UNIT-III

Measurement of Power & Energy

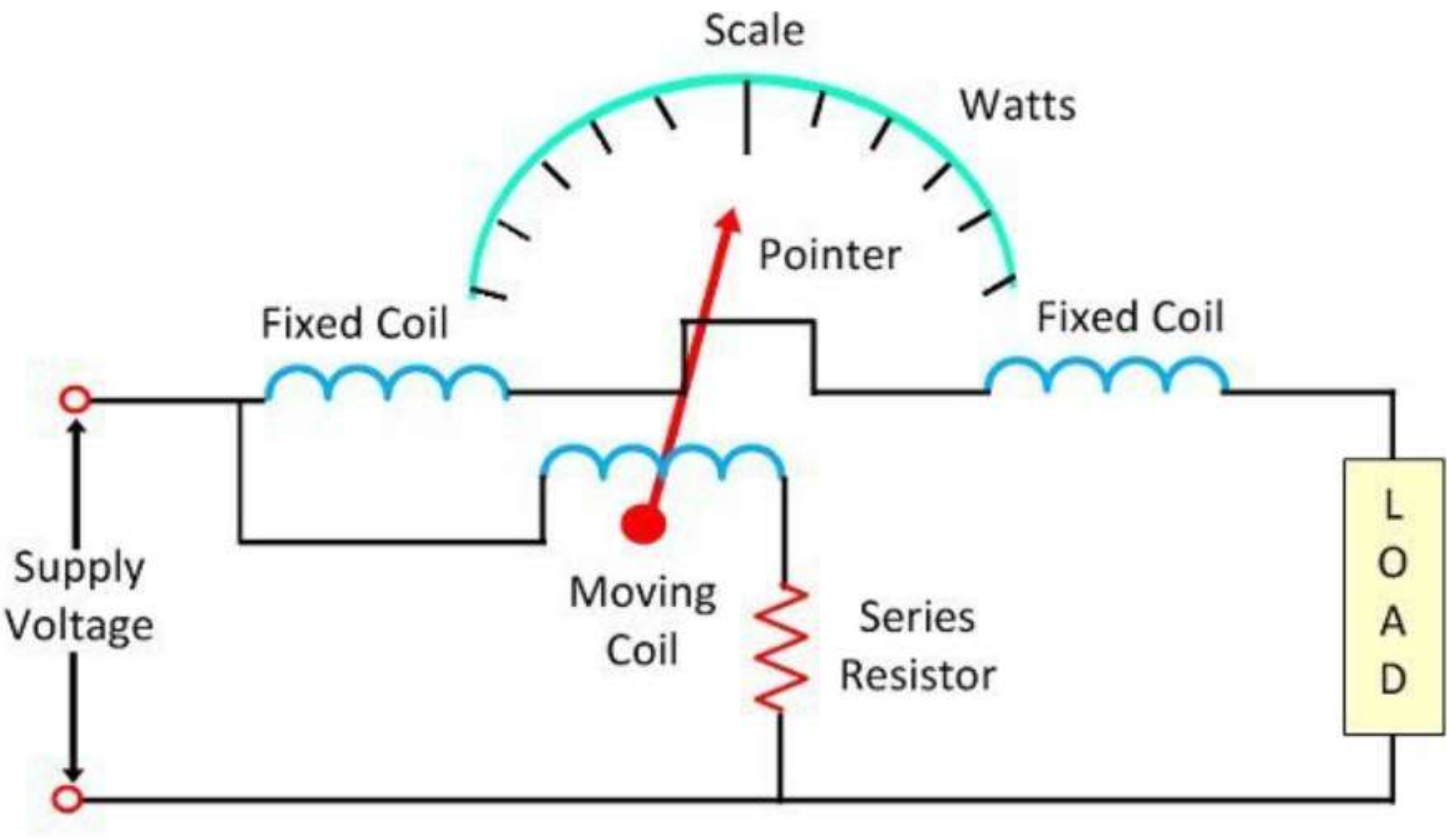
Single phase dynamometer wattmeter, LPF and UPF, Double element and three element dynamometer wattmeter, expression for deflecting and control torques – Extension of range of wattmeter using instrument transformers – Measurement of active and reactive powers in balanced and unbalanced systems. Single phase induction type energy meter – driving and braking torques – errors and compensations – testing by phantom loading using R.S.S.meter. Three phase energy meter – tri-vector meter, maximum demand meters.

Electrodynamo-meter Wattmeter.

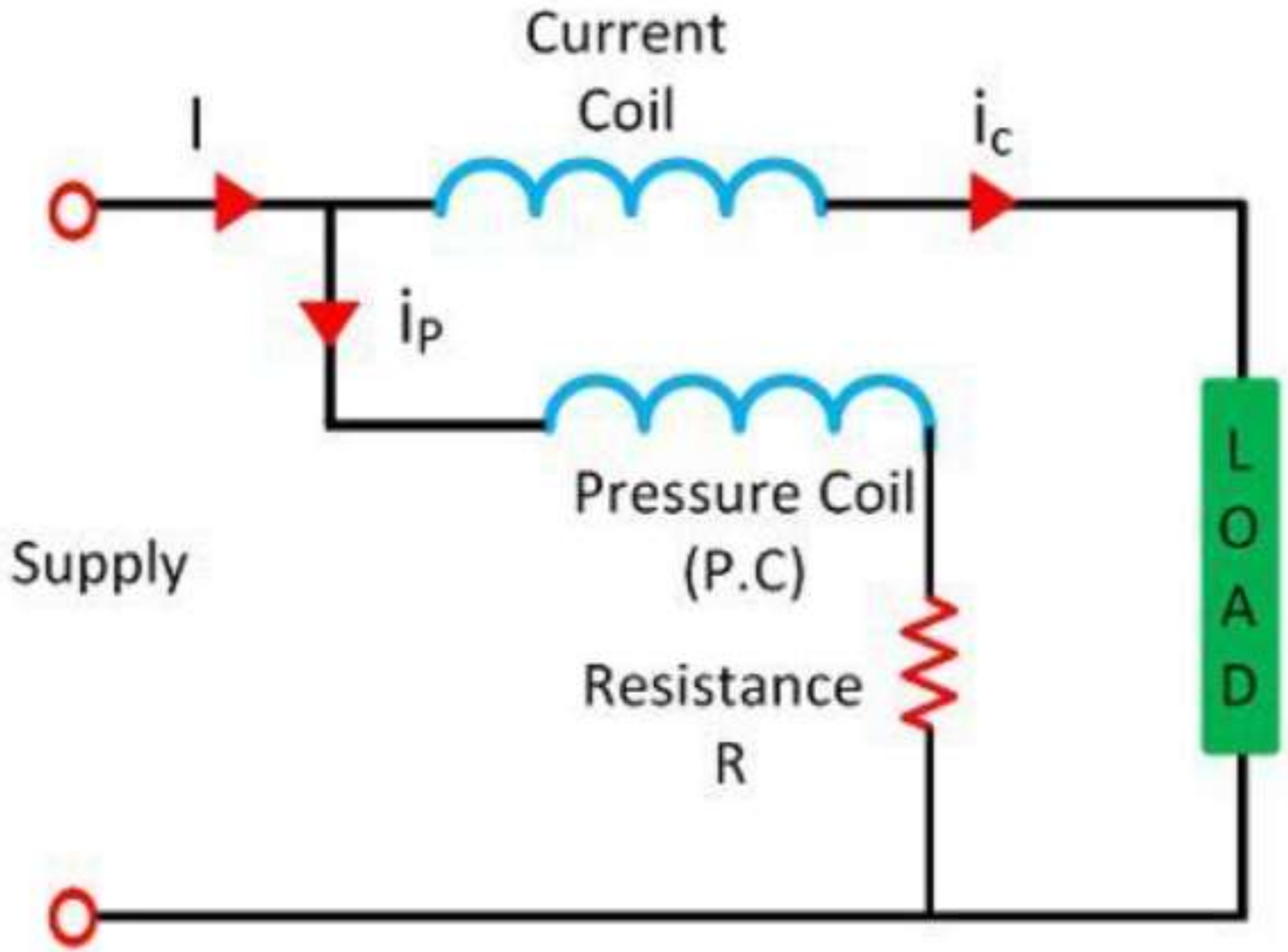
Definition: The instrument whose working depends on the reaction between the magnetic field of moving and fixed coils is known as the Electrodynamo-meter Wattmeter. It uses for measuring the power of both the AC and DC circuits.

working principle of the Electrodynamometer

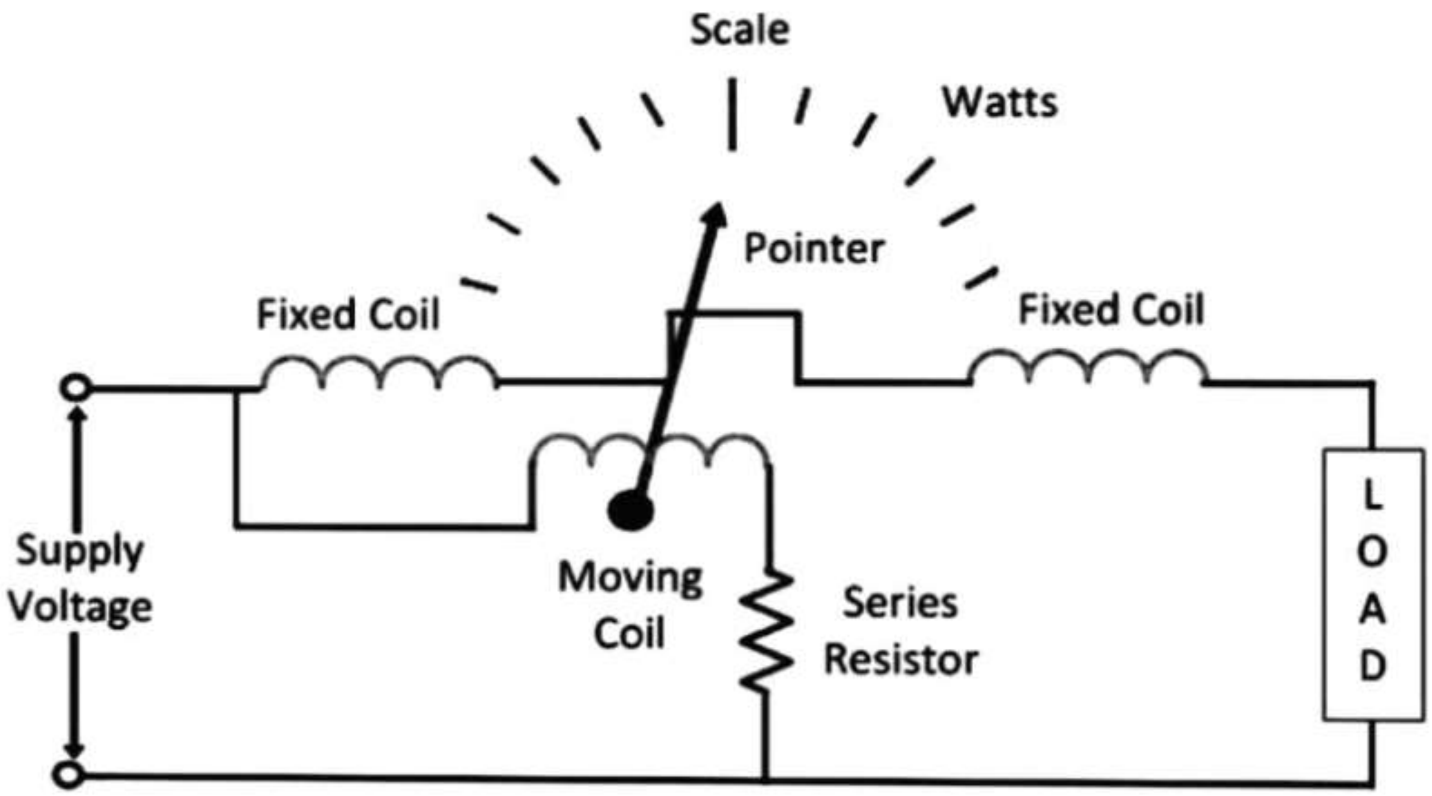
Their working depends on the theory that the current carrying conductor placed in a magnetic field experiences a mechanical force. This mechanical force deflects the pointer which is mounted on the calibrated scale



Electrodynameter Wattmeter



Circuit of Electrodynamo Wattmeter



Scale
Watts
Pointer
Fixed Coil
Fixed Coil
Supply
Voltage
Moving
Coil
Series
Resistor
L
O
A
D

Construction of Electrodynamometer Wattmeter

1.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.** 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.

2. 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.

3. Control :

The control system provides the controlling torque to the instruments. Electrodynamometer Wattmeter uses spring control system.

4. **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.

5.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.

DC Input

Let V be the supply voltage

i be the load current

R be the resistance of the moving coil

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

$$T_d \propto i_f i_m \propto \frac{Vi}{R}$$

Since R is constant

$$T_d \propto Vi$$

Deflecting torque is thus proportional to power.

AC Input

The expression for instantaneous torque in AC is given by

$$T_i = i_1 i_2 \frac{dM}{d\theta}$$

$$T_i = i_p i_c \frac{dM}{d\theta} \qquad (i)$$

Let the supply voltage is

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

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

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

Where

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

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 get

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

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

$$= \mathrm{I_p}\mathrm{I}\ [\ \cos\ \varphi - \cos\ (2\omega t - \varphi)\frac{\mathrm{dM}}{\mathrm{d}\theta}$$

The average deflecting torque will be

$$T_d(average) = \frac{1}{T}\int [I_p I\ [\ \cos\varphi - \cos\ (2\omega t - \varphi)\frac{dM}{d\theta}]\ d\omega t$$

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

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

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

$$T_d(average)\alpha\ P$$

Errors in Electrodynamometer Wattmeter

1.Pressure Coil Inductance – The pressure coil of the Electrodynamometer has some inductance. Because of the inductance, the current of the pressure coils lags behind the voltage. Thus, the power factor of the wattmeter becomes lagging, and the meter reads high reading.

2.Pressure Coil Capacitance – The pressure coil has capacitances along with the inductance. This capacitance increases the power factor of the instrument. Hence causes the error in the reading.

3.Error due to Mutual Inductance Effect – The mutual inductance between the pressure and current coil produces an error.

4. Eddy Current Error – The eddy current induces in the coil creates its own magnetic field. This field affects the main current flows through the coil. Thus, the error occurs in the reading.

5.Stray Magnetic Field – The stray magnetic field disturbs the main magnetic field of the Electrodynamic Wattmeter. Thus, affect their reading.

6.Temperature Error – The variation in temperature will change the resistance of the pressure coil. The movement of the spring, which provides the controlling torque also affected because of the temperature change. Thereby, the error occurs in the reading.

Advantages of Electrodynamometer Type Wattmeter :

- A high degree of accuracy in the readings can be obtained.
- The scale of the instrument is uniform.
- Can be used in both ac and dc circuits.
- Due to the good accuracy of the instrument, it can be used for calibration.

Disadvantages of Dynamometer Type Wattmeter

1. The instrument is expensive, but the high accuracy obtained compensates this disadvantage.
2. Its accuracy is affected by the external magnetic fields, hence it must be screened.
3. At low power factors, the inductance of the pressure coil (P.C) introduces a serious error.

Low Power Factor Wattmeter -

A low power factor (LPF) wattmeter is an instrument used to measure power in low power factor circuits. This type of wattmeters is employed for power measurement in circuits whose power factor is less than 0.5.

- Generally, wattmeters are used for measuring power in a circuit. But, the power measurement using normal electrodynamometer wattmeter in a circuit operating at low factors causes inaccurate in the readings due to the following reasons,
- When the ordinary wattmeter is connected to a low power factor circuit. Even though at full excitation of current and voltage coil, the deflecting torque produced on the moving coil is very small.
- Wattmeter operating at low factors introduces large errors due to voltage coil inductance.

Deflecting Torque

The deflecting of electrodynamometer wattmeter is proportional to the load power in DC as well as AC circuit.

$$Deflecting\,Torque(\tau_d) \propto\ l_1 l_2$$

Since the current I_2 is proportional to load voltage V. Thus,

$$Deflecting\,Torque(\tau_d) \propto\ l_1 V \propto\ Load\,Power$$

$$u = V_m \sin\theta$$

$$i = I_m \sin(\theta - \varphi)$$

$$Instantaneous\, deflecting\, torque \propto \; u\, i$$

Due to inertia of moving system, the pointer cannot follow the rapid changes in the instantaneous power. Hence the wattmeter indicates the average power.

$$\therefore \; Average\, Deflecting\, torque(\tau_d) \propto \; Average\, of\, vi\, over\, one\, cycle$$

$$\tau_d \propto \; \frac{1}{2\pi} \int_0^{2\pi} V_m I_m \sin\theta \sin(\theta - \varphi) d\theta \propto \; \frac{V_m I_m}{2} \cos\varphi \; \propto \; VI \cos\varphi$$

Where, V and I are RMS values

$$\tau_d \propto \; VI \cos\varphi \propto \; Load\, Power$$

Since the controlling torque in the wattmeter is provided by spring. Thus,

$$\tau_c \propto \theta$$

Under steady state condition,

$$\tau_d = \tau_c$$

Therefore,

$$\theta \propto \ Load\ Power$$

Hence the electrodynamometer wattmeter has uniform scale.

Single phase energy meter

- Induction type instruments are most commonly used as energymeter. It is an integrating instrument which measures quantity of electricity

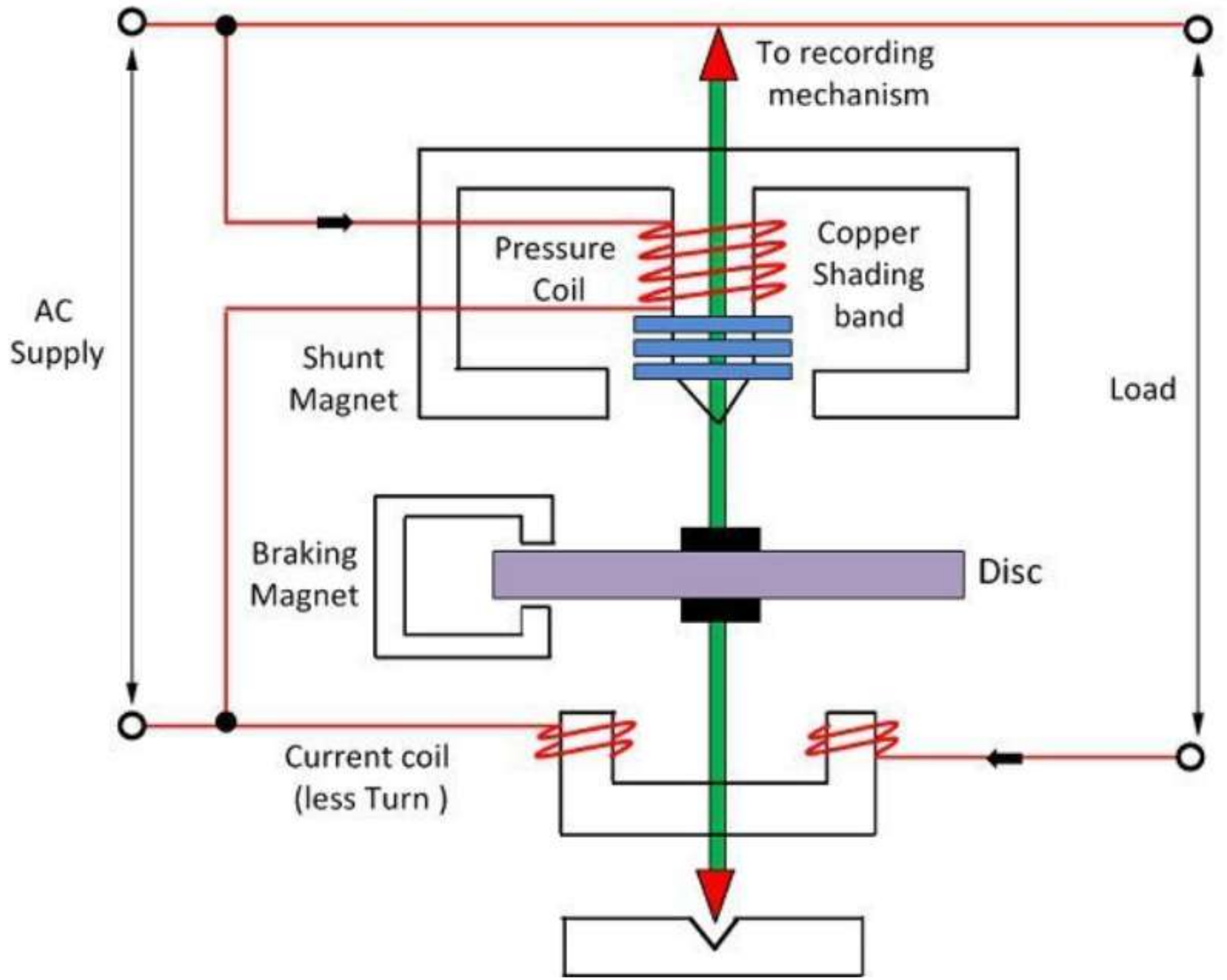
Working principle:

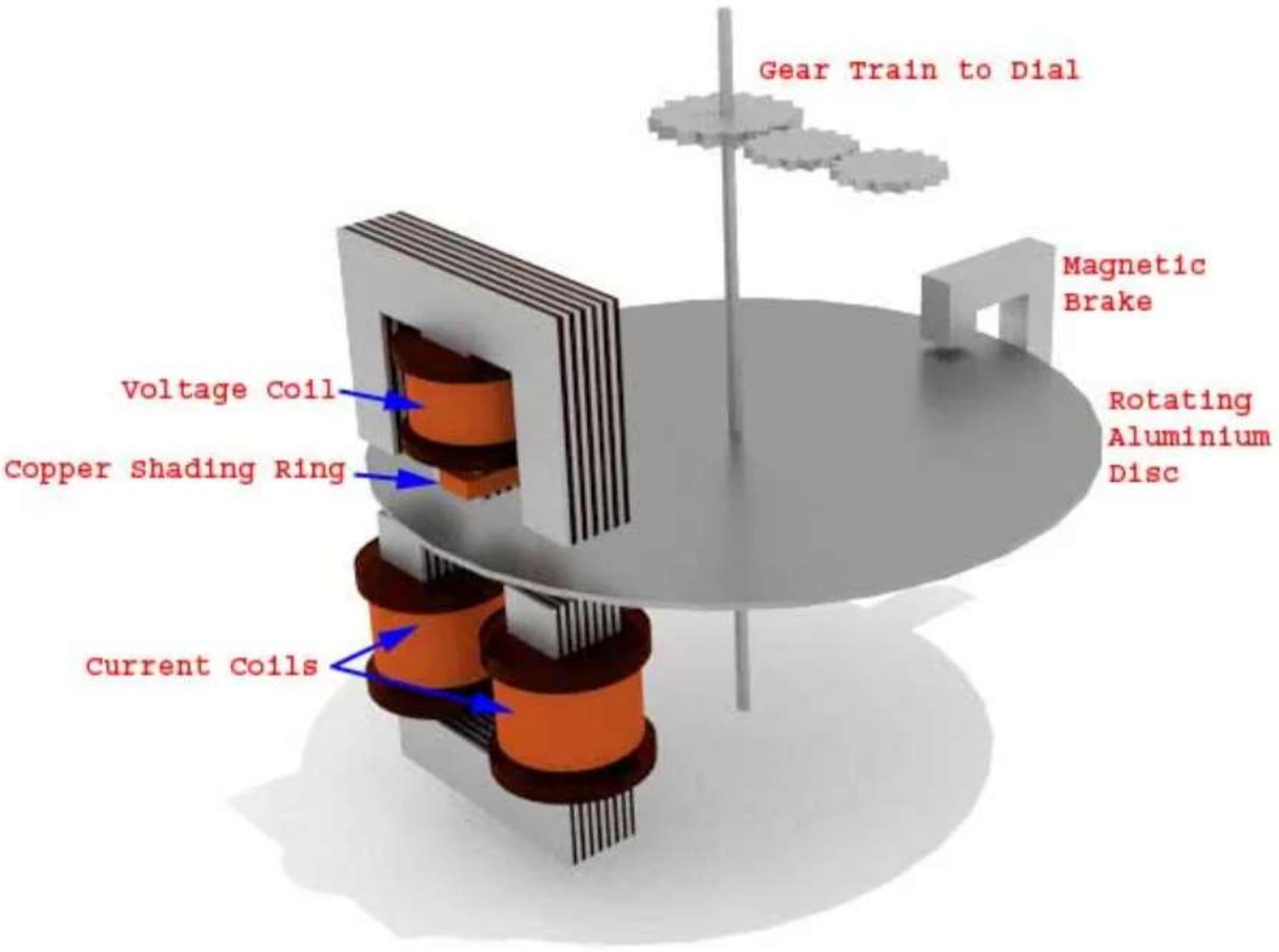
- In all induction meters, we have two fluxes which are produced by two different alternating currents on a metallic disc. Due to alternating fluxes, there is an induced emf, the emf produced at one point interacts with the alternating current of the other side resulting in the production of torque.
- Similarly, the emf produced at the point two interacts with the alternating current at point one, resulting in the production of torque again but in opposite direction. Hence due to these two torques which are in different directions, the metallic disc moves. This is the basic principle of working of an **induction type meters**.

Single phase energy meter

- Single phase induction type energy meter is also popularly known as ***watt-hour meter.*** In the energymeter, there is no controlling torque and thus due to driving torque only a continuous rotation of the disc is produced. To have constant speed of rotation, braking magnet is provided.
- Construction:
    1. Driving system
    2. Moving system
    3. Braking system
    4. Registering system

Single phase energy meter




Gear Train to Dial
Magnetic
Brake
Voltage Coil
Rotating
Aluminium
Disc
Copper Shading Ring
Current Coils


kW - h
0 0 0 0 0
KILOWATT-HOUR METER
SINGLE PHASE 220V
50Hz 10A 600r/kW-h

Single phase energy meter

The electromagnet is the main component of the **driving system**. It is the temporary magnet which is excited by the current flow through their coil. The core of the electromagnet is made up of silicon steel lamination. The driving system has two electromagnets. The upper one is called the shunt electromagnet, and the lower one is called series electromagnet.

The series electromagnet is excited by the load current flow through the current coil. The coil of the shunt electromagnet is directly connected with the supply and hence carry the current proportional to the shunt voltage. This coil is called the pressure coil.

The centre limb of the magnet has the copper band. These bands are adjustable. The main function of the copper band is to align the flux produced by the shunt magnet in such a way that it is exactly perpendicular to the supplied voltage.

Single phase energy meter

The **moving system** is the aluminium disc mounted on the shaft of the alloy. The disc is placed in the air gap of the two electromagnets. The eddy current is induced in the disc because of the change of the magnetic field. This eddy current is cut by the magnetic flux. The interaction of the flux and the disc induces the deflecting torque.

When the devices consume power, the aluminium disc starts rotating, and after some number of rotations, the disc displays the unit used by the load. The number of rotations of the disc is counted at particular interval of time. The disc measured the power consumption in kilowatt hours.

Single phase energy meter

Braking system

The permanent magnet is used for reducing the rotation of the aluminium disc. The aluminium disc induces the eddy current because of their rotation. The eddy current cut the magnetic flux of the permanent magnet and hence produces the braking torque.

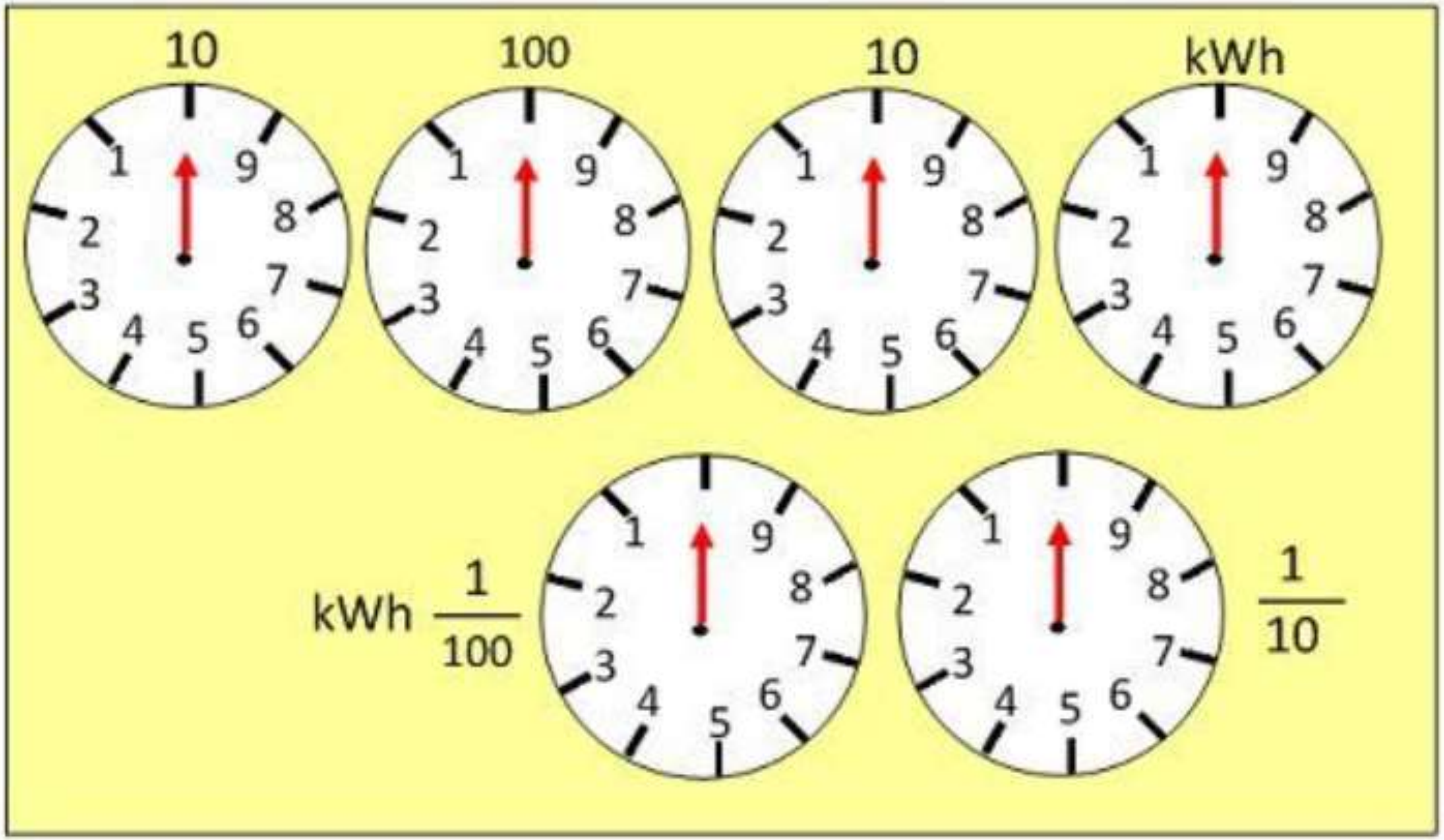
This braking torque opposes the movement of the disc, thus reduces their speed. The permanent magnet is adjustable due to which the braking torque is also adjusted by shifting the magnet to the other radial position.

Single phase energy meter

Registration (Counting Mechanism)

The main function of the registration or counting mechanism is to record the number of rotations of the aluminium disc. Their rotation is directly proportional to the energy consumed by the loads in the kilowatt hour.

The rotation of the disc is transmitted to the pointers of the different dial for recording the different readings. The reading in kWh is obtained by multiply the number of rotations of the disc with the meter constant.



Pointer Type of Register

Torque equation of energymeter

Let V= supply voltage

I_2- current through pressure coil proportional to V

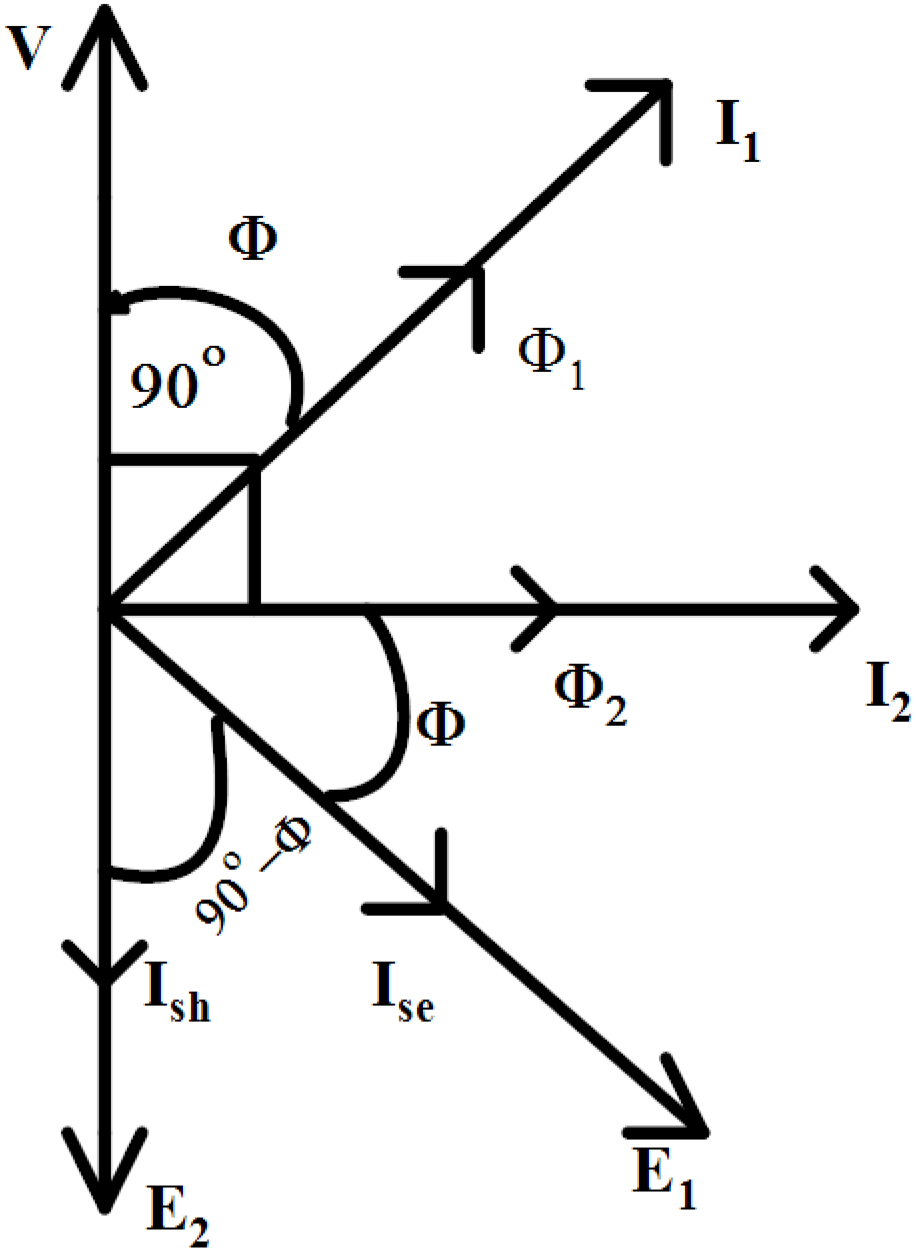
Φ_2 – flux produced by I_2

I_1- current through current coil (ie) load

Φ_1 – flux produced by I_1

I_2 lags V by 90^o as pressure coil is highly inductive and copper shading band. Φ_2 and I_2 are inphase

I_1 lags V by Φ , Where Φ is decided by load connected. Φ_1 and I_1 are inphase



V
I1
Φ
90°
Φ1
Φ2
I2
Φ
90° −Φ
Ish
Ise
E2
E1

E_1 = induced emf in disc due to Φ_1

E_2 = induced emf in disc due to Φ_2

Ish =Eddy current due to E_1

Ise= Eddy current due to E_2

Induced emf lags the respective flux producing it by 90^o. Eddy curents are inphase with the induced emf producing them.

Interaction between Φ_1 and I_{sh} which produces toeque T_1

Interaction between Φ_2 and I_{se} which produced torque T_2.

T_2 is opposite direction to T_1

Hence net deflecting torque is,

$T_d \alpha T_2 - T_1$

$\alpha \; \phi_2 I_{se} \cos(\phi_2 \wedge I_{se}) - \phi_1 I_{sh} \cos(\phi_1 \wedge I_{sh})$

$\phi_2 \wedge I_{se} = \phi$; $\phi_1 \wedge I_{sh} = 180 - \phi$

$T_d \alpha \; \phi_2 I_{se} \cos(\phi) - \phi_1 I_{sh} \cos(180-\phi)$

$\cos(180-\phi) = -\cos(\phi)$

Therefore, $T_d \alpha \; \phi_2 I_{se} \cos(\phi) + \phi_1 I_{sh} \cos(\phi)$

But , $\phi_2 \alpha I_2 \alpha V$; $I_{se} \alpha E_1 \alpha I_1$; $\phi_1 \alpha I_1$; $I_{sh} \alpha E_2 \alpha I_2 \alpha V$

$T_d = K_1 V I_1 \cos(\phi) + K_2 V I_1 \cos(\phi)$

$T_d = (K_1 + K_2) V I_1 \cos(\phi)$

$T_d \alpha V I_1 \cos(\phi)$ (ie) the power consumed by the load.

Braking torque is proportional to speed N with which the disc rotates.

$$T_b \; \alpha \; N$$

At constant speed,

$$T_d = T_b$$

$$N \alpha \; V \, I_1 \cos(\phi)$$

Multiply both sides by t

$$N \, t \;\; \alpha \;\; V \, I_1 \cos(\phi) \, t \;\; \alpha \;\; P \, t$$

Number of revolutions in time t α energy supplied

Thus, by counting the number of revolutions electrical energy consumed can be measured.

Adjustments in energy meter

1. Main speed adjustment:
   Speed of meter can be adjusted by changing the radius of the braking magnet.
2. Power factor adjustment:
   Meter should correctly measure for all power factor condition of the load. I2 lags supply voltage by 90^o. But iron loss and resistance of winding will not allow I2 to lag supply voltage by 90^o. Adjustment can be done by cu shading bands.
3. Friction adjustment:
   Inspite of proper design of the bearing an and registering mechanism, there exist some friction. This can be compensated by metallic loop or strips provided between the central limb of shunt magnet and Disc.
4. Creep adjustment:
   Without any current through Current Coil disc rotates due to the supply voltage exciting its pressure coil. This is called creeping. This is because of overfriction compensation. To eliminate this two holes are drilled in the disc 180^o opposite to each other.

Advantages of Induction Type Energy Meter

1.Cheap in cost.

2.Simple construction.

3.Low maintenance.

4.More accurate on a wide range of loads.

5.Good damping.

6.The moving element has no electrical contact with the circuit

Disadvantages of Induction Type Energy Meter

1.It can be used for AC circuits only.

2.They have non-linear scales.

3.They consume a considerable amount of power.

Three phase energy meter

- 3φ, 4 wire system -> measurement of energy is carried out by -> 3φ energy meter

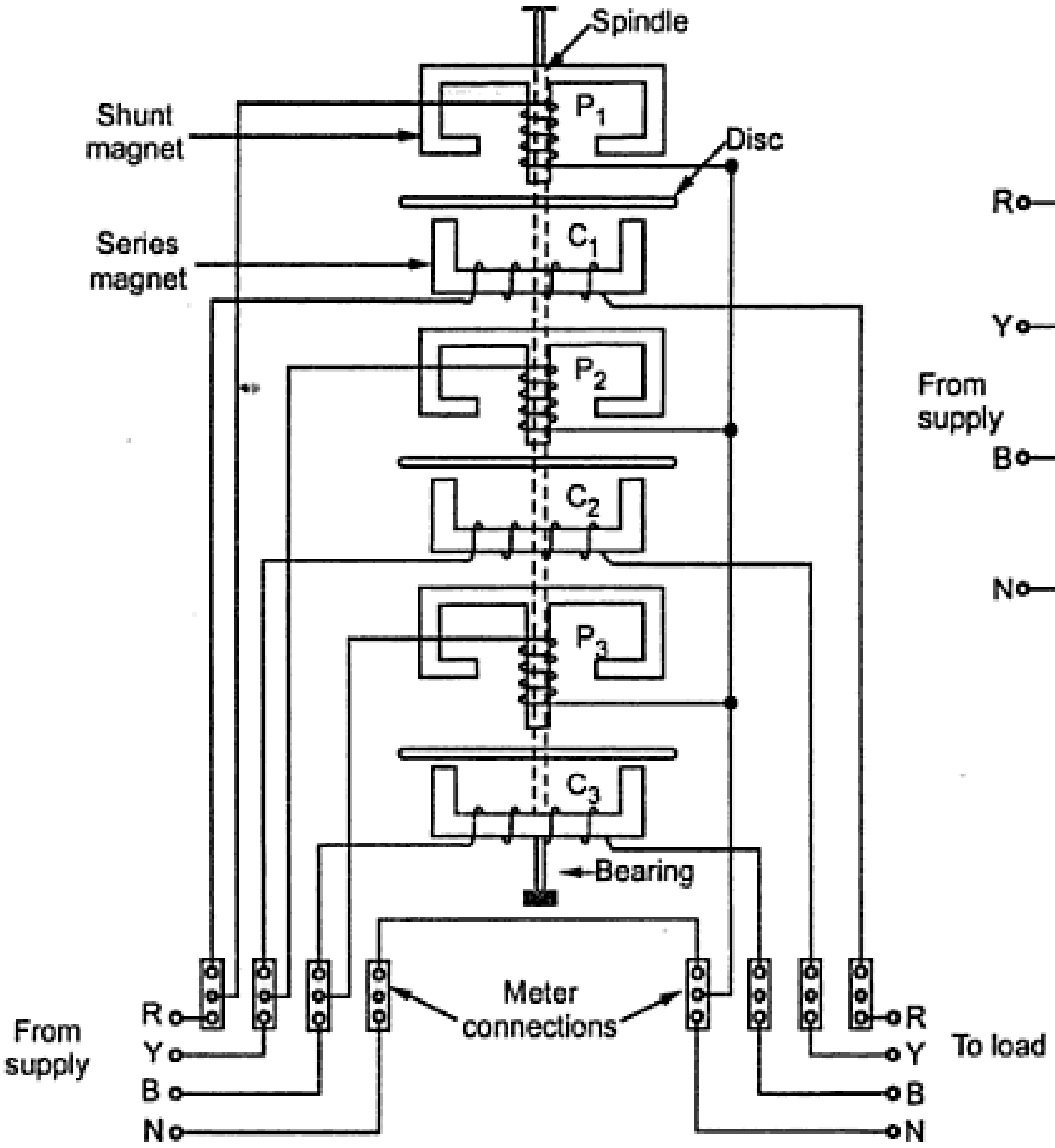
- 3φ, 3 wire system -> measurement of energy is carried out by -> 2 element energy meter (similar to 2 wattmeter for power measurement if 3φ, 3 wire system)

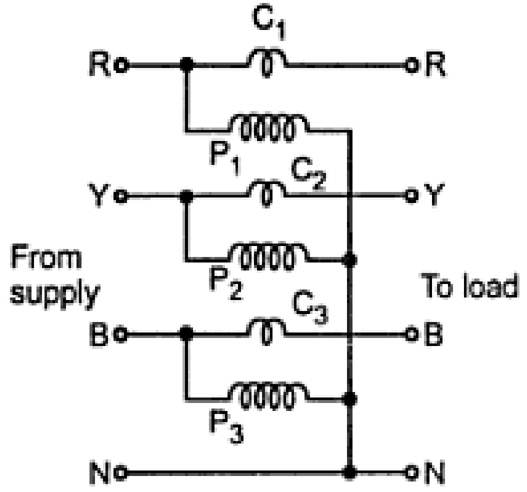
- Meters are classified as

➢ Three element energy meter

➢ Two element energy meter

Three element energy meter





- Meter consists of three elements.

- P1,p2,p3 → pressure coil, C1,C2,C3 → current coil.

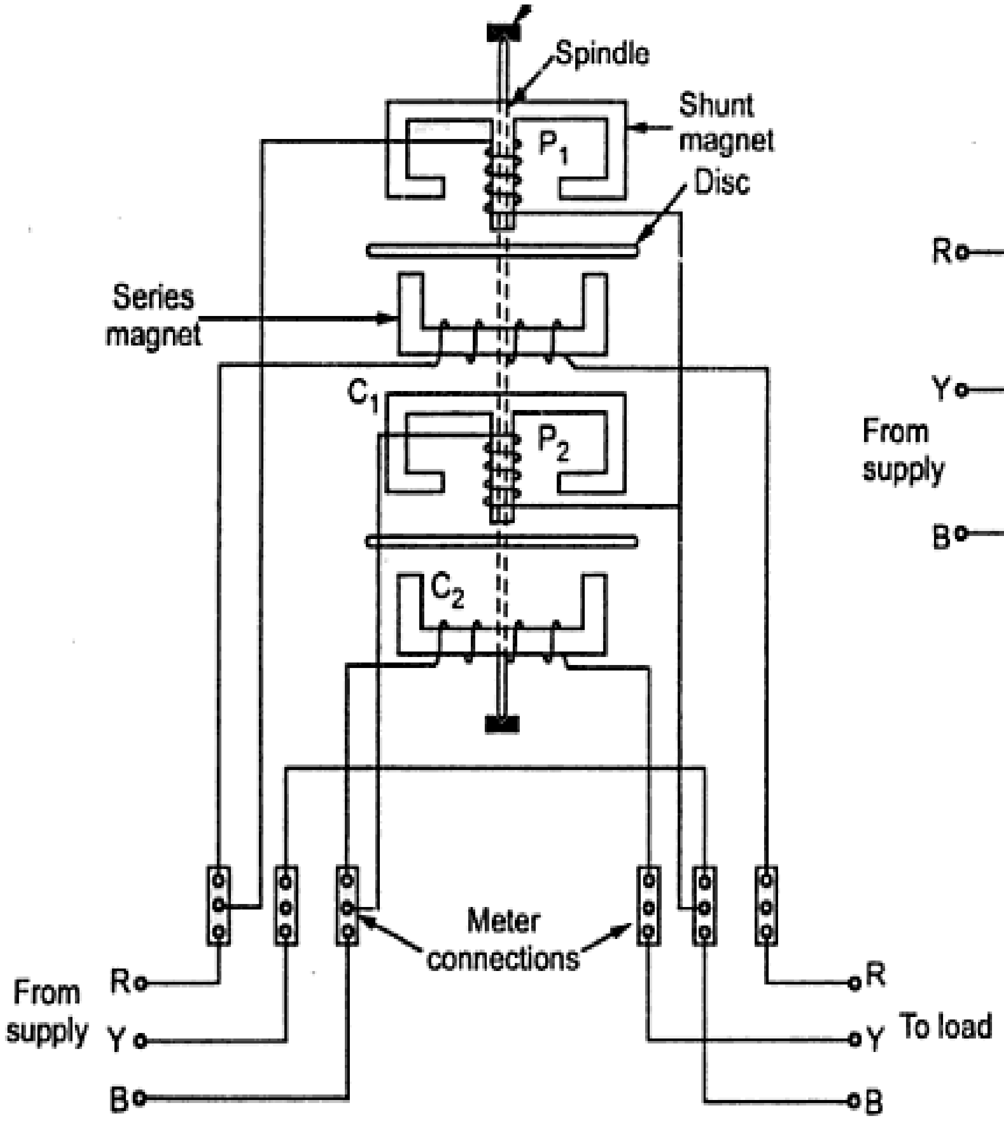
- All elements are connected vertically in common case and have a common spindle, gearing and registering mechanism. .

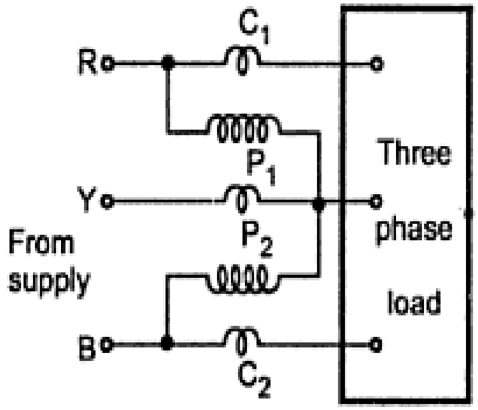
- Coils are connected such that the net torque produced is sum of the torques due to all the three elements.

- Three phase elements is always cheaper than three units of single phase energy meter.

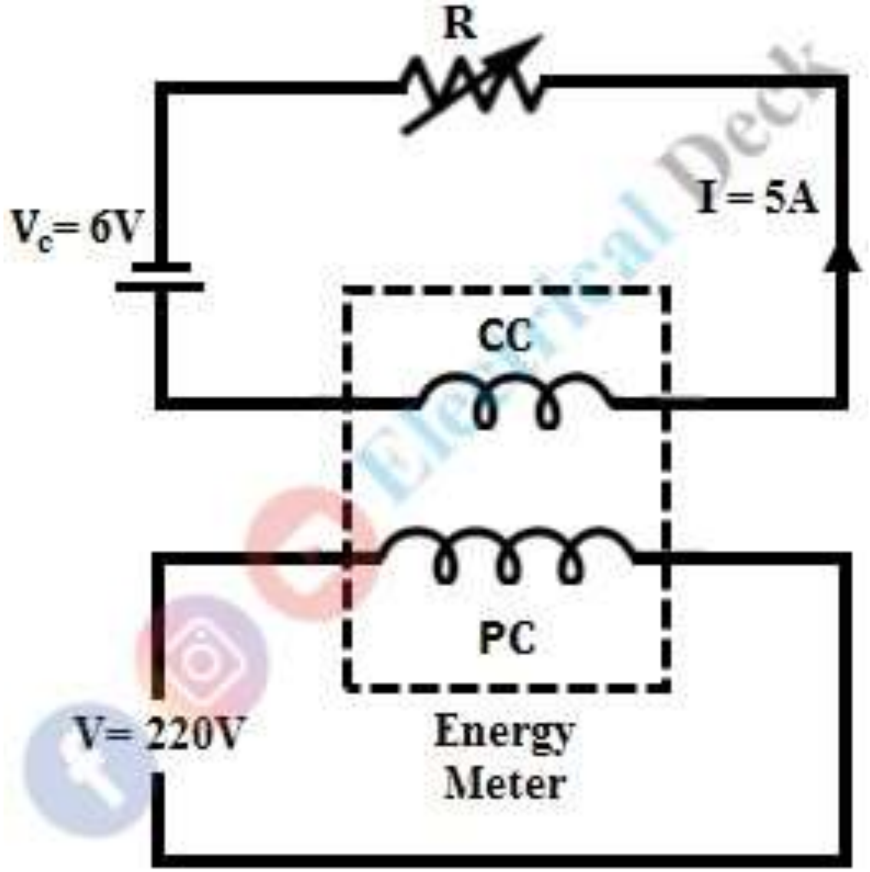
- Due to interactions between eddy currents produced by one element with flux produced by another element, errors may occur.

Two element energy meter





In the energy meter testing, the actual registration of energy (by the meter) is verified against known standard values at various loads and power factors. The energy meter testing helps in providing suitable adjustments in the meter so as to reduce errors. The actual registration is verified under the following test conditions.



Trivector Meter - Definition & Working

Trivector meter is used to measure the kVAh and kVA of maximum demand. It consists of two meters whose discs are coupled with a special kind of summator through a complicated gearing system. Among the two meters, one is an energy (kilowatt-hour) meter and the other is a reactive kilo volt ampere-hour meter.

The coupling system adds the speeds of the meters vectorially and hence the speed of the summator will be proportional to the kVAh. So, the meter registers the accurate value of kVAh at any power factor. This complicated gearing system consists of five typical gear systems. They are as follows,

Maximum Demand meter

Maximum Demand meter is used for monitoring thermal loading in Power Distribution systems, Networks, Machines etc. It indicates maximum loading current over a period. Short-period current peaks are not registered but long overloads are registered. In the Maximum Demand meter the measuring current flows through the bimetal spiral which is temperature sensitive. The free end of the spiral is connected to a black measuring pointer. The moving system is activated by heat generated by the current flowing through the spiral. The instrument is provided with an additional red slave pointer with a higher friction, which makes it to remain at its maximum position, which determines the maximum average loading current. The high torque of metallic movement drags the red pointer along with the black pointer. The red pointer remains stationary at the maximum value reached. This can be reset by rotating the knob provided on front facia. To prevent false indication due to fluctuations in ambient temperature, an additional bimetallic spiral is wound in opposite direction, which is mounted on the same spindle to compensate variation in temperature from 10 to +55 degrees Centigrade. Frequently there is a need to measure instantaneous current simultaneously & hence moving iron movement having the same range is incorporated in the same meter.