- Due to inertia of the moving system ,the pointer will oscillate about its final deflected position for quite sometime before coming to rest in steady state position.

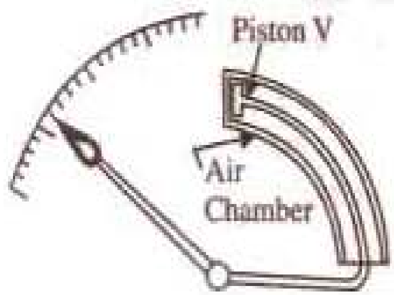
- If the Degree of the damping is low then pointer makes oscillation before settling at equilibrium position. In this case the instrument is said to be **under damped.**
- If the degree of the damping is too high then the pointer takes longer time to reach equilibrium position without making oscillations. In this case the instrument is said to be **over damped**
- If the degree of the damping is just sufficient to enable the pointer to rise quickly to equilibrium point without overshoot ,then the instrument is said to be **critically damped**

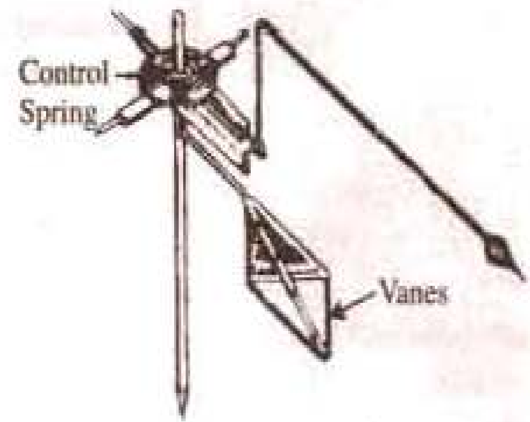
- The damping force can be produced by

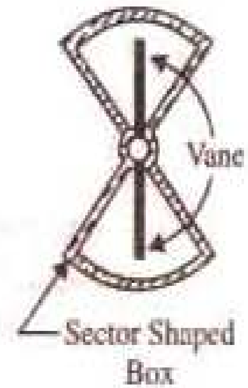
1. Air Friction damping

2. Eddy Current damping

3. Fluid friction damping


Piston V
Air
Chamber

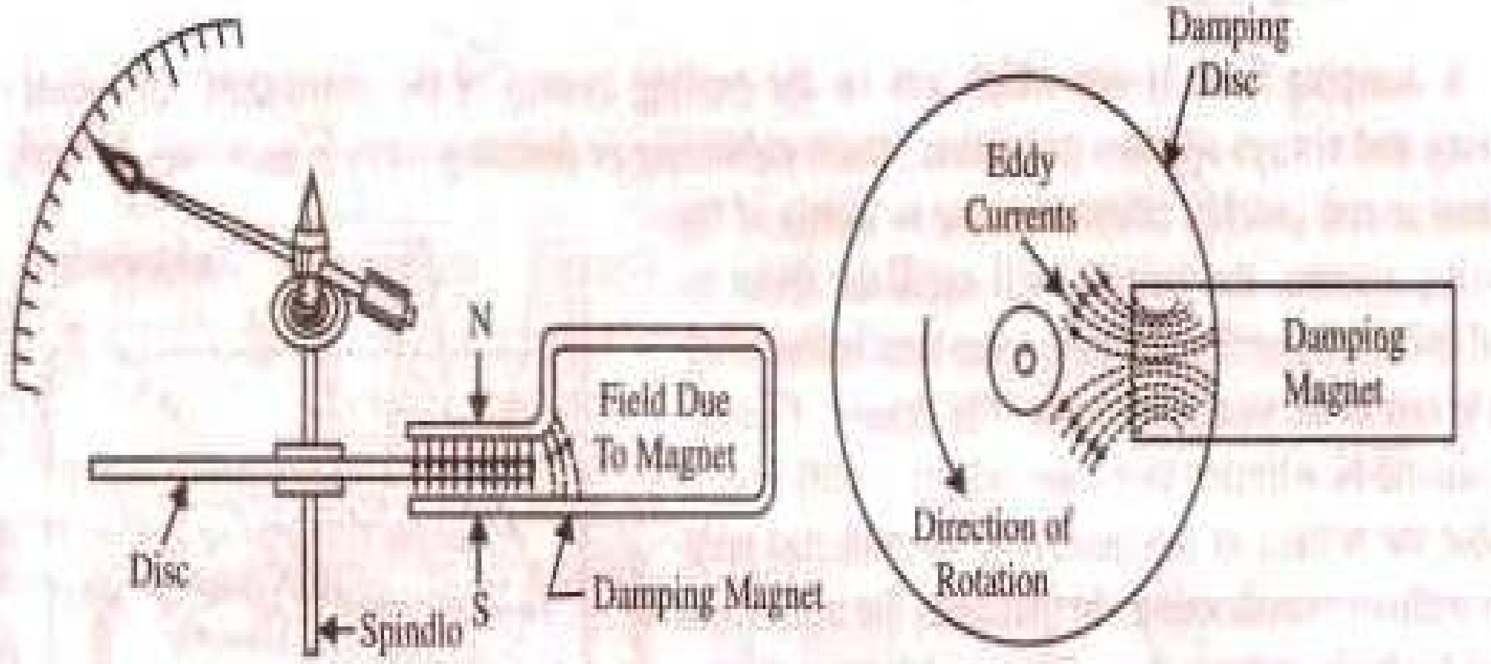

Control
Spring
Vanes


Vane
Sector Shaped
Box

- Light aluminium piston attached to the moving system of the instrument is arranged to travel with a very small clearance in fixed air chamber closed at one end.
- Damping of the oscillations is affected by the compression and suction action of the piston on the air enclosed in the chamber.
- Air friction damping with light aluminium vanes moving in a closed sector shaped boxes are more common type of providing air friction damping.

FLUID FRICTION DAMPING

- similar in action to air friction damping.
- Fluid with high viscosity is filled in the chamber instead of air.
- Main drawback of this type of damping are Creeping of oil, need to keep the meter vertical, unsuitability in portable type meters.



N
Field Due
To Magnet
Disc
S
Damping Magnet
Spindlo
Damping
Disc
Eddy
Currents
Damping
Magnet
Direction of
Rotation

EDDY CURRENT DAMPING

- This is the most efficient of the three.
- A thin disc of conducting but non-magnetic material like copper and aluminium mounted on the moving system spindle.
- The disc is placed in such a way when ever it rotates it cut the magnetic flux.
- Due to this eddy emf is induced in the disc which tries to oppose the movement of the disc. So the eddy current tries to retard the disc

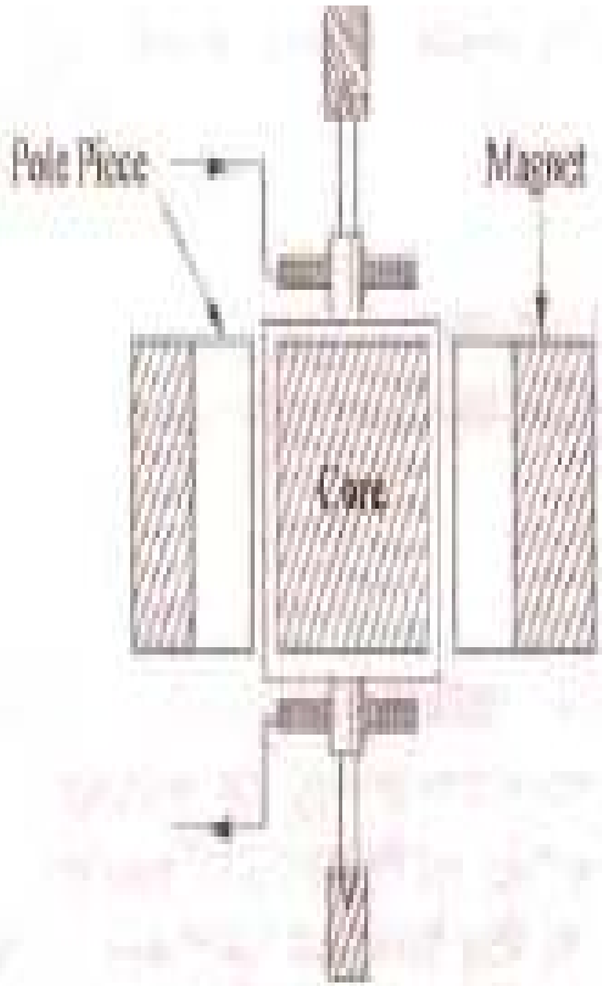
Ammeters and voltmeters

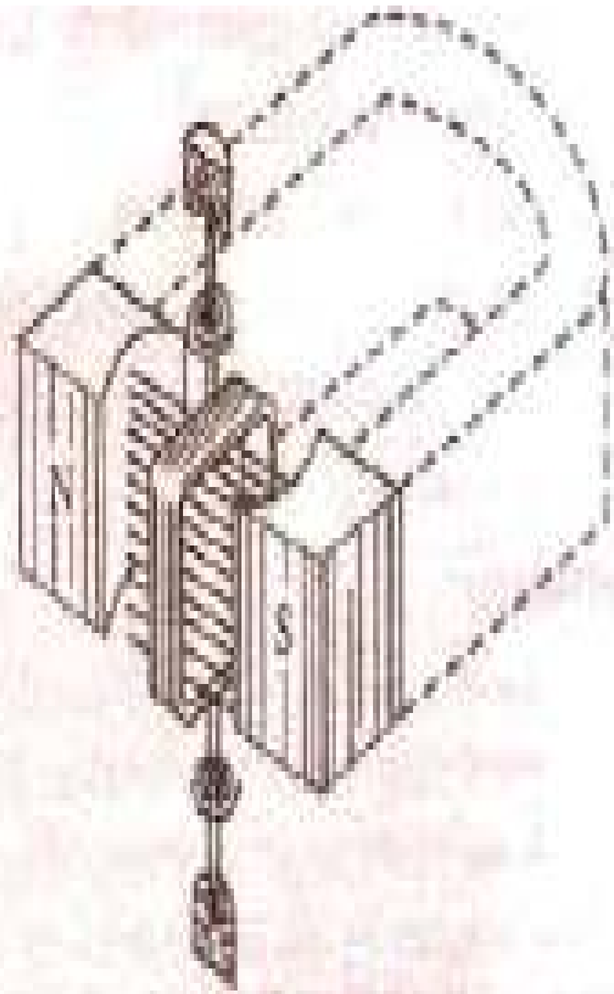
1. Moving-iron type (both for D.C/A.C.)
   - (a) *the attraction type*
   - (b) *the repulsion type*
2. Moving-coil type
   - (a) *permanent-magnet type* (for D.C. only)
   - (b) *electrodynamic or dynamometer type* (for D.C/A.C.)
3. Hot-wire type (both for D.C/A.C.)
4. Induction type (for A.C. only)
   - (a) *Split-phase type*
   - (b) *Shaded-pole type*
5. Electrostatic type-for voltmeters only (for D.C/A.C.)

MOVING-COIL INSTRUMENTS:

- These are of two types
  1. Permanent magnet type
  2. Dynamometer type

- PERMANENT MAGNET TYPE:-
  - Principle of Operation
  - When a current carrying conductor is placed in a magnetic field, It is acted upon by a force which tends to move it one side

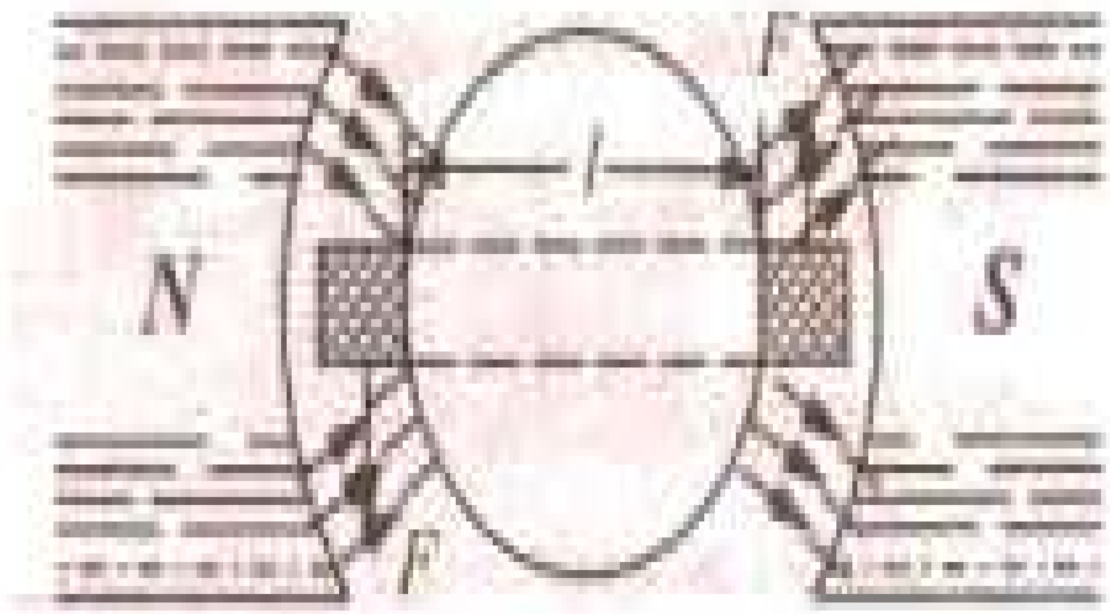

Pole Piece
Magnet
Core


N
S

- Construction:-

  This instrument consists of a permanent magnet made in U shape with alnico and soft iron end-poles.
- A rectangular coil of many turns wound on a light aluminium or copper former inside which an iron core is placed. And this rectangular coil is placed inside the end-pole of the U-shaped permanent magnet.
- The rectangular coil is placed on aluminium frame which is supported on a delicate bearing
- Pointer is attached to the moving system
- The aluminium frame provides damping torque.

- Deflecting torque:-



- When current is passed through the coil, the force acting on both the coil sides provides the deflecting torque.

- Deflecting Torque T_d=NBIA

where N= number of turns

B= flux density in wb/m^2

I=current passing through the coil in Amps

A=face area of the coil

- If B is constant then deflection torque is proportional to current passing through the coil

- These instruments are invariably spring controlled. So, the controlling torque is proportional to deflection angel.
- At the final deflection point $T_d=T_c$
- So, the deflection of the instrument on a pre calibrated scale gives the current.

Advantages

1. They have low power consumption.
2. their scales are uniform and can be designed to extend over an arc of 170° or so.
3. they possess high (torque/weight) ratio.
4. they can be modified with the help of shunts and resistances to cover a wide range of currents and voltages.
5. they have no hysteresis loss.
6. they have very effective and efficient eddy-current damping.
7. since the operating fields of such instruments are very strong, they are not much affected by stray magnetic fields.

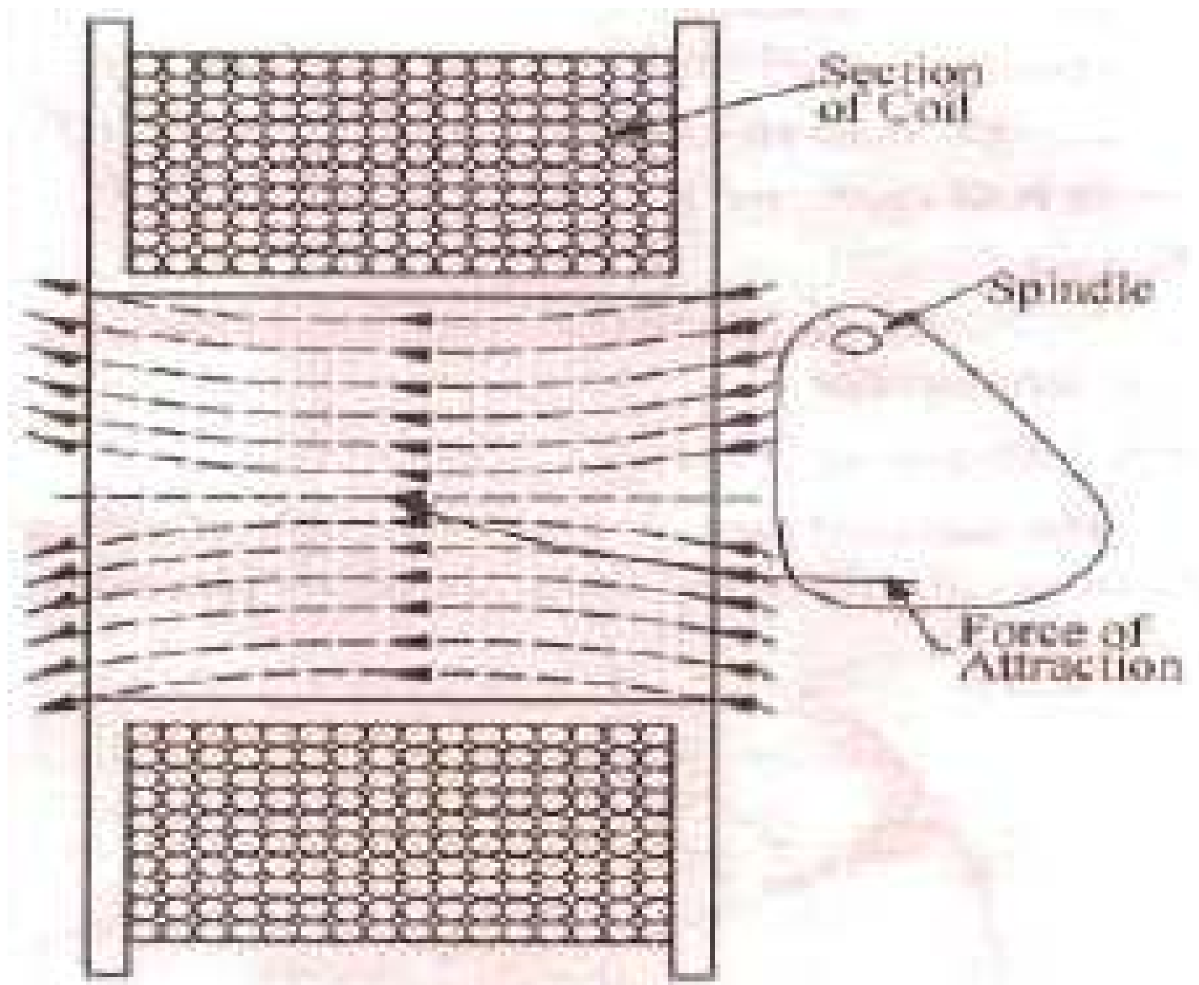
Disadvantages

1. due to delicate construction and the necessary accurate machining and assembly of various parts, such instruments are somewhat costlier as compared to moving-iron instruments.
2. some errors are set in due to the ageing of control springs and the parmanent magnets.

- MOVING IRON INSTRUMENTS:-

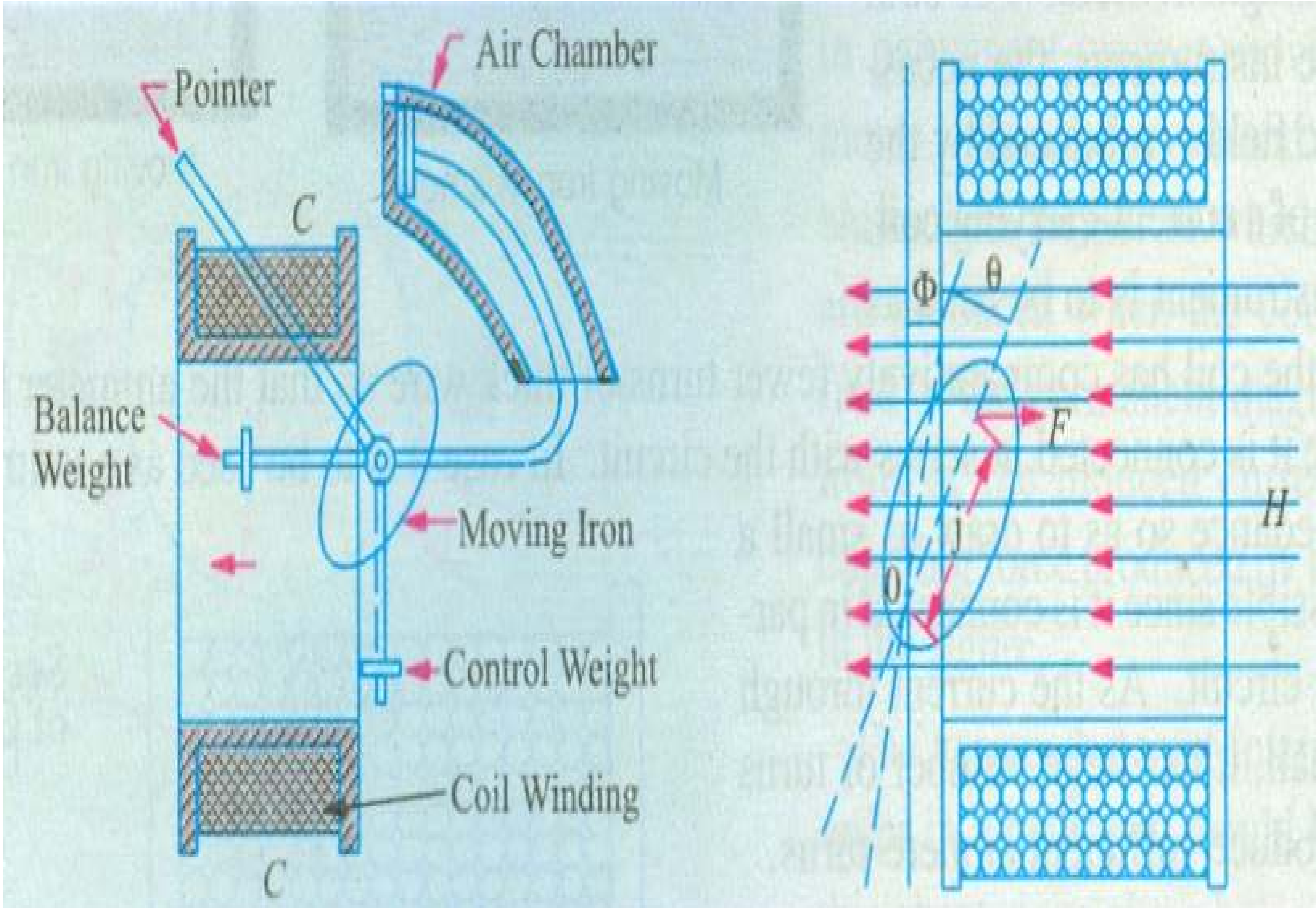
- These are of two types
  - 1. Attraction type
  - 2. Repulsion type

1. Attraction type



- Principle of operation:-
- If a piece of unmagnetised soft iron is brought up near either of the two end of a current carrying conductor, It would be attracted into the coil.
- As the field strength would be strongest at the center of the coil, the oval shaped soft-iron disc moves into the center of the coil.
- The amount of the deflecting torque is greater when the current producing the magnetic field is greater.
- Whatever is the direction of the current in the coil, the iron disc would always be magnetized in such a way that it is pulled inwards.
- Hence these meters can be used for both direct current as well as alternating current.

- DEFLECTING TORQUE



Let the axis of the iron disc, when in zero position, subtend an angle of ϕ with a direction perpendicular to the direction of the field H produced by the coil. Let the deflection produced be θ corresponding to a current I through the coil. The magnetisation of iron disc is proportional to the component of H acting along the axis of the disc *i.e.* proportional to $H \cos [90 - (\phi + \theta)]$ or $H \sin (\theta + \phi)$. The force F pulling the disc inwards is proportional to MH or $H^2 \sin (\theta + \phi)$. If the permeability of iron is assumed constant, then, $H \propto I$. Hence, $F \propto I^2 \sin (\theta + \phi)$. If this force acted at a distance of l from the pivot of the rotating disc, then deflecting torque $T_d = Fl \cos (\theta + \phi)$. Putting the value of F, we get

$$T_d \propto I^2 \sin (\theta + \phi) \times l \cos (\theta + \phi) \propto I^2 \sin 2 (\theta + \phi) = KI^2 \sin 2 (\theta + \phi)$$ ...sin l is constant

If spring-control is used, then controlling torque $T_c = K' \theta$

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

$\therefore \quad KI^2 \sin 2 (\theta + \phi) = K'\theta$; Hence $\theta \propto I^2$

If A.C. is used, then $\theta \propto I^2_{r.m.s.}$

However, if gravity-control is used, then $T_c = K_1 \sin\theta$

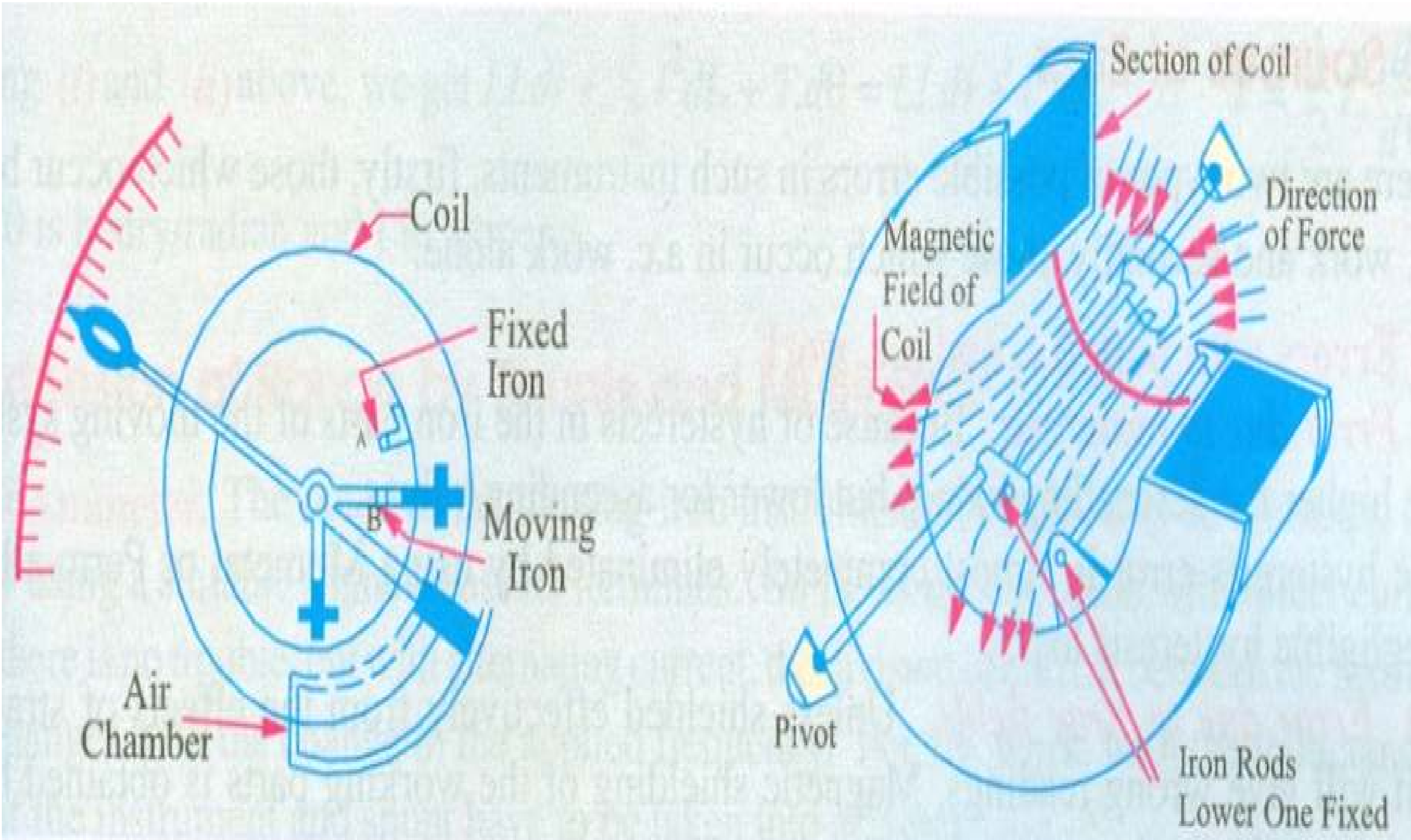
$\therefore \quad KI^2 \sin 2(\theta + \phi) = K_1 \sin\theta \quad \therefore \sin\theta \; \alpha I^2 \sin 2(\theta + \phi)$

In both cases, the scales would be uneven.

Damping

As shown, air-friction damping is provided, the actual arrangement being a light piston moving in an air-chamber.

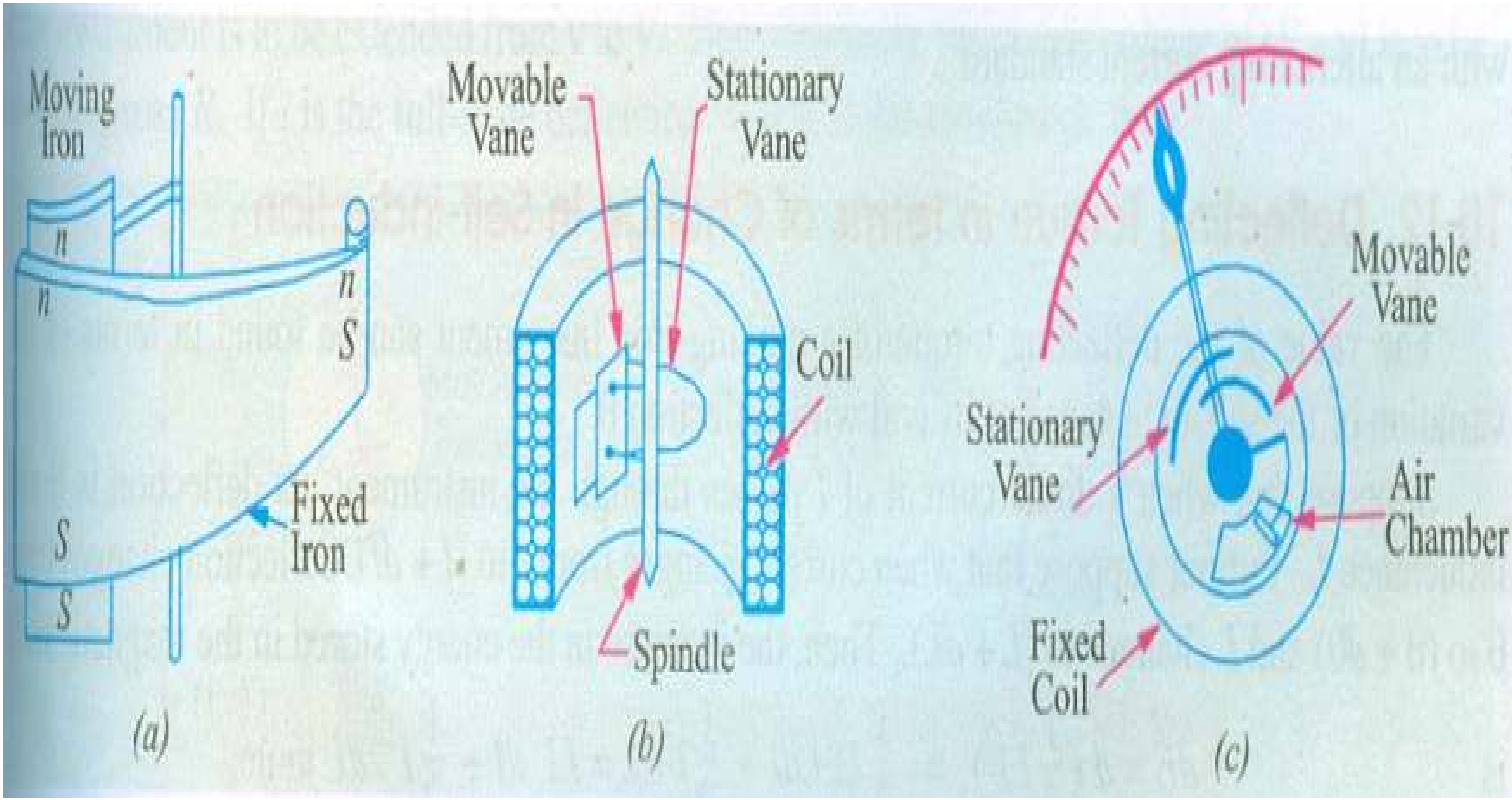
2. Repulsion type



- This instrument consists of a fixed coil inside which are placed two soft iron rods A and B parallel to one another along the axis of the coil.
- One of the coil A is fixed and another coil B is movable carries a pointer that moves on a calibrated scale.
- The current to be measured is passed through the fixed coil. It sets up its own magnetic field which magnetizes the rods similarly i.e.,

the adjacent points on the lengths of the rods will have the same magnetic polarity. Hence, they repel each other with the result that the pointer is deflected against the controlling torque of a spring or gravity. The force of repulsion is approximately proportional to the square of the current passing through the coil. Moreover, whatever may be the direction of the current through the coil, the two rods will be magnetised similaraly and hence will repel each other.

- Deflecting torque:



The deflecting torque is due to the repulsive force between the two similarly magnetised iron rods or sheets.

Instantaneous torque ∝ repulsive force ∝ $m_1 m_2$ ...product of pole strengths

Since pole strength are proportional to the magnetising force H of the coil,

∴ instantaneous torque ∝ H^2

Since H itself is proportional to current (assuming ***constant*** permeability) passing through the coil, ∴ instantaneous torque ∝ I^2

Hence, the deflecting torque, which is proportional to the mean torque is, in effect, proportional to the mean value of I^2. Therefore, when used on a.c. circuits, the instrument reads the r.m.s. value of current.

Scales of such instruments are uneven if rods are used and uniform if suitable-shaped pieces of iron sheet are used.

The instrument is either gravity-controlled or as in modern makes, is spring-controlled.

Damping is pneumatic, eddy current damping cannot be employed because the presence of a permanent magnet required for such a purpose would affect the deflection and hence, the reading of the instrument.

Since the polarity of both iron rods reverses simultaneously, the instrument can be used both for a.c. and d.c. circuits *i.e.* instrument belongs to the unpolarised class.

10.10. Sources of Error

There are two types of possible errors in such instruments, firstly, those which occur both in a.c. and d.c. work and secondly, those which occur in a.c. work alone.

(a) Errors with both d.c. and a.c. work

(i) *Error due to hysteresis.* Because of hysteresis in the iron parts of the moving system, readings are higher for descending values but lower for ascending values.

The hysteresis error is almost completely eliminated by using Mumetal or Perm-alloy, which have negligible hysteresis loss.

(ii) *Error due to stray fields.* Unless shielded effectively from the effects of stray external fields, it will give wrong readings. Magnetic shielding of the working parts is obtained by using a covering case of cast-rion.

(b) Errors with a.c. work only

Changes of frequency produce (i) change in the impedance of the coil and (ii) change in the magnitude of the eddy currents. The increase in impedance of the coil with increase in the frequency of the alternating current is of importance in voltmeters (Ex. 10.2). For frequencies higher than the one used for calibration, the instrument gives lower values. However, this error can be removed by connecting a capacitor of suitable value in parallel with the swamp resistance R of the instrument. It can be shown that the impedance of the whole circuit of the instrument becomes independent of frequency if $C = L/R^2$ where C is the capacitance of the capacitor.

- Advantages and Disadvantages

Such instruments are cheap and robust, give a reliable service and can be used both on a.c. and d.c. circuits, although they cannot be calibrated with a high degree of precision with d.c. on account of the effect of hysteresis in the iron rods or vanes. Hence, they are usually calibrated by comparison with an alternating current standard.