R. V. S. College of Engineering and Technology, Jamshedpur

Class notes: Fundamental of Measurement and Sensors (FMS)

Branch: CSE, EEE & ECE

2^{nd} Semester

Unit-I: Introduction of measuring Systems

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CLASSIFICATION OF INSTRUMENTS:

There are many ways in which instruments can be classified. Broadly instruments are classified into two categories:

1. Absolute instruments
2. Secondary instruments.

1) Absolute instruments: These instruments give the quantity under measurement in terms of the physical constant of the instrument.

Example: Tangent galvanometer, Rayleigh's current balance

2) Secondary instruments: These instruments are so constructed that the quantity being measured can only be measured by observing the output indicated by the instrument. These instruments are calibrated by comparing with an absolute instrument. Secondary instruments are most commonly used one.

Example: volt meter, glass thermometer and pressure gauge.

ANALOG AND DIGITAL INSTRUMENTS:

Secondary instruments works in two modes:

1. Analog mode and 2. Digital mode

1. Analog mode: Signals that vary in a continuous manner and take on an infinite number of values in any given range are called analog signals. The devices which produce these signals are called analog devices. Instruments constructed using analog devices are called analog instruments.

2. Digital mode: Signals vary in discrete steps and thus take up only finite different values in a given range are called digital signals. The devices which produce these signals are called digital devices. Instruments designed using these devices are called digital instruments.

The importances of digital instruments are increasing because of the increasing use of digital computers in automatic control systems. But the majority of the instruments are analog type. Hence it is necessary to have analog to digital computers at the input and digital to analog computers at the output of the computers.

INDICATING INSTRUMENTS: An indicating instrument consists of a moving system pivoted in jewel bearings. A pointer is attached to the moving system which indicates the electrical quantity to be measured on a graduated scale. In order to ensure the proper operation of the instruments, the following three torques are required.

1. Deflecting toque
2. Controlling torque
3. Damping torque

Example: Ammeter, voltmeter, etc.

Deflecting Force: The deflecting force is required for moving the pointer from its zero position. The system producing the deflecting force is called "deflecting system". Deflecting system converts the electric current (or) voltage into a mechanical force called deflecting force.

Deflecting force is provided by magnetic effect

Controlling Force: Controlling force is equal and opposite to the deflecting force at the final steady position of pointer in order to make the deflection of the pointer definite for a particular magnitude of current. Controlling force bring the moving system back to zero when deflecting force is removed.

Controlling force is provided by springs.

Damping Force: Damping force is the force required to damp the oscillations of pointer about its final steady position, so that pointer comes to the final position rapidly and smoothly without oscillation. These are difference methods of producing damping. They are

1. Air friction damping
2. Eddy current damping
3. Fluid friction damping
4. Electromagnetic damping

RECORDING INSTRUMENTS: Instruments that give a continuous record of the quantity being measured over a specified period is called recording instruments. The variations of quantity being measured are recorded by pen on a sheet of paper.

Example: Recording voltmeter on a substation which keeps record of the variation of supply voltage during the day.

INTEGRATING INSTRUMENTS: Integration means continuous summation. Integrating instruments totalize the events over a period of time. The summation which they give is a product of time and an electrical quantity.

Example: Ampere hour and watt hour meter.

INTRODUCTION: Current, voltage and resistance can be measured by Ammeter, Voltmeter and Ohmmeter respectively. Ammeters and Voltmeters are of Moving coil, Moving iron, Dynamometer, Induction, Electrostatic or rectifier type. Resistance can be measured by Bridge circuits, Megger, Earth tester and Millimeter.

Moving coil instruments, which are used to measure only DC currents and voltages are of Permanent Magnet Moving Coil(PMMC) type, and which are used to measure both AC & DC currents and voltages are of Dynamometer type. Moving iron which are used to measure both AC & DC currents and voltages are of two types, namely, Attraction and Repulsion type. Induction type instruments, which are used to measure only AC currents and voltages are of Shaded pole type. Apart from these, Electrostatic instruments are also used to measure DC voltages and Rectifier type instruments are used for AC measurements, by using a rectifier to convert AC into a unidirectional DC and then, to use a DC meter, to indicate the value of rectified AC.

Types of Instruments: The main types of instruments used as ammeters and voltmeters are:

1. Moving coil
    - i. Permanent magnet type (PMMC) D.C
    - ii. Dynamometer type (A.C/D.C)
2. Moving iron
    - i. Attraction type (A.C/D.C)
    - ii Repulsion type (A.C/D.C)
3. Hotwire instrument
4. Thermocouple
5. Induction type (A.C)

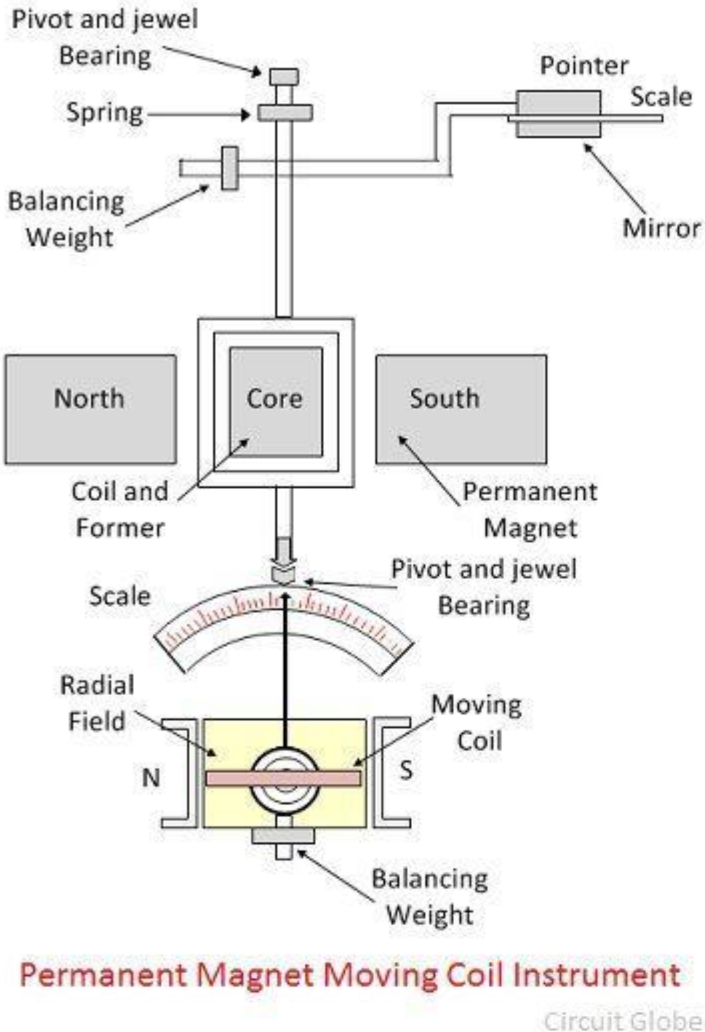
6. Electrostatic (A.C/D.C),

7. Rectifier type

MOVING COIL INSTRUMENTS

PERMANENT MAGNET MOVING COIL (PMMC) INSTRUMENTS CONSTRUCTIO

It consists of a coil wound on an aluminum frame between two poles of a permanent magnet, with soft iron pole pieces. Between the pole pieces, a soft iron cylinder is placed, to provide a uniform magnetic field. Ends of the coil are connected with two Phosphor-Bronze springs. It has a pointer which moves over a uniform scale. The spindle connected with the pointer is supported by two jewel bearings.



Permanent Magnet Moving Coil Instrument

Moving Coil – The coil is the current carrying part of the instruments which is freely moved between the stationary field of the permanent magnet. The current passes through the coil deflects it due to which the magnitude of the current or voltage is determined. The coil is mounted on the rectangular former which is made up of aluminium. The former increases the radial and uniform magnetic field between the air gap of the poles. The coil is wound with the silk cover copper wire between the poles of a magnet.

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Magnet System – The PMMC instrument using the permanent magnet for creating the stationary magnets. The Alcomax and Alnico material are used for creating the permanent magnet because this magnet has the high coercive force (The coercive force changes the magnetisation property of the magnet). Also, the magnet has high field intensities.

Control – In PMMC instrument the controlling torque is because of the springs. The springs are made up of phosphorous bronze and placed between the two jewel bearings. The spring also provides the path to the lead current to flow in and out of the moving coil. The controlling torque is mainly because of the suspension of the ribbon.

Damping – The damping torque is used for keeping the movement of the coil in rest. This damping torque is induced because of the movement of the aluminium core which is moving between the poles of the permanent magnet.

Pointer & Scale – The pointer is linked with the moving coil. The pointer notices the deflection of the coil, and the magnitude of their deviation is shown on the scale. The pointer is made of the lightweight material, and hence it is easily deflected with the movement of the coil. Sometimes the parallax error occurs in the instrument which is easily reduced by correctly aligning the blade of the pointer.

Torque Equation for PMMC Instrument

The deflecting torque induces because of the movement of the coil. The deflecting torque is expressed by the equation shown below.

$$T_d = NBLdI \ldots\ldots equ(1)$$

Where, N – Number of turns of coil
B – flux density in the air gap
l & d - the vertical and horizontal length of the side.
I - current through the coil.

$$Let, \quad G = NBld \ldots\ldots. equ.-2$$

$$\therefore T_d = GI$$

The spring provides the restoring torque to the moving coil which is expressed as:

$$T_c = K\theta \qquad \ldots\ldots(3)$$

Where, $K = Spring\ constant$

For final from equation (1) and (3) we get,

$$T_c = T_d$$

For final from equation (1) and (3) we get,

$$K\theta = GI$$

$$\theta = \frac{GI}{K} \qquad \ldots(4)$$

$$I = \frac{K}{G}\theta \qquad \ldots(5)$$

The above equation shows that the deflection torque is directly proportional to the current passing through the coil.

Reason for the suitability of PMMC instruments for DC only: The deflection of the pointer ϴ depends upon the polarity of the supply. For one polarity, deflecting torque is forward and the pointer shows forward reading. When the polarity is reversed, deflection of the pointer is also reversed and the meter indicates negative reading. In AC, the polarity reversals of 100 times per second for a 50 Hz supply cannot permit the pointer to move forward or reverse. If AC supply is given to a PMMC instrument, it just vibrates and no readings shown.

Advantages of PMMC Instruments:

The following are the advantages of the PMMC Instruments.

A. The scale of the PMMC instruments is correctly divided.
B. The power consumption of the devices is very less.
C. The PMMC instruments have high accuracy because of the high torque weight ratio.
D. The single device measures the different range of voltage and current. This can be done by the use of multipliers and shunts.
E. The PMMC instruments use shelf shielding magnet which is useful for the aerospace applications.

Disadvantages of PMMC Instruments

The following are the disadvantages of the PMMC instruments.

A. The PMMC instruments are only used for the direct current. The alternating current varies with the time. The rapid variation of the current varies the torque of the coil. But the pointer can't follow the fast reversal and the deflection of the torque. Thus, it cannot use for AC.
B. The cost of the PPMC instruments is much higher as compared to the moving coil instruments.

The moving coil itself provides the electromagnetic damping. The electromagnetic damping opposes the motion of the coil which is because of the reaction of the eddy current and the magnetic field.

MOVING IRON INSTRUMENTS

There are two types of moving iron instruments:

1. Attraction type

2. Repulsion type

A) ATTRACTION TYPE MOVING IRON INSTRUMENT CONSTRUCTION: It has a coil wound on a hollow cylindrical bobbin, a small soft iron piece, eccentrically mounted just outside the coil, a pointer and damping lever attached to a spindle, control weight, balance weight and a scale as shown in figure below.

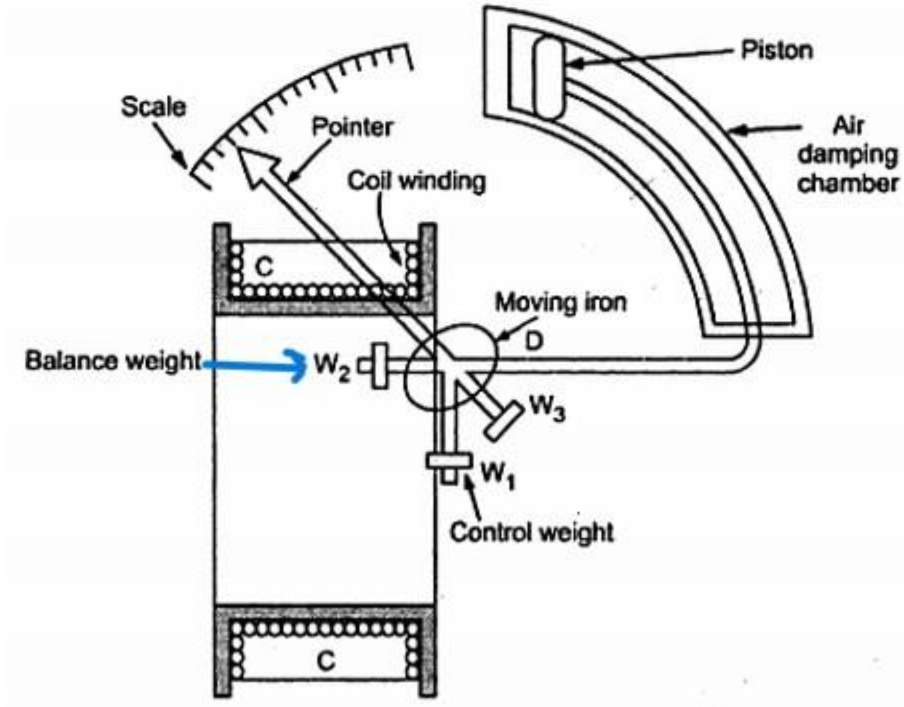


Fig2.2 Moving Iron (Attraction Type) Instrument

WORKING: When this instrument is connected to measure current or voltage in a circuit, a current is passed through the coil and a strong magnetic field is produced. The oval shaped soft iron piece is pulled within the bobbin, and thus, a deflecting torque is produced. The spindle connected with the soft iron piece also deflects and the pointer moves over a scale. Controlling force is obtained by air friction damping. Damping system consists of a vane in a sector shaped chamber.

B) REPULSION TYPE MOVING IRON INSTRUMENT

CONSTRUCTION: It consists of the following parts.

a. A hollow cylindrical bobbin carrying a coil
b. Two soft iron pieces or vanes
c. Placed face to face inside the bobbin
d. A pointer attracted with a spindle, which moves on a graduated scale, arrangements for spring control on spindle and arrangements for air friction damping.

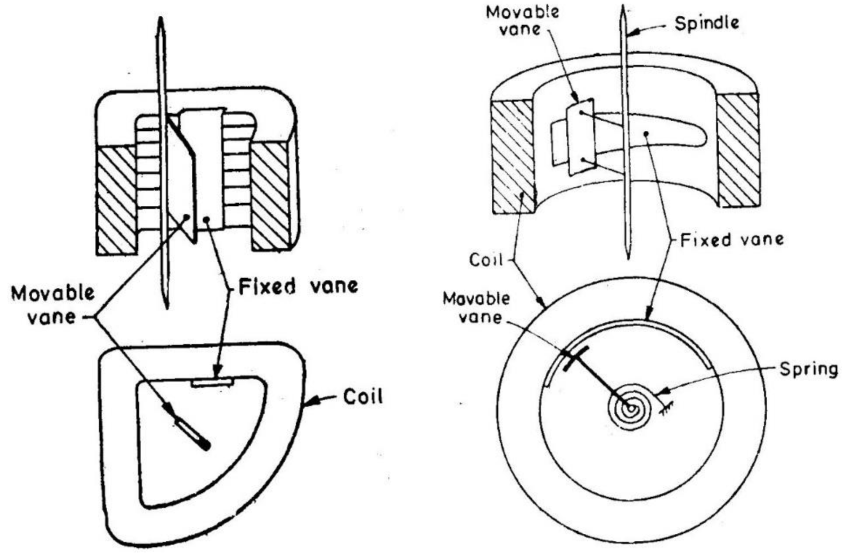


Fig2.3 Moving Iron (Repulsion Type) Instrument

WORKING: When a current is passed through the coil, a magnetic field is set up in the hollow cylindrical bobbin. The soft iron pieces/vanes get magnetized. Since the polarities of the two induced magnets are the same at both ends, they repel each other. Thus the pointer attached with the spindle moves over the scale.

TORQUE EQUATION FOR MOVING IRON INSTRUMENTS

Let, M= magnetic pole strength,

H= magnetic field strength,

F= force on the moving iron,

I= current flows through the coil,

θ= angle of deflection of the pointer,

The attractive or repulsive force on the moving iron= $F \propto H.H$

The attractive or repulsive force on the moving iron = $F \propto H^2$

Since H depends on I,

$$\therefore F \propto I^2$$

Deflecting torque is directly proportional to its force acted on the moving iron.

Therefore $T_d \propto I^2$

Controlling torque is directly proportional to the angle of deflection of the pointer.

Therefore $T_c \propto \theta$

At steady state deflection, deflecting torque is equal to controlling torque,

$$\therefore T_d = T_c$$

$$\Rightarrow \theta \propto I^2$$

Thus, it is proved that the deflection angle is directly proportional to square of the supply current.

REASON FOR USE IN BOTH AC & DC MEASUREMENTS: Since $\theta \propto I^2$ if the current reverses, I becomes –I and $(-I)^2$ becomes I^2, which is positive. So, irrespective of the supply polarity, the deflection will be forward/positive.

ADVANTAGES OF MOVING IRON INSTRUMENTS

a. Used to measure both AC & DC
b. Simple and robust construction
c. Less frictional errors
d. High accuracy
e. Greater scale length

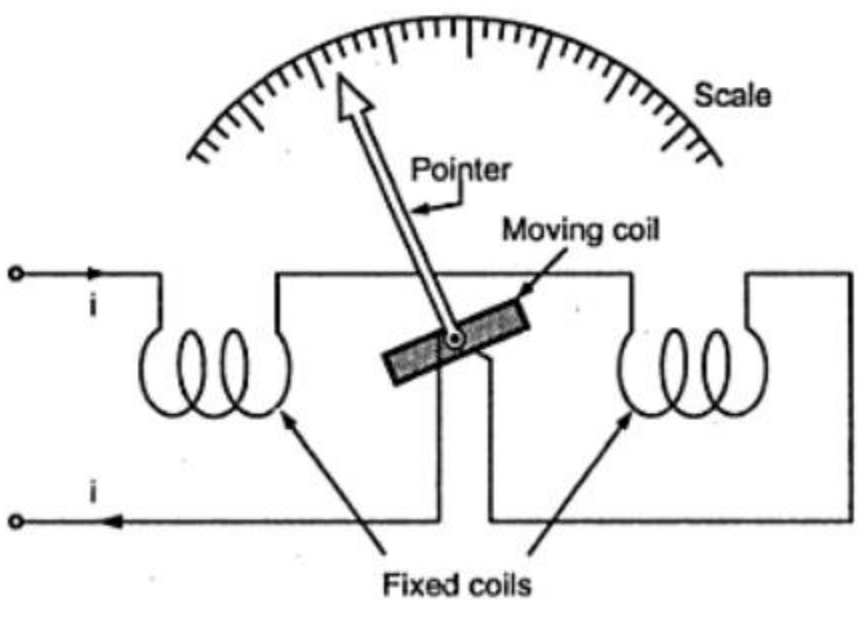
DISADVANTAGES OF MOVING IRON INSTRUMENTS

a. Non uniform scale
b. High power consumption at low voltages
c. Spring is affected by rise in temperature
d. Hysteresis and stray magnetic field errors possible.
e. Change of frequency also causes errors.

DYNAMOMETER TYPE INSTRUMENTS

PMMC instruments have permanent magnets. In dynamometer type instrument electromagnets are used. Similar to MC&MI instruments, they can also be used as ammeters and voltmeters.

CONSTRUCTION: To produce magnetic field, a fixed coil is used in these instruments. This coil is divided into two sections, and wound with heavy wire. Another coil, known as a moving coil is wound on a nonmetallic former and placed between the two parts of the fixed coil. It is a thin parts of the fixed coil. It is a thin wired coil of many turns and connected with a spindle with a pointer on top and jewel bearings at its two ends. Both the coils are air cored to avoid eddy current and hysteresis losses. Two springs made of phosphor bronze lead the current in and out of the moving coil.



Dynamometer Type Instrument

WORKING: When supply is applied to fixed (current) coil and moving (pressure) coils, a torque is produced in the moving coil which lies in the magnetic field of fixed coils. Controlling torque is achieved by spring control and damping torque by air friction damping.

Torque Equation

For AC Measurements

Let, I_1 = instantaneous value of current in the fixed coil in Ampere,

I_2 = instantaneous value of current in the moving coil in Ampere,

L_1 = self-inductance of fixed coil in H,

L_2 = self-inductance of moving coil in H,

M = mutual inductance between fixed and moving coil in H,

It can be proved that, Instantaneous deflecting torque = $T_i = I_1 I_2 dm/d\Theta$

Where Θ = deflection angle

For a complete cycle, for a time period of 'T' sec,

Deflecting torque $= \frac{1}{T}\int_0^T T_i dt$

$$T_d = I_1 I_2 \cos\emptyset dm/d\Theta$$

where, Ø = phase angle between I_1 & I_2

I_1, I_2 = runs value of current in coils

Controlling torque $= T_c = K\Theta$

At equilibrium, $T_d = T_c$

Therefore, $I_1 I_2 \cos\emptyset dm/d\Theta = K\Theta$

$$\Rightarrow \Theta = I_1 I_2/K \cos\emptyset dm/d\Theta$$

For ammeters, $I_1 = I_2 = I$ and $\emptyset = 0°$

Therefore, $T_d = I^2 \frac{dm}{d\Theta}$

and $\Theta = \frac{I^2}{K}. dm/d\Theta$

For voltmeters,

$$I_1 = I_2 = v/z \text{ and } \emptyset = 0°$$

Therefore, $T_d = (v/z)^2 dm/d\Theta$

For DC Measurements:

$$T_d = I_1 I_2 dm/d\Theta$$

$$T_c = K\theta$$

At steady state position, $T_d = T_c$

$\therefore I_1 I_2 dm/d\theta = K\theta$

$$\Rightarrow \theta = \frac{I_1 I_2}{K} dm/d\theta$$

Advantages:

a. Free from hysteresis and eddy current losses
b. High frequency
c. It can be used to measure both AC & DC
d. It is suitable for measuring rms value of voltages of sinusoidal and non-sinusoidal wave forms.

Disadvantages:

a. Low torque/weight ratio
b. High cost than pmmc of mi instruments
c. Sensitive to overloads
d. Consumers more power
e. Non-uniform scale
f. More frictional losses

WATTMETERS IN POWER MEASUREMENT:

Introduction to Wattmeter: A wattmeter is an electrical device used to measure the power consumed or supplied by an electrical circuit. It measures the rate at which electrical energy is being transferred, which is commonly referred to as power. The unit of power is the watt (W).

Watt meters are commonly used in various applications, such as electrical testing, power monitoring, energy management, and industrial control systems. They are essential tools for understanding and managing power consumption in electrical systems.

Working principle of a Wattmeter: A wattmeter is a device used for the measurement of electrical power in a circuit. It is an inherent combination of an ammeter and a voltmeter. Is has mainly two coils, namely the current coil (CC) and the potential coil (PC)

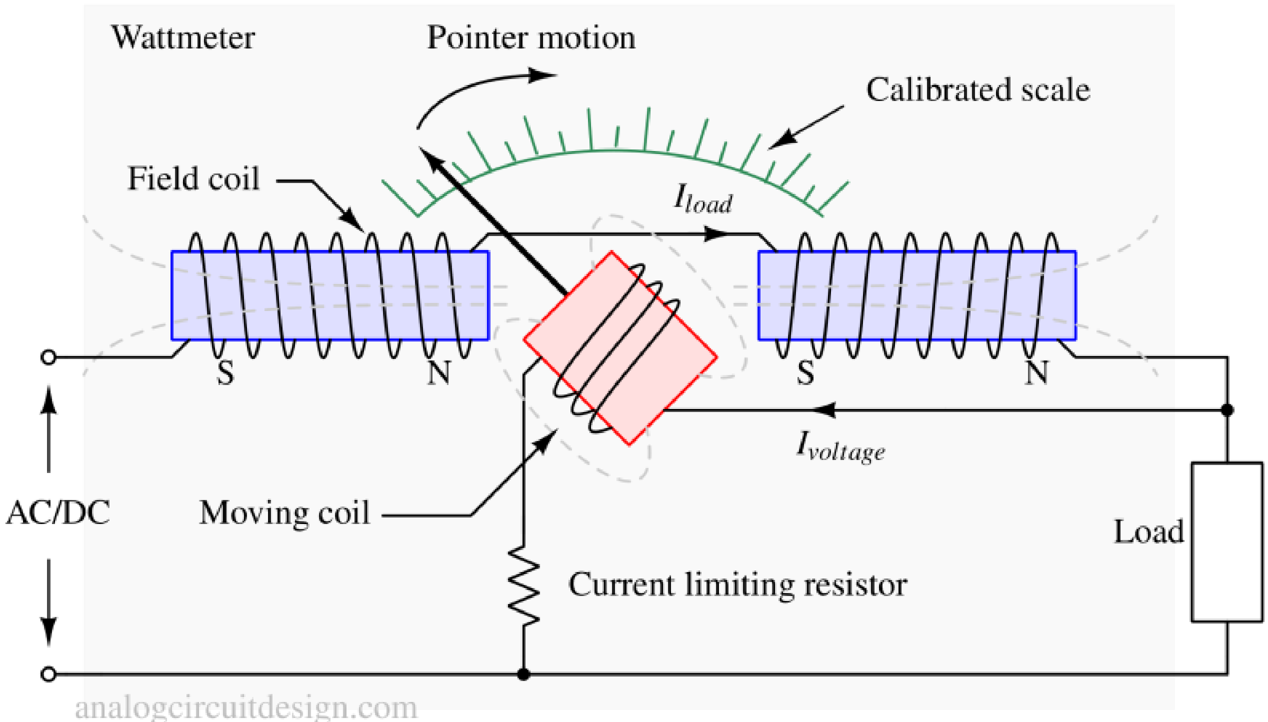
The principle of a wattmeter is based on the measurement of both current and voltage in an electrical circuit. It utilizes the relationship between these two variables to determine the power being consumed or supplied by the circuit.

Types of Wattmeter:

1. **Electrodynamometer Wattmeter:** Uses moving and fixed coils for AC power measurement, suitable for single phase and three-phase circuits.
2. **Induction Wattmeter:** Employs electromagnetic induction with a rotating disk for single-phase AC power measurement.
3. **Electrostatic Wattmeter:**
4. **Thermocouple Type Wattmeter:**
5. **Digital Wattmeter:** Utilizes digital technology for AC and DC power measurement, often with advanced features.

ELECTRODYNAMOMETER TYPE WATTMETER

This is similar in design and construction to electrodynamometer type ammeters and voltmeters. The fixed coils or current coil is connected in series with the load. The moving coil (voltages coil or pressure coil) is connected across the supply (load).



Electrodynamometer Wattmeter

- **Fixed coil**: – The fixed coil connects in series with the load. It is considered as a current coil because the load current flows through it. For making the construction easy the fixed coil divide into two parts. And these two elements are parallel connected to each other. The fixed coil produces the uniform electric field which is essentials for the working of the instruments. The current coil of the instruments is designed to carry the current of approximately 20 amperes for saving the power.
- **Moving Coil**: – The moving coil consider as the pressure coil of the instruments. It connects in parallel with the supply voltage. The current flows through them is directly proportional to the supply voltage. The pointer mounts on the moving coil. The movement of the pointer controls with the help of the spring. The current flows through the coil increases their temperature. The flows of currents control with the help of resistor which connects in series with the moving coil.
- **Control**: – The control system provides the controlling torque to the instruments. The gravity control and the spring control are the two types of control system. Out of two, the Electrodynamometer Wattmeter uses spring control system. The spring control system is used for the movement of the pointer.
- **Damping**: – The damping is the effect which reduces the movement of the pointer. In this Wattmeter the damping torque produces because of the air friction. The other types of damping are not used in the system because they destroy the useful magnetic flux.
- **Scales and pointers**: – The instruments use a linear scale because their moving coil moves linearly. The apparatus uses the knife edge pointer for removing the parallax error which causes because of oversights.

Dynamometer wattmeter use mirror type scales and knife edge pointers, to remove reading errors due to parallax.

Working of Electrodynamometer Wattmeter:

The Electrodynamometer Wattmeter has two types of coils; fixed and the moving coil. The fixed coil connects in series with the circuit whose power consumption use to be measured. The supply voltage applies to the moving coil. The resistor controls the current across the moving coil, and it is connected in series with it.

The pointer is fixed on the moving coil which is placed between the fixed coils. The current and voltage of the fixed and moving coil generate the two magnetic fields. And the interaction of these two magnetic fields deflects the pointer of the instrument. The deflection of the pointer is directly proportional to the power flows through it.

Torque equation:

For DC Input: Let

V→ be the supply voltage

I → be the load current

R→ be the resistance of the moving coil

The Current through the fixed coil is I_f = I, Current through the moving coil is I_m.

Since the moving coil is connected in parallel we can write

$$I_m = \frac{V}{R}$$

The deflecting torque is

$$T_d = I_m I_f = \frac{VI}{R}$$

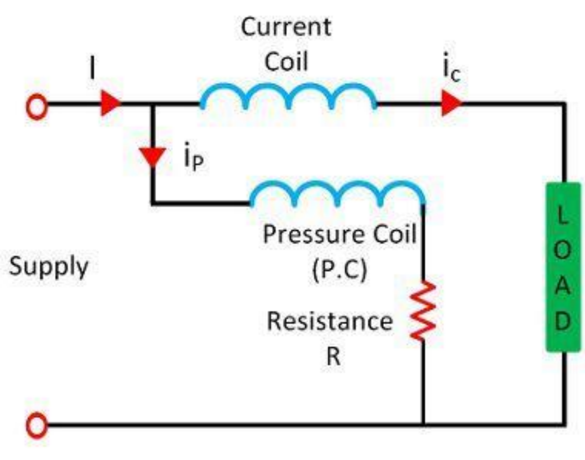
Since R is constant

$$T_d = VI$$

Deflecting torque is thus proportional to power.

For AC Input :

The expression for instantaneous torque in AC is given by,



Circuit of Electrodynamo Wattmeter

Circuit Globe

Where, ip – pressure coil current
ic– current coil current
dm/dθ – the rate of change of deflection of pointer concerning angle θ

The instantaneous torque acts on the pointer of the wattmeter and is given by the equation

$$T_i = i_p i_c \frac{dm}{d\theta}$$

Let the supply voltage is

$$v = \sqrt{2V} \sin \omega t$$

Let us assume that pressure coil has very high resistance and hence it is treated as a purely resistance. So,

$$i_p = \frac{V}{R} = \frac{\sqrt{2V} \sin \omega t}{R} = \sqrt{2}\ I_p \sin \omega t$$

$$I_p = \frac{V}{R}$$

Since the current coil is inductive, let us assume that i_c will lag supply voltage v by some angle φ. So let

$$i_c = \sqrt{2}\ I \sin\ (\omega t - \varphi)$$

Substituting in equation (i) we ge

$$T_i = (\sqrt{2}\ I_p \sin \omega t)(\sqrt{2}\ I \sin\ (\omega t - \varphi))\ \frac{dm}{d\theta}$$

$$= 2\ I_p\ I \sin \omega t \sin\ (\omega t - \varphi)\ \frac{dm}{d\theta}$$

$$= I_p\ I\ [2\sin \omega t\,.\sin\ (\omega t - \varphi)]\ \frac{dm}{d\theta}$$

$$= I_p\ I\ [\sin \varphi - \cos\ (\omega t - \varphi)]\ \frac{dm}{d\theta}$$

The average deflecting torque will be

$$T_d(average) = \frac{1}{T}\int_0^T \left[I_p\ I\ [\sin \varphi - \cos\ (\omega t - \varphi)]\ \frac{dm}{d\theta} \right] d(\omega t)$$

$$= I_p\ I\ \cos\ \varphi\ \frac{dm}{d\theta}$$

$$= \frac{V}{R}\ I\ \cos\ \varphi\ \frac{dm}{d\theta}$$

$$= \frac{P}{R}\ \frac{dm}{d\theta}$$

$$T_d(average) \propto P$$

Again controlling torque

$$T_d = k\theta$$

At equilibrium

$$\frac{P}{R}\frac{dm}{d\theta} = k\theta$$

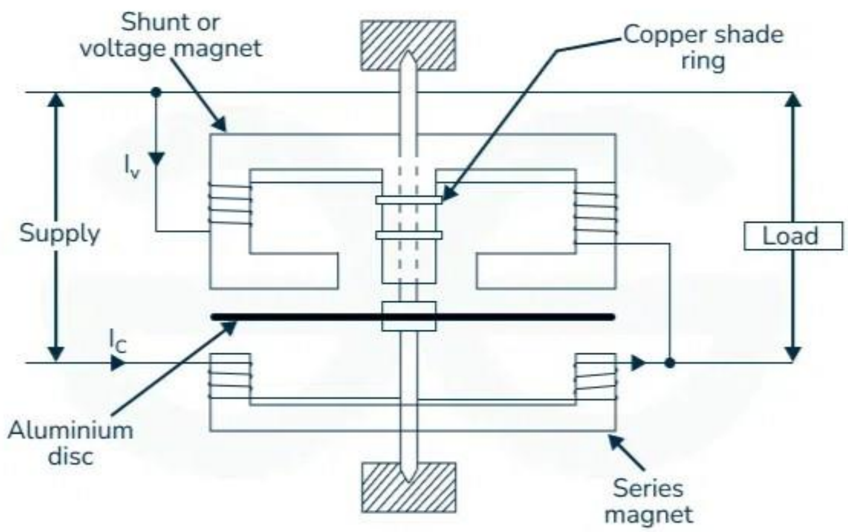
$$\frac{P}{R}\frac{dm}{d\theta} = k\theta$$

$$\Rightarrow P = \frac{k\theta R}{\frac{dm}{d\theta}}$$

Thus we can measure the power with the rate of change of deflection of pointer concerning angle θ.

Induction type wattmeter is used for only A.C. power measurement. Here the principle of mutual inductance is used for the measurement of A.C. power. It is used for such applications where frequency and supply voltage is constant.

Construction of Induction Type Wattmeter:



Induction type wattmeter has two laminated iron core electromagnets, namely the series magnet and the shunt magnet. The series electromagnet is excited by the load current and the shunt electromagnet is excited by the current proportional to the voltage of the circuit in which power is to be measured.

A aluminium disc is mounted between these two electromagnets in such a way so that it cuts both fluxes produced by these two electromagnets. These fluxes will produce eddy current in the aluminium disc. Due to the interaction between the flux and the eddy current of the disc a deflecting torque will be produced. The two voltage coils, connected in series are wound on the limbs of the shunt electromagnet in such a way so that both of them send flux through the central limb. The two current coils wound on the series electromagnet are connected in such a way so that both magnetize the core in the same direction. In order to make the resultant flux in the shunt magnet lag the applied voltage exactly by 90°, one or more copper rings, called shading bands are provided in the central limb of the shunt magnet. To obtain the correct phase difference between the series and shunt magnetic fluxes, the position of the copper bands are adjusted.

These type of wattmeter's also has spiral springs for controlling torque and a permanent magnet for damping torque. The scale of induction type wattmeter is almost uniform and extends over an angle of about 300°. Also this type of wattmeter can handle current up to 100A.

Operating Principle:

The phasor diagram of induction type wattmeter is shown in Fig.

Where,

V→ is the supply voltage.

I→ is the current through the current coil of the wattmeter.

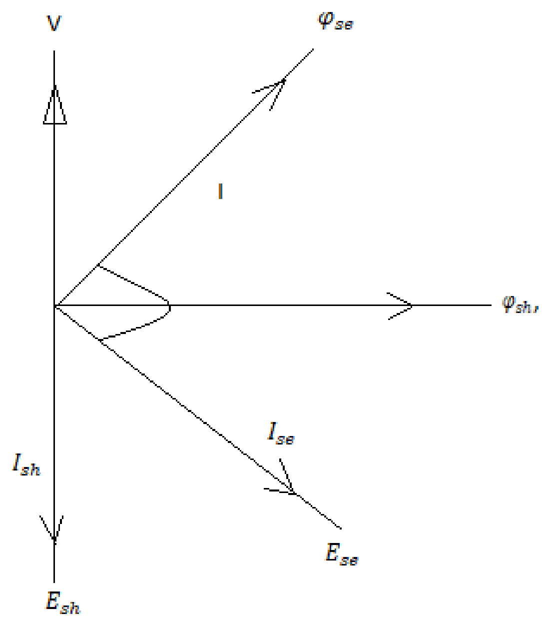
φ_{sh} →is the flux of the shunt electromagnet.

φ_{se} →is the flux of the series electromagnet.

E_{sh} → is the voltage induced due to flux φ_{sh}.

E_{se} → is the voltage induced due to flux φ_{se}.

I_{sh} I_{se}



Let,

$$\boldsymbol{V = V_m \ sin\ \omega t}$$

$$\boldsymbol{I = I_m \ sin\ (\omega t - \theta)}$$

Again,

$$\varphi_{se} \propto I$$

$$\Rightarrow \quad \varphi_{se} \propto \boldsymbol{I_m} \ \boldsymbol{sin}\ (\boldsymbol{\omega t} - \boldsymbol{\theta})$$

Also,

$$\varphi_{sh} \propto -\int V\, dt$$

$$\Rightarrow \quad \varphi_{sh} \propto -\int \boldsymbol{V_m} \ \boldsymbol{sin}\ \boldsymbol{\omega t}\, dt$$

$$\Rightarrow \quad \varphi_{sh} \propto -\frac{\boldsymbol{V_m}}{\omega} cos\, \omega t$$

Again

$$e_{sh} \propto \frac{d}{dt}\, \varphi_{sh}$$

$$\Rightarrow \quad e_{sh} \propto \frac{d}{dt}\left(-\frac{\boldsymbol{V_m}}{\omega} \cos \omega t\right)$$

$$\Rightarrow \quad e_{sh} \propto \boldsymbol{V_m}\, \boldsymbol{sin}\ \boldsymbol{\omega t}$$

Similatly,

$$e_{se} \propto \frac{d}{dt}\, \varphi_{se}$$

$$\Rightarrow \quad e_{se} \propto \frac{d}{dt}(\boldsymbol{I_m} \ \boldsymbol{sin}\ (\boldsymbol{\omega t} - \boldsymbol{\theta}))$$

$$\Rightarrow \quad e_{se} \propto \ \boldsymbol{I_m \omega} \ \boldsymbol{cos}\ (\boldsymbol{\omega t} - \boldsymbol{\theta})$$

And

$$i_{se} \propto \ \boldsymbol{I_m \omega} \ \boldsymbol{cos}\ (\boldsymbol{\omega t} - \boldsymbol{\theta})$$

$$i_{sh} \propto \ \boldsymbol{V_m} \ \boldsymbol{cos}\ (\boldsymbol{\omega t} - \boldsymbol{\theta})$$

Now deflection torque T_d is

$$T_d \ = \text{-}\varphi_{se}\, I_{sh} - \ \varphi_{sh}\, I_{se}$$

And

From the equation we can say the deflecting torque is proportional to the power inthecircuit.

Advantages of Induction Type Wattmeter :

1. It has greater working torque and large length of scale

2. It has a uniform scale.

Disadvantages of Induction Type Wattmeter:

1. It has less accuracy

2. It has high power consumption

Table:1.1: Comparison between dynamometer type and induction type wattmeters

Sl. No.	Dynamometer type wattmeter	Induction type wattmeter
1.	The current coil is divided into two parts.	Both the current coil and the potential coil is divided into two parts.
2.	Potential coil is the moving part.	Aluminium disc is the moving part
3.	Can be used for both DC and AC applications.	Can be used in AC applications.
4.	It has non linear scale	It has linear scale
5.	Can be used in circuits with variable frequency C	Cannot be used in the circuits with variable frequency