UNIT II   MEASUREMENT OF POWER & ENERGY

Dynamometer type wattmeter works on a very simple principle which is stated as "when any current carrying conductor is placed inside a magnetic field, it experiences a mechanical force and due to this mechanical force, deflection of conductor takes place."

Construction

It consists of the following parts:

Moving coil - Moving coil moves the pointer with the help of spring control instrument. A limited amount of current flows through the moving coil so as to avoid heating. So in order to limit the current we have connected the high value resistor in series with the moving coil. The moving is air cored and is mounted on a pivoted spindle and can moves freely. In electrodynamometer type wattmeter, moving coil works as pressure coil. Hence moving coil is connected across the voltage and thus the current flowing through this coil is always proportional to the voltage.

Fixed coil - The fixed coil is divided into two equal parts and these are connected in series with the load, therefore the load current will flow through these coils. Now the reason is very obvious of using two fixed coils instead of one, so that it can be constructed to carry considerable amount of electric current. These coils are called the current coils of electrodynamometer type wattmeter. Earlier these fixed coils are designed to carry the current of about 100 amperes but now the modern wattmeter are designed to carry current of about 20 amperes in order to save power.

Control system - Out of two controlling systems i.e. gravity control and spring control, only spring controlled systems are used in these types of wattmeter. Gravity controlled system cannot be employed because they will contain appreciable amount of errors.

Damping system - Air friction damping is used, as eddy current damping will distort the weak operating magnetic field and thus it may lead to error.

Scale - There is uniform scale is used in these types of instrument as moving coil moves linearly over a range of 40 degrees to 50 degrees on either sides.

Working of Dynamometer type wattmeter:

When power is to be measured in a circuit, the instrument is suitably connected in the circuit. The current coil is connected in series with load so that it carries the circuit current. The potential coil is connected across the load so that it carries current proportional to the voltage.
Due to the current in the coils, mechanical force exists between them. The result is that the moving coil, moves the pointer over the scale. The pointer comes to rest at a position where deflecting torque is equal to the controlling torque.

Reversing the current, reverses the field due to fixed coil as well as the current in the moving coil so that the direction of the deflection torque remains unchanged. Therefore, such instruments can be used for the measurement of a.c as well as d.c power.

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Dynamometer type Wattmeter
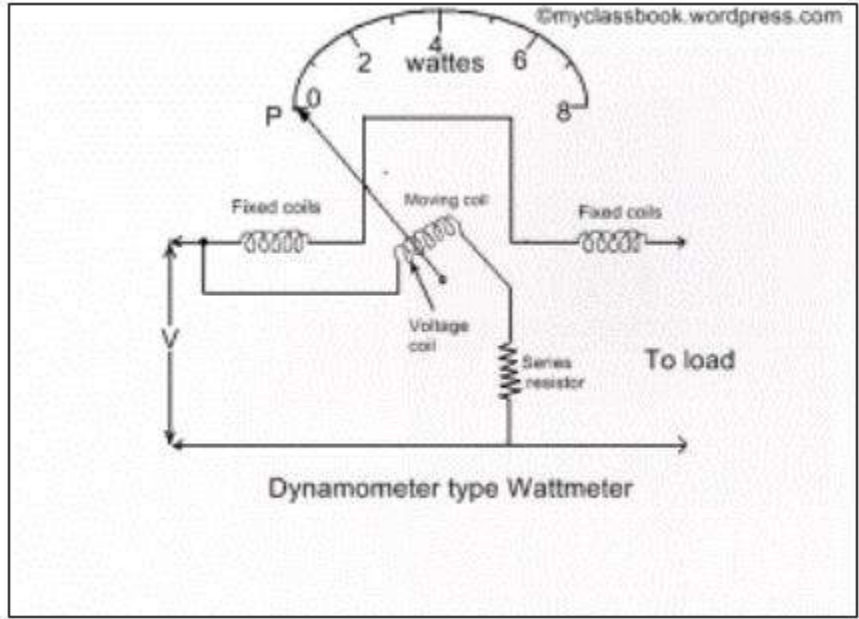
Deflecting torque:

It can be easily proved that deflecting torque is proportional to the power in the circuit.

Case-a: Torque expression based on energy concept

Let us assume that the fixed and moving coils having self-inductances L_f and L_m respectively. Further it is assumed that the mutual inductance between the fixed and movable coils is M.

Total energy stored in the magnetic field of the coils is given by

$$W = \frac{1}{2}L_f\, i_f^2 + \frac{1}{2}L_m\, i_m^2 + M\, i_f\, i_m \qquad (43.1)$$

where i_f and i_m are the currents through the fixed and moving coils. From equation (43.1) one can write the expression for torque developed as

$$T_d = \frac{dW}{d\theta} = i_f\, i_m\, \frac{dM}{d\theta} \qquad (43.2)$$

Note L_f and L_m are not functions of θ but the mutual inductance 'M' between the coils is a function of the deflection θ (i.e relative position of moving coil). The equivalent inductance between fixed and moving coils can be found out as

$L_{eq} = L_f + L_m + 2M$ (cumulative manner) and from this one can find the mutual inductance between them as

$$M = \frac{1}{2}\left[L_{eq} - (L_f + L_m)\right]$$

With all deflection type instruments, however, the mutual inductance varies with the relative positions of the moving and fixed coils. The maximum value M_{max} of the mutual inductance occurs when the axes of the moving and fixed coils are aligned with $\theta = 180°$, as this position gives the maximum flux linkage between coils. When $\theta = 0°$, $M = - M_{max}$. If the plane of the moving coil is at an angle θ with the direction of B that produced by the fixed coil, then the mutual inductance M is expressed by

$$M = - M_{max} \cos\theta \qquad (43.3)$$

D.C operation: Expression (43.2) for the developed torque is rewritten by setting $i_f = I_f(d.c)$ and $i_m = I_m(d.c)$

$$T_d = I_f I_m \frac{dM}{d\theta} = I_f I_m M_{max} \sin\theta \qquad (43.4)$$

If the control is due to spiral springs, the controlling torque is proportional to the angle of deflection θ.

Controlling torque $T_c = k_s \theta \qquad (43.5)$

where k_s is the spring constant.

Note that $T_d = T_c$ at steady deflection, i.e,

$$I_f I_m \frac{dM}{d\theta} = k_s \theta$$

$$\therefore \qquad \theta = \frac{I_f I_m}{k_s} \left(\frac{dM}{d\theta} \right) \qquad (43.6)$$

A.C operation: The dynamometer instrument is used to measure alternating current or voltage, the moving coil–due to its inertia takes up a position where the average deflecting torque over a complete cycle is balanced by the restoring torque of the spiral spring. The deflecting torque is proportional to the mean value of the square of the current or voltage (note both coils are connected in series for ammeters or voltmeters), and the instrument scale can therefore be calibrated to read r.m.s values of alternating current or voltage.

For a.c circuit: Let the applied voltage $v(t) = V_m \sin \omega t$; and the currents through the moving and fixed coils are given by

$$i_m(t) = \frac{V_m}{R} \sin \omega t \text{ (assuming inductance of moving coil is negligible)}$$

$$i_f(t) = i_L(t) = I_m \sin(\omega t \pm \phi)$$

where ϕ is the power factor angle of the load ($+\phi$ leading p.f of the load and $-\phi$ for lagging p.f of the load).

Instantaneous deflecting torque

$$T_d(t) \propto i_r(t) i_m(t) \frac{dM}{dt} \propto V_m I_m \sin\omega t \sin(\omega t \pm \phi) \tag{43.11}$$

The mean or average torque

$$T_{d,av} \propto \frac{1}{T} \int_0^T V_m I_m \sin\omega t \sin(\omega t \pm \phi)dt$$
$$\propto V I \cos\phi \tag{43.12}$$

where V and I are the r.m.s values of load voltage and current respectively. It may be noted that the developed torque must be equal to the controlling torque at steady state. In other words, the controlling torque $T_c \propto \theta$ and this implies that $\theta \propto$ power (average). Thus an electro-dynamic instrument, connected as shown in Fig. 43.6, becomes a wattmeter which will give a direct deflection of the power in either dc or ac circuit.

$$T_{d,av} = T_c$$
$$I_1 I_2 \cos\alpha \frac{dM}{d\theta} = k_s\theta$$
$$\therefore \quad \theta = \frac{I_1 I_2 \cos\alpha}{k_s} \frac{dM}{d\theta}$$

In case of ammeter or voltmeter, both the coils are connected in series and the same current is flowing through the coils. Equation (43.8) can be written as

$$\therefore \quad \theta = \frac{I^2}{k_s} \frac{dM}{d\theta} \tag{43.9}$$

where $I_1 = I_2 = I$ and $\alpha = 0^0$.

Merits –

Scale is uniform up to certain limit.

- They can be used for both to measure ac as well dc quantities as scale is calibrated for both.

Errors/Demerits –

- Errors in the pressure coil inductance
- Errors may be due to pressure coil capacitance
- Errors may be due to mutual inductance effects
- Errors may be due connections (i.e. pressure coil is connected after current coil)
- Error due to Eddy currents

- Errors caused by vibration of moving system

- Temperature error

- Errors due to stray magnetic field.

Wattmeter Errors:

A wattmeter is normally required to measure power in the load. Two modes of wattmeter connections to the load are shown in Fig. 43.7(a) and Fig.43.7(b). For the connection shown in Fig. 43.7(a), the power supplied by the source to load = $VI\cos\phi$ where ϕ is the load power factor.
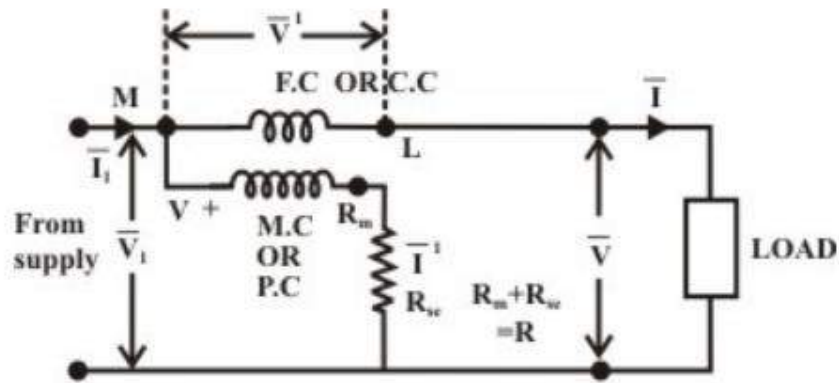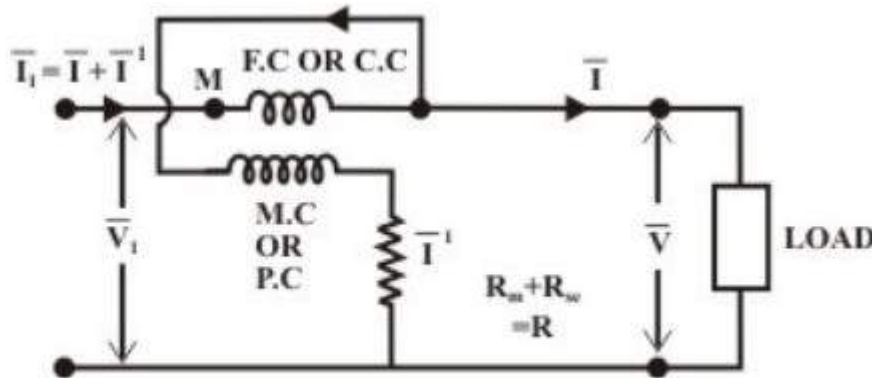

Fig. 43.7(a)

Fig. 43.7(b)

Equation (43.13) shows that the wattmeter reading is equal to the sum of power consumed in the load ($VI\cos\phi$) + power loss (I^2r) in the fixed coil of resistance 'r' Ω.

If the connections are those of Fig. 43.7(b) the total current $\overline{I}_1$ through the current coil will be the

vector sum of the load current $\overline{I}$ and the voltage coil or pressure coil or moving coil $\overline{I}'$ ($I = \dfrac{V}{R}$

where R is the resistance of the voltage coil). The wattmeter reading corresponding to the circuit configuration Fig. 43.7(b) is given by

Refer to Fig.43.7(a), and let us study the reading of the wattmeter and its is expressed as

$$\text{Wattmeter reading} = V_1 \, I \cos(\angle \overline{V}_1, \angle \overline{I}) = V_1 \, I \cos\theta = (V_1 \cos\theta)I$$
$$= (V\cos\phi + V')I \quad \text{(see phasor diagram)}$$
$$= VI \cos\phi + V'I = VI \cos\phi + I.r.I = VI \cos\phi + I^2 r \quad\quad (43.13)$$

Errors in Electrodynamometer Type Wattmeter

Following are the errors in the electrodynamometer type wattmeter:

1. Pressure coil inductance: In an ideal dynamo-meter type watt meter the current in pressure coil in phase with the applied voltage. But in practically the pressure coil of watt meter has an inductance and current in it will lag behind the applied voltage. If there is no inductance the current in pressure coil will be in phase with the applied voltage. In the absence of inductance in pressure coil of wattmeter, it will read correctly in all power factors and frequency. The wattmeter will read high when the load power factor is lagging ,as in that case the effect of pressure coil inductance is to reduce the phase angle between load current and pressure coil current . Hence the wattmeter will read high. This is very serious error. The wattmeter will read low when the load power factor is leading as in that case the effect of pressure coil inductance is to increase the phase angle between load current and pressure coil current. Hence the wattmeter will read low. Compensation for inductance of pressure coil. Inductance of pressure coil can be reduced by means of capacitor connected in parallel with a portion of multiplier (series resistance).

Instantaneous Torque Expression (neglecting inductance of voltage coil or moving coil):-
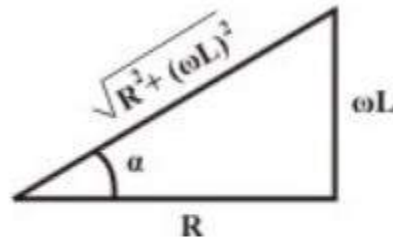
$$T_{inst} = \frac{V_m \sin\omega t}{R} I_m \sin(\omega t - \phi) \frac{dM}{d\theta}$$

$$T_{av} = \frac{1}{RT}\left[\int_0^T \frac{V_m I_m}{2} 2\sin\omega t \, \sin(\omega t - \phi)dt\right]\frac{dM}{d\theta}$$

$$= \frac{1}{RT}VI\left[\int_0^T [\cos(\phi) - \cos(2\omega t - \phi)dt]\right]\frac{dM}{d\theta}$$

$$= \frac{VI}{RT}[\cos\phi]_0^T = \frac{VI}{R}\cos\phi\frac{dM}{d\theta} \quad\quad (43.15)$$

In practice, the voltage–coil must posses some inductances; at a given frequency, let the resulting reactance be $X_L = \omega L$.

The instantaneous current through the voltage

$$i'(t) = \frac{V_m \sin(\omega t - \alpha)}{\sqrt{R^2 + (\omega L)^2}} \quad \text{where } \alpha = \tan^{-1}\frac{\omega L}{R}$$

where $v(t) = V_m \sin \omega t$ = voltage across the load.

$$T_{instantaneous}(t) = I_m \sin(\omega t - \phi) \frac{V_m \sin(\omega t - \alpha)}{\sqrt{R^2 + (\omega L)^2}} \frac{dM}{d\theta}$$

$$= \frac{V_m I_m}{\sqrt{R^2 + (\omega L)^2}} \sin(\omega t - \phi) \sin(\omega t - \alpha) \frac{dM}{d\theta}$$

$$T_{av} = \frac{1}{T} \int_0^T \frac{V_m I_m}{\sqrt{R^2 + (\omega L)^2}} \sin(\omega t - \phi) \sin(\omega t - \alpha) \frac{dM}{d\theta} dt$$

$$= \frac{VI}{\sqrt{R^2 + (\omega L)^2}} \cos(\phi - \alpha) \frac{dM}{d\theta}$$

$$= \frac{VI}{R} \cos\alpha \cos(\phi - \alpha) \frac{dM}{d\theta} \qquad (43.16)$$

Comparison of equations (43.15) and (43.16) shows that the correction factor by which the deflection must be multiplied is $\dfrac{\cos\phi}{\cos\alpha \cos(\phi - \alpha)}$.

Remarks:

- As α is very small, it is usually sufficiently accurate to take the correction factor as (i)

$$\frac{\cos\phi}{\cos(\phi - \alpha)} \qquad (43.17)$$

  for lagging power factor of the load. (ii) $\dfrac{\cos\phi}{\cos(\phi + \alpha)}$ for leading power factor of the load.
- The effect of inductance in the moving coil circuit is to cause the wattmeter to read high on **lagging power factor** (see the equation (43.16)).
- For **leading power factor** the wattmeter will read low.
- Correction factor is zero at load of unity power factor.

How to Compensate Wattmeter Error?

The error involves in wattmeter reading with the circuit configuration Fig 43.7(b) can easily be eliminated by introducing double–wound current coil. One conductor being the current coil as usual. The additional conductor is an internal connection, corresponding to the lead from L to V^+ of Fig. 43.8(a), which carries the voltage–coil current in a reverse direction through the winding.
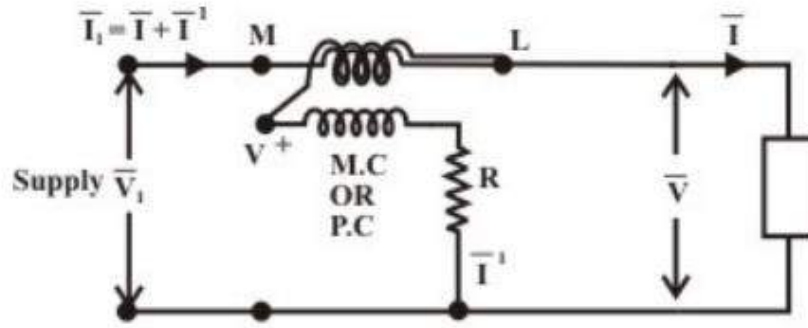

Fig. 43.8(a): Compensated wattmeter

Thus any extra torque due to the voltage–coil current in the current coil itself is neutralized by the torque due to the voltage–coil current in the additional winding.

Note: (i) There are watt-meters, that directly read the power consumed by the load P_L. In such a meter, the moving–coil (voltage coil) current goes through an additional fixed coil located so as to cancel the effect of I on the current in the fixed coil.
(ii) The input terminals of each coil (fixed and moving coils) is identified as ± sign as shown in Fig.43.8(b). The marked ± terminal of the current coil should be connected to the incoming line or to the source side and the voltage coil marked ± terminal should be connected to the positive side of the load. With the wattmeter terminal connection specified, the meter will read up-scale when power is delivered to the load. If one of the coils is connected in reverse polarity (backwards), the wattmeter will drive downscale and may be damaged. To get, up-scale reading of watt-meters, the current coil connection should be reversed.

2. Pressure coil capacitance. The pressure coil circuit may have capacitance in addition with inductance. This capacitance mainly due to the inter turn capacitance of the series resistance. The effect of capacitance is opposite to that due to inductance. Therefore the wattmeter will read high when the load power factor is leading. The inductance in pressure coil circuit will always more than inductance, hence the error caused by capacitance will be nullified by that due to inductance.

3. Error due to mutual inductance. Errors may occur due to the mutual inductance between the current and pressure coils of the watt meter. These errors are quite low at power frequencies. But they increased with increase in frequencies. The effect of mutual inductance can be avoided by arranging the coil system in such a way that they have no mutual inductance. So we can eliminate the errors due to mutual inductance. The Drysdale Torsion head wattmeter is an example for such type.

4. Eddy Current errors. Eddy currents are induced in the solid metal parts and within the thick conductors by the alternating magnetic field produced by the current coil. This eddy currents produce their own magnetic field and it will alter that produced by the main current in the current coil and thus error occurred. This error can be minimized by avoiding solid metal parts as much as possible and by using 32 stranded conductors for high current applications.

5. Stray Magnetic field Errors. The electrodynamometer type wattmeter has a weak operating field and therefore it is affected by stray magnetic fields it will result in serious errors. Hence these instruments should be shielded against stray magnetic field.

6. Errors caused by vibration of moving system. The torque on the moving system varies with frequency which is twice that of voltage. If the parts of the moving system have a natural frequency which is resonance with the frequency of torque pulsation, the moving system would vibrate with considerable amplitude. These vibrations will cause errors. This error can be reduced by design.

7. Temperature Error. The change in room temperature may affect the indication of wattmeter. This is because of change in temperature will change in resistance of pressure coil and stiffness of springs which provide controlling torque. This effect are opposite in nature and cancel each other. The use of material of having negligible temperature coefficient of resistance will reduce change in resistance the pressure coils with change in temperature.

Low Power Factor Wattmeter

If an ordinary electrodynamometer wattmeter is used for measurement of power in low power factor circuits, (PF<0.5), then the measurements would be difficult and inaccurate since:
• The deflecting torque exerted on the moving system will be very small and
• Errors are introduced due to pressure coil inductance (which is large at LPF)
Thus, in a LPF wattmeter, special features are incorporated in a general electrodynamometer wattmeter circuit to make it suitable for use in LPF circuits as under:
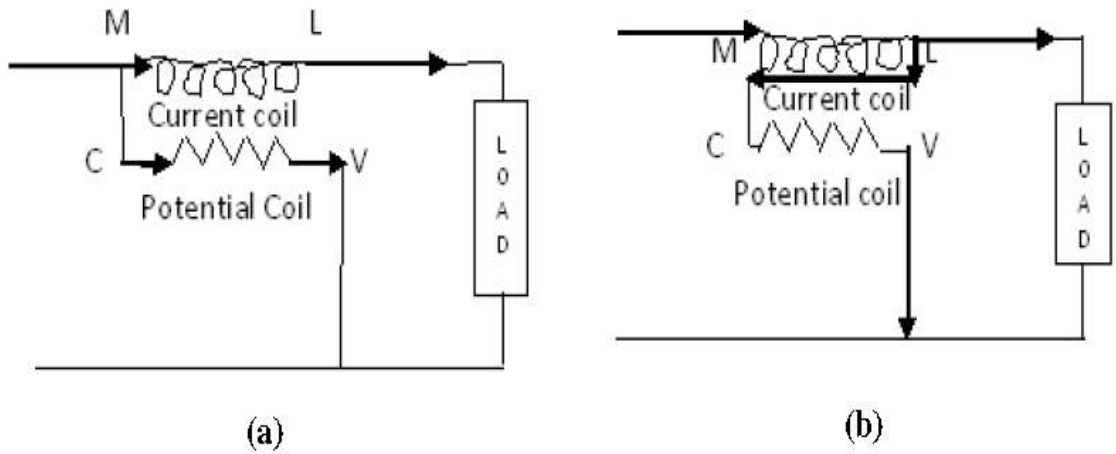
(a) Pressure coil current:

The pressure coil circuit is designed to have a low value of resistance so that the current through the pressure coil is increased to provide an increased operating torque.

(b) Compensation for pressure coil current:

On account of low power factor, the power is small and the current is high. In this context, there are two possible connections of the potential coil of a wattmeter as shown in figure 4.4. The connection (a) can not be used, since owing to the high load current, there would be a high power loss in the current coil and hence the wattmeter reading would be with a large error. If the connection (b) is used, then the power loss in the

pressure coil circuit is also included in the meter readings.

(a)   (b)

Fig. 4.4 Wattmeter Connections

Thus it is necessary to compensate for the pressure coil current in a low power factor wattmeter. For this, a compensating coil is used in the instrument to compensate for the power loss in the pressure coil circuit as shown in figure 4.5.

(c) Compensation for pressure coil inductance:

At low power factor, the error caused by the pressure coil inductance is very large. Hence, this has to be compensated, by connecting a capacitor C across a portion of the series resistance in the pressure coil circuit as shown in figure 4.5.

(d) Realizing a small control torque:

Low power factor wattmeters are designed to have a very small control torque so that they can provide full scale deflection (f.s.d.) for power factor values as low as 10%. Thus, the complete circuit of a low power factor wattmeter is as shown in figure 4.5.
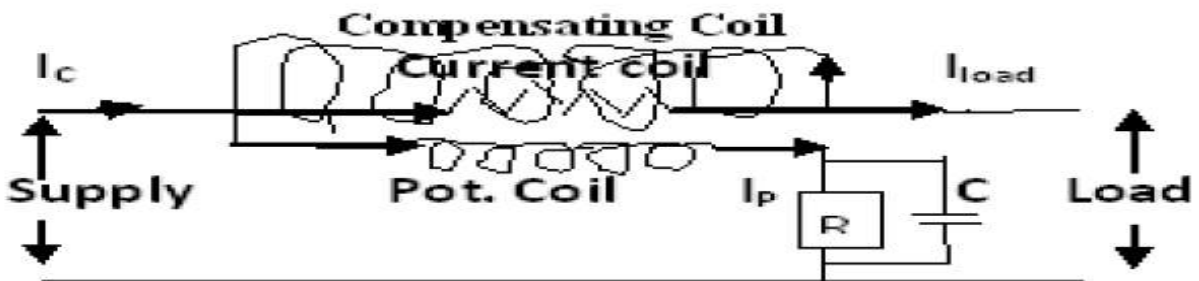
Fig. 4.5 LPF wattmeter

SINGLE PHASE ENERGY METER

The induction type single phase energy meters are universally used for energy measurements in domestic and industrial establishments since they possess some of the very useful features such as :

Accurate characteristics
Lower friction
Higher torque weight ratio
Cheaper manufacturing methods and
Ease of maintenance.

Constructional Details

The single phase induction energy meter is schematically shown in figure.Basically, it has four systems of operation: driving system, moving system, braking system and registering system.

Driving system consists of a series magnet and a shunt magnet. The coil of the series magnet is excited by load current while that of the shunt magnet is excited by a current proportional to the supply voltage. These two coils are respectively referred as current coil and potential coil (or pressure coil) of the energy meter.

Moving system consists of a freely suspended, light aluminum disc mounted on an alloy shaft and placed admidst the air-gap of the two electromagnets.

Braking system consists of a position-adjustable permanent magnet placed near one edge of the disc. When the disc rotates in the gap between the two poles of the brake magnet, eddy currents are set up in the disc. These currents react with the brake magnet field and provide the required braking torque damping out the disc motion if any, beyond the required speed.. The brakingtorque can be adjusted as required by varying the position of the braking magnet.

Recording system is a mechanism used to record continuously a number which is proportional to the revolutions made by the disc. Thus it is the counter part of the pointer and scale of indicating instruments. The shaft that supports the disc is connected by a gear arrangement to a clock mechanism on the front of the meter. It is provided with a decimally calibrated read out of the total energy consumption in KWh.
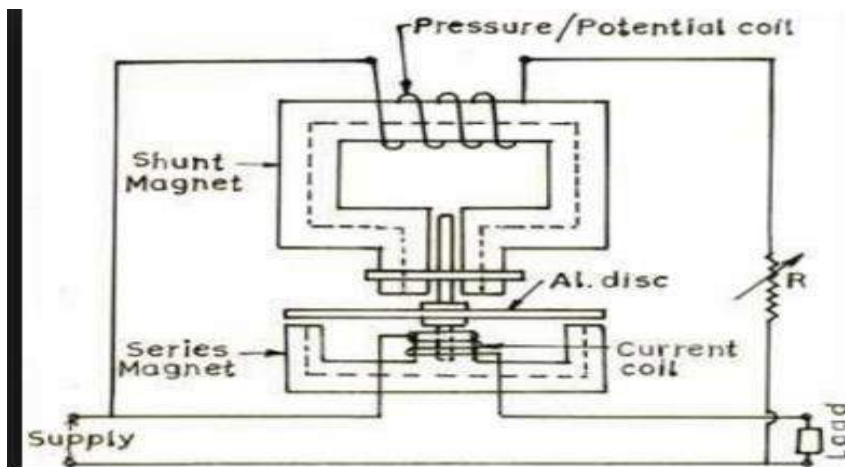
Theory of Operation

The energy meter operates on the principle of Ferraris type meter. The supply voltage is fed across the potential coil as shown in figure 8.3. The current through the potential coil is proportional to the applied voltage and lags it by nearly 90^0, since its winding resistance is very small. The potential coil current- I_P produces a flux- ϕ_{PT}, which divides into ϕ_g, a major portion across the side gaps and ϕ_P across the disc, whose magnitude is smaller. Thus, flux- ϕ_P is responsible for producing the driving torque. It is proportional to I_P and is in phase with it. Flux- ϕ_P induces an eddy EMF in the disc setting up an eddy current- i_P. The load current- I flows through the current coil and produces a flux- ϕ_S. It is proportional to I and is in phase with it. Flux- ϕ_S induces an eddy EMF in the disc setting up an eddy current- i_S. The phasor diagram of the energy meter under working conditions is as shown in figure 8.4. The eddy current- i_S interacts with ϕ_P to produce a torque. The eddy current- i_P also interact with ϕ_S to produce another torque. These two torques are in opposite directions and hence the net torque, which is the difference between them, causes the disc to rotate.

Let V be the applied voltage of frequency, f Hz., I be the load current, Z be the impedance to eddy current paths, ϕ_P & ϕ_S be the pressure coil and current coil flux values (rms), i_P,i_S be the corresponding eddy current values and & e_P,e_S, the eddy EMF values respectively. Also, let φ be the phase angle of load, Δ be the phase angle between supply voltage and pressure coil flux, α be the phase angle of eddy currents and β be the phase angle between the shunt coil and series coil flux values. Thus the mean torque deflecting the disc is given by the following analysis.

$$T_d = k \, [\, \phi_P \, i_S \cos (90 - \beta + \alpha) - \, \phi_S \, i_P \cos (90 + \beta + \alpha)]$$
$$= k \, [\, \phi_P \, i_S \sin (\beta - \alpha) + \, \phi_S \, i_P \sin (\beta + \alpha)] \tag{8.3}$$

Where k is a constant. Since we have, $e_s \propto f \, \phi_S$, $e_P \propto f \, \phi_P$, $i_P = e_P / Z$ and $i_S = e_S / Z$, we get after simplification from (8.3)
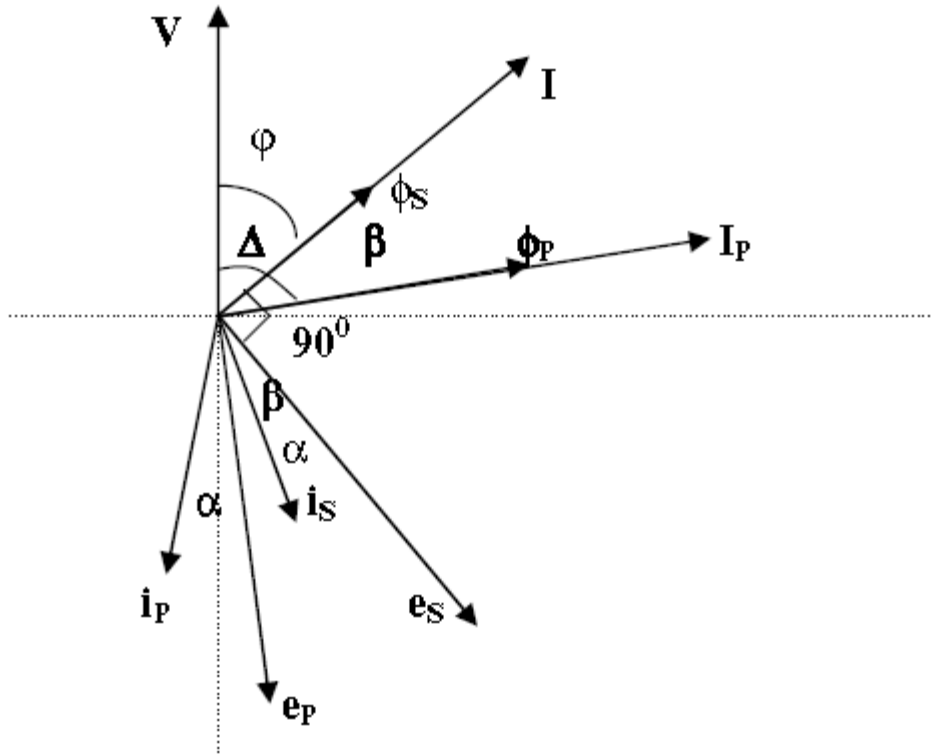
Figure 8.4 Energy meter Phasor diagram

$$T_d = k^I \; (\phi_P \; \phi_S \; f / Z) \; [\; \sin (\beta - \alpha) + \sin (\beta + \alpha) \;]$$
$$\quad = k^{II} \; (\phi_P \; \phi_S \; f / Z) \; [\; \sin \beta \cos \alpha \;] \qquad\qquad (8.4)$$

Further, since f, Z, α are constants and $\beta = (\Delta - \varphi)$, we have
$$T_d = k^{III} \; (\phi_P \; \phi_S) \sin (\Delta - \varphi) \qquad\qquad (8.5)$$

Also, $\phi_P \propto V$ and $\phi_S \propto I$, and hence we have
$$T_d = k^{IV} \; V \; I \sin (\Delta - \varphi) \qquad\qquad (8.6)$$

If N is the steady speed of rotation of the moving disc, then the braking or controlling torque, which is proportional to this speed, can be represented as
$$T_C \propto N$$
i.e., $T_C = k^V \; N \qquad\qquad (8.7)$
At steady speed, $T_d = T_C$ and so from (8.6) and (8.7), we have
$$N \propto V \; I \sin (\Delta - \varphi) \qquad\qquad (8.8)$$

If the potential coil flux and voltage phasors are maintained to be in quadrature, then we have $\Delta = 90^0$, so that, from (8.8) we get

$$N \quad \propto \quad V I \cos \varphi$$
$$\propto \text{ single phase power in AC circuits} \qquad (8.9)$$

Consider the total number of revolutions $= \int N \, dt$
$$= \int V I \sin(\Delta - \varphi) \, dt \qquad (8.10)$$

If $\Delta = 90^0$, then the no. of revolutions $= K \int V I \cos \varphi \, dt$
$$= K \int (\text{power}) \, dt$$
$$= K \, [\text{Energy}] \qquad (8.11)$$

Thus, the total number of revolutions made by the moving disc is a direct measure of the energy consumed by load circuit.

ERRORS AND COMPENSATIONS

The energy meter, also has some additional operational features for various purposes as discussed under.

Phase and speed error

It is necessary that the energy meter should give correct reading on all power factors, which is only possible when the field set up by shunt magnet flux lags behind the applied voltage by 90^0. Ordinarily the flux set up by shunt magnet does not lag behind the applied voltage exactly by 90^0 because of winding resistance and iron losses. The flux due to shunt magnet is made to lag behind applied voltage by 90^0 with the help of copper shading band provided on the central limb. An error due to incorrect adjustment of shading band will be evident when the meter is tested on a load of power factor less than unity.

An error on the fast side under these conditions can be eliminated by bringing the shading band nearer to the disc and vice versa. An error in the speed of the meter when tested on non inductive load can be eliminated by adjustment of the position of the brake magnet. Movement of the brake magnet in the direction of the spindle will reduce the braking torque and vice versa. Speed of disc is directly proportional to the distance between the disc and brake magnet.

13.3.2 Friction compensation

The two shading bands embrace the flux contained in the two outer limbs of the shunt electromagnet, and thus eddy current are induced in them which cause a phase displacement between the enclosed flux and main gap flux. As a result, a small driving torque is exerted on the disc, this torque being adjusted, by variation of the position of these bands, to compensate for frictional torque in the instrument.

In some energy meter, it is observed that the disc continue to rotate even when the load on the energy meter is zero and potential coil is in excited condition. This defect is known as creeping and is prevented by cutting two holes or slots in the disc on opposite sides of the spindle. The disc tends to remain stationary when one of the holes comes under one of pole of the shunt magnet. In some cases, a small piece of iron wire is attached to the edge of the disc. The force of attraction of the brake magnet upon this wire is sufficient to prevent continuous rotation of the disc under no load condition.

13.3.3 Temperature and frequency errors

The error due to variation in temperature is very small. Since the various effects due to change in temperature tends to neutralize each other on unity power factor if not on low power factor (lagging). Since the meters are used normally on fixed frequency and hence these can be adjusted to have a minimum error at declared supply frequency which is normally 50 cycles / second.

Lag Adjustment devices : They are used to introduce a magnetic shunt circuit which helps to provide an MMF in proper phase relation to bring the pressure coil flux in exact quadrature with the voltage. This is done by using either adjustable resistance or copper shading bands on the shunt magnet as shown in figure 8.2. The copper shading bands are provided on the central limb of the shunt magnet and they are position-adjustable. They bring the potential coil flux exactly in quadrature with the applied voltage.
Some times the lag plates are also useful for this purpose.

Friction or Low load Compensation : The friction errors are serious at low loads. To ensure proper reading at low loads, friction compensators are used, which provide a small torque, independent of the load. This torque is equal and opposite to the friction torque. The friction compensator consists of a small shading loop placed between the disc and shunt magnet, slightly towards one side of the disc, as shown in figure 8.2. It is correctly adjusted to ensure minimum friction at low loads.

Creep : In some energy meters, when the pressure coil is energized, a slow, but continuous rotation of the disc is observed even when there is no current in the current coil. This is called Creeping. This can be due to several reasons such as overcompensation for friction, vibrations, stray field effects and excessive pressure coil voltage. To prevent creeping, two diametrically opposite holes are drilled on the disc. The disc will stall when one of the holes comes under one of the poles of the shunt magnet.
Thus the rotation is restricted to a maximum of half a revolution.

Voltage Compensation: The errors due to voltage variations are compensated by increasing the reluctance of side limbs of shunt magnet.
Holes are provided on the side limbs of shunt magnet for this purpose.

Temperature Compensation: Owing to temperature effects, the energy meters may runs faster and register wrong values. In such cases, the compensation is provided by a temperature shunt on the brake magnet.

Over load Compensation: Over load compensators are used to minimize the self braking action of energy meters. They are in the form of a saturable magnetic shunt for the series magnet.

THREE PHASE ENERGY METER
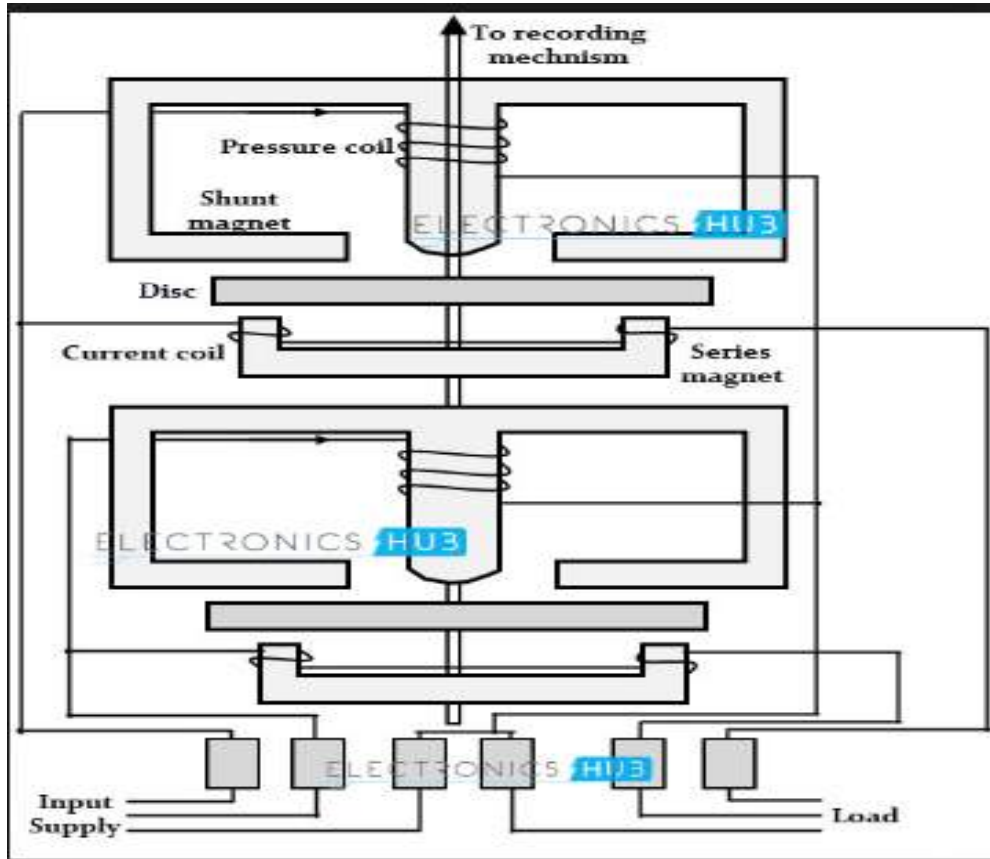
Three Phase Energy Meters

There are 2 fundamentally different types of energy meter presently in use. The first to appear was electro-mechanical, variously called a disc-type, induction or Ferraris meter.

This meter works on the same principle as the induction motor. An aluminium disc is placed inside a magnetic core with two limbs. One carries a voltage coil so its flux is proportional to voltage, the second carries a current coil so its flux is proportional to current. The two fluxes induce eddy currents to the disc, each of which interacts with the flux of the other to produce a torque, which accelerates the disc. This torque is proportional to flux $\times$ the eddy current, which equates to $V \times I$, or power. A permanent magnet creates another eddy current resulting in a torque proportional to speed that brakes the disc, the combined result of these actions is that the speed of the disc is proportional to power, and the total number of revolutions is proportional to the energy that has passed through the meter. The disc drives a chain of gears that turn a mechanical counter, called a 'register'.

The three-phase meter has three sets of coils and three discs on a common shaft. The torques add mechanically and in this way, the energy registered is the total energy drawn across all three phases.

Because of the mechanical nature of the meter, the moving parts are subject to friction. Although it is possible to alter the magnetic arrangement to produce a small torque that should exactly balance friction, this is rarely achieved in practice (because the customer would complain loudly if the disc were to move when no current was being taken). Therefore most meters have a minimum power below which, they do not register.

Single phase Electrodynamometer Power Factor Meter
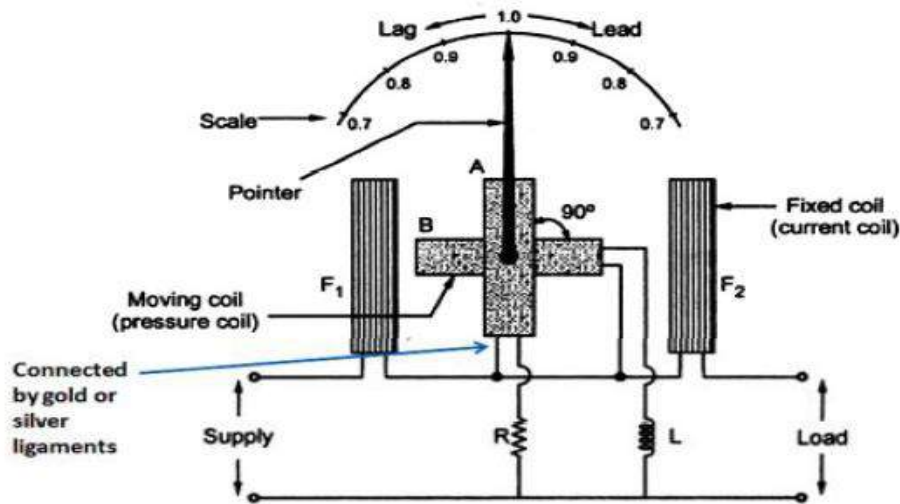
Construction of electrodynamometer type power factor meter.

Construction is shown in Fig.1
It consists of two coils 1.Fixed coil which acts as current Coil.
2. Moving coil or pressure coil.
Current coil:
1. Split into two parts and carries the current of the circuit under test.
2. The magnetic field produced by this coil is proportional to the main current.
Pressure coil:

1. Two identical coils A & B pivoted on a spindle.
2. Coil a has a non inductive resistance R connected in series with it.
3. Coil B has a highly inductive choke coil L connected in series with it.
4. The two coils are connected across the voltage of the circuit.
5. The value of R & L adjusted to carry the same current at normal frequency.
Working Principle:
1. Current in coil is in phase with the circuit voltage.
2. Current through coil B lags the voltage by an angle 90°( ).
3. The angle between the planes of the coils is made equal to   .
4. There is no controlling torque.
5. Minimum control effect using silver or gold ligaments for connecting moving coils.

Assumption made:
Current through coil B lags voltage by exactly 90°.
Angles between the planes of the coils is exactly 90°.
Now, there will be two deflecting torques:
1. Torque acting on coil A.
2. Torque acting on coil B.
The coil windings are arranged in such a way that the torques due to two coils are opposite in direction. Therefore the pointer will take up a position where these two torques are equal.

Consider the case of a lagging power factor of $\cos \varphi$.
Deflecting torque acting on coil a is:
$$TA = KVI\, Mmax\, \cos \varphi \sin\theta$$
Where θ = angular deflection from the plane of reference.

& Mmax = maximum value of mutual inductance between the two coils.
This torque acts in clockwise direction.
Deflection torque acting on coil B is:
$$TB = KVI\, Mmax\, \cos (90° - \varphi)\, \sin(90° + \theta) = KVI\, Mmax\, \sin \varphi \cos \theta.$$
This torque acts in the anticlockwise direction. The value of Mmax is the same in both the expressions, due to similar construction of coils.
The coils will take up a position where the two torques are equal.
or $KVI\, Mmax\, \cos \varphi \sin\theta = KVI\, Mmax\, \sin \varphi \cos \theta$ or $\theta = \varphi$
Therefore the deflection of the instrument is a measure of phase angle of the circuit. The scale of the instrument can be calibrated directly in terms of power factor.
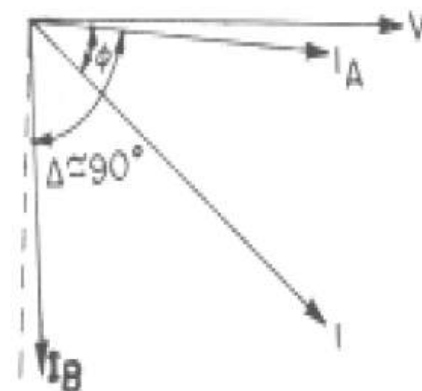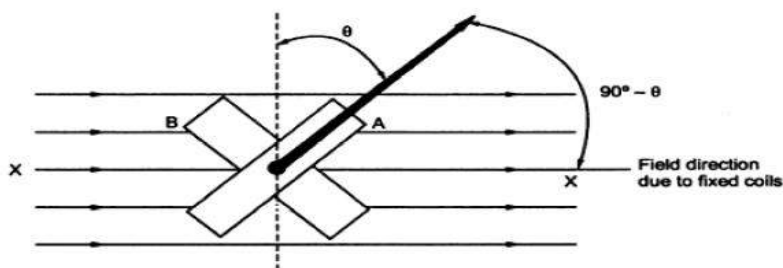
Advantages of Electrodynamic Type Power Factor Meters

1. Losses are less because of minimum use of iron parts and also give less error over a small range of frequency as compared to moving iron type instruments.
2. They high torque is to weight ratio.

Disadvantages of Electrodynamic Type Power Factor Meters

1. Working forces are small as compared to moving iron type instruments.
2. The scale is not extended over 360°.
3. Calibration of electrodynamometer type instruments are highly affected by the changing the supply voltage frequency.
4. They are quite costly as compared to other instruments.

MOVING IRON TYPE POWER FACTOR METER

One type of power factor meter suitable for 3-phase balanced circuits is shown. It consists of three fixed coils R, Y and B with axis mutually at 120° and intersecting on the centre line of the instrument, these coils are connected respectively in R, Y and B lines of the 3-phase supply through current transformers. When so energised, the three coils produce a synchronously rotating flux. There is a fixed coil B at the centre of three fixed coils and is connected in series with a high resistance across one of the pair of lines, say, across R and Y lines as shown. Coil B is threaded by the instrument spindle which carries an iron cylinder C to which are fixed sector-shaped iron vanes V$_1$ and V$_2$. The same spindle also carries damping vanes and pointer (not shown in fig.) but there are no control springs.

(a)   (b)
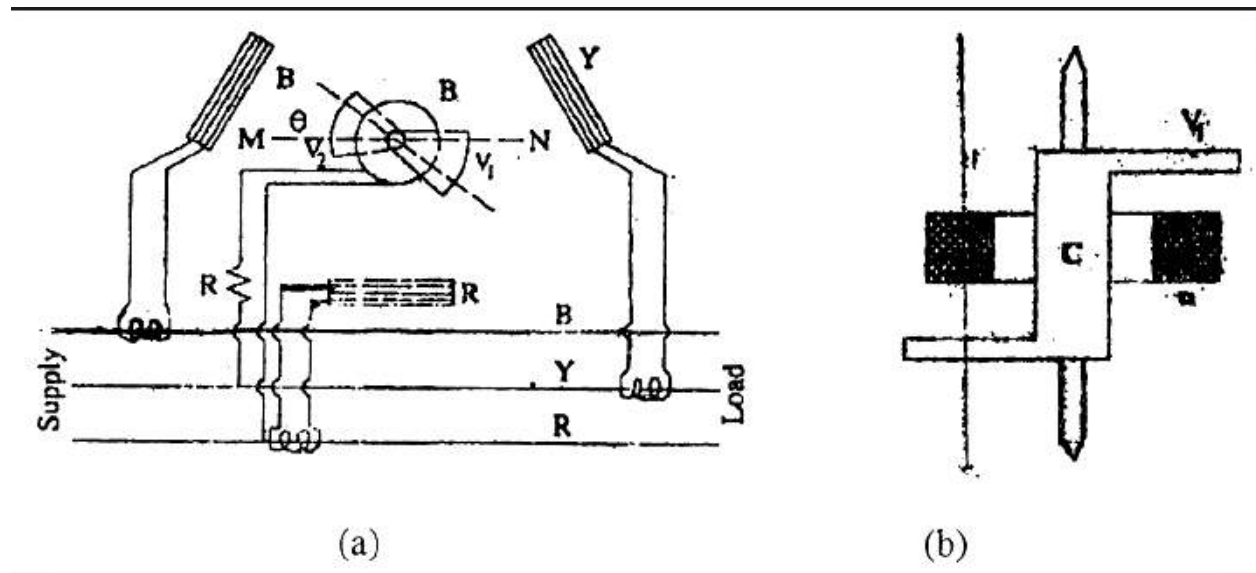
MAXIMUM DEMAND INDICATORS

Merz price maximum demand indicator indicates

A) maximum demand

B) average maximum demand over a specified period of time

C) maximum energy consumption

D) minimum prescribed demand

MDI instruments are designed in such a way that they record the base load requirement of electrical energy. They can also measure the peak load but are unable to record sudden short circuit or High motor Starting Currents. Its main construction parts are:

1. A Dial connected with moving system
2. A pointer on dial
3. Reset device
4. Fraction device
5. Indicating pin

Maximum demand indicator is often available as a built in feature of three phase energy meters, included in a single case.

Maximum Demand is calculated by

$$\text{Maximum Demand(KW)} = \frac{\text{Maximum Energy Recorded(KWh)}}{\text{Time(hours)}}$$

Since an electrical supply company must be ready to supply energy at whatever rate is needed, to meet the operating requirements of its consumers, generating and distribution equipment must be installed to provide for the maximum demand for electrical energy, rather than merely the average demand. The additional capacity installed, in order to take care of this maximum demand, involves an investment which would give return only for a portion of the time unless proper allow an were made for it in setting up rate schedules. This is achieved by changing the consumers at two-part tariff at the rate of Rs. X per annum (or month) per KW (or KVA in some cases) of maximum demand plus Rs.X per unit of total consumption. The fixed maximum demand charge coves the fixed annual cost of the supplier while the energy charge covers the running cost. Hence a meter, which records the maximum demand of a consumer during a particular period, is required. Such a meter is known as maximum demand indicator (MDI).

The chief requirement of such an instrument is that it should not record the consumer's momentary heavy demands, such as that produced by a short circuit on the system or by the high starting current of certain type of motors and penalize him unnecessary. The meter may either be a totally separate one or the energy meter may have an attached indicator for such measurement.

There are two types of M.D.I. common in use.
(a) Wright maximum Demand Indicator
(b) Merz-Price Demand Indicator

(a) Wright maximum Demand Indicator

This is the thermal type of maximum demand indicator and is based on the effect of increase in temperature, due to reading effect of current, of an air thermometer. The change in temperature is affected by passing the load current, or a definite fraction of it, through a heating coil positioned near the thermometer. Such and instrument indicates the maximum current passing through the meter irrespective of voltage, (voltage and power factor in case of a.c. measurements) across the circuit in which the meter is connected.

(b) Merz-Price Demand Indicator

Merz Price Demand Indictor: This indicator is not in the form of a separate unit, but it is an attachment which can be used with any type of motor or clock-meter and it based on the fact that it the energy flowing in a circuit is measured, say, in watt-hours, for a series of time intervals of equal duration, then the individual blocks of energy measured are themselves equal to the average power consumed.

This indicator is not in the form of a separate unit, but it is an attachment which can be used with any type of motor or clock-meter and it based on the fact that it the energy flowing in a circuit is measured, say, in watt- hours, for a series of time intervals of equal duration, then the individual blocks of energy measured are themselves equal to the average power consumed. This follows from the relation.

Average power in watts for the time period under consideration

= Energy measured in watt — hours/Time interval in hours

The same relation holds good while measuring Varh or Vah, during a definite interval of time, giving average Var or Va, respectively. Thus any mechanism which measure discreets blocks of Wh, Varh or Vah during a fixed time interval of short duration will be suitable for estimating their average values. It consists of a separate dial fitted inside the instrument, the pointer of which is driven by the spindle of the moving system of the meter through a train of gears and pin. Normally the pointer is driven forward for an half hour period or other period known as integrating time period and the energy consumed during this period is indicated on the dial by the pointer. At the end of time period, by means of a time switch and an operating mechanism the pointer is disconnected from the gearing, return to zero and reconnected to the gearing. A

maximum demand pointer is advanced by the driving pointer, but is held by fraction when not being driven. This pointer will be advanced to a new position when one half- hours energy consumption exceeds than that in any preceding half hour, but will not be affected during the half hour periods when the energy consumption is lower than that corresponding to its existing position.

RESETTING COIL   R

TIME SWITCH

SUPPLY END

R
Y
B

LOAD END
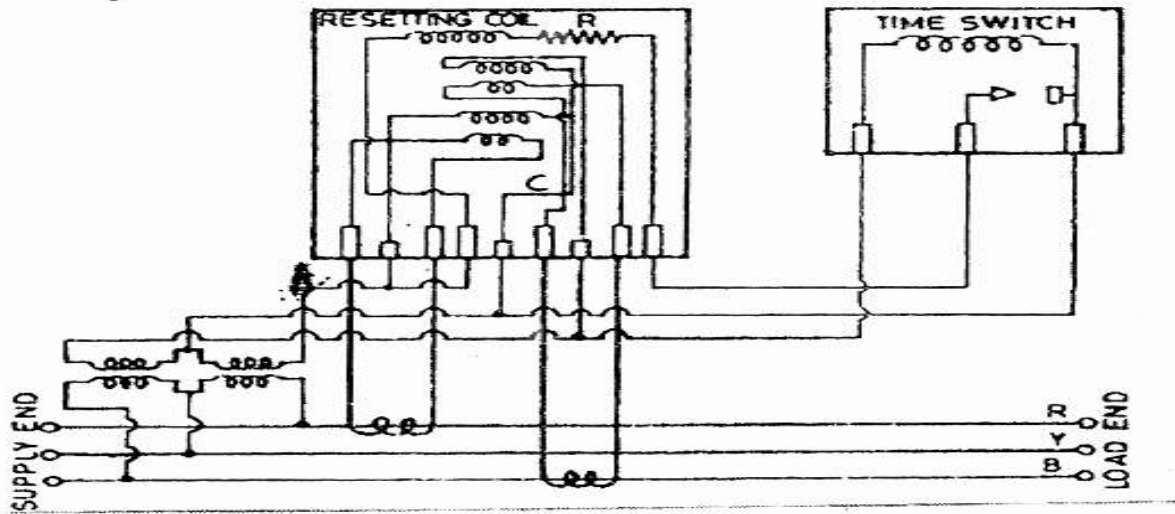
Wright Maximum Demand Indicator

Such an instrument consists of a glass U-tube having two bulbs of similar capacity at their upper ends as shown. The glass bulb on the left side of the tube consists of a metallic strip around it, which being connected in series with the load circuit, carries the load current, thus it forms a heater and heats the air inside this bulb. Just below the bulb on right side of the tube, there is a side tube leading to a narrow bore index tube fitted with a scale along it. The glass U-tube contains a liquid of low temperature co-efficient of expansion; dilute sulphuric acid as an indicator. The constructions and traps in the limbs of the tube are to prevent the passage of air from one bulb to the other.

When the indicator is set initially, the index tube contains liquid up to zero mark and the right hand tube contains the indicating solution up to the level of index tube. Now when the current flows through the heater, the air inside the bulb consisting of the heater expands and causes the liquid of right hand limb to spill into index tube.

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The greater the magnitude of current passing through the heating element of the indictor, the greater the expansion of liquid, and therefore, grater is the quantity of liquid overflowing in to the index tube. Now there will be not further overflow of the liquid in to the index tube until and unless the current passing through the heating element of the indicator surpasses the previous value. Hence the liquid in the indeed tube gives a true record of the maximum current drawn by the consumer during any given period.

Instrument does not record the momentary heavy current, since the instrument operates on the principle of heat production, which takes time.
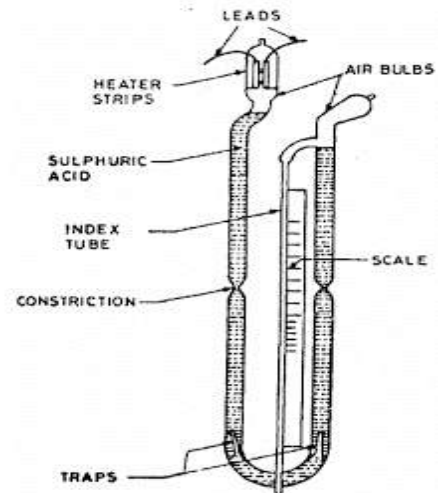
INSTRUMENT TRANSFORMERS

Instrument transformers are high accuracy class electrical devices used to isolate or transform voltage or current levels.

The most common usage of instrument transformers is to operate instruments or metering from high voltage or high current circuits, safely isolating secondary control circuitry from the high voltages or currents.

The primary winding of the transformer is connected to the high voltage or high current circuit, and the meter or relay is connected to the secondary circuit.

How will you measure AC currents and voltages of very high magnitude? You will need the measuring instruments having higher range, which literally mean huge instruments.

Or there's another way, using the transformation property of AC currents and voltages. You can transform the voltage or current down with a transformer whose turns ratio is accurately known, then measuring the stepped down magnitude with a normal range instrument. The original magnitude can be determined by just multiplying the result with the transformation ratio.

Such specially constructed transformers with accurate turns ratio are called as **Instrument transformers**. These instruments transformers are of two types - (i) **Current Transformers (CT)** and (ii) **Potential Transformers (PT)**.

Current Transformers (CT)

Current transformers are generally used to **measure currents of high magnitude**.

These transformers step down the current to be measured, so that it can be measured with a normal range ammeter.

A Current transformer has only one or very few number of primary turns. The primary winding may be just a conductor or a bus bar placed in a hollow core (as shown in the figure). The secondary winding has large number turns accurately wound for a specific turns ratio. Thus the current transformer steps up (increases) the voltage while stepping down (lowering) the current. Now, the secondary current is measured with the help of an AC ammeter. The turns ratio of a transformer is $N_P / N_S = I_S / I_P$
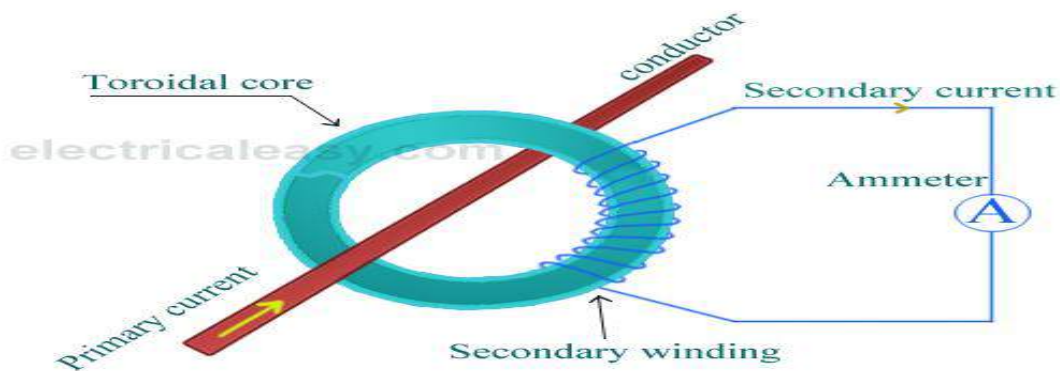
Current Transformer

One of the common **application of a current transformer** is in a 'Digital Clamp Meter'. Generally, **current transformers** are expressed in their primary to secondary current ratio. A 100:5 CT would mean the secondary current of 5 amperes when primary current is 100 amperes. The secondary current rating is generally 5 amperes or 1 ampere, which is compatible with standard measuring instruments.

$$\text{Turns Ratio} = \frac{N_P}{N_S} = \frac{V_P}{V_S} = \frac{I_S}{I_P}$$

Potential Transformer (PT)

Potential transformers are also known as **voltage transformers** and they are basically step down transformers with extremely accurate turns ratio.

Potential transformers step down the voltage of high magnitude to a lower voltage which can be measured with standard measuring instrument. These transformers have large number of primary

turns and smaller number of secondary turns.

A potential transformer is typically expressed in primary to secondary voltage ratio. For example, a 600:120 PT would mean the voltage across secondary is 120 volts when primary voltage is 600 volts.

The three main tasks of instrument transformers are:

1. To transform currents or voltages from a usually high value to a value easy to handle for relays and instruments.
2. To insulate the metering circuit from the primary high voltage system.
3. To provide possibilities of standardizing the instruments and relays to a few rated currents and voltages.

Instrument transformers are special types of transformers intended to measure currents and voltages. The common laws for transformers are valid.