Measurement of Resistance

* Depending on the values ~~of~~ the resistances are classified as i) low resistance ii) medium resistance iii) High resistance

* Any resistance of the order 1 Ω & less is considered as low resistance.

* The resistance whose value lies in b/n 1 Ω to 1,00,000 Ω is considered as medium resistance

* The resistance whose value is more than 1,00,000 Ω is considered as High resistance

The resistance of armature windings of electrical machines, the resistance of series field winding of a DC machine, resistance of shunts and lead wires are examples of low resistance.

* The insulation resistance of cables and wires are examples of high resistance.

* Measurement of Medium Resistance

The different methods used for the measurement of medium resistance are →

1) Ammeter - voltmeter method
2) Substitution method
3) Wheatstone bridge method
4) ohmmeter method.

* Wheatstone bridge method

* Above fig shows Wheatstone bridge circuit, which is used for the measurement of medium resistance.
* As shown above it consists of four resistive arms together with a source of emf E & galvanometer.

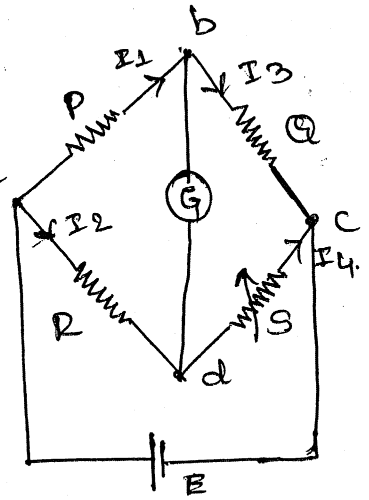


fig-a) Wheatstone bridge

* galvanometer is used as null detector, the current through the galvanometer depends on the potential difference b/n the points b & d.
* However the bridge is said to be balanced, when the c/n through the galvanometer is zero or when the potential difference b/n the points b and d is zero

When the bridge is balanced, their is no c/n flows through the galvanometer.

At balance $V_{ab} = V_{ad}$ $\quad I_1 P = I_2 R$ $\quad$ or $\frac{I_1}{I_2} = R/P$ —(1)

also, $V_{bc} = V_{cd}$ $\quad I_3 Q = I_4 S$ $\quad$ but $I_1 = I_3$ & $I_2 = I_4$.

$\therefore I_1 Q = I_2 S$

$\Rightarrow I_1/I_2 = S/Q$ —(2)

equating the equations (1) & (2) $\quad R/P = S/Q$.

$$\Rightarrow \boxed{R = \frac{P}{Q} S}$$ //

Where P & Q are the resistances of ratio arm

S = resistance of standard arm. R = unknown resistance

* Sensitivity of Wheatstone Bridge (S_B)

The sensitivity of the Wheatstone bridge is defined as the deflection of the galvanometer per unit fractional change in the value of unknown resistance.

i.e $S_B = \frac{\theta}{(\Delta R / R)}$ ——— (1)

Where θ = deflection of the galvanometer

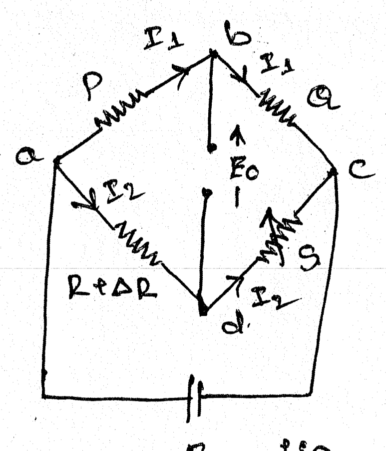
ΔR = change in the value of R.

The sensitivity to the unbalance may be computed by the solving the bridge circuit for a small unbalance.

When the bridge is balanced = $P/Q = R/S$ or $\frac{P}{P+Q} = \frac{R}{R+S}$ — (2)

Let R be changed to $(R+\Delta R)$, so that there is an unbalance, which will causes an emf e to appear across the galvanometer

Let the galvanometer is removed and the voltage across the galvanometer is represented by the Thevenin's voltage E_0. as shown below.



fig

from the fig

$V_{ab} = I_1 P = E \cdot \frac{P}{P+Q}$

$V_{ad} = I_2(R+\Delta R) = \frac{E \cdot (R+\Delta R)}{(S+R+\Delta R)}$

Now $V_{db} = E_0 = V_{ad} - V_{ab}$

$$\therefore V_{db} = E_0 = E\left[\frac{R+\Delta R}{(R+\Delta R+S)} - \frac{P}{P+Q}\right]$$

We know $P/_{P+Q} = R/_{R+S}$

$$\therefore V_{db} = E_0 = E\left[\frac{R+\Delta R}{R+\Delta R+S} - \frac{R}{R+S}\right]$$

$$= E\left[\frac{(R+\Delta R)(R+S) - R(R+\Delta R+S)}{(R+\Delta R+S)(R+S)}\right]$$

$$= E\left[\frac{R^2+RS+R\Delta R+S\Delta R-R^2-R\Delta R-RS}{(R+\Delta R+S)(R+S)}\right]$$

$$= \frac{ES\Delta R}{(R+\Delta R+S)(R+S)}$$

as ΔR is very small compared to $R+S$

$\therefore (R+\Delta R+S) \cong (R+S)$

$$\therefore V_{db} = E_0 = \frac{ES\Delta R}{(R+S)(R+S)}$$

$$E_0 = \frac{ES\Delta R}{(R+S)^2}$$

if $S_v = \frac{\theta}{E_0}$ is the voltage sensitivity of the galvanometer then

$$\theta = S_v E_0 = \frac{S_v ES\Delta R}{(R+S)^2} \quad \text{——— (3)}$$

But we have bridge sensitivity

$$S_B = \frac{\theta}{(\Delta R/R)}$$

$$\therefore S_B = \frac{S_v ES\Delta R}{(R+S)^2(\Delta R/R)}$$

$$S_B = \frac{S_v E S R}{(R+S)^2} = \frac{S_v E S R}{R^2+S^2+2RS}$$

divide Nr & Dr by RS

$$\therefore S_B = \frac{S_v E}{\left(\frac{R}{S} + S/R + 2\right)} = \frac{S_v E}{\left(P/Q + Q/P + 2\right)} \quad \text{———— ④}$$

from the above equation it is clear that, the bridge sensitivity S_B is maximum when $R/S = 1$

* Galvanometer current

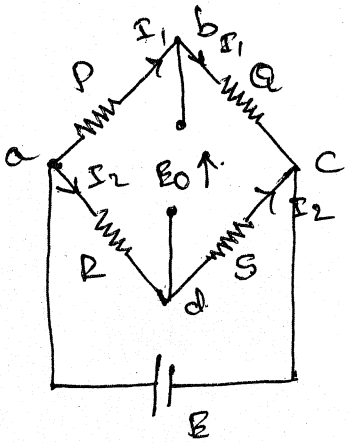


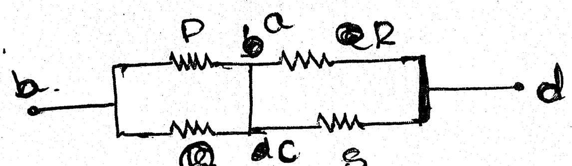
fig-a)

The current through the galvanometer is found by finding the thevenin's equivalent circuit of the bridge as shown below.

The open circuit voltage b/n the points b & d is obtained as $E_0 = V_{ad} - V_{ab} = E_0 = I_2 R - I_1 P$

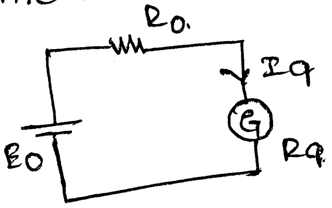
$$\therefore E_0 = \frac{E\ R}{(R+S)} - \frac{E\ P}{(P+Q)} = E\left[R/_{R+S} - P/_{P+Q}\right]$$

Now Thevenin's equivalent resistance is found by short circuiting the voltage source E & finding the equivalent resistance b/n the points b & d which is given by.



$$R_0 = \frac{PQ}{P+Q} + \frac{RS}{R+S}$$ if $P=Q=R=S$ then $R_0 = R$

The thevenin's equivalent circuit is as shown below the cin through the galvanometer is given by



$$I_g = \frac{E_o}{(R_o + R_g)}$$

fig-b

We know that, the deflection of the galvanometer for a small change R. ie ΔR.

$$\theta = \frac{S_v E S \Delta R}{(R+S)^2}$$

But $S_v = S_i / R_o + R_g$

$$\therefore \theta = \frac{S_i E S \Delta R}{(R_o + R_g)(R+S)^2}$$

But $S_B = \theta / \Delta R / R$

$$\therefore S_B = \frac{S_i E S \Delta R}{(R_o + R_g)(R+S)^2 \times \frac{\Delta R}{R}}$$

$$= \frac{S_i E S R}{(R_o + R_g)(R+S)^2}$$

~~$S_B = \frac{S_i E}{4}$~~ If $P = Q = R = S$

~~then $S_B = \frac{S_i E S R}{(R_o + R_g)(R^2 + S^2 + 2RS)}$~~

~~$= \frac{S_i E S R}{}$~~

* Limitations of Wheatstone Bridge

Wheatstone bridge is used for the measurement of medium resistance, the errors are gets introduced when it is used for the meast of low or high resistance. The limitations of wheatstone bridge are as fallows.

1) Resistance of leads :-

When the low resistances are measured, the resistance of the lead wires must be deducted to get the correct value of the resistance which is to be measured.

for example → A lead of 22 SWG wire having a length of 25cm has a resistance of about 0.012 Ω & it will introduces error when small resistances are measured.

2) Contact Resistance → errors are introduced due to a contact resistance of switches

3) Thermo-electric effects :- Thermo electric emfs are often present in the measuring circuit & they affect the galvanometer deflection. However these effects may be eliminated by reversing the battery connections to the bridge.

4) Temperature effects :- The errors are caused due to the change of change, & change of resistance is due to temperature, specially in the case of resistances

having large value of temperature co-efficient

5) When high resistances are measured using the Wheatstone bridge the sensitivity of the bridge is decreased & errors are introduced.

* Measurement of Low Resistance *

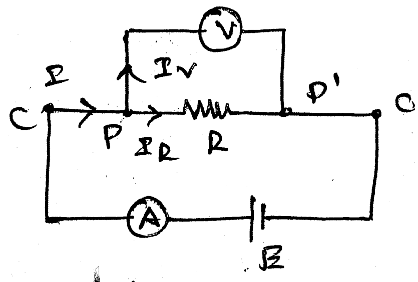


Fig.-

The construction for the measurement of low Resistance is as shown above

* It has four terminals, the pair of terminals cc' are called as current terminals they are used to lead the c/n to and from the resistor.
* The pair of terminals pp' are used to measure the voltage drop across the resistance.
* The voltage drop measured across the resistance does not include any contact resistance drop which may be present at the current terminals cc'.
* The contact resistance is a part of potential circuit whose resistance is usually very high and the contact resistance of the potential terminals is negligible as compared to that of the potential ckt

* Methods of Measurement of low resistance

1) Ammeter - voltmeter method
2) kelvin's double bridge method.
3) potentiometer method
4) ducter ohmmeter method.

* kelvin's double bridge

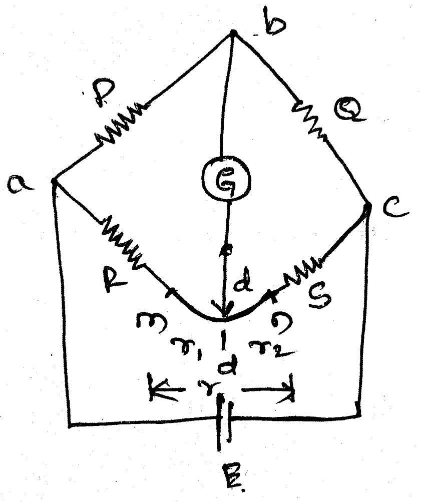


fig - kelvin's double bridge

KDB is the modification of the wheatstone bridge & it accurately measures low resistance.

Let us consider KDB as shown above where r represents the resistance of leads that connect unknown resistance R & standard resistance S b/n the terminals m & n. There is a sliding contact which can be moved from m to n.

The sliding contact is varied & the bridge is balanced when it is at point d. Then

$$R + r_1 = P/Q \, (S + r_2)$$

the value of r is such that $r_1/r_2 = P/Q$.

$$\frac{r_1}{r_1+r_2} = P/_{P+Q}$$

$$r_1 = \frac{P}{P+Q}\cdot(r_1+r_2) = P/_{P+Q}\cdot r$$

Similarly $r_2 = Q/_{P+Q}\cdot r$

$$\therefore \left[R + P/_{P+Q}\cdot r\right] = P/_Q\left[S + \frac{Q}{P+Q}\cdot r\right]$$

ie $P/_Q = R/_S$.

∴ the bridge is balanced at point d, & r will not affect the result.

* But however it is difficult to set the pointer exactly at point d, in order to keep bridge in a balanced condition.

* However kelvin's double bridge is modified in order to eliminate the effect of resistance of the leads during the measurement of low resistance. The arrangement is as shown below.

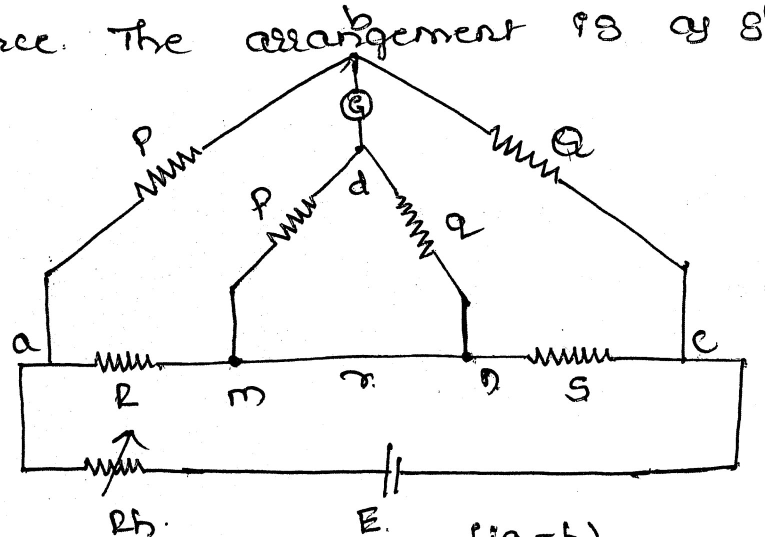


fig-b)

The KDB has two ratio arms i) P and Q ii) p and q such that $P/Q = p/q$, Hence it is called as kelvin's double bridge.

* converting the resistance p, q and r connected in Δ into Y, the bridge is redrawn as shown below.

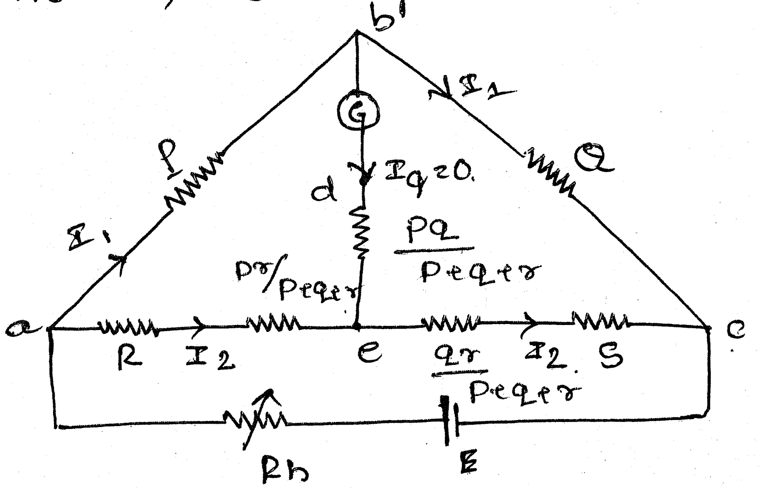


fig-e,

at balanced condition, there is no flow of current through the galvanometer.

$\therefore$ vab = vae

ie $PI_1 = \left(R + \frac{pr}{p+q+r}\right) I_2$ ——— (1)

& vcb = vce

$QI_1 = \left(S + \frac{qr}{p+q+r}\right) I_2$ ——— (2)

divide equation (1) by (2)

$$\frac{P}{Q} = \left[\frac{R + \frac{pr}{p+q+r}}{S + \frac{qr}{p+q+r}}\right] = \frac{\frac{R(p+q+r)+pr}{p+q+r}}{\frac{S(p+q+r)+qr}{p+q+r}}$$

$$\frac{P}{Q} = \frac{R(p+q+r)+pr}{S(p+q+r)+qr}$$

$$\frac{P}{Q}\cdot S(p+q+r)+qr = R(p+q+r)+pr$$

$$\frac{P}{Q}\left(S+\frac{qr}{p+q+r}\right) = R+\frac{pr}{p+q+r}$$

$$\therefore R = \frac{P}{Q}\cdot S + \frac{P}{Q}\cdot\frac{qr}{p+q+r} - \frac{pr}{p+q+r}$$

$$= \frac{P}{Q}\cdot S + \frac{qr}{p+q+r}\left[\frac{P}{Q}-\frac{p}{q}\right]$$

If $P/Q = p/q$ then the above equation becomes

$$\boxed{R = \frac{P}{Q}\cdot S}$$

∴ the above equation shows that, the resistance of the connecting leads has no effect on the measurement of R, with $P/Q = p/q$ if there is small difference b/n P/Q & p/q then error is introduced

The resistances measured with the help of KDB is usually b/n 0.1μΩ to 1.0Ω.

* In a Wheatstone bridge, the resistances of various arms are, $P = 1000\,\Omega$, $Q = 100\,\Omega$ $R = 2005\,\Omega$ and $S = 200\,\Omega$. The battery has an emf of 5V. and negligible internal resistance. The galvanometer has a c/n sensitivity of 10mm/µA and an internal resistance of $100\,\Omega$. Calculate the deflection of the galvanometer and the sensitivity of the bridge in terms of deflection percent change of resistance

⇒ Given $P = 1000\,\Omega$ $Q = 100\,\Omega$ $R = 2005\,\Omega$, $S = 200\,\Omega$

emf = 5V, c/n sensitivity of galvanometer = 10mm/µA

$r_g = 100\,\Omega$, $\theta = ?$

We know that at balanced condition

$$R = \frac{P}{Q} \cdot S = \frac{1000}{100} \times 200 = 2000\,\Omega$$

In actual bridge the unknown resistance is $2005\,\Omega$ ∴ Actual resistance = 2005 − 2000 = $5\,\Omega$

$$E_0 = E\left[\frac{R}{R+S} - \frac{P}{P+Q}\right] = 5\left[\frac{2005}{2005+200} - \frac{1000}{1000+100}\right] = 1.0308 \times 10^{-3}$$

$$R_0 = \frac{RS}{R+S} + \frac{PQ}{P+Q} = \frac{2005 \times 200}{2005+200} + \frac{1000 \times 100}{1000+100} = 272.77\,\Omega$$

$$I_g = \frac{E_0}{R_0 + R_g} = \frac{1.0308 \times 10^{-3}}{272.77 + 100} = 2.77\,\mu A$$

$$\theta = S_i I_g = 10 \times 2.77 = 27.7\,mm$$

$$S_B = \frac{27.7}{\text{Actual Resistance}} = \frac{27.7}{5} = 5.54\,mm/\Omega$$

* A Wheatstone bridge has ratio arms of 1000 Ω and 100 Ω and is used to measure a resistance of 50 Ω. Two galvanometers are available to be used as detectors. Galvanometer A has a resistance of 100 Ω and a sensitivity of 400 mm/μA. Galvanometer B has a resistance of 1000 Ω & a sensitivity of 800 mm/μA. Find out which of the two galvanometers is more sensitive to a small imbalance in the above bridge.

⟹

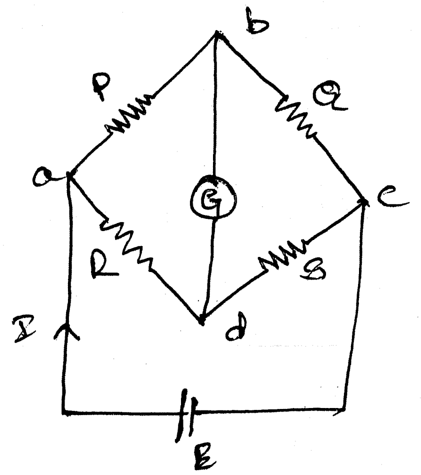


fig - Wheatstone bridge

Given $P = 1000$ $Q = 100$

$R = 50\ \Omega$

$R_{gA} = 100$ $(S_i)_A = 400\ mm/\mu A$

$R_{gB} = 1000$ $(S_i)_B = 800\ mm/\mu A$

$\therefore R = \frac{P}{Q} \cdot S$

$\Rightarrow S = \frac{Q}{P} \cdot R = \frac{100}{1000} \times 50$

$= 5\ \Omega$

Now $R_0 = \frac{RS}{R+S} + \frac{PQ}{P+Q}$

$= \frac{50 \times 5}{50+5} + \frac{1000 \times 100}{1000 + 100}$

$= 95.46\ \Omega$

We have the deflection in the galvanometer for a small change in resistance is given by $\theta = \frac{S_i E S \Delta R}{(R_0+R_g)(R+S)^2}$

$\therefore \frac{\theta_A}{\theta_B} = \frac{(S_i)_A E S \Delta R}{(R_0+R_{gA})(R+S)^2} \Big/ \frac{(S_i)_B E S \Delta R}{(R_0+R_{gB})(R+S)^2}$

$= \frac{(S_i)_A (R_0+R_{gB})}{(S_i)_B (R_0+R_{gA})}$

$= \frac{400}{800} \times \frac{95.46+1000}{(95.46+100)} = 2.8$

$\therefore \frac{\theta_A}{\theta_B} = 2.8$ from the equation it is clear that galvanometer A is 2.8 times more sensitive than galvanometer B.

* Thevenin's equivalent voltage of a Wheatstone bridge is 25mV & the galvanometer c/n is 20 μA. The resistance of the galvanometer is 50 Ω, the ratio arms have resistances of 1000 Ω & 5000 Ω respectively. Find the value of standard resistance for which the above conditions are satisfied. The value of the resistance to be measured is 600 Ω.

⇒ We have $I_g = \frac{E_0}{(R_0+R_g)}$ ⇒ $20\times10^{-6} = \frac{25\times10^{-3}}{R_0+50}$

$\therefore R_0 = 1950\ \Omega$.

$R_0 = \frac{RS}{R+S} + \frac{PQ}{P+Q}$ ⇒ $1950 = \frac{600\times S}{600+S} + \frac{1000}{(1000+5000)}$

$S = 1363.67\ \Omega$.

* **Earth Resistance measurement**

All the electrical equipments are earthed through the electrode to avoid the shocks to the person who touch the body of the equipment. The earthing provides ~~leakage~~ bypass of leakage currents. The various factors which affect the earth resistance are ⇒

i) shape and material of the earth electrodes.

ii) depth of the electrode at which they are buried in soil

iii) Specific resistance of the soil surrounding the electrode.

The specific resistance of the soil varies from one type of soil to another

* The amount of moisture present in the soil affects the specific resistance.

* Depending on the moisture content, the specific resistance of the soil varies from $80 \times 10^3 \Omega$-m to $80 \times 10^6 \Omega$-m.

* **Methods of measuring earth resistance**

There are two methods of measurement of earth resistance

i) Fall of potential method

ii) ~~By~~ using an earth tester.

* Fall of potential method

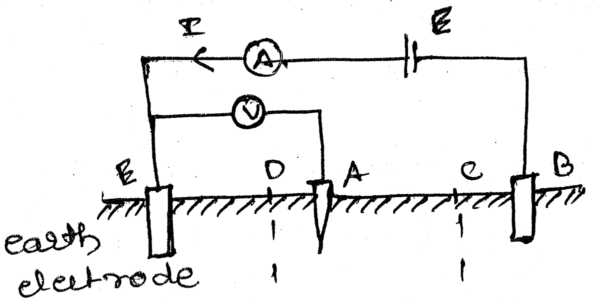


fig-a

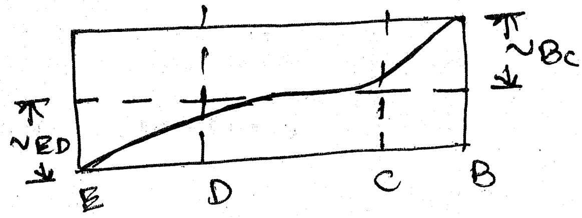


fig-b

Above fig shows the circuit diagram for the measurement of earth resistance using fall of potential method.

* A c/n I is passed through earth electrode E to an auxiliary electrode B, which is usually an iron spike, inserted in the earth at a certain distance away from the earth electrode.
* A second auxiliary electrode A is inserted in the earth b/n E and B.
* The potential difference b/n E and A is V, which is measured using a voltmeter.

The way in which the ground c/n flow b/n the electrodes E and B are as shown below.

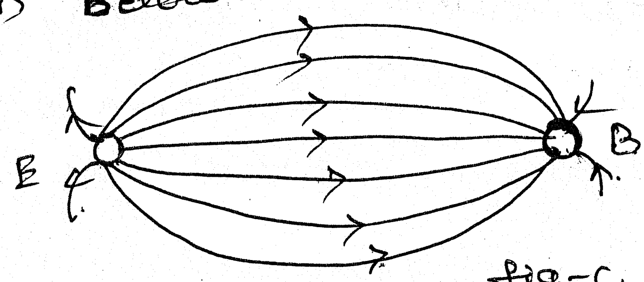


fig-C.

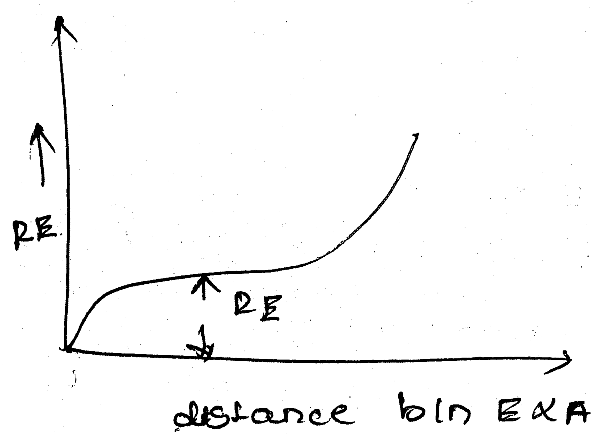
As shown above c/n at E diverge and converge at B. The potential distribution b/n the electrodes E and B are as shown above.

* from the fig it is clear that the potential rises in the proximity of electrodes E & B & it is constant along the middle section.

The resistance of the earth is given by $R_E = \frac{V_E}{I}$

* However the position of the electrodes E & B are fixed & position of the electrode A is changed & R_E is calculated for the various positions of electrode A.

* A graph is plotted b/n R_E and distance b/n the electrodes E & A.



from the graph it is clear that the RE depends on the position of the auxiliary electrode A.

* RE rises rapidly remains constant & rises again. as electrode moved from E to B.

* Megger

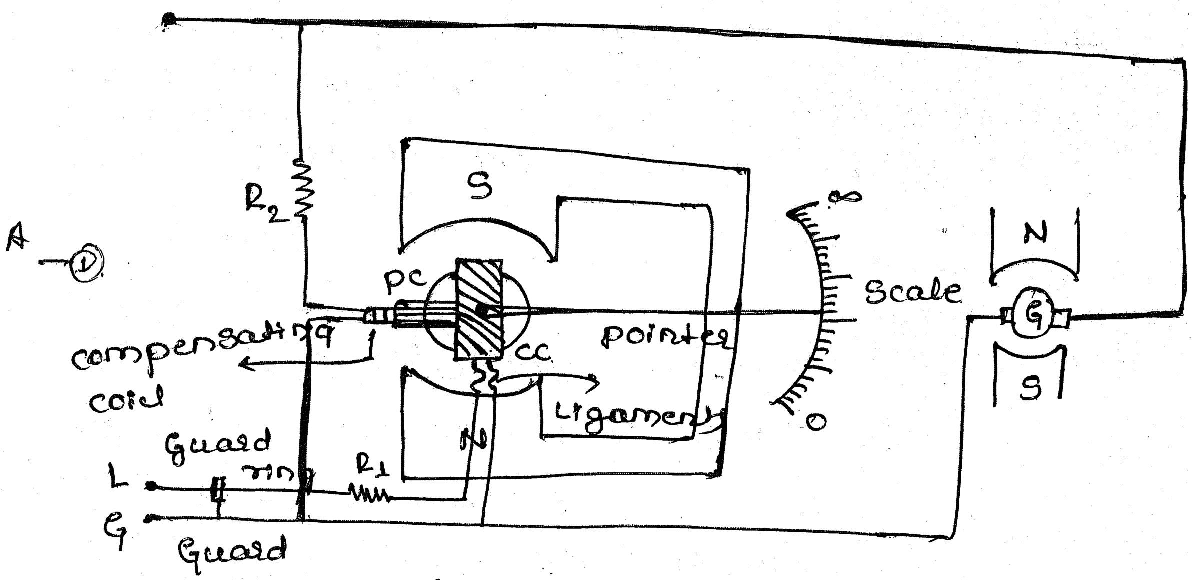


fig - Megger

Megger is an instrument which is used for the measurement of very high resistance of the order of megaohms such as insulation resistance

* Construction :- The construction of a ~~hand driven de generator~~ Megger is as shown ~~below~~ in the above fig. 1) It consisting of hand driven dc generator and a direct reading ohm meter, there is a potential coil PC and current coil CC, which are fixed to the spindle and which are free to rotate about a vertical axis b/n the poles N & S of a permanent Magnet

2) The coils are connected through flexible leads known as ligaments. The current coil is connected in series with a resistance R_1.

3) The potential coil is connected in series with an

compensating coil and resistance R_2 and across the generator terminals.

* The terminal G is known as Guard terminal, which is used to connect the guard ring to the insulation under test, the test voltage generated by an generator is usually 500V to 1000V.

* **Working principle**

The high resistance which is to be measured is connected b/n the test terminals L and G. The generator handle is rotated slowly at a uniform speed till the pointer gives steady reading, this reading gives the value of the resistance.

* The ~~test terminals~~ satisfactory working of Megger is tested as follows, The test terminals L & G are kept open, Now the resistance across L & G is infinite the generator is slowly rotated due to which c/n flows through the potential coil and there is no c/n through the current coil. ∴ the pointer rotates in such a direction that pointer deflects & comes to rest at point marked ∞ on the scale.

* next the test terminals are short circuited & generator handle is rotated, Now very large c/n flows through the CC & small c/n flows through the PC. The resultant torque produced deflects the pointer in opposite direction shows 0 reading on scale.

* after checking above two extreme conditions on scale, high resistance which is to be measured

is connected b/n the test terminals. the generator handle is rotated, Now reasonable amount of c/n flow in both PC & CC & torque deflects the pointer the pointer on calibrated scale which gives the value of resistance to be measured.

* Sources and detectors

Usually for ac circuits, a low voltage high frequency supply is required. Electronic oscillators are universally used as source for ac bridges as their frequency is constant.

* A typical electronic oscillator has a frequency range of 40Hz to 125kHz with power output of 7W.

* The detectors commonly used for ac bridges are i) vibration galvanometers
ii) Head phones
iii) Tunable amplifiers or CROS.

The vibration galvanometers are used for power & low audio frequency ranges

→ They can be used for frequency range of 5Hz to 100Hz.

* Head phones are used for frequency range 250Hz to 4kHz as they are very sensitive to these frequency ranges

* The tunable amplifier detectors used for the frequency range of 10 Hz to 100kHz. CRO can also be used as detector.

* **AC bridges** — AC bridges are used for the meast of L & C and some related quantities such as loss factor, Q factor etc.
* The arms of ac bridges are impedances consisting of individual elements of R, L & C or their combinations.

* **General equilibrium equations for ac bridges**

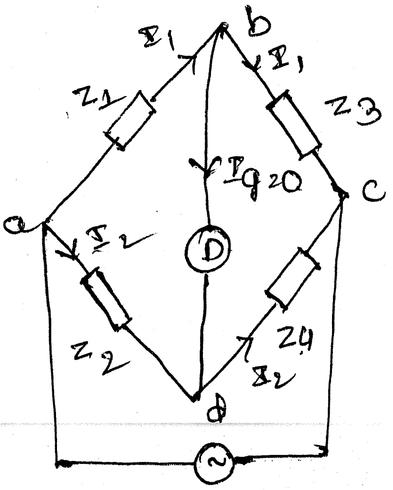


fig -

A general ac bridge also is as shown above

When the bridge is balanced there is no c/n through galvanometer ie $I_g = 0$

$\therefore V_{ab} = V_{ad}$

$I_1 Z_1 = I_2 Z_2$ — ①

& $V_{bc} = V_{dc}$

$I_1 Z_3 = I_2 Z_4$ —— ②

from equation ① x ② we get

$Z_1 / Z_3 = Z_2 / Z_4$

or $Z_1 Z_4 = Z_2 Z_3$ or $Y_1 Y_4 = Y_2 Y_3$ this is the balancing equation of ac bridge.

The product of the impedances of one pair of opposite arms must be equal to the product of the impedance of the other pair of opposite arms.

ie $|Z_1|\angle\theta_1 \times |Z_4|\angle\theta_4 = |Z_2|\angle\theta_2 \times |Z_3|\angle\theta_3$

ie $|Z_1||Z_4|\angle\theta_1+\theta_4 = |Z_2||Z_3|\angle\theta_2+\theta_3$

Hence the two balancing equations of a bridge are $|Z_1||Z_4| = |Z_2||Z_3|$ & $\angle\theta_1+\theta_4 = \angle\theta_2+\theta_3$

even the above equation can also be written as

$(R_1+jX_1)(R_4+jX_4) = (R_2+jX_2)(R_3+jX_3)$

or $R_1R_4 + j(X_1R_4+R_1X_4) - X_1X_4 = R_2R_3 + j(R_2X_3+X_2R_3) - X_2X_3$

$R_1R_4 - X_1X_4 = R_2R_3 - X_2X_3$

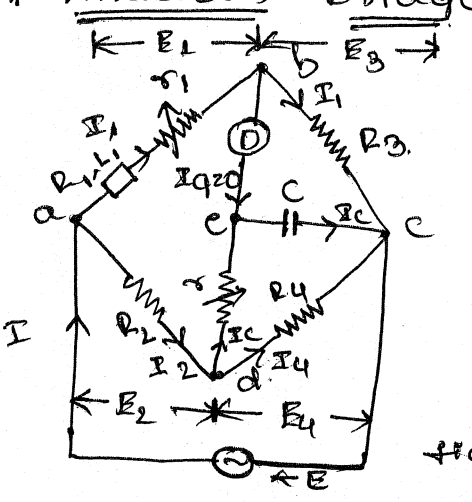
& $(X_1R_4+R_1X_4) = X_2R_3 + X_3R_2$ //

* Measurement of Self inductance.

There are various bridges can be used to measure the self inductance of a coil they are

1) Maxwell's inductance bridge
2) Maxwell's inductance - capacitance bridge
3) Hay's bridge
4) Anderson bridge.

* Anderson Bridge.



The above fig shows Anderson's bridge, in which the self inductance is measured in terms of a standard capacitor.

fig - Anderson bridge

& self inductance can be measured over a wide range of values.

as shown above

L_1 = Self - inductance of the inductor to be measured.

R_1 = resistance of self inductor

r_1 = resistance connected in series with self inductor.

R_2, R_3, R_4 = known non-inductive resistances

C = fixed standard capacitor.

* vector diagram => The vector diagram for Anderson's bridge is as shown below.

at balance

$V_{bc} = V_{ec}$ $\Rightarrow I_1 R_3 = I_C(-jX_C)$

$I_1 R_3 = \frac{I_C}{j\omega C}$ $\therefore I_C = j\omega C R_3 I_1$ — (1)

$V_{ab} = V_{ade}$

$I_1(R_1 + r_1 + j\omega L_1) = I_2 R_2 + I_C r$

$I_1 R_1 + I_1 r_1 + I_1 j\omega L_1 = I_2 R_2 + I_C r$ | we have $I_C = j\omega C R_3 I_1$

$\therefore I_1 R_1 + I_1 r_1 + I_1 j\omega L_1 = I_2 R_2 + j\omega C R_3 I_1 r$ — (2)

$I_1(R_1 + r_1 + j\omega L_1 - j\omega C R_3 r) = I_2 R_2$

& $V_{cd} = V_{ced}$.

$I_4 R_4 = I_C(r - jX_C)$

$= I_C\left(r + \frac{1}{j\omega C}\right)$ | we have $I_C = j\omega C R_3 I_1$

$(I_2 - I_C) R_4 = (j\omega C R_3 I_1)(r + 1/j\omega C)$

$(I_2 - j\omega C R_3 I_1) R_4 = j\omega C R_3 I_1 r + \frac{j\omega C R_3 I_1}{j\omega C}$

$I_2 R_4 - j\omega C R_3 R_4 I_1 - j\omega C R_3 I_1 r - R_3 I_1 = 0.$

$I_2 R_4 = j\omega C R_3 R_4 I_1 + j\omega C R_3 I_1 r + \frac{j\omega C R_3 I_1}{j\omega C}$

$I_2 R_4 = I_1(j\omega C R_3 R_4 + j\omega C R_3 r + R_3)$ — (3)

from equation (2) & (3) divide equation (2) by (3)

$$\frac{R_2}{R_4} = \frac{R_1 + r_1 + j\omega L_1 - j\omega C R_3 r}{j\omega C R_3 R_4 + R_3 + j\omega C R_3 R_4}$$

$R_1 R_4 + r_1 R_4 + j\omega L_1 R_4 - j\omega C R_3 R_4 r = j\omega C R_2 R_3 R_4 + R_2 R_3 + j\omega C R_2 R_3 R_4.$

equating real & imaginary parts.

$R_1 R_4 + r_1 R_4 = R_2 R_3$ or $R_1 = \frac{R_2 R_3}{R_4} - r_1$

$L_1 R_4 - C R_3 R_4 r = C R_2 R_3 r + C R_2 R_3 R_4.$

$r = 1363.67\ \Omega.$

* ~~Maxwell's~~ ~~Inductance~~ bridge

$$L_1 = CR_3R_4 r + CR_2R_3 r + CR_2R_3R_4$$

$$= CR_3 r + \frac{CR_2R_3}{R_4} r + CR_2R_3$$

$$= \frac{CR_3}{R_4}\left[rR_4 + R_2 r + R_2R_4\right]$$

$$= CR_3/R_4\left[r(R_2+R_4) + R_2R_4\right]$$

* Maxwell's Inductance bridge

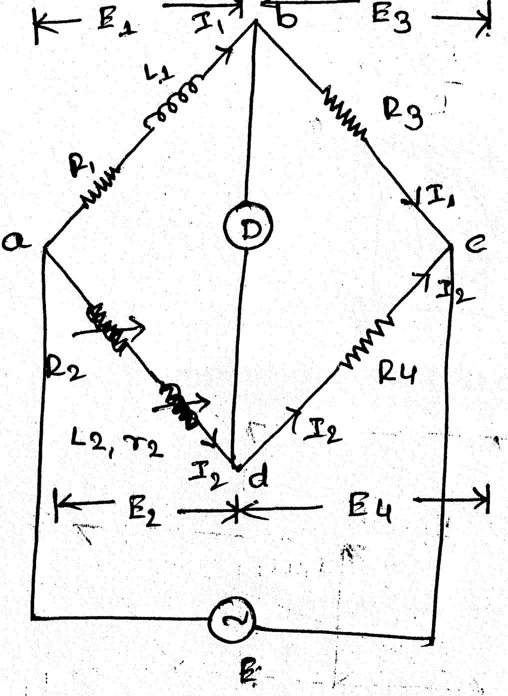


fig-a) Maxwell's Inductance bridge

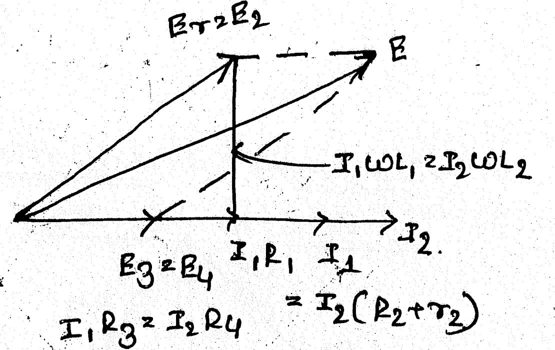


fig-b) phasor diagram

The above fig shows Maxwell's inductance bridge & its phasor diagram. The bridge circuit measures an inductance by comparision with standard self inductance.

Let L_1 = unknown inductance of resistance R_1,

L_2 = variable inductance of fixed resistance r_2

R_2 = variable resistance connected in series with inductor L_2.

R_3, R_4 = known non-inductive resistances.

When bridge is balanced. We know $Z_1 Z_4 = Z_2 Z_3$

ie $(R_1 + j\omega L_1) R_4 = (R_2 + r_2 + j\omega L_2) R_3$

$$R_1 R_4 + R_4 j\omega L_1 = R_2 R_3 + R_3 r_2 + j\omega L_2 R_3$$

Equating real & imaginary parts

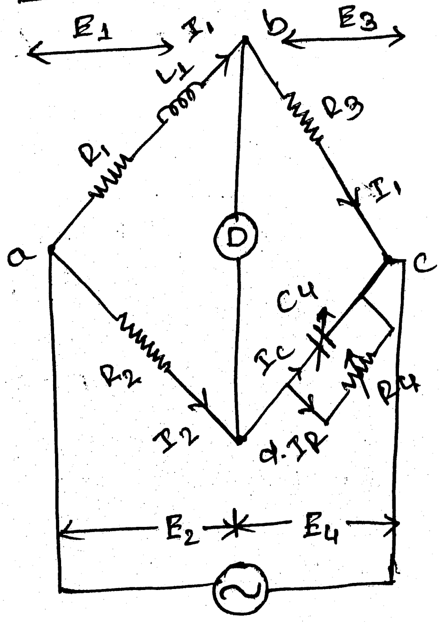
$$R_1 R_4 = R_2 R_3 + R_3 r_2$$

$$R_1 = \frac{R_3}{R_4}(R_2 + r_2)$$

Imaginary parts $j\omega L_1 R_4 = j\omega L_2 R_3$

$$L_1 = \frac{R_3}{R_4} \cdot L_2$$

* Maxwell's Inductance - Capacitance bridge.



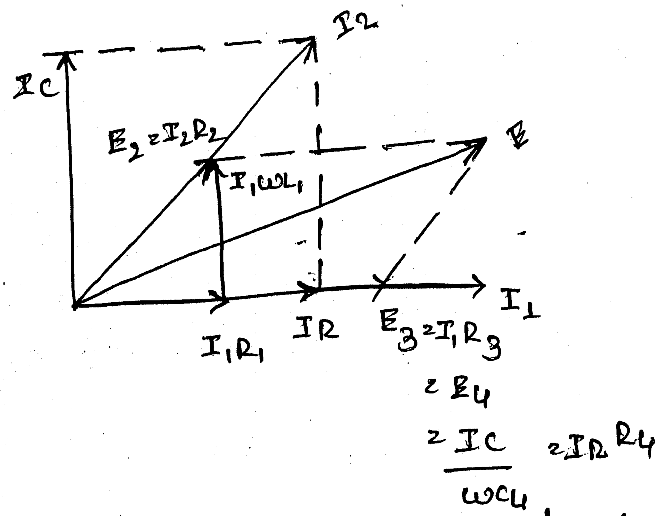


fig - Maxwell's inductance capacitance bridge.

In Maxwell's Inductance capacitance bridge, an inductance is measured by comparision with a standard varible capacitance. The bridge connection & phasor diagram is as shown above

Where L_1 = unknown inductance

R_1 = effective resistance of inductor L_1

R_2, R_3, R_4 = known non-inductive resistances

C_4 = varible standard capacitor.

at the balanced condition.

$$Z_1 Z_4 = Z_2 Z_3$$

$$(R_1 + j\omega L_1)\left(\frac{R_4}{1 + j\omega C_4 R_4}\right) = R_2 R_3$$

$$R_1 R_4 + j\omega L_1 R_4 = R_2 R_3 + j\omega C_4 R_4 R_2 R_3$$

Separating real and imaginary part

$R_1 R_4 = R_2 R_3$ & $L_1 R_4 = C_4 R_4 R_2 R_3$

$\therefore R_1 = \frac{R_2 R_3}{R_4}$ // $L_1 = C_4 R_2 R_3$ //

The expression for Q factor is $Q = \frac{\omega L_1}{R_1}$

$$= \frac{\omega C_4 R_2 R_3 R_4}{R_2 R_3}$$

$$Q = \omega C_4 R_4$$ //

* Advantages.

1) The two balance equations are independent if we choose R_4 and C_4 as varible elements.

2) The frequency does not appear in any of the two equations.

3) L_1 & R_1 is calcalated in simple way.

* disadvantage

1) The bridge requires varible capacitor which is expensive.

* Hays Bridge

The Hays bridge is a modification of Maxwell s bridge. The connection diagram for the bridge is as shown below

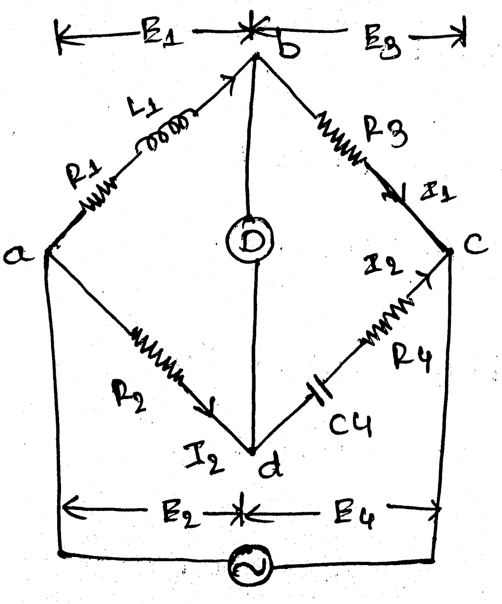


fig - Hays bridge

Let L_1 = unknown inductance having a resistance R_1

R_2, R_3, R_4 = known non-inductive resistance

C_4 = standard capacitor

at balanced condition. $Z_1 Z_4 = Z_2 Z_3$

$$(R_1 + j\omega L_1)\left(R_4 - \frac{j}{\omega C_4}\right) = R_2 R_3$$

$$R_1 R_4 - \frac{jR_1}{\omega C_4} + j\omega L_1 R_4 + \frac{L_1}{C_4} = R_2 R_3$$

separating real & imaginary parts.

$$R_1 R_4 + L_1/C_4 = R_2 R_3 \quad \text{—①}$$

$$j\omega L_1 R_4 = \frac{jR_1}{\omega C_4}$$

$$\omega^2 L_1 R_4 C_4 = R_1$$

$$L_1 = \frac{R_1}{\omega^2 R_4 C_4} \quad \text{—②}$$

put the value of L_1 in equation ①

$$\therefore\ R_1 R_4 + \frac{R_1}{\omega^2 R_4 C_4^2} = R_2 R_3$$

$$R_1\left(R_4 + \frac{1}{\omega^2 R_4 C_4^2}\right) = R_2 R_3$$

$$\Rightarrow R_1\left(\frac{\omega^2 R_4^2 C_4 + 1}{\omega^2 R_4 C_4^2}\right) = R_2 R_3$$

$$\therefore R_1 = \frac{\omega^2 R_4 C_4^2 R_2 R_3}{\omega^2 R_4^2 C_4 + 1} \quad \text{--- (3)}$$

$\therefore R_1 = \frac{R_2 R_3 C_4}{}$ put eqn (3) in below L_1

Now $L_1 = \frac{R_1}{\omega^2 R_4 C_4}$

$$\therefore L_1 = \frac{\omega^2 R_4 C_4^2 R_2 R_3}{(\omega^2 R_4^2 C_4 + 1)(\omega^2 R_4 C_4)}$$

$$L_1 = \frac{R_2 R_3 C_4}{(1 + \omega^2 R_4^2 C_4)}$$

Now Q factor is

$$Q = \frac{\omega L_1}{R_1} = \frac{\omega \times \left(\frac{R_2 R_3 C_4}{1 + \omega^2 R_4^2 C_4}\right)}{\frac{\omega^2 R_4 C_4^2 R_2 R_3}{(1 + \omega^2 R_4^2 C_4)}} = \frac{\omega R_2 R_3 C_4}{(\omega^2 R_4 C_4^2 R_2 R_3)}$$

$$\therefore Q = \frac{1}{\omega C_4 R_4}$$

* Advantages

1) It provides simple expression for unknown inductance for high Q coils,
2) It gives simple expression for Q factor.

* disadvantage :-

1) The Hays bridge is suitable for the measurement of high Q inductors, whose Q factor is more than 10

* Measurement of capacitance

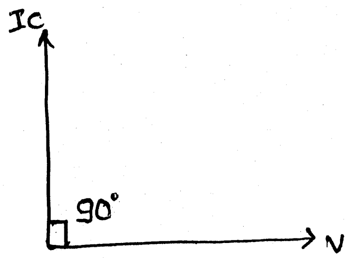


fig-a)

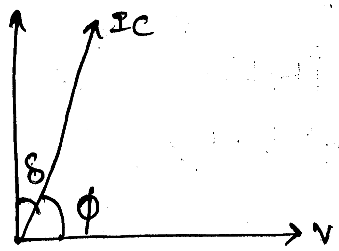


fig-b)

A pure capacitance does not consume power ie the dielectric loss is zero. The c/n Ic leads voltage by 90° as shown below in fig.

* In practice there will be some dielectric loss in the capacitor due to resistance component, during this case Ic leads v by an angle slightly less than 90° as shown in fig b. In which ϕ is known as pf angle & δ is known as loss angle or dissipation angle.

The power consumed by the capacitor is given by $p = VI_c\cos\phi = VI_c\cos(90-\delta) = VI_c\sin\delta$.

* A practical capacitor with its resistance in series is as shown below.

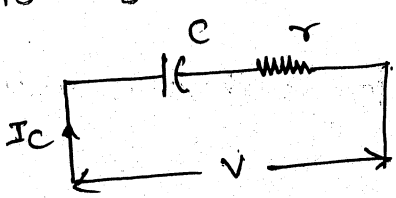


fig-c

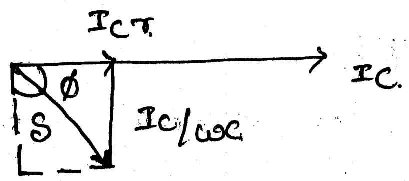


fig-d)

$V = I_c - jI_c\frac{1}{\omega c}$

$\tan\delta = \frac{I_c r}{I_c/\omega c} = \omega c r$ = loss factor or dissipation factor.

* A practical capacitor in ||el with resistance is as shown below

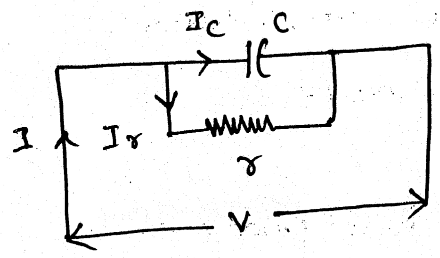


fig-e)

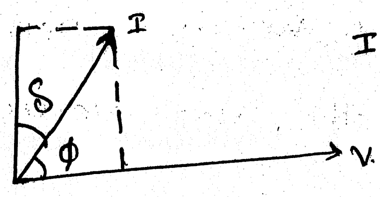


fig-f

$I = I_C + I_r$

$$\text{Loss factor} = \tan\delta = \frac{I_r}{I_C} = \frac{V/r}{V\omega C} = \frac{1}{\omega C r}$$

The pf of the capacitor is given by $\cos\phi = \cos(90-\delta) = \sin\delta$.

* There are two bridges that can measure capacitance.
  1) Schering bridge 2) Desautys bridge

* The Schering bridge is widely used for the measurement of capacitance, dielectric loss and pf of the capacitor. The best advantage of Schering bridge is it can be used for both low voltage & high voltage

* Low voltage Schering Bridge.

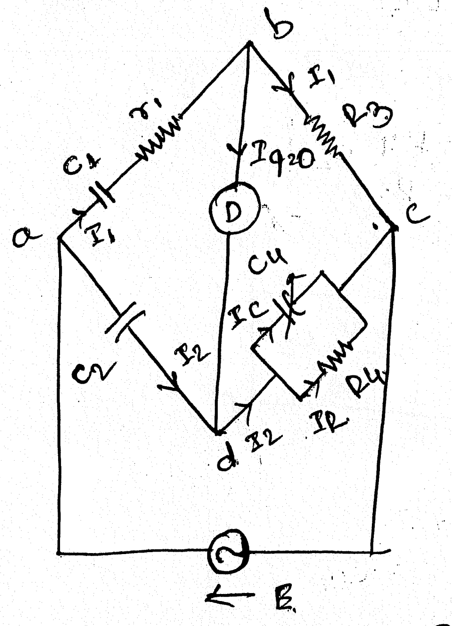


fig - Low voltage Schering Bridge.

The connection diagram for Low voltage Schering Bridge is as shown above.

Where C_1 = The unknown capacitance

r_1 = Resistance representing its loss component

C_2 = Standard loss free air capacitor.

R_3 = non-inductive resistance

C_4 = A variable capacitor

R_4 = A variable, non-inductive resistance

E is the low voltage ac source.

The detector may be head phone or a vibration galvanometer.

When the bridge is balanced.

$$Z_1 Z_4 = Z_2 Z_3$$

$$\left(r_1 + \frac{1}{j\omega C_1}\right)\left(\frac{R_4}{1 + j\omega C_4 R_4}\right) = \frac{1}{j\omega C_2} R_3$$

$$\left(r_1 + 1/j\omega C_1\right) R_4 = \left(1 + j\omega C_4 R_4\right) \frac{R_3}{j\omega C_2}$$

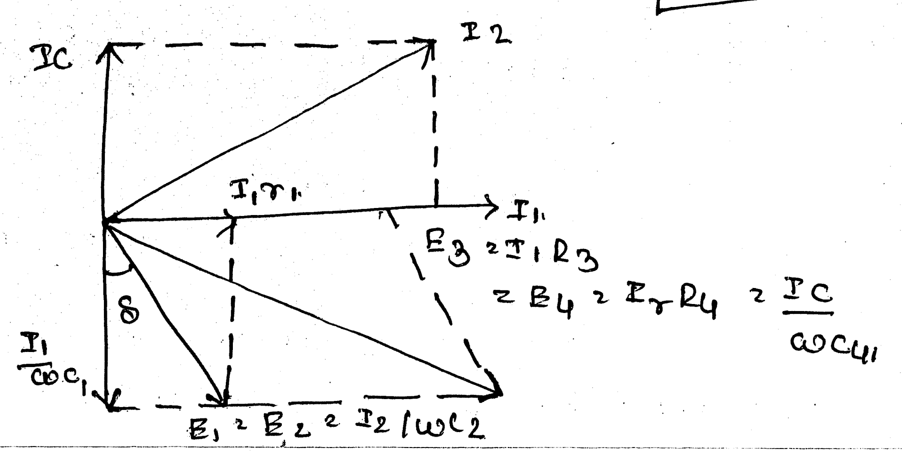
$$r_1 R_4 + \frac{R_4}{j\omega C_1} = \frac{R_3}{j\omega C_2} + \frac{R_3 R_4 C_4}{C_2}$$

equating real & imaginary parts we get

$$r_1 R_4 = \frac{R_3 R_4 C_4}{C_2} \quad \& \quad \frac{R_4}{C_1} = \frac{R_3}{C_2}$$

$$\therefore r_1 = \frac{R_3 C_4}{C_2}$$

$$\therefore C_1 = \frac{R_4}{R_3} C_2$$



Now the dissipation factor is obtained as

$$\tan\delta = \omega C_1 r_1 = \omega \frac{R_4}{R_3} \cdot C_2 \cdot \frac{C_4}{C_2} R_3 = \omega C_4 R_4.$$

However the values of C_4 and R_4 are alternatively varied to obtain balance, as each one of them appear in the two balancing equations separately.

* High voltage Schering Bridge

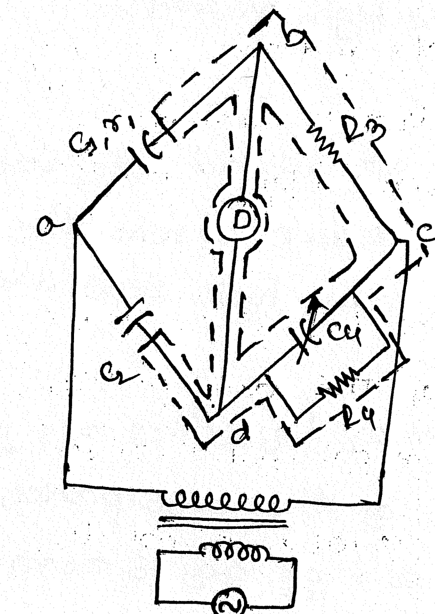


fig-b) High voltage Schering Bridge.

The schering bridge is generally used for the measurement of capacitance & their dissipation factors, but in particular it is used to measure the properties of insulators, condenser bushings, insulating oils & other insulating materials.

* High voltage schering bridge is used for the measurement of small capacitances.

* Special features of High voltage Schering Bridge are.

1) The high voltage supply is obtained from a transformer usually at 50Hz. The detector used is vibration galvanometer.

2). Arm ab and ad contain only capacitors. These capacitors are designed for high voltage work. The impedances of these arms are very high compared to those of arms bc & cd. The point c is earthed. Even when voltage of 100 kV is applied the voltages across bc & de ~~are a few volts~~ are above earth.

3) Spark gaps are provided across arms bc & de to prevent very high voltages appearing across these arms, when either of the high voltage capacitors breaking down.

4) The impedances of the arms ab and ad are very large and hence the current drawn from the source is very small. Hence, a very high sensitive detector has to be used.

5) The fixed standard capacitor C_2 has either air or compressed gas as dielectric as the dissipation factor of dry and clean air or gas is zero.

6) Earthed screens are used to avoid errors due to inter capacitance b/n high and low voltage arms of the bridge.

Instead of earthing one point of the circuit the earth capacitance effect on the galvanometer leads are eliminated by means of "Wagner earthing device".

* Sources of errors in Bridge circuits.

The various factors which cause errors in the bridge measurement are as follows ⇒

i) Electrostatic coupling b/n the impedances of ratio arms.
ii) Electromagnetic coupling b/n the impedancey of ratio arms.
iii) Stray capacitance effects.
iv) Resistance not being fully non-inductive.
v) Incorrect frequency and waveform of supply voltag

The errors which are introduced due to above effects they are considerably at high voltage & high frequency. Hence remedial measures have to be taken to reduce their effects.

① Errors due to electrostatic coupling :- If the adjacent branches of a bridge are at different potentials, there will be inter-capacitance effect due to which the electric field of the branches may interact they introduce errors

This error can be reduced by covering the impedances by metal shields.

② Errors due to electromagnetic ~~fields~~ coupling :-

When the adjacent arms of bridge contain inductive coils, there is mutual coupling b/n them and the effect of mutual inductance b/n the coils is not taken into consideration while deriving the balance equations, ∴ the errors are introduced in the measurement.

③ errors caused due to stray electric fields.

When the junction points of a bridge n/w are at different potentials, stray capacitance exist b/n these points and the earth due to which errors are introduced in the bridge meast.

The error due to this can be minimised by using special device known as "Wagner earthing device".

4) Errors due to resistancy being non-inductive :- If the resistances used in the bridge include small inductancy & the inductance values are not included during meast then errors are introduced during meast.

5) Errors due to Incorrect frequency and waveform of supply voltage.

If the supply frequency is not constant & changes from its value, as the magnitudes of the impedances of the various arms depends on the frequency, ∴ errors are introduced in the meast.

In order to minimise the errors due to this effect, frequency has to be checked frequently during the measurement.

If the waveform of the supply is not sinusoidal, then it may not be possible to obtain balance, as the bridge can't be simultaneously balanced both for the fundamental & harmonics. This difficulty may be overcome by using wave filters which will eliminate harmonics.

* Shielding of Bridge elements

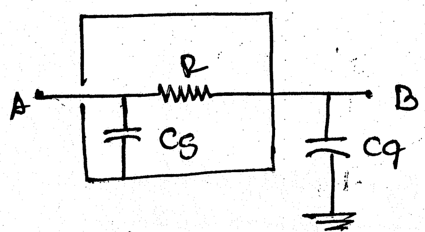


fig-a

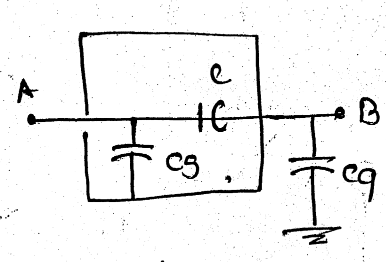


fig-b.

capacitance b/n the bridge elements and b/n the elements and earth affect the the accuracy of ac bridge measurements.

* An effective way of reducing the effect of these capacitances is to enclose the elements in earthed metallic shields.
* The shielding of the elements shift these capacitances where they do not harm.
* as shown in fig a resistance is shielded, a capacitance Cs exists b/n the resistor & the shield.
* capacitor Cg exists b/n the shield and ground, By shielding, all the stray capacitances are concentrated at point B, shielding of resistor makes its value definite & bridge can be balanced without any problem.
* as shown in fig b a capacitance is shielded, again a capacitance Cs exist b/n the capacitor & shield. & Cg exist b/n the shield and ground.
* By shielding of all the capacitances are concentrated at point B & their values are definite.

∴ bridge is balanced without any problem

* **De Sauty's bridge.**

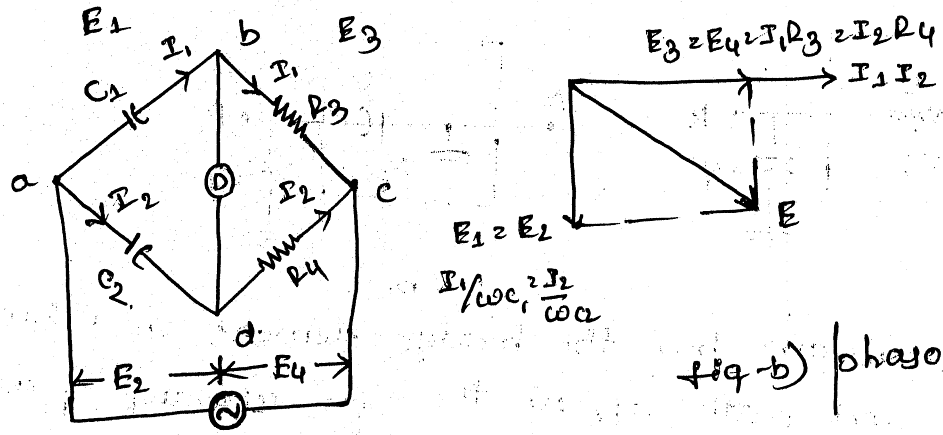


fig-a) desauty bridge.

fig-b) phasor diagram

Above fig shows desauty's bridge & phasor diagram of De Sauty's bridge.

Let C_1 = capacitor whose capacitance is to be measured

C_2 = a standard capacitor.

R_3, R_4 = non inductive resistors

When bridge is balanced condition. $Z_1 Z_4 = Z_2 Z_3$

$$\left(\frac{1}{j\omega C_1}\right) R_4 = \left(\frac{1}{j\omega C_2}\right) R_3$$

$$R_4/R_3 = j\omega C_1 / j\omega C_2$$

$$R_4/R_3 = C_1/C_2 \quad \text{---} (1)$$

The balance of bridge is obtained by varying either R_3 or R_4. With this method only loss-less capacitors like air capacitors can be compared.

In order to make measurement on imperfect capacitors, the bridge is modified, as shown below.

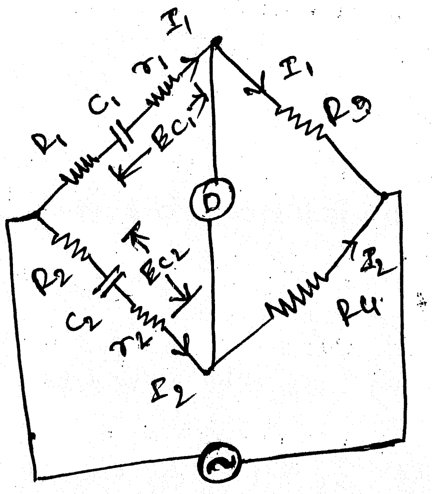


fig-c) Modified desautys bridge

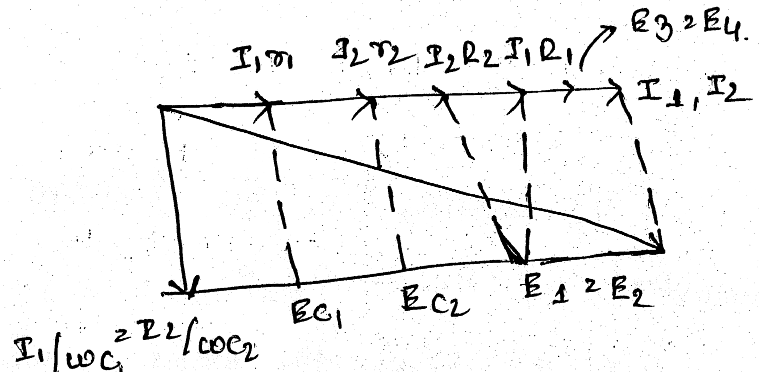


fig-d) phasor diagram

The Modified desautys bridge & corresponding phasor diagram is as shown in fig c & fig d respectively.

Resistors R_1 and R_2 are connected in series with C_1 and C_2, r_1 and r_2 are resistances representing the loss component of two capacitors connected in series with C_1 & C_2.

At balanced condition of bridge

$$Z_1 Z_4 = Z_2 Z_3$$

$$\left(R_1 + r_1 + 1/j\omega C_1\right) R_4 = \left(R_2 + r_2 + 1/j\omega C_2\right) R_3$$

$$R_1 R_4 + r_1 R_4 + \frac{R_4}{j\omega C_1} = R_2 R_3 + r_2 R_3 + R_3 / j\omega C_2$$

$$R_4 / R_3 = \underline{R_2 + r_2 + 1/j\omega C_2}$$

By solving the above equation we get

$$R_4/R_3 = \frac{R_2 + r_2}{R_1 + r_1} = C_1/C_2 \quad \text{—— (2)}$$

The balance of the bridge is obtained by the variation of R_1, R_2, R_3, R_4

fig d, shows the phasor diagram of the bridge under balance conditions. The angles δ_1 and δ_2 are the phase angles of capacitors C_1 and C_2 respectively

dissipation factor for the capacitors are ,

$D_1 = \tan\delta_1 = \omega C_1 r_1$ and $D_2 = \tan\delta_2 = \omega C_2 r_2$

the equation (2) can also be written as

$C_1(R_1 + r_1) = C_2(R_2 + r_2)$

$C_1R_1 + C_1r_1 = C_2R_2 + C_2r_2$

$C_2r_2 - C_1r_1 = C_1R_1 - C_2R_2$

~~$D_2 r/D_1$~~

$\omega C_2 r_2 - \omega C_1 r_1 = \omega C_1 R_1 - \omega C_2 R_2$

$D_2 - D_1 = \omega[C_1R_1 - C_2R_2]$ | $\because D_2 = \omega C_2 r_2$, $D_1 = \omega C_1 r_1$

But we know that $C_1/C_2 = R_4/R_3$

or $C_1 = C_2 R_4/R_3$

$\therefore D_2 - D_1 = \omega\left[C_2 R_4/R_3 \cdot R_1 - C_2R_2\right]$

$$D_2 - D_1 = \omega C_2\left[\frac{R_1R_4}{R_3} - R_2\right]$$

from the above equation it is clear if the dissipation factor of one capacitor is known, we can obtain the dissipation factor of second one

* An ac bridge has the following branches

Arm ab : an unknown impedance (R_1, L_1) in series with a non-inductive variable resistor r_1

Arm bc = a non inductive resistor R_3 = 100 Ω

Arm cd = " " " R_4 = 200 Ω

Arm da = " " " R_2 = 250 Ω

Arm de = a non inductive variable resistor r

Arm ec = lossless capacitor C = 1 μF and

Arm be = a detector.

chapter - 4.

Measurement of power & Related parameters

power is the rate at which energy is consumed, its unit is watt. In dc ckts the power is given by the product of voltage × current. ie $P = VI$ watts for dc, while in ac ckts the power given by product of voltage, current & power factor. ie $P = VI\cos\phi$ watts in ac.

However the wattmeter are universally used for the measurement of ac power.

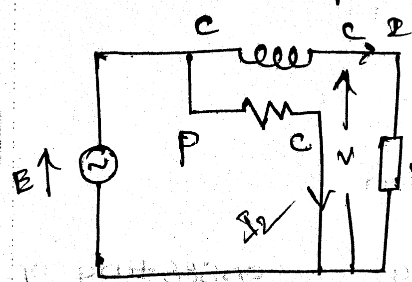


fig-a) wattmeter

as shown in the above fig a wattemeter consisting of cc & pc. current coil is connected in series with the load while the potential coil pc is connected across the supply. Here wattmeter directly ready the power consumed.

There are different type of wattmeter but the universally used wattmeter is the dynamometer type wattmeter.

* Dynamometer type wattmeter.

The below fig shows the dynamometer type of wattmeter which is universally used for the measurement of DC as well as AC power.

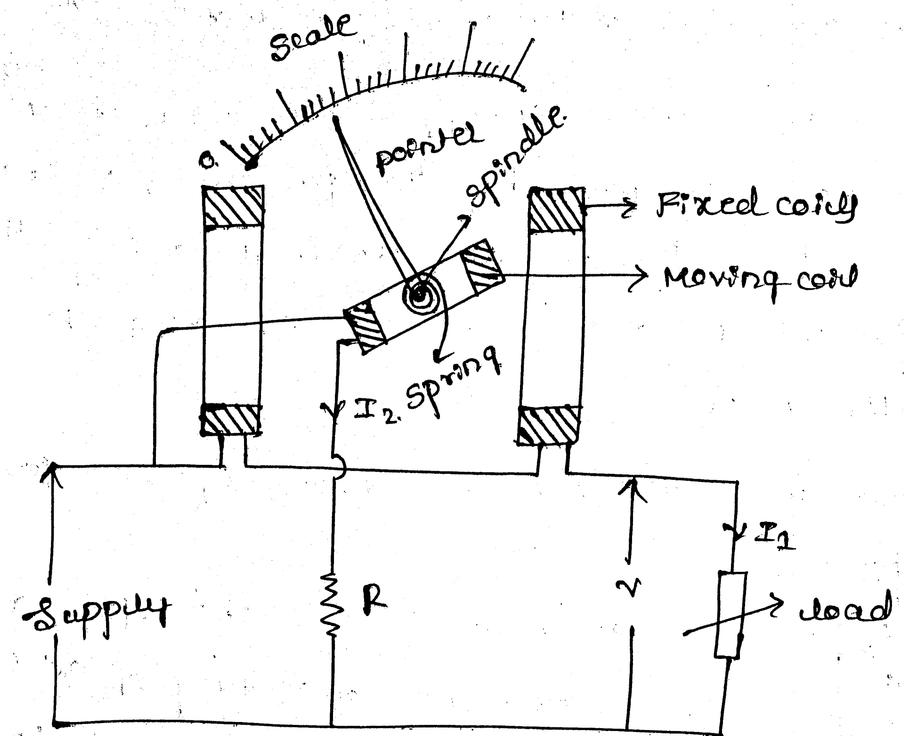


fig - Dynamometer Type wattmeter

Construction :- As shown in the above fig it consisting of fixed coil which forms the cc & it consisting of moving coil which forms the potential coil ie pc. The fixed coil is split into two equal parts & placed at a distance in parallel with each other & they are air cored to avoid hysteresis loss when used for the measurement of Ac power.

Fixed coils are connected in series with the load to carry the current I_1 where as the moving coil is ~~spindle~~ placed on the spindle, b/n two fixed coils. A pointer is attached to the spindle, which moves over a graduated scale, b/n the two fixed coils,

The moving coil is connected across the supply & it carries a current of I_2, which is proportional to the applied voltage

However a high resistance R is connected in series with the moving coil, to limit the current flowing through the coil.

Working principle :-

① When the c/n carrying moving coil is placed in the magnetic field, which is produced by another current carrying fixed coil, a force is produced on the coil sides of the moving coil, due to which a deflection torque is produced & the moving coil deflects.

[deflection torque →
controlling torque →

② Now the deflection torque is controlled by the controlling torque which is produced by the springs.

② When the direction of c/n is reversed in both the coils during the -ve half cycle, while measuring the AC power the direction of deflection torque remains same & hence the dynamometer type of wattmeter is used for the measurement for both AC & DC power.

③ When the moving coil deflects, the pointer attached to the spindle moves over a graduated scale ~~& comes to rest~~ & it comes to rest when deflection torque is equal to controlling torque.

DC power meast.

Let V = voltage across the load

I_1 = load current

I_2 = c/n through the moving coil

$I_2 \propto V$

Since the fixed coil is air-cored, hence the flux density produced in the fixed coil is directly proportional to the current $\therefore B \propto I_1$ —— ①

The deflection torque produced is given by

$T_d \propto B I_2$
$\propto I_1 I_2$
$\propto I_1 V$
$\propto$ power consumed by the load

$\therefore$ the deflection of the pointer due to the deflection torque T_d is proportional to power consumed by the load.

* AC power measurement

Let v = instantaneous voltage across the load
i_1 = " clr through the load
i_2 = " " through moving coil
V = rms value of the voltage across the load
I_1 = " " " clr through the load.

$\cos\phi$ = pf of the load

If $v = V_m \sin \omega t$, & $i_1 = I_m \sin(\omega t - \phi)$

assuming the load is inductive

Due to the inertia of the moving sim, the deflection is proportional to the average torque.

$\therefore$ Avg deflection torque $\propto$ average value of $(i_1 \times i_2)$
$\propto$ " " " $(i_1 \times v)$

ie $v i_1 = V_m \sin \omega t \, I_m \sin(\omega t - \phi)$

$v i_1 = V_m I_m \cdot \frac{1}{2}[\cos\phi - \cos(2\omega t - \phi)]$

$i_1 = \frac{1}{2} V_m I_m [\cos\phi - \cos(2\omega t - \phi)]$

power is a scalar quantity hence only its average value must be considered.

The above ~~term~~ equation contains the two terms

i) $\frac{1}{2} V_m I_m \cos\phi$

ii) $-\frac{1}{2} V_m I_m \cos(2\omega t - \phi)$

~~$\sin 2\theta = 2\sin\theta \cdot \cos\theta$~~

~~$\sin\theta = \frac{1}{2}\sin\theta/2 \cos\theta/2$~~

$\sin a \cdot \sin b = \frac{1}{2}\cos(a-b) - \cos(a+b)$

$\sin\omega t \cdot \sin(\omega t - \phi)$

$= \frac{1}{2}\cos[\omega t - \omega t + \phi]$

$- \cos[\omega t + \omega t - \phi]$

$= \frac{1}{2} V_m I_m \cos\phi - \cos(2\omega t - \phi)$

The second term is periodically varying term & hence its average value over a period of time is zero.

$\therefore$ Average value of $(v \times i_1) = \frac{1}{2} V_m I_m \cos\phi$

$\Longrightarrow = \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}} \cos\phi = V I_1 \cos\phi$ —— (2)

$\therefore T_d \propto V I_1 \cos\phi$

However $V I_1 \cos\phi$ gives average power consumed by the load,

$\therefore T_d \propto \theta \propto V I_1 \cos\phi$ —— (3)

At steady deflection $T_d = T_c$

From the equation (3) it is clear that the deflection of the pointer is proportional to the power consumed by the load.

* <u>Advantages</u>

1) Dynamometer type of wattmeter is used to measure both AC & DC power.

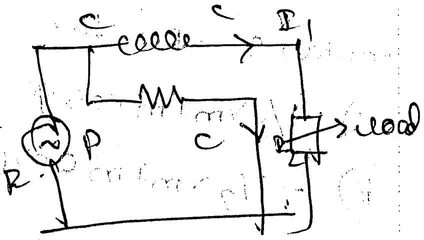
(7) They have a uniform scale

(8) They are accurate & reliable.

* Disadvantages

(1) At low power factor, the inductance of the potential coil causes the serious errors

(2) the reading of the meter is affected by stray magnetic fields acting on the moving coil.



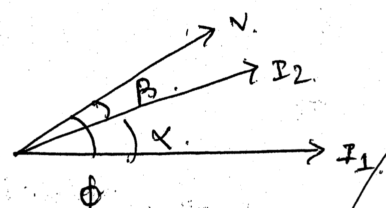
* Attendance — 1, 16, 22, 23, 32, 33

* Errors in dynamometer wattmeter

i) Due to the inductance of the pressure coil.

⟹ in a ideal wattmeter it is assumed that the pressure coil is purely resistive and the c/n through it is I_2 which is in phase with the applied vtg V.

However the pressure coil will have a small inductance L due to which c/n I_2 lags the applied voltage V by a small angle β as shown in the below fig.



where $\beta = \tan^{-1} \omega L / R_2$

Where $R_2 = r_2 + R$ = total resistance of the pc ckt.

r_2 = resistance of the pressure coil.

R = resistance in series with the pc.

I_1 = load c/n (c/n through the c/n).

In such case, the actual wattmeter reading is given by.

Errors in dynamometer type of wattmeter - UPR

i) Due to the inductance of the pressure coil :-

In an ideal wattmeter, it is assumed that the pc which is purely resistive, & the current through it is I_2, which is in phase with applied voltage. But However the pc will have small inductance L due to which the c/n I_2 lags the applied voltage V by a small angle β. as shown.

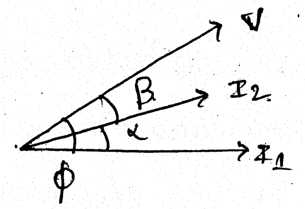


fig-a,

$\beta = \tan^{-1}\frac{\omega L}{R_2}$. Where $R_2 = R + r_2$ = total resistance of the pc ckt

r_2 = resistance of pressure coil

R = resistance in series with pc

I_1 = load current or c/n through the current coil

In such a case wattmeter reading is given by

$W_a = VI_1 \cos\beta \cos(\phi-\beta)$. —— ① The true power is given by

$W = VI_1 \cos\phi$ —— ②.

divide eqn ② by ①.

$$\therefore \frac{\text{True power}}{\text{Actual wattmeter reading}} = \frac{VI_1\cos\phi}{VI_1\cos\beta\cdot\cos(\phi-\beta)} = \frac{\cos\phi}{\cos\beta\cdot\cos(\phi-\beta)} = \text{correction factor}$$

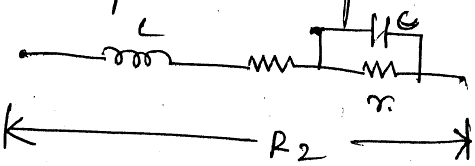
$$\therefore \text{True power} = \frac{\cos\phi}{\cos\beta\cdot\cos(\phi-\beta)} \times \text{actual wattmeter reading.}$$

$\therefore$ true power = correction factor × actual wattmeter reading

For leading power factor

$$\text{correction factor} = \frac{\cos\phi}{\cos\beta\cdot\cos(\phi+\beta)}$$

The errors due to small inductance of pressure coil can b reduced by connecting a suitable capacitor in parallel with a portion of resistance R.



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ii) <u>Due to the capacitance of the pressure coil</u>

⟹. The pressure coil of the circuit may have capacitance in addition to the inductance, The effect of this capacitance ~~may affect~~ on wattmeter is opposite to that of the inductance hence due to capacitance again wattmeter reads more lagging p.f of the load.

iii) <u>Due to the mutual inductance.</u>

Errors are introduced in the wattmeter due to the mutual inductance b/n the current coil & pressure coil of the wattmeter. These errors are very small at power frequency but at the high frequencies they are more.

But Nowdays the arrangements of both cc & pc are done in such way that, they have zero mutual inductance & hence reduction in the errors.

iv). <u>Due to the method of connection of cc & pc.</u>

There are two methods of connecting a wattmeter in a ckt as shown below.

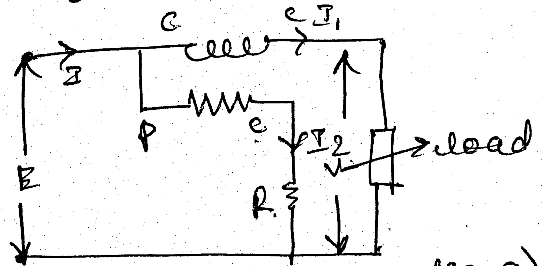


fig-a).

(2)

As shown in the above fig the pressure coil is connected on the supply side. ∴ The voltage applied to the pressure coil is the sum of the voltage across the load + the voltage drop across the current coil. 39

Thus the wattmeter reads the sum of power consumed by the load & the power loss in the c/n coil.

∴ power indicated by the wattmeter = power consumed by the load + power loss in the current coil

= power consumed by the load $+ I_1^2 R_1$

where R_1 is resistance of the c/n coil.

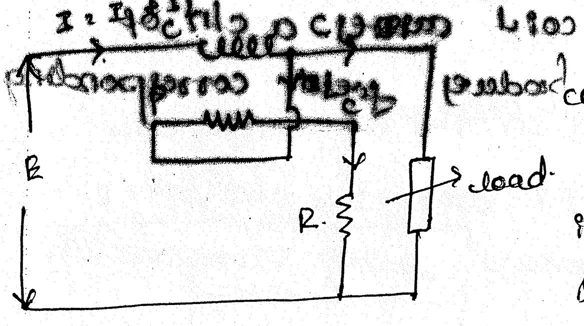


fig-b

As shown in the fig (B) the current coil is connected on the supply side of the c/n through the current coil. ∴ the c/n through the load is the sum of c/n through the load i.e. $I = I_1 + I_2$ & current through the pc. Hence the wattmeter reads the sum of power consumed by the load & power loss in pressure coil.

∴ power indicated by the wattmeter = power consumed by the load + power loss in pc

$= \text{load} + V^2/R_2$

V = vtg across load & R_2 = resistance of pc ckt.

Note – 1) If the load current is small then voltage drop in the current coil is small & it gives small error in the wattmeter reading hence fig a is considered for the

40 coil connection.

2.) If the load cln is large the cln in the pc ie I_2 is very small compared to load cln I_1 hence power loss in the pressure coil is reduced & hence fig (B) is taken

Finally instead of these two connection one more connection is preferred using compensating coil as shown below.

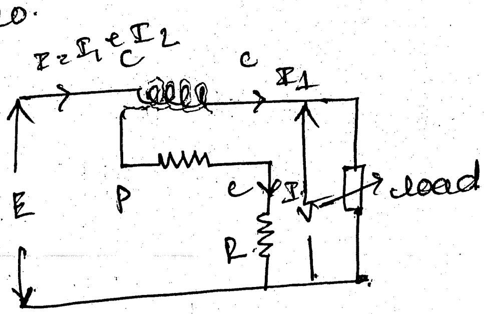


fig-C

(1) as shown in the above figure the cln coil carries a cln of $I = I_1 + I_2$ & produces field corresponding to the cln.

(2) The compensating coil is exactly similar to the cln coil which is connected in series with the pc. but carries a current of I_2 in such direction ie it should produce the field which is exactly opposite to the field produced by I_2 through current coil.

(3) ∴ the field produced by I_2 through current coil is compensated by the cln I_2 flowing through the compensating coil therefore the resultant field is produced just with the help of I_1,

(4) now the error caused is just by pressure coil cln I_2 which is flowing through the current coil.

& wattmeter directly reads power consumed by load.

Eddy current errors.

34 eddy currents are ~~intro~~ induced in the solid metal parts & within the thickness of the conductors of the c/n coil when the wattmeter is used for the meas of power in ac ckt.

These eddy currents will produce the field of their own & alter the magnitude & phase of c/n through the current coil & they cause errors.

Due to these errors the wattmeter reads low for lagging power factor & high for leading power factor.

In order to reduce these errors care must be taken while construction of wattmeter such that no metal parts are to be used & stranded conductors are used for the c/n coil.

* Stray magnetic effects.

The dynamometer wattmeter has a relatively a weak operating field which is affected by the stray magnetic effects. Hence the wattmeters must be shielded to avoid stray magnetic effects.

* errors due to the vibration of moving s/m.

The torque on the moving s/m of a wattmeter varies with the natural frequency which is two times the frequency of supply voltage. Again if the pointer, spring or any other moving parts s/m have a natural frequency which is equal to the frequency of the torque of the movt. sLm, due to which the pointer vibrates & we may not read 33 the deflection on scale properly thats finally again the errors are introduced.

This can be avoided just by selecting the natural frequency just away to the supply frequency.

* Temperature effects => The wattmeter reading is affected due to the change in temperature. Any change in temp changes the resistance of pressure coil & the stiffness of the springs. The errors caused by these two effects are opposite to one another & nearly neutralise each other.

Low power factor wattmeter.

As we know there are certain errors while measuring the power from dynamometer type of wattmeter such as

1) at the low power factor the inductance of the pressure coil introduces the errors.

2. The deflecting torque on the moving sLm is low even though when both current coil & pressure coil are fully excited.

Hence special features are introduced in the dynamometer type of wattmeter when they are used to measure the power in circuits at low power factor. They are as follows →

Chapter - 4

Measurement of power and Related parameters

Power is a rate at which energy is consumed, its unit is watt. In dc circuits the power is given by the product of voltage & current ie $p = VI$ watts for dc, while in ac circuits the power is given by product of voltage, current & power factor ie $p = VI\cos\phi$ watts in ac. However the wattmeters are universally used for the measurement of power.

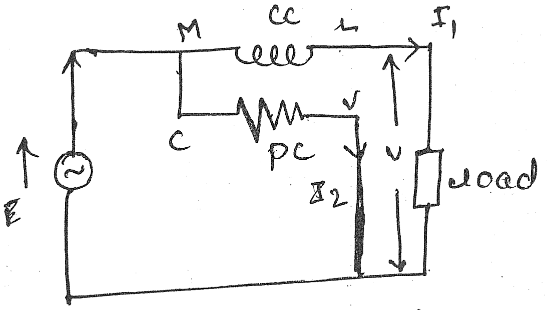


fig-a) Wattmeter

as shown in a fig wattmeter consisting of cc & pc, current coil is connected in series with load & potential coil the pc is connected across the supply. Here wattmeter directly reads the power consumed. There are different type of wattmeters are their but the universally used wattmeter is the dynamometer type of wattmeter

* Dynamometer type of Wattmeter.

The below fig shows the dynamometer type of wattmeter which is universally used for the meast of dc as well as ac power.

* Construction

As shown in the above fig it consisting of fixed coil which forms the current coil & it consisting of moving coil which forms the potential ie PC,

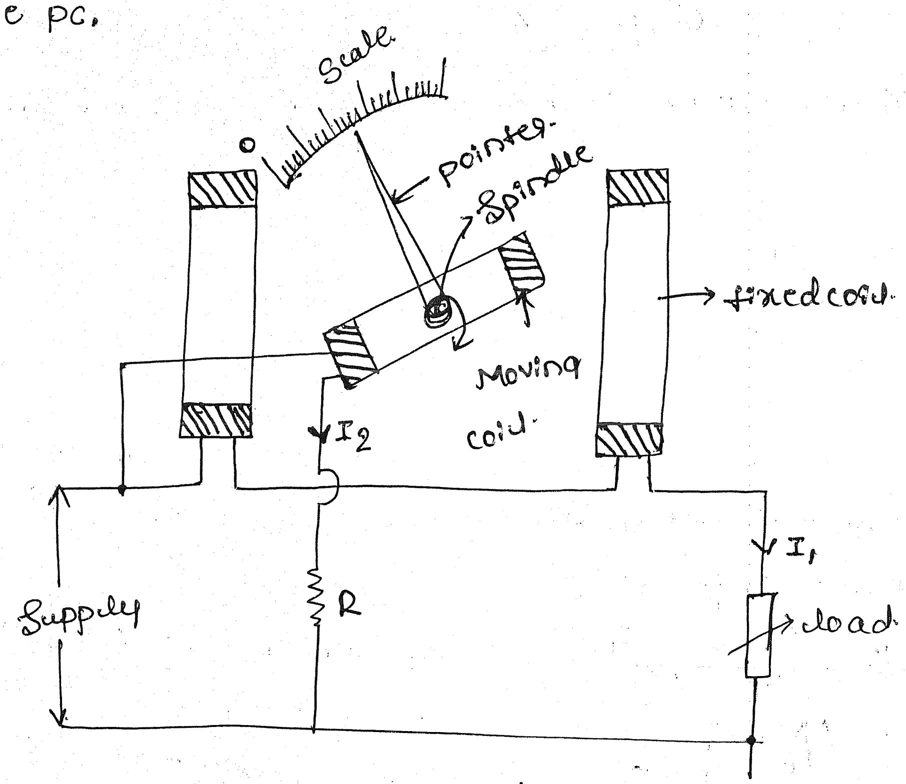


fig - Dynamometer type of wattmeter.

As shown above the fixed coil is split into two equal parts & placed at a certain distance in parallel with each other. & they are aircored to avoid hysteresis loss, when used for the measurement of AC power.

Fixed coils are connected in series with the load to carry the current I_1, where as moving coil is placed on spindle, b/n two fixed coils. A pointer is attached to the ~~placed on the~~ spindle, which moves over a graduated scale, b/n the two fixed coils.

The moving coil is connected across the supply & it carries a c/n of I_2, which is proportional to the applied voltage.

However a high resistance R is connected in series with the ving coil, to limit the current flowing through the coil.

Working principle :-

① When the c/n carrying moving coil is placed in the 3.1 magnetic field, which is produced by another current carrying fixed coil, a force is produced on the coil sides of the moving coil, due to which a deflection torque is produced & the moving coil deflects.

[deflection torque →
controlling torque →

② Now the deflection torque is controlled by the controlling torque which is produced by the springs.

② When the direction of c/n is reversed in both the coils during the -ve half cycle, while measuring the AC power the direction of deflection torque remains same & hence the dynamometer type of wattmeter is used for the measurement for both AC & DC power.

③ When the moving coil deflects, the pointer attached to the spindle moves over a graduated scale ~~& comes to rest~~ & it comes to rest when deflection torque is equal to controlling torque.

DC power meast.

Let V = voltage across the load

I_1 = load current

I_2 = c/n through the moving coil

$I_2 \propto V$

Since the fixed coil is air-cored, hence the flux density produced in the fixed coil is directly proportional to the current $\therefore B \propto I_1$ ——— ①

The deflection torque produced is given by

$$T_d \propto B I_2$$
$$\propto I_1 I_2$$
$$\propto I_1 V$$
$\propto$ power consumed by the load

$\therefore$ the deflection of the pointer due to the deflection torque T_d is proportional to power consumed by the load.

* Ac power measurement

Let v = instantaneous voltage across the load

i = " " c/n through the load

i_1 = " " " through moving coil

i_2 =

V = rms value of the voltage across the load

I_1 = " " " " c/n through the load.

$\cos\phi$ = pf of the load

If $v = V_m \sin \omega t$, & $i_1 = I_m \sin(\omega t - \phi)$

assuming the load is inductive

due to the inertia of the moving s/m, the deflection is proportional to the average torque.

$\therefore$ Avg deflection torque $\propto$ average value of $(i_1 \times i_2)$

$\propto$ " " " $(i_1 \times v)$

ie $v i_1 = V_m \sin \omega t \, I_m \sin(\omega t - \phi)$

$v i_1 = V_m I_m \cdot \frac{1}{2}[\cos\phi - \cos(2\omega t - \phi)]$

$i_1 = \frac{1}{2} V_m I_m [\cos\phi - \cos(2\omega t - \phi)]$

power is a scalar quantity hence only its average value must be considered.

The above ~~term~~ equation containg the two terms

i) $\frac{1}{2} V_m I_m \cos\phi$

ii) $-\frac{1}{2} V_m I_m \cos(2\omega t - \phi)$

~~$\sin 2\theta = 2\sin\theta \cdot \cos\theta$~~

~~$\sin\theta = \frac{1}{2} \sin\theta/2 \cos\theta/2$~~

$\sin a \cdot \sin b = \frac{1}{2} \cos(a-b) - \cos(a+b)$

$\sin\omega t \cdot \sin(\omega t - \phi)$

$= \frac{1}{2} \cos[\omega t - \omega t + \phi]$

$- \cos[\omega t + \omega t - \phi]$

$= \frac{1}{2} V_m I_m \cos\phi - \cos(2\omega t \phi$

The second term is periodically varying term & hence its average value over a period of time is zero.

$\therefore$ Average value of $(v \times i_1) = \frac{1}{2} V_m I_m \cos\phi$

$\Rightarrow = \frac{V_m}{\sqrt{2}} \cdot \frac{I_m}{\sqrt{2}} \cos\phi = V I_1 \cos\phi$ ——— (2)

$\therefore T_d \propto V I_1 \cos\phi$

However $V I_1 \cos\phi$ gives average power consumed by the load,

$\therefore T_d \propto \theta \propto V I_1 \cos\phi$ ——— (3)

At steady deflection $T_d = T_c$

From the equation (3) it is clear that the deflection of the pointer is proportional to the power consumed by the load.

* <u>Advantages</u>

1) Dynamometer type of wattmeter is used to measure both AC & DC power.

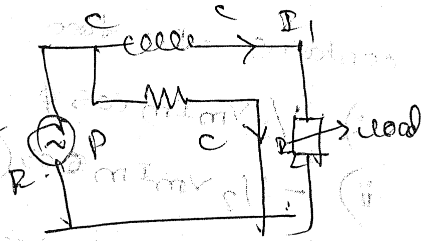
(2) They have a uniform scale

(8) They are accurate & reliable.

* **Disadvantages**

(1) At low power factor, the inductance of the potential coil causes the serious errors

(2) The reading of the meter is affected by stray magnetic fields acting on the moving coil.



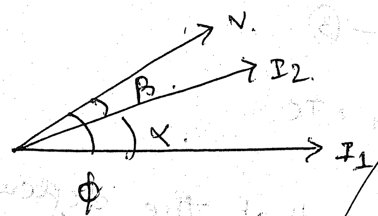
* **Attendance** — 1, 16, 22, 23, 32, 33

* **Errors in dynamometer wattmeter**

i) **Due to** the inductance of the pressure coil.

⟹ in a ideal wattmeter it is assumed that the pressure coil is purely resistive and the c/n through it i.e. I_2 which is in phase with the applied vtg. V.

However the pressure coil will have a small inductance L due to which c/n I_2 lags the applied voltage V by a small angle β as shown in the below fig.



where $\beta = \tan^{-1}\frac{\omega L}{R_2}$

Where $R_2 = r_2 + R$ = total resistance of the pc ckt.

r_2 = resistance of the pressure coil.

R = resistance in series with the pc.

I_1 = load c/n i.e. c/n through the c/n.

In such case, the actual wattmeter reading is given by.

Errors in dynamometer type of wattmeter - upR

i) Due to the inductance of the pressure coil :-

In an ideal wattmeter, it is assumed that the pc [37] is purely resistive, & the current through it is I_2, which is in phase with applied voltage. But However the pc will have small inductance L due to which the c/n I_2 lags the applied voltage V by a small angle β as shown.

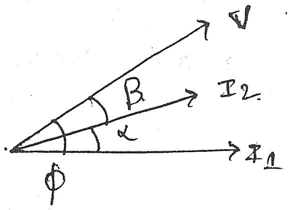


fig-a,

$\beta = \tan^{-1}\frac{\omega L}{R_2}$. Where $R_2 = R + r_2$ = total resistance of the pc ckt

r_2 = resistance of pressure coil

R = resistance in series with pc

I_1 = load current or c/n through the current coil

In such a case wattmeter reading is given by

$W_a = V I_1 \cos\beta \cos(\phi - \beta)$. —— (1)

The true power is given by

$W = V I_1 \cos\phi$ —— (2).

divide eqn (2) by (1).

$\therefore \frac{\text{True power}}{\text{Actual wattmeter reading}} = \frac{V I_1 \cos\phi}{V I_1 \cos\beta \cdot \cos(\phi-\beta)} = \frac{\cos\phi}{\cos\beta \cdot \cos(\phi-\beta)}$ = correction factor

$\therefore$ True power $= \frac{\cos\phi}{\cos\beta \cdot \cos(\phi-\beta)}$ × actual wattmeter reading.

$\therefore$ true power = correction factor × actual wattmeter reading

For leading power factor

correction factor $= \frac{\cos\phi}{\cos\beta \cdot \cos(\phi+\beta)}$

The errors due to small inductance of pressure coil can b reduced by connecting a suitable capacitor in parallel with a portion of resistance R.

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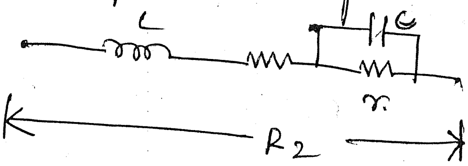


ii) Due to the capacitance of the pressure coil

⟹. The pressure coil of the circuit may have capacitance in addition to the inductance, The effect of this capacitance ~~may affect~~ on wattmeter is opposite to that of the inductance hence due to capacitance again wattmeter reads more lagging p.f of the load.

iii) Due to the mutual inductance.

Errors are introduced in the wattmeter due to the mutual inductance b/n the current coil & pressure coil of the wattmeter. These errors are very small at power frequency but at the ~~power~~ high frequencies they are more.

But Nowdays the arrangements of both cc & pc are done in such way that, they have zero mutual inductance & hence reduction in the errors.

iv). Due to the method of connection of cc & pc.

There are two methods of connecting a wattmeter in a ckt as shown below:

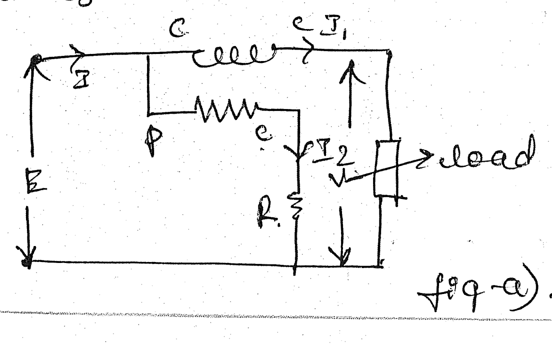


fig-a).

As shown in the above fig the pressure coil is connected on the supply side. ∴ The voltage applied to the pressure coil is the sum of the voltage across the load + the voltage drop across the current coil.

Thus the wattmeter reads the sum of power consumed by the load & the power loss in the c/n coil.

∴ power indicated by the wattmeter = power consumed by the load + power loss in the current coil

= power consumed by the load + $I_1^2 R_1$

where R_1 = resistance of the c/n coil.

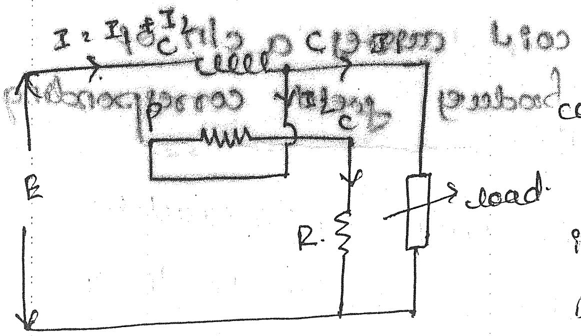


fig-b

As shown in the fig (B) the current coil is connected on the supply side. ∴ the c/n through the current coil is the sum of c/n through the load & current through the pc i.e. $I = I_1 + I_2$.

Hence the wattmeter reads the sum of power consumed by the load & power loss in pressure coil.

∴ power indicated by the wattmeter = power consumed by the load + power loss in pc

= load + V^2/R_2

V = vtg across load & R_2 = resistance of pc ckt.

Note - 1) If the load current is small then voltage drop in the current coil is small & it gives small error in the wattmeter reading hence fig a is considered for the
40 coil connection.

2.) If the load cln is large the cln in the pc ie I_2 is very small compared to load cln I_1 hence power loss in the pressure coil is reduced & hence fig (B) is taken

Finally instead of these two connection one more connection is preferred using compensating coil as shown below.

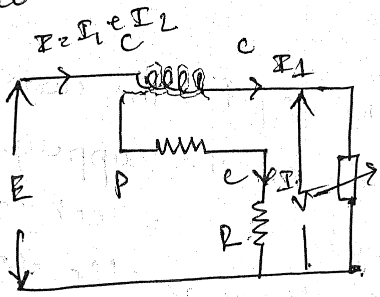


fig-C

① as shown in the above figure the cln coil carries a cln of I = $I_1 + I_2$ & produces field corresponding to the cln.

② The compensating coil is exactly similar to the cln coil which is connected in series with the pc. but carries a current of I_2. in such direction ie it should produce the field which is exactly opposite to the field produced by I_2 through current coil.

③ ∴ the field produced by I_2 through current coil is compensated by the cln I_2 flowing through the compensating coil therefore the resultant field is produced just with the help of I_1,

④ now the error caused is just by pressure coil cln I_2 which is flowing through the current coil. & wattmeter directly reads power consumed by load.

Eddy current errors.

34 eddy currents are ~~[illegible]~~ induced in the solid metal parts & within the thickness of the conductors of the c/n coil when the wattmeter is used for the meas of power in ac cir.

These eddy currents will produce the field of their own & alter the magnitude & phase of c/n through the current coil & they cause errors.

Due to these errors the wattmeter reads low for lagging power factor & high for leading power factor.

In order to reduce these errors care must be taken while construction of wattmeter such that no metal parts are to be used & stranded conductors are used for the c/n coil.

* Stray magnetic effects.

The dynamometer wattmeter has a relatively a weak operating field which is affected by the stray magnetic effects. Hence the wattmeters must be shielded to avoid stray magnetic effects.

* errors due to the vibration of moving s/m.

The torque on the moving s/m of a wattmeter varies with the natural frequency which is two times the frequency of supply voltage. Again if the pointer, spring or any other moving parts s/m have a natural frequency which is equal to the frequency of the torque of the moving sim, due to which the pointer vibrates & we may not read 33 the deflection on scale properly that guly again the errors are introduced.

This can be avoided just by selecting the natural frequency just away to the supply frequency.

* Temperature effects. ⇒ The wattmeter reading is affected due to the change in temperature. Any change in temp changes the resistance of pressure coil & the stiffness of the springs. The errors caused by these two effects are opposite to one another & nearly neutralise each other.

Low power factor wattmeter.

As we know there are certain errors while measuring the power from dynamometer type of wattmeter such as

1) at the low power factor the inductance of the pressure coil introduces the errors.

2. The deflecting torque on the moving sim is low even though when both current coil & pressure coil are fully excited.

Hence special features are introduced in the dynamometer type of wattmeter when they are used to measure the power in circuits at low power factor. They are as follows →

∴ ~~There value is~~ ~~expression~~.

* Special features of LPF dynamometer wattmeter

i) pressure coil circuit

The pc of the ckt are designed in such a way that they must have low resistance & hence the current flowing through the pc is increased to produce an increased operating torque

The resistance of the pc ckt in LPF wattmeter must be ~~less~~ 10 ~~times~~ less than ~~that~~ used in UPF wattmeter to produce reasonable deflecting torque.

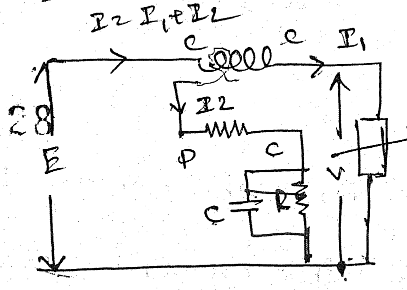
ii) compensation for pressure coil current

The power measured in low power factor ckts is small & the c/n through the current coil is high hence the connection as shown in fig (a) cant be used, because due to high c/n the power loss in the c/n coil is higher & wattmeter gives error in reading.

Again in case of fig (B). the power loss in the pressure coil is also includes the power loss in the c/n coil the wattmeter reading again shows error. hence it is necessary to compensate the effect of pressure coil c/n by compensating coil in series with pressure coil as shown in fig c

~~1, a, b, c, d, e, f, g, h, i, j, k, l~~ — ~~Morning~~ class

iii) compensation for the inductance of pc



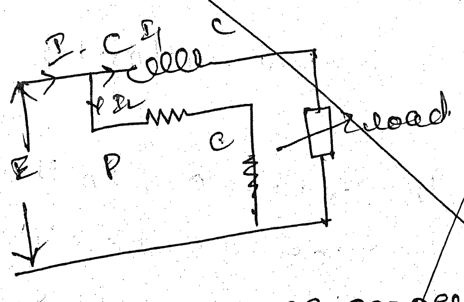
The error caused by pc inductance is given by $EI_1 \sin\phi \tan\beta$. If the pf is low, the value of ϕ becomes much more larger, & the error is more.

→ This error can be compensated just by connecting a capacitor of capacitance c in ||el with the part of resistance.

iv) Small control torque :- ~~Low~~ LPF wattmeters are designed to have a low control torque, hence they give full scale deflection for lpf = 0.1.

* Given c/n of Resistance $R_1 = 0.2\Omega$ & pc R is $R_2 = 5000\Omega$

Load is 20A, V = 250V, pf = 0.8



⟹ when pc is connected on supply side.

power consumed by the load $VI_1\cos\phi = 250 \times 20 \times 0.8$

$= 4000$ watts

power loss in c/n coil $= I_1^2 R_1 = 20^2 \times 0.2 = 80$ watts

% error $= 80/4000 \times 100 = 2\%$

1

* A Wattmeter has a current coil of resistance 0.2 Ω and a pressure coil of resistance 5000 Ω is connected to measure the power consumed by the load. Calculate the % error in the reading of the wattmeter, when the load takes 20A at 250V with 0.8 pf, when i) the pc is connected on the supply side and ii). When the current coil is connected on the supply side iii) What load c/n would give equal errors with the two connections

⇒ i) When the pc is connected on the supply side.

power consumed by the load $= VI_1\cos\phi = 250 \times 20 \times 0.8$

$= 4000$ Watts.

power loss in the current coil $= I_1^2 R_1 = 20^2 \times 0.2 = 80$ Watts

$\%\ \text{error} = \dfrac{80}{4000} \times 100 = 2\%$

ii) When the current coil is connected on the supply side

power loss in the pc $= V^2/R_2 = \dfrac{250^2}{6000} = 12.5\ W$

$\%\ \text{error} = \dfrac{12.5}{4000} \times 100 = 0.3125\%$

iii) For equal errors with two ~~wattmeters~~ connections.

$I_1^2 R_1 = V^2/R_2 \qquad I_1 = \sqrt{\dfrac{V^2}{R_1 R_2}}$

$= \sqrt{\dfrac{250^2}{0.2 \times 5000}} = 7.906\ A$

* A Wattmeter is connected to measure the power consumed by a load, which draws a current of 20A at 250V. The pf of the load ~~Thre~~ is 0.8 lagging. The cc has an impedance of $(0.08 + j0.04)\ \Omega$. The

resistance of the pc circuit is 6000 Ω. Find the error in the reading of the wattmeter for its two possible connections to measure the power.

⟹ Given load draws a current of 20A at 250V

pf = 0.8 , CC Resistance = 0.08 Ω , The R_2 of pc = 6000 Ω

i) When pressure coil is connected on supply side.

∴ power consumed by the load $P = VI\cos\phi$

$= 250 \times 20 \times 0.8$

$= 4000\,W$

power loss in the current coil

$= I_1^2 R_1 = 20^2 \times 0.08 = 16$ Watts

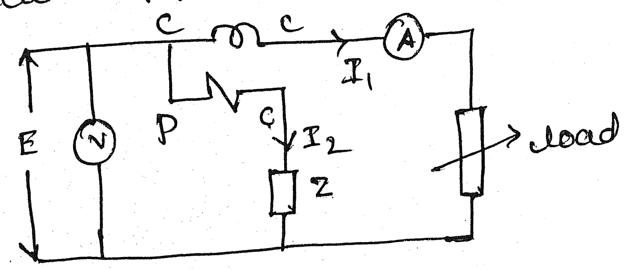
∴ % error $= \frac{16}{4000} \times 100 =$

ii). power loss in the pressure coil $= V^2/R_2 = \frac{250^2}{6000} = 10.42$

% error $= \frac{10.42}{4000} \times 100 =$

* A Wattmeter is connected to read the power consumed by an inductive load reads 25 W. The voltmeter connected across the supply and the pc circuit reads 250 V. The ammeter connected in series with the cc and the load reads 5A. The impedance of pc circuits is (2000 +j6) Ω. The voltage drops across the ammeter and voltmeter are neglected. Find the % error in the wattmeter reading.

⟹



phase angle of the pressure coil circuit is given by

$\beta = \tan^{-1} X_2/R_2 = \tan^{-1} 6/2000 = 0.172°$

True power $= I_1^2 R_L = I_1^2 Z_L \cos\phi$

Where Z_L = impedance of the inductive load

ϕ = pf angle of the load

$Z_L = \frac{V}{I_1} = E/I_1 = \frac{250}{5} = 50\Omega$

∴ True power $= 5^2 \times 50 \times \cos\phi = 1250 \cos\phi$.

True power $= \frac{\cos\phi}{\cos\beta \cdot \cos(\phi - \beta)}$ × wattmeter reading

ie $1250 \cos\phi = \frac{\cos\phi}{\cos\beta \cdot \cos(\phi - 0.172°)}$ $= 0.02$

$\phi - 0.172° = 88.854°$ ∴ $\phi = 89.026°$ ~~= 21.248 watt~~

∴ % error $= \frac{W_i - W_a}{W_a} \times 100$

$= \frac{25 - 21.248}{21.248} \times 100$

$= 17.658\%$

* Measurement of Real & reactive power in case of 3-ϕ ckts

1) Three-phase Wattmeter method [4th unit - PART A]

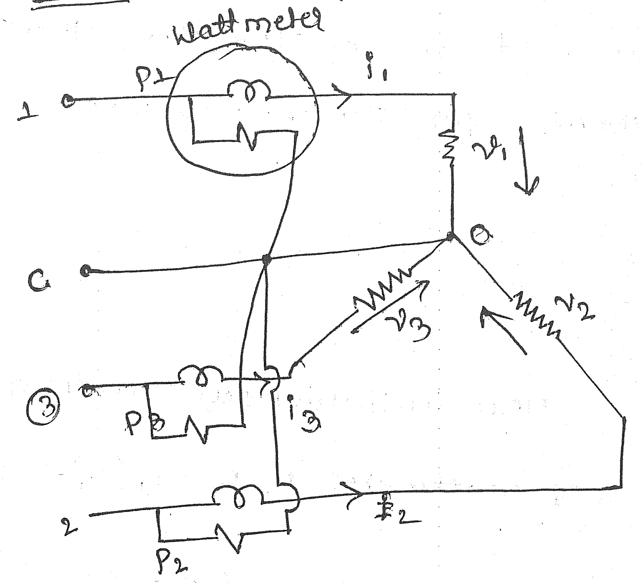


fig - three wattmeter method for a meast of power in 3 phase 4 wire circuit.

The above fig shows 3 wattmeter method for the meast of power in 3phase 4 wire circuit. in which the comman point C is of pressure coils & the netural is O point at which load coinside.

$\therefore$ $v = 0$ & $v_1 = v_1'$, $v_2 = v_2'$, $v_3 = v_3'$

Now sum of the instantenous readings of watt-meters is $p = P_1 + P_2 + P_3 = v_1 i_1 + v_2 i_2 + v_3 i_3$

instantenous power load $= v_1 i_1 + v_2 i_2 + v_3 i_3$

$\therefore$ Three wattmeters are used to measure the power of load.

* **Two - wattmeter method :-** In 3-phase ~~system~~, 3 wire system

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require three elements, but if we make the common points of the pressure coils coinside with one of the lines then we require only $n-1 = 2$ elements for the measurement.

* Star - connection

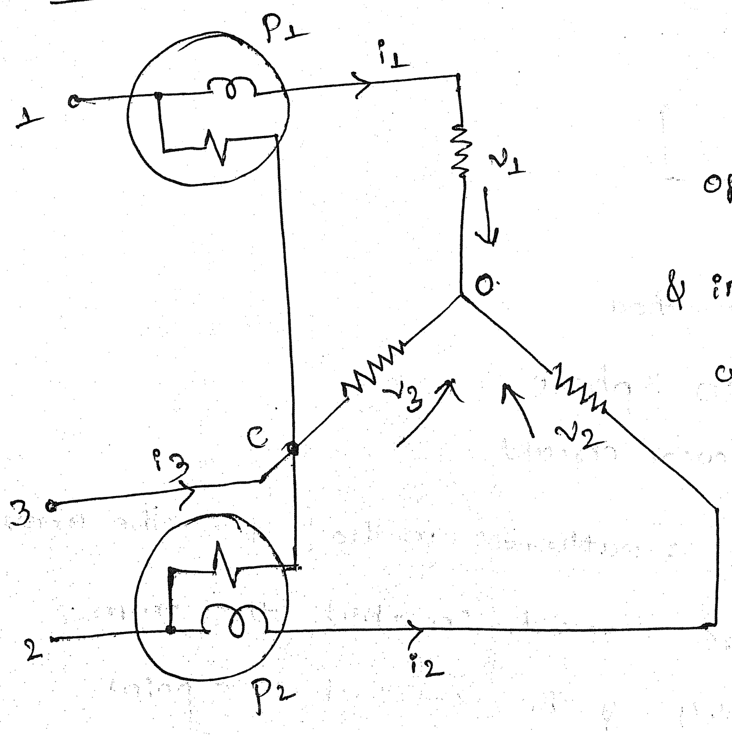

fig-a) two - wattmeter method (Star - connection)

Now instantaneous reading of wattmeter 1, $P_1 = i_1(v_1 - v_3)$

& instantaneous reading of wattmeter 2 is

$P_2 = i_2(v_2 - v_3)$

Now sum of instantaneous reading of both the wattmeters is

$p = P_1 + P_2$

$= i_1(v_1 - v_3) + i_2(v_2 - v_3)$

$= i_1 v_1 - v_3 i_1 + i_2 v_2 - i_2 v_3$

$= v_1 i_1 + v_2 i_2 - v_3(i_1 + i_2)$

Now from kirchoff's current law (KCL) $= i_1 + i_2 + i_3 = 0.$

& $i_1 + i_2 = -i_3.$

∴ sum of instantaneous power becomes

$p = v_1 i_1 + v_2 i_2 - v_3(-i_3) = v_1 i_1 + v_2 i_2 + v_3 i_3$ //

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∴ Sum of instantaneous power two wattmeter reading is equal to the power consumed by the load & Here the load may be balanced or unbalanced.

* Two wattmeter method (Delta connection)

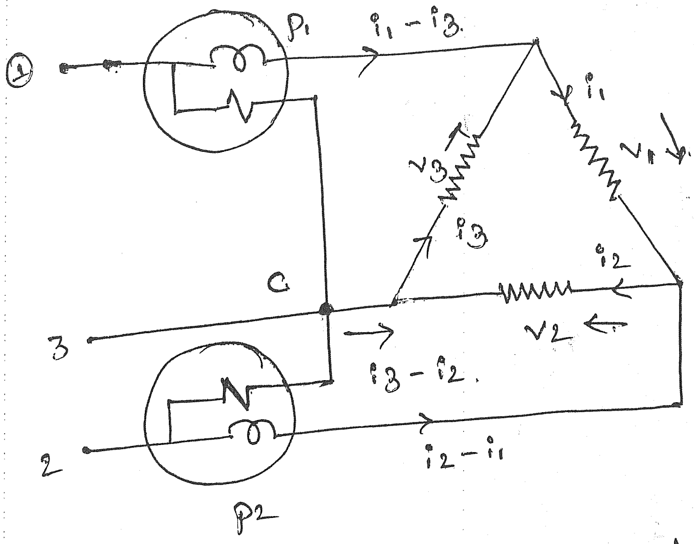

fig - two wattmeter method (Delta connection)

from the above fig, instantaneous reading of wattmeter 1 is $P_1 = -v_3(i_1 - i_3)$

for wattmeter 2 $P_2 = v_2(i_2 - i_1)$

∴ sum of the instantaneous readings of wattmeter P_1 & P_2

$$\therefore P_1 + P_2 = -v_3(i_1 - i_3) + v_2(i_2 - i_1)$$

$$= -v_3 i_1 + v_3 i_3 + v_2 i_2 - v_2 i_1$$

$$= v_2 i_2 + v_3 i_3 - i_1(v_2 + v_3) \quad \text{—— ①}$$

From the kirchoff's voltage law $v_1 + v_2 + v_3 = 0$

$\therefore v_2 + v_3 = -v_1$

∴ equation ① becomes $P_1 + P_2 = v_2 i_2 + v_3 i_3 + v_1 i_1$ —— ②

∴ the sum of two wattmeter readings is equal to the power consumed by the load. & this is irrespective of whether the load is balanced or unbalanced.

* Now let us consider the phasor diagram for a balanced star connected load as shown below.

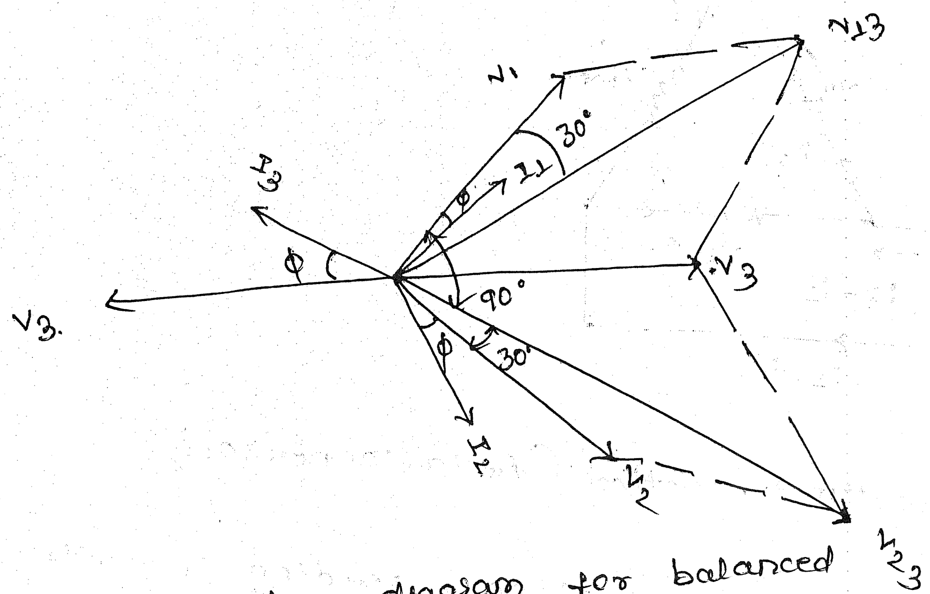

fig - phasor diagram for balanced star connected load.

The above fig shows the phasor diagram for balanced star connected load.

The load is balanced

∴ phase voltages $V_1 = V_2 = V_3 = V$ —— (1)

Line voltages $V_{13} = V_{23} = V_{31} = \sqrt{3}V$ —— (2)

phase currents $I_1 = I_2 = I_3 = I$ —— (3)

Line currents $I_1 = I_2 = I_3 = I$ —— (4)

power factor is $\cos\phi$.

∴ The phase currents lag the corresponding phasor voltages by an angle ϕ.

Now reading of wattmeter 1, $P_1 = V_{13} I_1 \cos(30° - \phi)$

$$= \sqrt{3}\, VI \cos(30° - \phi) \quad \text{—⑤}$$

reading of wattmeter ②, $P_2 = V_{23} I_2 \cos(30° + \phi)$

$$= \sqrt{3}\, VI \cos(30° + \phi) \quad \text{—⑥}$$

Sum of two wattmeters $P = P_1 + P_2$

$$= \sqrt{3}\, VI \left[\cos(30° - \phi) + \cos(30 + \phi)\right]$$

$$= \sqrt{3}\, VI \cos\phi$$

this is the power consumed by the load

$$P = P_1 + P_2.$$

$$\text{P.f} = \cos\phi = \cos\left[\tan^{-1} \sqrt{3}\, \frac{(P_1 - P_2)}{P_1 + P_2}\right]$$

* one wattmeter method.

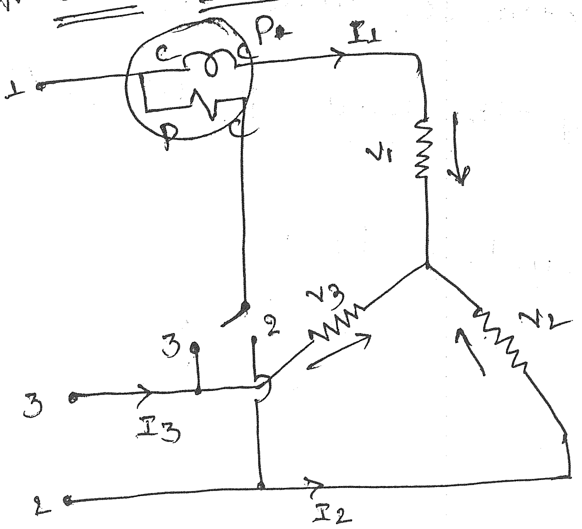

fig -a) one wattmeter method

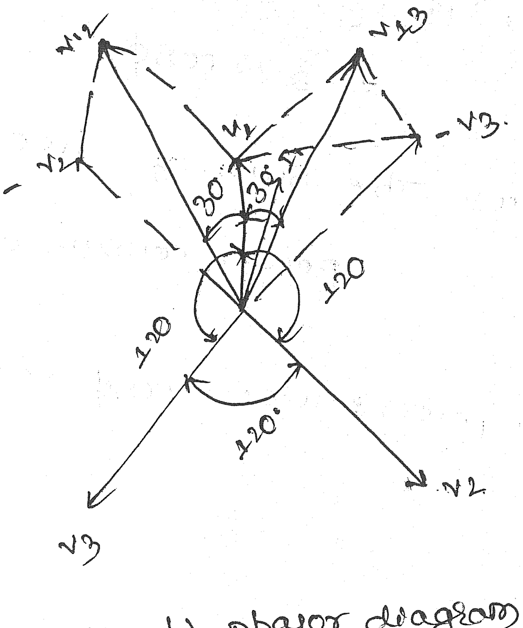

fig -b). phasor diagram of one wattmeter method

This method is used only when the load is balanced.
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as shown in the above fig the current coil is connected in one of the line, & one end of the pressure coil is connected to the same line, & other end is connected alternately to the other two ~~ends~~ lines.

We have $V_1 = V_2 = V_3 = V$ & $I_1 = I_2 = I_3 = I$.

& $V_{13} = V_{12} = \sqrt{3} V$.

Reading of wattmeter when switch at 3.

$P_1 = V_{13} I_1 \cos(30° - \phi) = \sqrt{3} VI \cos(30 - \phi)$ —— (1)

Now reading of wattmeter when switch is at (2)

$P_2 = V_{12} I_1 \cos(30° + \phi) = \sqrt{3} VI \cos(30 + \phi)$ —— (2)

Sum of the two wattmeter readings

$P_1 + P_2 = [\sqrt{3} VI \cos(30 - \phi) + \sqrt{3} VI \cos(30 + \phi)]$

$= 3 VI \cos\phi$

Thus the sum of two wattmeter readings = power consumed by the load $P = P_1 + P_2$.

& power factor $\cos\phi = \cos\left[\tan^{-1} \sqrt{3} \frac{P_1 - P_2}{P_1 + P_2}\right]$ //.

* Reactive power measurement in 3-φ circuits.

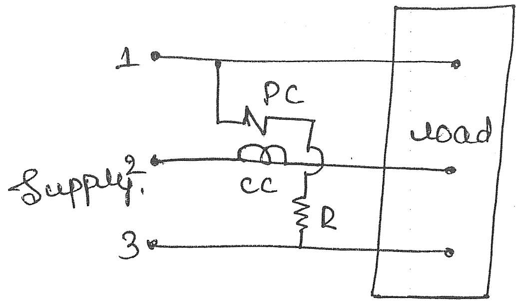

fig-a) Reactive power measurement with one wattmeter.

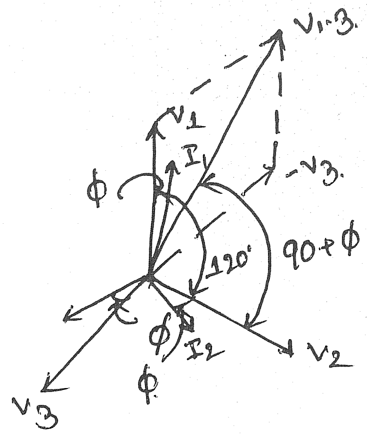

fig-b) phasor diagram

In case of balanced three phase circuits, it is simple to use a single wattmeter to read the reactive power.

→ as shown above the current coil of the wattmeter is connected in one line & the pressure coil is connected across two lines as shown above.

current through the current coil = I_2

voltage across the pressure coil = V_{13}

∴ Reading of Wattmeter $= V_{13} I_2 \cos(90+\phi)$

$= \sqrt{3}\, VI \cos(90+\phi)$

$= -\sqrt{3}\, VI \sin\phi$

Total reactive volt amperes of the circuit

$Q = 3 VI \sin\phi$

$= (-\sqrt{3}) \times$ Reading of wattmeter

phase angle $\phi = \tan^{-1}(Q/P)$

* Induction type of 1-φ energy meter.

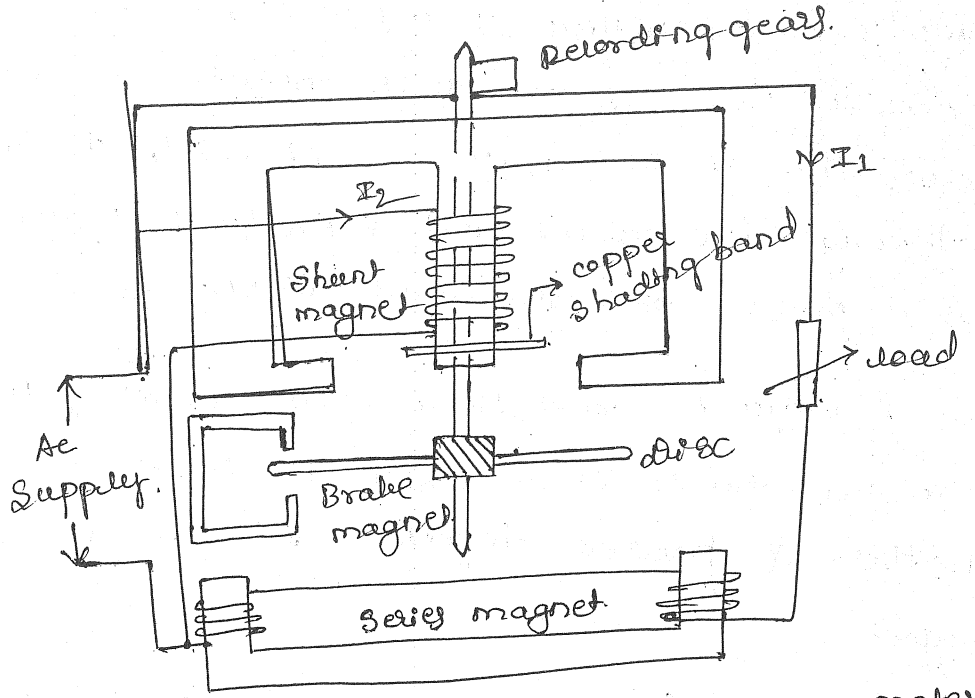

fig - Induction type of 1-φ energy meter.

(1). The above fig shows the Induction type 1-φ energymeter. Induction type of instruments are used to measure the only for AC measurements, hence Induction type 1-φ energy meter is used to measure energy consumed in AC ckt.

* construction

An Induction type of 1-φ energy meter mainly consisting of. i) a driving System ii) a moving system iii) a braking system iv) a recording mechanism.

* A driving System.

A driving System mainly consists two magnets
i) series magnet & Shunt magnet.
As shown in the above the series magnet contains

u shaped laminations of silicon steel, which are insulated from one another & pressed together to form a core.

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* A coil of thick wire consisting of a few turns ~~are~~ is wound on both the legs of core & is connected in series with the load; this is known as current coil. The load c/n I_1 flows through the current coil & produces a flux of ϕ_1 which is in phase with the load current I_1.

* Again a shunt magnet consisting of a number of m shaped silicon steel laminations which are insulated from one another & pressed together to form a core of shunt magnet.

* A coil of thin wires, having large number of turns is wound on the central limb of the shunt magnet. This is known as voltage coil or potential coil. & it is connected across supply. It is excited by c/n I_2 which is proportional to the applied voltage.

In order to obtain the deflecting torque, the c/n in the pc must lag the applied voltage by 90°, to achieve this copper ring is provided on the central limb of shunt magnet.

The shunt magnet produces a flux of ϕ_2 due to the c/n I_2, flowing through the coil & it is proportional to the applied voltage & in quadrature with the applied voltage.

ii) The moving System

The moving system contains light aluminium disc, mounted on the Spindle. The aluminium disc is placed in the airgap b/n the series magnet & Shunt magnet.

* due to the absence of control torque the disc continuously rotates under the action of deflecting torque which is produced due to the resultant magnetic field.

iii) Braking System

A permanent magnet, known as brake magnet is placed near to aluminium disc. when aluminium disc rotates under the influence of magnetic field produced by the brake magnet & induced emf in disc, the eddy currents will circulate in the disc in such a way that the torque produced will oppose the rotation of disc.

[* The eddy currents induced in the disc are proportional to the speed of disc, & hence the braking torque exerted on the mle is proportional to the speed.]

* The position of brake magnet can be adjusted hence the braking torque is also adjusted.

iv) Recording mechanism

The main function of Recording mechanism is to record the number of revolutions made by the disc.

* Working principle

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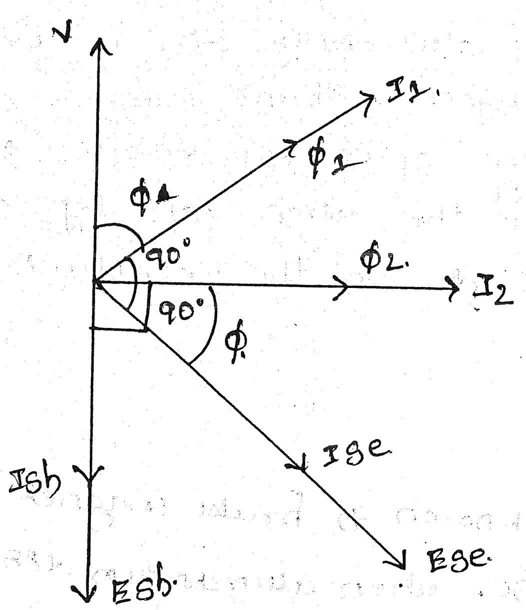


fig - phasor diagram.

1) Initially the energy meter is connected to a supply voltage, due to supply current I_2 flows in the pc & produce a flux of ϕ_2.

2) As potential coil is inductive in nature current I_2 lags the supply voltage V by an angle of 90°.

3) When the energy meter is connected to as load, a load current I_1 flow through the cln coil due to which a flux ϕ_1 is produced.

(8) The phase angle b/n the voltage & load current I_1 depends on the nature of load. If the load is inductive cln I_1 lags the voltage by an angle ϕ.

(v) due to shunt magnet flux ϕ_2 & series magnet flux ϕ_1 the emfs Esh & Ese are gets induced in the disc repectively.

The two emf E_{sh} & E_{se} lag the corresponding fluxes ϕ_2 & ϕ_1 by an angle of 90°.

The eddy currents I_{sh} & I_{se} are set up by the induced emf & they are assumed to be in phase with their respective emfs. due to these eddy currents two opposite torques are produced, one due to flux ϕ_2 & I_{se} & other torque due to flux ϕ_1 & I_{sh} etc. The difference b/n these two torque will drive the disc & disc starts rotating.

*Theory → the torque produced is given by

$$T_d \propto \phi_2 I_{se} \cos\phi - \phi_1 I_{sh} \cos(180-\phi)$$
$$\propto \phi_2 I_{se} \cos\phi + \phi_1 I_{sh} \cos\phi$$
$$\propto k_1 V I_1 \cos\phi + k_2 V I_1 \cos\phi$$
$$\propto V I_1 \cos\phi \, (k_1 + k_2)$$
$$\propto V I_1 \cos\phi$$
$\propto$ power consumed by the load.

But $T_b \propto N$. For steady speed $T_d = T_b$.

$\therefore N \propto$ power or $N \times t \propto$ power $\times t$.

power × t represents the power consumed in t seconds & N × t — represents the number of revolutions made by the disc.

Finally the speed of disc can be adjusted by suitably varying the position of brake magnet such that, the energy consumed by the load is equal to the energy supplied, this is called as calibration of energymeter.

* **Errors in single phase energymeter.**

The errors are mainly caused due to i) driving s/m ii) braking system.

errors caused by the driving s/m are.

1) **Incorrect magnitudes of fluxes**

Incorrect magnitudes of fluxes are mainly due to abnormal current & voltages. The error in the shunt coil flux is due to the changes in the resistance of pressure coil ckt & due to abnormal frequencies

2) **Incorrect phase angles** :- incorrect phase angles are mainly due to improper lag adjustments, abnormal frequencies & due to the change in resistance due to temperature variation.

3) **Lack of symmetry in magnetic ckt**

If the magnetic ckt is not symmetrical then a driving torque causes the energy meter to creep.

[creeping → In some energy meters the disc rotates eventhough their is no flow of c/n through the current coil is known as creeping]

* **The errors caused by braking s/m are.**

The errors caused by the brake magnet.

i) change in the strength of the brake magnet

ii) change in disc resistance

iii) self-braking effect of series coil flux

iv) abnormal friction of the moving parts.

[

[friction is defined as → ~~2~~, 4, 14, 23, ~~30~~, 33, 36, 42, 62, 69].

* Adjustments in 1-φ energymeter

When the energymeter is used for the measurement of energy consumed in the circuit, then it is necessary to make the certain adjustments in the meter, ∴ the energymeter should give the energy consumed correctly & error must be within allowable limits ±5%.

The adjustments made in the energymeter are →

i) preliminary light load adjustments.

This type of adjustment is done on the energy-meter to check whether the energy meter creeps or not. to check this the holes of disc are positioned in such way that, the holes are not under the influence of the series magnet. The rated voltage is applied across the pc & there is no c/n flowing through the current coil. The light load device is adjusted till the device should stop the rotating.

ii) Full load upf adjustment

In this case the pressure coil is connected across the rated supply voltage, where as rated current is passed through the current coil at upf. The position of brake magnet is adjusted such that the light aluminium disc should rotate at correct speed within the required limits of error.

iii) Lpf adjustment :- Again here the pressure coil is connected across the rated supply voltage, & rated c/n is passed through the current coil at 0.5 pf lagging. However the lag device is adjusted till the disc rotates at correct speed.

iv) Light load adjustment :- in this case a rated supply voltage is applied across the pressure coil & a very small c/n i.e about 5% of full load c/n is passed through the c/n coil at upf, the light load is adjusted in such a way the disc rotates at correct speed.

v) creep adjustment :-

to make the creep adjustment the pc is excited by 110% of rated voltage with zero load current. If the light load adjusted is correct then the meter will not creep.

* Calibration of 1-ϕ Energy meter. *

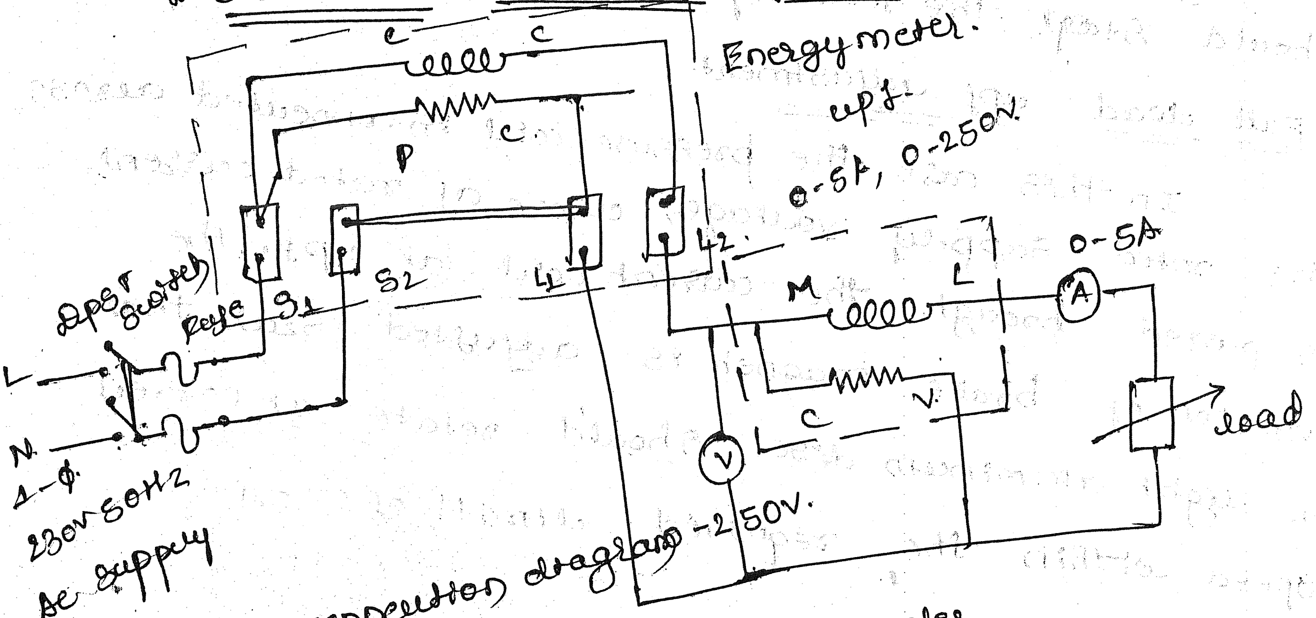


fig - connection diagram of calibration of energymeter.

The above fig shows connection diagram for the calibration of energymeter. Before the energymeter is used for the measurement of energy in any ckt, it has to be calibrated (checked), so that the indicated energy E_i is approximately equal to the actual energy consumed E_a. 39

* procedure for calibrating the energymeter is as follows

1. The connections are made as per the above circuit diagram
2. keep the load switch open & supply switch is closed.
3. Now the pc is energised & their is no current in the current coil, observe the disc, if disc is not rotating then their is no creeping, or else if the disc is rotating then the light load device is adjusted till the disc stops rotating.
4. Now the load switch is closed & a small current ie 5% of the full load current is made to flow through the current coil.

the load is considered as lamp load which is purely resistive, the pf of load is unity.

The readings of ammeter, voltmeter, wattmeter & time taken by the disc to make the revolutions is noted.

The wattmeter constant is calculated by using the formula.

$$\text{Wattmeter constant } k = \frac{V\text{ range} \times \text{current range} \times p.f.}{\text{full scale deflection of wattmeter}}$$

Now the actual energy consumed by the load is given by $E_a = W \times k \times t / 3600 \times 1000$ kWH —(1)

The energy indicated by the energymeter is given by

40 $E_i = D/E_k$ kWH ——(2)

Where E_k = is the constant of energymeter in revolution/kwH

Which is mentioned on the name plate of energymeter.

[ie 700 rev/kwH, 1000 rev/kWH etc)

$$\% \text{ error} = \frac{E_i - E_a}{E_a} \times 100 \quad \text{——(3)}$$

If the %error is less than ±5% low load pf adjustment is not required. If the % error is more than ±5%, then the load adjustment is done, until the %error ~~really~~ reduces to ±5%.

(5). Now, the load is gradually applied, till the load cln flowing through the cln coil. again the % of error is calculated by along above steps. If the error is less than ±5% then no adjustment is required, if it is more then the position of brake magnet is adjusted till the error reduces to less than ±5%.

finally energy meter is calibrated & used for the measurement of energy consumption.

* Electronic energymeter

~~An electronic energy meter extensively uses integrated circuits for its operation.~~

~~The block diagram is as shown below.~~

* Electrodynamometer type of 1-ϕ pf meter.

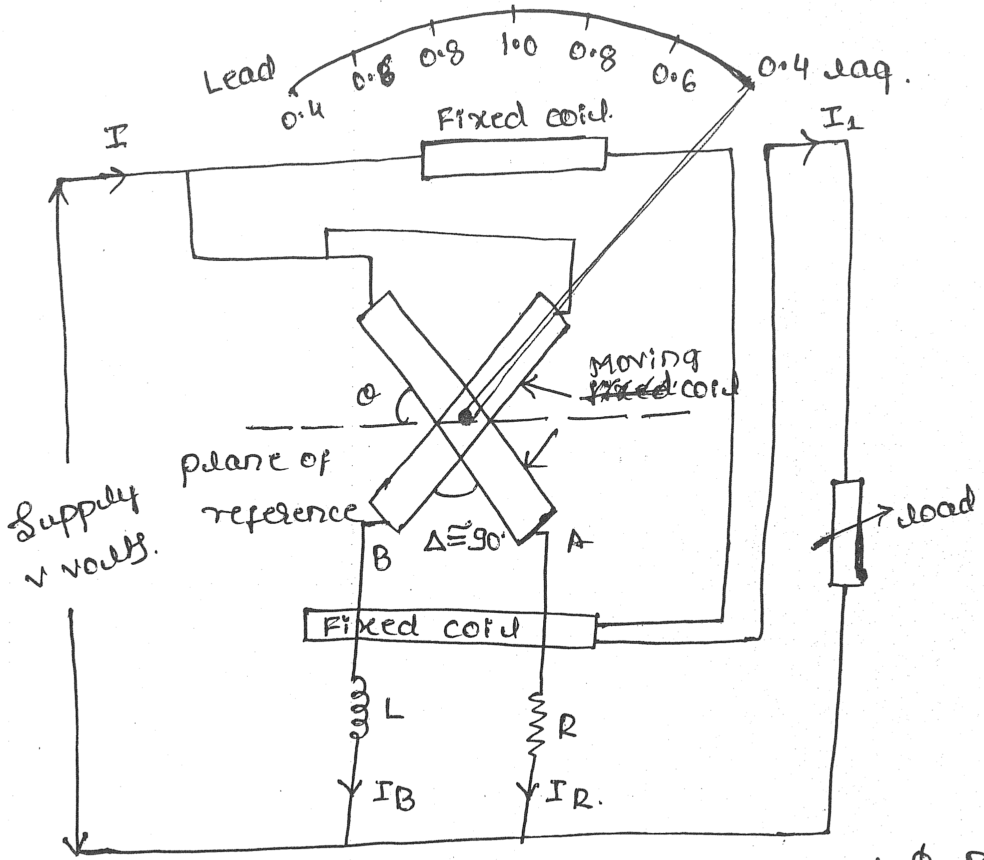


fig - Electrodynamometer type of 1-ϕ pf meter.

① The above fig shows the construction of electro-dynamometer type of 1-ϕ pf meter.

② It consisting of a current coil which is in the form of two fixed coils, which is connected in series with load & carry a current of I amps. However the magnetic flux produced by the current coil is directly proportional to load current

③ Again it consisting of two pressure coils A & B which are fixed to a spindle & they will form the moving system of pf meter.

④. As shown in the above fig A non inductive resistance R is connected in series with coil A

& a high inductive choke L is connected in series with pressure coil Both the pressure coils are connected across the supply voltage.

(5) The values of R & L are adjusted in such a way that both the coils should carry a same current at normal frequency ie $R = \omega L$.

(6) The current through the pressure coil A is I_A which is in phase with the applied voltage, while the c/n through the pressure coil B is I_B, which lags the applied voltage by an angle of Δ which is approximately equal to 90°

(7) However the angle b/n both the pressure coils A & B are also adjusted to an angle Δ, No controlling torque is required provided in the instrument.

(8) The connections of moving coils are made with the help of silver or gold ligaments, which are flexible in nature. & they offer minimum controlling torque on the moving system.

* **Working principle** :- When the supply is given to the terminals of pf meter, two deflecting torques are produced, one is acting on coil A & other is acting on coil B. The windings of these two coils are arranged in such a way that torques acting on both the coils must have opposite direction. The moving system starts deflecting due to the difference b/n these two torques & it shows reading when both the torques become equal & at this

pointer indicates the p.f of the ckt on calibrated scale.

Theory of operation

Let us assume that pf of the circuit is cos ϕ, which is lagging. The phasor diagram for the pf meter connection is as shown below.

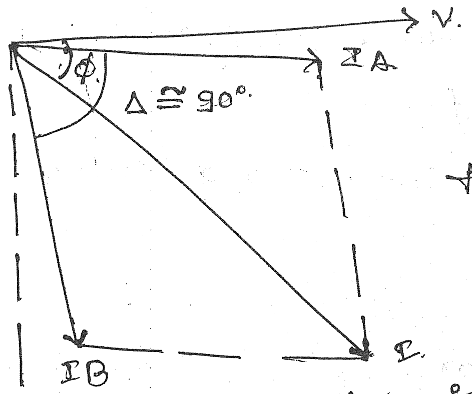


fig- phasor diagram

For the sake of simplicity, it is assumed that the angle Δ ≅ 90° & the angle b/n the two pressure coils is also assumed as 90°. The deflecting torque on coil A is given by.

$T_A = kVIM_{max} \cos\phi . \sin\theta$. —— (1)

where k = a constant V = applied voltage.

I = load current = Supply current

M_{max} = maximum value of the mutual inductance b/n the coils A & B.

θ = angular deflection of coil A from the plane of reference

ϕ = p.f angle.

Let us consider the torque T_A act in the clockwise direction. The deflecting torque on coil B is given by $T_B = kVIM_{max} \cos(90-\phi) \sin(90+\theta)$

$= kVIM_{max} \sin\phi \cos\theta$ —— (2)

Now the torque T_B acts in anticlockwise direction. Therefore due to the action of two oppositely directed torques the moving slm comes to rest at position when both the torques are equal.

Hence at equilibrium $T_A = T_B$.

$\therefore KVI M_{max} \cos\phi \sin\theta = KVI M_{max} \sin\phi . \cos\theta$

or $\cos\phi . \sin\theta = \sin\phi . \cos\theta$

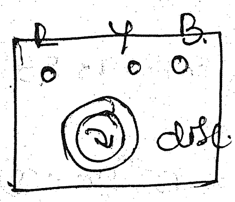
or $\theta = \phi$.

$\therefore$ The deflection of the moving system gives the phase angle of the circuit.

* phase sequence indicator.

The phase sequence of a three phase supply is the order in which the maximum values of the phase voltages V_R, V_Y, V_B occur during their operation. The phase sequence of 3-ϕ supply can be either RYB or RBY. During the synchronization of two different 3-ϕ AC supplies their phase sequences have to be same. $\therefore$ a phase sequence indicator is used during synchronization. There are two types i) Rotating type ii) static type.

* Rotating type of phase sequence indicator.



the principle of working of these meters is same as 3-ϕ IM. The appearance of Rotating type of phase sequence indicator is as shown above. It consists of three coils which are mounted on 120° apart in space. The three ends of coils are brought out & connected to RYB terminals of the meter. 39

② The three coils are connected in star fashion & excited by the 3-ϕ supply, whose phase sequence is to be determined.

③ When the supply is given to the three coils, a rotating magnetic field is produced, due to which an emf is gets induced in the disc which circulates the eddy currents in the disc.

④ Finally the eddy currents interact with the rotating magnetic field & a torque is produced due to which disc starts rotating in a particular direction. The direction of rotation of the disc indicates the phase sequence of the supply.

⑤ An arrow is marked on the disc which indicates the direction of rotation. If the direction of rotation is same as mentioned on the disc then the phase sequence is same as the terminals of RYB. If the disc rotates in the opposite direction ie anti-clockwise direction, the phase sequence of supply must be RBY

* Weston frequency meter *

① The above fig^n shows constructional details of weston frequency meter. It consists of two coils A & B. which are mounted perpendicular to each other & Each coil is divided into two sections.

⑥ ⑤. ~~20~~, 21, 22, 23, 31, 35, 63, 70, → 22/09/14

(2) A resistance RA is connected in series with coil A & a inductance LB is connected in series with coil B.

(3) An inductance LA is connected in parallel with coil A & a resistance RB is connected in parallel with coil B. However the moving system is a soft iron needle

(4) There is no controlling force. L is a series reactance coil which is used to supress the harmonics in the ckt, which is flowing through the meter, thereby reducing the errors

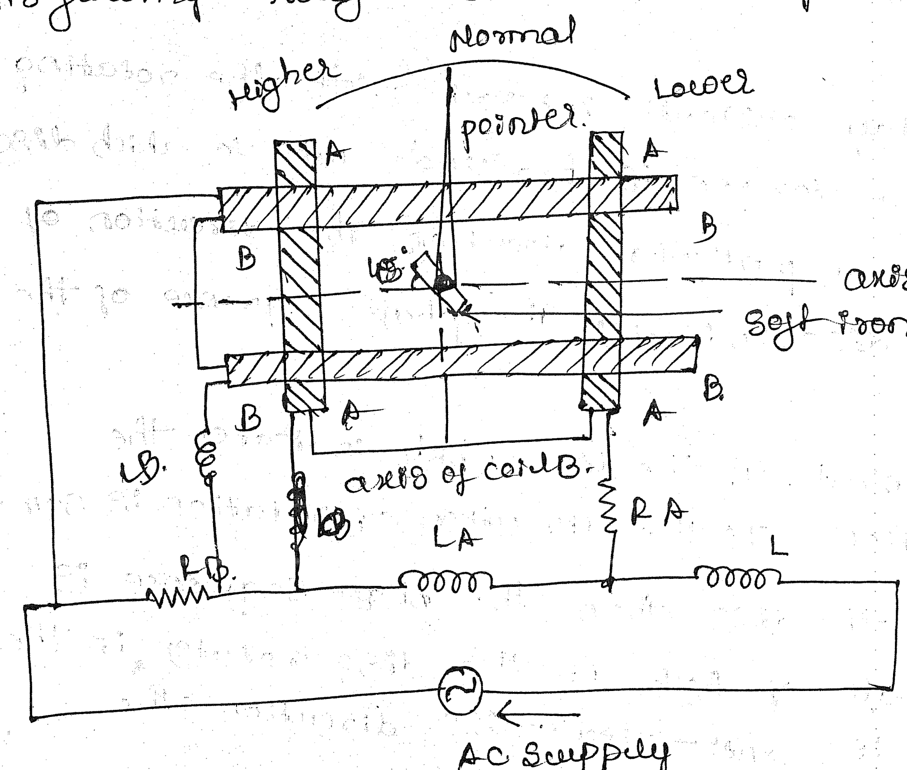


fig - Weston frequency meter.

* Working principle

(1) When the frequency meter is connected across the supply the current will flow in both the coils A & B respectively. & set up the two magnetic fields which are right angle to each other.

② However the strength of magnetic fields produced by both the coils depends on magnitude of current flowing through both the coils.

③ The values of resistances & inductances in the frequency meter are selected in such a way that, at the normal frequency the voltage drop across L_A & R_B must send equal currents through the coils A & B.

∴ the needle takes a position which is 45° to both the coils & pointer deflects to the centre of scale

④ If the frequency is more than a normal value, the reactances of L_A & L_B increases, while the values of R_A & R_B remains same ∴ the voltage impressed on coil A will be more than the voltage impressed on coil B, due to which current in coil A increases & c/n in coil B decreases

⑤ due to the c/n the strength of field produced by coil A will be more than the field produced by coil B, ∴ the pointer deflects to left side where the higher frequencies are marked

⑥ If the frequency is less than the normal frequency the pointer deflects to right side of the scale where lower frequencies are marked By calibrating the scale the deflection of the pointer can be made directly to read the frequency of the supply on scale.

* phase Sequence indicator

ii) Static type of phase sequence indicator

The circuit diagram of phase sequence indicator is as shown below

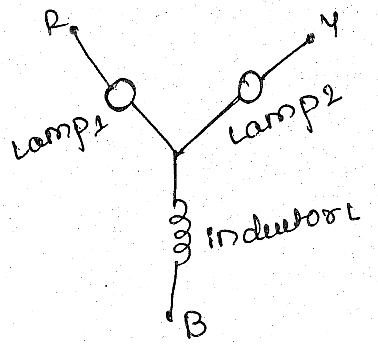


fig-a)

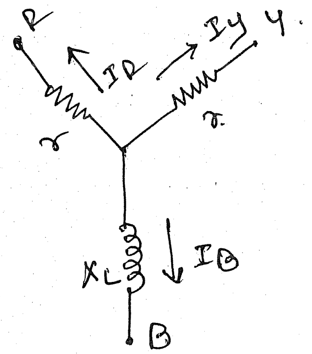


fig-b

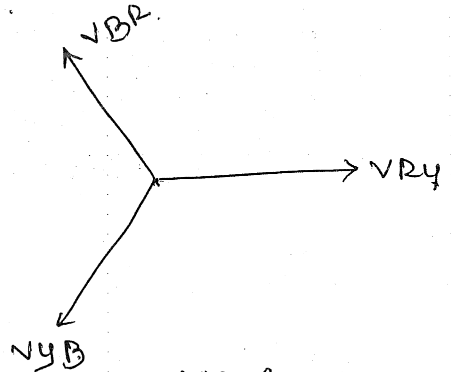


fig-c.

As shown in the above fig it consisting of two lamps & one inductor. When phase sequence is RyB the lamp 1 will glow dim while lamp ② will glow brightly. When the phase sequence is RBy Lamp1 will be bright & Lamp ② will glow dim. This phenomena can be analysed as follows

Initially assume that the phase sequence is RyB & the phasor relations of V_{Ry}, V_{yB} & V_{BR} are as shown in fig c

$\therefore V_{Ry} = V[1+j0] = V\angle 0^\circ$

$V_{yB} = V[-0.5 - j0.866] = V\angle -120^\circ$

$V_{BR} = V[-0.5 + j0.866] = V\angle 120^\circ$

| $\cos\theta + j\sin\theta$
| $\cos\angle -120^\circ + j\sin(-120^\circ)$

Now let us assume the direction of currents as shown in fig ⓑ.

ie $I_R + I_y + I_B = 0$ —— ①

from the fig ⓑ & fig c it is clear that

$V_{Ry} + I_y r - I_R r = 0$ —— ②

$V_{yB} + I_R j X_L - I_y r = 0$ —— ③

By solving the equations ② & ③ we get

$$\frac{I_R}{I_y} = 1 + \frac{(1 + j2X_L/r)}{(V_{yB}/V_{Ry}) - jX_L/r}$$

But we have $\frac{V_{yB}}{V_{Ry}} = -0.5 - j0.866$

∴ If the inductor is designed such that $X_L = R$ at the line frequency we get $I_R/I_y = 0.27$

∴ the voltage drop across Lamp 1 is 27% that of across Lamp ② ∴ if the phase sequence is RYB lamp ① glows dimly while lamp ② glows brightly

Now if the inductor is replaced by the capacitor the value is I_R/I_y = is 3.7 it means that lamp ① glow brightly & lamp ② glow dim if the phase sequence is RBY

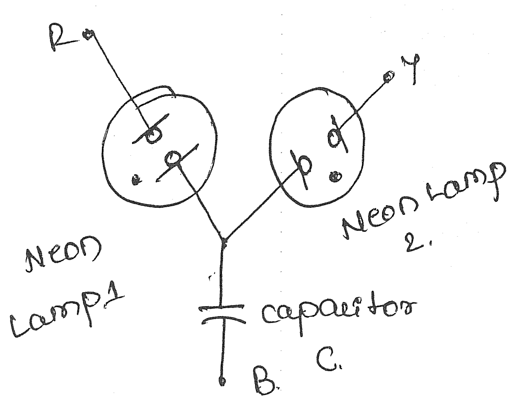


fig-a)

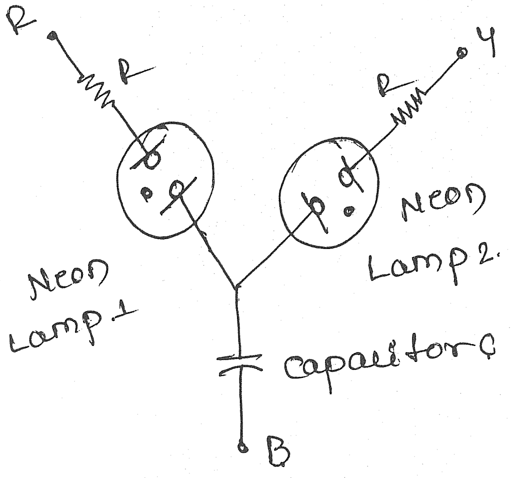


fig-b)

Another similar phase sequence indicator consists of two neon lamps & a capacitor as shown in fig ⓐ. As shown in fig ⓑ a resistor is connected in series with neon lamp to limit the current.

When the phase sequence is RYB, lamp1 will glow & lamp B will be dark, this is because when neon lamps are used as indicators, the lamp which has a lower voltage will not glow at all, as the voltage across it is lower than the breakdown voltage of the lamp//.

* Three phase Electrodynamometer type of power factor meter.

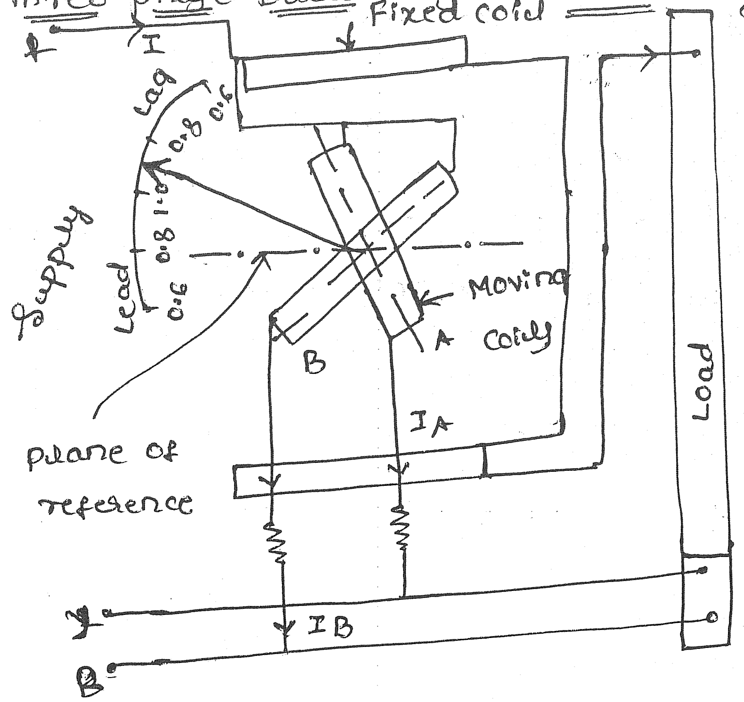


fig a) - 3 phase dynamometer type of power factormeter

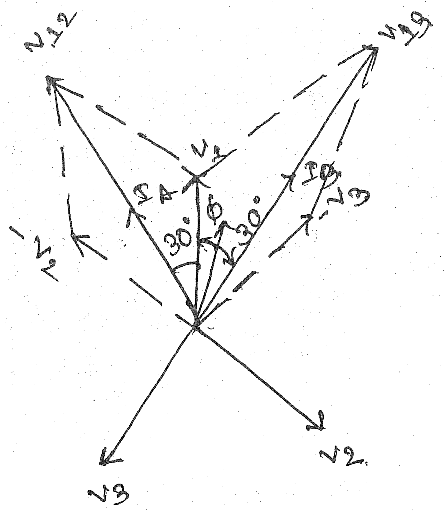


fig b) phasor diagram of 3-ϕ pf meter

The above fig-a) shows construction of electrodynamometer type 3-ϕ power factor meter, this meter is useful for balanced loads

* As shown above the two moving coils are arranged in such a way ~~Therefore~~ the angle b/n both moving coils is 120°, both the coils are connected across two different phases of supply.
* The coil A is connected b/n R and Y while coil B is connected by R and B phases as shown above.
* The phase difference b/n the currents through two moving coils is automatically created due to phase difference b/n the supply itself hence external R and L are not required as in case of single phase circuit.

* The moving coils A and B are connected to the supply lines Y and B through series resistance.
* The voltage across coil A is V_{12} and c/n I_A is in phase with V_{12} & voltage across coil B is V_{13} & c/n I_B is in phase with V_{13} as coil circuit is resistive in nature

Let ϕ = phase angle of circuit

θ = angular deflection from the plane of reference

$V_1 = V_2 = V_3 = V$

Torque acting on coil A is

$T_A = k V_{12} I M_{max} \cos(30° + \phi) \cdot \sin(60 + \theta)$

$= \sqrt{3} k V I M_{max} \cos(30° + \phi) \sin(60 + \theta)$

Now torque acting on coil B is

$T_B = k V_{13} I M_{max} \cos(30 - \phi) \cdot \sin(120° + \theta)$

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

Torque T_A and T_B act in the opposite direction & moving coil comes to rest when $T_A = T_B$

$\therefore \cos(30° + \phi) \sin(60 + \theta) = \cos(30° - \phi) \sin(120° + \theta)$

$\therefore \theta = \phi$.

$\therefore$ the angular deflection of the pointer from the plane of reference is equal to the phase angle of the circuit to which meter is connected

* Three phase energy meters

In 3-ϕ, 4 wire system the measurement of energy is carried out by 3-ϕ energy meter.

→ For 3-ϕ, 3 wire system the energy measurement is carried out by two element energy meter.

→ 1) Three element energymeter
   2) two element energymeter.

* Three Element Energy meter.

Three Element Energy meter consists of three elements, The construction of an individual element is similar to that of a single phase energymeter.

→ The pressure coils are denoted as P_1, P_2, P_3, the current coils are denoted as C_1, C_2 & C_3

→ The coils are arranged in such a manner that the net torque produced is sum of the torques due to all the three elements.

→ The current coils are connected in series with the lines while pressure coils are connected across the line and a neutral

→ one unit of three phase element is always cheaper than three units of 1-ϕ energymeter. But due to the interaction of eddy currents produced by one element with the flux produced by another element, there may be errors in the measurement by 3-ϕ energy meter, such errors are reduced by suitable adjustments

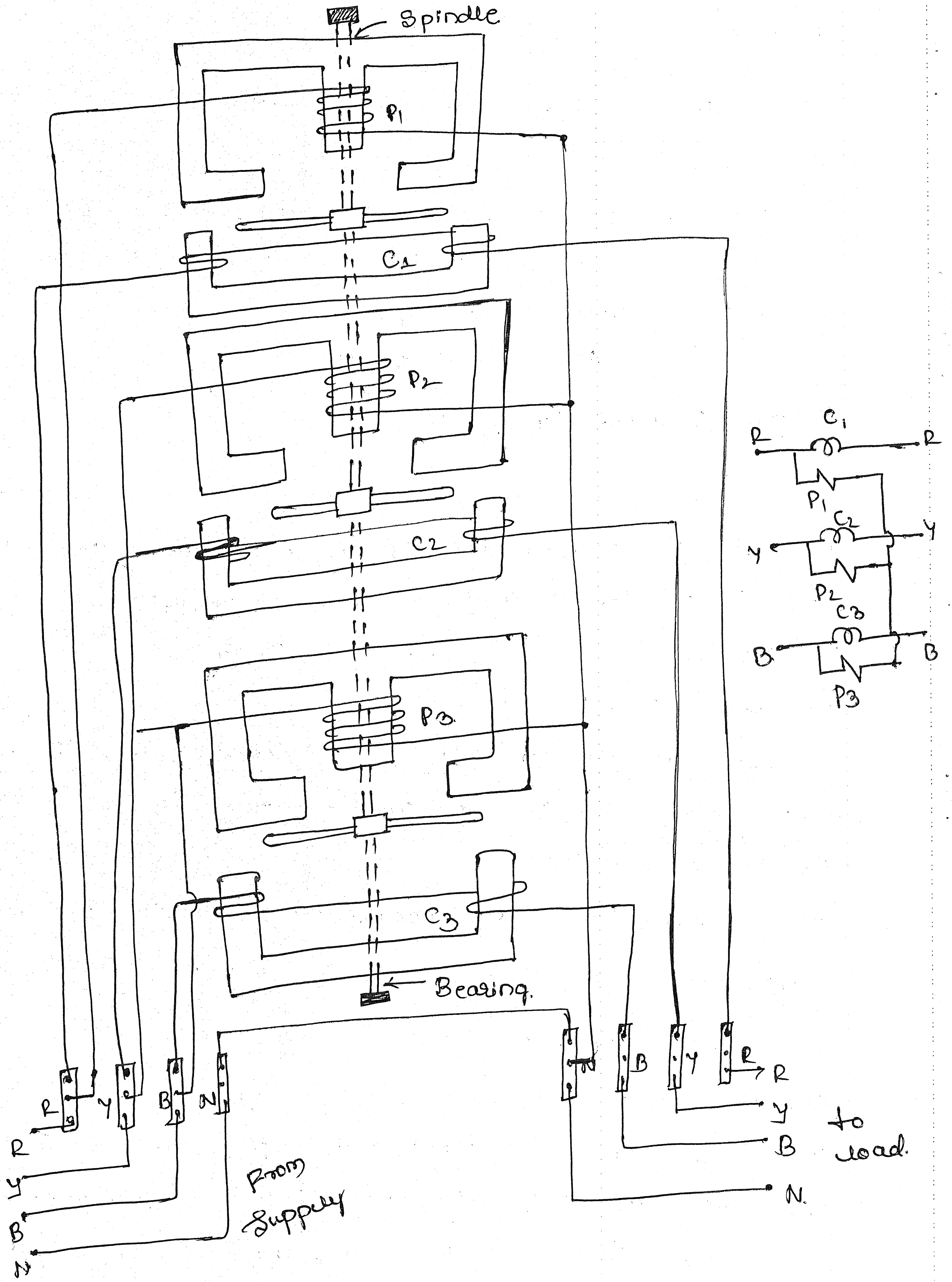


fig- three element Energy meter.

* Two element Energy meter.

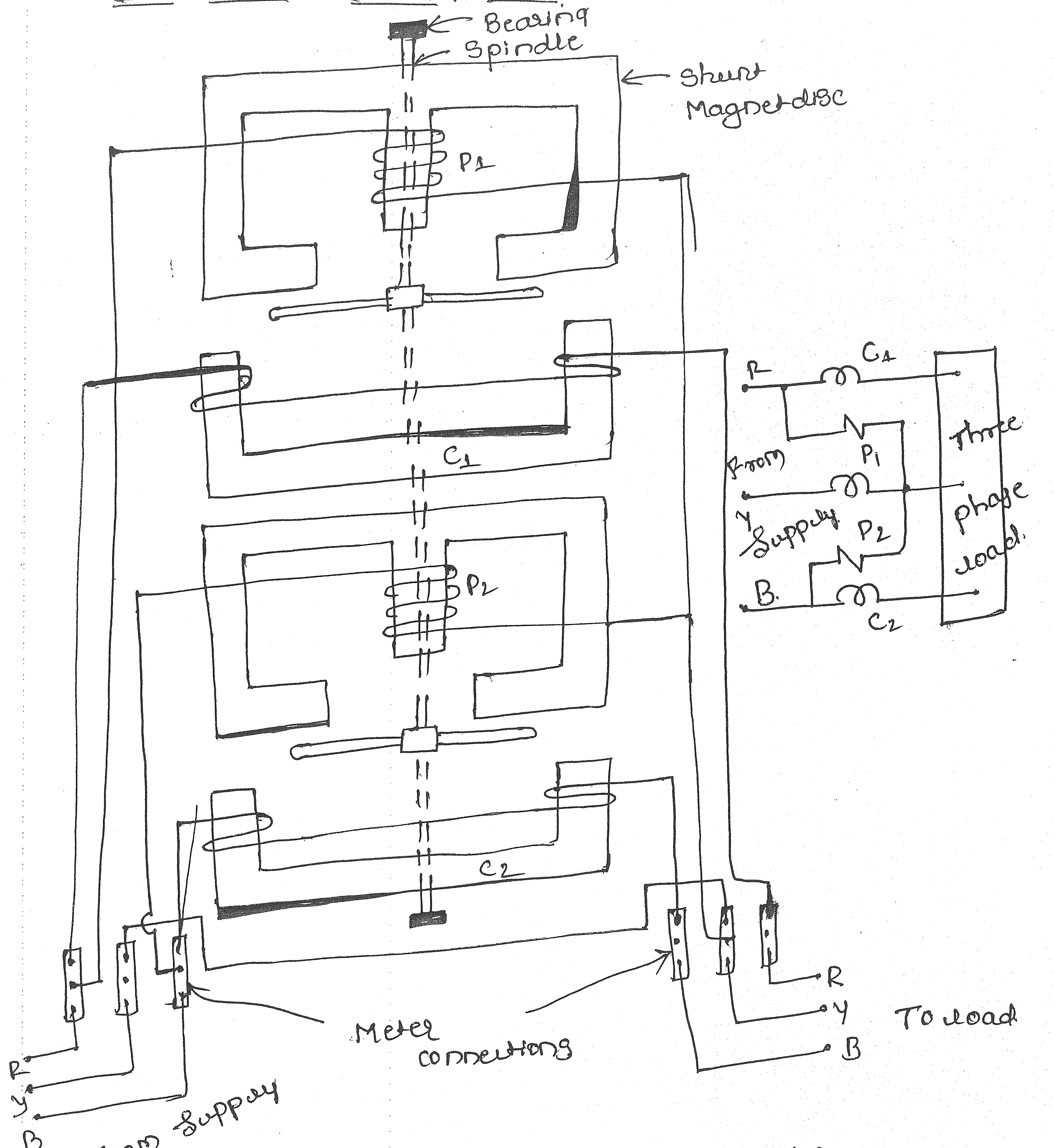


fig - Two element energy meter.

The above fig shows two element energy meter. This energymeter is used for three phase, three wire systems. The shunt magnet forms the pressure coils & series magnet forms current coils of meter.

* The pc is connected in parallel and current coils are connected in series. The connections are similar to that of two wattmeter for measurement of power in 3phase 3wire system.

* The total torque ~~on the registering~~ is applied to moving system, which is the torque of the individual elements.

* The rotation of of light aluminium disc gives the total power consumption for particular time.//

Module - 3

* Extension of Instrument Ranges

The range of any electrical instrument depends on how much c/n can be safely passed through the coil of instrument, which act as leads of c/n to the instrument.

* Normally the moving coil instruments such as ammeters & voltmeters are designed to carry a maximum c/n of 50mA & withstand a voltage of 50mV.

* However for the measurement of larger currents & voltages the ranges of these instruments are increased.

* Basically there are four methods for the extension of instrument ranges.

i) By using shunts to increase the ranges of dc ammeters
ii) By using multipliers to increase the of dc voltmeters
iii) By using current x'ers to increase the ranges of ac ammeters.
iv) By using potential transformer to increase the ranges of ac voltmeters.

* Shunts

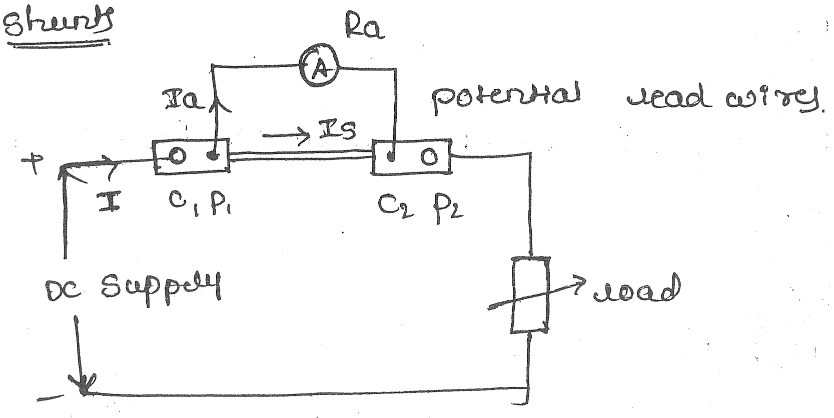


fig -

The connection diagram of shunt in ||el with a low range ammeter to measure large current through the circuit is as shown in the above fig.

* As shown in the above fig, a shunt is a very low resistance connected in parallel with the coil circuit of ammeter in order to extend its range.

* By introducing a shunt, larger currents can also measured using a low range ammeter.

* A shunt has four terminals two c/n terminals C_1 & C_2, & two potential terminals P_1, & P_2. The two c/n terminals are connected in series with the main circuit & they have high c/n carrying capacity.

* The two potential terminals have low c/n carrying capacity & across these terminals a low range ammeter is connected.

Let us consider an ammeter A of Resistance Ra which includes the resistance of potential lead wires & it carries a current of Ia.

From the above fig, Let Is = current flowing through the shunt.

$I_a R_a = I_s R_s$

$R_s = \frac{I_a R_a}{I_s}$

$= \frac{I_a R_a}{(I - I_a)}$ divide Nr & Dr by Ia. & $I_s = I - I_a$

$\therefore R_s = \frac{R_a}{(I/I_a - 1)}$

$R_s = \frac{1}{(N-1)} R_a$ where $N = I/I_a$ = multiplying factor of shunt.

$\therefore R_s = \frac{R_a}{(N-1)}$ —— (1)

The above can also be written as

$N = 1 + \frac{R_a}{R_s}$

$\therefore$ it is clear that to increase the range of ammeter N times, the shunt must have a resistance of Rs.

* Shunts of AC ammeters

A shunt is usually used to extend the range of DC ammeters but they are also used to extend the ranges of AC ammeter also.

When a shunt is used to extend the range of an AC ammeter, the inductances of both shunt & ammeter is taken into consideration.

If La & Ls be the inductances of ammeter along with leads & that of the shunt, the ratio of two impedances is given by.

$$\frac{Z_a}{Z_s} = \frac{\sqrt{R_a^2 + \omega^2 L_a^2}}{\sqrt{R_s^2 + \omega^2 L_s^2}} \quad \text{—— (1)}$$

The above ratio must be constant for all frequencies, so that the cln div b/n ammeter & shunt remains constant for all frequencies, However this is possible only when the time constants of the ammeter & the shunt are same

ie $T_a = T_s$

ie $L_a/R_a = L_S/R_S = k$.

we know that the multiplying factor of shunt is

$$N = I/I_a = \frac{I_a + I_S}{I_a} = 1 + I_S/I_a = 1 + \frac{V/Z_S}{V/Z_a}$$

$\therefore N = 1 + Z_a/Z_S$

$$= 1 + \frac{\sqrt{R_a^2 + \omega^2 L_a^2}}{\sqrt{R_S^2 + \omega^2 L_S^2}}$$

$$= 1 + \frac{R_a \sqrt{1 + \omega^2 (L_a/R_a)^2}}{R_S \sqrt{1 + \omega^2 (L_S/R_S)^2}}$$

$$N = 1 + \frac{R_a \sqrt{1 + \omega^2 k^2}}{R_S \sqrt{1 + \omega^2 k^2}} = 1 + R_a/R_S$$

$N = 1 + R_a/R_S$ $\therefore$ the above equation shows that a shunt can also be used to extend the range of an AC ammeter.

* Multipliers.

A multiplier is a non-inductive high resistance used to extend the range of a dc voltmeter.

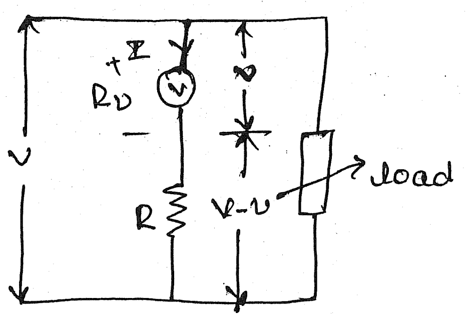


fig.

Let us consider a low range voltmeter whose range has to be increased upto V volts, which is connected in series with the multiplier.

Let R - be the resistance of multiplier which is connected in series with the voltmeter to extend its range.

Let V be the applied voltage.

R_v - resistance of the voltmeter

I = c/n through the voltmeter

Then $v = IR_v$ & $R = \frac{V-v}{I}$

$\Rightarrow RI = V-v$ divide LHS & RHS by v

$$\frac{RI}{v} = \frac{V}{v} - 1 = N-1$$

Where $N = V/v$ = multiplying factor of multiplier

$\frac{RI}{v} = N-1$ | where $v = IR_v$

ie $\frac{RI}{IR_v} = N-1$

$R/R_v = N-1$

$\therefore N = 1 + R/R_v$ —— (1) or $R = R_v(N-1)$ —— (2)

Hence to increase the range of voltmeter by N times, the multiplier must have the resistance of $(N-1)R_v$.

Multiplier for Ac voltmeter

A multiplier is used to extend the range of Dc Voltmeter & they can also be used to extend the ranges of AC voltmeters, when multiplier is used to extend the ranges of AC voltmeter it has to satisfy the condition that the total impedance of the voltmeter and the multiplier circuit must be constant at all frequencies.

* To satisfy the above condition the inductance of the multiplier should be very small, so that the total inductance of the whole circuit will be small.

Let L = inductance of the voltmeter, then the cl.n through the voltmeter is given by.

$$I = \frac{V}{\sqrt{(R+R_v)^2+\omega^2L^2}}$$

the voltage drop across the voltmeter is given by

$$v = I\sqrt{R_v^2+\omega^2L^2}$$

ie $$v = \frac{V\sqrt{R_v^2+\omega^2L^2}}{\sqrt{(R+R_v)^2+\omega^2L^2}}$$

$$\frac{V}{v} = \frac{\sqrt{(R+R_v)^2+\omega^2L^2}}{\sqrt{R_v^2+\omega^2L^2}}$$ = N the multiplying factor.

* A PMMC instrument gives a full scale deflection of 100mV & 20mA. Explain how the above instrument can be used as i) a voltmeter of range 0-300V
ii) an ammeter of 0-100A range.

⇒ i) As voltmeter → Let R be the resistance connected in series with the small range voltmeter.

$\therefore V = v + IR$

ie $300 = 100 \times 10^{-3} + 20 \times 10^{-3} R$

$\therefore R = 14995\,\Omega$

ii) AS ammeter

Let Rs be the resistance of the shunt connected across the ammeter.

$\therefore$ $I_s = I - I_a$

$= 100 - 20 \times 10^{-3}$

$= 99.98\,A$

& $I_a R_a = I_s R_s$

$\therefore R_s = \frac{I_a R_a}{I_s}$

$= \frac{20 \times 10^{-3} \times 5}{99.98}$

$\therefore R_s = 0.001\,\Omega$

* A moving coil instrument has a resistance of 5 Ω & it gives full scale reading of 50mA. calculate i) the shunt resistance required to increase the range to 200A ii) the series resistance required to use it as a voltmeter of range 0-750V iii) power consumed in both the cases.

⇒ i)

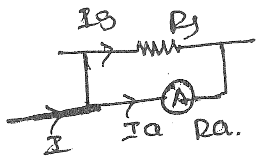


fig-a.

Given $I = 200A$

$I_a = 50mA$

$\therefore I_g = I - I_a$

$= 200 - 50\times10^{-3} = 199.95A$

We know that $I_aR_a = I_gR_g$.

$\therefore R_S = \frac{I_aR_a}{I_S} = \frac{50\times10^{-3}\times5}{199.95}$

$\therefore R_S = 0.0012503\,\Omega$

$R_S = \underline{1.2503m\Omega}$

power consumed in the shunt $= I_S^2R_S$

$= (199.95)^2\times1.2503mA$

$= 49.99W$

$\therefore$ the power consumed by the voltmeter is small hence it is neglected.

ii) voltmeter.

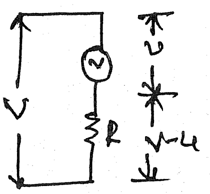


fig-b)

the total voltage is given by.

$V = v + IR$

$750V = IR_v + IR$

$= 50\times10^{-3}\times5 + 50\times10^{-3}R$.

$\therefore R = 14995\,\Omega$

$\therefore$ the power consumed, by the series

$I^2R = (50\times10^{-3})^2\times14995$

$= \underline{37.4875W}$. //

* Instrument Transformer

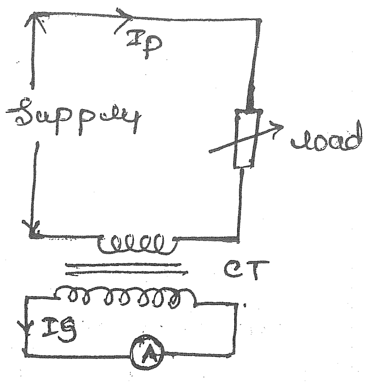


fig-a

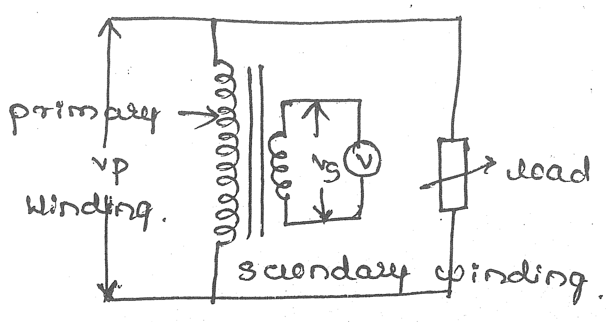


fig-b

Instrument transformers are used to extend the range of AC instruments.

* If the x^{Tel} is used to extend the range of AC ammeter it is known as current Transformer.
* If the x^{Tel} is used to extend the range of AC voltmeter it is known as potential Transformer.
* Instrument transformers are used to measure high voltages and high currents along with low range ammeter and voltmeter respectively.
* fig a, shows how a CT is used to measure large currents along with low range ammeter.
* The primary winding of CT consisting of only few no of turns which are connected in series with load through which large current Ip flows.
* The secondary winding of CT consisting of large no of turns which is connected to an ammeter through which a small c/n Is flows. The Ip is measured as

$I_p = n I_s$ where $n = N_s/N_p$ = turns ratio.

N_s = no of turns in the secondary winding

N_p = no of turns in the primary winding.

* fig b, shows how a potential transformer is used to measure large voltages using low range voltmeters

* The primary winding of PT consisting of large no turns N_p which is connected across the large voltage which is to be measured.

* However the secondary winding consists of only few no of turns N_S across which a low range voltmeter is connected, whose range is enough to measure the secondary voltage V_S.

Now the value of V_p is $V_p = n V_S$ $n = \frac{N_p}{N_S}$ = turns ratio

* <u>Advantages of Instrument transformers</u>

1) When IT'S are used to extend the ranges of AC instruments their readings do not depend on the constants R, L & C as in case of shunts and multipliers.

2) The CTS are standardized at 5A secondary winding current & voltage xTey are standardized to the 110V secondary winding voltage. which are very moderate ratings. Thus a 5A ammeter can measure upto 1000A using 1000/5A CT. Similarly a 110 voltmeter can measure voltage upto 110kV using 110kV/110V PT. Hence very cheap & moderate rating instruments are used to measure large cln & large voltages

3) As secondary windings of CT & PT are standardized it is possible to standardize the instruments around these ratings & replacement of IT'S is easy

4) The low rating secondary windings of IT'S

are electrically isolated from high rating primary windings.

5) There is low power consumption in the metering circuit.

6) several instruments can be operated using a single instrument transformer.

* Ratios of Instrument Transformer

three different ratios are defined for ITS.

1) Transformation Ratio (R) [Actual Ratio]

The transformation ratio of an IT is defined as it is the ratio of the magnitude of the actual primary phasor to the magnitude of the actual secondary phasor

$$\text{Transformation Ratio} = \frac{\text{primary phasor}}{\text{secondary phasor}}$$

$$TR = \frac{\text{Magnitude of the actual primary winding c/n}}{\text{Magnitude of the actual Secondary wdg c/n}}$$

ie CT = I_P / I_S

for PT = V_P / V_S

$$= \frac{\text{Magnitude of actual primary wdg voltage.}}{\text{Magnitude of actual secondary wdg voltage.}}$$

ii) Nominal Ratio :- (k_n)

The nominal ratio of an instrument transformer is defined as the ratio of rated primary wdg current or voltage to the rated secondary wdg current or voltage.

$$k_n = \frac{\text{rated primary wdg c/n}}{\text{rated secondary wdg c/n}} \quad \text{for CT.}$$

$$k_n = \frac{\text{rated primary wdg voltage}}{\text{rated Secondary winding voltage}} \text{ for PT.}$$

* **Turns Ratio (n)**

The turns ratio of an instrument transformer is defined as

for CT $$n = \frac{\text{No of turns in the secondary wdg}}{\text{No of turns in the primary wdg}} \text{ ie } N_S/N_P$$

for PT $n = N_P/N_S$

* **Ratio correction factor (RCF)**

The RCF of an instrument transformer is the ratio of its transformation ratio to its nominal ratio $RCF = R/k_n$ or $R = RCF \times k_n$

* **Burden of an IT**

The Burden of an IT is the permissible load across the secondary winding terminals expressed in volt-Amperes at the rated secondary terminal voltage or rated secondary current, with errors not exceeding the limits for particular class.

$$\text{Total Secondary winding burden} = \frac{(\text{Secondary wdg induced voltage})^2}{\text{total impedance of secondary circuit.}}$$

* $$\text{Secondary winding burden due to load} = \frac{(\text{Secondary wdg terminal vtg})^2}{\text{Impedance of the load on Secondary winding.}}$$

* <u>Current Transformer</u>

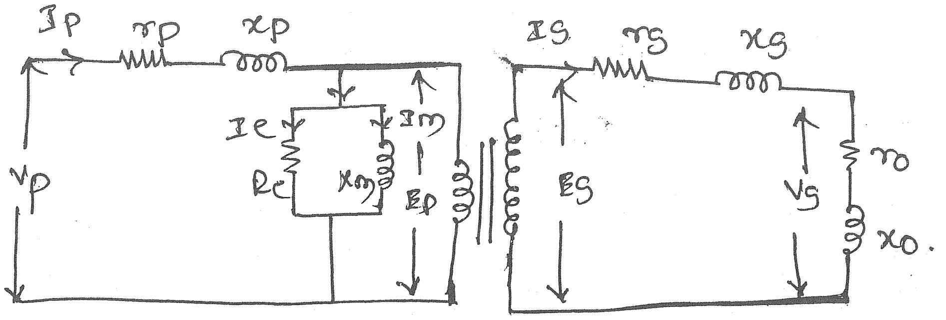


fig-a equivalent circuit of CT

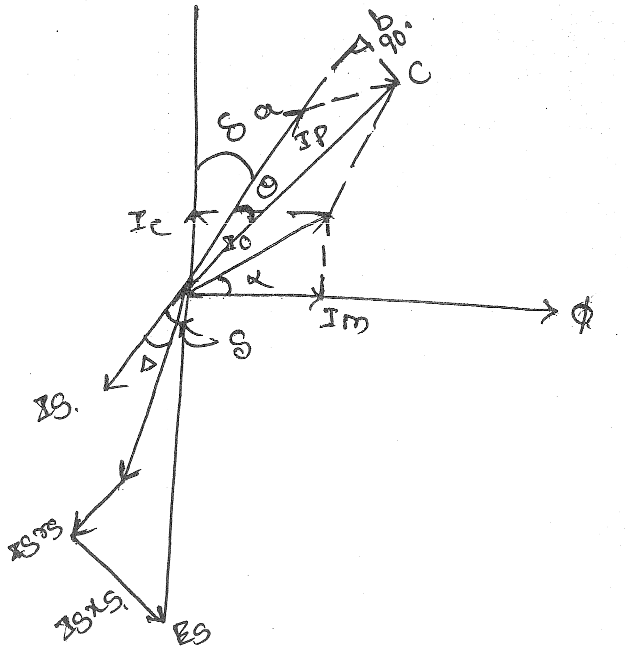


fig-b) vectordiagram of CT

n = turns ratio = $\frac{\text{no of secondary turns}}{\text{no of primary turns}}$ = Ns/Np

rs, xs = resistance & reactance of the secondary winding respectively.

rp, xp = resistance & reactance of the primary winding respectively

Np = primary applied voltage

Ep, Es = primary & secondary induced voltages respectively

V_S = Secondary terminal voltage

ϕ = flux of X^{rel}

I_0 = exciting current

I_m = magnetising component of I_0

I_e = core loss component of I_0

θ = phase angle of X^{rel}.

δ = Angle b/n E_S & I_S ie $\tan^{-1}\left[\frac{x_S + x_e}{r_S + r_e}\right]$

Δ = phase angle of the secondary load circuit

$= \tan^{-1} x_e/r_e$

α = angle b/n I_0 and flux ϕ

* $R = \frac{I_p}{I_S} = n + \frac{I_0}{I_S} \sin(\alpha + \delta)$

$= n + I_0/I_S \; \sin\alpha \cdot \cos\delta + \cos\alpha \sin\delta$

$= n + \frac{I_0 \sin\alpha \cdot \cos\delta + I_0 \cos\alpha \sin\delta}{I_S}$

$R = n + \frac{I_e \cos\delta + I_m \sin\delta}{I_S}$ //.

* **phase angle θ**

$\theta = \frac{180}{\pi}\left[\frac{I_m \cos\delta - I_e \sin\delta}{n I_S}\right]$ degrees

* **Errors in current transformers**

i) Ratio error ii) phase angle error

Ratio error = $\frac{\text{Nominal ratio} - \text{Actual ratio}}{\text{Actual ration}} = \frac{k_n - R}{R}$

% ratio error = $\frac{k_n - R}{R} \times 100$

* The phase angle is given by

$$\theta = \frac{180^\circ}{\pi}\left[\frac{I_m \cos\delta - I_e \sin\delta}{nI_s}\right] \text{ degrees.}$$

The instrument burden is largely resistive with negligible inductance and hence δ is very small.

∴ we will get the equation for transformation Ratio R is $R = n + I_e/I_s$ & $\theta = \frac{180^\circ}{\pi}\left[\frac{I_m}{nI_s}\right]$ degrees

From the above equations it is clear that the ratio error is mainly due to the iron loss component I_e of exciting current I_o & phase angle error is mainly due to the magnetizing component I_m of exciting c/n I_o.

* **Design features of current transformers**

1) **Number of primary Ampere-turns**

In order to keep ratio and phase angle errors of a current transformer as small as possible, it is necessary that the exciting current I_o and hence, the exciting ampere turns $N_p I_o$ must be a small proportion of the total Number of primary ampere-turns $N_p I_p$. The primary ampere turns should be at least of the order 500 to 1000 to give accurate measurements. When low loss alloy such as mumetal is used as the core material, the c/n through the bar primary of CT may be at least 100A & it gives accurate measurements.

2) **core** :- To minimize the exciting c/n I_o to reduce the errors in the CT. The core must have low reluctance

small iron loss. The flux density in the core must be limited to 0.1 wb/m². The three forms of core normally used for the construction of core of CT are 1) rectangular type 2) shell type 3) ring type.

* The rectangular type is built of L shaped punchings. The windings are placed on one of the shorter limbs. with primary normally wound over the secondary. This type of core structure is suitable for high voltage work.

* In shell type the windings are placed on central limb & hence they provide considerable protection to the windings.

* In ring type of core of core, the secondary winding is uniformly distributed over the core & the primary winding is single bar.

* **Windings** :- The secondary leakage reactance of CT increases its ratio error and leakage reactance should be kept as small as possible. The secondary leakage reactance can be reduced by placing the windings close together

* **Insulation** :- The coils of CT are separately wound & they are insulated from tape and varnish for lower line voltages. However the windings are wound over one another on cylinders of bakelite and mounted on a sheet steel tank filled with transformer oil. For higher voltages the transformers enclosed in a tank, which is filled solid insulating compound.

* **Turns compensation**

Turns compensation is used in most current xTers in order to obtain the transformation ratio (R) is nearly equal to nominal ratio (k_n), if the turns ratio is made equal to nominal ratio of the x^{TC} then we get the equation for transformation ratio of CT is $R = n + I_e/I_s$ where n = turns ratio.

from the above equation we find that by reducing the no of secondary turns by 1% will reduce R.

* <u>open circuiting the secondary circuit of current x^{Tr}.</u>

In a current transformer, the number of primary ampere-turns is a fixed quantity & it is not reduced when the secondary circuit is opened, as in case of power transformer. ∴ if the secondary circuit of CT is opened, when ckt is flowing in the secondary circuit, A very high flux density is produced in the core causing the absence of demagnetizing ampere turns.

This high flux density results in increased induced voltage in the secondary winding, which may damage the insulation & cause danger to operator.

∴ the secondary of CT should never be open circuited when the current is flowing through the primary winding.//

* A 1000/5A, 50Hz current transformer has a bar primary and a rated secondary burden of 15VA. The secondary winding has 195 turns and a leakage reactance of 0.96mH. The load burden is purely resistive. At rated

load, the magnetisation mmf is 20A and core loss excitation is 12A. Find the ratio and phase angle errors.

$\Rightarrow$ $Z_s = E_s/I_s = \frac{E_s I_s}{I_s^2} = \frac{15}{5^2} = 0.6\,\Omega = R_s$ ($\because$ secondary burden is purely resistive).

$X_s = 2\pi \times 50 \times 0.96 \times 10^{-3}$

$X_s = 0.3\,\Omega$

$\delta = \sin^{-1} X_s/R_s = \sin^{-1}\frac{0.3}{0.6} = \sin^{-1} 0.5$

$\therefore$ $\sin\delta = 0.5$ and $\cos\delta = \sqrt{1-0.5^2} = 0.866.$

$n = N_S/N_P = 195/1 = 195$ $\quad K_n = \frac{1000}{5} = 200.$

$I_m = \frac{20}{1} = 20A,$ and $I_e = 12/1 = 12A$

$R = n + \frac{I_e\cos\delta + I_m\sin\delta}{I_s} = 195 + \frac{12 \times 0.866 + 20 \times 0.5}{5}$

$= 195 + 4.0784$

$= 199.0784$

$\therefore$ % Ratio error $= \frac{K_n - R}{R} \times 100 = \frac{200 - 199.078}{199.078} \times 100 = 0.463\,\%$

$\theta = \frac{180}{\pi}\left[\frac{I_m\cos\delta - I_e\sin\delta}{nI_s}\right]$ degrees.

$= \frac{180}{\pi}\left[\frac{20 \times 0.866 - 12 \times 0.5}{195 \times 5}\right]$ degrees

$= 0.665^\circ = 39.91'$

* Theory of potential Transformer

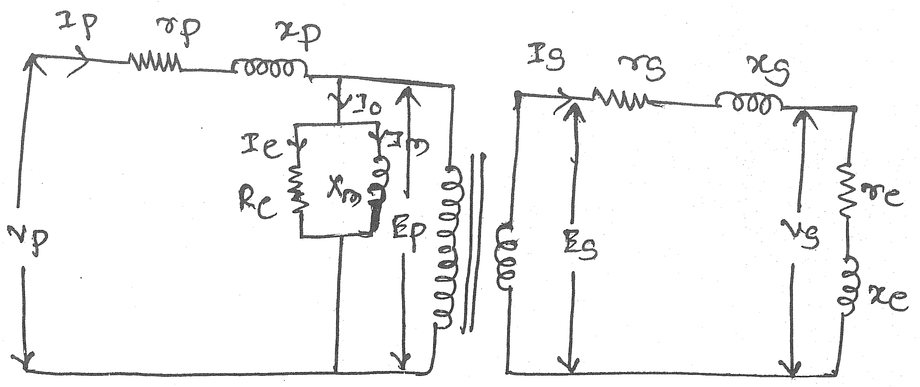


fig a) equivalent circuit of PT

The above fig shows equivalent circuit diagram of PT

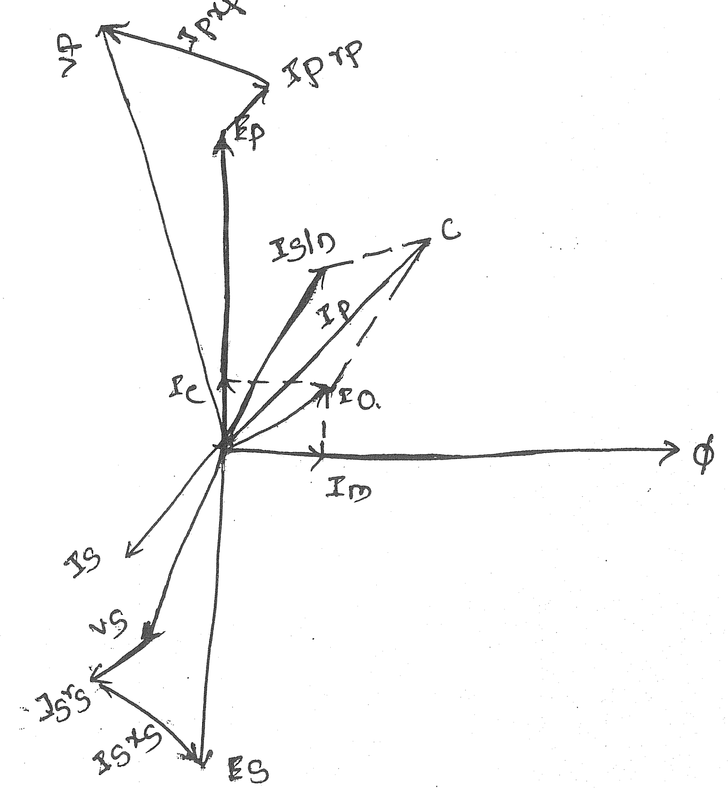


fig-b) phasor diagram of PT

ϕ = Working flux in the core of the transformer.

I_o = exciting current or no-load current

I_m = Magnetising component of exciting current

I_e = core loss component of exciting ct.

V_p = primary applied voltage

E_p = primary induced voltage

E_s = Secondary induced voltage

V_s = Secondary terminal voltage

N_p, N_s = primary & Secondary winding turns respectively

r_p, x_p = resistance & reactance of primary wdg respectively.

r_s, x_s = resistance & reactance of secondary wdg respectively

r_e, x_e = resistance & reactance of load respectively

Δ = phase angle of the secondary load circuit

$= \tan^{-1} x_e/r_e$.

* **Expression for actual ratio (R)**

Turns ratio $n = N_P/N_S = E_P/E_S$

$$R = V_P/V_S = n + \frac{n I_s(R_s \cos\Delta + X_s \sin\Delta) + I_e r_p + I_m x_p}{V_S}$$

$$R - n = \frac{n I_s(R_s \cos\Delta + X_s \sin\Delta) + I_e r_p + I_m x_p}{V_S}$$

Where $R_s = r_s + r_P/n^2$

$X_s = x_s + x_P/n^2$

*phase angle $\theta = \frac{I_s}{V_s}(X_s \cos\Delta - R_s \sin\Delta) + \frac{I_e x_p - I_m r_p}{n V_s}$ radians

$x_P/n^2 = X_s \quad R_P/n^2 = R_s$

* Reduction of errors in potential transformer.

Both ratio error & phase angle error can be minimized in p.T by making certain modifications in the design of P.T.

1) Reduction of magnetising (I_m) & iron loss components of exciting current (I_o).

$$R - n = \frac{n I_s (R_s \cos\Delta + X_s \sin\Delta) + I_e r_p + I_m x_p}{V_s}$$

from the above equation it is clear that R depends on secondary current I_s, magnetising current I_m & iron loss component of exciting current. Hence ratio error can be minimized by reducing I_m & I_e, which can be achieved by using short magnetic path, good quality of core material, & suitable precaution in the assembly of the core.

2) By reducing the resistance & leakage reactance.

⟹ the resistances of windings can be reduced by using thick conductors & by usage of small length of turn. The leakage reactances can be reduced by reducing the leakage fluxes, & reduced leakage fluxes can be obtained by placing the windings as close as possible.

3) Turns compensation

At the no load condition $I_s = 0$, the actual ratio exceeds the turns ratio (n) by the amount $\frac{I_e r_p + I_m x_p}{V_s}$

Hence in order to reduce the ratio error. the secondary turns must be reduced such the actual Ratio (R) must be equal to nominal ratio (K_n)

40

* characteristics of potential transformer

1) effect of secondary burden (VA).

With increase in the secondary burden secondary current increases & which leads to increase of primary current Hence winding voltage drop will increase on both sides of PT [ie Both secondary & primary winding voltage]
∴ for the given supply voltage V_p, the value of load voltage V_s decreases & actual ratio increases. [∵ $R = n \propto 1/V_s$]
∴ ratio error increases & it becomes more negative due to the secondary burden.

2) effect of p.f on secondary burden

If the p.f of the secondary burden is reduced then the angle Δ increases & which makes I_p to shift towards to I_0. The voltage V_p comes close to V_s, with E_p & E_s respectively. which results in increase of V_p relative to E_p. but anyhow supply voltage V_p is constant ∴ E_p is gets reduced, similarly the load voltage V_s is reduced relative to E_s. ∴ The transformation ratio is increased

3] Effect of frequency.

At a constant voltage, if the frequency is increased the flux is reduced Hence both I_m & I_e are reduced, this decrease of value is not much as compared with the increase of leakage reactances due to increase of frequency which causes the increased leakage reactances drops & ratio of voltages are increased.

End

* A 500/100V PT has the following constants $R_p = 47.25\Omega$, $R_s = 0.45\Omega$, primary reactance $x_p = 33.1\Omega$, X_s = negligible, the no load primary current is 0.1A at 0.6pf calculate
① the no load angle b/w the primary winding & reverse secondary voltage.
② The value of the secondary winding current at upf when $\theta = 0$ &

⟹ $\therefore n = 500/100 = 5.$

$I_e = I_0 \cos\phi = 0.1 \times 0.6 = 0.06.$

$\sin\phi = \sqrt{1-\cos^2\phi} = \sqrt{1-(0.6)^2} = 0.8$

$I_m = I_0 \sin\phi = 0.1 \times 0.8 = 0.08$

We have

① $$\theta = \frac{I_S/n\,(x_p \cos\Delta - R_p \sin\Delta) + I_e x_p - I_m r_p}{nV_S.}$$

at noload $I_S = 0.$

$$\therefore \theta = \frac{I_e x_p - I_m r_p}{nV_S} = \frac{0.06 \times 33.1 - 0.08 \times 47.25}{5 \times 100}$$

$\theta = -12.92$

② at upf $\cos\Delta = 1$ & $\sin\Delta = 0$

$$\therefore \theta = \frac{I_S/n \cdot x_p + I_e x_p - I_m r_p}{nV_S} = 0$$

$$\frac{I_S}{n} \cdot x_p = I_m r_p - I_e x_p$$

$$\therefore I_S = [I_m r_p - I_e x_p] \cdot \frac{n}{x_p}$$

∴ $I_S = [0.08 \times 47.25 - 0.06 \times 33.1) \times 5/$ See in A.k.Sawhney

$= 0.270.$

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now $P = V_S I_S = 0.270 \times 100 = 27.09$ watts.

* A PT with nominal ratio of 2000/100V R.C.F of 0.995 at a phase angle of 22' is used with a CT of nominal ratio 100/5A, RCF of 1.005 & phase angle of 10' to measure the power to a single phase inductive load. The meters connected to the IT read correct readings of 102V, 4A & 375 watts determine the true values of voltage, c/n & power supplied to the load?

⟹ For PT k_n = rated primary / rated secondary

$= 2000 / 100V.$

$= 20.$

now Ratio correction factor $RCF = R/k_n$

$\Rightarrow R = RCF \times k_n = 0.995 \times 20 = \underline{\underline{19.9}}$

ratio error $= \frac{k_n - R}{R} \times 100 = \frac{20 - 19.9}{19.9} \times 100 = 0.5025$
$= 5.12.$

Now $R = V_P/V_S \Rightarrow V_S = V_P/R = 102/19.9$

For CT. $k_n = 100/5 = 20.$

$RCF = R/k_n = R/20 \Rightarrow R = RCF \times k_n$
$= 1.005 \times 20 = 20.1.$

% Ratio error $= \frac{k_n - R}{R} \times 100 = \frac{20 - 20.1}{20.1} \times 100 = -0.49\%$

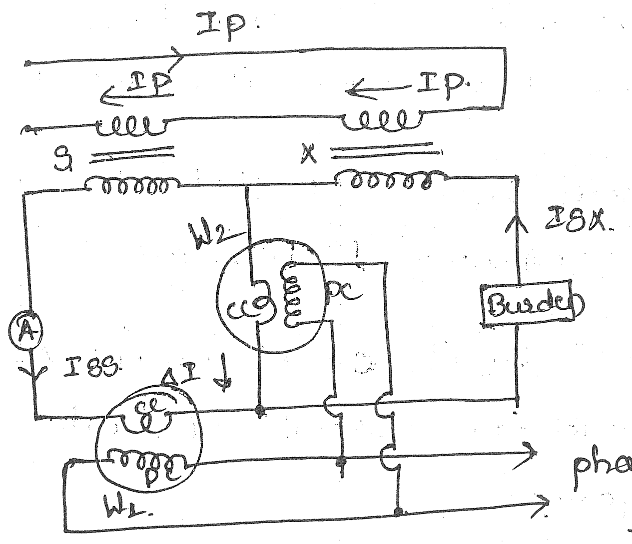
We have $R = I_P/I_S$

$\Rightarrow I_S = I_P/R = 4/20.1 = 0.199$ ~~= 0.49~~

* Testing of current transformer using silsbee's method

Silsbee's method is a comparision method, Basically there are two types of silsbee's method ie deflection & null

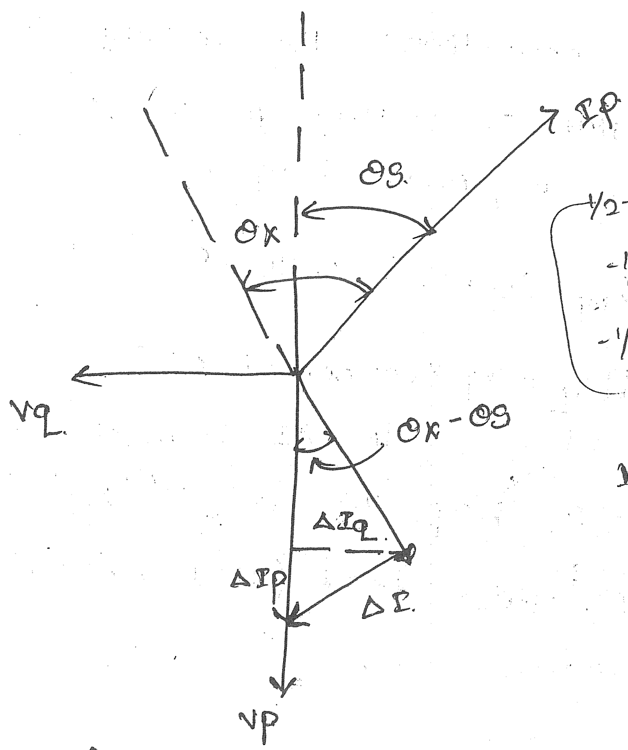
* The arrangement for the deflection method is as shown below



X – test transformer

S – standard transformer

fig - silsbee's deflection method



0+1/2+1/3+0+1/5+0

1/2+1/3+1/5	-1/2	1/3
-1/2	1/2+1/6	-1+1/6
-1/3	1/6	1/3+1/4+1/6

1.03

fig-b) phasor diagram of silsbee's method

As shown in the above fig the ratio and phase angle of the test transformer X is determined in terms of the standard transformer S having same nominal ratio

* The primaries of two transformers are connected in series, An adjustable burden is put in the secondary ckt of transformer when the transformer is under test.

* The current coil of wattmeter W_1 is connected to carry the secondary current of standard transformer S.

* The current coil of wattmeter W_2 is carries current ΔI which is the difference b/n the secondary currents of both standard & test transformer

* The pressure coils of wattmeters are supplied in parallel from a phase shifting transformer. at a constant voltage V

* The phase of voltage is adjusted such that the wattmeter W_1 reads zero. Under these conditions the voltage V is in phase with I_{SS}. The position of voltage phasor is for this case is shown as V_q in phasor diagram.

Reading of wattmeter W_1. $W_{1q} = V_q I_{SS} \cos 90° = 0$. —(1)

" " " W_2 $W_{2q} = V_q$ X component of c/n ΔI in phase with —(2)

$W_{2q} = V_q I_{Sx} \sin(\theta_x - \theta_s)$

$V_q = V_q I_q = V_q I_{Sx} \sin(\theta_x - \theta_s)$

θ_x = phase angle of C.T, i.e under test (i.e test x^Ter x)

θ_s = " " " standard C.T.

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(2) Now the phase of voltage V is shifted through $90°$ & now it occupies the position V_p & is in phase with I_{SS}.

Reading of wattmeter W_1 is $W_{1p} = V_p I_{SS} \cos 0 = V_p I_{SS}$ —(3)

Reading of wattmeter W_2 $W_{2p} = V_p \times$ component of ΔI in phase with V_p.

i.e $W_{2p} = V_p \times \Delta I_p = V_p[I_{SS} - I_{SX}\cos(\theta_x - \theta_s)]$ —(4)

If the voltage is considered as same for both the test condition then $V_p = V_q = V$.

∴ the equation (1) (2) & (3), (4) becomes

$W_{1q} = V I_{SS} \cos 90 = 0$

$W_{2q} = V I_{SX} \sin(\theta_x - \theta_s)$

$W_{1p} = V I_{SS}$ ~~cos 0~~

$W_{2p} = V_p[I_{SS} - I_{SX}\cos(\theta_x - \theta_s)]$

∴ We have

$W_{2q} = V I_{SX} \sin(\theta_x - \theta_s)$

~~$W_{1p} = V I_{SS} \cos 0$~~

$W_{2p} = V[I_{SS} - I_{SX}\cos(\theta_x - \theta_s)]$

$= V I_{SS} - V I_{SX}\cos(\theta_x - \theta_s)]$

$= W_{1p} - V I_{SX}$.

as $\theta_x - \theta_s$ is very small ∴ $\cos(\theta_x - \theta_s) = 1$

∴ $V I_{SX} = W_{1p} - W_{2p}$

Actual ratio of transformer under testing $R_x = I_p / I_{SX}$ —(5)

Actual ratio of standard transformer is

$R_s = I_p / I_{SS}$ —(6).

taking the ratio equation ⑤ & ⑥ ie actual ratio of test transformer and standard transformer.

$$\frac{R_X}{R_S} = \frac{I_P/I_{SX}}{I_P/I_{SS}} = \frac{I_{SS}}{I_{SX}}$$ Multiplying Nr & Dr by v

$$\therefore \frac{R_X}{R_S} = \frac{V I_{SS}}{V I_{SX}} = \frac{W_{1p}}{W_{1p} - W_{2p}}$$ = divide Nr & Dr by W_{1p}.

$$\therefore \frac{R_X}{R_S} = \frac{1}{1 - (W_{2p}/W_{1p})} \simeq 1 + W_{2p}/W_{1p}$$

$$\therefore R_X = R_S\left[1 + W_{2p}/W_{1p}\right]$$

We have $W_{2q} = VI_{Sx} \sin(\theta_x - \theta_s)$ & $W_{2p} = VI_{SS} - VI_{Sx}\cos(\theta_x - \theta_s)$

$$\Longrightarrow \sin(\theta_x - \theta_s) = W_{2q}/VI_{Sx} \quad (7), \quad \cos(\theta_x - \theta_s) = \frac{VI_{SS} - W_{2p}}{VI_{Sx}}$$

We have $VI_{SS} = W_{1p}$

$$\therefore \cos(\theta_x - \theta_s) = \frac{W_{1p} - W_{2p}}{VI_{Sx}} \quad (8)$$

divide equation ⑦ by ⑧

$$\frac{\sin(\theta_x - \theta_s) = W_{2q}/VI_{Sx}}{\cos(\theta_x - \theta_s) = \frac{W_{1p} - W_{2p}}{VI_{Sx}}}$$

$$\therefore \tan(\theta_x - \theta_s) = \frac{W_{2q}}{W_{1p} - W_{2p}}$$

$$\text{or } (\theta_x - \theta_s) = \frac{W_{2q}}{W_{1p} - W_{2p}} \text{ rad.}$$

phase angle of test transformer is $\theta_x = \frac{W_{2q}}{W_{1p} - W_{2p}} + \theta_s$ rad

W_{2p} is very small ∴ it is neglected

$$\therefore \theta_x = \frac{W_{2q}}{W_{1p}} + \theta_s \text{ rad} \quad \text{—— (9)}$$

from the above equation it is clear that, if the ratio & phase angle error of standard transformer is known then we can calculate the error of test transformer.

W_2 is a sensitive instrument it carry a c/n of 0.25A

* difference between CT & PT.

1) The secondary of the CT can't be open circuited, when the primary winding is carrying a current, but however in PT the secondary can be kept open circuited without carrying any damage to the transformer or operator.

2) The primary current in CT is independent of the secondary circuit conditions, whereas the primary current in PT depends on the secondary burden.

3) The excitation current of a CT varies over a wide range of normal operation where as the exciting current of PT is almost constant under normal operation.

4) As the current transformers are connected in series with the line a small voltage exist across its primary terminals, where as in PT, full voltage is applied across terminals as they are connected across the line

* The exciting c/n of CT is 2A lagging 40° to the secondary voltage reversed. The CT has a bar primary and a nominal ratio of 100/1A. The external burden is 1.5Ω & the resistance of the secondary winding is 0.25Ω, when

1A of ctn flowing through the secondary winding calculate the actual ratio of CT & its phase angle.

$\Rightarrow$ $k_n = n = I_P / I_S = 100/1 = 100$

$Z_S = 1.5 + 0.25 = 1.75$ as $x_S = 0$ $\delta = 0$

$\alpha = 90° - 40' = 50°$

$R = n + I_0 / I_S \sin(\alpha + \delta)$

$= n + 2/1 \sin(50° + 0°)$

$= 100 + 1.532$

$R = \underline{\underline{101.532}}$

$\theta = \frac{180}{\pi} \left[\frac{I_0 \cos(\alpha + \delta)}{n I_S} \right]$

$= \frac{180}{\pi} \left[\frac{2 \cos(50 + 0)}{100 \times 1} \right]$

$= 0.737° = 44.195'$ //.

3, 15, 21, 25, 28, 35, 40, 47, 50, 54, 61, -

Magnetic Measurements

The measurement of various property of Magnetic Material is known as Magnetic Measurement.

* The Magnetic materials play an important role in the operation of Electrical Machines hence measurement of various characteristics of Magnetic material is important.

* The Magnetic Measurement includes.

1) Measurement of flux density B in a specimen of ferro-magnetic material.
2) measurement of Magnetizing force H, producing the flux density B, in air
3) determination of B-H curve & hysteresis loop
4) determination of eddy current & hysteresis loss
5) testing of Permanent Magnets.

* Types of tests :- Many methods are used for testing of magnetic materials, & attempt is made to reduce inaccuracy. They are →

i) Ballistic test :- These tests are generally used for ~~obtain~~ determination of B-H curves and hysteresis loops of ferromagnetic materials.

* In this method direct current is used to provide adjus. mmf for the magnetic circuit, ballistic galvanometer or Flux meter is used for the meast of flux density.

ii) AC testing :- These tests may be carried at power, audio or radio frequency, these tests give the information about eddy current & hysteresis losses in magnetic materials.

iii) Steady State test :- These tests are used for determination of flux density in a specimen, & determination of B-H curve & plotting hysteresis loop.

* Measurement of flux density.

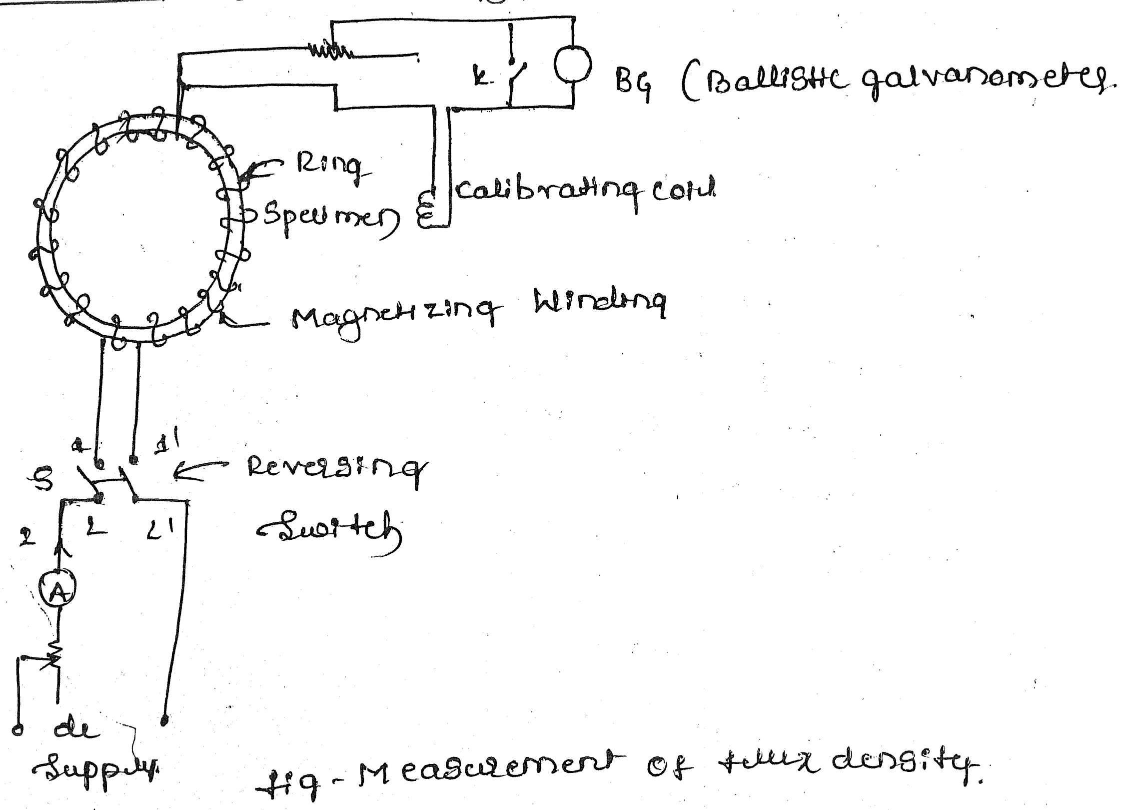


fig - Measurement of flux density.

Let us consider the ~~steady~~ measurement of flux density in a ring specimen. as shown above a coil with sufficient number of turns wound on a ring specimen.

* As shown above the coil is connected to the ballistic galvanometer.
* The magnetizing winding carries a c/n I & produces the flux to be measured. The c/n I in the magnetizing coil is reversed using reversing switch.

* With the change of direction of c/n, changes induced emf in it, This emf drives a c/n through the ballistic galvanometer, causing the corresponding deflection. (2)

Let ϕ = flux linking with search coil

N = Number of turns of search coil

R = Resistance of ballistic galvanometer circuit

t = Time required to reverse c/n I, ie time required to reverse the flux ϕ.

The avg emf induced in the search coil is

$e = N\, d\phi/dt$ Volts

Initial flux is ϕ, after reversal $-\phi$.

$\therefore\ d\phi = \phi - (-\phi) = 2\phi$

$dt = t$

$\therefore\ e = N \cdot \frac{2\phi}{t}$ V.

the avg c/n through the ballistic galvanometer is

$i = e/R = \frac{N 2\phi}{tR}$ V.

charge Q, discharged through the galvanometer during t secs is

$Q = it = \frac{N 2\phi t}{Rt} = \frac{2N\phi}{R}$ coulombs

Now the deflection of galvanometer is proportional to charge $\therefore\ Q = k\theta_1$

$2N\phi/R = k\theta_1$

or $\phi = \frac{k\theta_1 R}{2N}$.

Thus if A is the area of cross section of the specimen then flux density is given by

$$B = \phi/A = \frac{R k \theta_1}{2NA} \text{ wb/m}^2$$, Thus flux & flux density can be measured from deflection of the ballistic galvanometer.

* **Correction of Air flux**

In the above discussion, it is assumed that the flux is uniform throughout the specimen and area of cross section of search coil and specimen is equal.

But practically the cross-section of search coil is higher than that of the specimen. Hence total flux linking with the search coil is sum of the flux in the specimen and flux existing in the air gap b/n search coil & the specimen.

∴ Total flux observed = flux in specimen + flux in air gap coil & specimen

Let B' = observed value of flux density

B_t = true value of flux density

A_c = area of cross section

$$B'A = B_t A + \mu_0 H (A_c - A)$$

$$B_t = B' - \mu_0 H \left[\frac{A_c}{A} - 1\right]$$

* Measurement of Magnetizing force H.

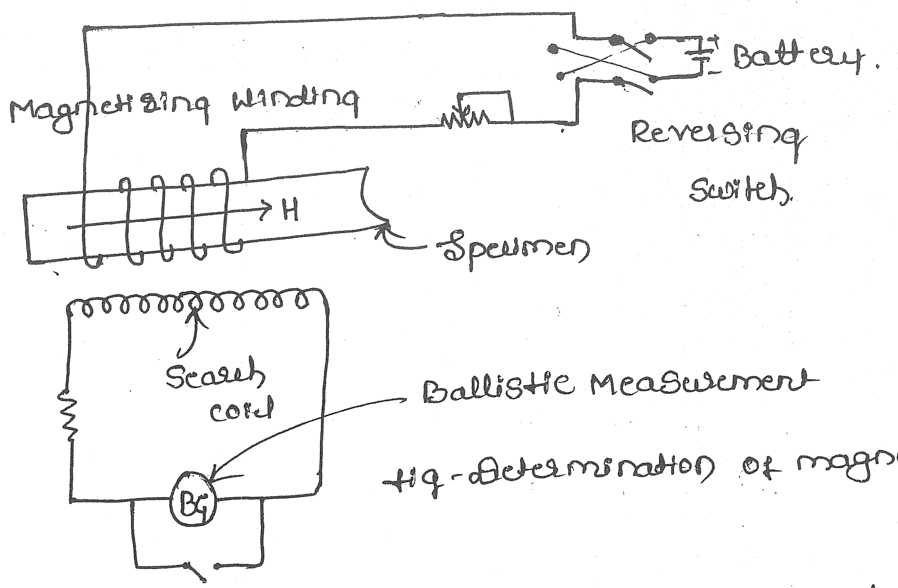


fig - Determination of magnetizing force H.

The magnetizing force H is also measured by using a search coil and a ballistic galavanometer the arrangement is as shown above.

* In such method H can't be obtained directly but it is calculated by measuring flux density by the method of current reversal.
* The position of search coil as shown above, which is used for the measurement of flux density Ba in air, by reversing current I with the help of reversing switch.
* The search coil used for such measurement is called H coil, once Bo is measured then H can be obtained as

$$H = B_0/\mu_0 \ A/m$$

where $\mu_0 = 4\pi \times 10^{-7}$ H/m.

∴ the search is to be placed in the airgap itself if H in the air gap is to be measured

* If the Magnetising force H, within the ferro-magnetic material is to be obtained, then H is measured on the surface of the specimen as tangential components of field are equal in magnitude for both the sides of the interface.

The value of H inside a specimen is calculated as

$$H = \frac{NI}{l} \ AT/m$$

Where l = mean circumference of the ring in m

N = no of turns of specime.

I = current flowing through specimen

* ~~permeameters~~ * **permeameters**

Most of the methods employed in magnetic testing are designed to avoid the errors and difficulties of the simpler ring or bar tests, these methods include the good qualities of both bar and ring specimens.

1) Hopkinson permeameter (Bar and Yoke method)

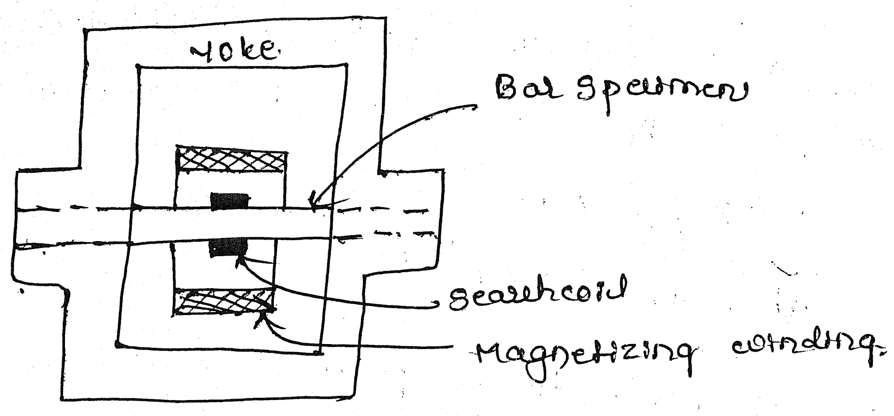


fig - Bar and Yoke method

As shown in the above fig, the test coil is wound on the central part of the Bar specimen.

* The bar is clamped b/n two halves of massive iron yoke, whose reluctance is low compared to that of the bar specimen.

* The yoke provide the return path for the flux & bar specimen is wound with a magnetizing winding.

Let N = No of turns on the magnetizing winding

I = current in the magnetizing winding

l = length of the bar specimen b/n two halves of the yoke

As = area of cross section of specimen.

μs = permeability of the specimen when the magnetizing c/n I.

Ry = Reluctance of yoke

Rj = reluctance of the joints b/n the bar specimen and yoke.

ϕ = flux in the magnetic circuit.

now the reluctance of the specimen is $R_s = 1/\mu s A_s$

$$\phi = \frac{mmf}{\text{reluctance of the magnetic circuit}}$$

$$\therefore \phi = \frac{NI}{R_y + R_j + (1/\mu s A_s)} \quad \text{—— (1)}$$

$\therefore$ the flux density in the specimen

$$B = \phi / A_s = NI \Big/ A_s(R_y + R_j + 1/\mu s A_s) \quad \text{—— (2)}$$

Magnetising force $H = \phi / A_S = \frac{NI}{A_S(R_y + R_j + 1/\mu_S A_S)}$

Let m = $\frac{\text{reluctance of (yoke+joints)}}{\text{reluctance of Specimen}}$

$$= \frac{R_y + R_j}{l/\mu_S A_S} = \frac{\mu_S A_S (R_y + R_j)}{l} \quad \text{—— (2)}$$

$$H = NI / l(1+m) \quad \text{—— (4)}.$$

$$= NI / l\left(1 + \frac{\mu_S A_S}{l}(R_y + R_j)\right)$$

now the value of m is made small by keeping the reluctance of the yoke & that joints to a small This can be done carefully by fitting into the yoke and making the cross section of yoke larger.

If m is made small then we have

$$H = \frac{NI}{l}(1-m) \quad \text{—— (2)}$$

& the value of flux density is measured is equal way by using a ballistic galvanometer. //

* Measurement of Lekage factor

In electrical Machines and other devices, the flux crossing the air gap is called useful flux while the flux in actual pole is called total flux. The useful flux is less than the total flux due to lekage flux.

* The lekage is specified by a factor called lekage factor which is the ratio of the total flux to the useful flux denoted as λ.

$$\therefore \lambda = \frac{\text{Total flux}}{\text{useful flux}}$$

* The arrangement for lekage factor measurement is as shown below.

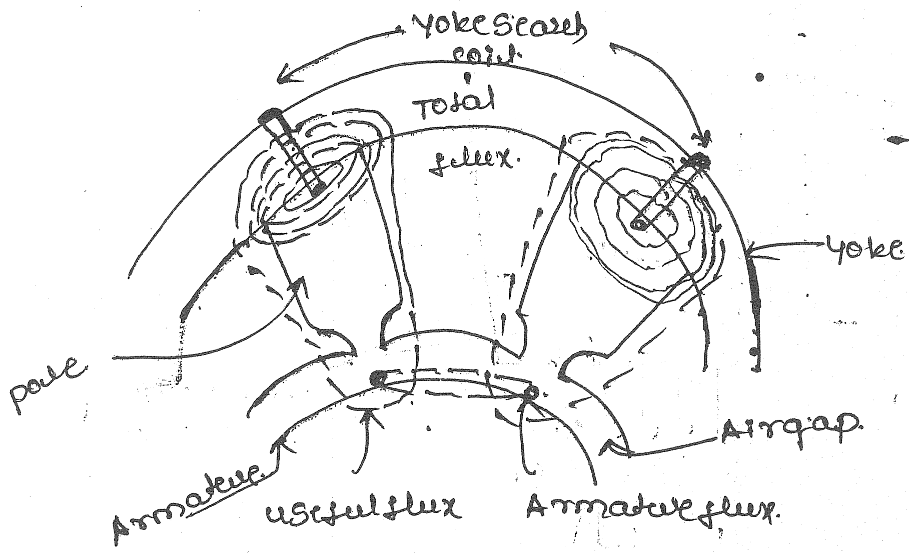


fig - Measurement of lekage factor.

* As shown above the yoke of machine carry total flux produced by the field winding wound on poles.

* Two search coils are wound on yoke of the machine

one each on the other side of pole as shown above.

* to measure the total flux the two search coils are connected in series. & the coils are connected to the fluxmeter which gives total flux of machine.

* The flux which reaches armature through airgap is called useful flux.

* Finally the ratio of two readings are obtained, which is the leakage factor of the machine.

* The search coil with only one turn are preferred in such measurements so that the flux meter directly gives the reading of the required flux

* **Measurement of iron loss using wattmeter method.**

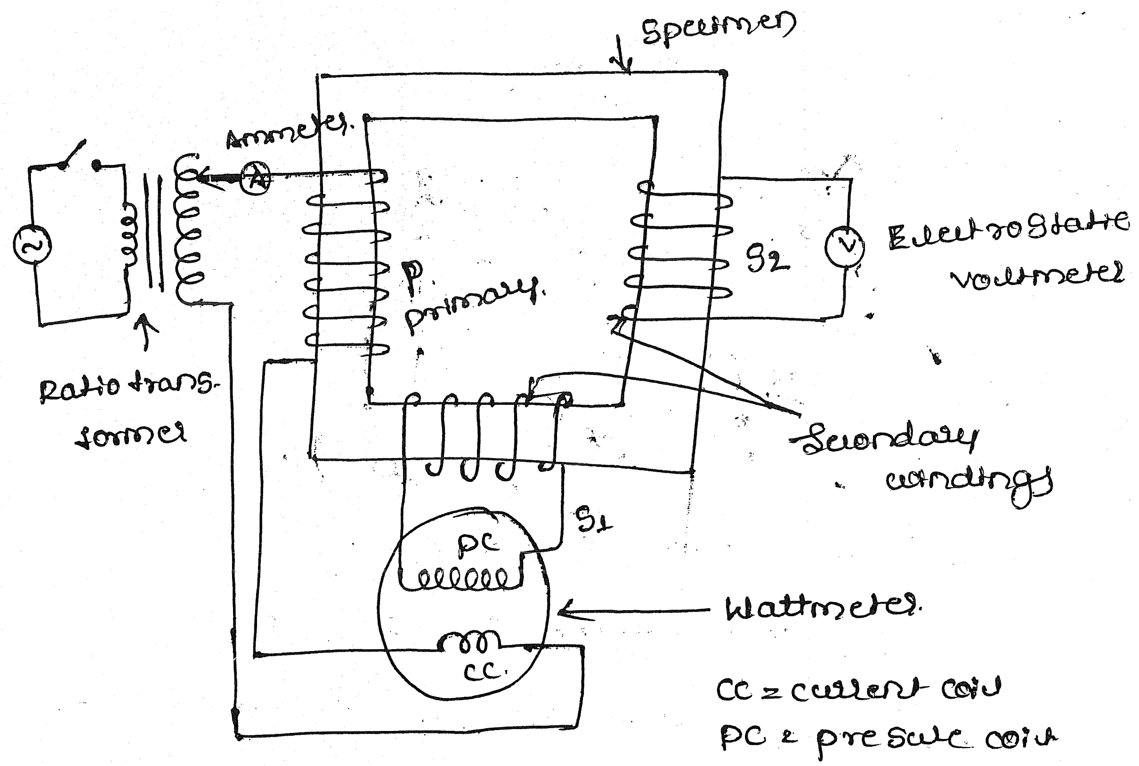


fig - Measurement of iron loss using wattmeter method.

* The above fig shows the connection diagram for the measurement of total iron loss by wattmeter method
* The weight and cross section of specimen is determined before the test
* The four Magnetizing coils are connected together to form a primary winding, it is connected to the xTR secondary through CC. of the wattmeter
* The pc is connected across one of the secondary windings$_1$ & other secondary winding S_2 is connected to the very high impedance Electrostatic voltmeter.
* The frequency of supply is adjusted to the required value, The wattmeter is LPF wattmeter with a pf = 0.2.

* Theory

The supply voltage is adjusted using the tappings on the secondary of the ratio transformer, till the required maximum flux density B_m is reached in the specimen. The voltage induced in the secondary S_2 is measured on voltmeter & the wattmeter reading is adjusted.

The voltage measured by the voltmeter is given by, $E = 4k_f(B_m' A_s) f N_2$ —(1) where $B_m' A_s = \phi_m$

Where k_f = form factor = 1.11 for sinusoidal flux

B_m' = Apparent value of max flux density in wb/m2

A_s = cross-sectional area of specimen in m^2

N_2 = No of turns in winding S_2

f = frequency in Hz

$B_m' = E / 4k_f A_S f N_2$ —— (2)

* The secondary winding S_2 encloses the flux in air gap b/n specimen & the coil, in addition to the flux in specimen.

$\therefore B_m = B_m' - \mu_0 H \left[\frac{A_c}{A_S} - 1 \right]$ —— (3)

Where B_m = maximum flux density required.

A_C = cross section of coil in m^2

A_S = cross section of specimen in m^2

H_m = Magnetizing force required to develop max flux density in A/m.

* The H_m can be obtained from B-H curve for the specimen.

* The wattmeter reading (W) consists of

V_{PC} = voltage across the pc in V

I_{pc} = current through the pc in A

r_p = Resistance of pc in Ω.

r_S = resistance of the secondary winding in Ω.

E = voltage induced, S_2 = Voltmeter reading

The voltage induced in S_1 is same as S_2

∴ voltage induced in S_1 = E

Neglecting the leakage reactance of S_1 & leakage reactance of pc as it is highly resistive

$E = I_{pc} r_p + I_{pc} r_s = I_{pc}(r_p + r_s)$ —— (4)

while $V = I_{pc} r_p$.

∴ The total iron loss (P_i) in specimen + total copper loss in the secondary circuit $= \frac{WE}{V}$

Total copper loss in the secondary circuit is

$= I^2_{pc}(r_p + r_s) = E^2/(r_p + r_s)$ —— (5)

$\therefore P_i = \frac{WE}{V} - \frac{E^2}{(r_p + r_s)}$ | where $E = I_{pc}(r_p + r_s)$, $V = I_{pc} r_p$.

$= \frac{W I_{pc}(r_p + r_s)}{I_{pc} r_p} - \frac{E^2}{(r_p + r_s)}$ ~~divide Nr & Dr~~ by ~~$I_{pc} r_p$~~

$= W\left[1 + \frac{r_s}{r_p}\right] - E^2/(r_p + r_s)$ watts.

However by conducting test at different frequencies iron loss can be separated from hysteresis loop//.

* Measurement of Air gap flux.

The various methods for the measurement of airgap flux are →

1. Deflection of a pivoted magnetic needle → the classical magnetometer method.
2. The rapid rotation of search coil through 180° - for example - classical earth indicator.
3. continuous rotation of a search coil fitted with a commutator to give a dc output.

(4) continous rotation of search coil fitted with slip-rings to give an ac output.

(5) The force on a current - carrying inductor in the field

(6) The effect of field on the magnetization of a small piece of soft iron by an ac in a magnetizing winding.

* Measurement of field strength by withdrawl of search coil.

1) In this method a search coil is placed in a magnetic field & the terminals of search coil are connected to ballistic galvanometer.

2) The search coil is suddenly withdrawn from the magnetic field, due to which the flux linking with the search coil changes

3) The change of flux induces an emf in the search coil which causes the galvanometer to deflect & we can measure from the galvanometer the flux density & field strength.

* Measurement of constant field strength by Nuclear Magnetic Resonance.

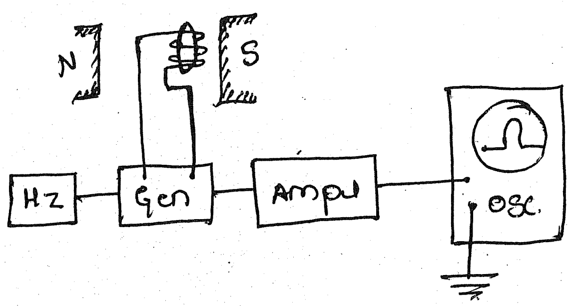


fig - Measurement of field strength by nuclear magnetic resonance

When an alternating magnetic field of high (8)
frequency is superimposed on atomic nuclei is located in a
constant magnetic field, resonance absorption of energy
from high-frequency field is liable to occur at a
specific ratio of the constant field strength H to
frequency f of the alternating field.

The laws of quantum mechanics postulate
that the magnetic moment of hydrogen nucleus may be
oriented either in the same direction as that of the
external magnetic field or in opposition to it.

The orientation of proton magnetic moment
can be changed by application of an energy quantum hf
where h is planck's constant & f is frequency.

The difference b/n the two energy states of the
proton amounts to 2mpH where mp is the proton
magnetic moment.

Evidently, $hf = 2m_pH$ & we know that $\omega = 2\pi f$
& $f = \omega/2\pi$.

$\therefore h \times \frac{\omega}{2\pi} = 2m_pH.$

$\omega = \frac{4\pi m_pH}{h}$

$= \nu pH.$

or $H = \frac{2\pi f}{\nu p} = \omega/\nu p.$ —(1)

Where νp is gyromagnetic ratio of nucleus, ie the ratio
of magnetic moment to the mechanical moment.

According to this method the magnetic
strength of a constant field is determined by measuring

the frequency at which nuclear magnetic resonance occurs. Resonance is detected by sharp change in the amplitude of the resonance curve traced on the screen of the cathode-ray oscillograph at a change in the oscillator frequency. This method is more suitable for the measurement of field having a magnetic strength of 800 to 1.6×10^6 A/m. The accuracy of meast lies within ± 0.01 %.

[illegible] 20/10, [illegible], 18, [illegible]

Module - 4 Electronic and digital Instruments

* ~~Essentials of electronic instruments~~

* Comparision

Electronic meters	conventional analog meters
1) The electronic components such as rectifiers, transistors, diodes etc are used	1) The electronic components are not used
2) Amplifiers are present	2) Amplifiers are absent
3) Low Level signal detection is possible	3) Low level signal detection is not possible
4) power consumption is low	4) power consumption is high
5) Loading effects are less	5) very severe loading effects
6) sensitivity is high	6) sensitivity is less
7) Input impedance is very high	7) Input impedance is low
8) The frequency is very high	8) The frequency range is limited
9) The accuracy is very high	9) The accuracy is comparatively less
10) The meters are compact and portable	10) The meters are not compact and portable.
11) The meters are not rugged	11) The meters are rugged.

* Electronic instruments

Ordinary conventional instruments such as ammeter, voltmeter, ohmmeter & wattmeter measures the c/n, voltages, resistance, & power. The sensitivity of these instruments is very small, they can't be constructed for full scale sensitivity less than 50μA or 10mV ~~for full scale sensitivity less than 50~~. in such case the Electronic instruments use the amplifiers to measure the values.

* The advantages of Electronic instruments are

1) **Detection of low level signals** :- It is possible to measure the currents & voltages of smaller range than 50μA & 10mV using electronic ammeter & voltmeters.

2) **Low power consumption** :- The sensitivity of an ordinary voltmeter is about 20kΩ/V for 0 - 0.5V range voltmeter & has an input resistance of 10kΩ & full scale c/n of 50μA, But However the electronic voltmeter have an input resistance of 10MΩ to 100MΩ & it has less loading effects & the power consumption in electronic instruments is far less than the conventinal instrument

* **High frequency range** → With the help of electronic voltmeters the voltage of source can be measured whose frequency can vary from zero Hz to several hundreds of MHz, However the response of these electronic instruments can also be made independent of the frequency.

iv) Electronic instruments are used to measure both low as well as high voltages. ②

v) the response of electronic instrument is faster & flexible 27

vi) Electronic instruments can be used to monitor remote signals.

* True RMS Reading voltmeter

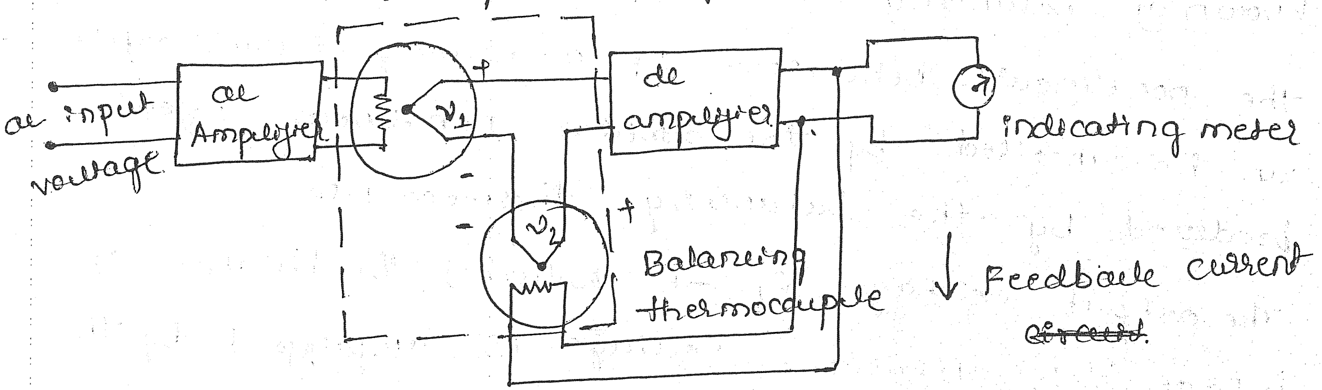


fig- True rms Reading voltmeter.

1) True rms values of the voltages of complex wave-forms of any type i.e sine, square, saw tooth etc can be accurately measured with the help of true rms reading voltmeter.

2) Initially an ac supply voltage of any complex waveform is applied to the input terminals of the meter, the input voltage is amplified with the help of ac amplifier

3. The amplified voltage is applied to the heating element of measuring thermocouple.

4) Thermocouple is a junction of two dissimilar metals whose contact potential is a function of the temperature of the junction.

(5) The heat produced in the measuring thermocouple increases the temperature of thermocouple & produces a voltage of v_1, which is proportional to E^2_{rms} of the applied voltage.

(6) one difficulty with this technique is, that the thermocouple is often nonlinear in its behaviour this difficulty can be overcome by connecting another thermocouple known as balancing thermocouple.

(7) the nonlinear behaviour of measuring thermocouple can be cancelled by the similar non linear effect produced by the balancing thermocouple.

(8) The output voltage v_1 disturbs the balance of bridge. this unbalance voltage is amplified by the dc amplifier & feedback to the heating element of balancing thermocouple.

(9) The balance of the bridge is achieved when the sufficient amount of heat, is produced in the balancing thermocouple due to fedback. & it produces an o/p vtg v_2.

(10) The output voltages of both the thermocouples are equal & opposite in direction hence the bridge is balanced.

(11) When the bridge is balanced the output voltage of the measuring thermocouple v_1 becomes equal to the balancing thermocouple. v_2 i.e $v_1 = v_2$

(12) when the bridge is balanced the dc i/p flowing through the balancing thermocouple becomes equal

to rms value of ac current flowing through the (3).
measuring thermocouple. This dc current is directly proportional to the rms value of input voltage & which is indicated by indicating meter.

* Electronic multimeter (VOM)

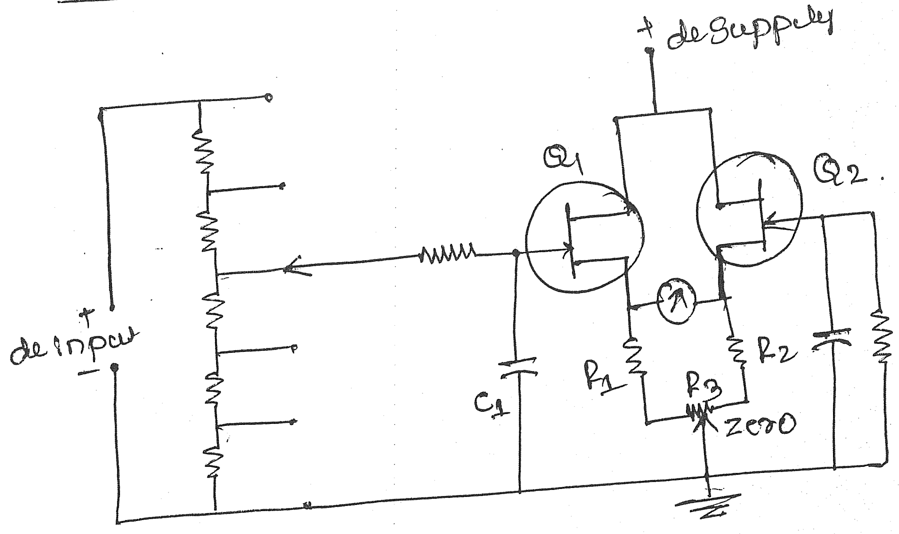


fig - Electronic multimeter.

An electronic multimeter is also called as volt-ohm meter it is one of the most important laboratory instrument, which is used to measure both dc and ac voltages & resistances.

The above fig shows schematic diagram of electronic multimeter it consisting of following elements.

1) A balanced bridge dc amplifier with an indicating meter.

2) An input Range switch, to limit the magnitude of input voltage to the desired value.

3) A rectifier to convert ac input to a propotional dc-voltage.

4) internal battery & additional circuitary, for the measurement of resistance.

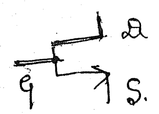
5) A functional switch to select various function measurement of meter.

In addation to the above all elements it has built in power supply for operation on ac power lines & one or more batteries for the operation of portable measuring instrument.

The balanced bridge dc amplifier consists of two FET'S (Field effect transistors), They must have the same current gain for the thermal stability of the circuit.

* The two FET'S will form the upper arm of bridge while the Resistor R_1, R_2 & with zero adjustment resistor R_3 will form the lower arm of bridge.
* The indicating meter is connected in b/n the two source terminals of FET'S.
* When their is no input supply the gate terminal of FET is at its ground potential & no. c/n flow through the indicating meter. under this condition the bridge is balanced
* Due to small difference in the operating characteristics of two FET'S & slight tolerance b/n the various resistors of the bridge ckt. their must be slight unbalance in drain currents & indicating meter shows small deflection from zero.
* the balance of bridge can be done by adjusting R_3 resistor. this electronic multimeter can be used either as a voltmeter or ohm meter.

Q. (8), 8b, 8c



* Electronic voltmeter ⇒ (1) When a +ve voltage is applied to ~~drain~~ gate terminal of FET Q_1, its drain current increases due to which the voltage at the source terminal increases.

(2) then their is a unbalance b/n the source voltages of Q_1 & Q_2, due to which the pointer of the indicating meter deflects on the scale, which gives the applied input vtg.

(3) The maximum voltage that can be applied to the gate of Q_1 is determined by its operating range, which is usually of the order of few volts.

The range of input voltages to be measured can be easily extended with the help of range switch as shown below.

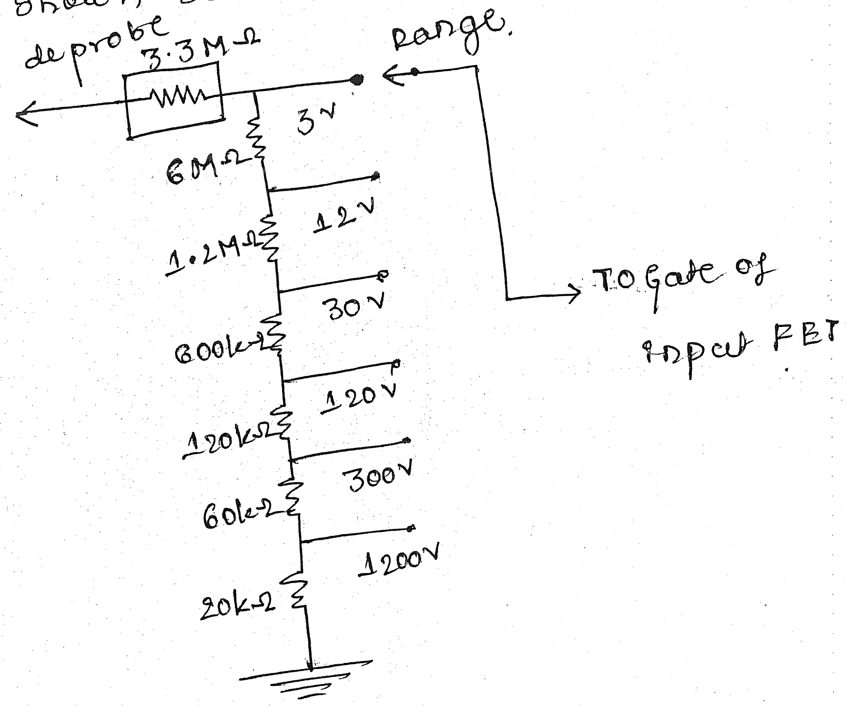


fig - Range switch.

* The unknown dc input voltage is applied through ⑤
a large resistor in the probe body to a resistive
voltage divider, * with a Range switch at 3V position, as
shown above

* The voltage at the gate of the input FET Q_1 is
developed across 8 MΩ of the total resistance 11.3 MΩ
& the ckt is arranged so that the indicating meter should
deflect to full scale with 3V.

* With the range switch on 12V position the gate voltage
is developed across 2 MΩ of the total resistance 11.3MΩ
& input voltage of 12V is required for full scale
deflection of the indicating meter.

* The range switch allows the selection of the desired
voltage range from 3V to 1200V. ~~the~~

* Electronic ohmmeter

1) When the electronic multimeter is used as electronic
ohmmeter, the function switch on the front panel of
the meter is placed on OHMS position.

2) The unknown resistance is connected in series with
the internal battery & the meter measures the voltage
drop across the unknown resistance.

3) The resistance range selector switch along with
amplifier & indicating meter is as shown below.

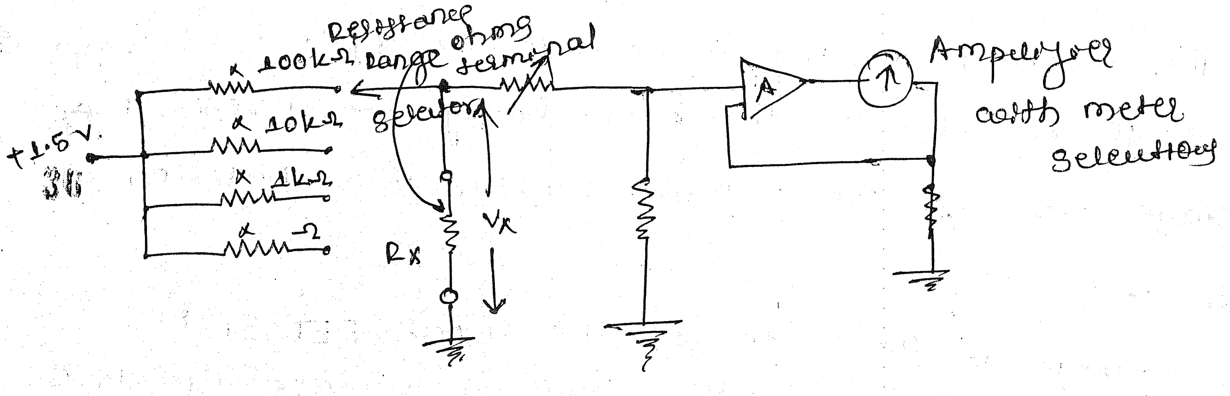


fig - Resistance range selector circuit

(4) A separate divider network is used for the purpose measuring the resistance, which provides different ranges.

(5) When the unknown resistance Rx is connected to the OHMS terminal of the multimeter, it is connected in series with an internal battery of 1.5V. This internal battery supplies the current through the one of the resistor of range & unknown resistor to ground

(6) The voltage drop across Rx is ~~determined by the meter~~ applied to the input of bridge amplifier due to which the indicating meter shows the deflection.

(7) the voltage drop Vx is directly proportional to unknown resistance value Rx.

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A — ~~4, 5, 11, 12~~, ~~17~~, 28, ~~33~~, 34, 42, 43, 46, ~~47~~, ~~48~~, 56, 57, 58, ~~59~~, ~~61~~,
62, 63,

* Digital voltmeters

A DVM displays the measurement of dc or ac voltages as discrete numericals, unlike a pointer deflection on a scale in analog meters.

* The general outstanding operating & performance characteristics of a DVM are as follows.

i) **Measurement Range** :- From ± 1.000000 V to ± 10,00,000 V with automatic range selection and overload indication

ii) **Accuracy** :- The accuracy is high as ± 0.005% of the reading.

iii) **Stability** :- 0.002 % for a short term period of 24 hours and 0.008% for a long period of 6 months.

iv) **Resolution** :- 1 part in 10^6 ie 1 μV can be read on 1V range voltmeter

v) **Input characteristics** :- The input resistance is about 10 MΩ & input capacitance is about 40 pF.

vi) **calibration** :- The calibration is independent of the measuring ckt & is derived from stabilized from reference source

vii) **output signal** :- The output to printer is BCD for digital processing or recording.

* classification of digital voltmeters

1) Ramp type of DVM
2) Integrating DVM
3) potentiometric DVM
4) Successive-approximation DVM

* Ramp type DVM

1) The principle of operation of Ramp type of DVM is based on the measurement of time taken by a linear ramp voltage to rise from 0V to the level of input voltage or it is time taken to decrease from the level of input voltage to zero volt.

② This time can be measured with the help of electronic time - interval counter. & the no of counts are displayed as a digital number on electronic indicating tubes.

③ Now the conversion of voltage to a time interval is illustrated with the help of waveform as shown below

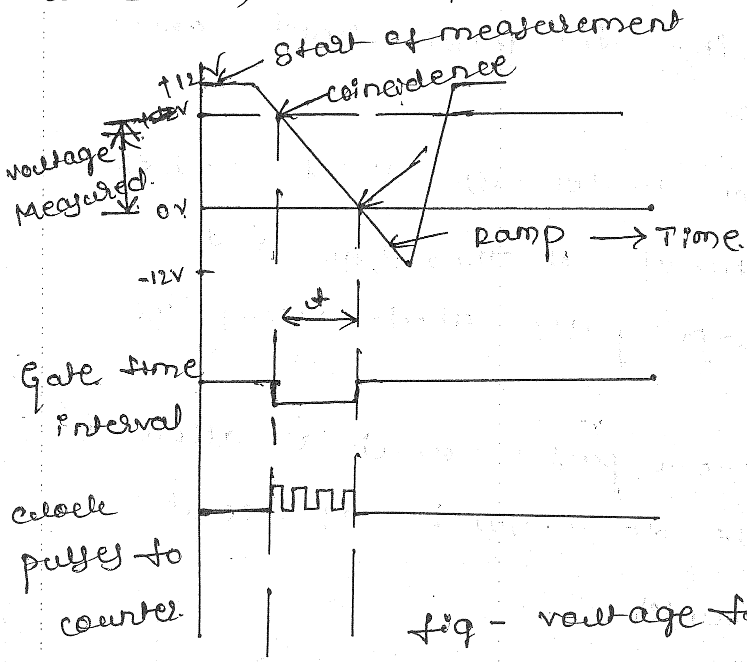


fig - voltage to time conversion

④ As shown in the above fig at the start of measurement cycle, a ramp voltage is initiated, which may be a +ve going or -ve going.

⑤ In the above a -ve going ramp voltage is continuously compared with the input voltage. At the certain instant when ramp voltage becomes equal to the input voltage

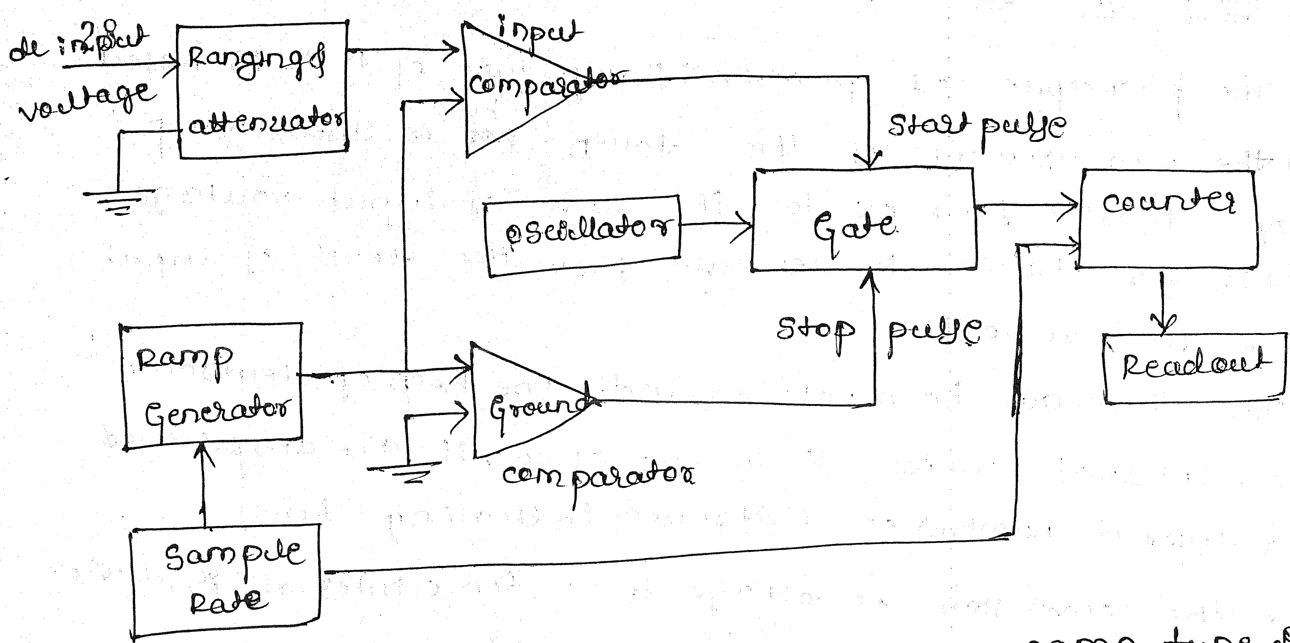


fig-b. Block diagram of ramp-type DVM.

a comparator will produces the the pulse which opens the gate as shown in fig b.

(5) A ramp voltage continues to decrease & it reaches a zero volt. or ground potentional, at this type 2nd comparator generates an output pulse which closes the gate.

(6) An oscillator generates clock pulses which are allowed to pass through the gate to a number of decade counting units (DCU). or counter.

(7) The total number of pulses are displayed in decimal number with the help of indicator tubes associated with DCU'S., it is measure of the magnitude of the input voltage.

* Integrating type of DVM

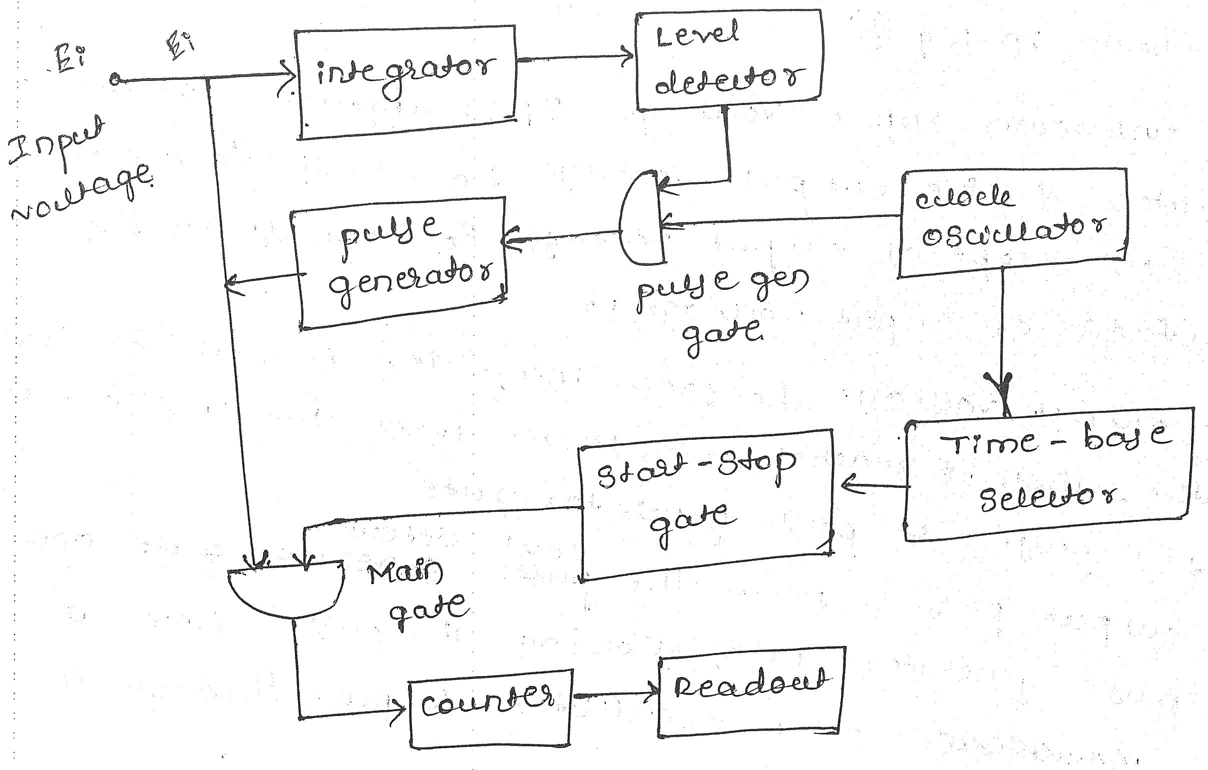
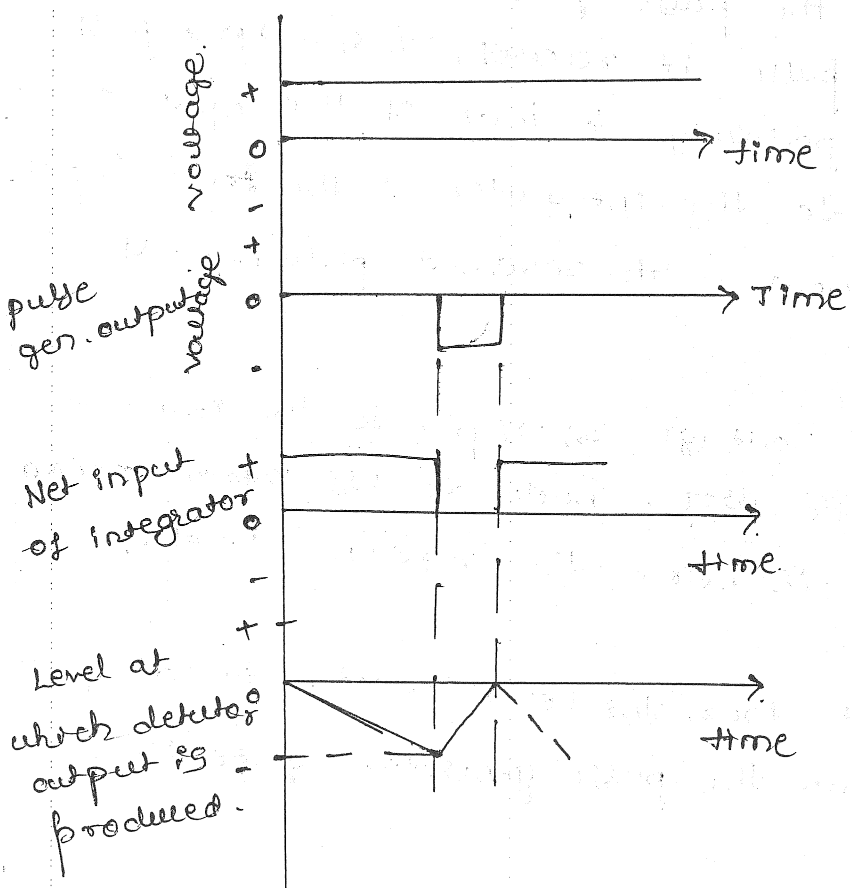


fig - a) integrating - type DVM.



1) The Block diagram of integrating type of DVM is as shown in fig (a) & the corresponding waveforms are shown in fig (b).

(2) The unknown input voltage Ei is applied to the integrator & the output voltage Eo starts to increase. Here the slope of output voltage Eo depends on the magnitude of input voltage Ei.

(3) The output voltage Eo from integrator is fed to level detector, when it reaches a reference level, the level detector sends a pulse to pulse generator gate.

(4) The output pulse from the ~~pulse~~ Level detector ~~generator gate~~ opens the pulse generator gate, allowing the pulses from a fixed ~~magnitude~~ clock oscillator to pass through the pulse generator.

(5) The output pulse of the pulse generator is of fixed magnitude & every pulse it receives. This output pulse is have the opposite polarity to that of the input voltage & which is feedback to the integrator. ∴ the ~~total~~ input to the integrator is now with reversed polarity as shown in fig (b).

(6) due to the reversed voltage as input to the integrator the output voltage Eo drops back to its ~~input voltage~~ original level, which is below the reference Level of Level detector.

(7) ∴ their no output from the Level detector to the pulse generator gate & hence the pulse generator gate is closed.

(8) When the pulse generator gate is closed there is (9) no pulses from the clock oscillator will pass to pulse generator to trigger it.

9) When the output voltage will pass from the pulse generator. Ei is again restored & Eo starts increasing the same procedure will repeats. Thus the output voltage Eo will be in saw tooth waveform, whose raise time depends on the value of output voltage Eo & fall time depends on the width of the output pulse from the pulse generator.

10). The frequency of the sawtooth wave may be measured by counting the number of pulses for the given time interval.

1). The pulses from the clock oscillator are applied to the time base selector. The 1st pulse pass through the start - stop gate, produces an output which is applied to the Maingate. thus it opens the maingate due to this the same output pulse will pass from the pulse generator through main gate.

12) The next pulse from the time base selector closes the start - stop gate hence the main gate is also closed.

13) Now the counter & Readout meter will reads number of pulses that have passed during the specified time interval. indicator gives the voltage to be measured The amplitude & width of the pulses from the pulse generator can be adjusted to make the counter to read voltage directly.

* potentiometer DVM.

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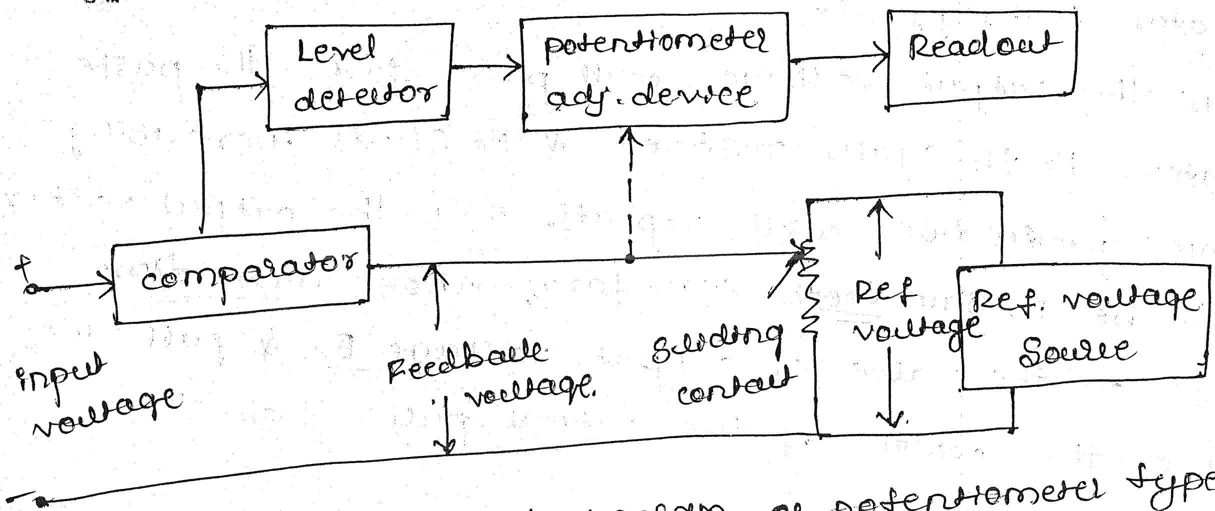

fig - Block diagram of potentiometer type DVM.

1) The block diagram of potentiometer type of DVM is as shown above, in which the unknown voltage is compared with the reference voltage whose value is fixed.

2) When the unknown voltage is applied to the meter, the balance is automatically obtained & the unknown voltage is directly read with the help of readout provided in the circuit. Hence this potentiometer meter is also known as self balancing potentiometer.

3) The unknown voltage is filtered & attenuated to a suitable level. The input voltage is applied to the comparator, which is also known as error detector.

4) The unknown voltage is obtained from the fixed voltage source & it is applied to the potentiometer R.

5) The value of feedback voltage depends on the position of sliding contact.

* The unknown voltage & reference voltage are compared (10)
in the comparator & its output is the difference of both
33
the voltage, which is known as error signal.

* The error signal is amplified and fed to the potentiometer adjustment device, which moves the sliding contact of the potentiometer.

* The direction of the movement of sliding contact depends on whether the feedback voltage is larger or input voltage is larger.

* The movement of sliding contact stops when the feedback voltage is equal to the unknown voltage. hence there is no error signal & no input to the potentiometer adjustment device

* The position of the potentiometer adjustment device at this point is indicated in numerical form on the digital readout device. the reading of this readout meter gives the value of the unknown voltage.

* the automatic adjustment of the sliding contact is done by a two phase servometer.

* Successive - Approximation DVM

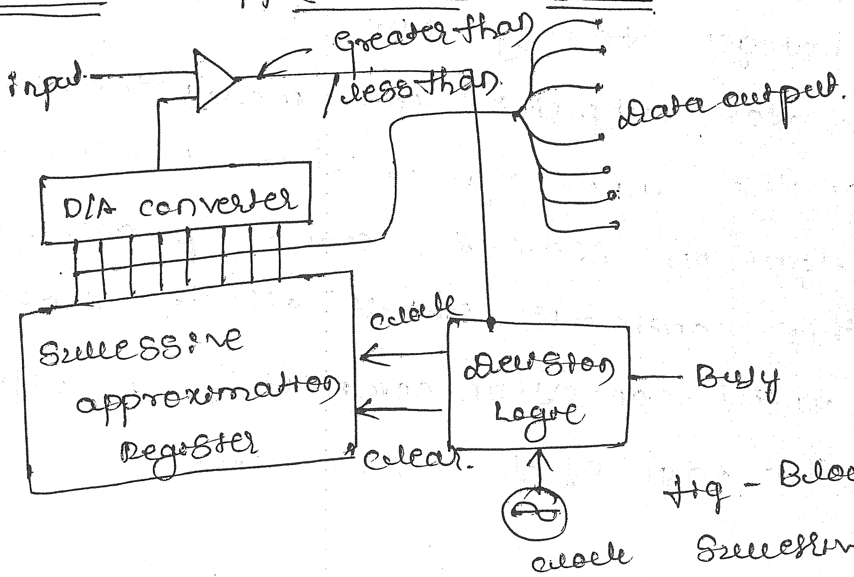

fig - Block diagram of Successive - Approximation DVM

1) A very effective & relatively inexpensive method of A/D conversion is the method of Successive Approximation method.

2) this is a electronic implementation which is known as regression. The electronic implementation of the successive approximation is a straight forward & the block diagram of ADC uses this principle.

3) As shown in the above fig D/A converter provides estimate & it is compared with the input signal. An estimate is a numeral which is approximately around the voltage which is to be measured. However equal to or greater than, less than decision is made by the comparator.

④ A special shift register known as successive approximation register (SAR) is used to control D/A converter & they the estimate.

⑤ At the beginning of the conversion all the outputs from SAR is logic zero.

⑥ If the estimate is greater than input, the comparator output is high & the 1st SAR o/p reverses state & 2nd output changes to logic one.

⑦ If the comparator output is low, means the estimate is lesser than the input signal then the 1st o/p remains in logic one state & second o/p assumes logic one state this continues, ~~until all the states~~ to all states until conversion completes. An estimate is made on the edge of the SAR clock.

* Q-meter (11)

Q meter is an instrument, which is used to measure some of the electrical properties of inductive coils & capacitors. The principle on which Q meter works is the principle of reasonance.

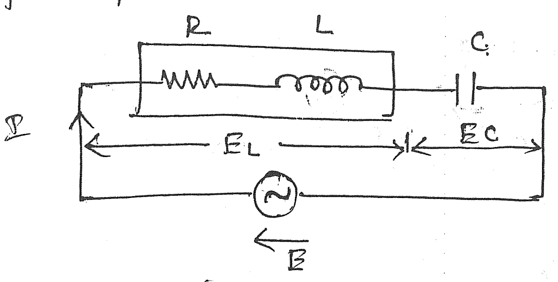

fig-a) series reasonant circuit

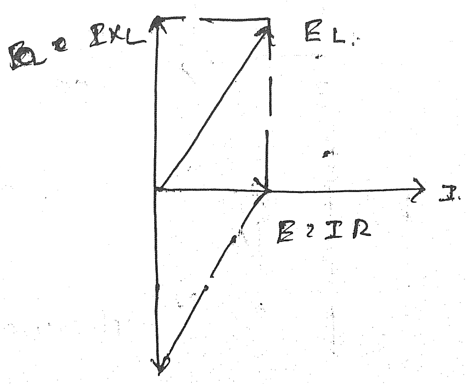

fig b) vector diagram

The above fig ⓐ & fig ⓑ represent a series reasonant circuit & vector diagram respectively. at reasonance p.f of the circuit is unity & we have certain conditions at the resonance

$X_L = X_C$ —— ①

$E_C = IX_C = IX_L$ & $E = IR$ —— ②.

where E = applied voltage, I = current in the circuit

X_L = inductive reactance of the coil,

R = Resistance of the coil

X_C = capacitive reactance of the capacitor.

E_C = voltage across the capacitor.

The Q factor of the circuit is the voltage modification of the ckt under resonant conditions

ie $Q = X_L/R = X_C/R = E_C/E$ —— ③.

from the above equation it is clear that if E is maintained constant then voltmeter connected across capacitor directly read Q factor of the circuit.

imp. * The circuit diagram for the measurement of Q factor is as shown below.

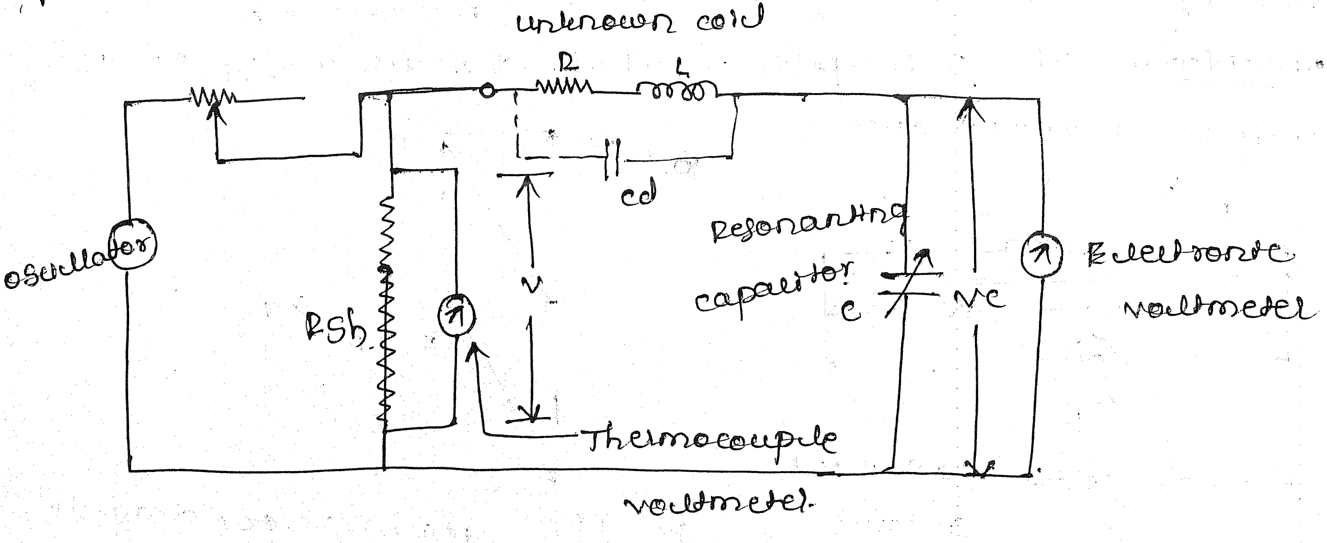

fig - Q-meter circuit

1) As shown in the above fig a wide-range of oscillator with the frequency range of 50kHz to 50MHz is used as power supply to the circuit, this oscillator supplies current to a low range shunt resistance Rsh. However the value of shunt resistance is low of the order 0.02Ω.

2) The low value shunt resistance introduces a no resistance into the oscillatory circuit & therefore it represents a voltage source of magnitude E with small internal resistance.

3) The voltage E across the shunt is measured with thermocouple voltmeter

4) Now the voltage across the variable capacitor ie Ec is measured by the electronic voltmeter whose scale is calibrated ~~to~~ read the Q factor directly

5) to measure the Q factor of the circuit, the inductive coil is connected across the test terminals of the

instrument & the circuit is tuned to resonance (12) either by varying the frequency of the supply from the oscillator or by varying the value of resonanting capacitor. If the electronic voltmeter is not calibrated to read the Q factor of the ckt.

The two voltage ratios E_c & E are noted at the resonance the ratio of both the voltages gives the Q factor ie $Q = E_C/E$ —(4)

The real value of the Q factor is slightly more than the value indicated by the meter.

Now the inductance of the coil can be calculated by the known values of the frequency & the capacitance of the resonanting capacitor.

At resonance $X_L = X_C \Rightarrow 2\pi f L = 1/2\pi f C$

$$\therefore L = 1/(2\pi f)^2 C.$$

* Measurement of Low impedance components

The low impedance components such as low value resistors, small coils & high value capacitors are measured by connecting them in series with the measuring circuit as shown below.

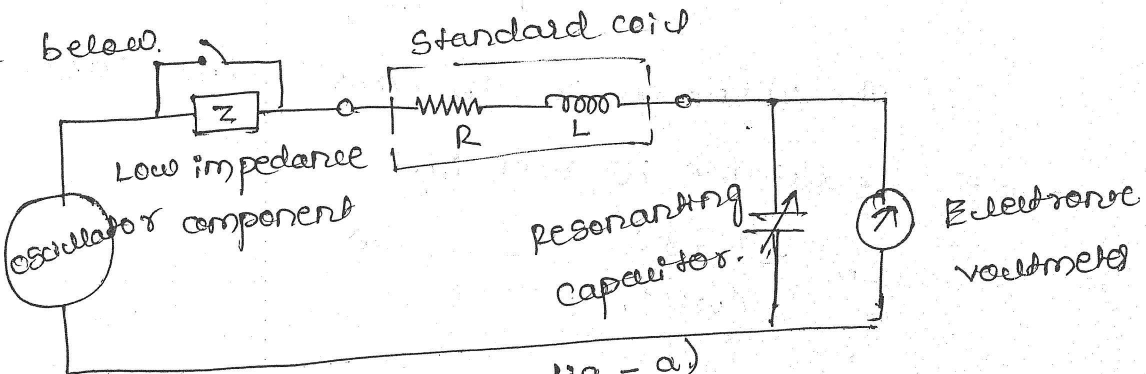

fig - a)

① As shown in the above fig the component which value is to be measured ie Z is connected in series with a standard coil whose R & L are accurately known & which is connected across test terminals
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② two measurements are to be made, in the 1st meast the unknown component Z is short circuited by small shorting strap & the value of resonating capacitor is adjusted to C_1 for which the circuit is under resonant condition. the corresponding values of C, & Q factor Q_1 are noted as follows.

At resonance $X_L = X_{C_1} \Rightarrow \omega L = 1/\omega C_1$ —— ①

$$Q_1 = \frac{\omega L}{R} = \frac{1}{\omega C_1 R} \quad \text{—— ②}$$

* In the 2nd measurement the shorting strap is opened & the value of resonating capacitor is adjusted to value C_2. at which the circuit is under resonant condition. the value of Q_2 is noted as follows

$X_L = X_{C_2}$

$\Rightarrow X_L + X_m = X_{C_2}$ where X_m = reactance of the unknown impedance

$$X_m = X_{C_2} - X_L$$
$$= X_{C_2} - X_{C_1}$$
$$= 1/\omega C_2 - 1/\omega C_1 = \frac{C_1 - C_2}{\omega C_1 C_2} \quad \text{—— ②}$$

If the unknown Z is small inductance then the value of inductance is given by

$$L_m = \frac{C_1 - C_2}{\omega^2 C_1 C_2} \quad \text{—— ③}$$

L_m is inductive if $C_1 > C_2$ & L_m is capacitive if $C_1 < C_2$

Now the Resistance R_m of the unknown impedance Z is calculated as $R_2 = X_{C2}/Q_2$ Where $R_2 = R + R_m$ = total resistance of the circuit.

$\therefore R_m = R_2 - R$

$$= \frac{X_{C2}}{Q_2} - \frac{X_{C1}}{Q_1} = \frac{1}{\omega C_2 Q_2} - \frac{1}{\omega C_1 Q_1} = \frac{C_1 Q_1 - C_2 Q_2}{\omega C_1 C_2 Q_1 Q_2} \quad (3)$$

*If the unknown impedance is purely resistive then the value of capacitor is $C_1 = C_2$

$$\therefore R_m = \frac{Q_1 - Q_2}{\omega C_1 Q_1 Q_2} \quad (4)$$

Now Q-factor of unknown impedance is

$$Q_m = \frac{X_m}{R_m} = \frac{C_1 - C_2 / \omega C_1 C_2}{C_1 Q_1 - C_2 Q_2 / \omega C_1 C_2 Q_1 Q_2}$$

$$\therefore Q_m = \frac{(C_1 - C_2) Q_1 Q_2}{C_1 Q_1 - C_2 Q_2} \quad (5)$$

If the unknown impedance Z is large capacitor then

$$C_m = 1/\omega X_m = \frac{\omega C_1 C_2}{\omega [C_1 - C_2]} = \frac{C_1 C_2}{C_1 - C_2} \quad (6)$$

By using equation (5) we calculate the Q factor.

* Measurement of High impedance components

The high impedance components such as high value resistors, inductors & low value capacitors are measured by connecting them in ||el with the measuring circuit as shown below.

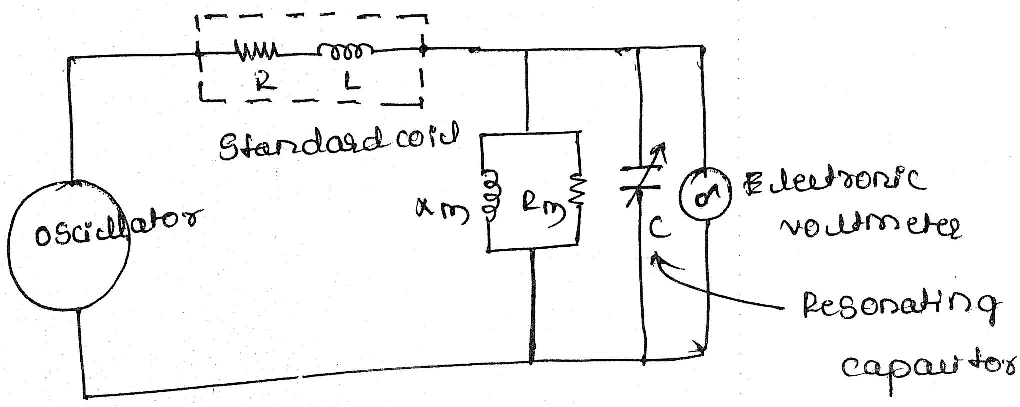


fig -

As shown in the above fig the unknown impedance z is a ||el combination of X_m and R_m

during 1st measurement the unknown impedance z is not connected in the circuit & the value of resonating capacitor is adjusted to a value C_1 at which the circuit is in resonance

at resonance $X_L = X_{C_1} \Rightarrow \omega L = 1/\omega C_1$ —— (1)

$Q_1 = \frac{\omega L}{R} = 1/\omega C_1 R$

* during 2nd measurement the unknown impedance z is connected in the circuit, now the value of resonating capacitor is adjusted to C_2 at which the circuit is in resonance

the reactance of the standard coil X_L is

∴ now the reactance equal to ||el combination of unknown reactance X_m & reactance of resonating capacitor X_{C_2}

$$\therefore X_L = \frac{X_m \, || \, X_{C_2}}{X_m + X_{C_2}}$$

$$\text{or } X_L (X_m + X_{C_2}) = X_m X_{C_2}$$

or ~~X_m~~ = ~~$\frac{X_L (X_m + X_{C_2})}{X_{C_2}}$~~

$$X_L X_m + X_L X_{C2} = X_m X_{C2}$$

$$X_{C2} X_m - X_L X_m = X_L X_{C2}$$

$$X_m (X_{C2} - X_L) = X_L X_{C2}$$

$$\therefore X_m = \frac{X_L X_{C2}}{X_{C2} - X_L} = \frac{1/\omega C_1 \times 1/\omega C_2}{1/\omega C_2 - 1/\omega C_1} = \frac{1}{\omega (C_1 - C_2)} \quad \text{—— (2)}$$

If the unknown impedance is inductive then $X_m = \omega L_m$ and hence

$$\therefore L_m = X_m/\omega = 1/\omega^2 (C_1 - C_2)$$

* If the unknown impedance is capacitive then $X_m = 1/\omega C_m$ and $C_m = C_1 - C_2$
* In a parallel resonant circuit, the total resistance of the circuit at resonance is equal to the product of Q factor of the circuit Q_2 & reactance of the standard coil X_L

$$\therefore R_T = Q_2 X_L$$
$$= Q_2 X_{C_1}$$
$$= Q_2/\omega C_1$$

* The resistance of the unknown impedance i.e R_m is determined by taking conductance

$$\therefore G_T = G_m + G_L = 1/R_T = \omega C_1/Q_2$$

now $G_m = G_T - G_L$

$$1/R_m = 1/R_T - 1/R_L$$
$$= \frac{\omega C_1}{Q_2} - R/R^2 + \omega^2 L^2$$

$$1/R_m = \frac{\omega C_1}{Q_2} - 1/R\left[\frac{1}{1+Q_1^2}\right]$$

normally the value of Q_1 is very large $\therefore 1+Q_1^2 = Q_1^2$

$$\therefore 1/R_m = \frac{\omega C_1}{Q_2} - 1/RQ_1^2$$

We have $Q_1 = 1/\omega C_1 R$

$Q_1^2 = 1/\omega^2 C_1^2 R^2$

$$= \frac{\omega C_1}{Q_2} - \frac{1}{RQ_1 \cdot Q_1}$$

$$= \frac{\omega C_1}{Q_2} - \frac{1}{RQ_1 \cdot \frac{1}{\omega C_1 R}}$$

$$= \frac{\omega C_1}{Q_2} - \frac{\omega C_1}{Q_1} = \frac{\omega C_1 Q_1 - \omega C_1 Q_2}{Q_1 Q_2} = \frac{\omega C_1 (Q_1 - Q_2)}{Q_1 Q_2}$$

or $R_m = Q_1 Q_2 / \omega C_1 (Q_1 - Q_2)$

now Q factor of the circuit is $Q_m = \frac{R_m}{X_m}$

* Errors

1) Error due to distributed capacitance.

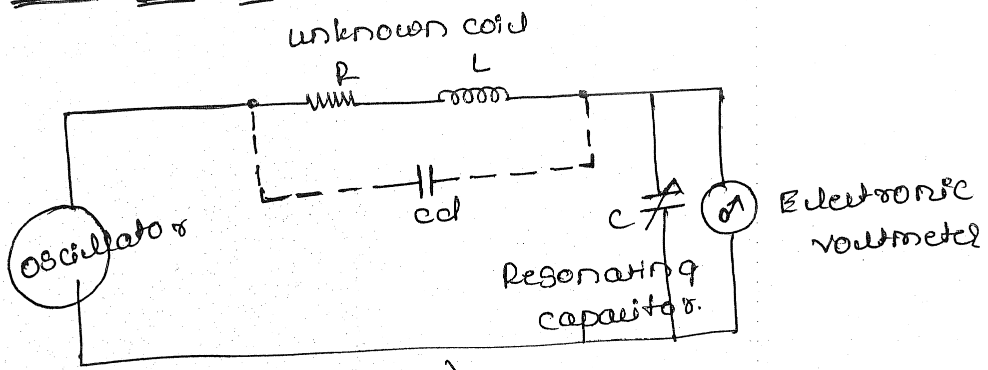


fig - a)

The distributed capacitance Cd or self capacitance of the measuring circuit is the important source of error during the measurement of Q factor & inductance of the coil. The value of Cd of a coil is measured by making two measurements at two frequencies of the circuit as shown below (15)

The coil under test is directly connected b/n test terminals of the measuring circuit. The resonanting capacitor is tuned at two different frequencies f_1 & f_2. & two values of C_1 & C_2 are noted down.

Normaly $f_2 = 2f_1$

Then $f_1 = \frac{1}{2\pi\sqrt{L[C_1+Cd]}}$ —— (1)

& $f_2 = 1/2\pi\sqrt{L(C_2+Cd)}$ —— (2)

as $f_2 = 2f_1 \Rightarrow f_2 = \frac{2}{2\pi\sqrt{L[C_1+Cd]}}$ —— (3)

from equations (2) & (3)

$$\frac{1}{2\pi\sqrt{L[C_2+Cd]}} = \frac{2}{2\pi\sqrt{L[C_1+Cd]}}$$

squaring on both the side

$$\frac{1}{L[C_2+Cd]} = \frac{4}{L[C_1+Cd]}$$

$$1/C_2+Cd = 4/C_1+Cd$$

$$\therefore Cd = \frac{C_1 - 4C_2}{3}.$$

However the effective value of Q with Cd is less than the true value of Q of the coil.

True value of Q factor is given by

$$Q = Qe\frac{C+Cd}{C}$$

Where Qe is the effective value of Q or indicated value of Q.

ii) **Error due to insertion resistance Rsh.**

The value of insertion resistance is very small is of the order 0.02 Ω. The error due to Rsh depends on the magnitude of the unknown impedance. However the error due to insertion Resistance Rsh is neglected, if the coil resistance is 10 Ω, but it must be considered when coil resistance is 0.1 Ω.

iii) **error due to residual inductance of the instrument**

The residual inductance of the instrument is very small, of the order 0.015 μH and affects the meast of only small inductors of values less than 0.5 μH However its effect may be neglected when higher values of inductances are measured.

iv) **Error due to conductance of Q voltmeter.**

The conductance of the Q voltmeter has a shunting effect on the tuning capacitor at high frequencies, However this effect is usually neglected.

* A standard coil is connected across the terminals of a Q meter and resonance is attained, when the frequency of the supply is 160kHz and the value of the resonant capacitor is 200pF and the Q factor read is 80. An unknown impedance is connected in series with a standard coil and resonance is obtained ~~when~~ when the value of the ~~the value of the resonant~~ resonant capacitor is 180PF and the Q factor read

is 50, frequency of the supply being the same. calculate the resistance and inductance of the coil. (16)

⇒ Solution :-

$$R_m = \frac{C_1 Q_1 - C_2 Q_2}{\omega C_1 C_2 Q_1 Q_2}$$

$$= \frac{200 \times 10^{-12} \times (80 - 180) \times 10^{-12} \times 50}{2\pi \times 160 \times 10^3 \times 200 \times 10^{-12} \times 180 \times 10^{-12} \times 80 \times 50}$$

$$R_m = 48.354\,\Omega$$

$$X_m = \frac{C_1 - C_2}{\omega C_1 C_2} = \frac{200 \times 10^{-12} - 180 \times 10^{-12}}{2\pi \times 160 \times 10^3 \times 200 \times 10^{-12} \times 180 \times 10^{-12}}$$

$$= 552.62\,\Omega$$

$$L_m = \frac{X_m}{2\pi f} = \frac{552.62}{2\pi \times 160 \times 10^3} = 0.5497\,mH$$

* A coil is tuned to resonance at 600kHz with a resonating capacitance of 40μμF. At 800kHz, the resonance is obtained with a resonating capacitance of 17μμF. Find the self-capacitance of the coil and its inductance

⇒ $$C_d = \frac{C_1 - 4C_2}{3} = \frac{175 \times 10^{-12} - 4 \times 40 \times 10^{-12}}{3} = 5 \times 10^{-12}\,F = 5\mu\mu F$$

$$f_1 = \frac{1}{2\pi\sqrt{L(C_1 + C_d)}}$$

$$300 \times 10^3 = \frac{1}{2\pi\sqrt{L(175 \times 10^{-12} + 5 \times 10^{-12})}}$$

$$L = \frac{1}{(2\pi \times 300 \times 10^3)(180 \times 10^{-12})} = 1.564\,mH$$

* Compute the value of the shunt capacitance of a coil when the Q meter circuit is tuned to resonance

i) When $f_1 = 2MHz$, $C_1 = 450pF$ and ii) when $f_2 = 5MHz$, $C_2 = 60pF$.

$\Rightarrow$ $f_1 = 1/2\pi\sqrt{L[C_1+Cd]}$ and $f_2 = 1/2\pi\sqrt{L[C_2+Cd]}$

or $\frac{f_2}{f_1} = \frac{\sqrt{L[C_1+Cd]}}{\sqrt{L[C_2+Cd]}}$ or $\frac{f_2^2}{f_1^2} = \frac{C_1+Cd}{C_2+Cd}$

$$\frac{5^2}{2^2} = \frac{450\times10^{-12}+Cd}{60\times10^{-12}+Cd}$$

$\therefore Cd = 14.29\ pF$

* A coil with a resistance of 12Ω is connected across the test terminals of a Q meter circuit and resonance occurs when the frequency of the oscillator is 1000kHz and the capacitance of resonating capacitor is 75pF. Calculate the % error introduced in the calculated value of Q due to an insertion resistance of 0.02Ω across the oscillator?

$\Rightarrow$ Actual value of Q-factor $Q = Qa = 1/\omega CR$

$$Q = Qa = \frac{1}{2\pi\times1000\times10^3\times75\times10^{-12}\times12} = 176.84.$$

Indicated value $Q = Qi = 1/\omega C(R+0.02)$

$= 1/2\pi\times1000\times10^3\times75\times10^{-12}\times(12+0.02)$

$= 176.54.$

$$\%\ error = \frac{Qa-Qi}{Qa} = \frac{176.84-176.54}{176.84}\times100 = 0.17\%$$

* **Electronic energymeter**

An electronic energymeter has the following advantages over the conventional energymeter.

1) There are no friction losses.

2) The various adjustment for low load, full load, pf, creeping etc, are not necessary.

3) The common errors found in the conventional energymeter are not found in electronic energymeter.

4) Accuracy is more which is about ±1%.

*

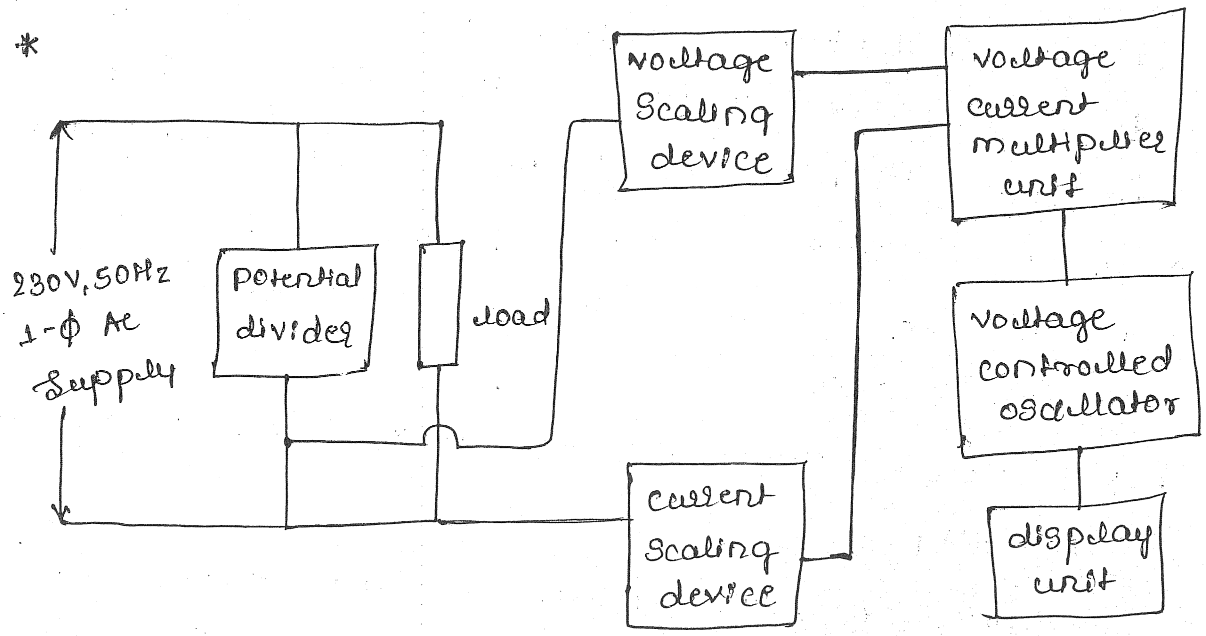


fig - Electronic Energymeter.

The blockdiagram of Electronic Energymeter is as shown above, An electronic energymeter extensively uses integrated circuits for its operation.

* the measurement of energy is basically a process of the measurement of power & the time duration of its consumption.

* The electronic energymeter operates in two stages. in the 1st stage it acts as wattmeter and measures the power consumed by the load in watts.

* In the 2nd stage the power consumed for a particular interval of time is monitored. However the conversion of watts into watt-hours takes in the 2nd stage.

The operation of electronic energymeter is explained with the help of block diagram as shown above.

The average power is equal to the mean product of the instantaneous voltage across the load & instantaneous current through it. The supply voltage is brought to proper level by voltage scaling device

* Another voltage developed by the c/n is proportional to the load current is determined by the current scaling device.

* Both these voltages are feed to a 4 quadrant voltage c/n multiplier unit

* multiplier performs product of alternating voltage & c/n, oscillator generates a square wave, the frequency of which depends on the output current of the quadrant multiplier.

* The combination of power dependent c/n & frequency dependent c/n gives the energy consumed by the load in watt hours.

* The analog signal is ~~coverted to~~ converted to digital using ADC and displayed on display unit.

Module - 5 - Display devices.

In any electrical & electronic measurements, it is necessary to display the information about the quantity being measured, in order to have a record of what is to be measured.

* A recorder is a device whose function is to record the value of a quantity which is to be measured.
* A recorder helps to preserve the experimental data which could be obtained at any instant & it also gives the information about waveforms, transient behaviour & phase relationships of the quantities recorded in the different parts of circuit.

* Segmental displays.

The segmental displays are either 7 or 14 segmental, depending on whether the display is numeric or alphanumeric.

* Seven Segment display.

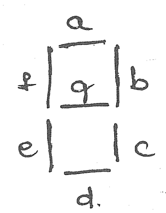


fig - 7 segment display.

The above fig shows a 7 segment display, used for numeric display. It consists of seven segments a, b, c, d, e & f, and g.

* By illuming proper segments any numeric can displayed.
* as shown above if all the segments are illuminated & the digit displayed is 8.

* If only the segment f & c is illuminated then the displayed digit is 1. like this way all the digits from 0 to 9 is displayed.

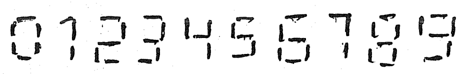


fig - Seven Segment display of digits

* The display is incandescent & it operates on low voltages (12.48 V) and it requires 10 to 50mA c/n when using LEDS, LCDS are also used for 7 segment displays.

b) Fourteen Segment displays

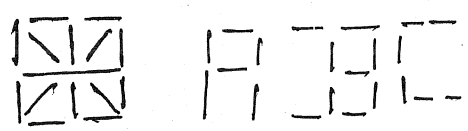


fig-a) 14 Segment display

fig-b) display of alphabets A, B & C.

for the display of alphanumeric, a fourteen segment display is used, as shown above.

* Nixie tubes.

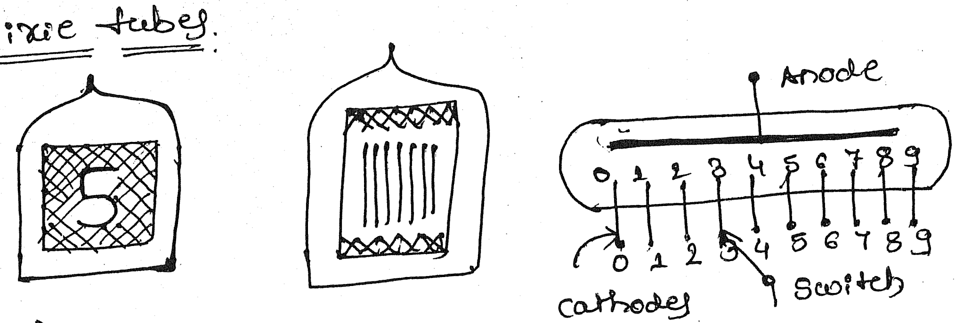


fig-a) Front view

b) side view

c) Schematic diagram

A nixie tube is a non-polarnar digital display device as shown in fig a, b & c.

* It is a cold cathode glow discharge tube, which is popularly known as nixie ~~tube~~, The display works based on the principle that, when gas breaks down, a glow discharge is produced

* A ~~s~~ gauge electrode with a +ve voltage supply functions as anode, as shown above it consisting of 10 separate cathode wires, each in the shape of numeral from 0 to 9

* The electrodes are enclosed in a gas filled envelope with connecting pins at the botoom, usually a neon gas is used which gives an orange red glow, when it is activated, different gases can be used for different colours

* it consisting of one anode & 10 cathode, when -ve voltage is applied to the selected cathode, a simple gas discharges & selected digit will lights

* The nixie tubes are bulkier in size than seven segment displays.

* Modern nixies not only display ~~decimal~~ digits from 0 to 9 but it also display decimal symbol, + and - signs.

* They have 15 cathode segments, which are used to display numeric as well as alphanumeric characters.

* Light Emitting diode (LED)

The LED is a device which produces visible light, when it is energised.

* LEDs are semiconductor diodes which normally use gallium arsenide and gallium arsenide phosphide, which emit visible electromagnetic radiation, red in colour under forward biased condition.

* However the combination of other semiconductor materials give other colours such as amber, green, yellow etc.

* due to lower power requirement, high operating speed, & high reliability made LED's are favoured type of displays.

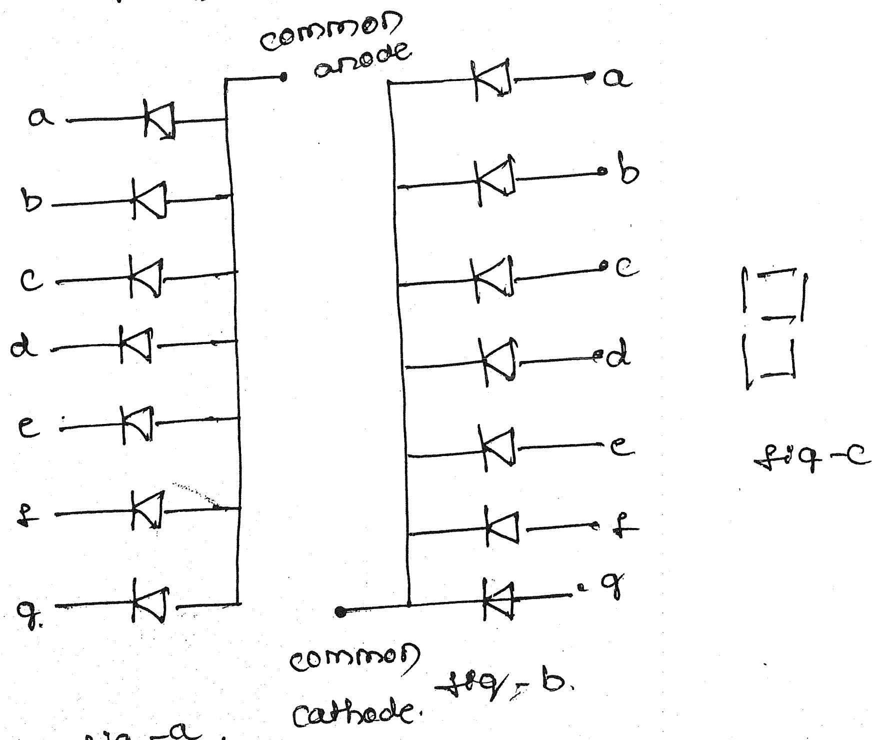


fig-a, fig-b. fig-c

fig-1a) wiring pattern of LED

* Liquid crystal display (LCD)

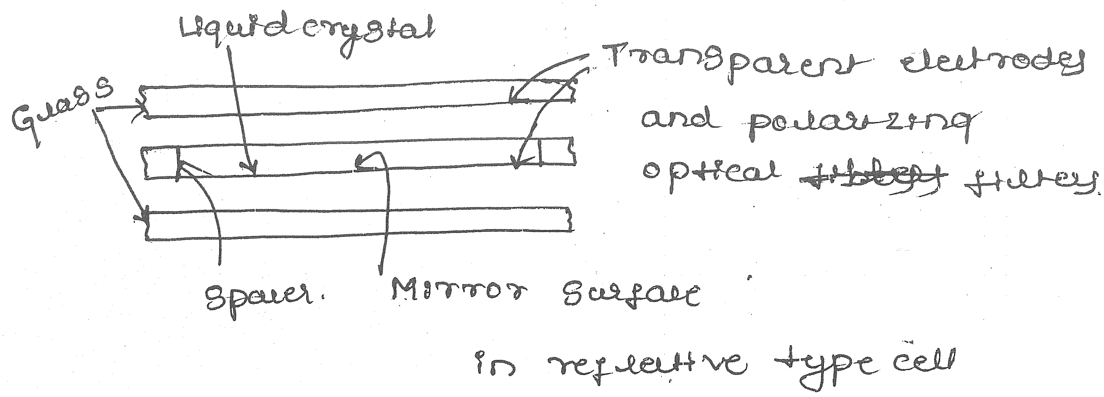


fig-a) construction of LC cell

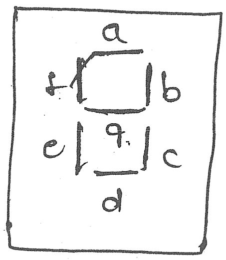


fig-b) Liquid crystal cell, 7 segment display

* The Liquid crystals exhibit properties of liquid as well as solid. They are the compounds having crystalline arrangement of molecules, but they still flow like liquid.

* However the liquid crystal displays do not emit or generate light, but they alter externally generated illumination.

* depending on the principle of operation there are two types of LCDs.

i) dynamic scattering LCD.

ii) field effect LCD.

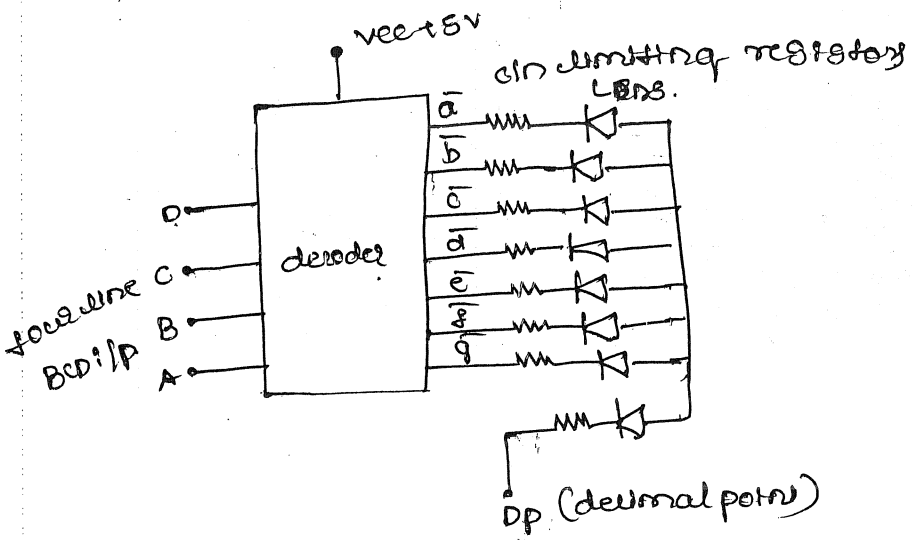


fig-2) LED 7 segment display driver.

The above fig a represents the wiring pattern of LED 7 segment display having common anode for all seven segments. & fig b represents common cathode display.

The common cathode LEDS have to be driven by 'active-high' decoder ICs and the common anode LEDS are driven by active low decoders which is connected to seven-segment display as shown above.

Current limiting resistors are included in series with each of the LED'S corresponding to the seven segments.

* An additional LED corresponding to the decimal point is also provided in the display along with c/n limitting resistor. The values of series resistor is 150Ω & c/n is 20mA.

* principle of operation

The cross section of field effect liquid crystal cell is as shown in fig a

* The liquid crystal material may be one of several organic compounds that exhibit the optical property of crystal.
* as shown above it consists of two glass plates, a liquid crystal fluted, is sandwitched b/n two glass sheets with transparent electrodes deposited on the inside faces.
* When the Lc cell is not energized, the liquid crystal material twists & the light passes through the cell which allows the light to pass through the optical filters and cell disappears into the background.
* When cell is energized, their is no twisting of light & energized cell in 7-segment display stand out against their background as shown in fig b.

* advantages of LCD

1) Low cost
2) uniform brightness with good contrast.
3) Less consumption of energy

* disadvantages

1) Reliability is less.
2) Limited temp range.
3) Slow speed (4) it requires an ac drive

* Liquid vapour display.

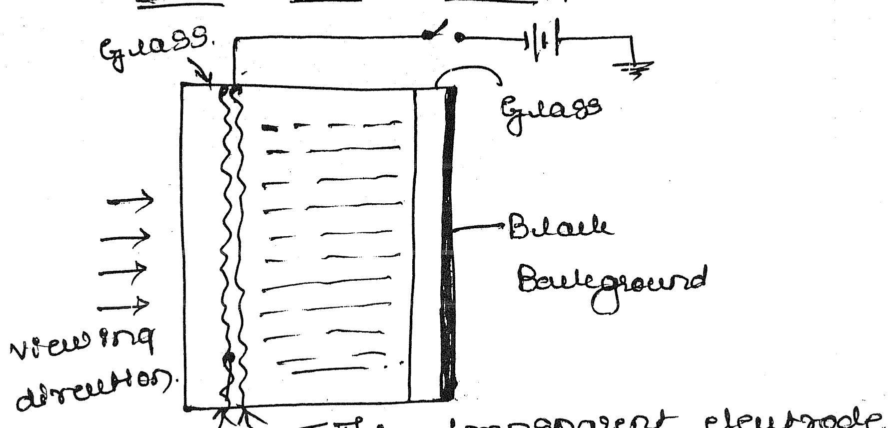


fig - LCD cell.

The construction of liquid vapour display is as shown in the above fig,

* as shown above it consisting of two Glass plates with transparent liquid enclosed in it.
* The background of a rear glass is totally black.
* The voltage drive is used to heat a transparent electrode,
* during OFF condition of the display, only the black background is viewed through transparent glass electrode.
* To make display on, voltage is applied to the electrode, generating heat in electrode.
* which evaporates the liquid, ∴ around the Roughened surface vapour films & vapour bubbles are formed.
* due to which there is discontinuity b/n the glass plate & liquid surface hence light scattering

takes place

* However, refractive index of the liquid should be close to the glass.

* The drawback of LVD is speed of operation is very low.

* **Dot Matrix display.**

A dot matrix display uses a LED at each dot location in Matrix. A matrix is formed with the wiring patterns

* The most commonly used dot matrices are 5x7, 5x8, 7x9, out of these three patterns, 5x7 wiring pattern is most commonly used.

* The wiring patterns may be a common anode or common cathode type.

* **Bar Graph display.**

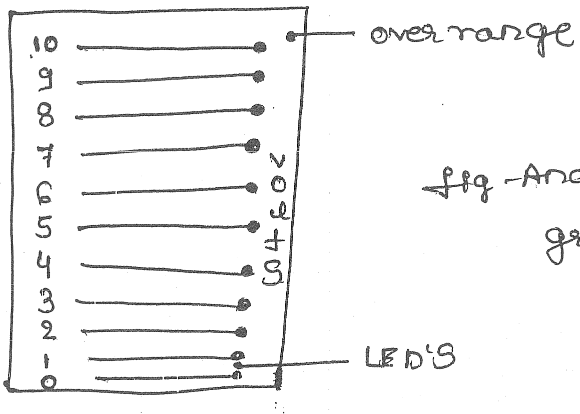


fig - Analog meter using bar graph of LED'S.

The bar graph display is an analog display. In this display, the display elements are arranged in a column. in a linear array.

* The dot LEDS are independently driven so that

the length of the array corresponds to the voltage or current measured

* These are used in panel meters which accept analog input signals & produce equivalent display of input signal.

[* Incandescent

A seven-segment display is a set of seven bar-shaped LED or LCD elements. ~~arranged to form a squared~~ A few seven segment displays use other illumination devices such as incandescent or gas-plasma ("neon") lamps.

* An incandescent bulb, incandescent lamp or incandescent light globe is an electric light with a wire filament heated to such a high temperature that it glows with visible light.

* The filament is heated by passing an electric current through it, it is protected from oxidation with a glass or quartz bulb which is filled with inert gas.

* Fluorescent (vacuum fluorescent display) - is a display device which is commonly used on consumer-electronics equipment such as video cassette recorders, car radios & microwave ovens. A VFD - ~~works~~ operates such as CRT.]

* Character formats

The choice between the display devices and recorders depends on i) the excepted use of the output ii) The information content of the output.

The 1st factor depends on whether whether the o/p is useful for human observation or to be stored for other purpose or it is an input to the digital computer.

* The 2nd factor is influenced by the fact that the output is single valued or is in the form of time or frequency

* depending on the type of output format required, the devices are divided into fallowing types

1) Single no output device :- In such devices the output is time invariant quantity over a particular period of time, and it is displayed as a single number representing the value of quantity being measured.

* the single number may be a short interval of time for example - indicating instruments & digital display devices

2) Time domain output devices => In such a device, the o/p being measured is the function of time, & display units are not satisfactory except for outputs which change very slowly with time.

If the information is to be stored for a particular time, then storage type CRT can be used.

3) Machine interruptible output devices :- In such a device, the o/p must be in such format that, a machine

a mle must be abde to read it

* The mlc interruptible output may be in the analog form or digital form

* A ~~single~~ signal recorded on a magnetic tape, punched card, a floppy disc or hard disc may be used as an input for output devices like digital display unit a printer or a digital computer.

* Incandescent & Fluorscent displays

There are various types digital display s/m is the visual form. The LED and LCD displays are very popular & they are most commonly used in hand held mlcs like calculators

* Some of the other forms used in displays are Incandescent & Fluorscent displays.

* Incandescent displays can be made in wide range of sizes and colours & they are brightest displays

* the main disadvantage of Incandescent display is a low reliability due to segment failure

* The incandescent displays have seven segment filaments contained within a single vacuum envelope & they are compatible with std TTL voltages

* Multiplexing is not advantageous for this type of display, since each of the display segment require a diode to prevent leakage paths.

* The fluoroscent displays are mainly used in calculators & the colour of display is blue-green

The character height is upto 1.5cm, their low c/n ≃1mA, and low voltage (30V) are ideal for multiplexing.

* **Display multiplexing.**

In a display device the digits are driven by a decoder. By time sharing the decoder, it is possible to reduce the count of components & interconnections in display systems.

A typical circuit scheme for multiplexing eight seven segment displays is as shown below.

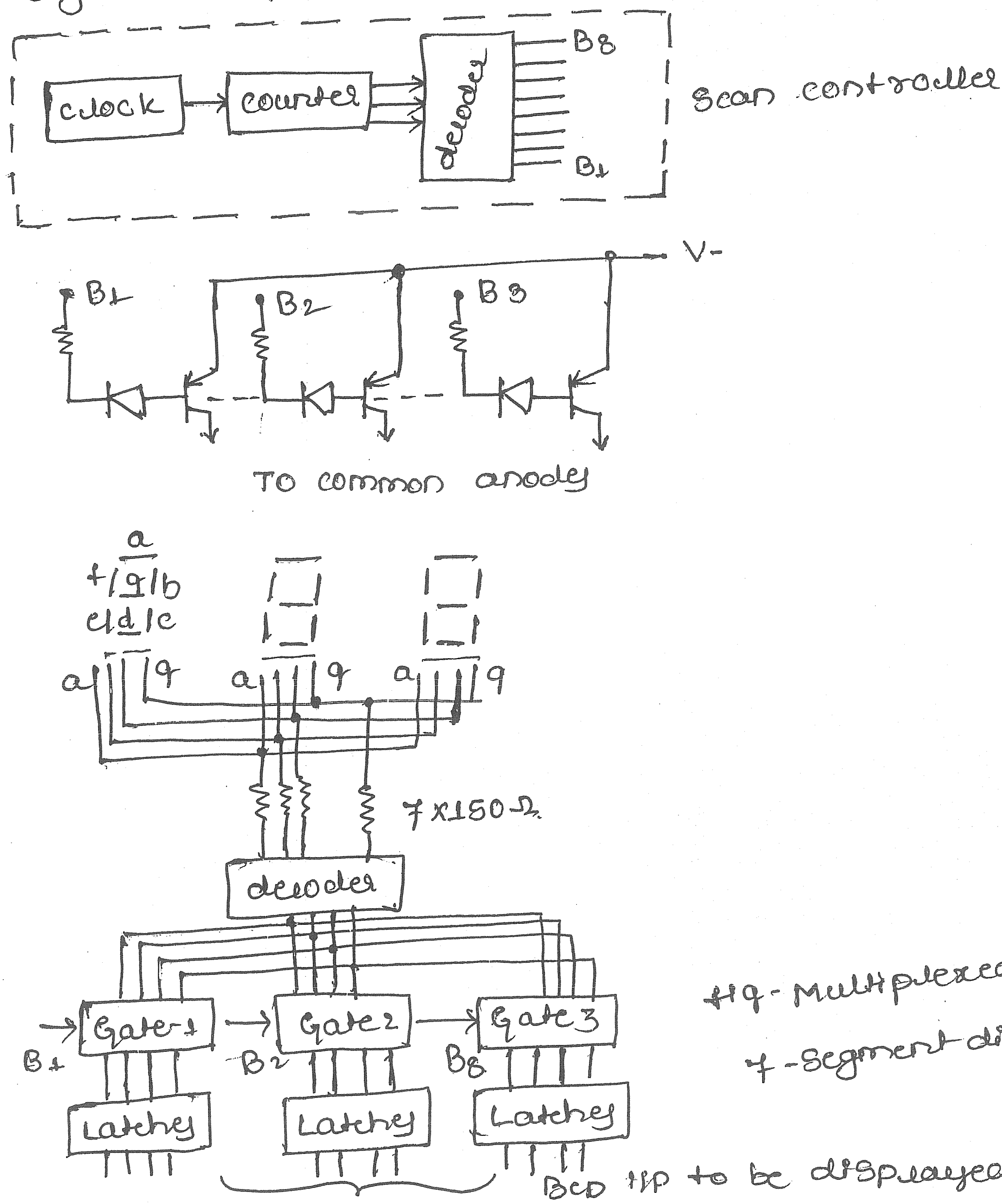


fig - Multiplexed 7-segment display

The input in BCD form is applied to the latches whose outputs are fed to the open collector gates

* The outputs of gates are "wired-OR" and fed to a single "BCD to seven segment" decoder

* The seven segments of each of the eight display digits are paralled & fed ~~from~~ through the decoder through current limiting resistors.

* at any instant, however, only one of the digits is displayed as selected by decoder output from the scan collector.

* For any particular digit to be selected, the transistor connected to common anode of that digit is turned ON & gate corresponding to that digit is enabled.

* In this way each digit is enbaled sequentially

* other displays such as incandescent & fluorescent displays can also be multiplexed in similar way.

* **Zero Suppression**

In multi digit displays with dp. (decimal point) it is advantageous to suppress zeros preceding the significant digits & following the decimal point.

* for example the display 0007.200 may be displayed as 7.2. ~~In order to suppress~~

* The decoder devices of many seven segment are provided with additional input/output controls named as ripple banking input (RBI) & Ripple banking o/p (RBO).

RBO assumes a '1' level when the character being measured /displayed is a '0'

* The application of this '1' level as RBI for the decoder in the next lower significant ~~digit position~~ will ensure that the displayed character is zero.
* The RBO of the second decoder will return form RBI for the next lower significant decoder
* Since the suppression of the least significant integer is zero. which is not usually desired.
* A similar procedure in the reverse order is used for the banking of trailing edge zeros

rd

d

* Cathode Ray tube (CRT)

The CRT is the heart of CRO, The CRT generates the electron beam, accelerates the beam, deflects the beam

The main parts of CRT are

i) Electron gun   ii) deflection System

iii) Fluorescent screen   iv) Glass tube

v) Base.

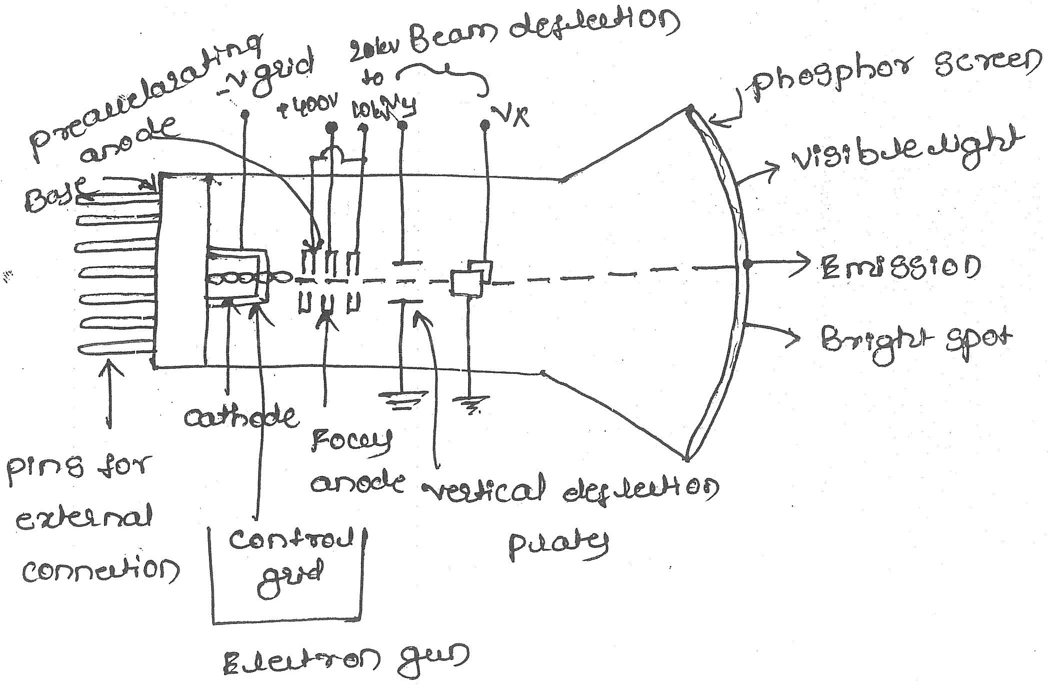


fig - cathode Ray tube.

* electron gun :- The electron gun section of CRT provides sharply focused electron directed towards the fluorescent - coated Screen.

* initially thermally heated cathode emits the electrons, The control grid is at its negative potential wrt to cathode. & it controls the no of electrons in beam

* The momentum of the electrons determines the intensity, or brightness, of the light emitted from the screen due to bombardment.
* The light emitted is usually of the green colour.
* The electrons are -vely charged, a repulsive force is created by the applying -ve voltage to the control grid.
* The similar charges on the electron repel each other. To compensate for such repulsion forces, an adjustable field is created b/n two cylindrical anodes called the focusing anodes.
* The preaccelerating and accelerating anodes are connected to a common +ve high voltage which varies b/n 2kV to 10kV.
* The focusing anode is connected to a lower +ve voltage of about 400 V to 500 V.

* Deflection System

When the electron beam is accelerated it passes through the deflection s/m, with which beam can be positioned anywhere on the screen.

* The deflection s/m of CRT consists of two pairs of ||el plates referred as vertical and horizontal deflection plates. One terminal is grounded and at another terminal is connected to certain vtg.

* A +ve sig i/p is applied to the Y-input terminal, causes the beam to deflect vertically.

Similarly a +ve voltage is applied to X-i/p terminal which causes the electron beam to deflect horizontally.

* The amount of vertical or horizontal deflection is directly propotional to the corresponding applied voltage.

* When the voltages are applied simultaneously to vertical and horizontal deflecting plates, the electron beam is deflected due to the resultant of these two voltages.

* The face of the screen can be considered as an X-Y plane. The (x,y) position of the beam spot is directly influenced by horizontal and vertical voltages applied to the deflection plates V_x & V_y respectively.

* The horizontal deflection (x) produced is propotional to the horizontal deflecting voltage V_x, applied to X-input.

$\therefore x \propto V_x$

$x = k_x V_x$. where k_x is propotionality constant.

* Similarly, the vertical deflection (y) produced will be propotional to the vertical deflecting voltage V_y, applied to the y-input.

$\therefore y = k_y V_y$, k_y is the vertical sensitivity, will be expressed as cm/volt or division/volt

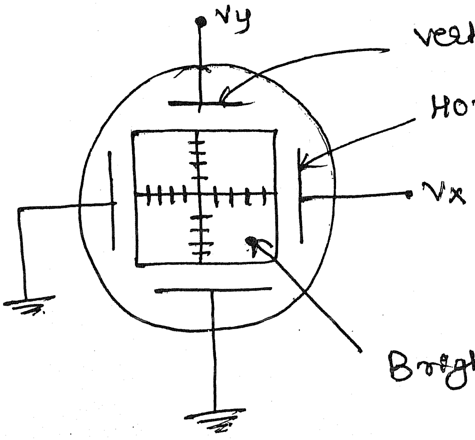


fig- Arrangement of plates in CRT

* **Fluorescent screen**

The light produced by the screen does not disappear immediately when the signal becomes zero.

* The time period for which the trace remains on the screen after the signal becomes zero is known as "persistence"
* The persistence may be as short as a few microsecond or as long as tens of seconds or even minutes.
* Medium persistence traces are mostly used for general purpose applications.
* Long persistence traces are used in the study of transients. However it helps in the study of transients since the trace is still seen on the screen after even the transient has disappeared.
* Short persistence is extremely needed for high speed phenomena.
* The screen is coated with a fluorescent material called phosphor which emits light when

bombarded by the electrons. various phosphors are available which differ in colour, persistence and efficiency.

* Glass tube

All the components of CRT are enclosed in an evacuated glass tube called envelope, which allows the emitted electrons to move freely from one end of the tube to other end.

* Base :- The base is provided to the CRT through which the connections are made to the various parts.

* Recording devices.

A recorder records both electrical & non-electrical as a function of time & it relates the signals of various quantities recorded.

* electrical quantities such as current, voltage etc can be read directly & non electrical quantities such as pressure, temperature, speed etc are indirectly by 1st converting them into electrical quantities in the form of signals using transducers or sensors.

* Recording devices are of two types namely
 i) Analog Recorders ii) digital recorders.

* X-y recorders.

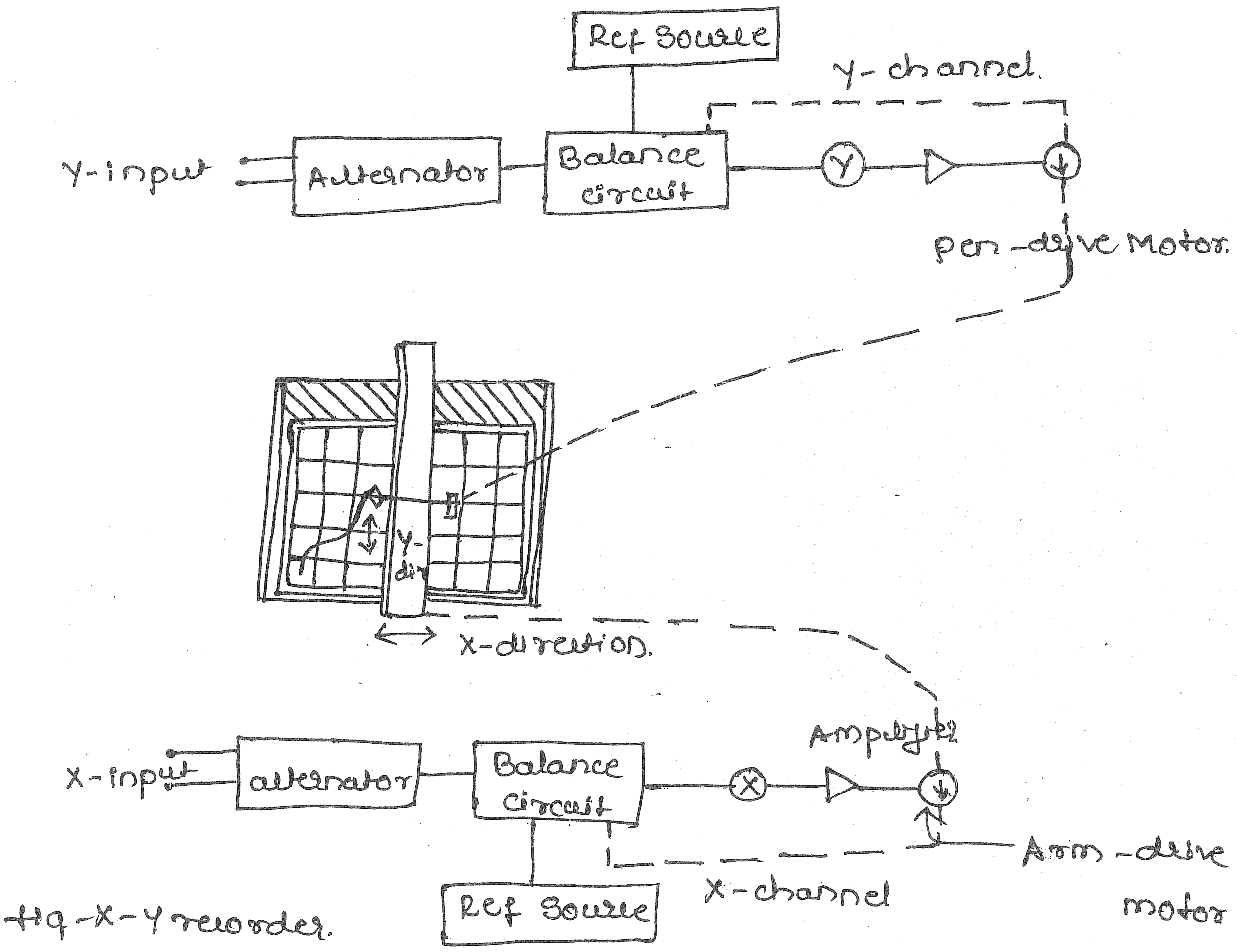


fig-X-Y recorder.

Above fig shows an X-Y recorder, it consists of a pair of servo-systems, a driving recording pen in two axes through a proper sliding pen and movinary arm arrangement, with reference to a stationary paper chart.

* attenuators are used to bring the input signals to the certain level acceptable by the recorder

* as shown above the signal enters each of the two channels, the signal is attenuated to a certain range of the recorder.

* each signal is then passes to a balance circuit, where it is compared with an ref voltage.

* The error signal is the difference b/n the two input signal voltage and the reference voltage,

* The signal is amplified with the help of amplifier inorder to actuate a servomotor, which is used to balance the s/m & hold it in balance as the value of the quantity being recorded.

* The above action takes place in both x and y axis simultaneously, they giving a record of one quantity as a varible with respect to other quantity.

* An X-Y recorder may have sensitivity of 10μV/mm, a slewing speed of 1.5m/s & a frequency response of 6Hz for both axes, the accuracy of recorder is about ±0.3%

The use of X-Y recorder in Laboratories simplifies many meas & tests such as

1) Speed-torque characteristics of motor.
2) regulation curves of power amplifiers.
3) plotting stress-strain & hysteresis curves.
4) variation of resistance with temp curves etc.
5) plotting the characteristics of electronic devices such as vacuum tubes, zener diodes, rectifiers, transistors etc.

* Galvanometric Recorder

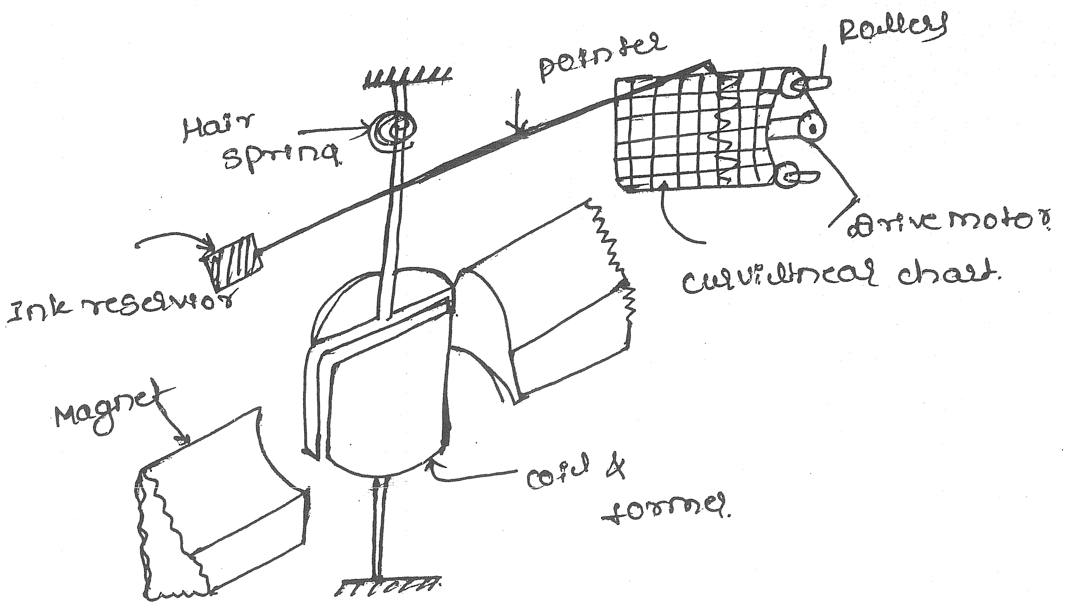


fig-a) Galvanometric type recorder.

* principle of operation

The galvanometric type of recorder is a strip chart type recorder, this type of recorder is based on the principle of D'Arsonal movement. it uses D'Arsonal galvanometer. The galvanometer produces the deflection

When current passes through the coil.

* The deflection of galvanometer produces torque which is used for recording purpose
* The c/n which is passed through the coil is directly proportional to the physical quantity to be measured

* **Construction** :- The above fig shows galvanometric type of recorder, as shown above the moving coil with pointer is kept in the strong magnetic field.
* The pen-ink slm is fitted to pointer for recording the input signal.
* The pen-ink slm consisting of recording pen at one end while ink reservior at other end.
* due to gravity & capillary action, ink flows from reservior to pen through tube
* The paper is pulled with the help of roll mechanism which is driven by motors.

* **operation** :- The pointer starts deflecting when c/n flows through the coil, as c/n is related to i/p signal flows through the coil, the magnetic field density changes.
* The variation of magnetic field is according to the i/p c/n, the change in magnetic field interacts with magnetic field produced by the permanent magnet used, which causes the rotation of moving coil in angular direction.

* as the coil is moving as per ~~the~~ the i/p current, the pen is deflected across the pen. & i/p signal is to be recorded.
* If the amplitude i/p signal is more the deflection of the pointer is more, when the pointer comes to rest the pen also comes to rest, the pointer comes to rest due to torque exerted by the hair spring.
* The recorder uses curvilinear sys of tracing. The paper used in this recorder is generally heat sensitive & pen-ink mechanism is replaced with a heated tip stylus.

* Advantages.

1) The sys is comparatively inexpensive
2) The galvanometric type recorder records very low frequency ac signals
3) It offers multiple channel operation.
4) As the speed of paper is determined by the gear ratio, we can change the speed of paper as per requirement.

* Disadvantages

1) It is having very small bandwidth of about 0-10Hz
2) It is having small sensitivity of about 0.4V/mm.
3) It can record fast varying signals such as current, voltage or power.
4) Its performance is affected by friction losses due to large mass of the moving coil & stylus.

* Circular chart Recorder.

It is basically a graphic recorder which records the data on a flat circular chart, the below fig shows circular chart Recorder.

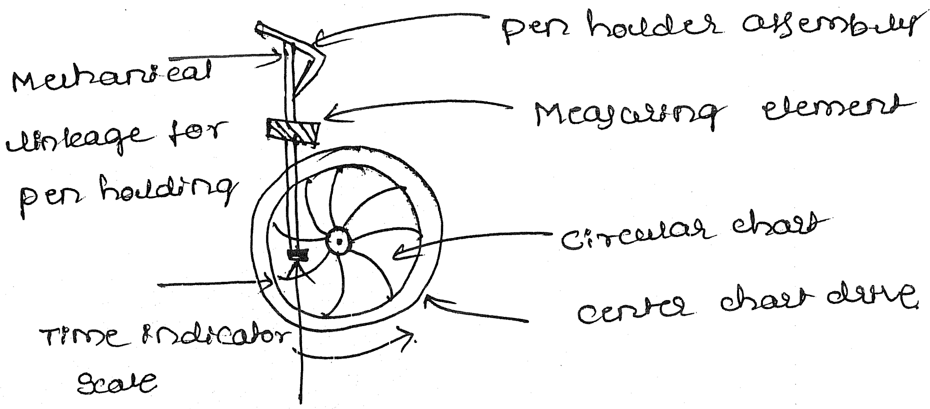


fig- circular chart recorder.

* It consists of important blocks namely measuring element, operating mechanism, chart drive & recording device.
* A circular chart with scale printed on it is mounted on flat plate supported with spring.
* a measuring element operates with operating mechanism through mechanical linkage, which is used to pass parameter measured by the measuring element, to the recording device.
* different types of drives are used to drive circular chart. The drives are mechanical, pneumatic, electric type.
* The most commonly used drive is synchronous mle.

* Frequency Modulation Recording (FM) recording.

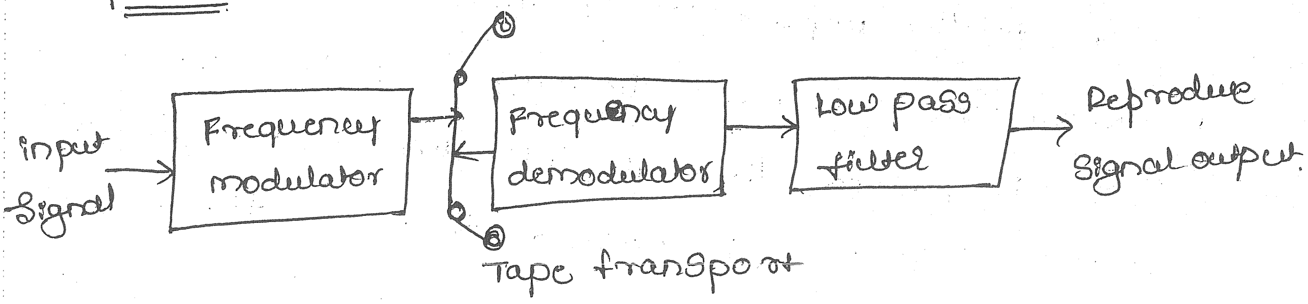
The major disadvantage of direct loading is that it is difficult to record dc signal, this difficulty can be overcome by using FM recording.

* principle of operation.

In the FM recording, the carrier frequency fc is modulated by the input signal. FM recording uses the variation of frequency to carry the required information instead of varying the amplitude

* The modulating signal is recorded using the recording head in normal way & then reproduced signal is passed through FM demodulator, low pass filter to get original signal.

* operation



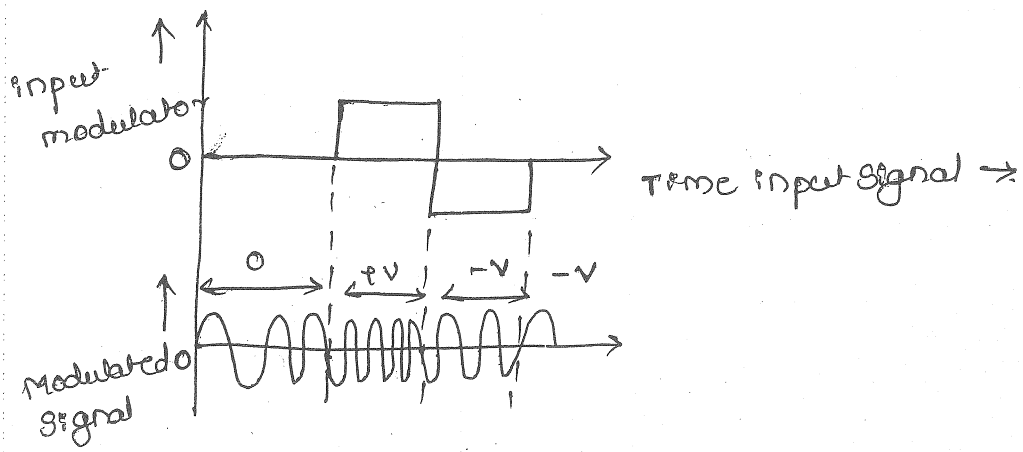


fig - Basic FM Recording system

* In this system, the carrier frequency is called as center frequency fc., this frequency is modulated by the level of the input signal.
* When the input signal is zero, the modulation contains only the center frequency oscillation.
* The +ve i/p voltage deviates the carrier frequency by specified % in one direction, The -ve voltage deviates the carrier frequency by specified % in other direction.
* When i/p is dc, the modulated o/p is a signal of constant frequency & when i/p is ac modulated output is a signal of variable frequency.
* However the frequency variation is directly proportional to the amplitude of input signal.
* during the playback, the output of the reproducing head is passed through FM demodulator. The demodulated signal is is passed through the filter which removes carrier frequency fc and the unwanted signals.
* FM demodulator converts the difference b/n center frequency and frequency on the tape to a voltage which is proportional to frequency difference
* The frequency deviation selected is ±40% about carrier frequency. When tape speed is changed there is proportional change in the carrier frequency, ∴ for signal the wavelength λ remains same as de

$\lambda = V/f$ and speed v changes, the frequency also changes

* there are two factors related to FM recording

i) percentage deviation

ii) deviation ratio.

* **Percentage deviation** :- It is defined as the ratio of carrier deviation to center frequency. It is denoted by M.

$\therefore$ percentage deviation $= M = \frac{\Delta f}{f_c} \times 100$. It is also known as modulation index.

* **Deviation ratio** :- It is the ratio of carrier deviation from center frequency to the signal frequency or modulating frequency. denoted by δ

$$\delta = \frac{\Delta f}{f_m}$$ where f_m = modulating frequency.

* **Advantages of FM recording**

1) FM recording is useful mainly to record dc components.
2) It has wide frequency range from 0 Hz to several kHz.
3) Amplitude variation is neglected in FM recording & input signal is correctly recorded.
4) FM recording is used for recording non electrical quantities such as force, pressure etc.
5) used for multiplexing in the instrumentation & process sim.

* **Disadvantages**

1) The tape speed fluctuations affect FM recording.

2) For FM recording high speed is required.
3) It is expensive.
4) the circuitary used for FM recording is complicated compared to direct recording.