Power Factor Measurement

- **PF** is Cosine of phase angle b/n $\mathbf{V_{ph}}$ **&** $\mathbf{I_{ph}}$ of a given ac system
- Power in 1 ph ac ckt, P = VI **Cos Φ** & 3 ph ckt is, 3 V_{ph} I_{ph} **Cos Φ**

  where **Cos Φ** is the power factor of the circuit
- **Cos Φ** can be calculated by measuring V, I and P i.e., **Cos Φ** = P/VI
- Is it accurate?
- Errors of all meters cause large error in measurement of **PF**
- Also not suitable for circuits where **PF** is varying according to ckt and load
- Exclusive meters are necessary to indicate **PF** directly
- Meter that indicates instantaneous **PF** of a ckt is called PF Meter

Power Factor Meter

- Usually PF Meter consists of 2 ckts viz. current ckt and voltage ckt
- Current ckt carries **I** or fraction of **I** of the ckt whose PF is to be measured
- Voltage ckt is split into two parallel paths – one inductive and the other non-inductive – **I** in two paths are proportional to **V**
- Thus, deflection depends upon the phase difference between the main current through current ckt and currents in the two paths of voltage ckt i.e. PF of the ckt
- Two types of PF Meters: **(1)** Electrodynamometer Type PF Meter (similar to Wattmeter) and **(2)** Moving Iron Type PF Meter

Electrodynamometer Principle

- Similar to the PMMC-type elements except that the magnet is replaced by two serially connected fixed coils that produce the magnetic field when energized
- **Fixed coil:** The magnetic field is produced by the fixed coil which is divided into two sections to give more uniform field near the centre and to allow passage of the instrument shaft
- **Moving coil:** is wound either as a self-sustaining coil or else on a non-magnetic former. A metallic former cannot be used, as eddy currents would be induced in it by alternating field.
- Light but rigid construction is used for the moving coil
- It should be noted that both fixed and moving coils are air cored

Electrodynamometer Principle

- **Springs:** The controlling torque is provided by two control springs. These hairsprings also act as leads of current to the moving coil
- **Damping:** Air friction damping is employed and is provided by a pair of Aluminum vanes attached to the spindle at the bottom
- **Shielding:** Since the magnetic field produced by fixed coils is weaker than that in other types of instruments, these meters need a special magnetic shielding
- Effectively shielded from the effects of external magnetic fields by enclosing the mechanism in a laminated iron hollow cylinder with closed ends

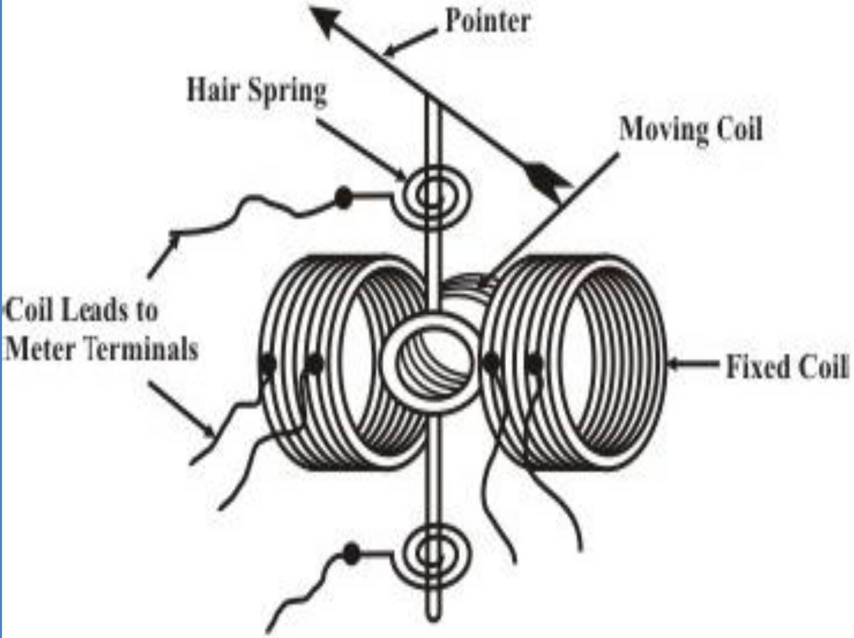
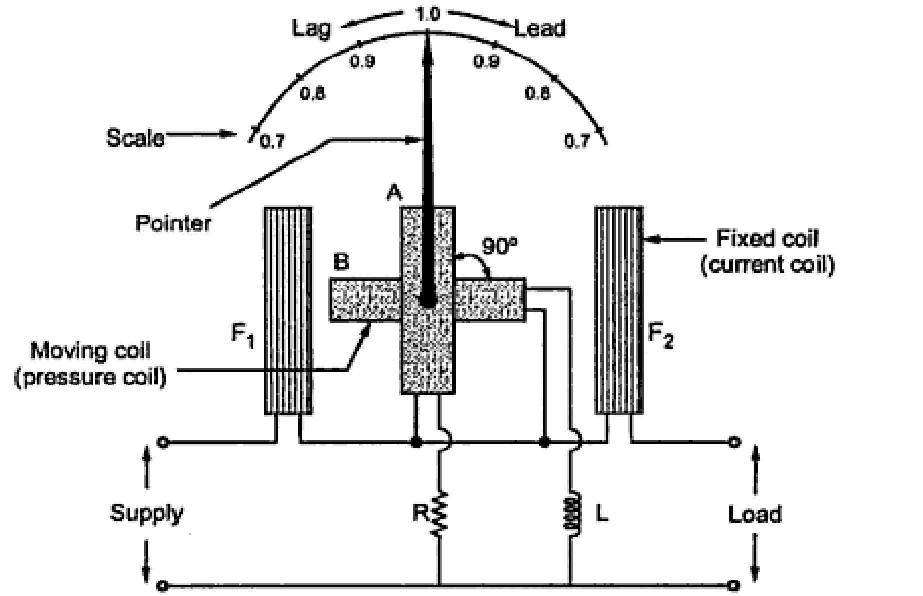
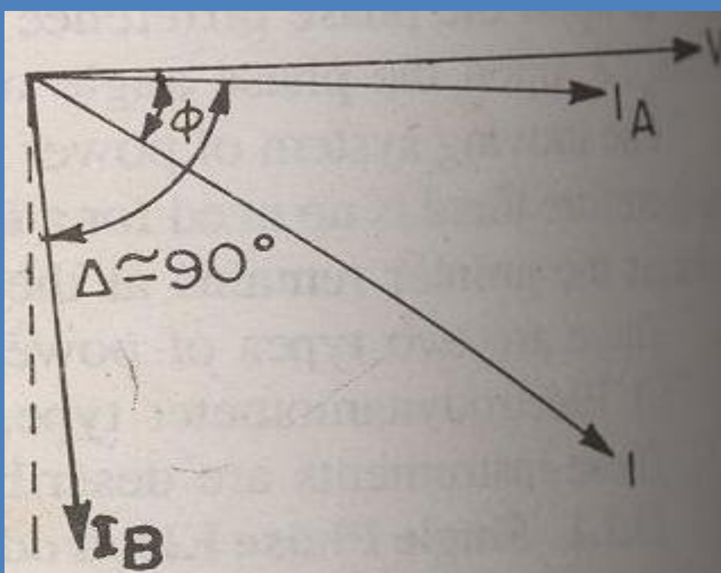
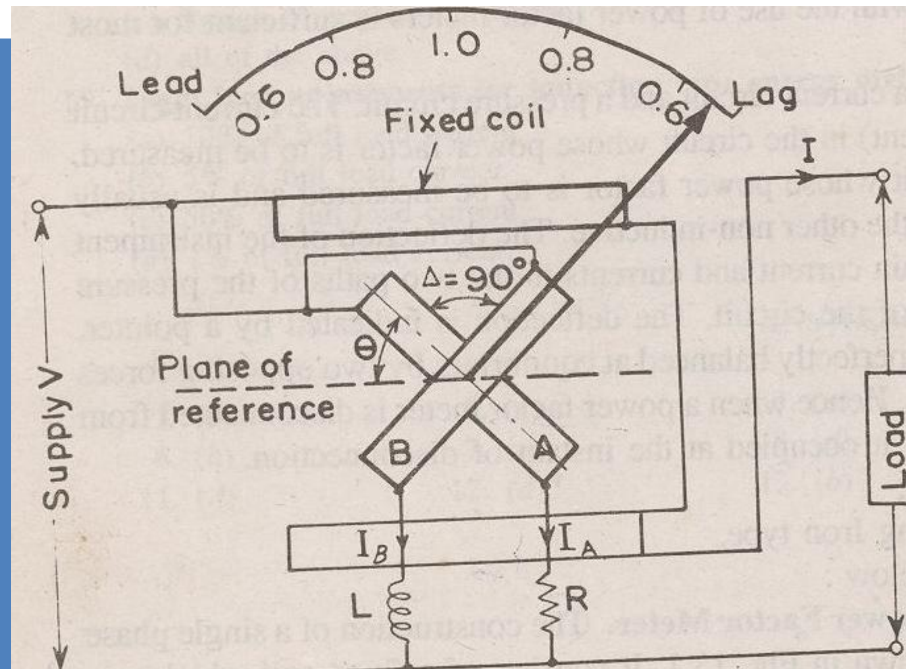


Fig. Basic principle of Electrodynamometer type instrument



Single phase electrodynamometer type power factor meter





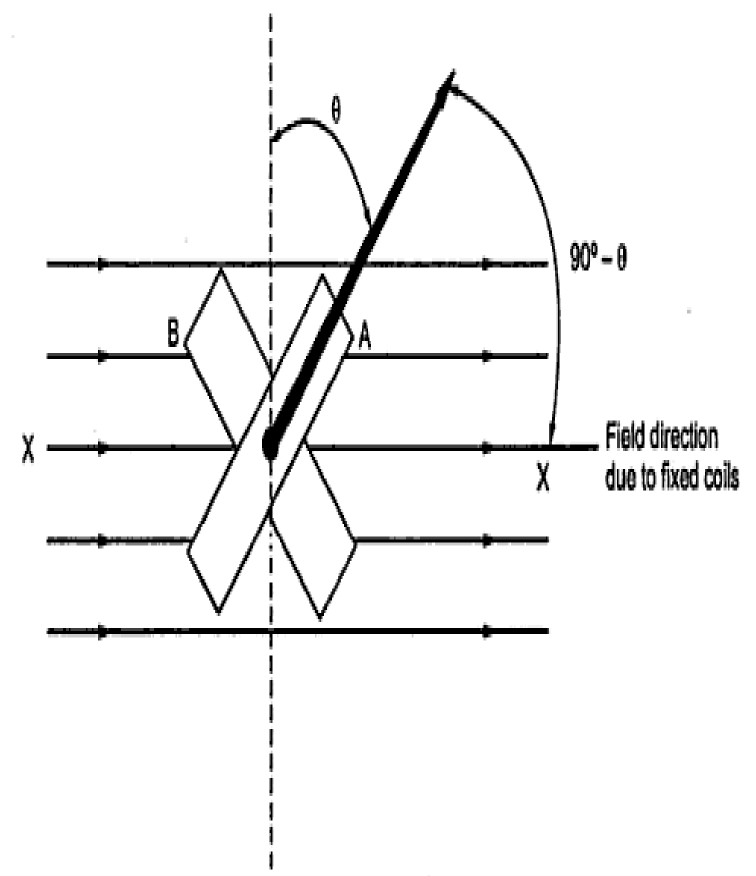
Single Phase Electrodynamometer Type Power Factor Meter

- **F_1 & F_2** are two fixed coils connected in series and carry main current
- If I is large, a fraction of I is made flow through fixed coils
- Magnetic field produced by fixed coils is proportional to main current
- **A & B** are two moving coils rigidly connected to each other so that their axes are at **90^0** to each other i.e. mutually perpendicular to each other
- **A & B** are identical
- **A & B** move together and carry the pointer which indicates PF
- (See fig.) **A & B** are connected in parallel to the supply and hence called pressure coils or voltage coils
- **I_A & I_B** are proportional to the supply voltage, **V**
- **A** has series non – inductive resistance and **B** has series inductance
- R and L values are so adjusted that **I_A & I_B** are equal at normal frequency
- So at normal frequency $R = \omega L$
- **I_A** is in phase with **V** due to R & **I_B** lags **V** by nearly **90^0** due to L
- **I_A** is independent of frequency & **I_B** frequency dependent due to L

Single Phase Electrodynamometer Type Power Factor Meter

- I_A & I_B are equal and produce magnetic fields of equal strength, which have phase difference of **90^0**
- Controlling torque is absent
- Moving coil contacts are made with the help of extremely fine ligaments which give no controlling effect on moving system
- Assume field produced by FCs is uniform
- Due to the interaction of fields produced by various coil currents , MCs **A & B** experience a torque

Consider the position of the moving system as shown in the Fig. shown below



Single Phase Electrodynamometer Type Power Factor Meter

- Coils are arranged in such a way that the **torques** experienced by coils **A & B** are **opposite** to each other
- Pointer attains equilibrium position when these two torques are equal
- Torque on each coil, for a given coil current will be maximum when the coil is parallel to the field produced by F_1 & F_2 i.e. direction X-X
- Derivation of Deflection Torque
- Let **Φ** be **PF angle** and **θ** be **Deflection angle** from the plane of reference and M_{max} be the maximum value of mutual inductance
- **θ** is measured from the **vertical axis,** in the **equilibrium** position
- Now, Torque on coil A is given by, $T_A = K\,VI\,M_{max}\,\cos\phi\,\cos\left(90^0 - \theta\right)$ ....(1)

where **K** is a constant

Single Phase Electrodynamometer Type Power Factor Meter

- Eqn. (1) is similar to Torque eqn. of dynamometer type instrument
- **I_A** is in phase with **V** & it moves in a magnetic field proportional to **I**, and **dM/ dθ** (generally constant for radial field and not constant for parallel field) is proportional to **Cos (90^0 – θ)**
- Similarly **I_B** lags **V** by **90^0** and it moves in same field
- **T_B** is proportional to **Cos (90^0 – Φ)** i.e. **Sin Φ** and **Cos θ**

$$T_B = K\ VI\ M_{max}\ Sin\ \phi\ Cos\ \theta \ldots\ldots\ldots (2)$$

- **At equilibrium $T_A = T_B$**

$$Cos\ \phi\ Cos\ (90^0 - \theta) = Sin\ \phi\ Cos\ \theta$$

$$\frac{Sin\ \theta}{Cos\ \theta} = \frac{Sin\ \phi}{Cos\ \phi}$$

$$Tan\ \theta = Tan\ \phi$$

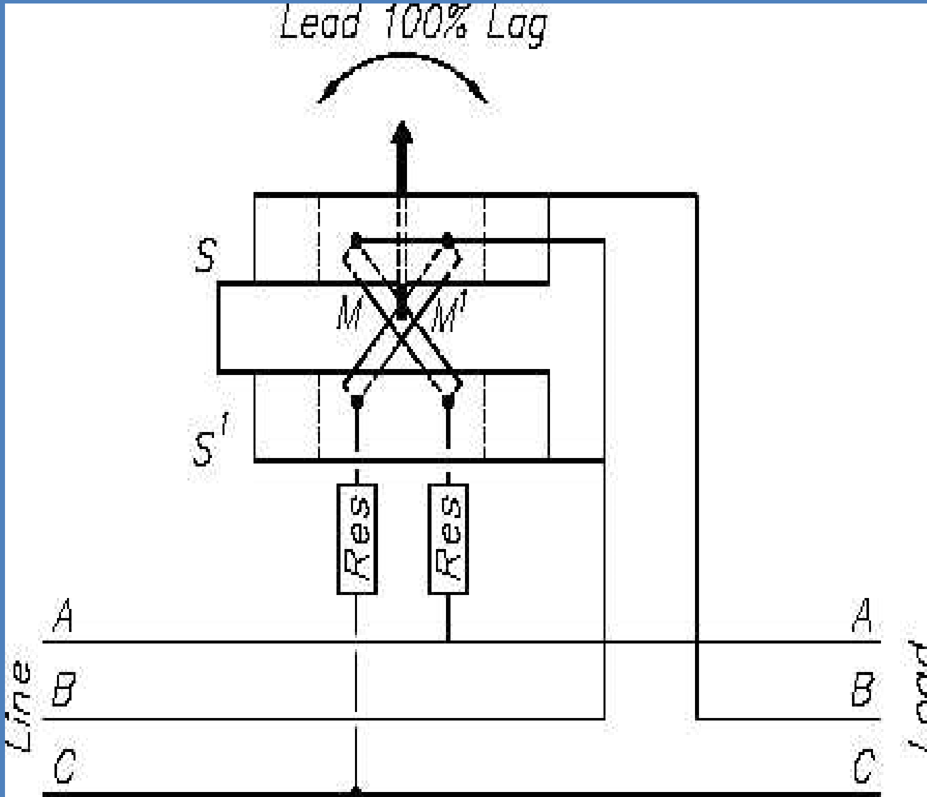
$$\therefore \quad \theta = \phi$$

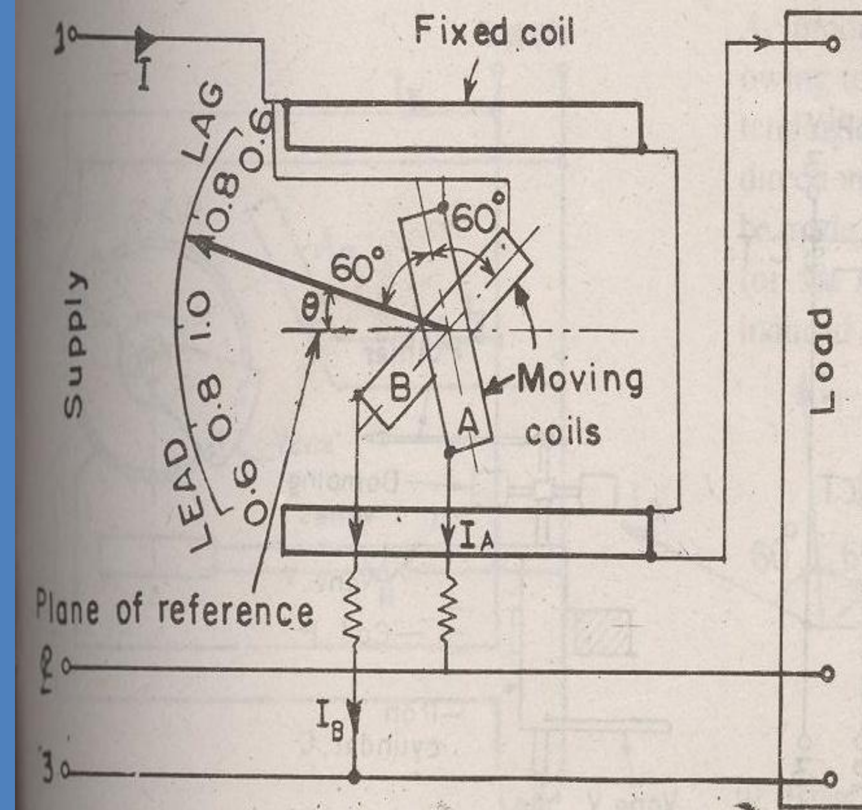
- Thus angular position equals PF angle
- Scale is calibrated in terms of PF

- Operation is dependent on **f**
- If **f** changes or it contains harmonics, then **L** changes due to which errors occur
- Operation is **not dependent** on **I & V** values but **dependent** on **f** and **waveform**

Three Phase Electrodynamometer Type Power Factor Meter

- Electrodynamometer movement is made with two movable coils set at right angles to each other
- Two stationary coils, S and S^1, are connected in series in Phase B
- Coils M and M^1 are mounted on a common shaft, which is free to move without restraint or control springs
- M and M^1 are connected with their series resistors from phase B to phase A & from phase B to phase C
- At upf one potential coil current leads and one lags the current in phase B by 30 ; thus, the coils are balanced in the position shown in Fig.
- Change in pf will cause **I** of one potential coil to become more in phase and the other potential coil to be more out of phase with **I** in phase B, so that the moving element and pointer take a new position of balance to show new pf





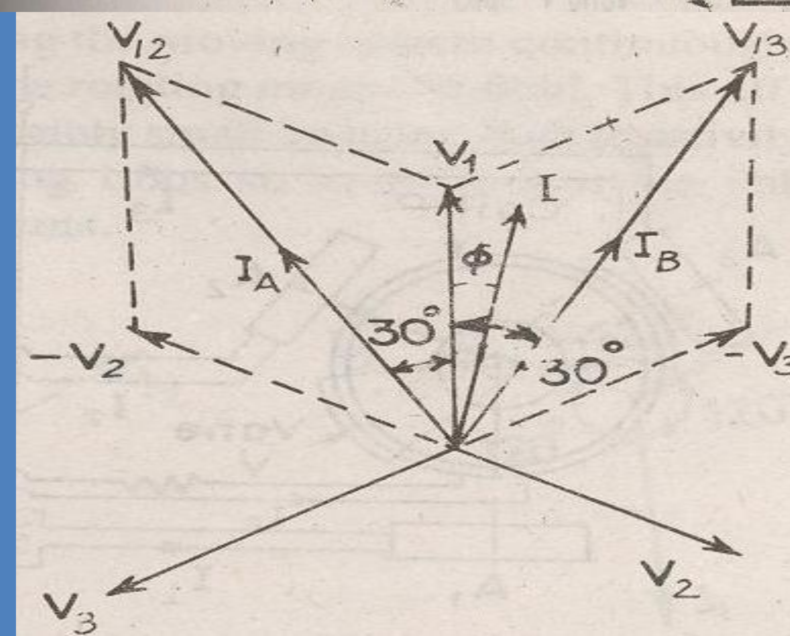


Fig. Schematic of 3 - Ph Power Factor Meter

- Required phase displacement between current I_A & I_B is obtained from supply itself
- Hence, angle between the plane of the coils is 120°

Operation:

Assume, V_{12} – voltage applied across coil A

V_{13} – voltage applied across coil B

$V_{12} = V_{13} = \sqrt{3}\, V$

Let θ 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,

$$T_A = K\, V_{12}\, I\, M_{max} \cos(30^o + \phi) \sin(60^o + \theta)$$

$$= \sqrt{3}\, K\, V\, I\, M_{max} \cos(30^o + \phi) \sin(60^o + \theta)$$

Deflecting torque acting on coil B,

$$T_B = K\, V_{13}\, I\, M_{max} \cos(30^o - \phi) \sin(120^o + \theta)$$

$$= \sqrt{3}\, K\, V\, I\, M_{max} \cos(30^o - \phi) \sin(120^o + \theta)$$

The two torques acts in opposite direction

The coil will take up a position such that the two torques are equal

Hence at equilibrium, $T_A = T_B$

i.e., $\cos(30^o + \phi) \sin(60^o + \theta) = \cos(30^o - \phi) \sin(120^o + \theta)$

Solving, $\theta = \phi$

Thus, deflection of the instrument is a measure of phase angle of the circuit

Error due to change in **f** is eliminated as **I** in both the coils are equally affected

Moving Iron Type PF Meter

According to principle of operation these may be classified as,

(1) ROTATING FIELD TYPE

(2) ALTERNATING FIELD (NALDER LIPMAN) TYPE

THREE PHASE ROTATING FIELD POWER FACTOR METER

Fixed Coils

- A_1, A_2, A_3 are 3 fixed coils connected respectively in lines 1, 2 and 3 of 3-phase supply through current transformers

Axes of A_1, A_2 & A_3 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 R 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

Operation:

Current I_p, 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 A_1, A_2 and A_3

This causes moving system to take up a position determined by the phase angle of the system

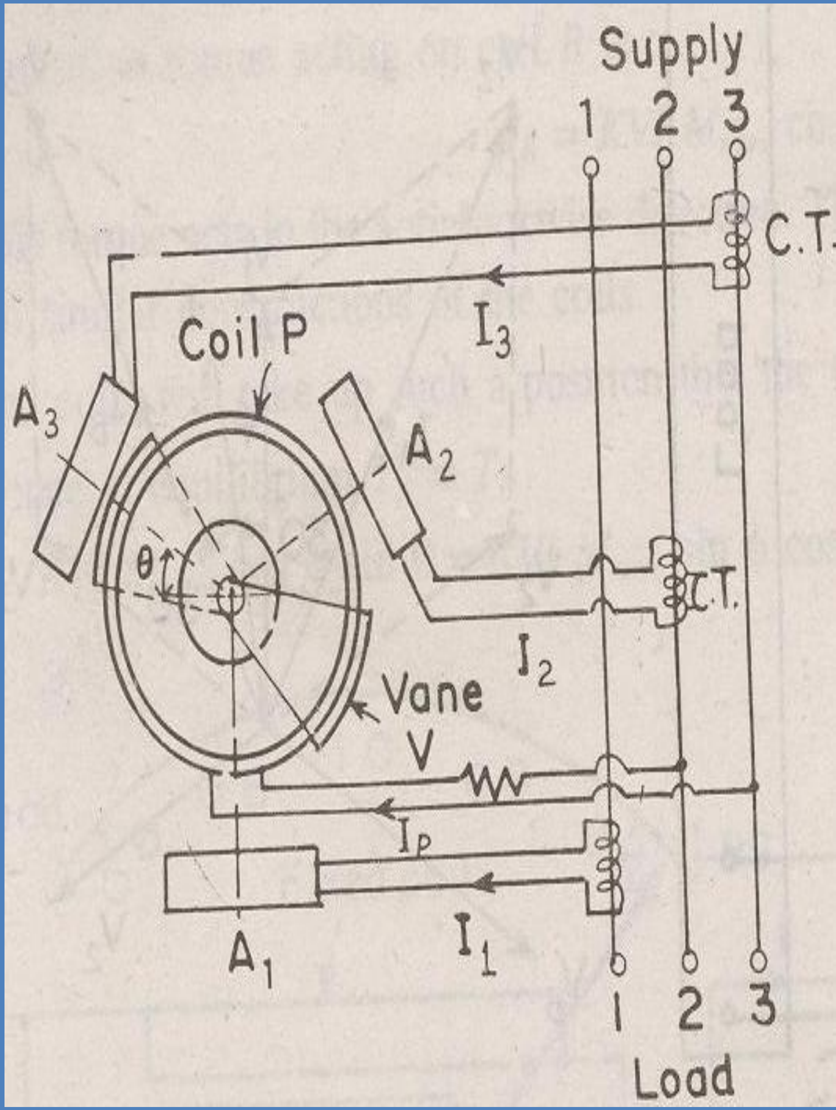
Total deflecting torque,

$$T_d \propto [\, I_1 I_p \cos(90^\circ - \Phi) \sin(90^\circ + \theta) + I_2 I_p \cos(330^\circ - \Phi) \sin(210^\circ + \theta) + I_3 I_p \cos(210^\circ - \Phi) \sin(330^\circ + \theta) \,]$$

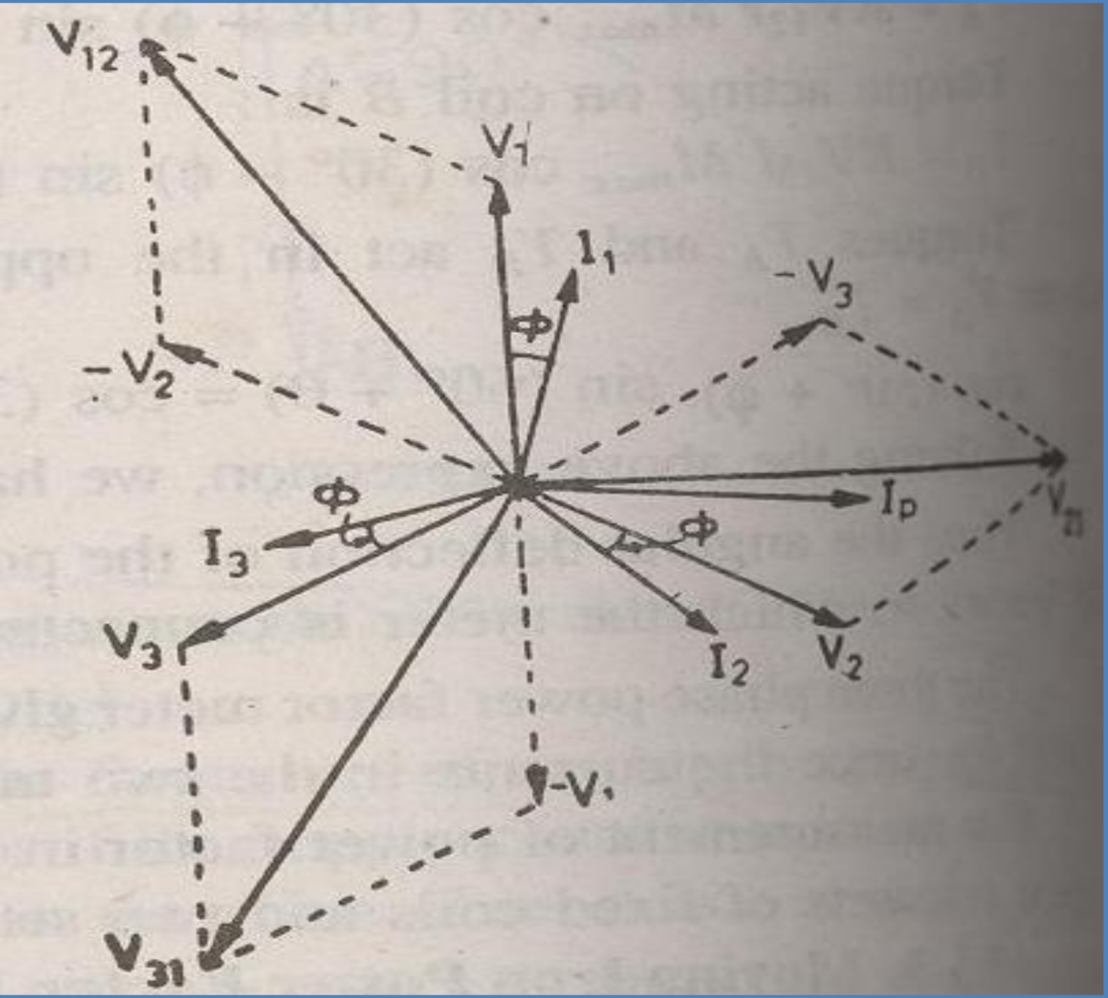
For a steady deflection, the total torque must be zero. Also considering system to be balanced i.e., $I_1 = I_2 = I_3$, we have,

$$\cos(90^\circ - \Phi) \sin(90^\circ + \theta) + \cos(330^\circ - \Phi) \sin(210^\circ + \theta) + \cos(210^\circ - \Phi) \sin(330^\circ + \theta) = 0$$

Solving, $\boldsymbol{\theta = \Phi}$



Rotating Field Moving Iron PF Meter



Note:

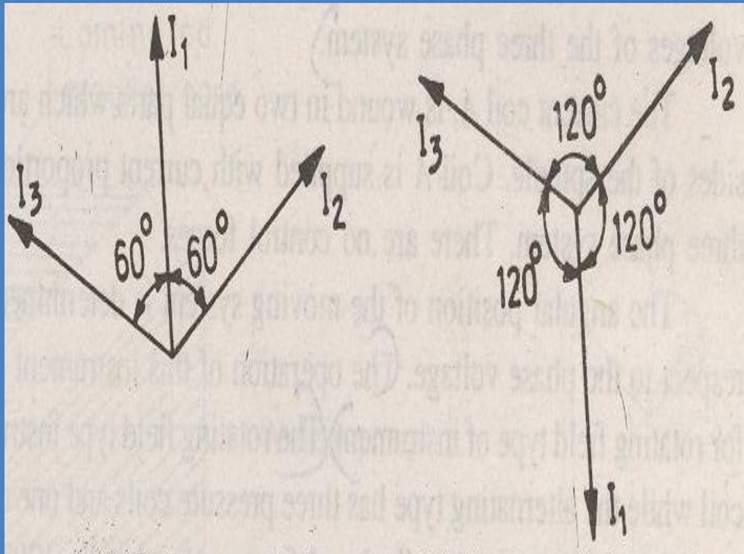
The three fixed coils A_1, A_2, A_3 produce a rotating magnetic field. In order to prevent induction motor action high resistivity metal is used for the moving irons so as to reduce the values of induced currents

SINGLE PHASE ROTATING FIELD PF METER

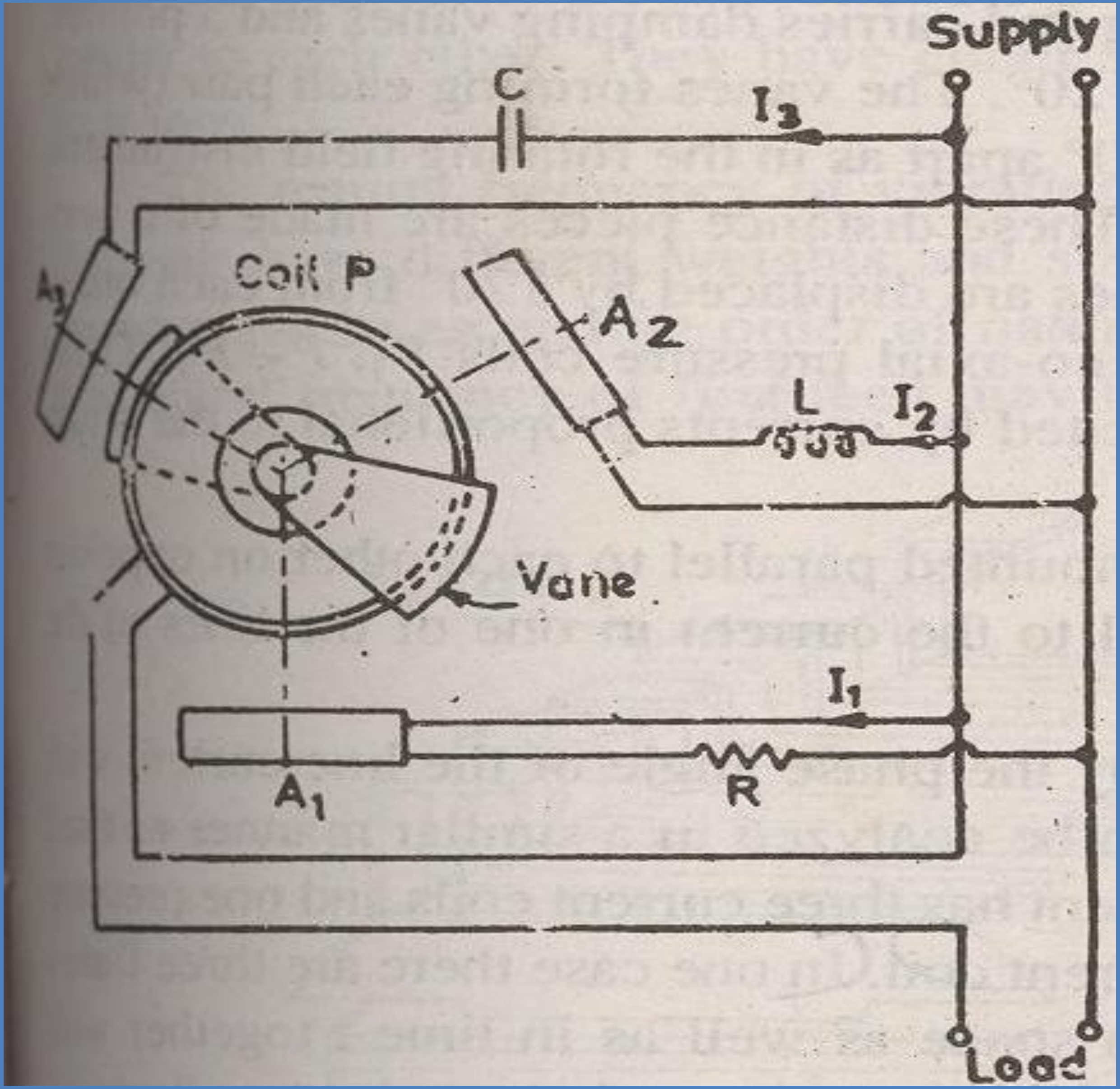
Fixed Coils

- A_1, A_2, A_3 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 A_1 is in phase with the line voltage
- Current in coil A_2 lags by 60^0
- Current in coil A_3 leads 60^o

- Connections of coil A_1 are reversed w.r.t connections of other coils so that currents in the 3 coils are 120^o out of phase with each other
- Rest is similar to that of 3-phase power factor meter

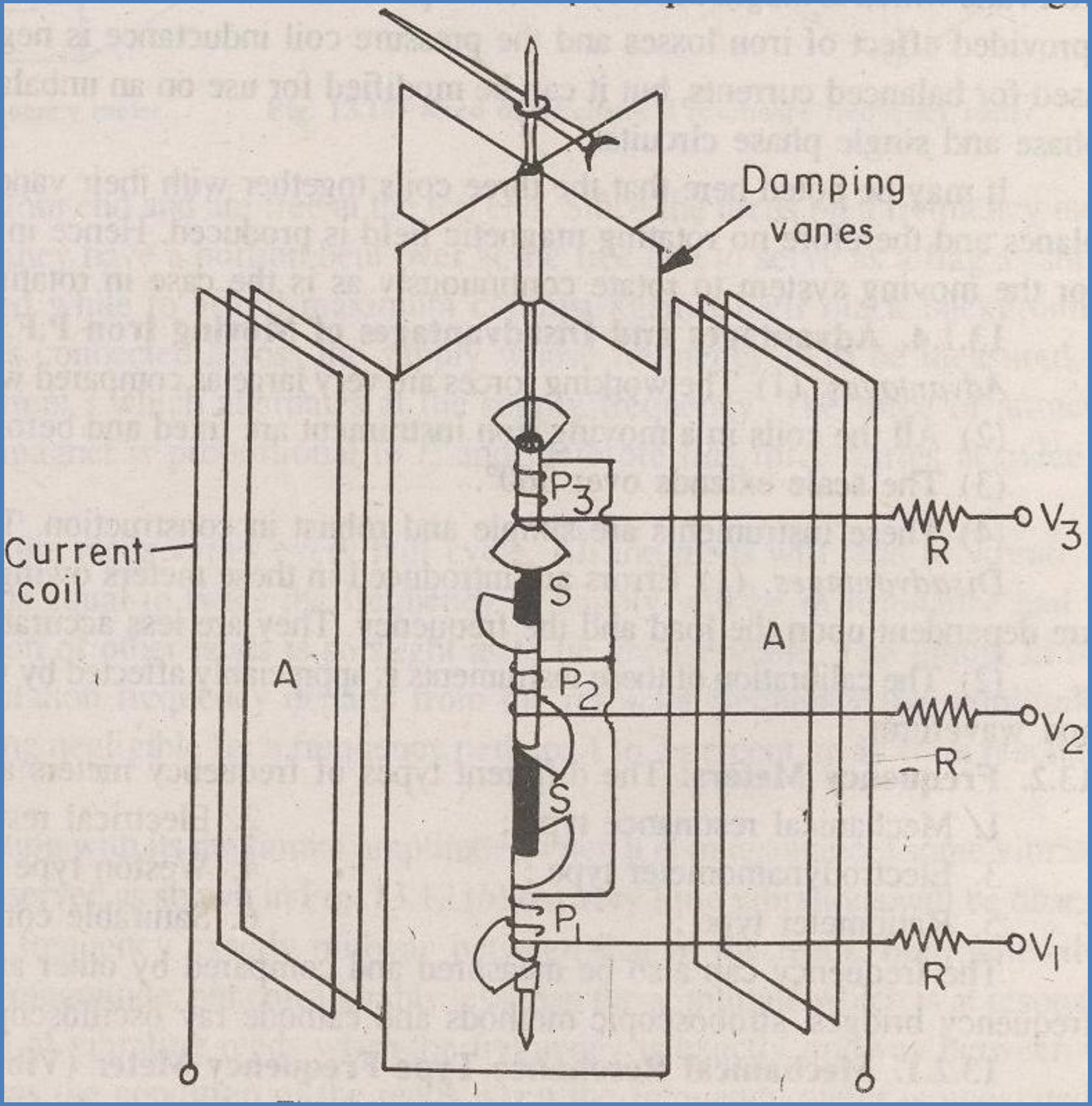


(i) Before reversal of connections of coil A_1
(ii) After reversal of connections of coil A_1



Operation: Similar to that of 3-phase power factor meter

THREE PHASE ALTERNATING FIELD POWER FACTOR METER



THREE PHASE ALTERNATING FIELD POWER FACTOR METER

- Moving system comprises of 3 pairs of iron vanes & cylinders which are fixed to a common spindle pivoted in jewel bearings & carries damping vanes & pointer
- Iron vanes are sector shaped with arc subtending 120^o & each pair are fixed 180^o apart
- Also 3 pairs of iron vanes are displaced from each other by 120^o
- Cylinders are separated by distance pieces S made of non – magnetic material
- Current coil A is wound in two equal parts mounted parallel to each other on opposite sides of the spindle
- Iron cylinders & the vanes are magnetized by 3 fixed co-axial pressure coils P_1, P_2, P_3 mounted co-axially with the spindle

THREE PHASE ALTERNATING FIELD POWER FACTOR METER

Operation:

- P_1, P_2, P_3 are excited by currents proportional to the phase voltages of the 3-phase system producing 3 fluxes
- Coil is supplied with current proportional to current in one of the lines of the 3-phase system and it also produces a flux
- Due to the interaction of these fluxes, moving system deflects into such a position that the mean torque on one pair of vanes is neutralized by the other two torques, so that resultant torque is zero
- In this steady position, the deflection of the iron vane is equal to phase angle of the circuit

Note: It is used for balanced currents but it can be modified for use on unbalanced 3-phase circuit & for 2-phase & 1-phase circuits

No rotating magnetic field is produced here

Advantage of Moving Iron power factor meter

- Working forces are very large
- All coils are fixed. Hence the use of ligaments is eliminated
- 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