# SECTION C

**WATTMETERS & ENEGRY METERS and POWER FACTOR & FREQUENCY METERS**

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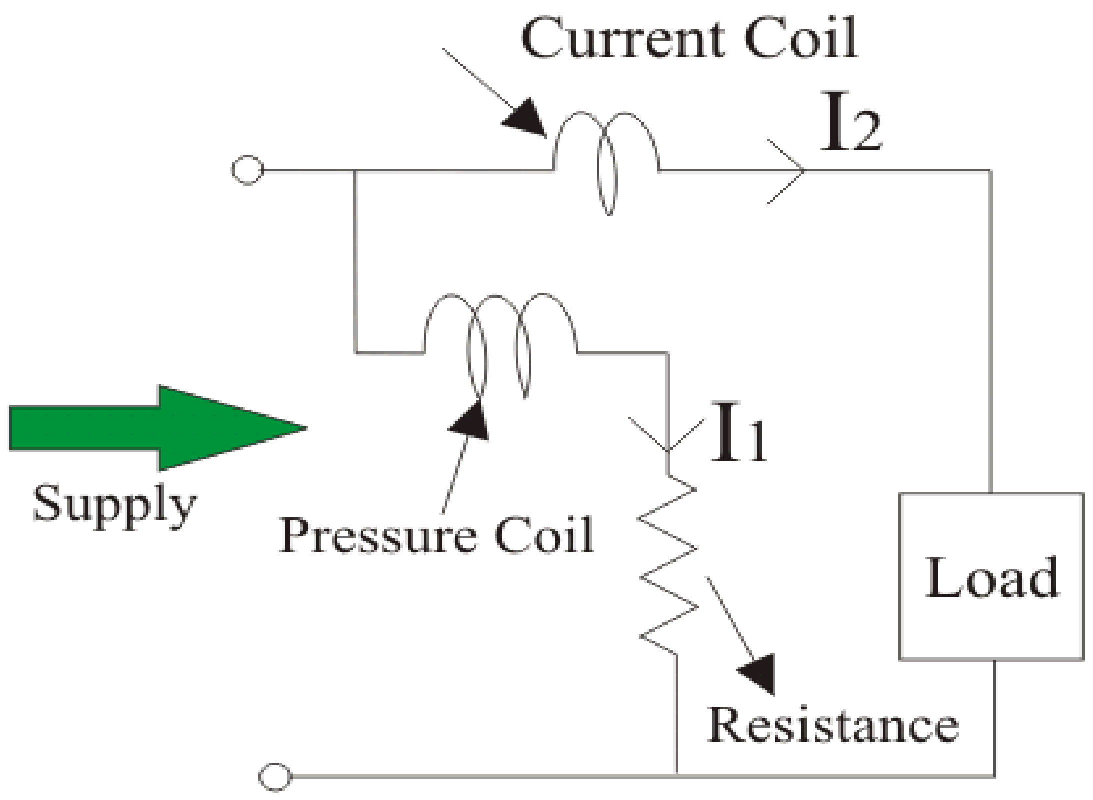
- **WATTMETERS & ENEGRY METERS:**

**Construction, operating principle, Torque equation, Shape of scale, Errors, Advantages & Disadvantages of Electrodynamic & Induction type Wattmeters; & single phase induction type Energy meter, Compensation & creep in energy meter.**

- **POWER FACTOR & FREQUENCY METERS: Construction, operation, principle, Torque equation, Advantages & disadvantages of Single phase power factor meters (Electrodynamic & Moving Iron types)& Frequency meters (Electrical Resonance Type, Ferrodynamic & Electrodynamic types).**


Current Coil
I2
I1
Supply
Pressure Coil
Load
Resistance

## Construction of Electrodynamic type wattmeters

It consists of following parts-

There are two types of coils present in the electrodynamometer.

(a) **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 electric current we have connect 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.

(b) 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.

(c) Control system: Out of two controlling systems i.e.

(1) Gravity control

(2) Spring control, only spring controlled systems are used in these types of wattmeter. Gravity controlled system cannot be employed because they will appreciable amount of errors.

(d) Damping system: Air friction damping is used, as eddy current damping will distort the weak operating magnetic field and thus it may leads to error.

(e) 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. Now let us derive the expressions for the controlling torque and deflecting torques

# Operating principle

We know that instantaneous torque in electrodynamic type instruments is directly proportional to product of instantaneous values of currents flowing through both the coils and the rate of change of flux linked with the circuit. Let $I_1$ and $I_2$ be the instantaneous values of currents in pressure and current coils respectively. So the expression for the torque can be written as: where x is the angle. Now let the applied value of voltage across the pressure coil be

Assuming the electrical resistance of the pressure coil be very high hence we can neglect reactance with respect to its resistance. In this the impedance is equal to its electrical resistance therefore it is purely resistive.

The expression for instantaneous current can be written as $I_2 = v / R_p$ where $R_p$ is the resistance of pressure coil.

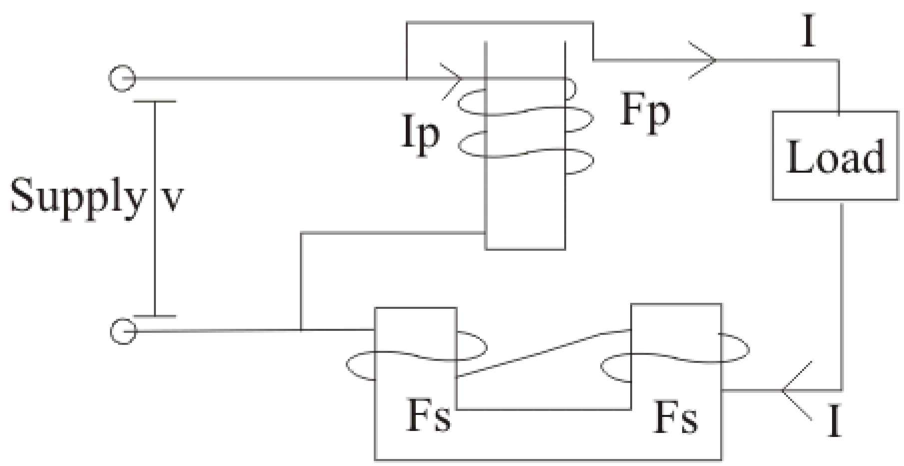
If there is phase difference between voltage and electric current, then expression for instantaneous current through current coil can be written as

As current through the pressure coil in very very small compare to current through current coil hence current through the current coil can be considered as equal to total load current.

- Hence the instantaneous value of torque can be written as

  Average value of deflecting torque can be obtained by integrating the instantaneous torque from limit 0 to T, where T is the time period of the cycle.

  Controlling torque is given by $T_c = K_x$ where K is spring constant and x is final steady state value of deflection.


I
Fp
Ip
Load
Supply v
Fs
Fs
I

# Advantages of Electrodynamometer Type Wattmeter

Following are the advantages of electrodynamometer type wattmeters and they are written as follows:

(a) Scale is uniform upto certain limit.

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

# Errors in Electrodynamometer Type Wattmeter

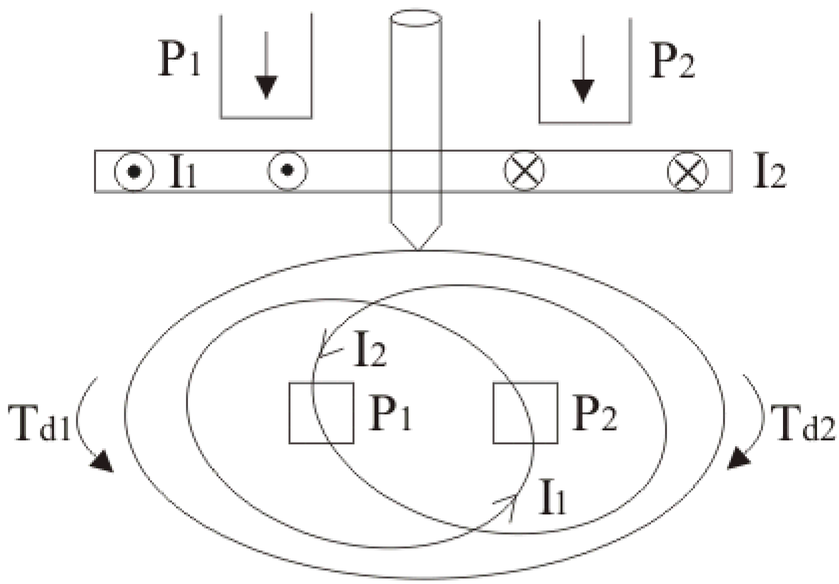
Following are the errors in the electrodynamometer type wattmeters:

(a) Errors in the pressure coil inductance.
(b) Errors may be due to pressure coil capacitance.
(c) Errors may be due to mutual inductance effects.
(d) Errors may be due connections.(i.e. pressure coil is connected after current coil)
(e) Error due to Eddy currents.
(f) Errors caused by vibration of moving system.
(g) Temperature error.
(h) Errors due to stray magnetic field.

# Induction type wattmeter

The principle of working and construction of **induction type meter** is very simple and easy to understand that's why these are widely used in measuring energy in domestic as well as industrial world. 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 (as shown in the figure given below) interacts with the alternating current of the other side resulting in the production of torque.

# Construction



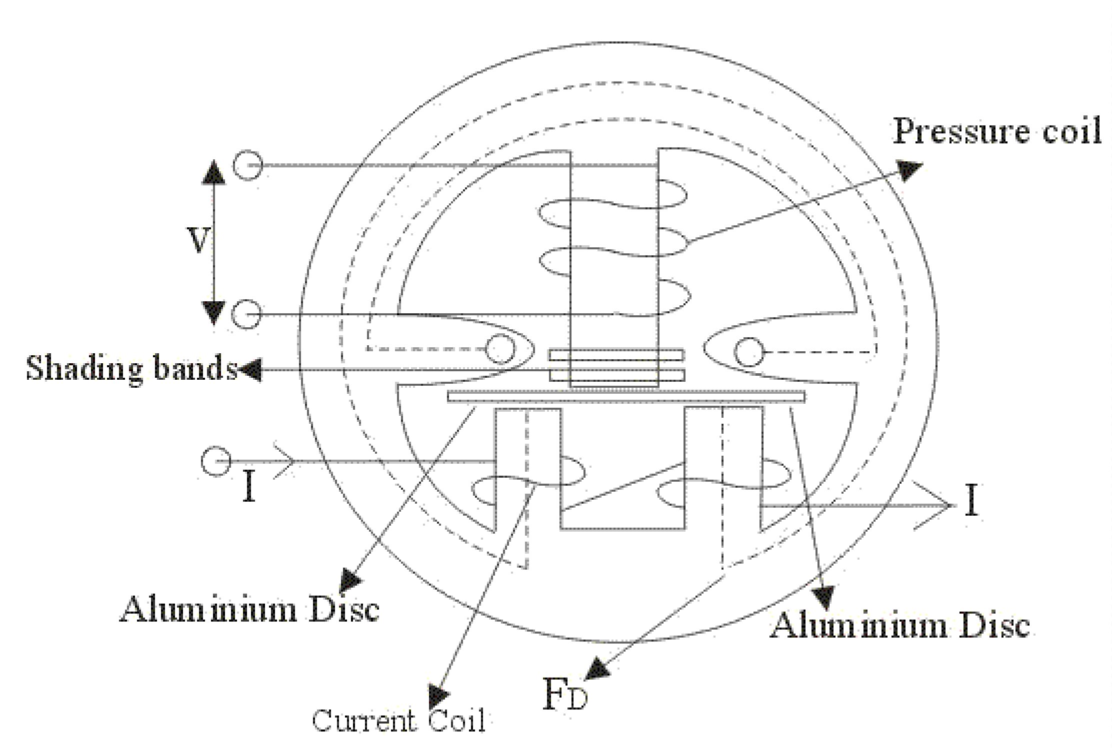
# Torque Equation

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 basic principle of working of an **induction type meters**. Now let us derive the mathematical expression for deflecting torque. Let us take flux produced at point one be equal to $F_1$ and the flux and at point two be equal to $F_2$. Now the instantaneous values of these two flux can written as:

where $F_{m1}$ and $F_{m2}$ are respectively the maximum values of fluxes $F_1$ and $F_2$, B is phase difference between two fluxes.

We can also write the expression for induced emf's at point one be
at point two. Thus we have the expression for eddy currents at point one is

# Construction details



# Construction Details

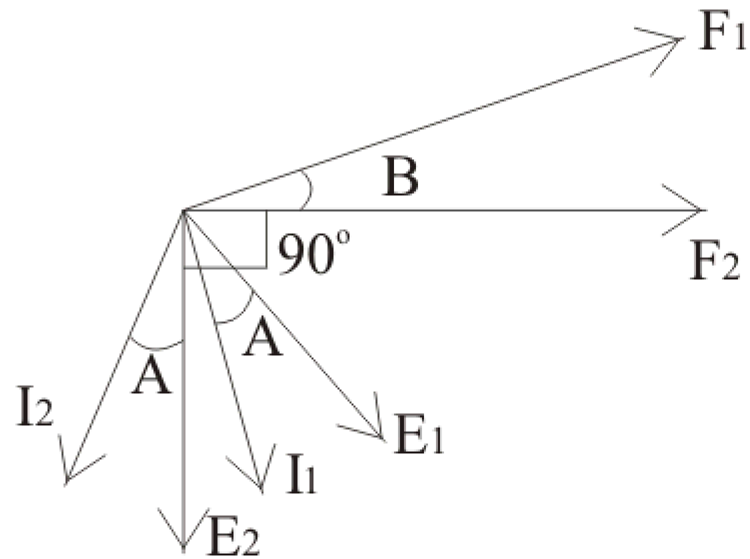
Driving system : Driving system consists of two electromagnets on which pressure coil and current coils are wounded, as shown above in the diagram. The coil which consisted of load current is called current coil while coil which is in parallel with the supply voltage (i.e. voltage across the coil is same as the supply voltage) is called pressure coil. Shading bands are wounded on as shown above in the diagram so as to make angle between the flux and applied voltage equal to 90 degrees.

Moving system : In order to reduce friction to greater extent floating shaft enegry meter is used, the friction is reduced to greater extinct because the rotating disc which is made up of very light material like aluminium is not in contact with any of the surface. It floats in the air. One question must be arise in our mind is that how the aluminium disc float in the air? To answer this question we need to see the constructional details of this special disc, actually it consists of small magnets on both upper and lower surfaces. The upper magnet is attracted to an electromagnet in upper bearing while the lower surface magnet also attracts towards the lower bearing magnet, hence due to these opposite forces the light rotating aluminium disc floats.

Braking system : A permanent magnet is used to produce breaking torque in single phase induction energy meters which are positioned near the corner of the aluminium disc.

Counting system : Numbers marked on the meter are proportion to the revolutions made by the aluminium disc, the main function of this system is to record the number of revolutions made by the aluminium disc. Now let us look at the working operation of the single phase induction meter. Inorder to understand the working of this meter let us consider the diagram given below:

# Phasor Diagram



# Description of Phasor Diagram

Here we have assumed that the pressure coil is highly inductive in nature and consists of very large number of turns. The current flowin in the pressure coil is $I_p$ which lags behind voltage by an angle of 90 degrees. This current produces flux F. F is divided into two parts $F_g$ and $F_p$.

(1) $F_g$ which moves on the small reluctance part across the side gaps.

(2) $F_p$: It is responsible for the production of driving torque in the aluminium disc.

where K is some constant and f is frequency.

Let us draw phasor diagram clearly showing $F_1$, $F_2$, $E_1$, $E_2$, $I_1$ and $I_2$. From phasor diagram, it clear that $I_1$ and $I_2$ are respectively lagging behind $E_1$ and $E_2$ by angle A. Phasor of Induction Type Meter The angle between $F_1$ and $F_2$ is B. From the phasor diagram the angle between $F_2$ and $I_1$ is (90-B+A) and the angle between $F_1$ and $I_2$ is (90+B+A). Thus we write the expression for deflecting torque as

Similarly the expression for Td2 is, The total torque is $T_{d1}$ - $T_{d2}$, on substituting the value of $T_{d1}$ and $T_{d2}$ and simplifying the expression we get
Which is known as the general expression for the deflecting torque in the induction type meters.

Now there are two types of induction meters and they are written as follows: (a)Single phase type (b) Three phase type induction meters. Here we are going to discuss about the single phase induction type in detail. Given below is the picture of single phase induction type meter.

It moves from high reluctance path and is in phase with the current in the pressure coil. $F_p$ is alternating in nature and thus emf $E_p$ and current $I_p$. The load current which is shown in the above diagram is flowing through the current coil produces flux in the aluminium disc, and due this alternating flux there on the metallic disc, an eddy current is produced which interacts with the flux Fp which results in production of torque. As we have two poles, thus two torques are produced which are opposite to each other. Hence from the theory of induction meter that we have discussed already above the net torque is the difference of the two torques.

- **Advantages of Induction Type Meters**

Following are the advantages of induction type meters:

(1)They are inexpensive as compared to moving iron type instruments.

(2)They have high torque is to weight ratio as compared to other instruments.

(3)They retain their accuracy over wide range of temperature as well as loads.

Induction type energy meters are most commonly form of an A. c. KWh meter used to measure the energy consumed in any a.c. circuit in a prescribed period when supply voltage and frequency are constant, in day today life & in industrial installation. Energy meter is an integrating instrument which measure the total quantity of electrical energy supplied to the circuit in a given period.  These meters measure electrical energy in Kilowatt hours.

# Power Factor meters

Measurement of power factor accurately is very essential everywhere. In power transmission system and distribution system we measure power factor at every station and electrical substation using these **power factor meters**. Power factor measurement provides us the knowledge of type of loads that we are using, helps in calculation of losses happening during the power transmission system and distribution. Hence we need a separate device for calculating the power factor accurately and more precisely.

- General construction of any power factor meter circuit include two coils pressure coil and current coil. Pressure coil is connected across the circuit while current coil is connected such it can carry circuit electric current or a definite fraction of current, by measuring the phase difference between the voltage and electric current the power factor can be calculated on suitable calibrated scale. Usually the pressure coil is splits into two parts namely inductive and non-inductive part or pure resistive part. There is no requirement of controlling system because at equilibrium there exist two opposite forces which balance the movement of pointer without any requirement of controlling force. Now there are two types of power factor meters-
- (1) Electrodynamometer type and
  (2) Moving iron type .

# Construction Details

General construction of any power factor meter circuit include two coils pressure coil and current coil. Pressure coil is connected across the circuit while current coil is connected such it can carry circuit electric current or a definite fraction of current, by measuring the phase difference between the voltage and electric current the power factor can be calculated on suitable calibrated scale. Usually the pressure coil is splits into two parts namely inductive and non-inductive part or pure resistive part. There is no requirement of controlling system because at equilibrium there exist two opposite forces which balance the movement of pointer without any requirement of controlling force. Now there are two types of power factor meters-

# Electrodynamometer Type Power Factor Meter

- In **electrodynamometer type power factor meter** there are further two types on the basis of supply voltage
- (1) Single phase
  (2) Three phase.
- The general circuit diagram of single phase electrodynamometer power factor meter is given below.

# Construction of Electrodynamometer Type Power Factor Meter

Fixed Coil or Current Coil

- Current Coil is split into 2 parts

- It carries current of circuit under test and produces magnetic field proportional to the main current

Pressure Coil or Moving Coil

- There are 2 identical pressure coils A and B connected across the voltage of the circuit

- Pressure coil A has a non-inductive resistance R connected in series with it.

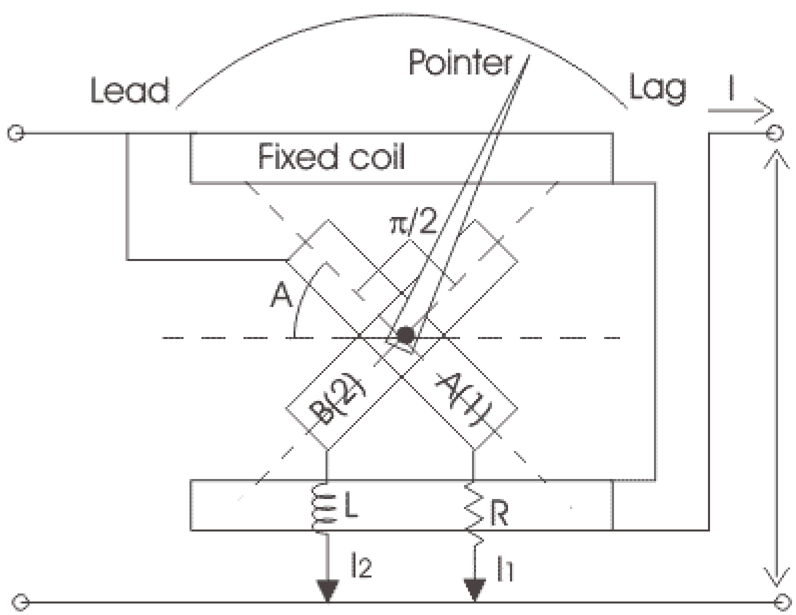
- Pressure coil B has a highly inductive choke coil L connected in series with it.

- Current through coil A is in phase with the circuit voltage while that in coil B lags voltage by an angle , which is nearly equal to $90^o$

- Angle between the plane of the coils A & B is also

- At normal frequency, values of L and R are such that current through both the coils have same magnitude i.e., R = wL

- Connections to the moving coils are made through thin silver or gold ligaments


Lead
Pointer
Lag
I
Fixed coil
π/2
A
B(2)
A(1)
L
R
I2
I1

# Power Factor Meters | Electrodynamometer Type Power Factor Meter

**Operation:**

Let's assume that current through coil B lags the voltage by exactly 90º. Therefore, angle between plane of coils is 90º. Let q be the angular deflection from the plane of reference and $M_{max}$ be the maximum value of mutual inductance. Consider the case of lagging power factor:

Deflecting torque acting on coil A,

$$T_A = K\ V\ I\ M_{max} \cos f \sin q$$

Deflecting torque acting on coil B,

$$T_B = K\ V\ I\ M_{max} \cos (90^o - f) \sin (90^o + q)$$

$$T_B = K\ V\ I\ M_{max} \sin f \cos q$$

The two torques acts in opposite direction. The coil will take up a position such that the two torques are equal. Hence at equilibrium,

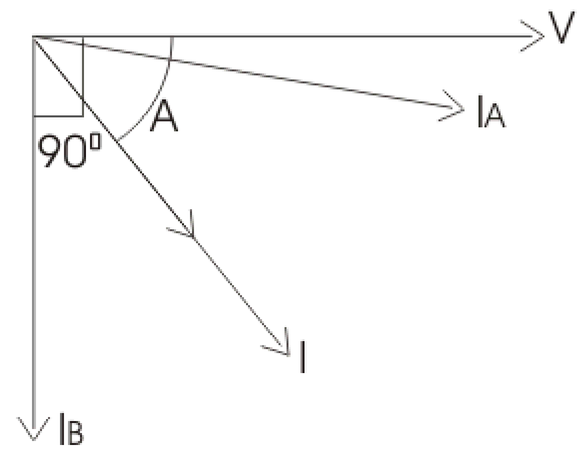
$T_A = T_B$

$K\ V\ I\ M_{max} \cos f \sin q = K\ V\ I\ M_{max} \sin f \cos q$

$q = f$

Thus, deflection of the instrument is a measure of phase angle of the circuit. Scale of instrument can be directly calibrated in terms of power factor.

# Phasor Diagram



- Now the pressure coil is spitted into two parts one is purely inductive another is purely resistive as shown in the diagram by resistor and inductor. At present the reference plane is making an angle A with coil 1. And the angle between both the coils 1 and 2 is 90°. Thus the coil 2 is making an angle (90°+A) with the reference plane. Scale of the meter is properly calibrated shown the value values of cosine of angle A. Let us mark the electrical resistance connected to coil 1 be R and inductor connected to coil 2 be L. Now during measurement of power factor the values of R and L are adjusted such that R=wL so that both coils carry equal magnitude of current. Therefore the electric currentpassing through the coil 2 is lags by 90° with reference to current in coil 1 as coil 2 path is highly inductively in nature.

## Application of Electrodynamometer Type Power Factor meter

Measurement of power factor accurately is very essential everywhere. In **power transmission system** and distribution system we measure **power factor** at every station and **electrical substation** using these **power factor meters**. Power factor measurement provides us the knowledge of type of loads that we are using, helps in calculation of losses happening during the **power transmission system** and distribution. Hence we need a separate device for calculating the power factor accurately and more precisely.

# 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) 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.

# Errors in Electrodynamic Type Power Factor Meters

- Error in the indication may be caused by change in reactance of the coil due to,
- change in supply frequency (other than the one it is calibrated at)
- presence of harmonics in the supply

# MOVING IRON POWER FACTOR METER

According to principle of operation these may be classified as,

1. **ROTATING FIELD POWER FACTOR METER**

2. **THREE PHASE ROTATING FIELD POWER FACTOR METER**

## Construction

### Fixed Coils

-A1, A2, A3 are three fixed coils connected respectively in lines 1, 2 and 3 of 3-phase supply through current transformers.

- Axes of A1, A2 and A3 are120$^o$ displaced from each other and intersecting on the central line of the instrument

# Equivalent moving coil

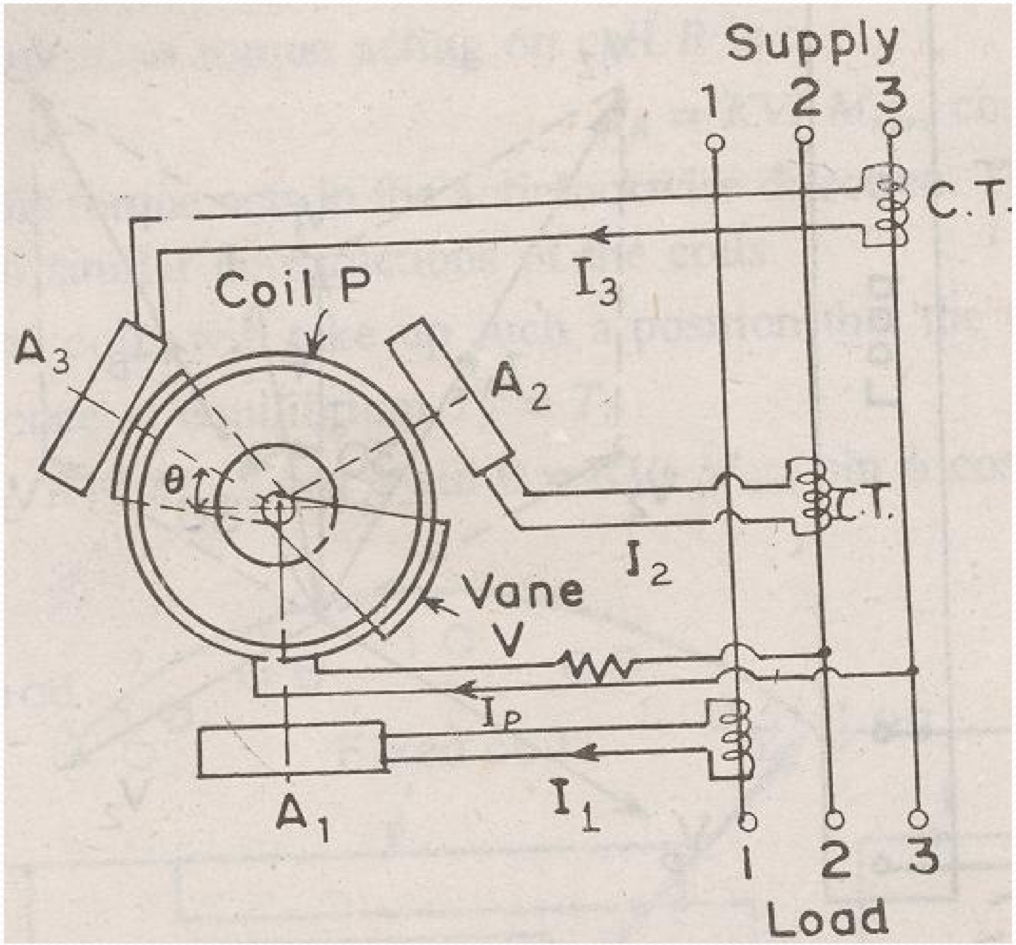
- Fixed coil P is connected in series with a high resistance across one pair of lines (2 & 3)

- Iron cylinder C is placed inside the coil P pivoted on a spindle. Two sector shaped iron vanes 180$^{o}$ apart are fixed to the cylinder

- Spindle also carries damping vanes and a pointer

- Iron Cylinder, Vanes and coil P are equivalent electromagnetically to a rectangular moving coil

There are no control springs


Supply
1
2
3
C.T.
I3
Coil P
A3
A2
θ
C.T.
I2
Vane
V
IP
A1
I1
1
2
3
Load

# Operation:

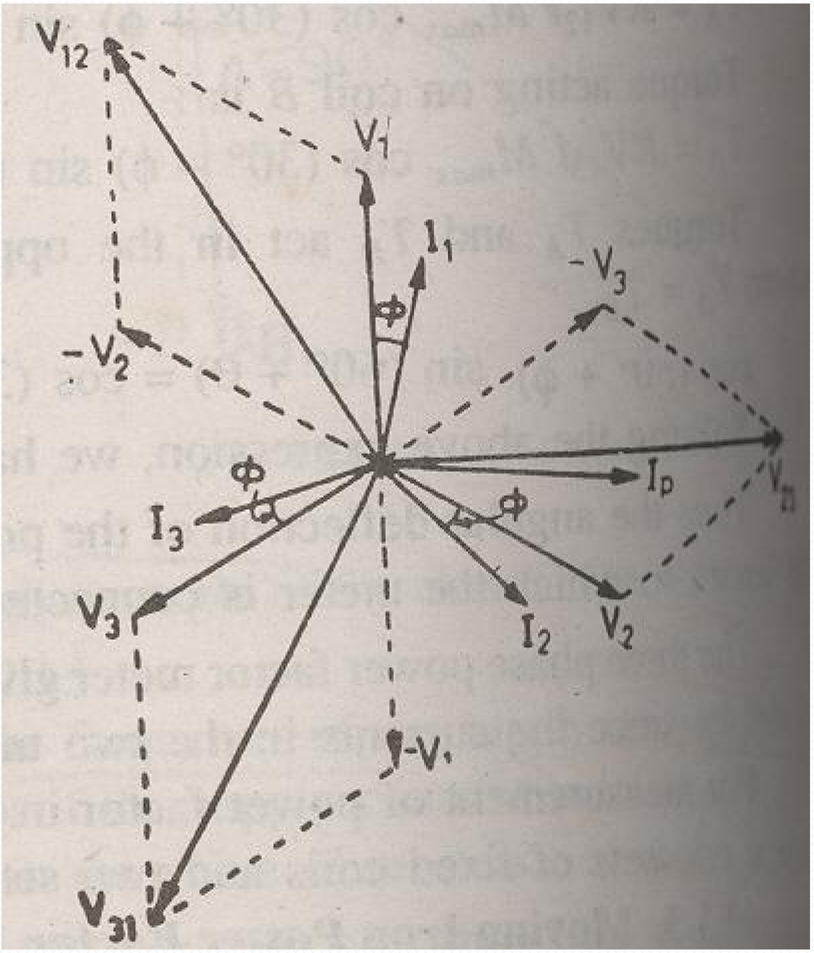
Current Ip, which is in phase with and proportional to line voltage (due to the large resistance in series), magnetizes coil P and the vanes. The alternating flux produced interacts with the fluxes produced by coils A1, A2 and A3. This causes moving system to take up a position determined by the phase angle of the system.

Total deflecting torque,

$T_d$ a [ $I_1$ $I_p$ cos (90° – f) sin (90° + q) + $I_2$ $I_p$ cos (330° – f) sin (210° + q) + $I_3$ $I_p$ cos (210° – f) sin (330° + q) ]

For a steady deflection, the total torque must be zero. Also considering system to be balanced i.e., $I_1 = I_2 = I_3$, we have,

cos (90° – f) sin (90° + q) + cos (330° – f) sin (210° + q) + cos (210° – f) sin (330° + q) = 0



V12
V1
I1
-V3
-V2
Φ
Φ
Ip
V23
Φ
I3
V3
I2
V2
-V1
V31

# SINGLE PHASE ROTATING FIELD POWER FACTOR METER

## Construction:

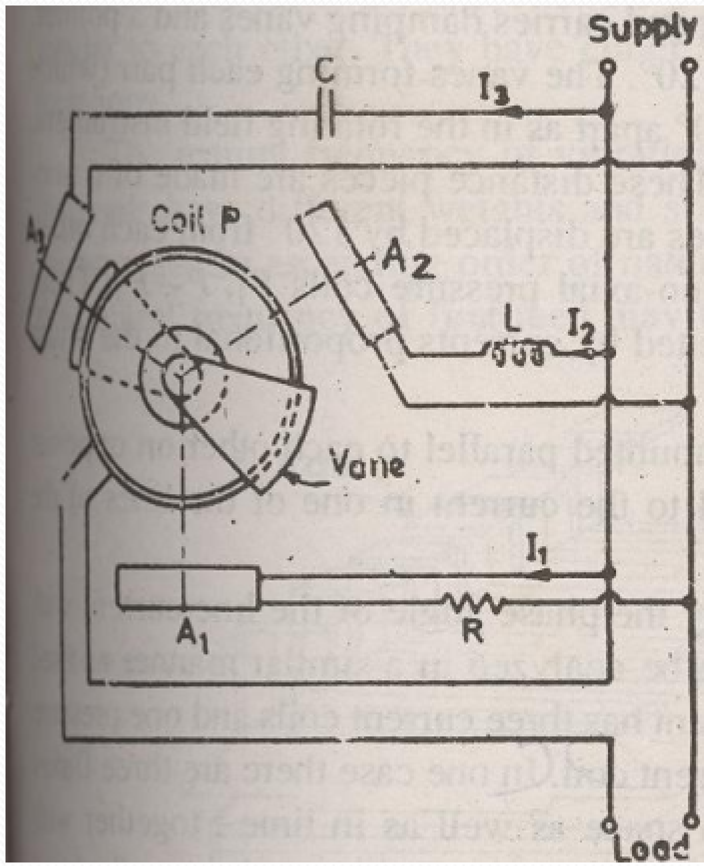
Fixed Coils

- A1, A2, A3 are three fixed coils connected respectively in lines 1, 2 and 3 of 3-phase supply with resistor R, inductor L and a capacitor C in series with it respectively.

- Current in coil A1 is in phase with the line voltage

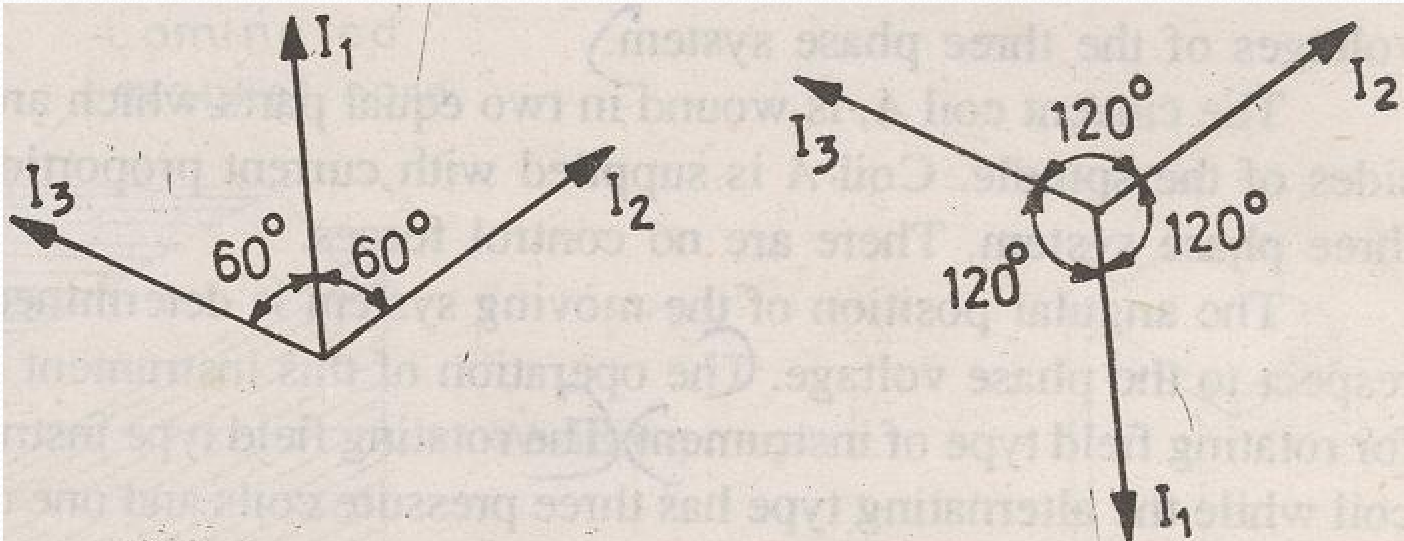
Current in coil A2 lags by $60^0$

Current in coil A3 leads $60^o$



Supply
C
$I_3$
$A_3$
Coil P
$A_2$
L
$I_2$
Vane
$I_1$
$A_1$
R
Load

- Connections of coil A1 are reversed w.r.t connections of other coils so that currents in the 3 coils are 120º out of phase with each other
- Rest is similar to that of 3-phase power factor meter
-




(*i*) Before reversal of connections of coil $A_1$

(*ii*) After reversal of connections of coil $A_1$

**Advantage of Moving Iron power factor meter**

Working forces are very large

All coils are fixed. Hence the use of ligaments is elminated

Scale extends over 360o

Simple & robust in construction

Cheap

**Disadvantage of Moving Iron power factor meter**

Less accurate due to iron losses

Calibration is affected by variations in supply frequency, voltage & waveform

# Frequency meter

The main principle of working of **weston type frequency meter** is that "when an electric current flows through the two coils which are perpendicular to each other, due to these currents some magnetic fields will produce and thus the magnetic needle will deflects towards the stronger magnetic field showing the measurement of frequency on the meter". Construction of weston frequency is as compared to ferrodynamic type of frequency meter. In order to construct a circuit diagram we need two coils, three inductors and two resistors. Given below is the circuit diagram for the **weston type frequency meter**.

Now when we apply voltage at standard frequency then the pointer will take normal position, if there increase the frequency of the applied voltage then we will see that the pointer will moves towards left marked as higher side as shown in the circuit diagram. Again we reduce the frequency the pointer will start moving towards the right side, if lower the frequency below the normal frequency then it cross the normal position to move towards left side marked lower side as shown in the figure.

# MECHANICAL RESONANCE TYPE OR VIBRATING REED TYPE FREQUENCY METER

**Construction:**

Reeds

- Thin steel strips called reeds are placed in a row alongside close to an electromagnet.

All reeds are similar with their natural frequencies of vibration different (as they have slightly different dimensions) & are arranged in ascending order of frequencies.

- Reeds are fixed at bottom end and are free at top end with a portion bend to serve as flag.

Electromagnet

- Electromagnet has a laminated iron core on which coil is wound. The coil is connected in series across the supply whose frequency is to be measured

- **Operation:**
- Frequency Meter is connected across the supply whose frequency is to be measured the coil of electromagnet carries a current *i*, which alternates at the supply frequency. The force of attraction between the reeds and the electromagnet is proportional to $i^2$ and therefore this force varies twice at the frequency supply frequency. Thus, the force exerted on the reeds varies every half cycle. All the reeds tend to vibrate, but the reed whose natural frequency is equal to twice the frequency of supply tends to vibrate the most. Vibration of other reeds is unobservable.

# ELECTRICAL RESONANCE TYPE

Two types of electrical Resonance Meters are described below:

**FERRODYNAMIC TYPE OF FREQUENCY METER:**

**Construction:**

Magnetizing Coil

- Consists of a fixed coil called magnetizing coil, which is connected across the supply whose frequency is to be measured
- It is mounted on a laminated iron core

Iron core

- Cross section of iron core varies gradually over the length , being maximum near the end where magnetizing coil is mounted and minimum at the other end.

Moving Coil

- Moving coil is pivoted over the iron core
- A pointer is attached to moving coil
- Terminals of moving coil are connected to a suitable capacitor C

No provision for controlling force

# Principle of Operation:

Magnetizing coil carries a current I and produces flux f in phase with current I. Flux f induces emf E in the moving coil lagging behind it by 90º. Emf E circulates current $I_m$ in the moving coil. Phase of current $I_m$ depends upon inductance L of the moving coil and capacitance C.

Circuit of moving coil is inductive & therefore current $I_m$ lags behind emf E by an angle a. The torque acting on the moving coil is,

$T_d$ a $I_m$ I cos (90º + a)

Circuit of moving coil is capacitive & therefore current $I_m$ leads emf E by an angleb. The torque acting on the moving coil is,

$T_d$ a $I_m$ I cos (90º - b)

Inductive reactance of the circuit of moving coil is equal to its capacitive reactance & therefore current $I_m$ is in phase with emf E. The torque acting on the moving coil is,

$T_d$ a $I_m$ I cos 90º = 0

# Working:

For a fixed frequency, capacitive reactance is constant but inductive reactance of moving coil depends upon the position it occupies on the iron core. Inductive reactance is maximum when moving coil occupies a position close to the magnetizing coil and is minimum at the other end.

The figure shows the position of moving coil at normal frequency. At this position, inductive reactance is equal to the capacitive reactance.

Suppose the frequency increases above its normal value then, $X_L > X_C$ & therefore torque is produced. This torque pulls the moving coil to an equilibrium position i.e., moving coil deflects towards the section of iron core having minimum cross section. So inductive reactance decreases and moving coil comes to rest at a position where $X_L = X_C$.

Suppose the frequency decreases below its normal value then, $X_L < X_C$ & therefore torque is produced. This torque pulls the moving coil to an equilibrium position i.e., moving coil deflects towards the section of iron core having maximum cross section. So inductive reactance increases and moving coil comes to rest at a position where $X_L = X_C$.

# Advantage:

Great sensitivity

# ELECTRODYNAMOMETER TYPE OF FREQUENCY METER:

**Construction:**

Fixed coil

Fixed coil is divided into two parts 1 and 2 which forms two separates resonant circuits

- Fixed coil 1 is in series with an inductance $L_1$ and a capacitance $C_1$ forming a resonant circuit of frequency $f_1$.
- Fixed coil 2 is in series with an inductance $L_2$ and a capacitance $C_2$ forming a resonant circuit of frequency $f_2$.

Moving Coil

- Current through the moving coil is sum of the currents through the 2 parts of fixed coil
- Torque on the movable element is proportional to the current through the moving coil

A small iron vane mounted on the moving system provides controlling torque.

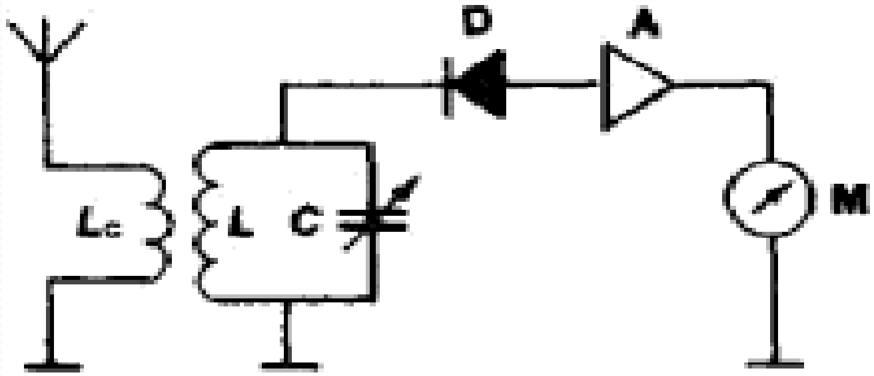
# Operation:

At a particular frequency, the current through circuit of fixed coil 1 lags behind applied voltage (as $X_{L1}>X_{C1}$) while the current through circuit of fixed coil 2 leads applied voltage (as $X_{L2}<X_{C2}$). Therefore torques produced by 2 coils act in opposition on the moving coil. The resultant torque is a function of frequency of the applied voltage.

## Application:

- For power frequency measurements
- In power system, for monitoring the frequency

# Electro-Resonance Frequency Meter



The frequency of electromagnetic oscillations in the radio-frequency and microwave-frequency ranges is measured by means of electronic frequency meters (wavemeters), such as the resonant, heterodyne, and digital types.

The operation of a resonant-type frequency meter is based on the comparison of the frequency being measured with the frequency of natural oscillations in an electrical circuit (or a microwave resonator) that is tuned to resonance with the frequency being measured. The meter consists of an oscillatory circuit with a coupling loop that picks up the electromagnetic oscillations (radio waves), a detector, an amplifier, and a resonance indicator (Figure 3). During measurement, the circuit is tuned by means of a calibrated capacitor (or the plunger of a microwave resonator) to the frequency of the electromagnetic oscillations being picked up until resonance is achieved, as shown by the greatest deflection of the pointer on the indicator. The measurement error ranges from $5 \times 10^{-3}$ to $5 \times 10^{-4}$.