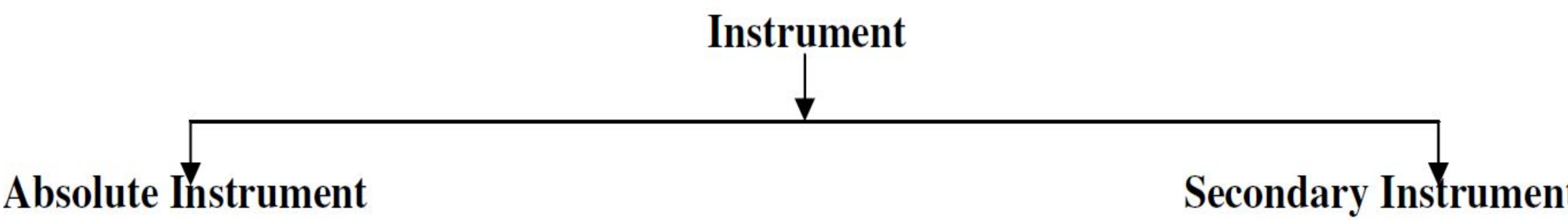
INTRODUCTION TO MEASURING INSTRUMENTS

Module 1

DEFINITION & CLASSIFICATION

- An instrument is a device in which we can determine the magnitude or value of the quantity to be measured. The measuring quantity can be voltage, current, power and energy etc.
- Generally instruments are classified in to two categories.

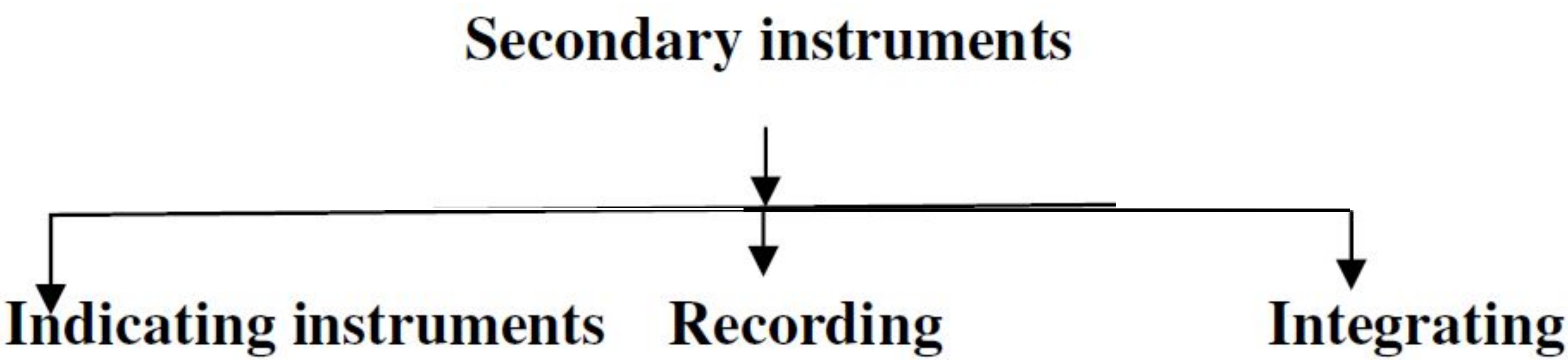


ABSOLUTE INSTRUMENT

- An absolute instrument determines the magnitude of the quantity to be measured in terms of the instrument parameter. Each time the value of the measuring quantities varies, we have to calculate the magnitude of the measuring quantity, analytically which is time consuming.
- These types of instruments are suitable for laboratory use.
- Example: Tangent galvanometer, absolute electrometer, Rayleigh current balance.

SECONDARY INSTRUMENT

- These are the instruments whose output is measured to give the value of the quantity directly. The quantity to be measured is determined by the deflection value of these instruments.
- They are calibrated against an absolute instrument.
- Examples: Ammeter, voltmeter, wattmeter, etc.



SECOMDARY INSTRUMENT..CONTD.

- INDICATING: This instrument uses a dial and pointer to determine the value of measuring quantity. The pointer indication gives the magnitude of measuring quantity.

  examples: ammeter, voltmeter, etc.

- RECORDING: This type of instruments records the magnitude of the quantity to be measured continuously over a specified period of time.

  examples: seismograph, etc.

- INTEGRATING: This type of instrument gives the total amount of the quantity to be measured over a specified period of time.

  examples: energy-meter, etc.

MEASURING INSTRUMENT

- In case of measuring instrument, the effect of unknown quantity is converted into a mechanical force, which is transmitted to the pointer moving over a calibrated scale.

- For satisfactory operation, the following systems must be present in an instrument:
  1. Deflecting system producing deflecting torque.
  2. Controlling system producing controlling torque.
  3. Damping system producing damping torque.

DEFLECTING SYSTEM:

- When there is no input signal to the instrument, the pointer will be at its zero position. To deflect the pointer from its zero position, a force is necessary which is known as deflecting force. A system which produces the deflecting force is known as a deflecting system. Generally a deflecting system converts an electrical signal to a mechanical force.

- The deflecting system uses on of the following effects produced by current or voltage to produce the deflecting torque:

1. Magnetic effect.
2. Thermal effect.
3. Electrostatic effect.
4. Induction effect.
5. Hall effect.

DEFLECTING SYSTEM..CONTD.:

- Magnetic effect: When a current carrying conductor is placed in an uniform magnetic field, it experiences a force which causes it to move.

  eg: MI, PMMC instruments.

- Thermal effect: The current to be measured is passed through a small element, which heats it to cause rise in temperature, which is converted to emf by a thermocouple attached to it.

- Electrostatic effect: When two plates are charged, there is a force exerted between them, that moves one of the plates.

DEFLECTING SYSTEM..CONTD.:

- Induction effect: When a non-magnetic conducting disc is placed in a magnetic field produced by electromagnets which are excited by alternating current, an emf is induced in it. If a closed path is provided, there is a flow of current in the disc. The interaction between the induced current and the alternating magnetic field exerts a force on the disc which causes to move it. Eg: energymeters.

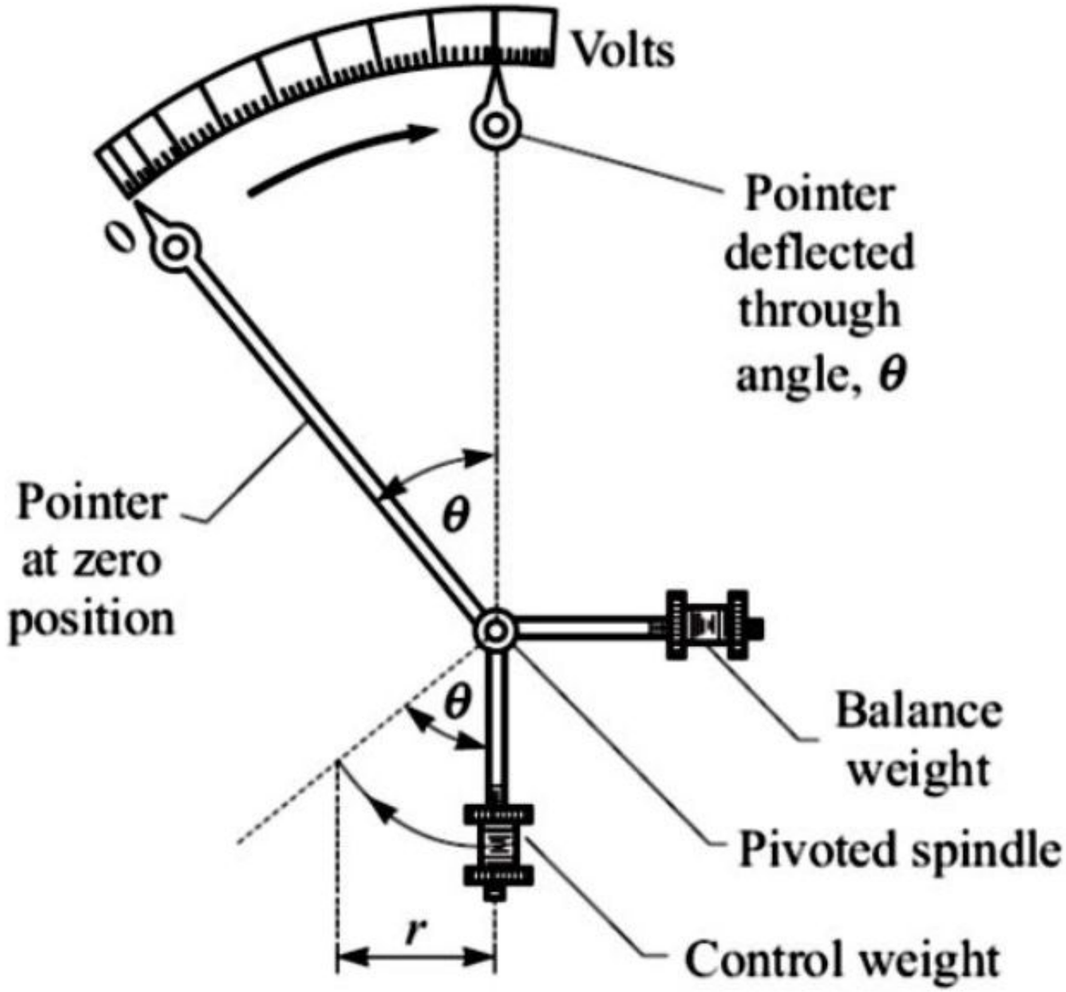
- Hall effect: If a bar of semiconductor material is placed in an uniform magnetic field and if the bar carried current, then an emf is produced between thw two edges of the conductor. The magnitude of tis emf depends on the flux density, current, and hall co-efficient. Eg: fluxmeters.

CONTROLLING SYSTEM:

- This system should provide a force so that the current or other quantity will produce deflection of the pointer proportional to its magnitude. It has the following important functions:
  1. To produce a forcce equal and opposite to the deflecting force in order to make the pointer deflection at a definite magnitude. Otherwise, the pointer will swing beond its final steady state position and deflection will become indefintie.
  2. To bring the moving system back to zero position, when the force causing the pointer movement is removed.

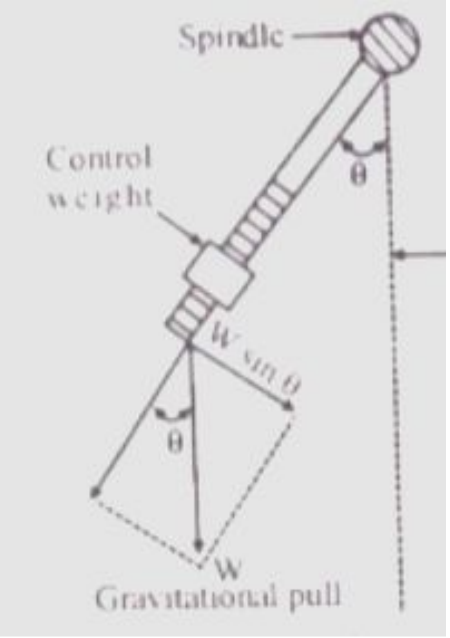
- It can be provided by:
  1. Gravity control.
  2. Spring control.

GRAVITY CONTROL:



GRAVITY CONTROL…CONTD.:

- It consists of a small weight attached to the moving system whose position is adjustable. This weight produces a controlling torque due to gravity. This weight is called control weight.



$$T_c = W\sin\theta \times L = WL\sin\theta$$

Thus, $T_c \propto \sin\theta$

As, $T_d \propto I$

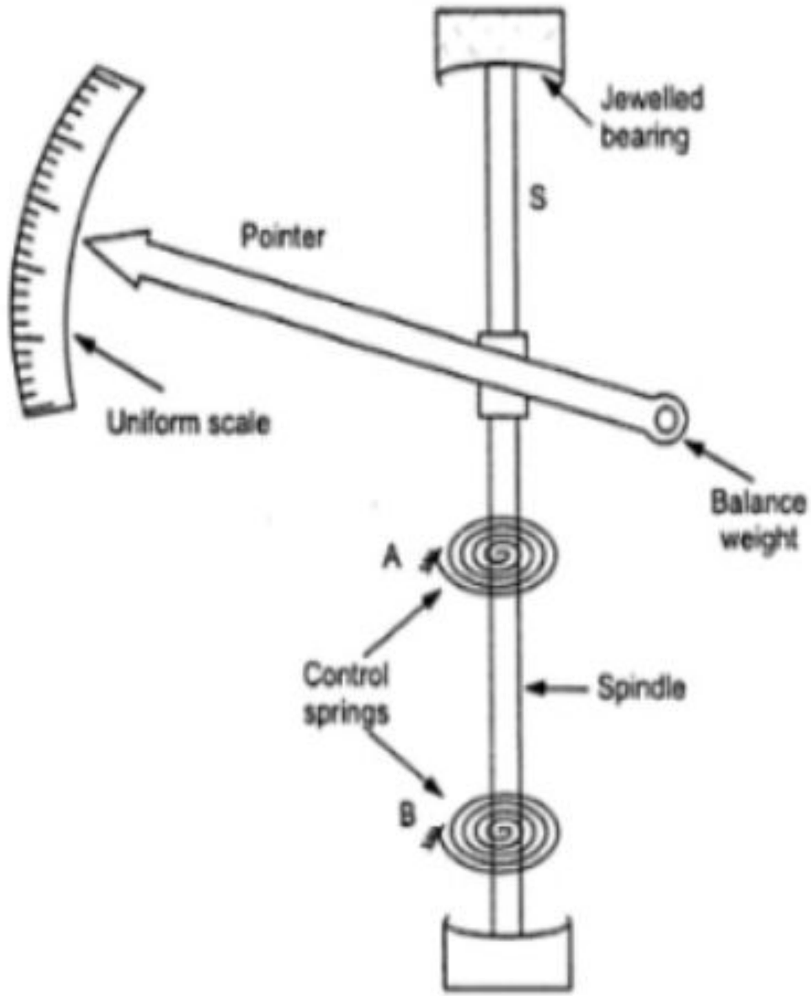
$T_c \propto \sin\theta$

- At steady state position deflection torque=controlling torque

Thus, $I \propto \sin\theta$

- Thus the scale of the gravity control type instrunts is non-uniform.

SPRING CONTROL:



SPRING CONTROL…CONTD.:

- It utilizes two spiral hairsprings of non magnetic alloy such as phosphorous-bronze or beryllium-copper.
- The springs are oppositely wound so when the moving system deflects, one spring winds up while the outer unwind thus the controlling torque is produced by the combined torsion of spring, since the torsional torque is proportional to the angle of twist, the controlling torque is directly proportional to the angular deflection of pointer.

  $T_d \propto I$,

  Also, $T_c \propto \theta$
- At final deflection or steady state position:

  $T_c = T_d$

  Therefore $\theta \propto I$
- Scale of spring control type instruments is uniform.

DAMPING SYSTEM:

- It is that part of the instrument which provides damping force to damp the oscillations of the pointer before come to a rest.
- Because of the inertia, the pointer of the instrument oscillates about its final deflected position for some time before coming to rest. This causes waste of time in taking readings, thus damping force acts as a brake to prevent the oscillations of the moving system and brings the pointer to it's final deflected position quickly.

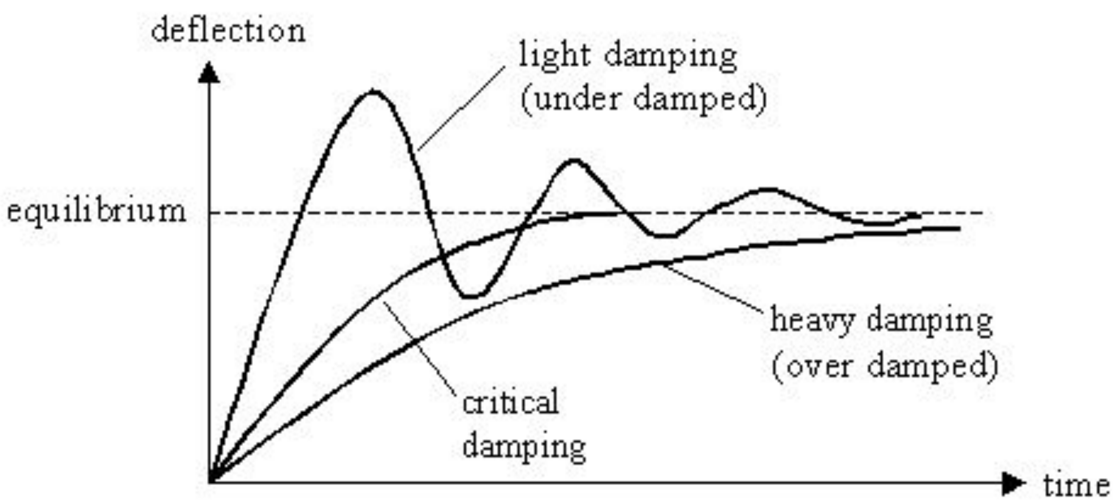
DAMPING SYSTEM…CONTD.:

- There are three types of damping instruments:

  1.Critically-damped- Pointer rises quickly to its final position without oscillation.

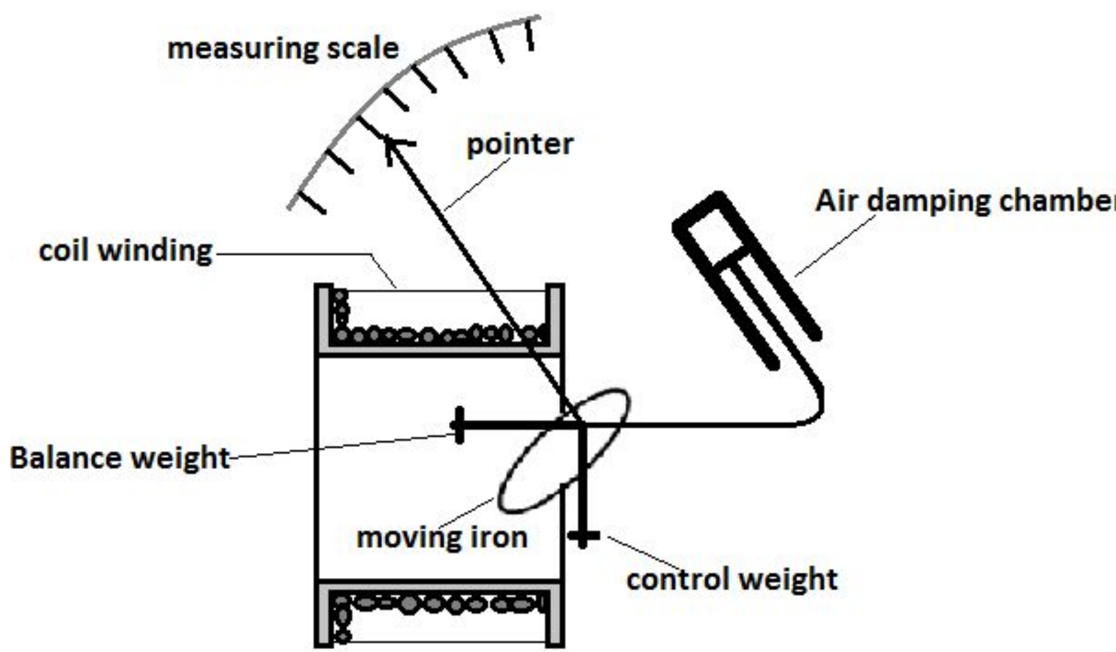
  2.Under-damped- Oscillations of the system will not be completely prevented.

  3.Over-damped: In this the response of the system is slow.



METHODS OF DAMPING SYSTEM:

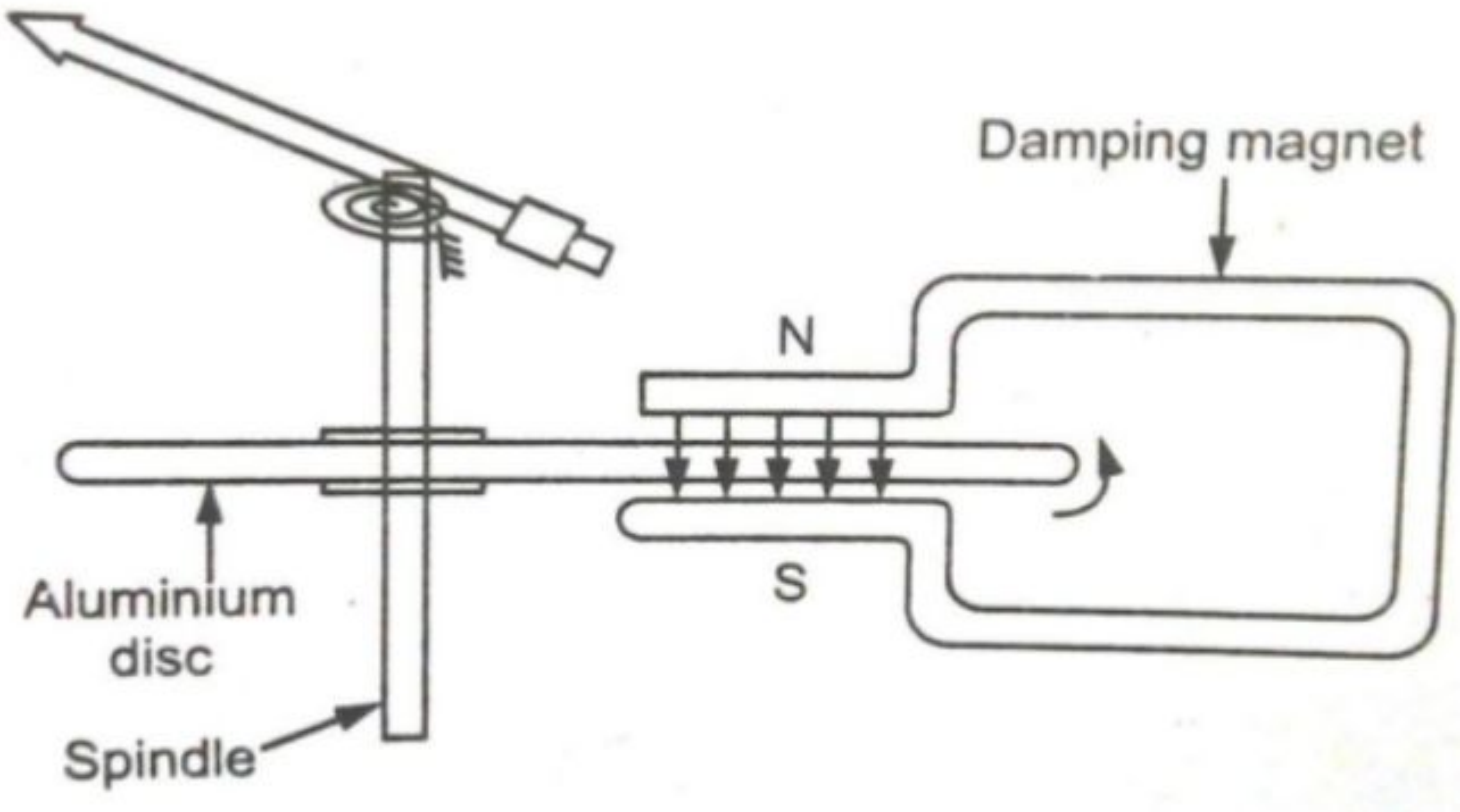
- Methods of damping:
  1. Air friction damping
  2. Eddy current damping
  3. Fluid friction damping
- AIR FRICTION DAMPING:



AIR FRICTION DAMPING:

- In this system a light aluminium piston is attached to the spindle of the instrument and is arranged to move in a fixed air chamber closed at one end. The cross section of the chamber may be either circular or rectangular and the clearance between the piston and the side of the chamber is small and uniform. Compression and suction action of the piston on the air in the chamber damp the possible oscillations of moving system, because the motion of the piston in either direction is oppose by the air.

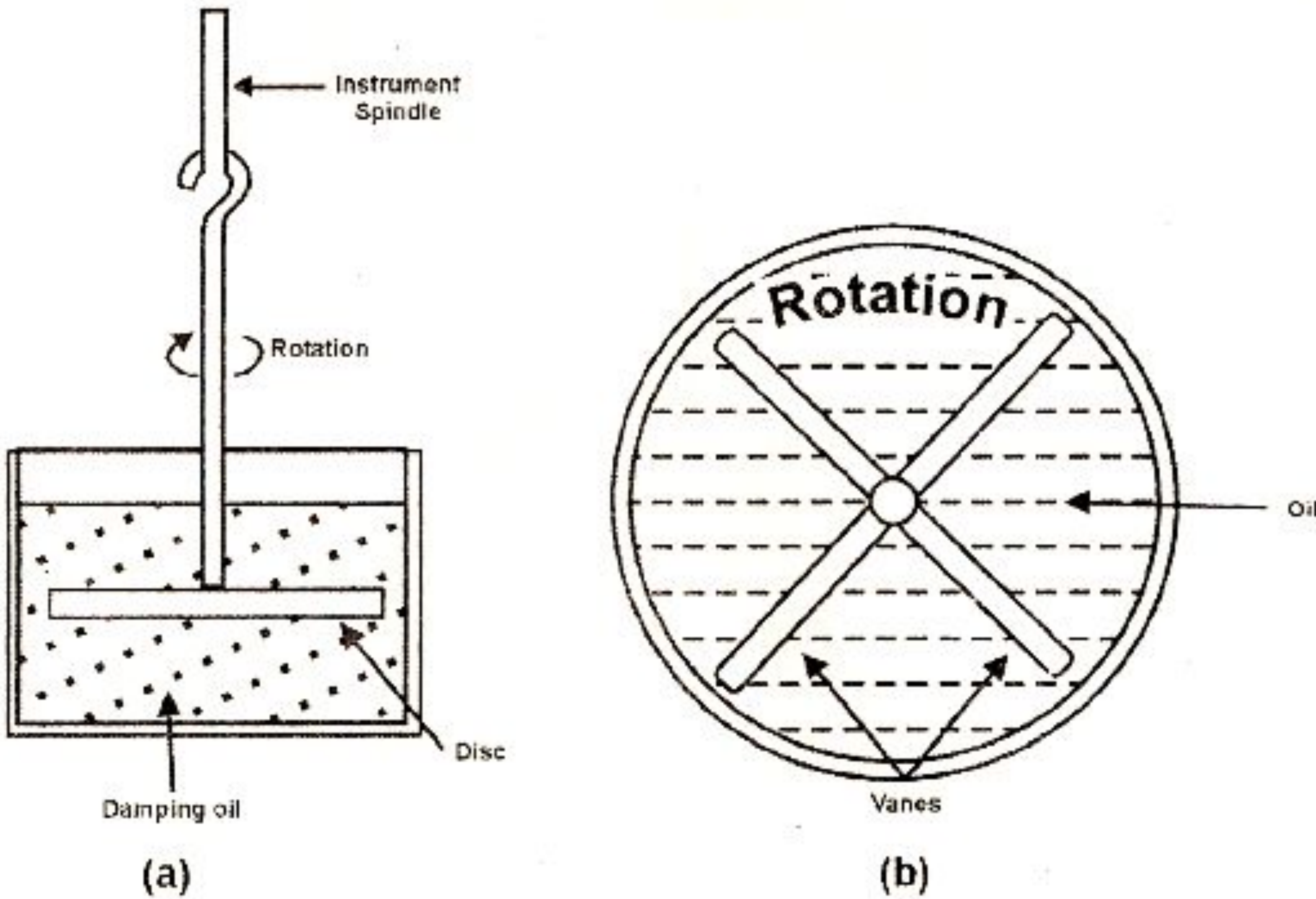
EDDY CURRENT DAMPING:



EDDY CURRENT DAMPING…CONTD.:

- It is the most efficient type of the damping.
- In this, a thin disc usually of copper or aluminium is mounted on the spindle. When this disc moves in the magnetic field of the permanent magnet, lines of force are cut and eddy currents are set up in it.
- The force that exists between the current and magnetic field is always in the direction opposing the motion (Lenz's law) and therefore, provide necessary damping.
- The magnitude of the induced current and therefore of the damping force which is dependent on it, is directly proportional to the velocity of the moving system.

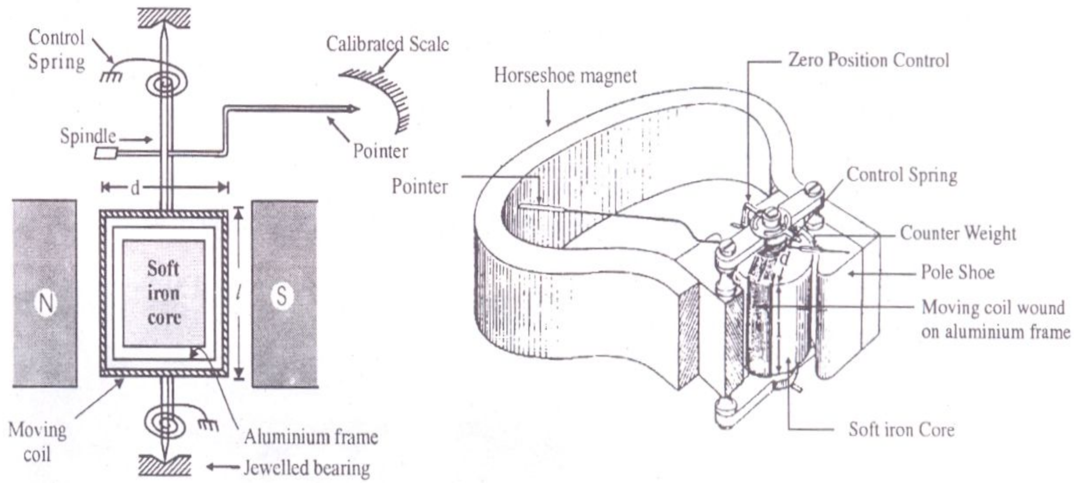
FLUID FRICTION DAMPING:



FLUID FRICTION DAMPING…CONTD.:

- In this method of damping, a light disc is attached to the spindle of the moving system and completely submerged in the damping oil in a pot.
- The motion of the disc is always opposed by a frictional drag on the disc. This frictional drag is zero when the disc is stationary and increases with the speed of the rotation of the disc.
- Disadvantage: Fluid friction damping can only be used in the instruments which are used in the vertical position.

Permanent Magnet Moving Coil Instruments



Construction

- It consists of permanent magnet which is stationary.
- Moving system consists of a spindle attached to a rectangular aluminum frame. A coil made up of thin copper wire is wound over the frame. The current to be measured is passed through this coil.
- A soft iron core is placed in the in the space within the alluminium frame.
- Two spiral springs are mounted on the spindle to produce control torque. Control spring also serves an additional purpose & acts as control lead.
- Pointer is mounted on spindle. Mirror is provided below the scale to avoid parallax error. The spindle is supported by jeweled bearings.

Permanent Magnet Moving Coil Instruments

Construction

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2. Moving system consists of a spindle attached to a rectangular aluminum frame. A coil made up of thin copper wire is wound over the frame. The current to be measured is passed through this coil.
3. A soft iron core is placed in the in the space within the alluminium frame. This core is stationary and is provided to reduce the reluctance of the magnetic path between two poles of the permanent magnet.
4. Two spiral springs are mounted on the spindle to produce control torque. The control spring also serves an additional purpose and acts as control lead. Pointer is mounted on spindle. Mirror is provided below the scale to avoid parallax error. The spindle is supported by jeweled bearings.

Working

1. The current to be measured is passed through moving coil via control springs.
2. A current carrying moving coil is now in a magnetic field. According to Flemings left hand rule, torque is produced on the coil and coil moves, pointer deflects.
3. Damping torque is provided by eddy current damping method.

- Torque equation- Deflection is proportional to current

Link for working of PMMC type Instrument

- https://youtu.be/ZtBKC6WSjD0
- https://youtu.be/CqW5rmmqv_Y

Torque Equation for PMMC type

The equation for the delevoped torque of the PMMC can be obtained from the basic law of electromagnetic torque. The deflecting torque is given by, Td = NBAI

Where,

- Td = deflecting torque in N-m
- B = flux density in air gap, Wb/m^2
- N = Number of turns of the coils
- A = effective area of coil m^2
- I = current in the moving coil, amperes

Therefore, Td = GI

- Where, G = NBA = constant

Contd..

The controlling torque is provided by the springs and is proportional to the angular deflection of the pointer.

$$T_c = K\phi$$

Where, T_c = Controlling Torque

- K = Spring Constant Nm/rad or Nm/deg
- ϕ = angular deflection

For the final steady state position,

$$T_d = T_c$$

Therefore $GI = K\phi$

So, $\phi = (G/K)I$ or $I = (K/G)\,\phi$

Thus the deflection is directly proportional to the current passing through the coil. The pointer deflection can therefore be used to measure current.

Permanent Magnet Moving Coil Instruments

Errors in PMMC Instruments

- Weakening of permanent magnet due to ageing and temperature effects
- Weakening of springs due to ageing and temperature effects
- Change of resistance of moving coil with temperature.

Merits

- Uniform scale for the instrument
- Power consumption is very low
- A single instrument can be used for different current and voltage ranges
- The toque-weight ratio is high gives higher accuracy.

Demerits

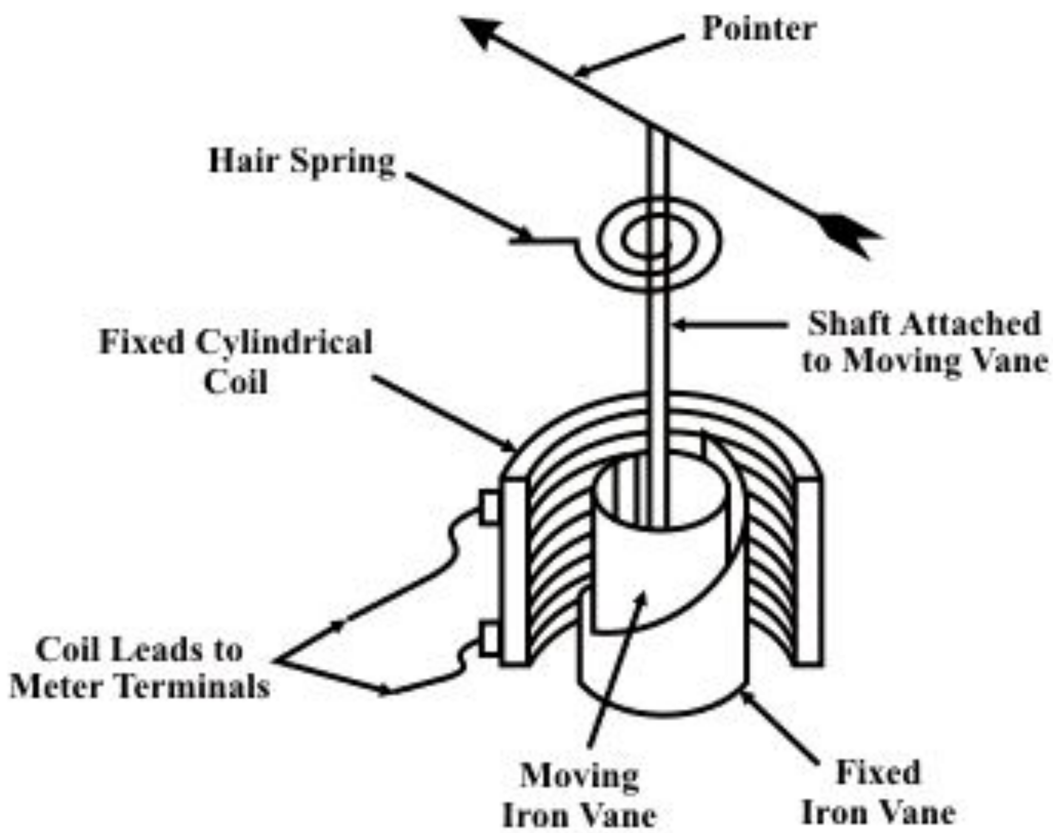
- This instrument can be used only on DC supply
- The cost of the instrument is more than M.I. Instruments

MOVING IRON INSTRUMENT:

- Moving-iron instruments are generally used to measure alternating voltages and currents. In moving-iron instruments the movable system consists of one or more pieces of specially-shaped soft iron, which are so pivoted as to be acted upon by the magnetic field produced by the current in coil.
- There are two general types of moving-iron instruments namely:

1. **Repulsion (or double iron) type**
2. **Attraction (or single-iron) type**

REPULSION TYPE:

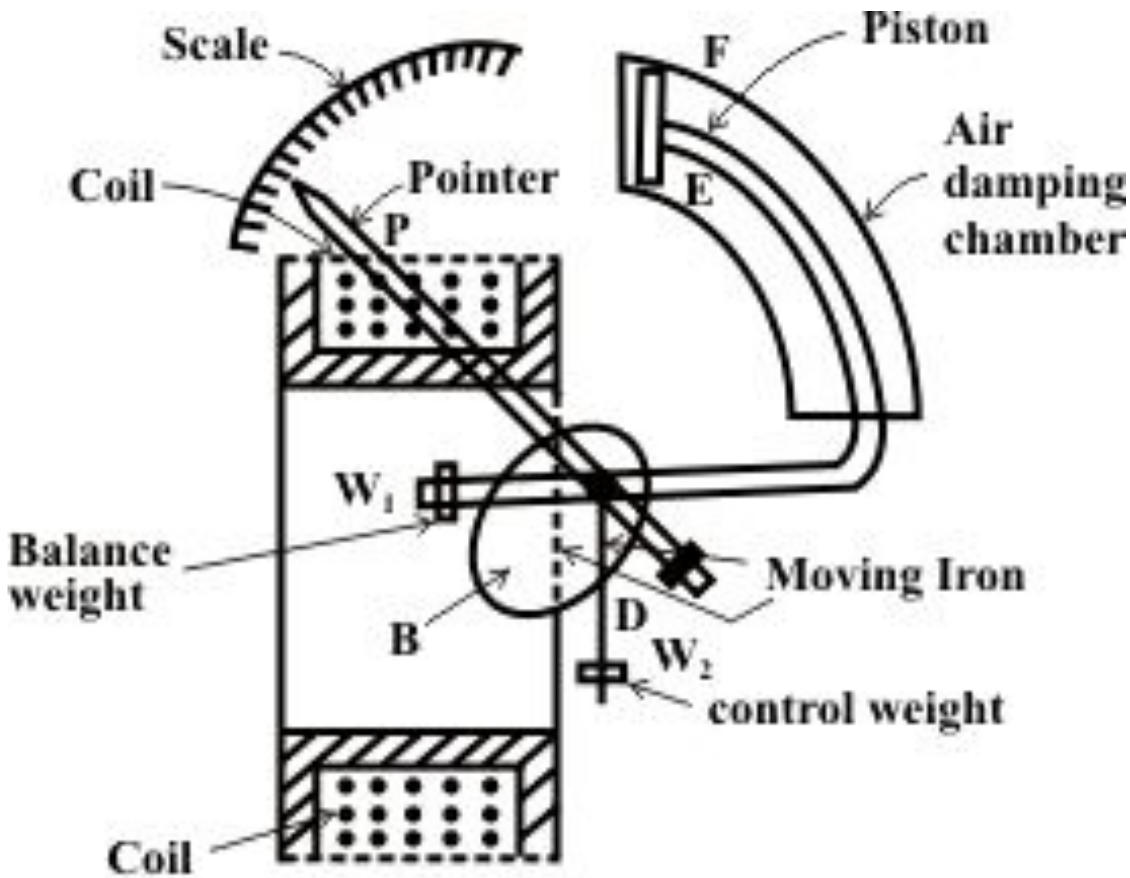


Repulsion type.

REPULSION TYPE…CONTD:

- **Construction:** The repulsion type instrument has a hollow fixed iron attached to it. The moving iron is connected to the spindle. The pointer is also attached to the spindle in supported with jeweled bearing.
- **Principle of operation:** When the current flows through the coil, a magnetic field is produced by it. So both fixed iron and moving iron are magnetized with the same polarity, since they are kept in the same magnetic field. Similar poles of fixed and moving iron get repelled. Thus the deflecting torque is produced due to magnetic repulsion. Since moving iron is attached to spindle, the spindle will move. So that pointer moves over the calibrated scale.
- Damping: Air friction damping is used to reduce the oscillation.
- Control: Spring control is used.

ATTRACTION TYPE:



Attraction type

ATTRACTION TYPE…CONTD.:

- **Construction:** The moving iron fixed to the spindle is kept near the hollow fixed coil. The pointer and balance weight are attached to the spindle, which is supported with jeweled bearing. Here air friction damping is used.
- **Principle of operation:** The current to be measured is passed through the fixed coil. As the current is flow through the fixed coil, a magnetic field is produced. By magnetic induction the moving iron gets magnetized. The north pole of moving coil is attracted by the south pole of fixed coil. Thus the deflecting force is produced due to force of attraction. Since the moving iron is attached with the spindle, the spindle rotates and the pointer moves over the calibrated scale. But the force of attraction depends on the current flowing through the coil.

Link for working of MI type Instrument

- **Attraction Type:**

https://youtu.be/L9wHaLyv94Q

- **Repulsion Type:**

https://youtu.be/bYGgMvXMJMo

Torque equation for MI type instrument

Deflecting torque in Moving iron Instruments is given as

- $Td = (1/2)I^2(dL/d\Theta)$

From the above torque equation, we observe that the deflecting torque is dependent on the rate of change of inductance with the angular position of iron van and square of rms current flowing through the coil.

In moving iron instruments, the controlling torque is provided by spring. Controlling torque due to spring is given as

- $Tc = K\Theta$; Where K = Spring constant, Θ = Deflection in the needle

In equilibrium state, deflecting and controlling torque shall be equal as below.

Deflecting Torque = Controlling Torque

$\Rightarrow Td = Tc$

$\Rightarrow (1/2)I^2(dL/d\Theta) = K\Theta$

$\Rightarrow \Theta = (1/2)(I^2/K)(dL/d\Theta)$

- From the above torque equation, we observe that the angular deflection of needle of moving iron instruments is square of rms current flowing through the coil. Therefore, the deflection of moving iron instruments is independent of direction of current.

Electrodynamometer type Instrument

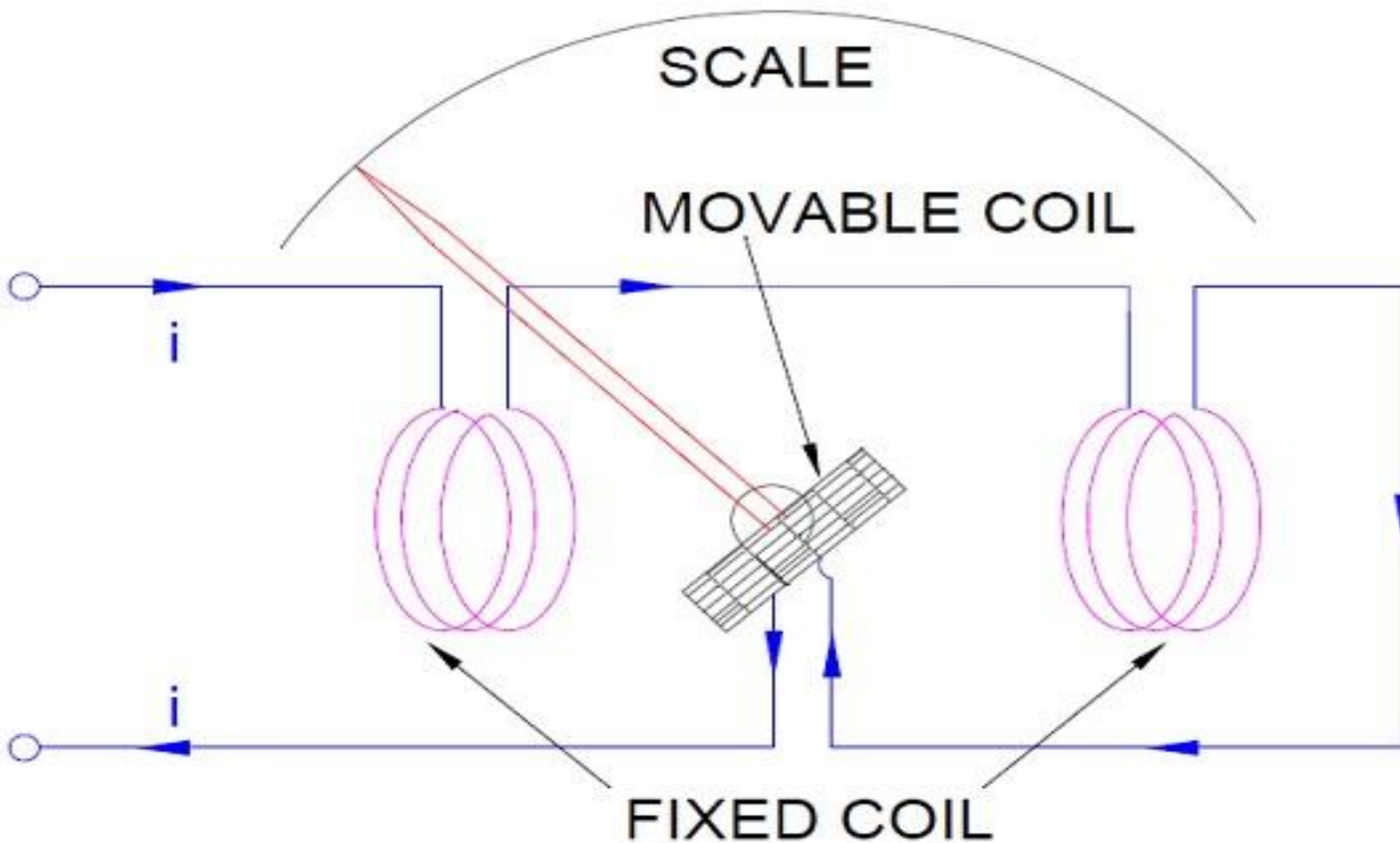
- Electrodynamometer Instruments are widely used as an ammeter, voltmeter and wattmeter. This instrument can measure AC as well as DC quantities.
- **Construction of Electrodynamic Type Instrument:**

An electrodynamic type instrument consists of Two Fixed Coil, a Moving Coil, Control Spring, Damping Device and Magnetic Shielding arrangement.

- Fixed Coil:

  Fixed coil is provided for the sake of production of magnetic field. This fixed coil is divided into two sections so that a uniform magnetic field may be achieved at the centre. Further, splitting up fixed coil in two section facilitates passage of instrument's moving shaft.

Diagram of EDM type instrument



- Moving Coil:

Moving coil is serves the purpose of converting the actuating quantity into readable value on the scale. It is generally wound on a non magnetic metallic former. Metallic former shall never be used as it will lead eddy current generation due to changing flux. This eddy current will introduce inaccuracy as eddy current damping is not used in Electrodynamic Instrument.

- Damping

Air friction damping is employed in electrodynamic type instrument. To provide air friction damping, a pair of aluminium vane is attached to the spindle at the bottom. These vanes move in a sector shaped chamber.

Working Principle of Electrodynamic Type Instrument

- Since the direction of current is changing in each half cycle, there will be a corresponding change in the direction of magnetic flux. Because of this change of magnetic flux, the torque on moving coil will also change in each half cycle of AC quantity to be measured. Suppose the torque on moving coil for positive half cycle of AC quantity is clockwise then it will change to anticlock wise direction in the negative half cycle. Thus ideally the needle of PMMC instrument shall swing back and forth around zero position. Due to the inertia of instrument, the needle cannot follow the rapid change in direction of torque at power frequency and therefore merely vibrates around zero position.

Contd…

- if we were able to reverse the direction of magnetic flux each time the direction of AC quantity changes through the moving coil then we can have a unidirectional torque. Thus we can measure the AC quantity. Actually this method of reversing the magnetic flux is used in Electrodynamic or Electrodynamometer type instrument.
- As Fixed Coil as well as Moving coil is in series, so the direction of current in the moving coil is same as that in the fixed coil. This means that as the direction of magnetic field changes, the direction of current in moving coil also changes. Thus the torque on the moving coil will not change rather it will be unidirectional.

Link for working of EDM type Instrument

- https://www.youtube.com/watch?v=jt_0upfSH0M

Torque equation for EDM type instrument

- Case-1: When DC quantity is being measured.

Let I_1 and I_2 be the current in fixed and moving coil respectively. Therefore deflecting torque $Td = I_1 I_2 dM/d\Theta$

But this deflecting torque is controlled by the spring. Spring provides the controlling torque. The controlling torque due to spring for a deflection of Θ

$Tc = K\Theta$ where K is spring constant.

At equilibrium the controlling torque and deflecting torques are equal, hence

- $Tc = Td$
- $\Rightarrow K\Theta = I_1 I_2 dM/d\Theta$
- $\Rightarrow \Theta = (I_1 I_2 dM/d\Theta)/K$

Torque equation for EDM type instrument

- Case-II: When AC quantity is being measured.
- Let i_1 and i_2 are sinusoidal current having a phase displacement of Ø. Therefore we can write as
- $i_1 = I_{m1} Sinwt$
- $i_2 = I_{m2} Sin(wt-Ø)$

Thus the instantaneous deflecting torque is given as

- $Td = (I_{m1} Sinwt)[\, I_{m2} Sin(wt-Ø)] dM/dϴ$

The average torque for one time period of the currents are given by

- $Td = (I_1 I_2 CosØ) dM/dϴ$

Where I_1 = RMS Value of i_1 , I_2 = RMS value of i_2