MEASURING INSTRUMENTS

TIJU BABY

Topics:

- **General Principle of measurements:** Absolute and working standards- in Measurements, Classification of instruments: Essentials of indicating instruments - moving coil , Moving iron, Shunts and multipliers

MEASURING INSTRUMENTS

"The device used for comparing the unknown quantity with the unit of measurement or standard quantity is called a Measuring Instrument."

OR

"An instrument may be defined as a machine or system which is designed to maintain functional relationship between prescribed properties of physical variables & could include means of communication to human observer."

STANDARDS OF MEASUREMENT

- International standards
- Primary standards or absolute standards
- Secondary standards
- Working standards

STANDARDS OF MEASUREMENT

International Standards

International standards are defined as the international agreement. These standards, as mentioned above are maintained at the International Bureau of Weights and Measures and are periodically evaluated and checked by absolute measurements interms of fundamental units of Physics. These international standards are not available to the ordinary users for the calibration purpose. For the improvements in the accuracy of absolute measurements, the international units are replaced by the absolute units in 1948. Absolute units are more accurate than the international units.

STANDARDS OF MEASUREMENT

Primary Standards

These are highly accurate absolute standards, which can be used as ultimate reference standards. These primary standards are maintained at National Standard Laboratories in different countries. These standards representing fundamental units as well as some electrical and mechanical derived units are calibrated independently by absolute measurements at each of the national laboratories. These are not available for use, outside the national laboratories.

The main function of the primary standards is the calibration and verification of secondary standards.

STANDARDS OF MEASUREMENT

Secondary Standards

As mentioned above, the primary standards are not available for use outside the national laboratories. The various industries need some reference standards. So, to protect highly accurate primary standards the secondary standards are maintained, which are designed and constructed from the absolute standards. These are used by the measurement and calibration laboratories in industries and are maintained by the particular industry to which they belong. Each industry has its own standards.

For example, the national bureau of standards has set up National Secondary Standards in the United States of America. The particular industry maintaining the secondary standards is responsible for the calibration of these standards. These standards are periodically sent to the national standard laboratories for calibration. The national laboratories sent them back to the industries with the certification, comparing them with the primary standards. The certification indicates the measuring accuracy of secondary standards interms of a primary standard.

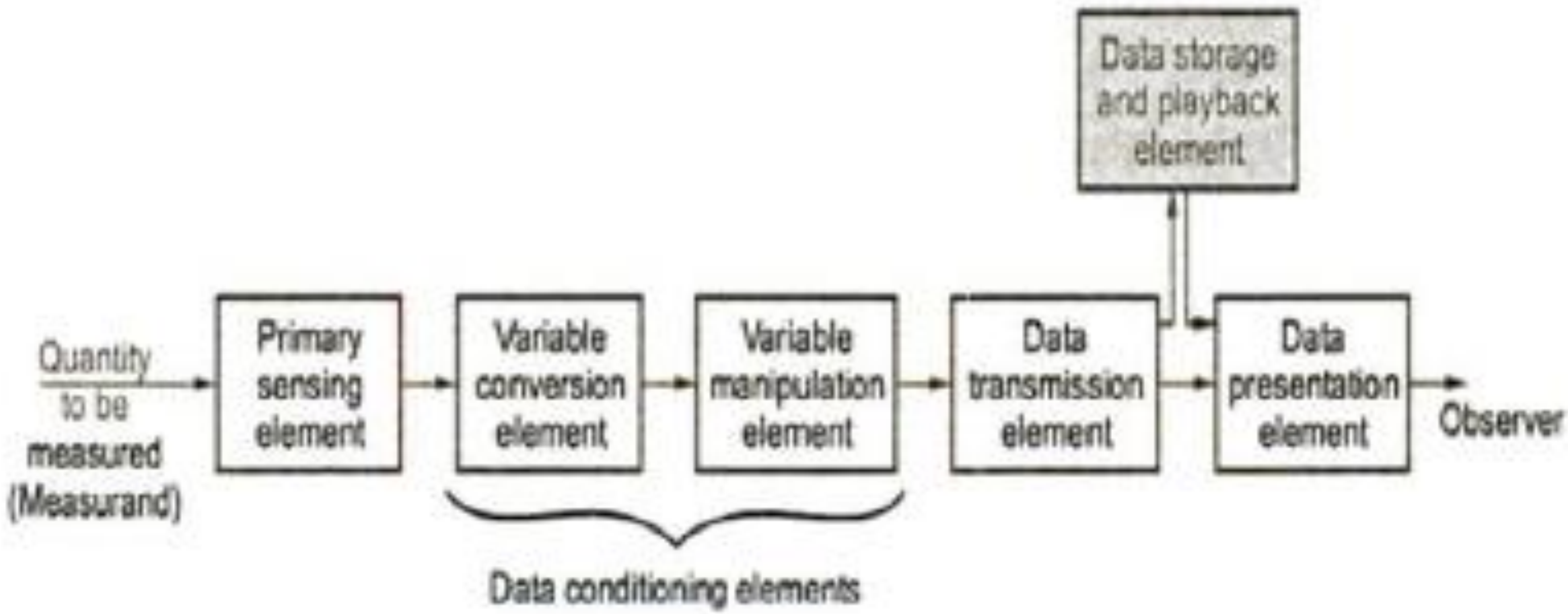
STANDARDS OF MEASUREMENT

Working Standards

These are the basic tools of a measurement laboratory and are used to check and calibrate the instruments used in laboratory for accuracy and the performance. For example, the resistor manufacturing industry maintains a standard resistor in the laboratory for checking the values of the manufactured resistors. The manufacturer verifies that the values of the manufactured resistors are well within the specified accuracy limits. Thus, the working standards are some what less accurate than the primary standards.

Thus, the working standards are used to check and calibrate general laboratory instruments for accuracy and performance.

ELEMENTS OF GENERALIZED MEASUREMENT SYSTEM



ELEMENTS OF GENERALIZED MEASUREMENT SYSTEM

- **Primary Sensing Element:** The quantity under measurement makes its first contact with the primary sensing element of a measurement system.

- **Variable Conversion Element:** It converts the output of the primary sensing element into suitable form to preserve the information content of the original signal.

- **Variable Manipulation Element:** The level of the output will not be sufficient to drive the next stage. Variable manipulation element manipulates the signal preserving the nature of original signal

  eg: Amplifier

ELEMENTS OF GENERALIZED MEASUREMENT SYSTEM

- **Data Transmission Element:** When the elements of the system are physically separated, it is necessary to transmit data from one stage to another, So data transmission element is used.
- **Data Presentation Element:** The information about the quantity under measurement has to be conveyed to the personnel handling the instrument or the system for monitoring, control or analysis purpose
- **Data Storage Element:** If the data needs to be stored, then data storage and play back element is used

AMMETER

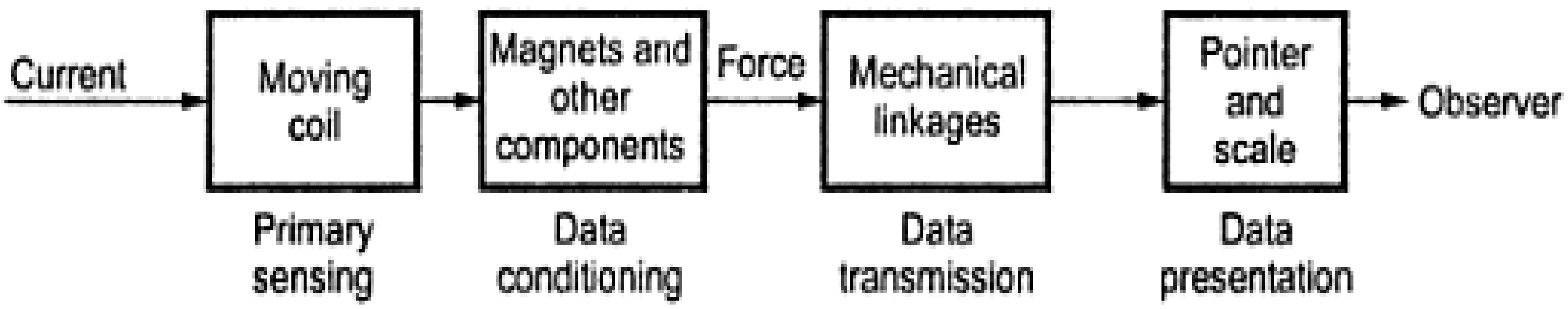
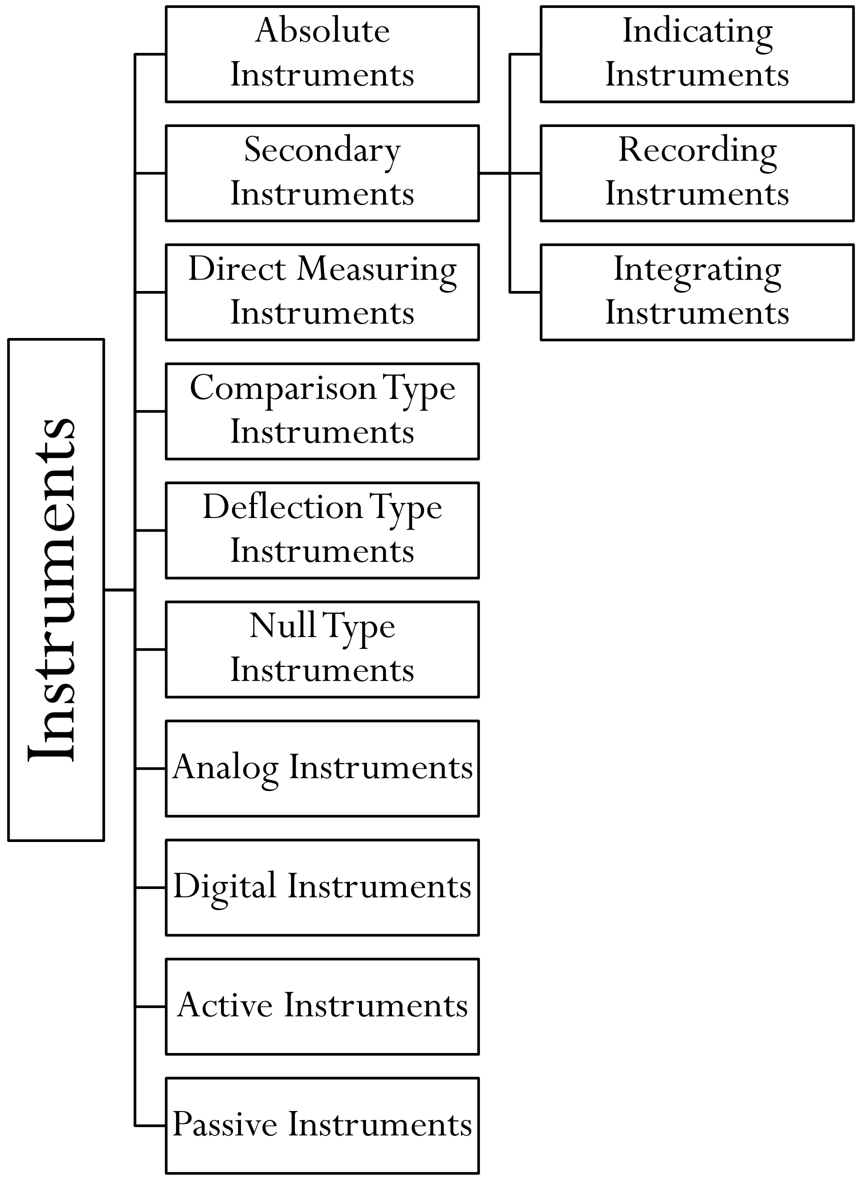


Fig. 1.2 Block schematic of an ammeter

CLASSIFICATION OF INSTRUMENTS



ABSOLUTE INSTRUMENTS

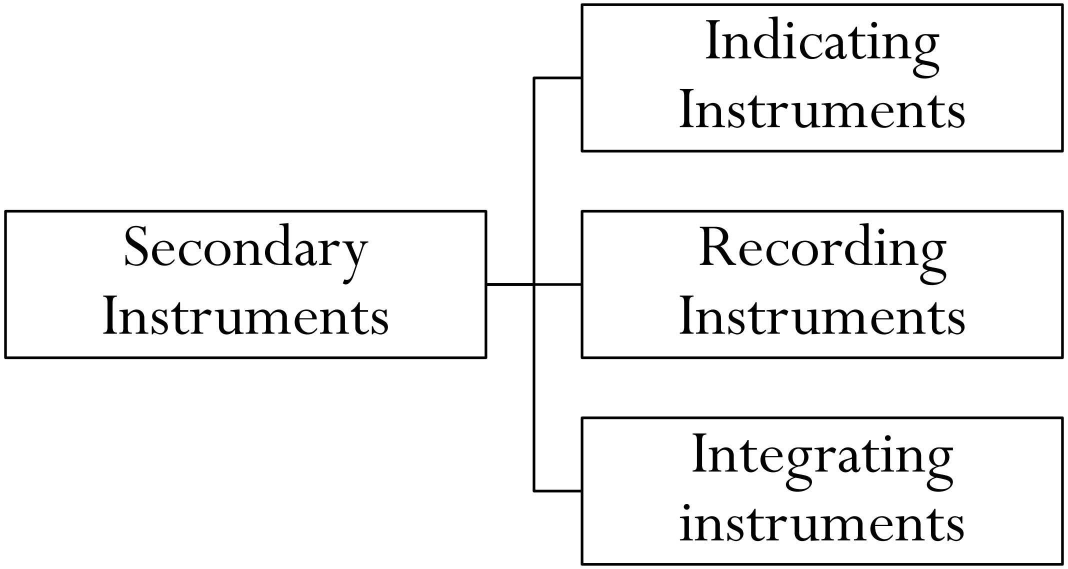
- It gives quantity to be measured in terms of instrument constant and its deflection
- Does not require any comparison with standard instruments
- Eg: 1) Tangent galvanometer – current is measured in terms tangent of angle deflection, horizontal component of earth's magnetic field, radius and turns of wire used

  2) Rayleigh's current balance

  3) Absolute electrometer
- Used in labs and standardization
- Disadvantage : work is time consuming

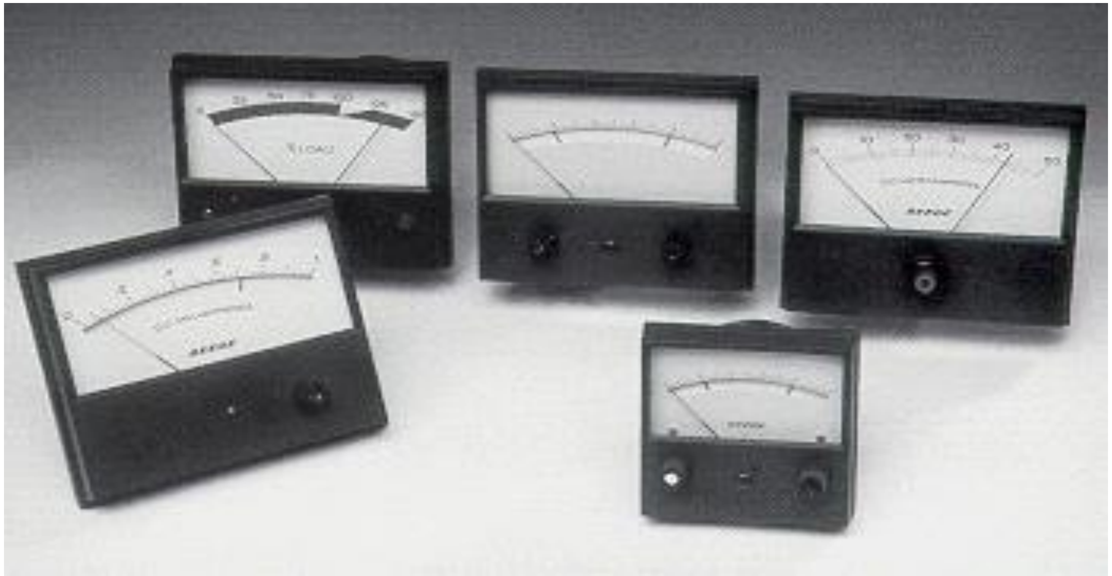
SECONDARY INSTRUMENTS

- Measurand (quantity to be measured) can be measured by observing the output of the instrument
- Calibrated in comparison with absolute instruments or instrument that is already calibrated
- Eg: Ammeter, Voltmer, Wattmeter, thermometer, pressure gauge etc..



INDICATING INSTRUMENTS

- Instruments which indicate the magnitude of electrical quantity at the time when it is measured
- Indications are given on a pointer or graduated dial
- Eg: Ammetrs, Voltmeters, Frequency meters, power factor meters, wattmeters etc..



RECORDING INSTRUMENTS

- Instruments which keep a record of variations of electrical quantity measured over a definite period of time
- It consists of X-Y plotter, X axis – time, Y- axis magnitude of measurand
- The curve plotted shows the variation of magnitude of measurand over a definite period of time
- Application: In power stations where current, voltage etc,, to be maintained in specified values

INTEGRATING INSTRUMENTS

- Instruments that measure total quantity of the measurand over a particular period of time.
- Summation given by such instrument is the product of time and quantity under measurement (measurand).
- Eg: Energy meter, Ampere hour meter, Trivector meter

DIRECT MEASURING INSTRUMENTS

- It converts energy of the measurand directly to the deflection of instrument
- The value of the measurand (quantity to be measured) is given by the deflection.

- Eg: Voltmeters, Ammeters, Wattmeters etc..

COMPARISON INSTRUMENTS

- Instruments measure the measurand by comparing it with a standard that is often contained in the instrument case such as resistance measuring bridges
- Used when high accuracy is required

DEFLECTION TYPE INSTRUMENTS

- Measurand produces some physical effect which deflects or produces mechanical displacement of the moving system of instrument,
- An opposing effect is build in instrument which tries to oppose deflection or mechanical displacement that can be directly observed.
- The opposing effect increases until balance is achieved
- At balance deflection is proportional to measurand
- Eg: PMMC Ammeter- deflection proportional to current

NULL TYPE INSTRUMENTS

- Deflection is attempted to maintain zero by suitable application of an effect opposing that generated by measurand.
- A detector of unbalance and means for restoring balance is necessary for these instruments
- Deflection is kept at zero, so accurate knowledge of magnitude of opposing effect is required
- Eg: potentiometer- deflection proportional to voltage
- **Advantages:** accurate, calibration of detector not required,covenient
- **Disadvantages:** not suitable for dynamic instruments, deflection must be large

COMPARISON

Sr.No.	Null Type Instrument	Deflection Type Instrument
1.	It uses null detector, the effect produced by measured quantity and opposite effect to obtain null condition.	In this instrument the quantity to be measured produces some effect which deflects the pointer against controlling torque.
2.	The accuracy is high.	The accuracy is less.
3.	Highly sensitive as null detector has to cover a small range around the nullpoint.	Less sensitive.
4.	Not suitable for the dynamic and rapid measurements.	Preferred for the dynamic measurements.
5.	The example is d.c. potentiometer.	The example is moving coil ammeter.

ANALOG INSTRUMENTS

- Signals that vary in a continuous fashion and take infinite number of values in a given range is known as analog signals.
- Devices producing analog signals are called analog devices
- **Analog instrument** provides an output which varies continuously as measurand chages
- Output of analog instrument can have infinite number of values in the range of the instrument.
- Eg: Analog voltmeter, energymeter, ammter etc..

ANALOG INSTRUMENTS

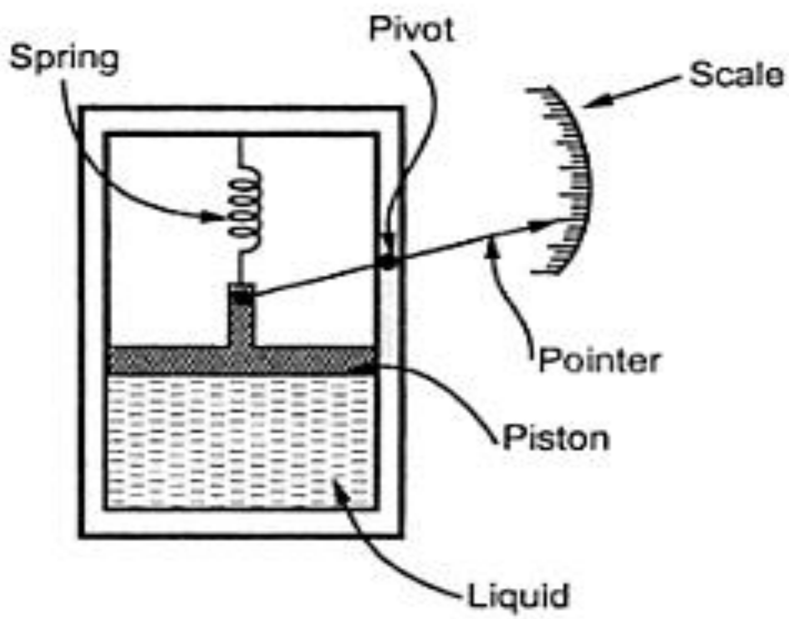


Fig. 1.3 Pressure gauge

Analog pressure gauge

DIGITAL INSTRUMENTS

- Signals which vary in discrete steps and thus takes only finite different values in a given range are called digital signals
- Devices producing such signals are called digital devices

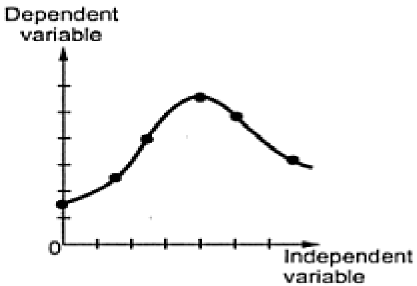


Fig. 1.8 Analog signal

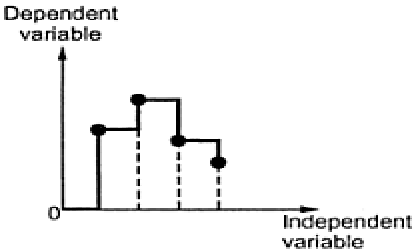


Fig. 1.9 Digital signal

DIGITAL INSTRUMENTS

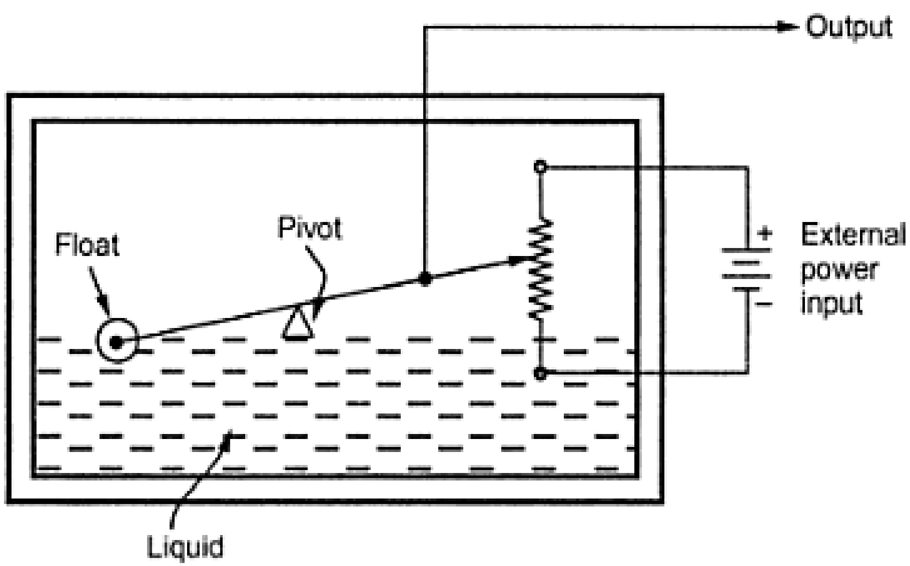
- Digital instrument has an output which varies in discrete steps ans also have finite number of values
- Eg: Digital Revolution Counter

COMPARISON

Sr. No.	Parameter	Analog	Digital
1.	Accuracy	Less upto ± 0.1 % of full scale.	Very high accuracy upto ± 0.005 % of reading.
2.	Resolution	Limited upto 1 part in several hundreds.	High upto 1 part in several thousands.
3.	Power	Power required is high hence can cause loading.	Negligible power is required hence no loading effects.
4.	Cost	Low in cost.	High in cost compared to analog but now-a-days cost of digital instruments is also going down.
5.	Frictional errors	Errors due to moving parts are present.	No moving parts hence no errors.
6.	Range and polarity	No facility of autoranging and autopolarity.	Has the facility of autoranging and autopolarity.
7.	Input impedance	Low input impedance.	Very high input impedance.
8.	Observational errors	Errors such as parallax errors and approximation errors are present.	Due to digital displays, the observational errors are absent.
9.	Compatibality	Not compatible with modern digital instruments.	The digital output can be directly fed into memory of modern digital instruments.
10.	Speed	Reading speed is low.	Reading speed is very high.
11.	Programming facility	Not available.	Can be programmed and well suited for the computerised control.

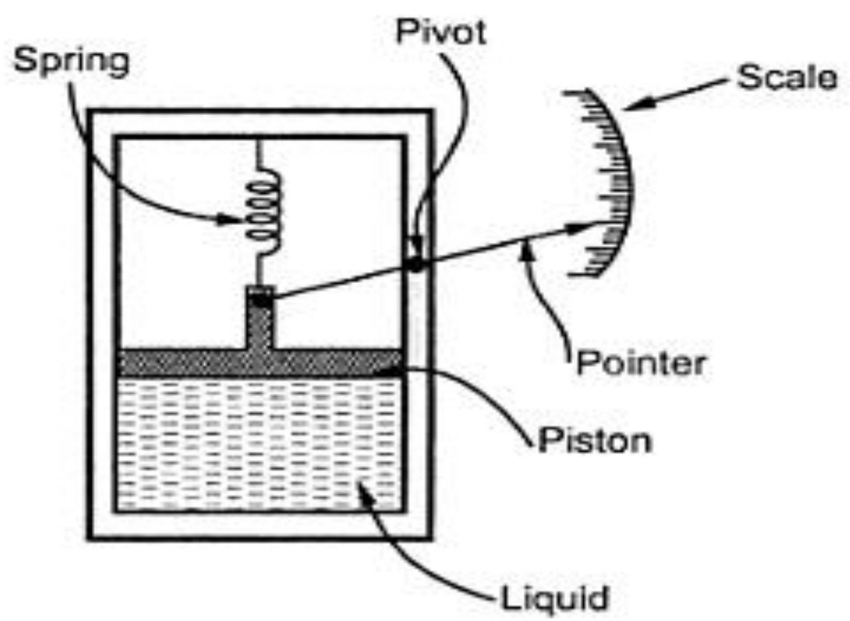
ACTIVE INSTRUMENTS

- Measurand activates some external power input source which in turn produces the measurement
- Apart from measurand some another energy source is present
- Eg: Liquid level indicator



PASSIVE INSTRUMENTS

- Output is produced entirely by the measurand
- Eg: Pressure guage



COMPARISON

Sr.No.	Passive Instruments	Active Instruments
1.	The output is produced entirely by the quantity being measured.	The quantity to be measured activates some external power input source, which inturn produces the output.
2.	Additional energy input source not required.	Additional external energy input source is required.
3.	The resolution is less.	The resolution is high.
4.	The resolution can not be easily adjusted.	The resolution can be adjusted by adjusting the magnitude of the external energy input.
5.	Simple to design.	Complicated to design.
6.	Cheaper hence economical.	Due to complex design and higher number of elements, it is costlier.
7.	Examples are pressure gauge, voltmeter, ammeter.	Examples are liquid level indicator, flow indicator.

ESSENTIALS OF INDICATING INSTRUMENTS

As defined above, indicating instruments are those which indicate the value of quantity that is being measured at the time at which it is measured. Such instruments consist essentially of a pointer which moves over a calibrated scale & which is attached to a moving system pivoted in bearing. The moving system is subjected to the following three torques:

1. A deflecting (or operating) torque;
2. A controlling (or restoring) torque;
3. A damping torque.

DEFLECTING TORQUE

- The deflecting torque is produced by making one of the magnetic, heating, chemical, electrostatic and electromagnetic induction effect of current or voltage and cause the moving system of the instrument to move from its zero position.
- The method of producing this torque depends upon the type of instrument.

CONTROLLING TORQUE

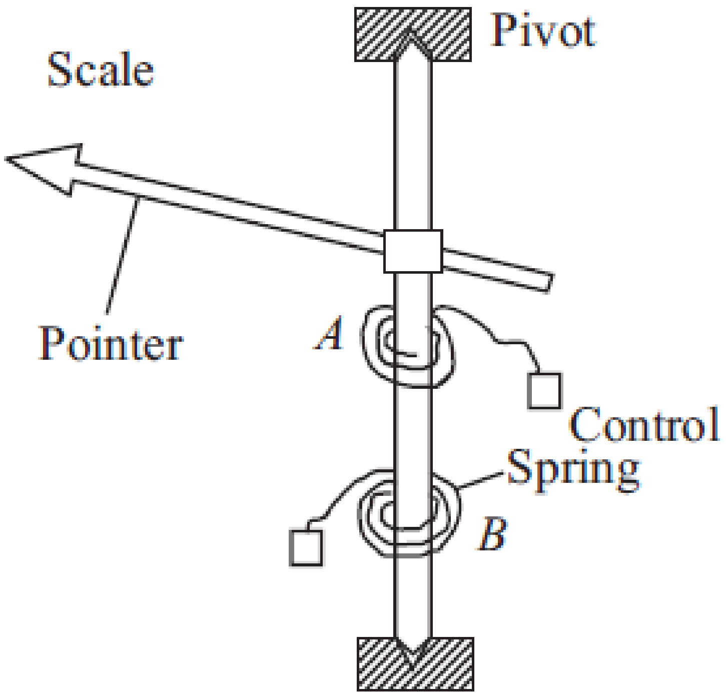
- The magnitude of the moving system would be some what indefinite under the influence of deflecting torque, unless the controlling torque existed to oppose the deflecting torque.
- It increases with increase in deflection of moving system.
- Under the influence of controlling torque the pointer will return to its zero position on removing the source producing the deflecting torque.
- Without controlling torque the pointer will swing at its maximum position & will not return to zero after removing the source.
- Controlling torque is produced either by spring or gravity control

Spring Control:

- .

When the pointer is deflected one spring unwinds itself while the other is twisted.

- This twist in the spring produces restoring (controlling) torque, which is proportional to the angle of deflection of the moving systems.



SPRING CONTROL

$$T_c \alpha \ \theta$$

$$T_c = K_s \theta$$

$$T_d \propto I$$

$$T_d = K_s I$$

$$T_c = T_d$$

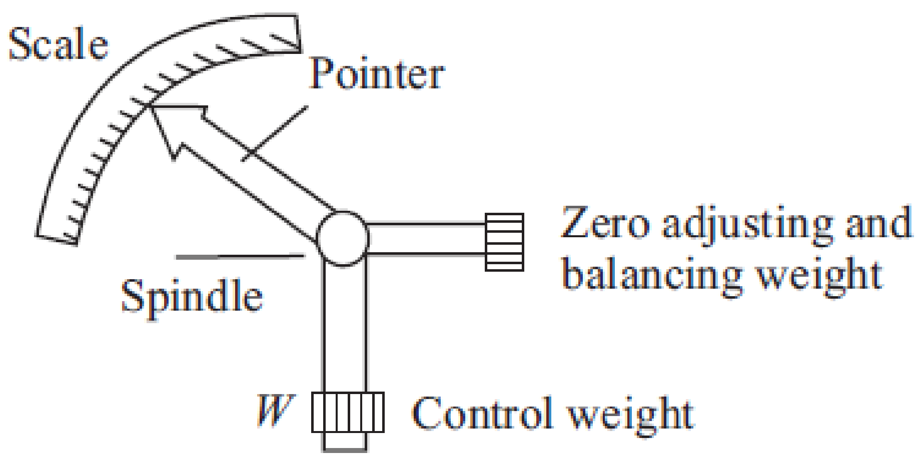
$$\theta = I$$

SPRING CONTROL

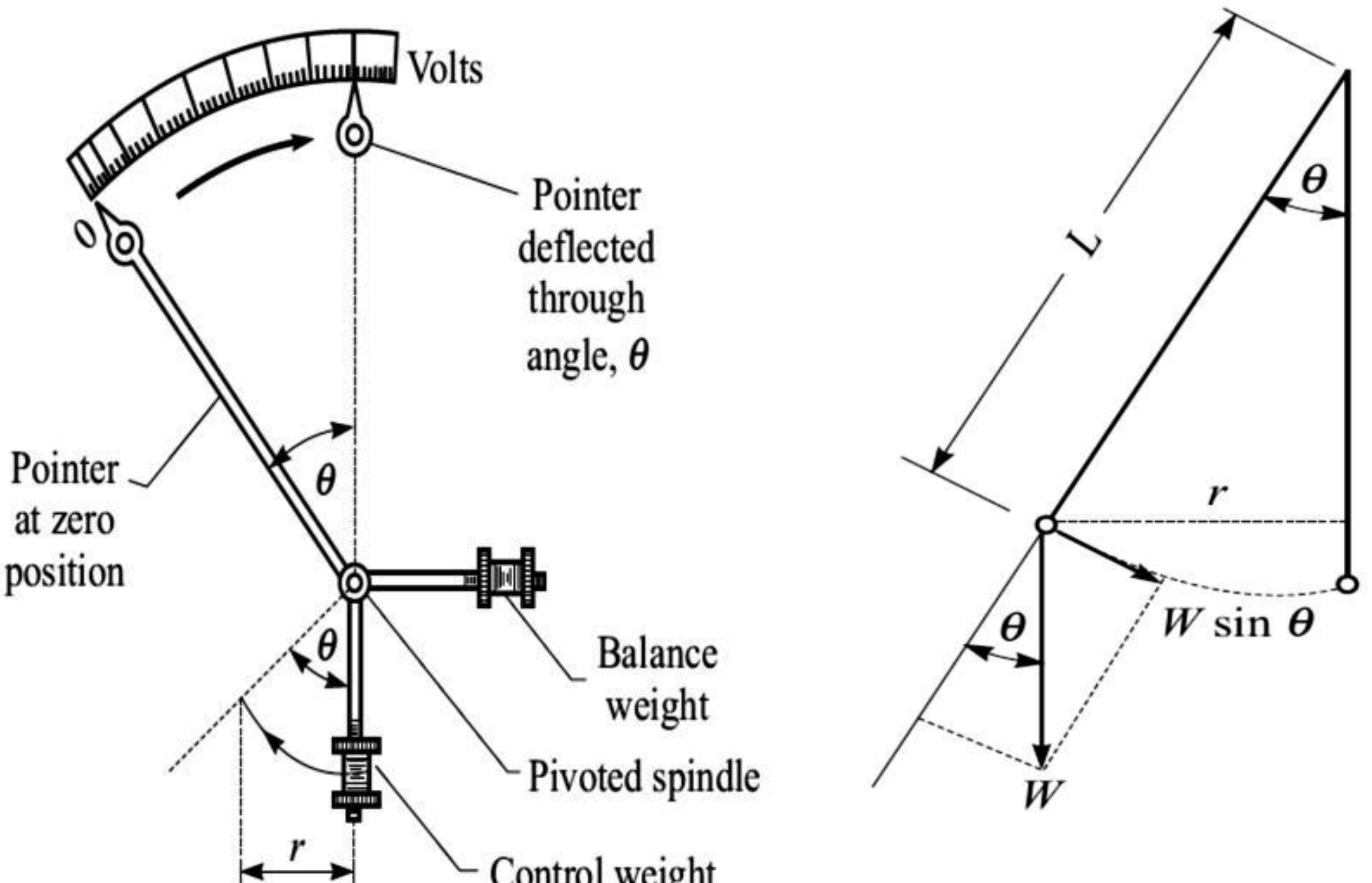
- Since deflection is proportional to current, shape of scale is uniform
- Springs should be non magnetic and protected against mechanical fatigue
- Disadv: Temperature coefficient of spring, elastic yield of spring.

Gravity Control

- In gravity controlled instruments, *a small adjustable weight is attached to the* spindle of the moving system such that the deflecting torque produced by the instrument has to act against the action of gravity.
- Thus a controlling torque is obtained. This weight is called the *control weight. Another adjustable weight is also attached is the moving system for zero adjustment and balancing* purpose. This weight is called *Balance weight*.



Gravity Control



Gravity Control

$$\tau_c = (W \sin\theta) \times L = WL \sin\theta$$

Since $\tau_d \propto I$, and $\tau_c = \tau_d$

or $\quad WL \sin\theta = kI$

$$\Rightarrow \quad I = \left(\frac{WL}{k}\right) \sin\theta$$

or $\quad I \propto \sin\theta$

Gravity Control

- I α sin θ
- Thus the controlling torque is propotional to the sine of the angle of deflection of the moving system.
- The scale of gravity controlled instrument is damped at their lower ends.
- As approaches 90^0 the distance AB increases by only a relatively small amount for a given change in the angle than when θ is just increasing from its zero value.

GRAVITY CONTROL

Its **advantages** are :

1) Its performance is not time dependent.

2) It is simple and cheap.

3) The controlling torque can be varied by adjusting the position of the control weight.

4) Its performance is not temperature dependent.

Its **disadvantages** are :

1) The scale is nonuniform causing problems to record accurate readings.

2) The system must be used in vertical position only and must be properly levelled. Otherwise it may cause serious errors in the measurement.

3) As delicate and proper levelling required, in general it is not used for indicating instruments and portable instruments.

Comparison of Controlling Systems

Sr. No.	Gravity control	Spring control
1.	Adjustable small weight is used which produces the controlling torque.	Two hair springs are used which exert controlling torque.
2.	Controlling torque can be varied.	Controlling torque is fixed.
3.	The performance is not temperature dependent.	The performance is temperature dependent.
4.	The scale is nonuniform.	The scale is uniform.
5.	The controlling torque is proportional to $\sin\theta$.	The controlling torque is proportional to θ.
6.	The readings cannot be taken accurately.	The readings can be taken very accurately.
7.	The system must be used in vertical position only.	The system need not be necessarily in vertical position.
8.	Proper levelling is required as gravity control.	The levelling is not required.
9.	Simple, cheap but delicate.	Simple, rigid but costlier compared to gravity control.
10.	Rarely used for indicating and portable instruments.	Very popularly used in most of the instruments.

DAMPING TORQUE

- We have already seen that the moving system of the instrument will tend to move under the action of the deflecting torque.
- But on account of the control torque, it will try to occupy a position of rest when the two torques are equal and opposite.
- However, due to inertia of the moving system, the pointer will not come to rest immediately but oscillate about its final deflected position as shown in figure and takes appreciable time to come to steady state.
- To overcome this difficulty a damping torque is to be developed by using a damping device attached to the moving system.

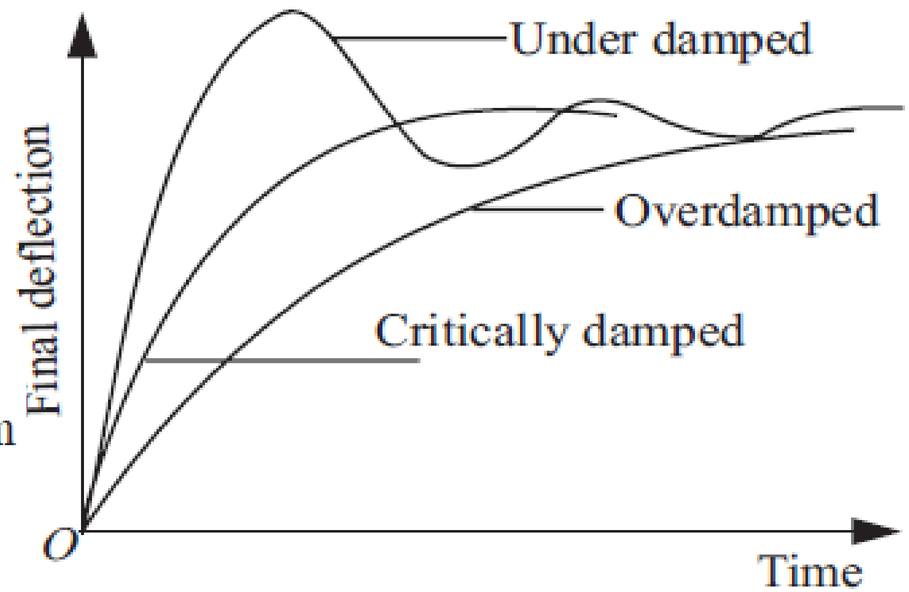
DAMPING TORQUE

- The damping torque is proportional to the speed of rotation of the moving system, that is

$$T_v = k_v \frac{d\theta}{dt}$$

where k_v = damping torque constant

$\frac{d\theta}{dt}$ = speed of rotation of the moving system



- Depending upon the degree of damping introduced in the moving system, the instrument may have any one of the following conditions as depicted in above graph.

DAMPING TORQUE

1. **Under damped condition:**

   The response is oscillatory

2. **Over damped condition:**

   The response is sluggish and it rises very slowly from its zero position to final position.

3. **Critically damped condition:**

   When the response settles quickly without any oscillation, the system is said to be critically damped.

The damping torque is produced by the following methods:

1.Air Friction Damping
2.Fluid Friction Damping
3.Eddy Current Damping

AIR FRICTION DAMPING

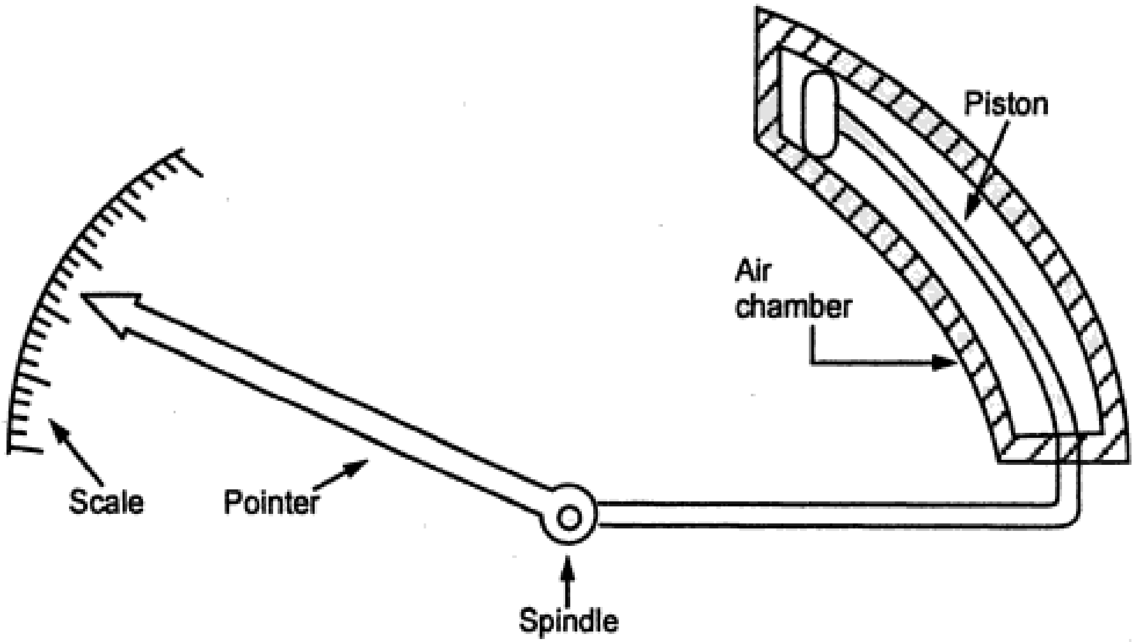


Fig. 2.5 Air friction damping

AIR FRICTION DAMPING

- A light aluminum piston is attached to the moving system.
- The piston moves with minimum clearance in fixed air chamber closed at one end.
- If the piston moves rapidly into chamber the air is compressed and pressure opposes the motion of piston.

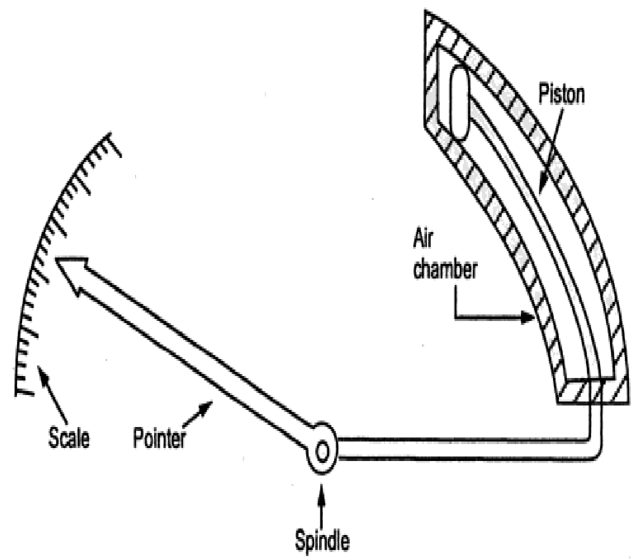


Fig. 2.5 Air friction damping

AIR FRICTION DAMPING

- If the piston is moving outside, pressure inside falls and outside pressure becomes greater and again motion is opposed.
- The arm carry the piston should not be bend and should not touch the sides of the chamber
- Difficult to straighten & causes friction if it touches.

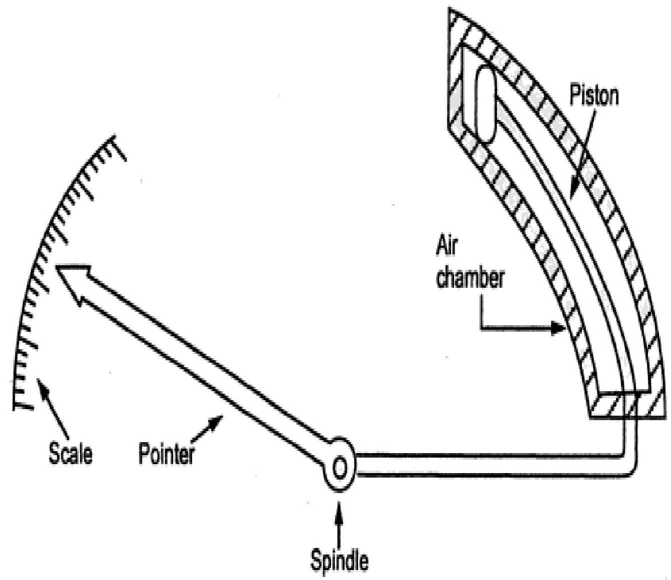


Fig. 2.5 Air friction damping

FLUID FRICTION DAMPING

2.5.2 Fluid Friction Damping

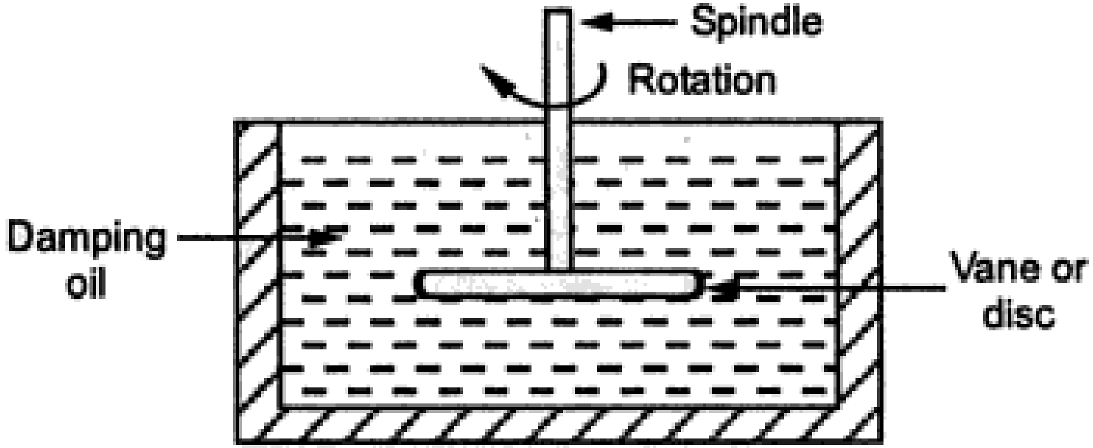


Fig. 2.6 Fluid friction damping

FLUID FRICTION DAMPING

- Light vanes or disc are attached to the spindle of the moving system.
- They move in the damping oil.
- Damping oil should be good insulator, non-evaporating and non-corrosive .
- Viscosity not change with temperature.

2.5.2 Fluid Friction Damping

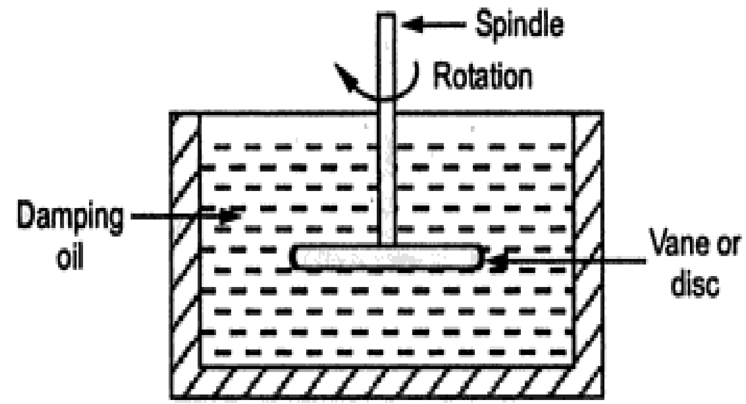


Fig. 2.6 Fluid friction damping

FLUID FRICTION DAMPING

- The vanes are dipped into a pot of damping oil and should be completely submerged.
- The motion of moving system is opposed by the friction of damping oil on vanes.

2.5.2 Fluid Friction Damping

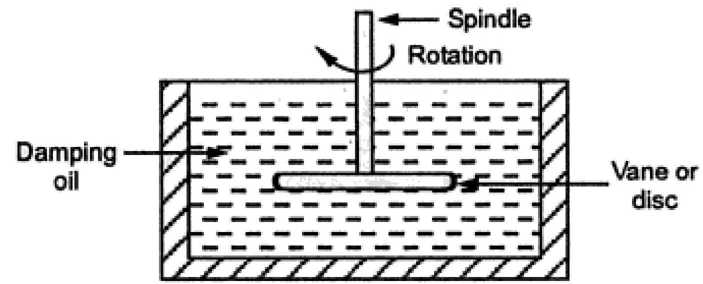


Fig. 2.6 Fluid friction damping

FLUID FRICTION DAMPING

- Damping force thus created.
- It should increase with velocity of vanes.
- No damping when stationary.

2.5.2 Fluid Friction Damping

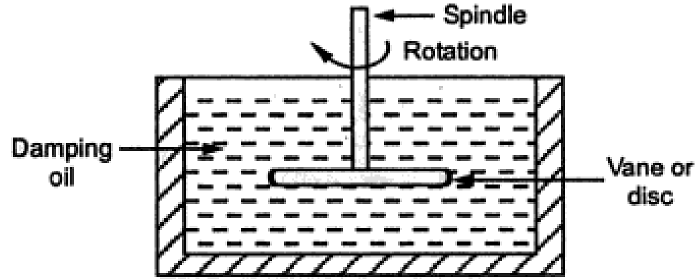


Fig. 2.6 Fluid friction damping

EDDY CURRENT DAMPING

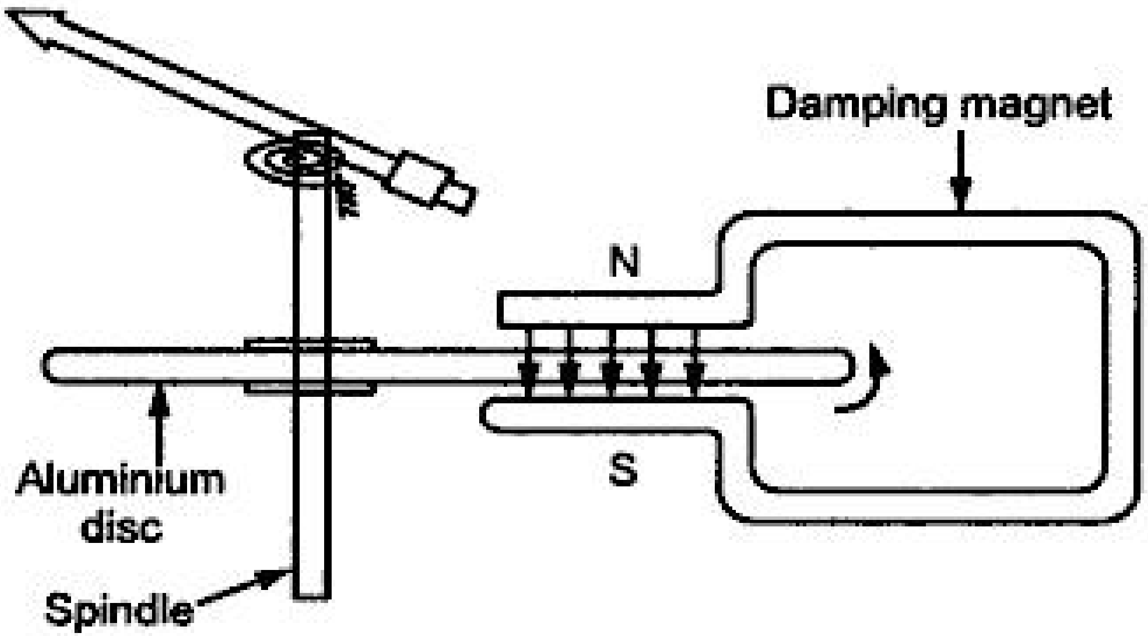


Fig. 2.7 Eddy current damping

EDDY CURRENT DAMPING

- Whenever a sheet of conducting but nonmagnetic materiel like copper or aluminum moves in a magnetic field.
- They cut through the lines of force.
- Eddy currents are generated in the sheets.
- A force opposing the motion of the sheet is experienced between them and the magnetic field.

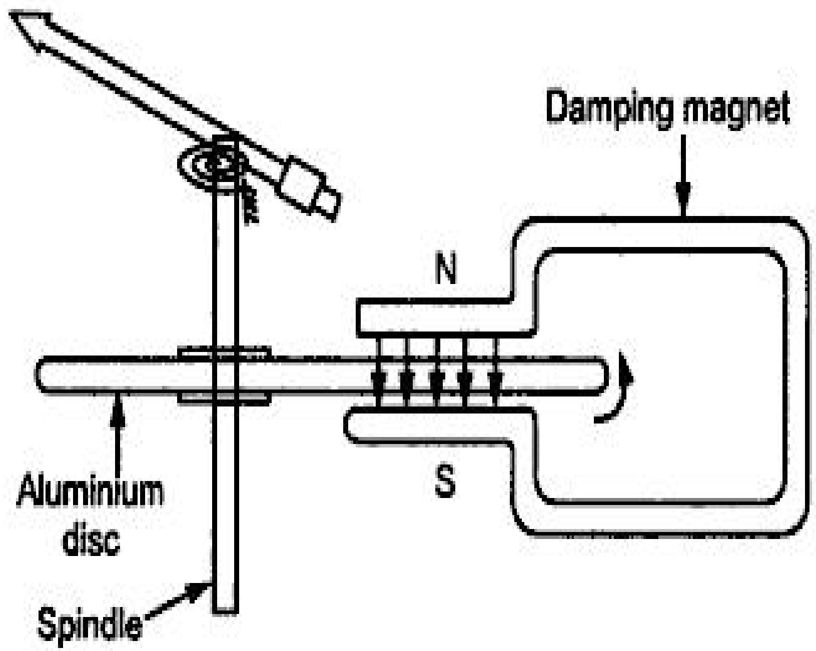


Fig. 2.7 Eddy current damping

EDDY CURRENT DAMPING

- This force proportional to eddy current and strength of magnetic field.
- Eddy current proportional to velocity of moving system.
- Strength of magnetic field constant then damping force directly proportional to velocity of moving vanes.

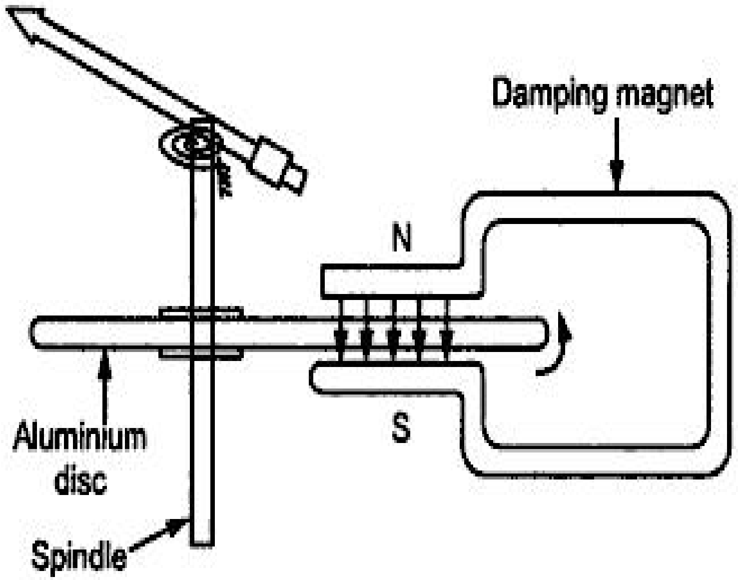


Fig. 2.7 Eddy current damping

EDDY CURRENT DAMPING

- Thin disc or vane of conducting material is mounded on spindle carrying the moving system and pointer.
- The disc is allowed to freely rotate in the damping magnet have north and south poles thus creates damping force.

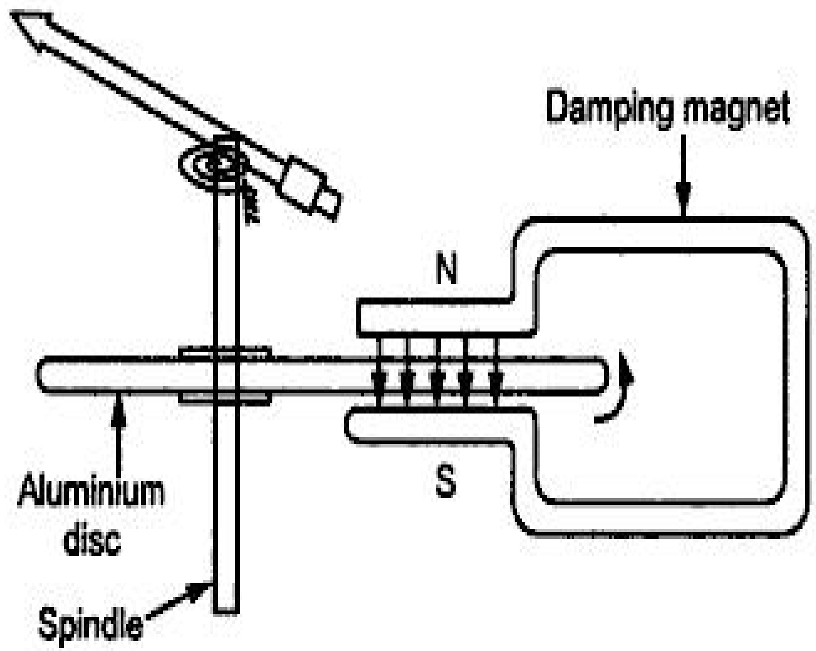


Fig. 2.7 Eddy current damping

TYPES OF MEASURING INSTRUMENTS

Measuring instruments	Moving coil Type	Permanent magnet type
		Dynamometer type
	Moving iron type	Attraction type
		Repulsion type
	Thermal type	Hot wire type
		Thermocouple type
	Electrostatic type	Quadrant type
		Attracted disc type
	Induction type	Split phase
		Shaded pole
	Rectifier type	

MOVING COIL INSTRUMENTS

- Moving coil instruments
  - Permanent magnet moving coil type
  - Dynamometer type

Permanent magnet moving coil type (PMMC) instruments

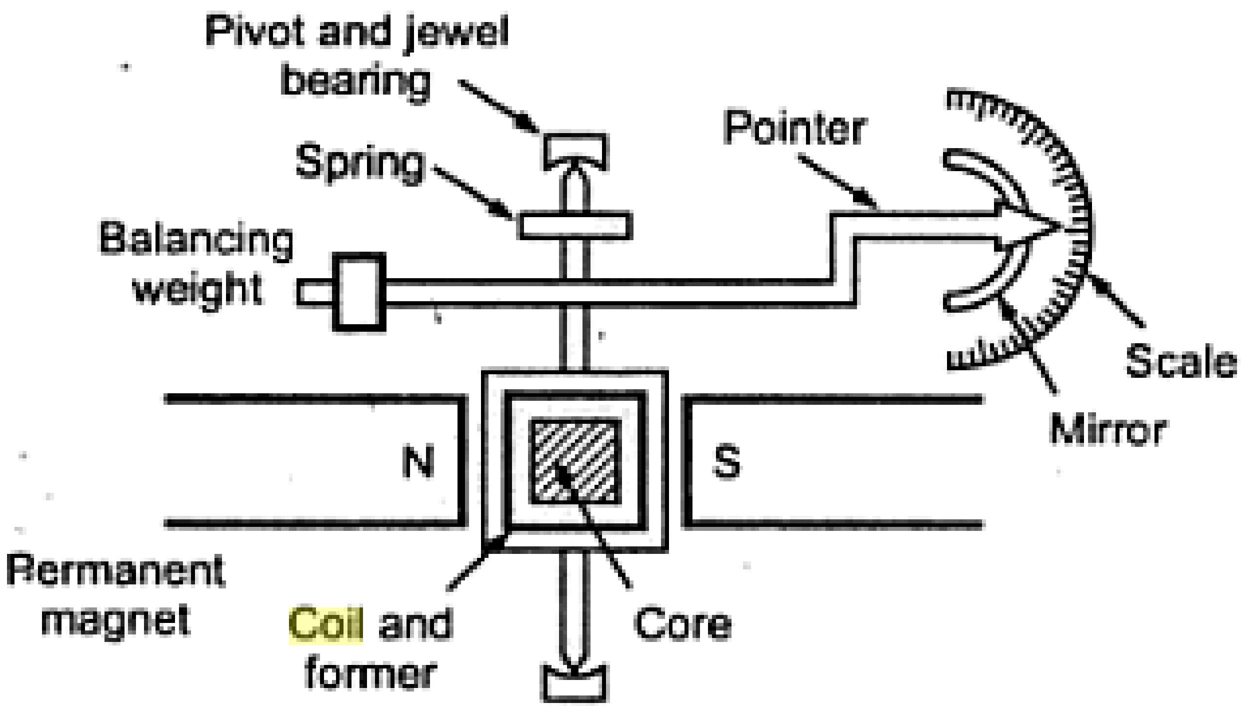


Fig. 2.8 Construction of PMMC instrument

PMMC Instruments

- Accurate for dc measurements
- Working base on motoring principle- “Current carrying conductor kept in a magnetic field experiences a force”
- Coil is moving and magnet is permanent – PMMC meter
- This is D’ Arsonoval principle
- Force experienced by the coil is proportional to current passing through the coil

PMMC Instruments Construction

- Moving coil is rectangular or circular in shape
- Coil is suspended and free to turn on vertical axis
- Coil is placed in uniform, horizontal and radial magnetic field of permanent magnet in the form of a horse shoe

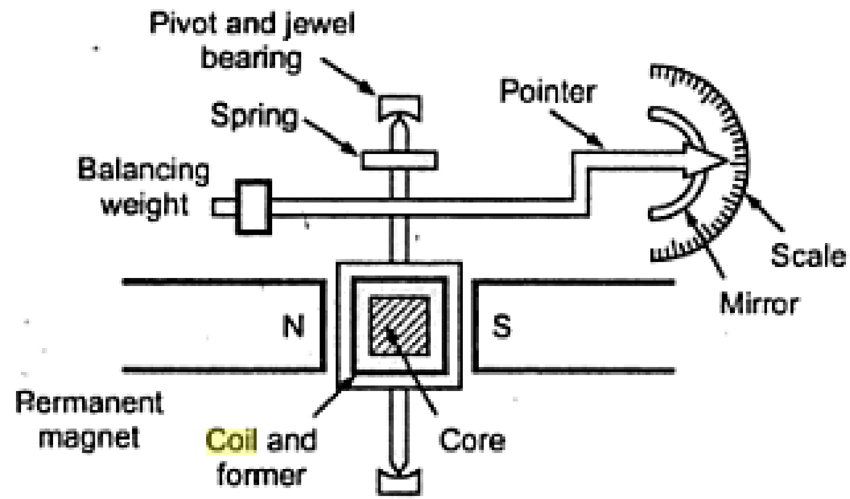


Fig. 2.8 Construction of PMMC Instrument

PMMC Instruments Construction

- The iron core is spherical if coil is circular
- Iron core is cylindrical if coil is rectangular
- Due to iron core deflecting torque increases so sensitivity is high
- Control torque is provided by hair springs
- Damping is eddy current damping

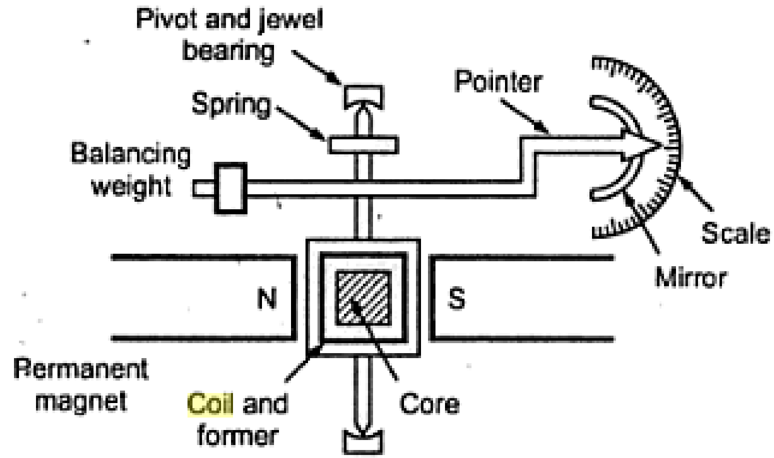


Fig. 2.8 Construction of PMMC Instrument

PMMC Instruments Construction

- Pointer carried by the spindle is moved over a graduated scale
- Pointer has light weight, so deflects rapidly
- Mirror is placed below the pointer to avoid parallax error
- Weight of the instrument is counter balanced by balancing weight

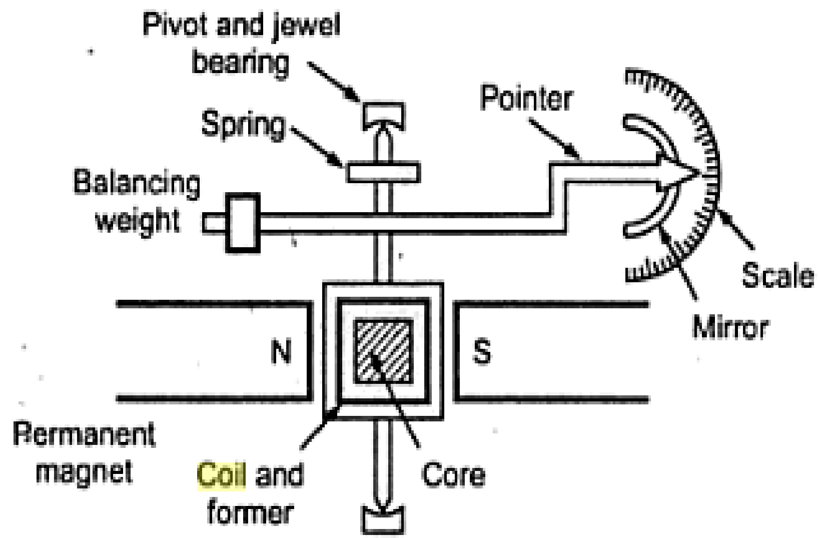


Fig. 2.8 Construction of PMMC instrument

PMMC INSRTRUMENT

- Side view

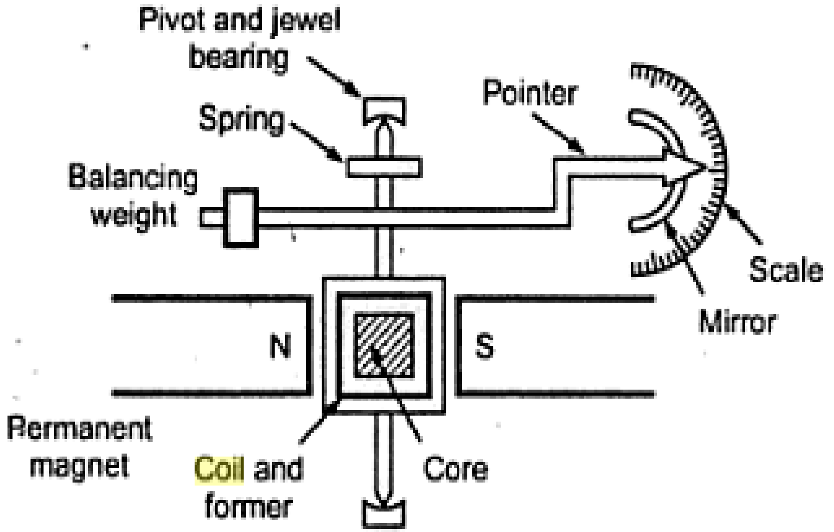


Fig. 2.8 Construction of PMMC instrument

- Top view

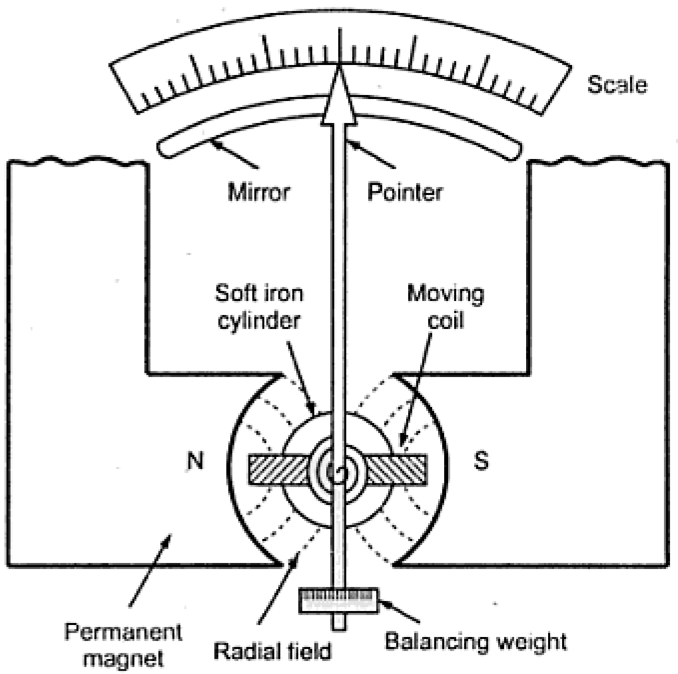


Fig. 5.9 PMMC instrument

PMMC Instrument
TORQUE EQAUTION

The equation for the developed torque can be obtained from the basic law of the electromagnetic torque. The deflecting toque is given by,

$$T_d = NBAI$$

where T_d = deflecting torque in N-m

B = flux density in air gap, Wb / m^2

N = number of turns of the coil

A = effective coil area m^2

I = current in the moving coil, amperes

$$\therefore \quad T_d = GI$$

where $G = NBA$ = constant

PMMC Instrument
TORQUE EQAUTION

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

$$T_c = K\theta$$

where T_c = controlling torque

K = spring constant, Nm/rad or Nm/deg

θ = angular deflection

For the final steady state position,

$$T_d = T_c$$

$$\therefore \quad GI = K\theta$$

$$\therefore \quad \theta = \left(\frac{G}{K}\right) I$$

PMMC Instrument
TORQUE EQAUTION

- Angular deflection is proportional to current passing through the coil
- So these instruments are suitable for dc measurements

The power requirement of PMMC instrument is very small, typically of the order of 25 μW to 200 μW. Accuracy is generally of the order of 2 to 5% of the full scale reading.

SIMPLE PROBLEM

Example 5.1 : *A PMMC instrument has a coil of dimensions 10 mm × 8 mm. The flux density in the air gap is 0.15 Wb/m². If the coil is wound for 100 turns, carrying a current of 5 mA then calculate the deflecting torque. Calculate the deflection if the spring constant is 0.2×10^{-6} Nm/degree.*

Solution : The deflecting torque is given by,

$$T_d = NBAI = 100 \times 0.15 \times (A) \times 5 \times 10^{-3} \text{ Nm}$$

Now $\quad A = \text{area} = 10 \times 8 = 80 \text{ mm}^2 = 80 \times 10^{-6} \text{m}^2$

$\therefore \quad T_d = 100 \times 0.15 \times 80 \times 10^{-6} \times 5 \times 10^{-3} = 6 \times 10^{-6} \text{ Nm}$

Now $\quad T_d = T_c = K\theta$

$\therefore \quad 6 \times 10^{-6} = 0.2 \times 10^{-6} \times \theta$

$$\therefore \quad \theta = \frac{6 \times 10^{-6}}{0.2 \times 10^{-6}} = 30 \text{ degrees}$$

ERRORS IN PMMC INSTRUMENTS

1. *Frictional error* – This can be avoided by winding of coil carefully.
2. *Temperature error* – It can be avoided as discussed in Art. 3.8.3.
3. *Error due to weakening of permanent magnet* – It can be eliminated completely by weakening of mechanical control and attaching a symmetrical iron or steel needle to the coil. The magnetic needle is so arranged that magnetic control provided by it diminishes or the magnet becomes weaker.
4. *Stray magnetic field error* – This error can be avoided by using an iron case for ordinary type instruments.

PMMC INSTRUMENTS ADVANTAGES

1) It has uniform scale.
2) With a powerful magnet, its torque to weight ratio is very high. So operating current is small.
3) The sensitivity is high.
4) The eddy currents induced in the metallic former over which coil is wound, provide effective damping.
5) It consumes low power, of the order of 25 W to 200 μW.
6) It has high accuracy.
7) Instrument is free from hysteresis error.
8) Extension of instrument range is possible.
9) Not affected by external magnetic fields called stray magnetic fields.

PMMC INSTRUMENTS DISADVANTAGES

1) Suitable for d.c. measurements only.
2) Ageing of permanent magnet and the control springs introduces the errors.
3) The cost is high due to delicate construction and accurate machining.
4) The friction due to jewel-pivot suspension.

DYNAMOMETER TYPE INSTRUMENTS

- In this type of operating field is created by another fixed coil rather than permanent magnets
- Capable of service as "transfer instruments"(calibrated in dc and used in ac without any modification)
- Employed as ac voltmeters, ammeters both in the range of power frequencies and audio frequency range

DYNAMOMETER TYPE INSTRUMENTS CONSTRUCTION

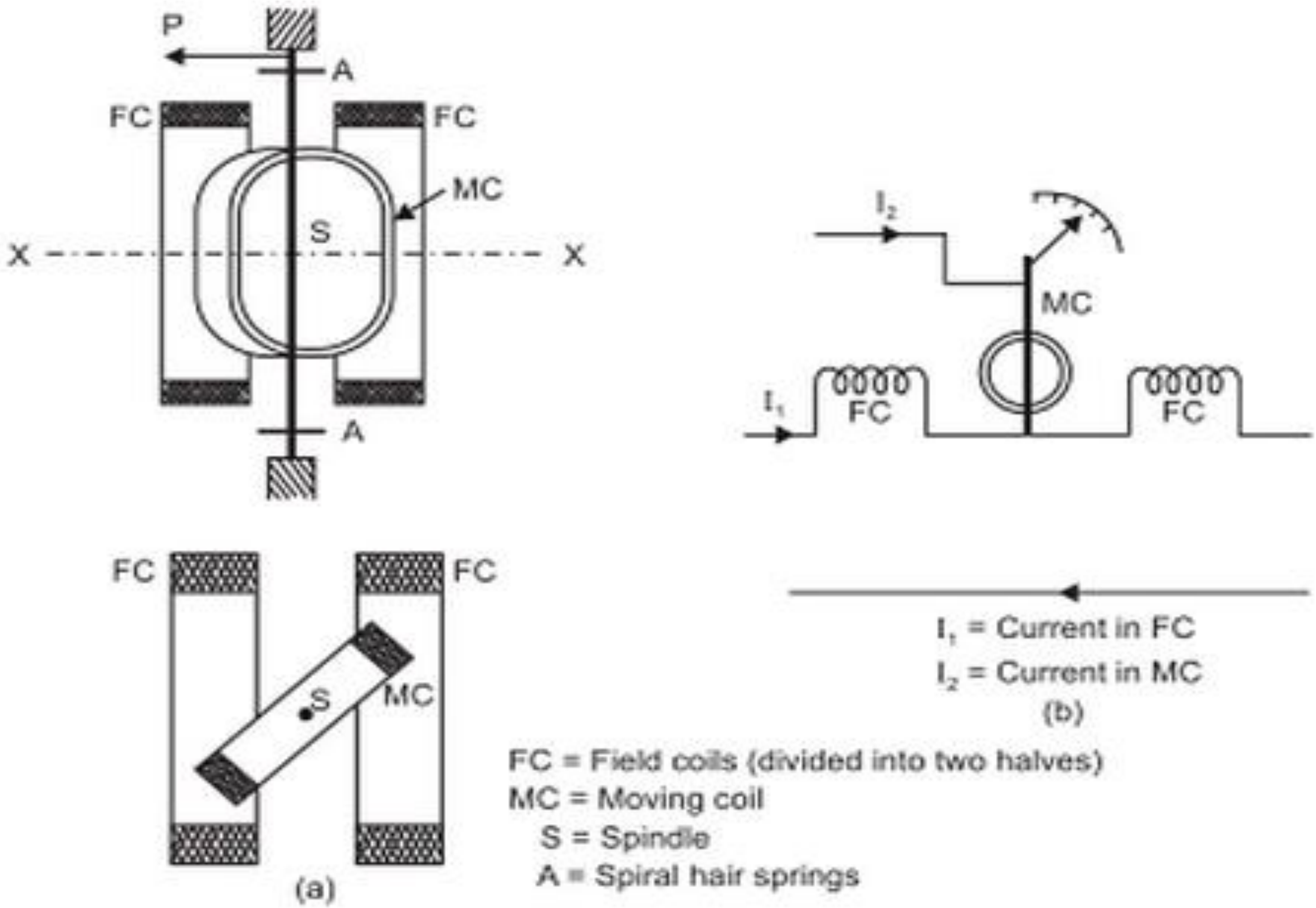
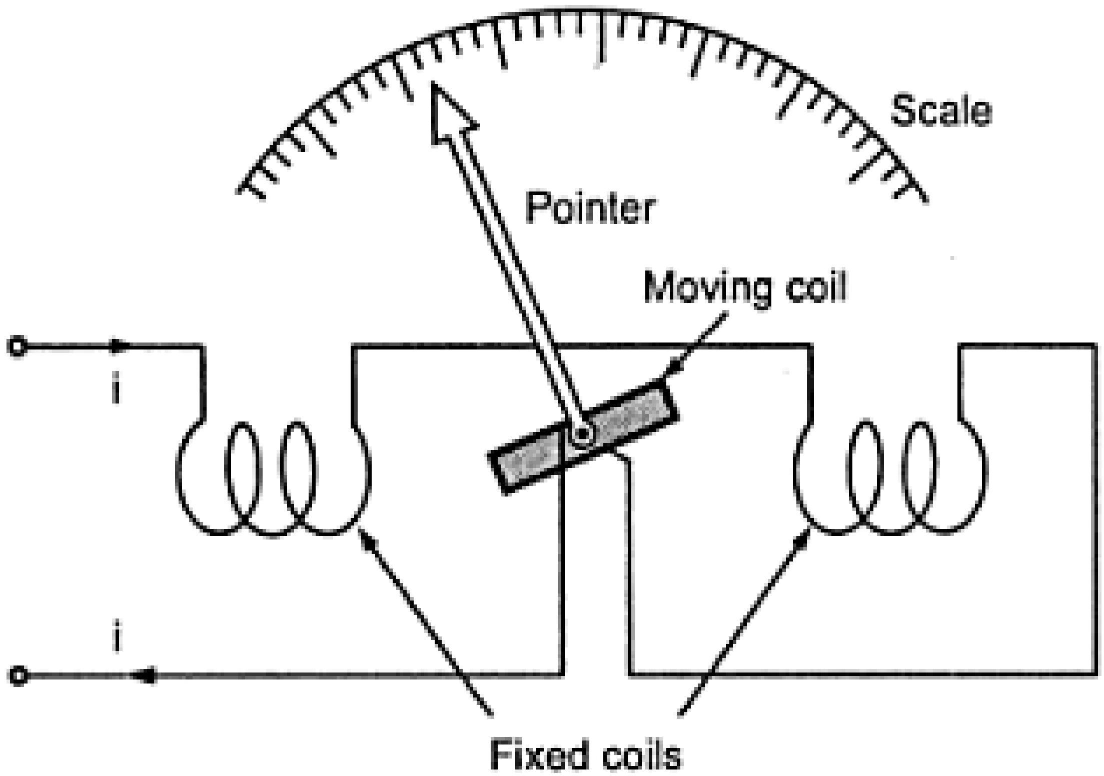


Fig. 3.44. Electrodynamic or dynamometer type instrument.

DYNAMOMETER TYPE INSTRUMENTS CONSTRUCTION



DYNAMOMETER TYPE INSTRUMENTS CONSTRUCTION

- Field system-fixed coil
- Moving system-moving coil
- Control system- hair springs
- Damping system- air friction damping
- Shielding
- Cases and scales

DYNAMOMETER TYPE INSTRUMENTS TORQUE EQUATION

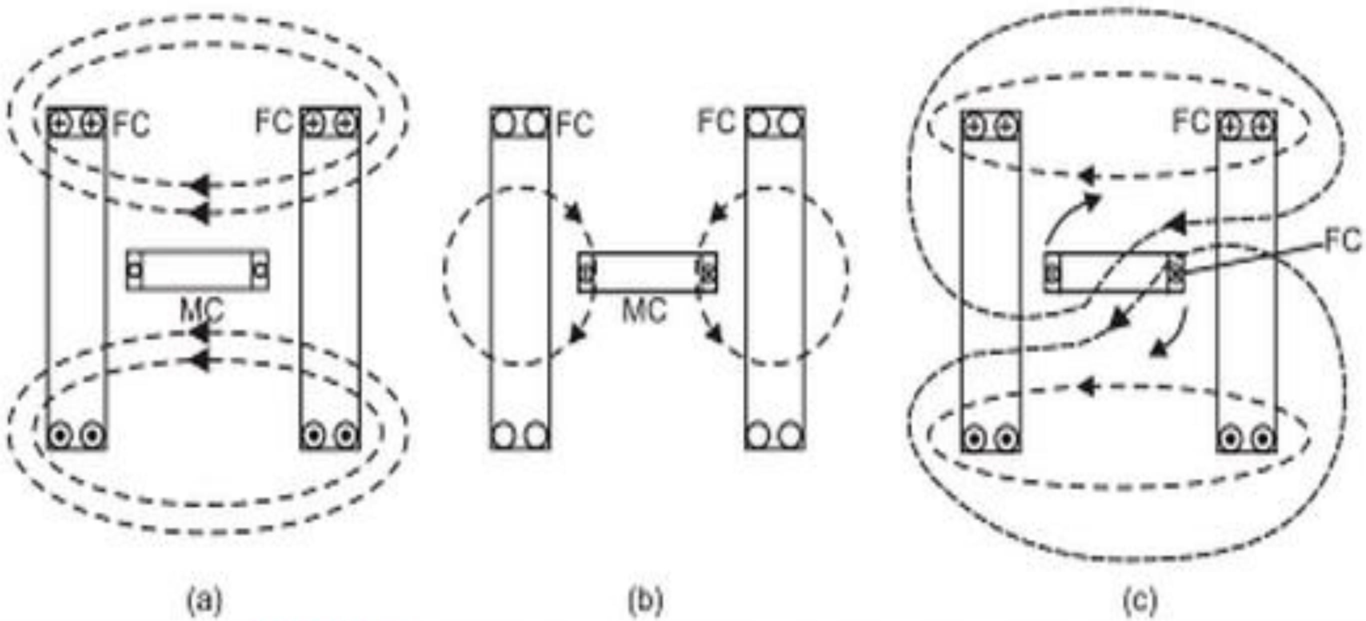


Fig. 3.45. Magnetic fields due to fixed and moving coils.

DYNAMOMETER TYPE INSTRUMENTS GENERAL TORQUE EQUATION

$$T_d \propto I_1 \times I_2$$

or, $T_d = KI_1I_2$ where, K is a constant.

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

$$T_c \propto \theta \quad \text{or} \quad T_c = K'\theta$$

The two torques (T_d and T_c) are equal and opposite in the final deflection position.

i.e., $T_d = T_c$

or, $KI_1I_2 = K'\theta$

or, $\theta \propto I_1I_2$

or, $\theta \propto I^2$ since $I_1 \propto I$ and $I_m \propto I$

DYNAMOMETER TYPE INSTRUMENTS TORQUE EQUATION IN TERMS OF MUTUAL INDUCTANCE

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

$$E = \frac{1}{2}L_1 I_1^2 + \frac{1}{2}L_2 I_2^2 + I_1 I_2 M \qquad ...(3.89)$$

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 of the coil magnetic field attains maximum value.

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

where $d\theta$ 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 :

$$T_d = I_1 I_2 \frac{dM}{d\theta} \qquad ...(3.90)$$

DYNAMOMETER TYPE INSTRUMENTS TORQUE EQUATION IN TERMS OF MUTUAL INDUCTANCE

For direct current :

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

Deflecting torque (T_d) rotates the moving coil through an angle θ, at which restoring torque (T_c) of strings is equal to T_d.

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

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

or, Deflection, $$\theta = \frac{I_1 I_2}{C} \cdot \frac{dM}{d\theta} \quad ...(3.91)$$

DYNAMOMETER TYPE INSTRUMENTS TORQUE EQUATION IN TERMS OF MUTUAL INDUCTANCE

For alternating current :

When the coils carry alternating currents i_1 and i_2 the instantaneous deflecting torque,

$$(T_d)_i = i_1 i_2 \frac{dM}{d\theta} \quad \text{...(3.92)}$$

The average deflecting torque over a complete cycle,

$$(T_d)_{av.} = \frac{1}{T}\int_0^T T_{di}\, dt$$

or,

$$(T_d)_{av.} = \frac{dM}{d\theta}\frac{1}{T}\int_0^T i_1 i_2\, dt \quad \text{...(3.93)}$$

DYNAMOMETER TYPE INSTRUMENTS TORQUE EQUATION IN TERMS OF MUTUAL INDUCTANCE

If currents i_1 and i_2 are *sinusoidal and are displaced by a phase angle* ϕ, *i.e.*,

$$i_1 = I_{max.1} \sin \omega t, \quad \text{and} \quad i_2 = I_{max.2} \sin(\omega t - \phi),$$

then, the *average deflecting torque*,

$$(T_d)_{av.} = \frac{dM}{d\theta} \cdot \frac{1}{T} \int_0^T i_1 i_2 \, dt$$

$$= \frac{dM}{d\theta} \cdot \frac{1}{2\pi} \int_0^{2\pi} I_{max.1} \sin \omega t \cdot I_{max.2} \sin(\omega t - \phi) \, d(\omega t)$$

or,

$$(T_d)_{av.} = \frac{I_{max.1} \cdot I_{max.2}}{2} \cos \phi \frac{dM}{d\theta} = I_1 I_2 \cos \phi \frac{dM}{d\theta} \quad \text{...(3.94)}$$

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

At steady deflection state,

$$T_d = T_c$$

DYNAMOMETER TYPE INSTRUMENTS TORQUE EQUATION IN TERMS OF MUTUAL INDUCTANCE

or, $$I_1 I_2 \cos\phi \frac{dM}{d\theta} = C\theta$$

$\therefore$ $$\text{Deflection, } \theta = \frac{I_1 I_2}{C} \cos\phi \cdot \frac{dM}{d\theta}$$

From the above equation, deflection is proportional to cosine of angle between currents in fixed coil and moving coil

APPLICATION OF DYNAMOMETER TYPE INSTRUMENTS

Use of the instrument as an ammeter. When the instrument is used as an ammeter then same current passes through both moving coil (*MC*) and fixed coils (*FC*) as shown in Fig. 3.46. In this case, $I_1 = I_2 = I$, hence $\theta \propto I^2$ or $I \propto \sqrt{\theta}$. The connections of Fig. 3.46 are used when *small currents* are to be measured.

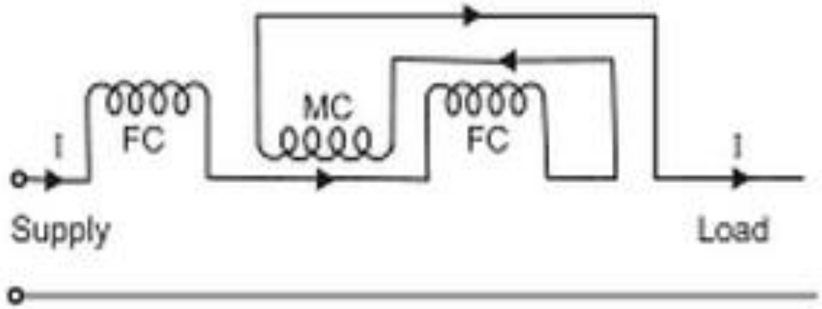


Fig. 3.46. Measurement of small currents.

APPLICATION OF DYNAMOMETER TYPE INSTRUMENTS

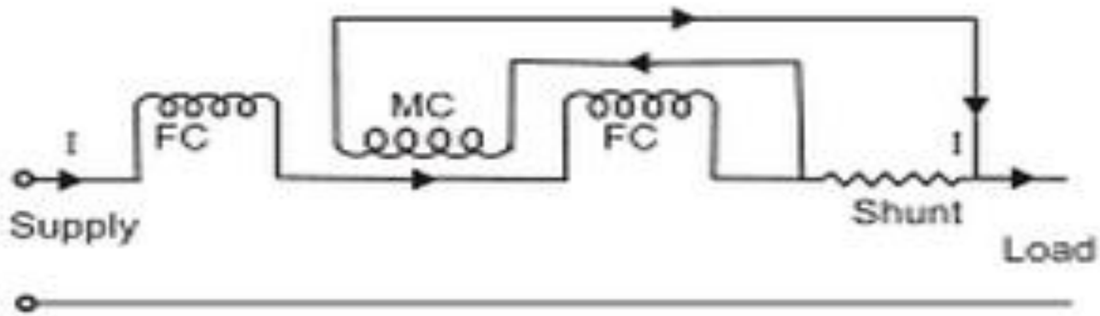


Fig. 3.47. Measurement of heavy currents.

APPLICATION OF DYNAMOMETER TYPE INSTRUMENTS

- Voltmeter

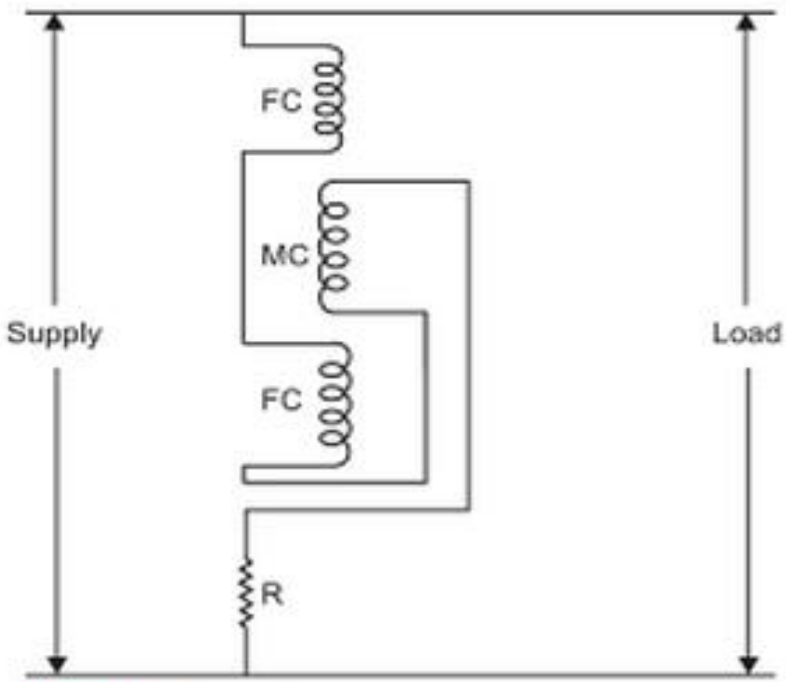


Fig. 3.48. Use of the instrument as a voltmeter.

$I_1 = I_2 = I,$

$$I = \frac{V}{R} \cdots\cdots \text{in D.C. circuits}$$

$$I = \frac{V}{Z} \cdots\cdots \text{in A.C. circuits}$$

$$\theta \propto V \times V \quad \text{or} \quad \theta \propto V^2$$

$$V = \sqrt{\theta}$$

ERRORS IN DYNAMOMETER TYPE INSTRUMENTS

(*i*) Frictional error;
(*ii*) Temperature error;
(*iii*) Error due to stray magnetic fields;
(*iv*) Frequency error;
(*v*) Error due to eddy currents.

ERRORS IN DYNAMOMETER TYPE INSTRUMENTS

1. ***Frictional error :*** In these instruments frictional error is high. So, in order to have high accuracy of measurement this error needs to be minimised to the lowest possible, this is achieved as follows :

(*i*) By a reasonable reduction in weight;

(*ii*) By proper selection of materials for bearings and spindle, and adequate polishing of these parts.

However, these measures increase the cost of the instrument and make it more sensitive to overloads and mechanical impacts.

ERRORS IN DYNAMOMETER TYPE INSTRUMENTS

2. ***Temperature error :***

- High currents are carried by coils which produce heat. *Self-heating of coils produces errors.*
- High accuracy instruments contain *temperature compensating resistors* which tend to *neutralise* the effects of changes in temperature.

3. ***Errors due to stray magnetic fields :*** In order to avoid the influence of stray fields a good amount of *screening is necessary.*

ERRORS IN DYNAMOMETER TYPE INSTRUMENTS

4. ***Frequency error :*** This error in these instruments is largely due to variation of self-reactance of coils, with frequency.

- In order to reduce frequency error in dynamometer ammeters, the ratio of currents in fixed and moving coils *i.e.* $\frac{I_1}{I_2}$ should be independent of frequency. This requires that *time constant* $\left(\frac{L}{R}\right)$ *of two circuits should be same.*
- For reducing frequency errors in voltmeters the *coil winding is made a very small part of the circuit.* This makes inductive reactance ($X_L = 2\pi fL$), a *small fraction* of total impedance, and therefore $Z = \sqrt{R^2 + (2\pi fL)^2} = R$. This means frequency does not affect the calibration of the instrument. In fact, dynamometer voltmeters may be used, in general, within their guaranteed accuracy from D.C. to about 125 Hz.

ERRORS IN DYNAMOMETER TYPE INSTRUMENTS

5. ***Error due to eddy currents :***

- The eddy currents are induced in metal parts of the instrument and develop a torque because of coupling between the moving coil and the neighbouring metal part.
- This error can be *reduced* by keeping the metal in the supports of the coil and other structural parts to the *minimum possible* and selecting the metal, to be used, of *high resistivity*.

ADVANTAGES OF DYNAMOMETER TYPE INSTRUMENTS

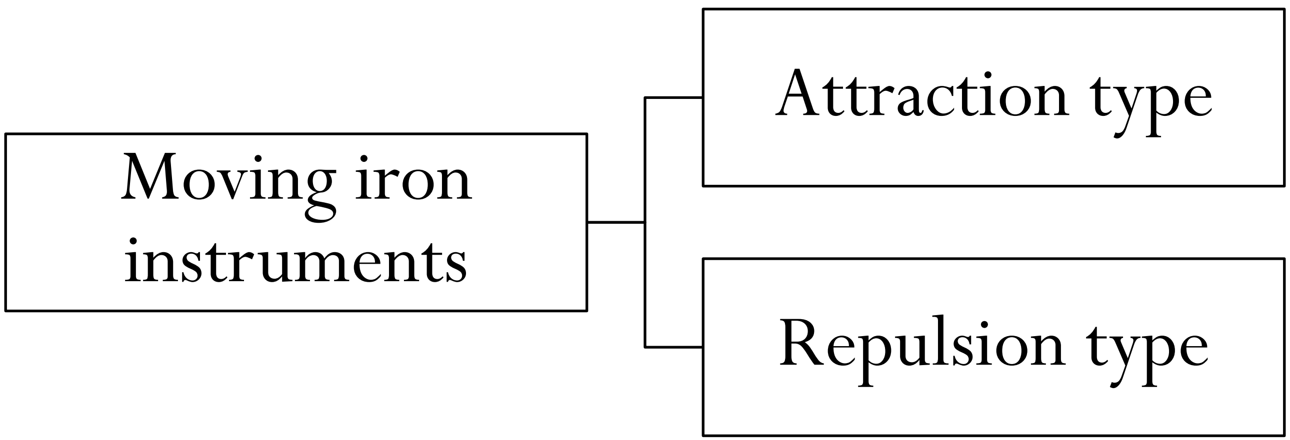
1. Can be used on both D.C. as well as A.C. systems (as the instrument has square law response).
2. They are free from hysteresis and eddy current errors, because of absence of iron in the operating parts of the instrument.
3. It is possible to construct ammeters upto 10 A and voltmeters upto 600 V with precision grade accuracy.
4. Very useful for accurate measurement of r.m.s. values of voltages irrespective of waveforms.
5. Owing to precision grade accuracy and same calibration for D.C. and A.C. measurements, these instruments are used as *transfer and calibration instruments*.

DISADVANTAGES OF DYNAMOMETER TYPE INSTRUMENTS

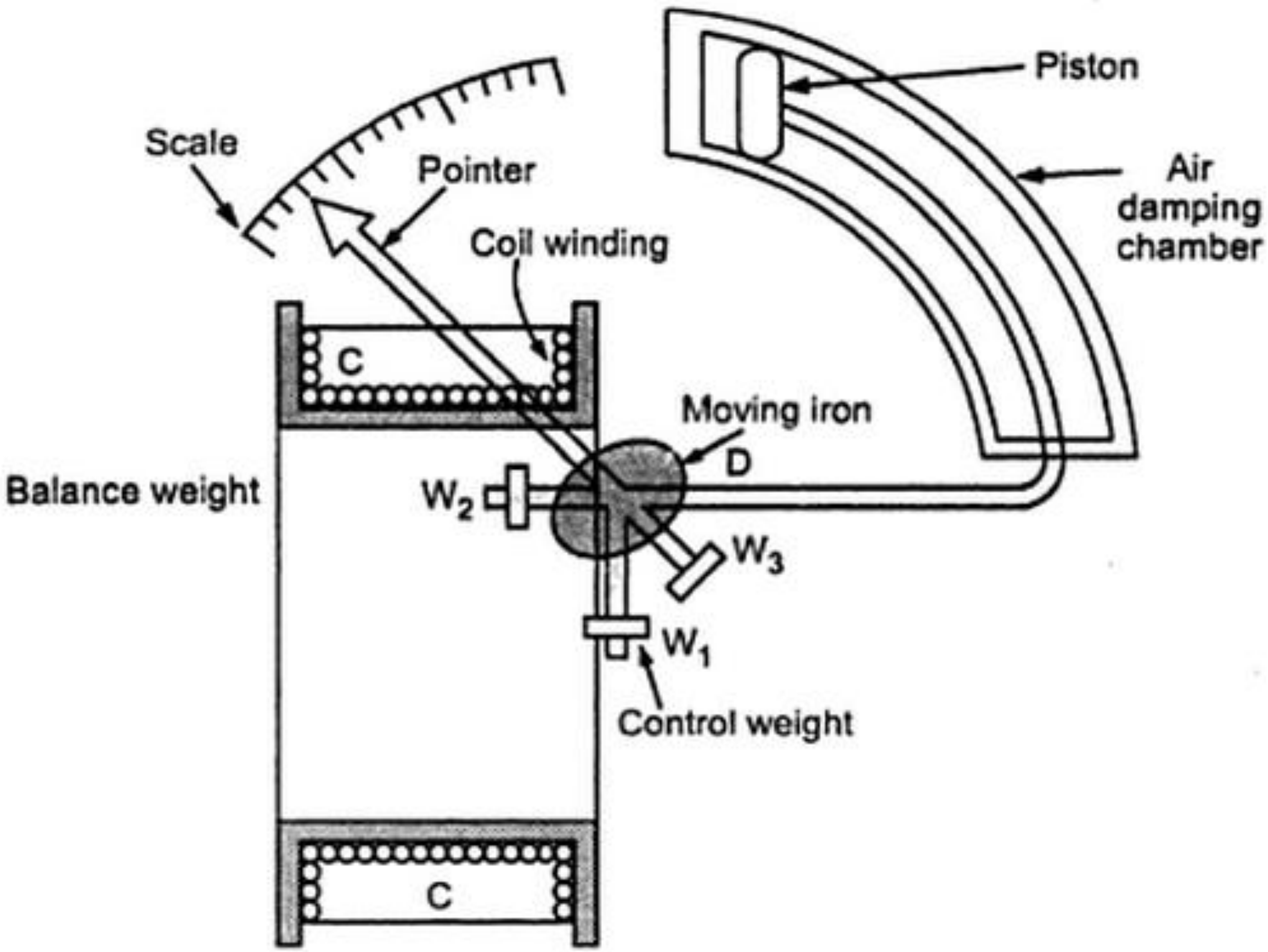
1. Since torque/weight ratio is small, such instruments have *low sensitivity.*
2. The *scale is not uniform* because $\theta \propto \sqrt{I}$.
3. Cost of these instruments is *higher* in comparison to those of moving-iron instruments. So, these are *only used as voltmeters and ammeters for precision measurements.*
4. *Higher frictional losses.*
5. These instruments are sensitive to overloads and mechanical impacts. Therefore, they *must be handled with care.*
6. In these instruments the operating current is large and consequently they have a *higher power consumption than PMMC* instruments.

MOVING IRON TYPE INSTRUMENTS

- Moving iron instruments are used in labs and switch boards at commercial frequencies
- They are cheaper and more accurate

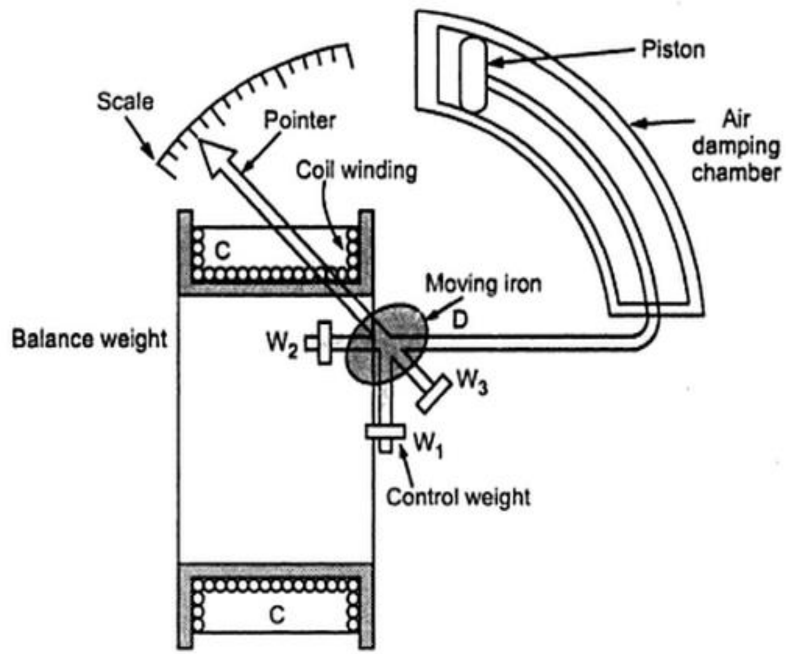


ATTRACTION TYPE MOVING IRON INSTRUMENTS



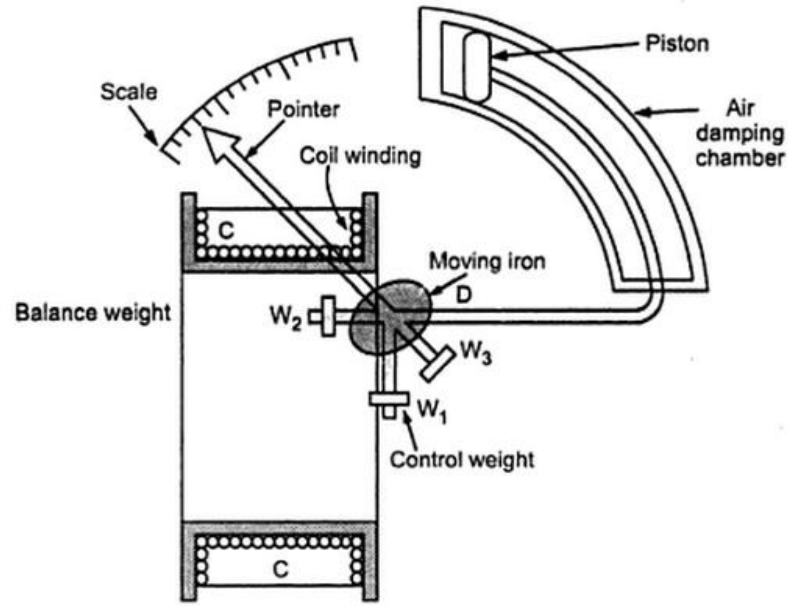
ATTRACTION TYPE MOVING IRON INSTRUMENTS

- Principle:
  - Soft iron piece brought near a magnet will get attracted to the magnet



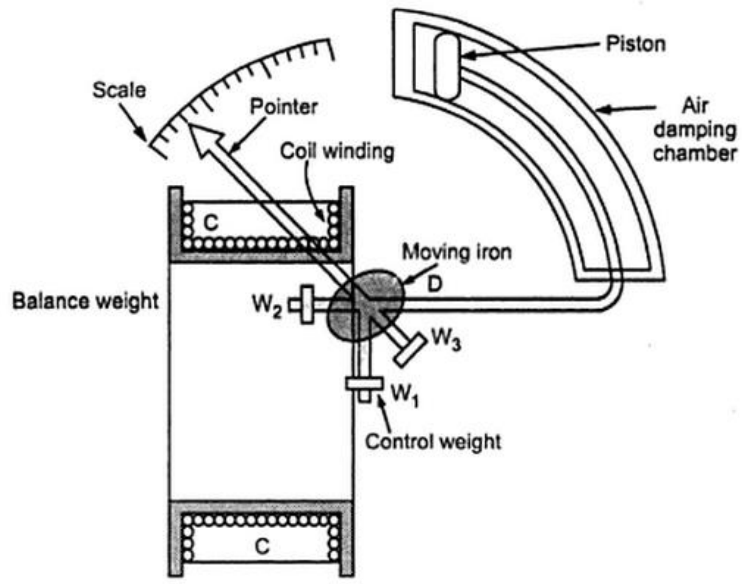
ATTRACTION TYPE MOVING IRON INSTRUMENTS

- Construction:
  - Fixed coil C
  - Moving iron D
  - Coil is flat and has narrow slot like opening
  - Moving iron is flat disc which is eccentrically mounted on spindle



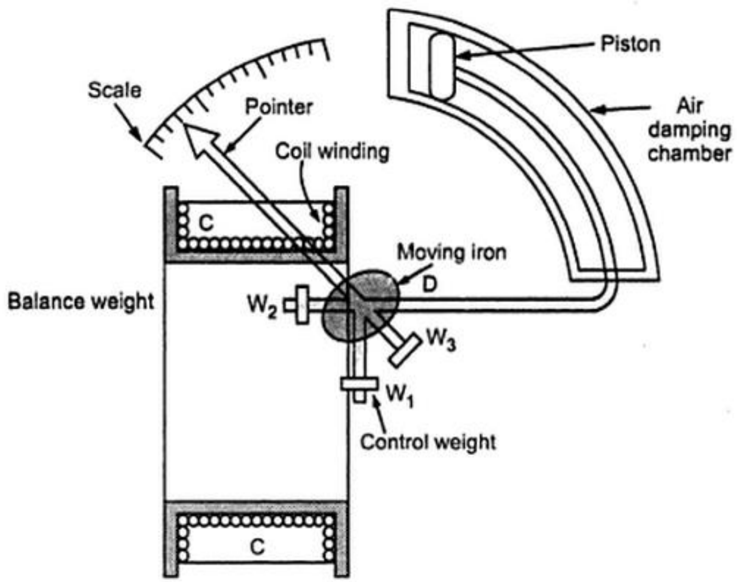
ATTRACTION TYPE MOVING IRON INSTRUMENTS

- Spindle is supported on jewel bearings
- Spindle carries pointer which moves over graduated scale
- Number turns of coil depend on range of instrument
- For high current, low number of turns is required



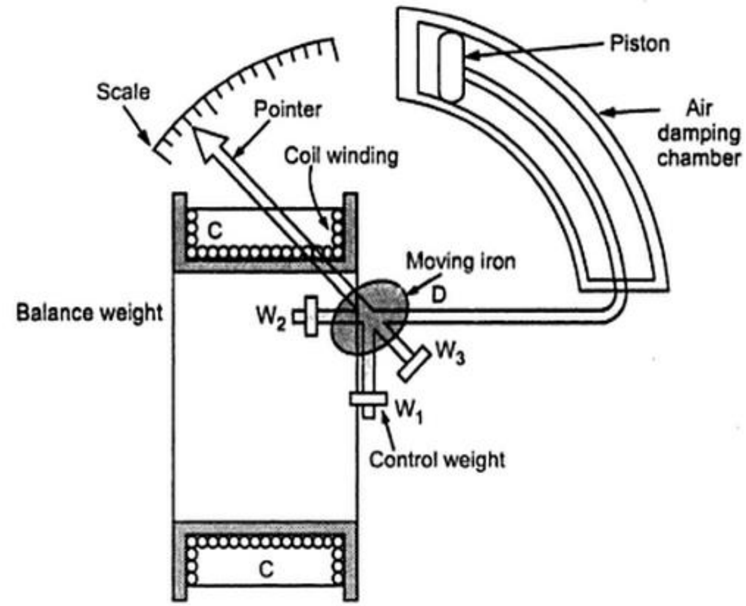
ATTRACTION TYPE MOVING IRON INSTRUMENTS

- Control torque is produced by spring or gravity control
- For vertically mounted type instruments, gravity control is used



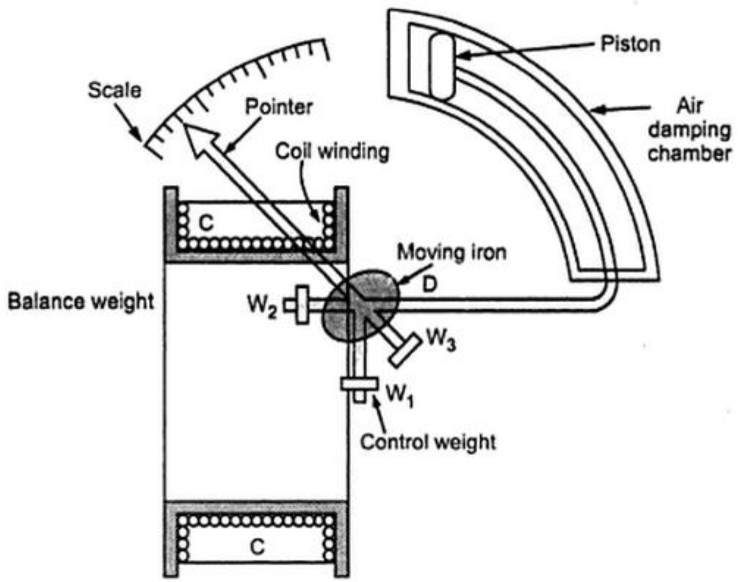
ATTRACTION TYPE MOVING IRON INSTRUMENTS

- Damping torque is provided by air friction damping
  - A light Al piston is attached to moving system
  - It moves in a closed chamber
- Air friction damping can also be given by vanes attached to moving system
- Since operating field is weak, eddy current damping is not used



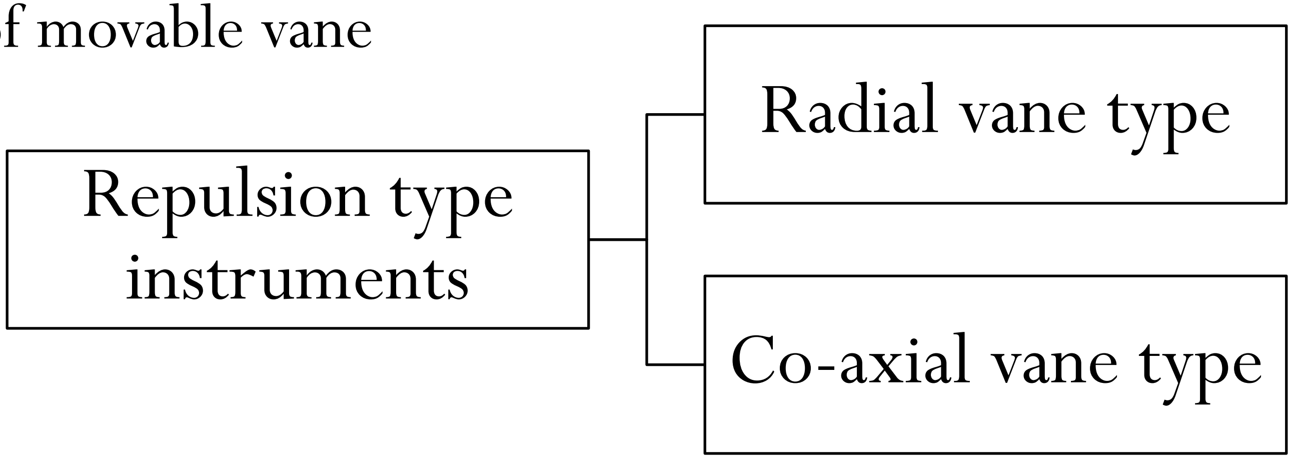
ATTRACTION TYPE MOVING IRON INSTRUMENTS

- Working:
  - Coil C is energized
  - Moving iron disc will get attracted towards the coil
  - So deflecting torque is produced by electromagnetic action
  - Pointer deflects from zero position
  - Control torque is provided by gravity or spring control
  - Damping torque is provided by air friction damping

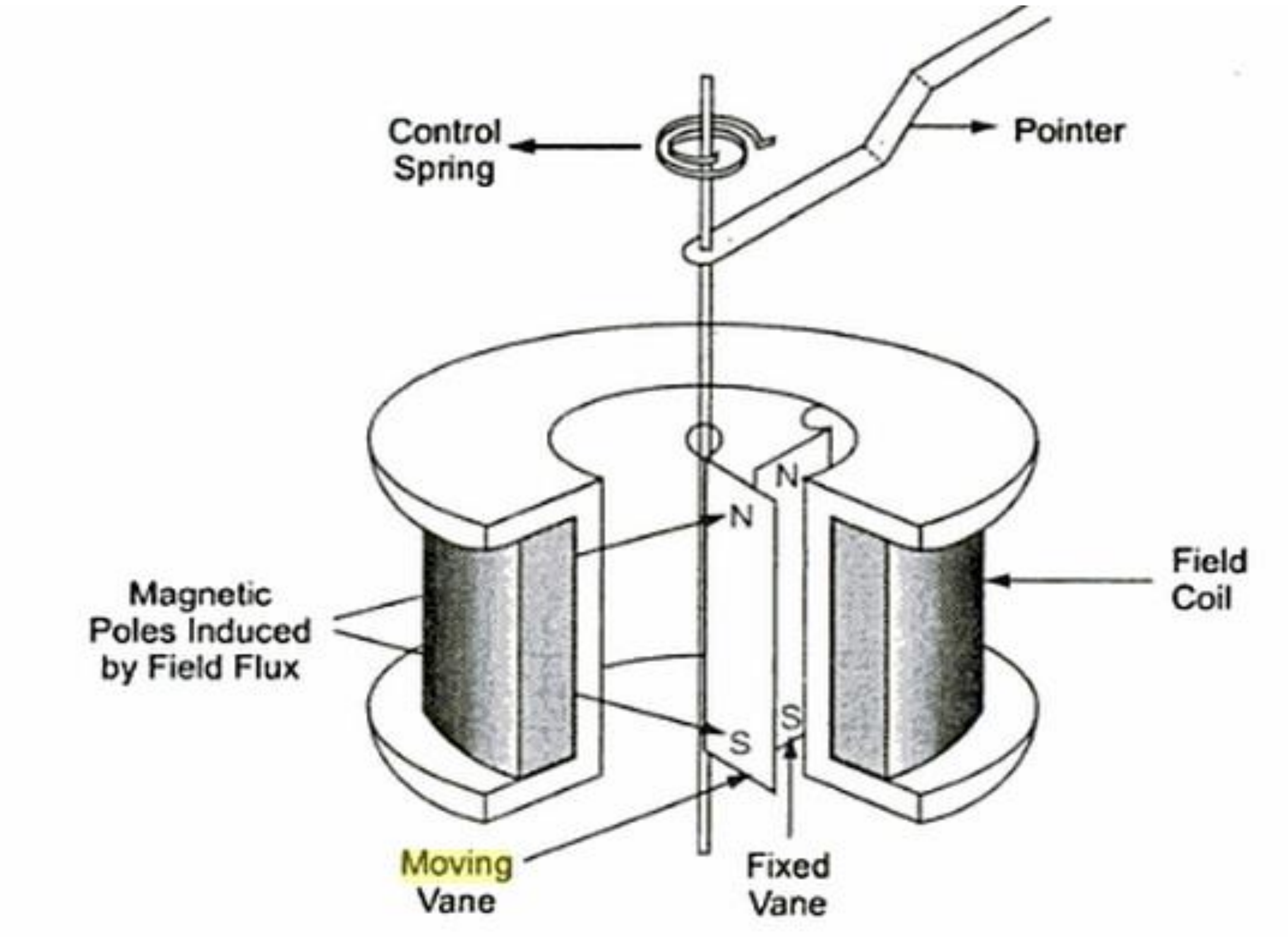


REPULSION TYPE
MOVING IRON INSTRUMENTS

- These type of instruments have two vanes inside the coil, one is fixed and other is movable
- When current passes through the coil, vanes gets magnetized with same polarities on same side
- So there is a repulsion between two vanes causing the motion of movable vane

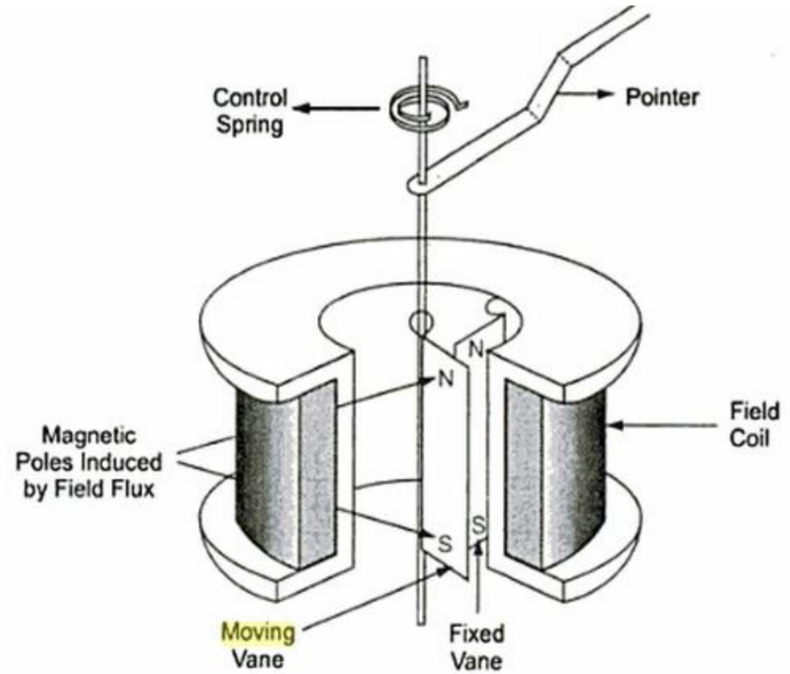


RADIAL VANE REPULSION TYPE MOVING IRON INSTRUMENTS



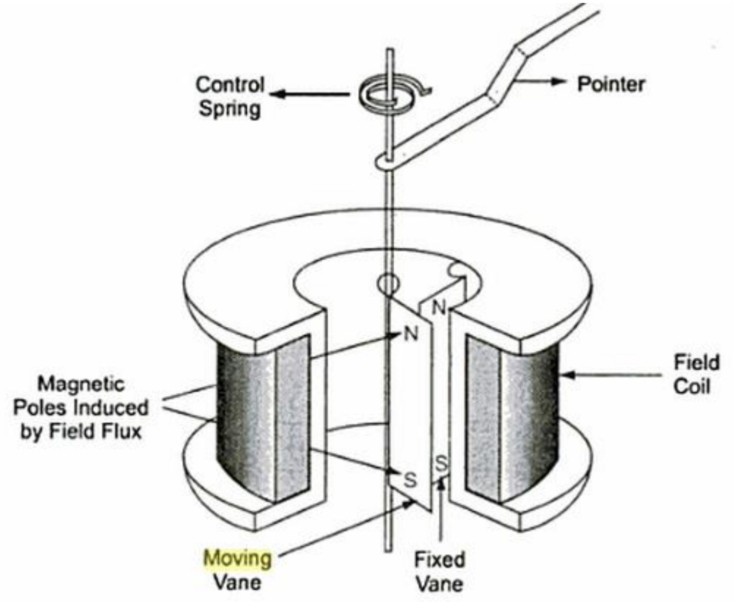
RADIAL VANE REPULSION TYPE MOVING IRON INSTRUMENTS

- Compared to othe MI instruments this is more sensitive and has a linear scale
- The two vanes are radial strips of iron
- Fixed vane is attached to coil
- Movable vane is attached to spindle and suspended in induction field
- Pointer is attached to movable vane

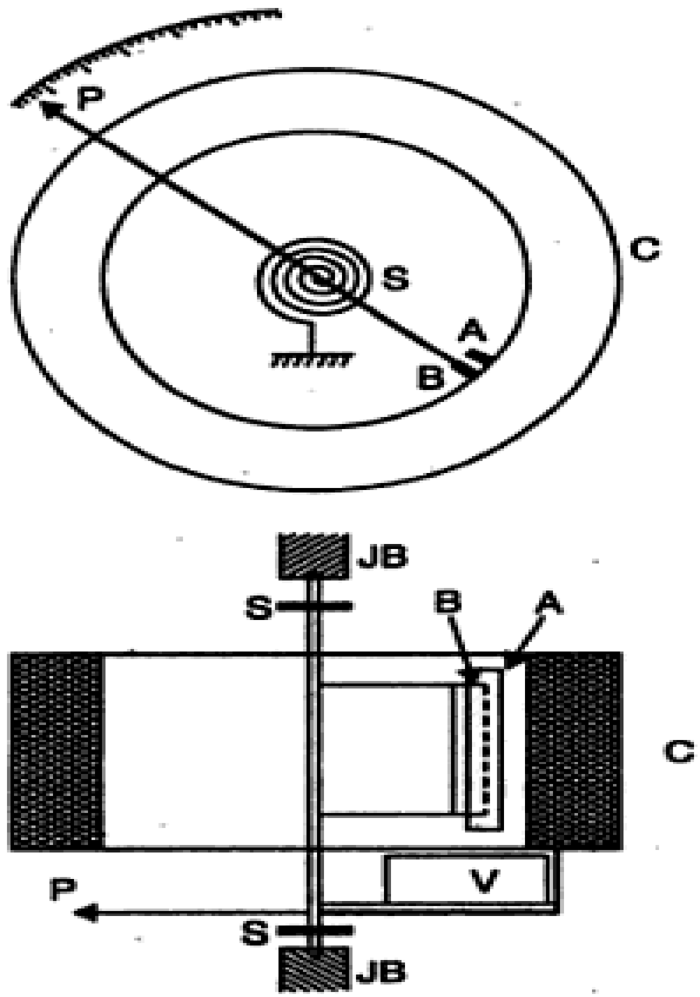


RADIAL VANE REPULSION TYPE MOVING IRON INSTRUMENTS

- Current through the coil is alternating
- Like poles of fixed and moving vanes repel
- So deflection will always be in the same direction
- The deflection is proportional to square of current and calibrated in voltage or amperes
- Calibration is only accurate in designed frequency, since impedance is different for various frequencies

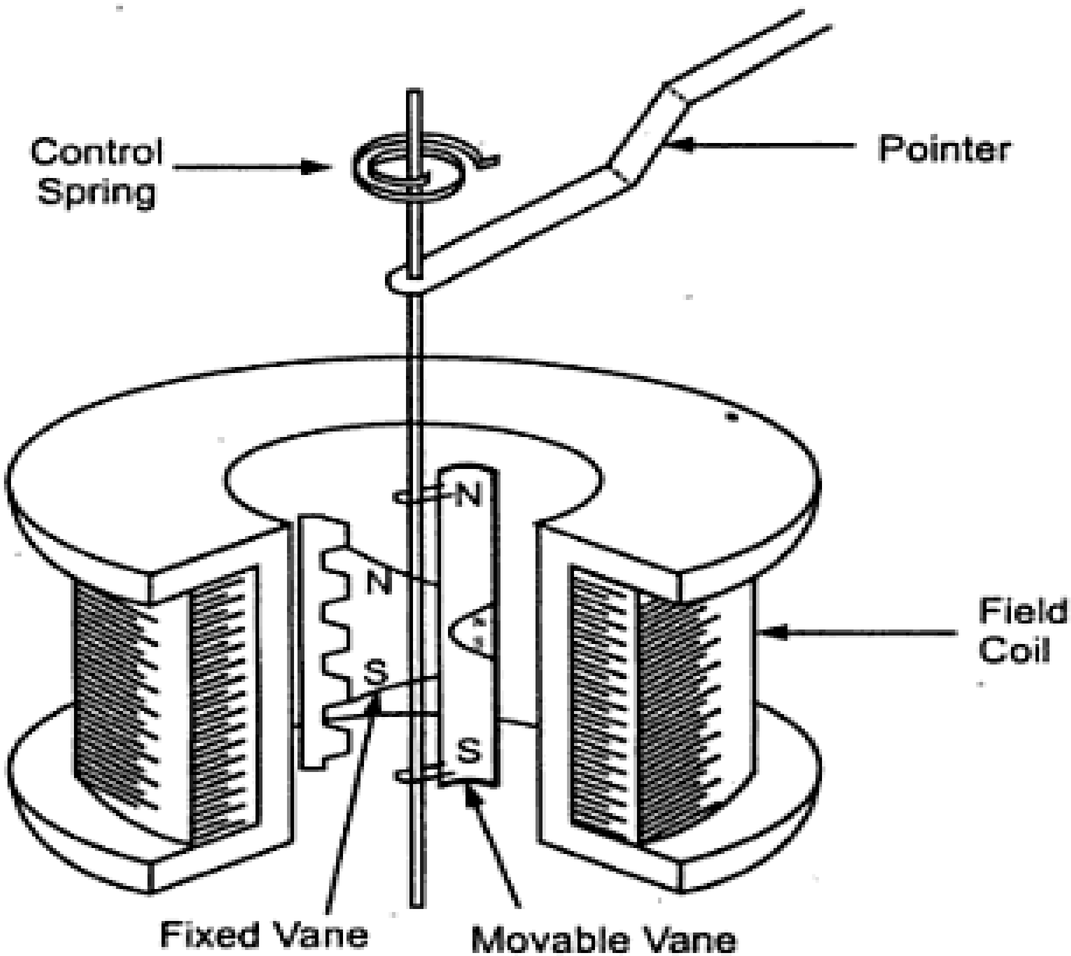


TOP VIEW AND SIDE VIEW OF RADIAL VANE REPULSION TYPE INSTRUMENT



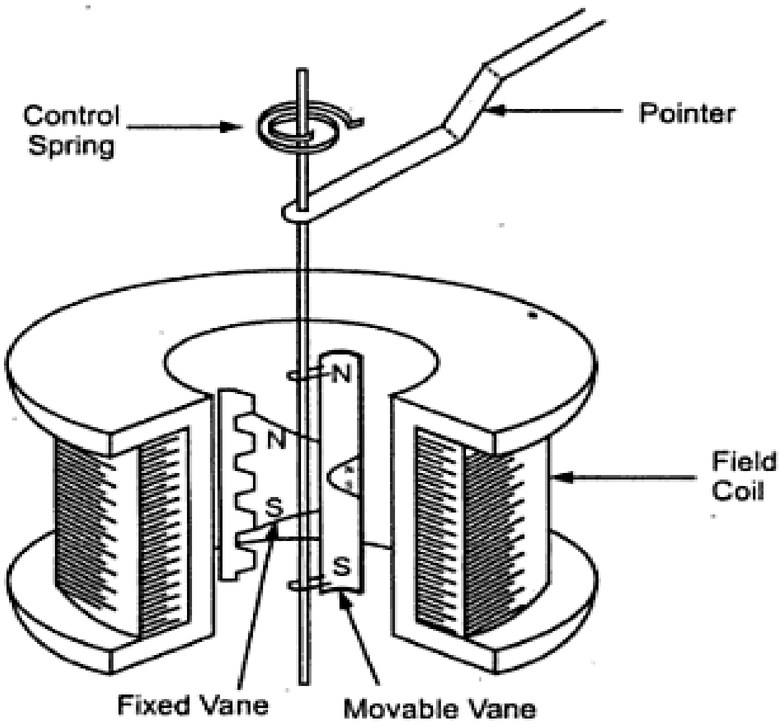
A = Fixed iron
B = Moving iron
C = Solenoid/Coil
JB = Jewelled bearing
S = Spring
V = Vane
P = Pointer

CO AXIAL VANE REPULSION TYPE MOVING IRON INSTRUMENTS



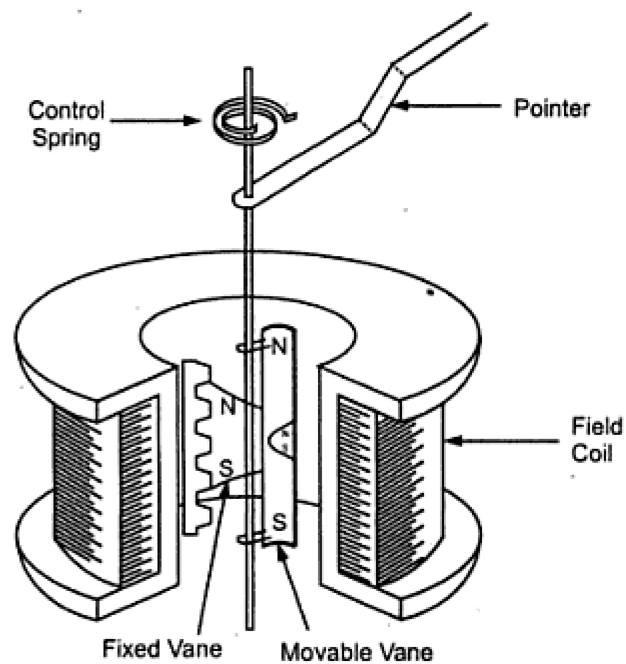
CO AXIAL VANE REPULSION TYPE MOVING IRON INSTRUMENTS

- Construction
  - It has two concentric vanes
  - Hence called concentric vane type instrument
  - One vane is attached rigidly to coil frame
  - Other vane can rotate co axially inside the stationary vane



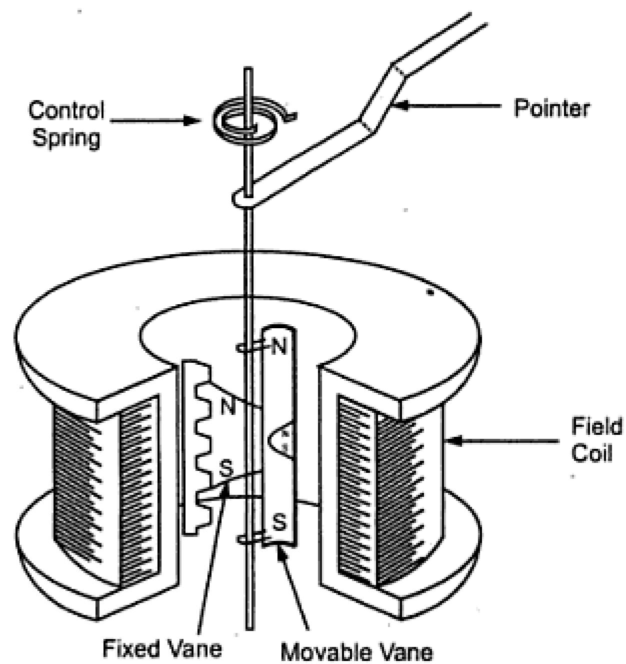
CO AXIAL VANE REPULSION TYPE MOVING IRON INSTRUMENTS

- Working
  - Coil is energized
  - Two vanes gets magnetized with same polarity
  - So they repel each other
  - Repulsion causes deflection of pointer
  - Deflection is proportional to square of current through the coil
  - Since square law response is there, scale is non uniform



CO AXIAL VANE REPULSION TYPE MOVING IRON INSTRUMENTS

- It can be used for both ac and dc measurements



TORQUE EQUATION OF MOVING IRON INSTRUMENTS

Consider a small increment in current supplied to the coil of the instrument.Due to this current let $d\theta$ be the deflection under the deflecting torque T_d. Due to such deflection, some mechanical work will be done.

$$\therefore \text{ Mechanical work } = T_d d\theta$$

TORQUE EQUATION OF MOVING IRON INSTRUMENTS

- Change in energy stored due to change in inductance
- This is because vanes try to occupy a position of minimum reluctance

Let

I = initial current

L = instrument inductance

θ = deflection

dI = increase in current

$d\theta$ = change in deflection

dL = change in inductance

TORQUE EQUATION OF MOVING IRON INSTRUMENTS

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

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

$$= I\frac{dL}{dt} + L\frac{dI}{dt} \qquad \text{as both I and L are changing.}$$

The electrical energy supplied is given by,

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

The stored energy increases from $\frac{1}{2}LI^2$ to $\frac{1}{2}(L+dL)(I+dI)^2$

TORQUE EQUATION OF MOVING IRON INSTRUMENTS

Hence the change in the stored energy is given by,

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

Neglecting higher order terms, this becomes, $IL\,dI + \frac{1}{2} I^2\,dL$

The energy supplied is nothing but increase in stored energy plus the energy required for mechanical work done.

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

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

TORQUE EQUATION OF MOVING IRON INSTRUMENTS

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

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

While the controlling torque is given by,

$$\boxed{T_c = K\,\theta}$$

where K = spring constant

$$\therefore \qquad K\,\theta = \frac{1}{2} I^2 \frac{dL}{d\theta} \qquad \text{under equilibrium}$$

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

Thus the deflection is proportional to the square of the current through the coil. And the instrument gives square law response.

ADVANTAGES OF MI INSTRUMENTS

1) The instruments can be used for both a.c. and d.c. measurements.
2) As the torque to weight ratio is high, errors due to the friction are very less.
3) A single type of moving element can cover the wide range hence these instruments are cheaper than other types of instruments.
4) There are no current carrying parts in the moving system hence these meters are extremely rugged and reliable.
5) These are capable of giving good accuracy. Modern moving iron instruments have a d.c. error of 2% or less.
6) These can withstand large loads and are not damaged even under severe overload conditions.
7) The range of instruments can be extended.

DISADVANTAGES OF MI INSTRUMENTS

1) The scale of the moving iron instruments is not uniform and is cramped at the lower end. Hence accurate readings are not possible at this end.
2) There are serious errors due to hysteresis, frequency changes and stray magnetic fields.
3) The increase in temperature increases the resistance of coil, decreases stiffness of the springs, decreases the permeability and hence affect the reading severely.
4) Due to the non linearity of B-H curve, the deflecting torque is not exactly proportional to the square of the current.
5) There is a difference between a.c. and d.c. calibrations on account of the effect of inductance of the meter. Hence these meters must always be calibrated at the frequency at which they are to be used. The usual commercial moving iron instrument may be used within its specified accuracy from 25 to 125 Hz frequency range.
6) Power consumption is on higher side.

ERRORS IN MI INSTRUMENTS

1) **Hysteresis errors :** Due to hysteresis effect, the flux density for the same current while ascending and descending values is different. While descending, the flux density is higher and while ascending it is lesser. So meter reads higher for descending values of current or voltage. So remedy for this is to use smaller iron parts which can demagnetise quickly or to work with lower flux densities.

ERRORS IN MI INSTRUMENTS

2) **Temperature error :** The temperature error arises due to the effect of temperature on the temperature coefficient of the spring. This error is of the order of 0.02% per ℃ change in temperature. 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. Hence manganin is generally used for the series resistances.

ERRORS IN MI INSTRUMENTS

3) **Stray magnetic field error :** The operating magnetic field in case of moving iron instruments is very low. Hence effect of external i.e. stray magnetic field can cause error. This effect depends on the direction of the stray magnetic field with respect to the operating field of the instrument.

SHUNTS AND MUTIPLIERS

- Refer notebook