Unit 4

Measurment of power :- Power is the rate at which you consume energy to do work. lifting the apple onto the table quickly requires more power than doing it slowly, but the same amount of work is performed.

Measurement of power in dc circuit :-

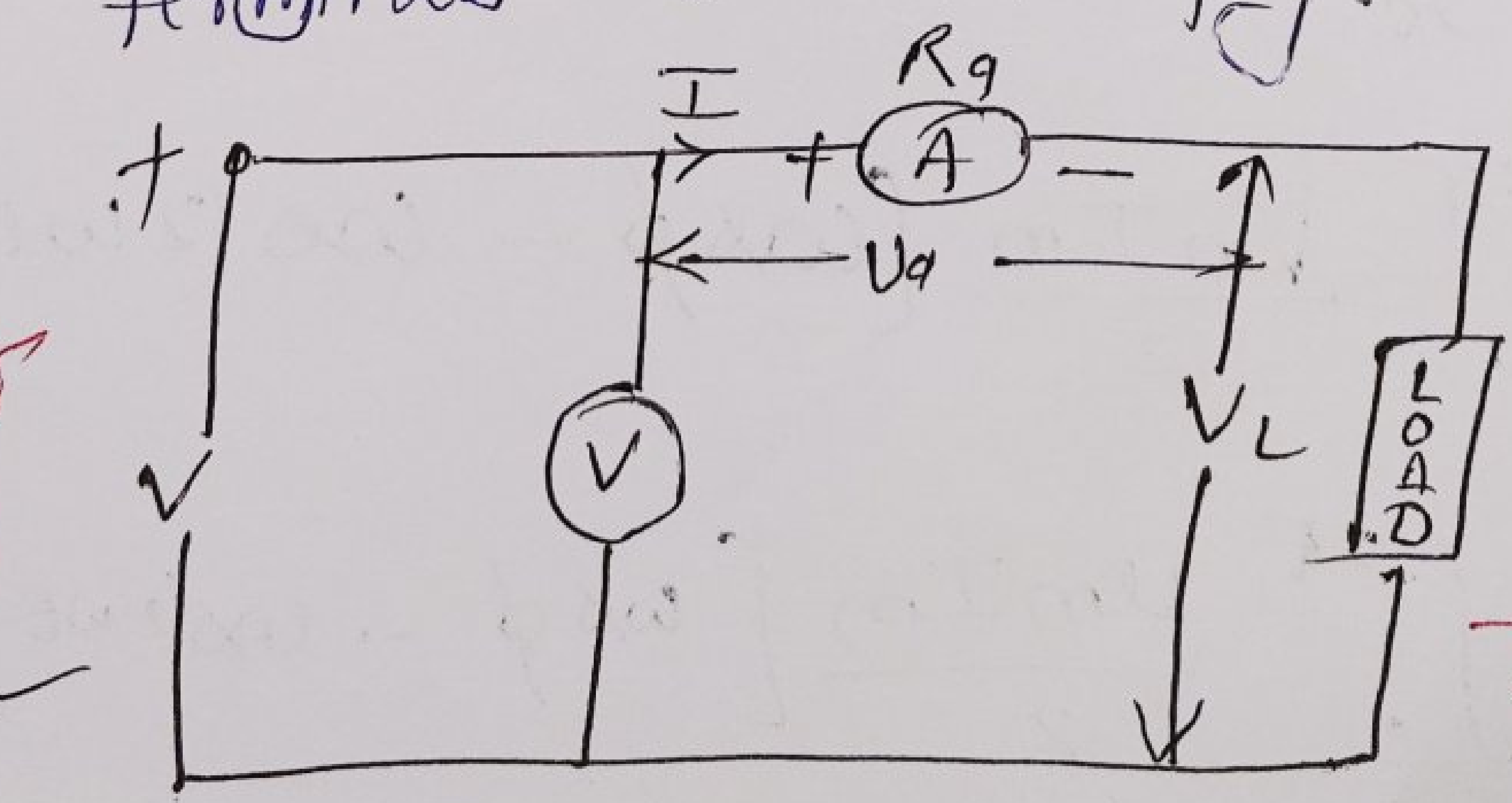
→ for dc circuits power across the load is the product of voltage across it & current flowing through it. Its unit is watt

$$\boxed{P = VI \text{ watt}}$$

→ The power factor of the circuit is always Unity, hence only wattmeter & ammeter is sufficient to measure the power in a dc circuit.

→ The power indicated by the instrument is equal to the power in a dc circuit is consumed by the load plus the power consumed by the instrument nearer to the load terminals as in fig.

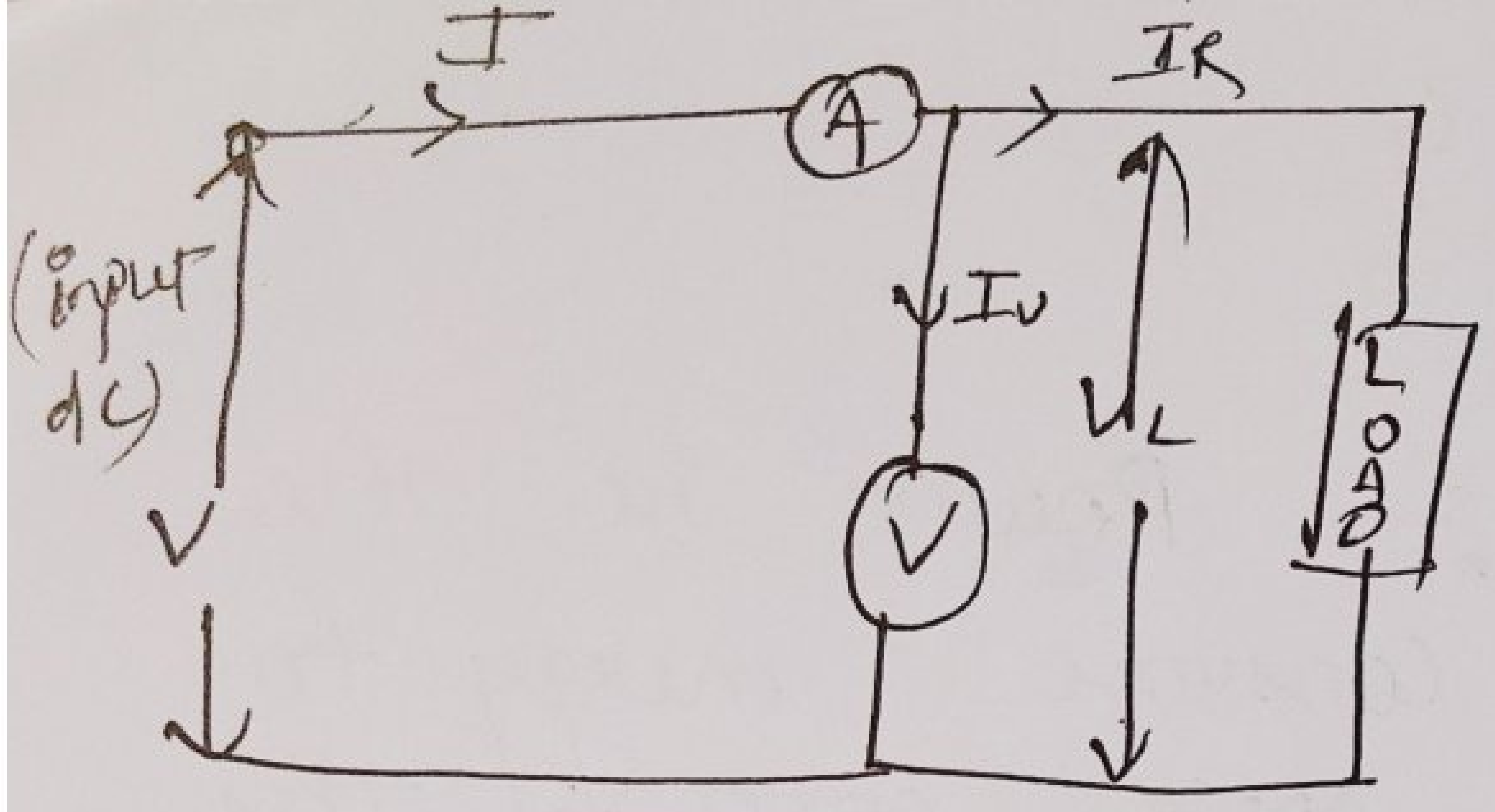
(input dc)



power consumed by the load —

$VI + I^2 R_a$

T[illegible] power + power loss in ammeter



Power consumed by load
$VI + V^2/R_V$.
True power + power loss in wattmeter.

Measurement of power in ac circuit :-

In a.c. circuit, power of the circuit varies due to alternating nature of voltage & current. Thus we must find the average value of power over a cycle.

Let
$$v = V_m \sin\omega t$$
$$i = I_m \sin(\omega t - \phi) \quad \text{(for lagging load)}$$

Instantaneous power of the circuit --

$$p = vi = V_m I_m \sin\omega t \cdot \sin(\omega t - \phi)$$
$$= \frac{V_m I_m}{2}\left[\cos\phi - \cos(2\omega t - \phi)\right]$$

Now average power is -

$$P_{avg} = \frac{1}{T}\int_0^T p \cdot d(\omega t)$$

$$= \frac{1}{T}\int_0^T \frac{V_m I_m}{2}\left[\cos\phi - \cos(2\omega t - \phi)\right] d\omega t$$

$$\Rightarrow P_{avg} = \frac{1}{2\pi}\int_0^{2\pi} \frac{V_m I_m}{2}\left[\cos\phi - \cos(2\omega t - \phi)\right] d\omega t$$

$$P_{avg} = \frac{V_m I_m}{2\pi . 2} \left[\cos\phi . \omega t + \sin(2\omega t - \phi) \times 2 \right]_0^{2\pi}$$

$$P_{avg} = \frac{V_m I_m}{2\pi . 2} \left[2\pi . \cos\phi + \sin(4\pi - \phi) \times 2 \right] - 0$$

$$P_{avg} = \frac{V_m I_m}{\cancel{2\pi} . 2} . \cancel{2\pi} . \cos\phi = \frac{V_m I_m}{2} . \cos\phi$$

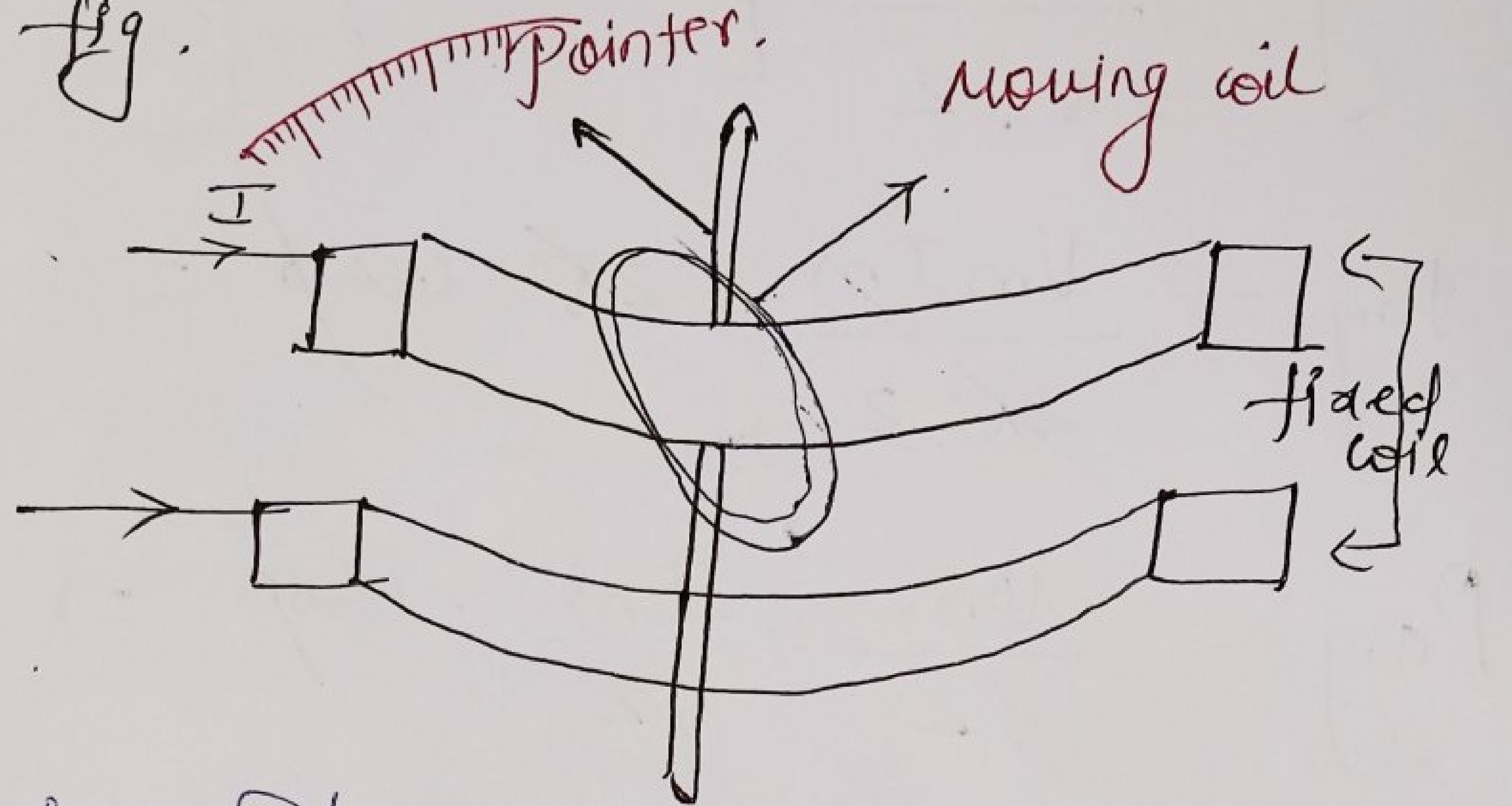
$$P_{avg} = \frac{V_m}{\sqrt{2}} . \frac{I_m}{\sqrt{2}} . \cos\phi \Rightarrow V_{rms} . I_{rms} . \cos\phi$$

an power factor is included in the power measurement of an a.c. circuit therefore voltmeter & ammeter alone can't measure the power.

Thus wattmeter is required for the measurement of power in a.c. circuit. We use electrodynamometer wattmeter for this purpose.

Electrodynamometer Wattmeter :-

It works on the principle of electro-dynamometer, its construction & circuit diagram is shown in fig.



The different parts of an wattmeter consist of-

a) **Fixed coil** :- The fixed coil or current coil are connected in series with the load & carry the load current.

→ These are also called simply a C.C. of the wattmeter.

→ The C.C. current lags or leads the ~~power~~ supply voltage depending on the load power factor.

→ The C.C. are wound with heavy wires & are laminated to avoid eddy current losses.

b) **Moving coil** :- The moving coil is connected across the load & carries current proportional to voltage. It is also called potential coil or pressure coil.

→ A high non-inductive resistance is connected in series with the P.C. to limit the current to a small value (usually up to 100 mA).

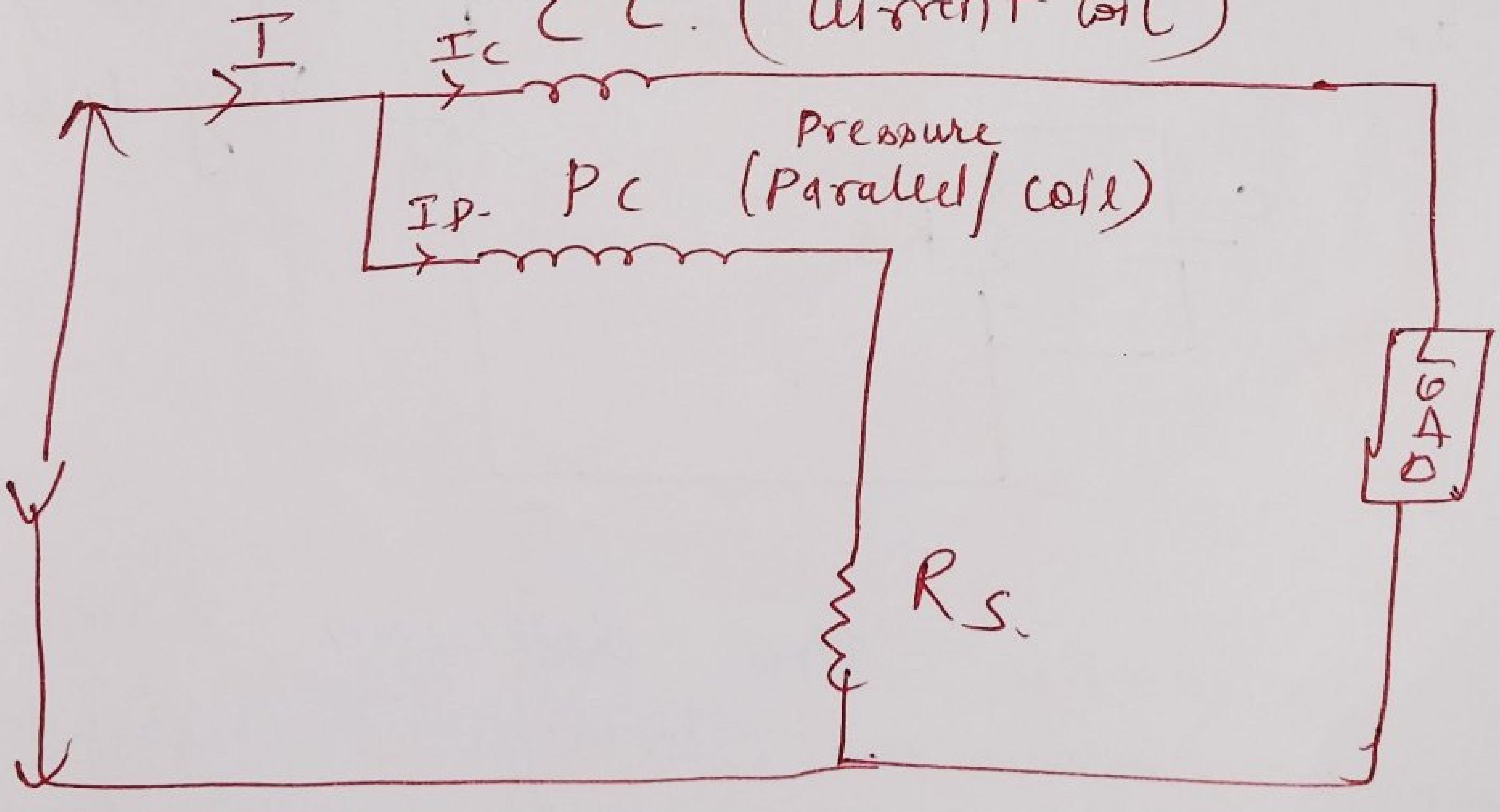
→ Spring control is used for the movement.

→ Both fixed & moving coil are air-cored.

c) Damping :- Air friction damping is used in these wattmeters.

d) Control :- Spring is used which provides the control torque.

e) Scales & pointers :- These wattmeters uses mirror type scales & knife edge pointers to eliminate parallax errors.



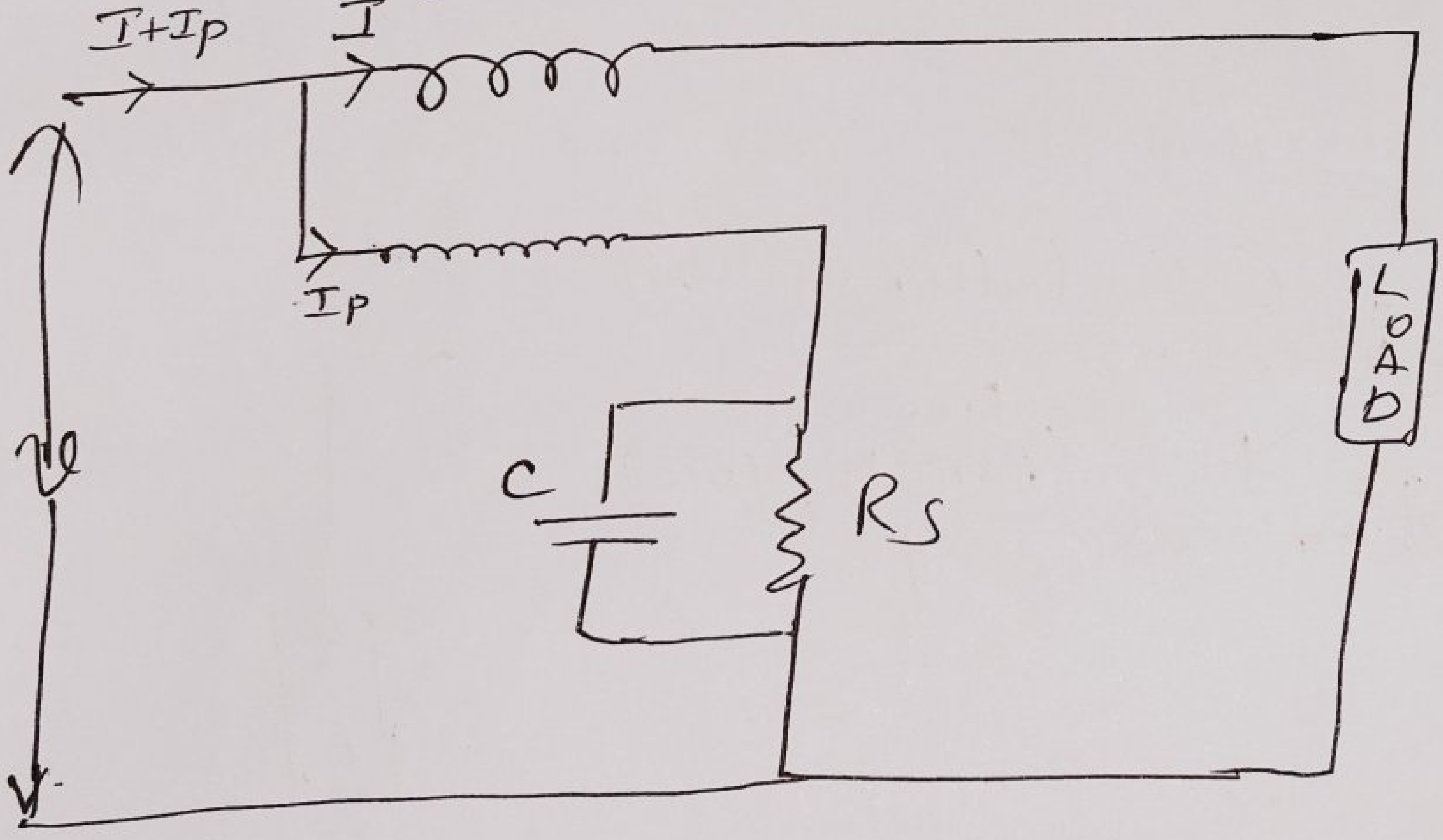
Low Power factor wattmeter :-

Measurement of power in circuits having low power factor by an ordinary electrodynamometer wattmeter is difficult & inaccurate because :-

(i) The deflecting torque become small due to low Power factor.

(ii) Errors are introduced due to inductance of pressure coil.

Some modifications are required ~~to~~ in an Electrodynamometer wattmeter to measure power at low power factor.



Pf = cos φ
Very low.

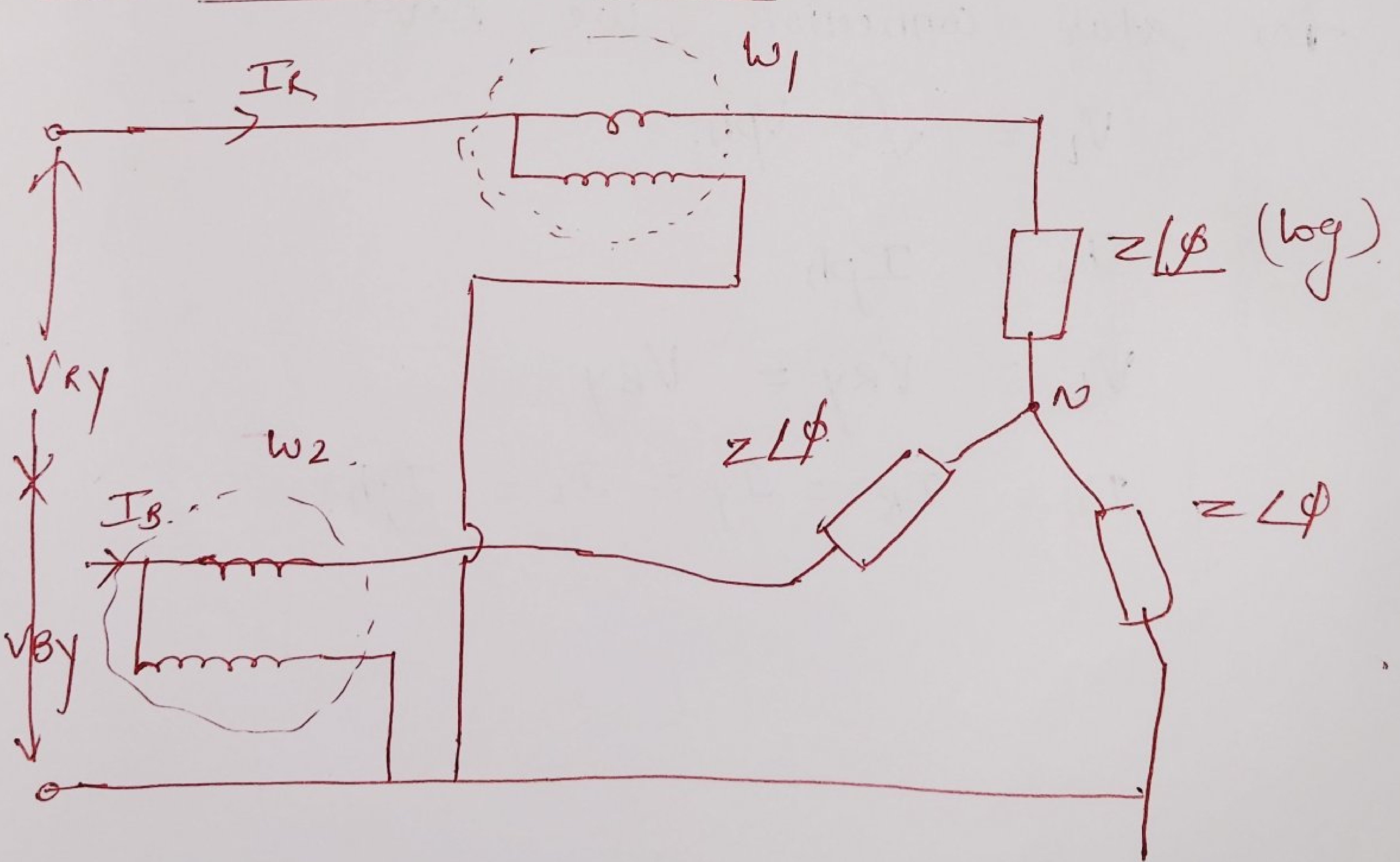
→ For increasing the deflecting torque, the current flowing through the potential coil is increased by keeping the low value of series multiplier resistance Rs.

→ To reduced the inductance effect in the potential coil, a compensating capacitor is connected in Parallel with the series resistance R_s so that the error in the measurement of power is reduced.

→ Low power factor wattmeters are designed with to have a small control torque so that they give full scale deflection for power factor as low as 0.1

→ for compensation of pressure coil current compensating coil is used which is connected in series with the pressure coil.

Two wattmeter Method :-



→ In a 3-phase, 3-wire system we required 3 elements to measure power but by the common points of the pressure coil coincide with one of the lines only two wattmeter or element are required to measure the power.

Let load be balanced ~~of~~ 3-phase load ie $Z\angle\phi$ lagging.

Wattmeter readings are —

$$W_1 = V_{RY} . I_R \cos(\text{Angle between } V_{RY} \,\&\, I_R)$$

$$W_2 = V_{BY} . I_B \cos(\text{Angle between } V_{BY} \,\&\, I_B)$$

~~for~~ star connection, we have

$$V_L = \sqrt{3}\, V_{ph}.$$

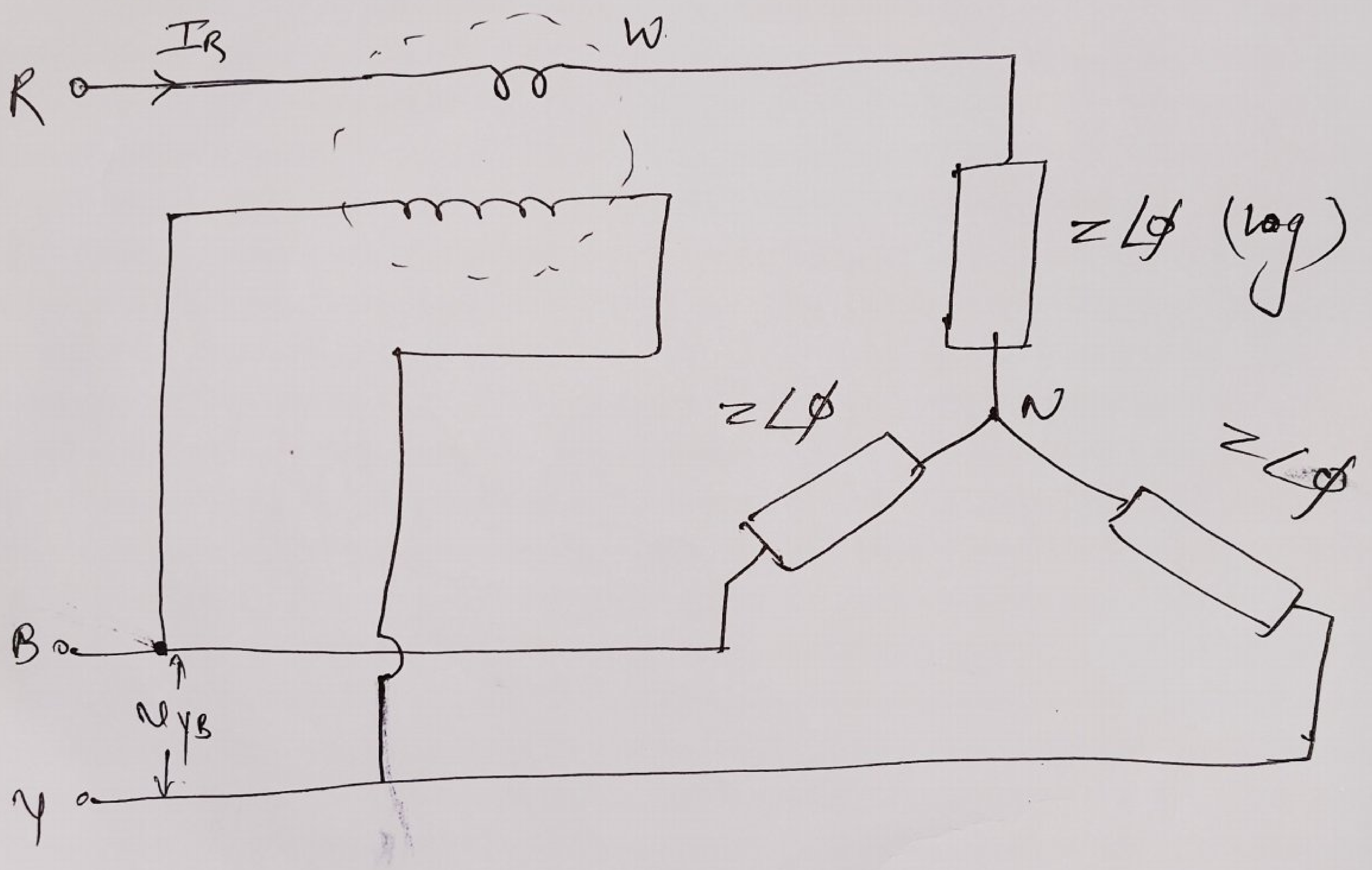
$$I_L = I_{ph}$$

$$V_L = V_{RY} = V_{BY}$$

$$I_B = I_R = I_Y = I_L = I_{ph}.$$

for measurement of Reactive Power using Wattmeter :-

for reactive power, the current coil is connected between one of the phases of R, Y, B ie (R) the potential coil should be connected between the remaining two phases ie (Y & B).



Wattmeter reading,

$W = V_{YB} \cdot I_B \cos$ (angle between V_{YB} & I_R)

$= V_L I_L \cos(90 - \phi)$

or $W = V_L I_L \sin\phi = 1 - \phi$ (Reactive power)

three phase reactive power is,

$Q = \sqrt{3} \cdot W = \sqrt{3} \cdot V_L I_L \sin\phi$

Measurement of power factor

$W_1 = V_L I_L \cos(30 + \phi)$ —— (1)

$W_2 = V_L I_L \cos(30 - \phi)$. —— (2)

$W = \sqrt{3} V_L I_L \cos\phi$. —— (3)

Also $W_1 - W_2 = V_L I_L \sin\phi$. —— (4)

$$\frac{W_1 - W_2}{W_1 + W_2} = \frac{\cancel{V_L I_L} \sin\phi}{\sqrt{3} \cancel{V_L I_L} \cos\phi}$$

$$\frac{W_1 - W_2}{W_1 + W_2} = \frac{\tan\phi}{\sqrt{3}}, \quad \tan\phi = \sqrt{3}\left(\frac{W_1 - W_2}{W_1 + W_2}\right)$$

Pf angle $\phi = \tan^{-1}\left[\frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}\right]$

Pf of circuit $= \cos\phi$.

Measurement of Energy :-

Energy is the total power consumed or delivered over a time period.

Energy = power x time   Joule / watt sec.

$= \int_0^t P.\, dt = \int VI\cos\phi . dt$

If time in hour. then

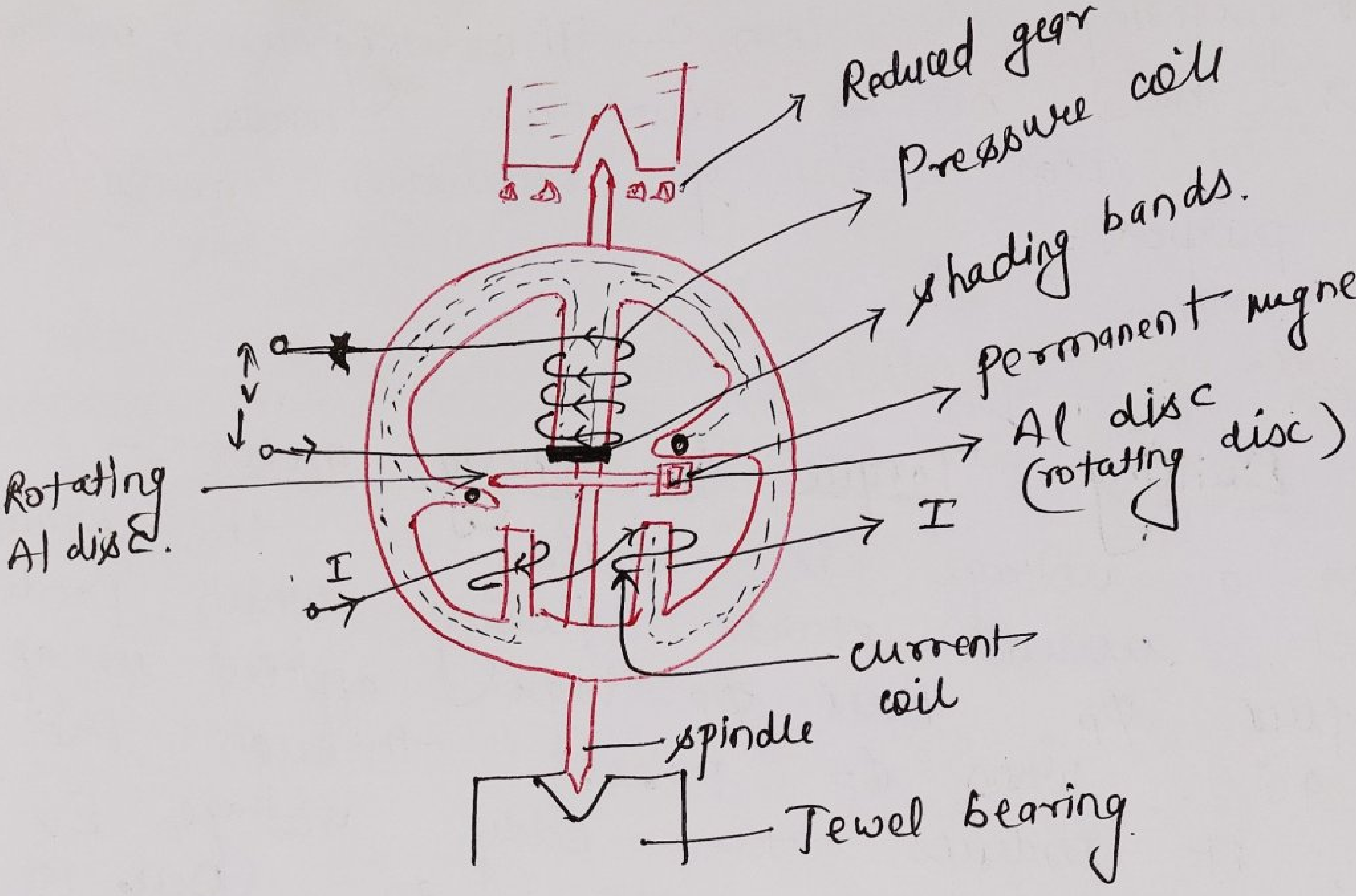
Unit of energy = watt hour.

$\underline{1 \text{ Kwh}} = \underline{1}$ unit of energy.

for a.c. circuit → energy is Kwh.

for d.c. circuit → energy is Amp hour.

Energy meter is used to measure energy in a.c circuit which is an integrating instrument & works on the principle of induction.



Construction :- The main parts of operating mechanism in a single phase energy meter are -

(i) Driving Mechanism :- It consist of two coils carried current proportional to the supply voltage. Therefore the two electromagnets are called series & shunt magnet. These magnets provide driving torque in the energy meter.

(ii) Rotating Mechanism :- It consists of an Al disc positioned in the air gap between series & shunt magnet. When the Al disc revolves, it cuts through the field of the permanent magnet.

(iii) Braking Mechanism :- A permanent magnet positioned near the edge of the Al disc forms the braking system which is adjusted. It provided braking torque.

(IV) Registering Mechanism :- The registering mechanism counts the no. of revolutions made by the disc. It uses train of reduction gears for this purpose.

Principle of operation :-

(i) Driving Torque in Energy meter :-

When a voltage is applied to the shunt magnet, current startes flowing which produces a flux ϕ_P. flux ϕ_P lags applied voltage by 90°. When ϕ_P passes through the disc, it induces the eddy voltage E_V lagging ϕ_P by an angle 90°. Due to this eddy voltage, an eddy current circulates in the disc lagging by an impedance angle α, α depends on the impedance of the rotating disc.

Similarly, the current in the ~~coil~~ current coil, I produces a flux ϕ_c in phase with $I = I_L$ (load current). When this flux passes through the disc induces an eddy voltage E_c which lags ϕ_c by 90° & this E_c produces a current I_c & which lags E_c by an angle α depending on the impedance of the disc.

(ii) Braking Torque in Energy meter :-

The permanent Magnet produces a constant flux ϕm , Let $N =$ disc speed in rps

→ When the disc ~~rot~~rotates, a voltage is induced in the disc which is proportional to the disc. speed & ϕm.