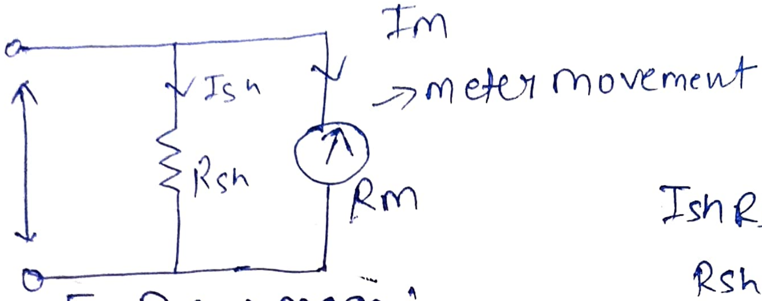
16/08/2022

Measurement and Measuring Instrument

Ammeter shunt

m = multiplying power of shunt



For DC → maganin

$$I = I_{sh} + I_m$$

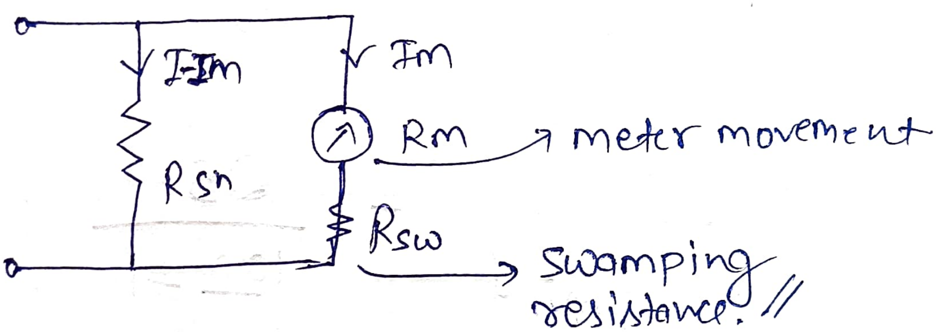
$$I_{sh} = -I_m + I$$

$$I_{sh} = I - I_m$$

$$I_{sh} R_{sh} = I_m R_m$$

$$R_{sh} = \frac{I_m R_m}{I - I_m} = \frac{R_m}{\frac{I}{I_m} - 1} = \frac{R_m}{m - 1}$$

Arrangement for temp. effect Correction



For DC Suitable material - maganin

for AC → Constantan.

Swamping resistor is used for temp. Compensation

Q) A moving coil instrument whose resistance is 25 Ω gives a full scale deflection with a current of 1mA. This instrument is to be used with a manganin shunt to extend its range to 100mA.

Calculate the error caused by the 10°C rise in temp.
when -
(1) copper moving coil is connected directly across a manganin shunt.
(2) A 75Ω manganin resistance is used in series with instrument moving coil.

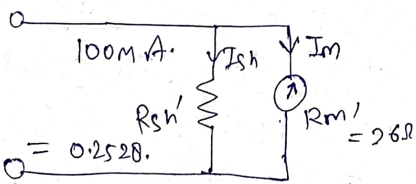
The temp. coefficient of copper is $0.004/°C$ and for manganin $0.00015/°C$

$$R_{sh} = \frac{R_m}{I/I_m - 1} = \frac{25}{\frac{100}{1} - 1}$$

$$R_{sh} \Rightarrow \frac{25}{99} = 0.2525\Omega$$

for 10°C ↑

$R_t = R_0(1+\alpha t)$ for 10°c



$R_m' = 25(1+0.004\times 10) = 26\Omega$

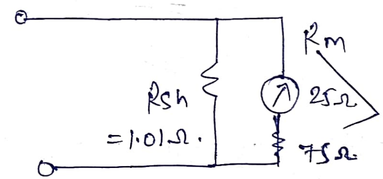
$R_{sh}' = 0.2525(1+0.00015\times 10)$

$= 0.2528\Omega$

$$I_m' = \frac{100\times 0.2528}{0.2528+26} = 0.96.$$

$$\% error = \frac{0.96-1}{1}\times 100$$

$= -4\%$



$$R_{sh} = \frac{R_{mt}}{m-1}$$

$$= \frac{R_{mt}}{I/I_m - 1} = \frac{100}{100/1 - 1} = 1.01\Omega.$$

for 10°C rise.

$$\frac{R_{mt}'}{R_{sh}''} =$$

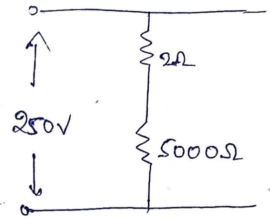
$$\frac{R_{mt}'}{R_{sh}''} = \frac{25(1+0.004\times10)+75(1+0.00015\times10)}{1.01(1+0.0015\times10)}$$

$$\frac{R_{mt}'}{R_{sh}''} = \frac{101.102\,\Omega}{1.011\,\Omega}$$

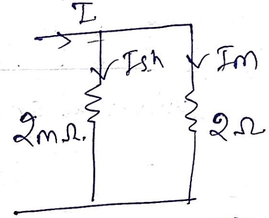
$$I_m'' = 100 \times \frac{1.011}{1.011-101.102} = 0.99A.$$

$$\Rightarrow \frac{0.99-1}{1}\times 100 = -1\%$$

Q) A moving coil instrument has a resistance of 2Ω and it reads upto 250 Volt, When a resistance of 5000Ω is connected in series with it, find the current range of instrument when it is used an ammeter with the coil connected across the shunt resistance of 2mΩ.



$$I_m = \frac{250}{2+5000} = 0.0499A$$



$$I_{sh}R_{sh} = I_m R_m$$

$$I_{sh} = \frac{R_m I_m}{R_{sh}}$$

$$I_{sh} = 49.9A$$

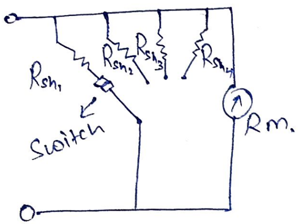
$$I = I_m + I_{sh}$$

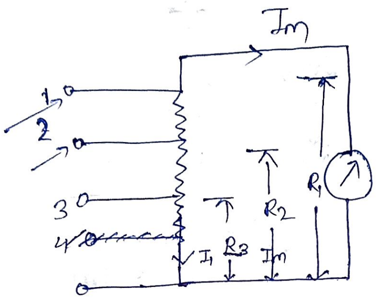
$$= 0.0499 + 49.9A = 49.94A$$

17/08/2022

Q) Design a multi-Range dc ammeter using a basic movement with an internal resistance of 50Ω and a full scale deflection current $I_m = 1mA$. The ranges required are 0–1A, 0–50A, 0–10A.

Multi-range ammeter





universal shunt

$$(I_1 - I_m) R_{sh_1} = I_m R_m$$

$$R_{sh_1} = \frac{I_m R_m}{I_1 - I_m}$$

$$= \frac{R_m}{\frac{I_1}{I_m} - 1} = \frac{R_m}{M_1 - 1}$$

for R_1

$$(I_1 - I_m) R_1 = R_m I_m$$

$$R_1 = \frac{R_m I_m}{I_1 - I_m}$$

$$R_1 = \frac{R_m}{I_1/I_m - 1} = \frac{R_m}{M_1 - 1}$$

for R_2

$$(I_2 - I_m) R_2 = (R_1 - R_2 + R_m) I_m$$

$$R_2 R_2 - I_m R_2 = I_m R_1 - R_2 I_m + I_m R_m$$

$$R_2 = \frac{I_m (R_1 + R_m)}{I_2}$$

$$R_2 = \frac{R_1 + R_m}{I_2/I_m} = \frac{R_1 + R_m}{M_2}$$

for R_3

$$(I_3 - I_m) R_3 = (R_1 - R_3 + R_m) I_m$$

$$I_3 R_3 - \cancel{I_m R_3} = I_m R_1 - \cancel{R_3 I_m} + I_m R_m$$

$$I_3 R_3 = I_m (R_1 + R_m)$$

$$R_3 = \frac{R_1 + R_m}{I_3/I_m} = \frac{R_1 + R_m}{M_3}$$

Soln 1) $R_1 = \frac{R_m}{M - 1} \Rightarrow \frac{50}{\frac{1}{10^{-3}} - 1} = \frac{50}{999} = 0.05$

$R_2 = \frac{R_1 + R_m}{M_2} \Rightarrow \frac{50.05}{\frac{5}{10^{-3}}} \Rightarrow 0.01\Omega$

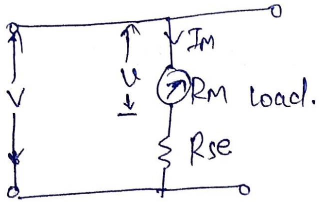
$R_3 = \frac{R_1 + R_m}{M_3} \Rightarrow \frac{50.05}{10/10^{-3}} \Rightarrow 0.005$

$\therefore r_1 = R_1 - R_2 \quad = 0.04\,\Omega$

$r_2 = R_2 - R_3 \quad = 0.005\,\Omega$

$r_3 = R_3 \quad = 0.005\,\Omega$

Voltmeter Multiplier



$v = I_M R_M, \quad I_M = v/R_M$

$V = I_M (R_M + R_{se})$

$R_{se} + R_M = \frac{V}{I_M}$

$R_{se} = \frac{V}{I_M} - R_M$

$= \frac{V}{v/R_M} - R_M$

$= mR_m - R_M$

$\Rightarrow R_m(M-1)$

$$\boxed{R_{se} = R_M(M-1)}$$

Q) A moving coil instrument has a resistance of 10Ω and gives full scale deflection when carrying a current of 50mA show how it can be adopted to measure voltage upto 750 volt and current upto 1000 A.

$R_{sh} = \frac{R_M}{M-1} = \frac{R_M}{I/I_M - 1} = \frac{10}{\frac{1000}{50\times10^{-3}} - 1}$

$\Rightarrow 0.005 \qquad \frac{10\times10^{-3}\times50}{1000\times1000}$

$R_{se} = R_M(M-1)$

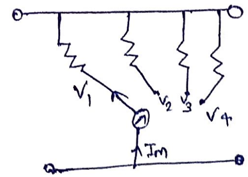
$R_{se} \Rightarrow \frac{V}{I_M} - R_M$

$\Rightarrow \frac{7500000}{50} - 10.$

$\Rightarrow 14990$

MULTIRANGE DC VOLTMETER

10/08/2022



Individual Multipliers

$v = I_M R_M$

$I_m = v/R_M$

$R_{s1} = \frac{V_1}{I_m} - R_M$

$= \frac{V_1}{v/R_M} - R_m$

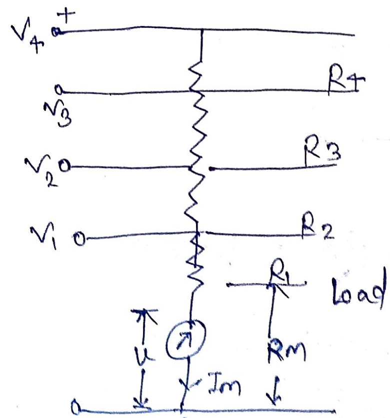
$= M_1 R_m - R_m$

$$\boxed{R_{s1} = R_M(M_1 - 1)}$$

$V_1/v = M_1,$

$$\boxed{R_{s2} = R_M(M_2 - 1)}$$

$$\boxed{R_{s3} = R_M(M_3 - 1)}$$



Potential divider Arrangement

for R_1

$$v = I_M R_M \rightarrow I_M = v/R_M \Rightarrow V_1/v = M_1$$

$$V_1 = I_m (R_1 + R_M)$$

$$R_1 = \frac{V_1}{I_M} - R_M$$

$$= \frac{V_1}{v/R_M} - R_M$$

$$= M_1 R_M - R_M$$

$$\boxed{R_1 = R_M (M_1 - 1)}$$

for R_2

$$V_2 = I_m (R_2 + R_1 + R_M)$$

$$R_2 = \frac{V_2}{I_M} - R_1 - R_M$$

$$= \frac{V_2}{v/R_M} - R_M(M_1 - 1) - R_M$$

$$= M_2 R_m - R_M M_1 + \cancel{R_m} - \cancel{R_M}$$

$$\boxed{R_2 \Rightarrow R_M (M_2 - M_1)}$$

for R_3

$$V_3 = I_M (R_M + R_1 + R_2 + R_3)$$

$$R_3 = \frac{V_3}{I_M} - R_m - R_1 - R_2$$

$$R_3 = M_3 R_m - \cancel{R_m} - R_M M_1 + \cancel{R_M} - R_M M_2 + M_1 R_m$$

$$R_3 = R_M (M_3 - M_2)$$

for R_4

$$V_4 = I_m (R_M + R_1 + R_2 + R_3 + R_4)$$

$$R_4 = \frac{V_4}{I_M} - R_M - R_1 - R_2 - R_3$$

$$= M_4 R_M - R_M - R_M (M_1 - 1) - R_M (M_3 - M_1)$$

$$R_4 = R_M (M_4 - M_3)$$

Q) A Basic meter movement, with an internal resistance $R_M = 100\,\Omega$ and full scale current $I_M = 1mA$ is to be converted into a multirange d.c voltmeter, with ranges 0–10V, 0–50, 0–250V, 0–500V find the values of various resistance, using 'potential divider arrangement'

0-10, 0-50, 0-250, 0-500   1%

$R_1 = R_m(M_1 - 1)$

$R_1 = 100\left(\frac{V_1}{V} - 1\right)$

~~$R_1 = \frac{10}{10^{-3}} + 100$~~

$R_1 = 100000 - 100$

$= 99{,}900$

$R_2 = \frac{50}{10^{-3}} - 99900 - 100$

$\Rightarrow 400{,}000$

$R_3 \Rightarrow 250\times10^3 - 400000 - 99900 - 100$

$R_3 = 2000\,K\Omega$

$R_4 \Rightarrow 500\times10^3 - 2000{,}000 - 400000 - 99900 - 100$

$\Rightarrow 2500\,K\Omega.$

Q) A moving coil ammeter is a fixed shunt of 0.02Ω with a coil resistance R = 1000Ω and a potential difference of 500mV across it, full scale deflection is obtained—

1) To what shunted current does this correspond

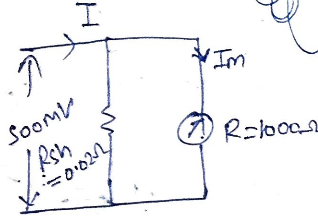
2) Calculate the value of R to give full scale deflection when shunted current I_{sh} is a) 10A, b) 75A

3) with what value of R 40% deflection is obtained with $I_{sh} = 100A$

Soln

$500\times10^{-3} = I_m(1000 + 0.02)$

a) $R = 1000\Omega$.



$V = 0.05V$

$R_{sh} = 0.02\Omega$

$I_{sh} = \frac{0.05\times10}{0.02} \Rightarrow 25A = I_{sh}$

$\left(I_m = \frac{0.5}{10^3}A\right)$

ii) $R = \frac{V}{I_m} = \frac{0.2}{0.5\times10^{-3}} = 400\Omega.$

$V = I_{sh}\cdot R_{sh} = 0.02\times10 = 0.2V$

$V = 0.2$

$V_{Rsh} = 75\times0.02 = 1.5V$

$R = \frac{1.5}{0.5\times10^{-3}} = 3000\Omega$

100 A → 40%

$x \rightarrow \frac{100}{40}$ %

$x \rightarrow 250$ Am

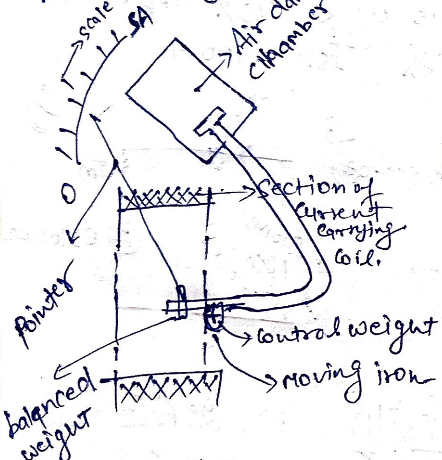
Vol. across $R_{sh} = 0.02 \times 250$
$= 5V$

(3) $R = \frac{5}{0.5 \times 10^{-3}} = 10^4 = 10k\Omega$

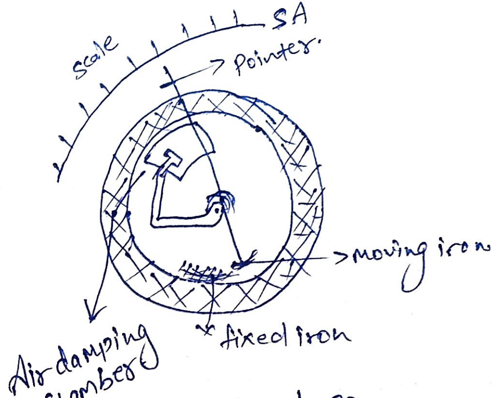
23/08/2022

Moving Iron Instruments

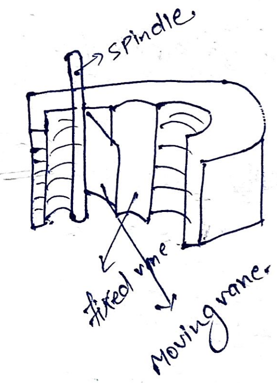
- Attraction type
- Repulsion type
  - Radial vane type.
  - Co-axial vane type



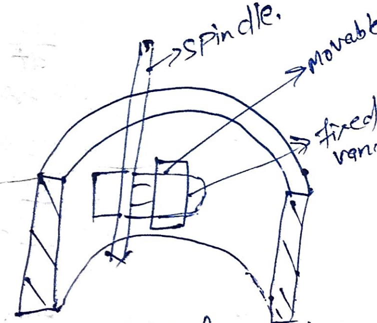
Attraction type.



Repulsion type.



Radial vane type.



Coaxial vane type.

MOVING IRON INSTRUMENT

24/08/2022

General torque equation –

$T_d \rightarrow$ deflecting torque
$d\theta \rightarrow$ deflection.

$\therefore$ Mechanical work done $= T_d . d\theta$.

$\therefore I \rightarrow dI$
$L \rightarrow dL$
$\theta \rightarrow d\theta$

$$e = \frac{d}{dt}(LI)$$

$$= L\frac{di}{dt} + I\frac{dL}{dt} \rightarrow (i)$$

$\therefore$ Electrical energy ~~sp~~ supplied

$= eIdt$

$\Rightarrow \cancel{L}Idi + I^2 dL$

$\Rightarrow LIdi + I^2 dL \rightarrow (ii)$

Change in stored energy

$$= \frac{1}{2}(I+dI)^2(L+dL) - \frac{1}{2}LI^2$$

$$\Rightarrow \frac{1}{2}(I^2 + (dI)^2 + 2IdI)(L+dL) - \frac{1}{2}LI^2$$

$$\Rightarrow \frac{1}{2}\left[\cancel{LI^2} + L(dI)^2 + 2LIdI + I^2dL + dL(dI)^2 + 2IdIdL\right) - \cancel{\frac{1}{2}LI^2}$$

$$\Rightarrow \cancel{\frac{L(dI)^2}{2}}^{0} + \frac{\cancel{2}LIdI}{\cancel{2}} + \frac{\cancel{2}IdIdL}{\cancel{2}}^{0} + \frac{I^2dL}{2} + \cancel{\frac{dL(dI)^2}{2}}^{0}$$

{neglect 2nd and higher order term}

$$\Rightarrow LIdI + \frac{1}{2}I^2dL$$

$\therefore LIdI + \frac{1}{2}I^2dt$ — (iii)

From principle of conservation of energy

electrical energy supplied = change in stored energy + Mechanical work done.

$$LI\cancel{dI} + I^2dL = LI\cancel{dI} + \frac{1}{2}I^2dL + T_d . d\theta.$$

$$I^2dL = \frac{1}{2}I^2dL + T_d . d\theta.$$

$$\frac{1}{2}I^2dL = T_d . d\theta.$$

$$\boxed{\frac{1}{2}I^2\frac{dL}{d\theta} = T_d.}$$

At steady state position,

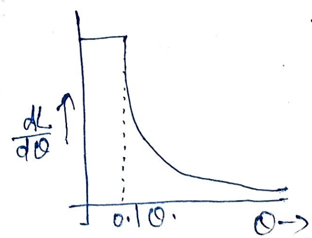
$T_d = T_c$ and $T_c = K\theta$.

$$T_d = T_c$$

$$K\theta = \frac{1}{2}I^2\frac{dL}{d\theta}$$

$$\boxed{\theta = \frac{1}{2}\frac{I^2}{K}\frac{dL}{d\theta}}$$

SCALE OF MOVING IRON INSTRUMENT –



For linear scale.

$I \propto \theta$.

$I = C\theta$

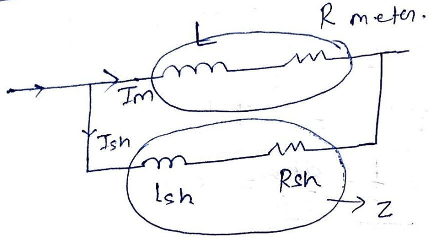
$$\theta = \frac{1}{2}\frac{I^2}{K}\frac{dL}{d\theta}.$$

$$\frac{dL}{d\theta} = \frac{2K\theta}{I^2} = \frac{2K\cancel{\theta}}{c^2\theta^{\cancel{2}}} = \frac{2K}{c^2\theta}$$

$\theta \; \frac{dL}{d\theta} = \frac{2K}{C^2}$

constant

SHUNT IN MOVING IRON INSTRUMENTS



$$Z_1 = \sqrt{R^2 + \omega^2 L^2}$$

$$Z_2 = \sqrt{Rsh^2 + \omega^2 Lsh^2}$$

$$I_M Z_1 = I_{sh} Z_2$$

$$I_M \times \sqrt{R^2 + \omega^2 L^2} = I_{sh} \times \sqrt{R_{sh}^2 + \omega^2 Lsh^2}$$

$$\frac{I_{sh}}{I_m} = \frac{\sqrt{R^2 + \omega^2 L^2}}{\sqrt{Rsh^2 + \omega^2 lsh}} = \frac{R\sqrt{1 + \left(\frac{\omega L}{R}\right)^2}}{Rsh \sqrt{\left(1 + \frac{\omega Lsh}{Rsh}\right)^2}}$$

For frequency independent –

$$\frac{L}{R} = \frac{Lsh}{Rsh}, \quad \text{then} \quad \frac{I_{sh}}{I_m} = \frac{R}{Rsh}$$

Q) The inductance of a moving iron ammeter is given by, the following equation –

$$L = (20 + 10\theta + 2\theta^2)\,\mu H$$

$\theta \rightarrow$ is the deflection in radians, $K = 24 \times 10^{-6}$ NM/R

Calculate the value of deflection of A current of 5A

$L = 10 - 5\theta + 2\theta^2$

$\frac{dL}{d\theta} \Rightarrow 0 + 5 + 4\theta$

$\theta = \frac{1}{2}\frac{I^2}{K}\frac{dL}{d\theta}$

$L \Rightarrow -2\theta^2 + 10\theta + 20$

$\frac{dL}{d\theta} \Rightarrow -4\theta + 10$

$$\theta = \frac{1}{2}\frac{(25)}{24 \times 10^{-6}} \times (4\theta + 10) \times 10^{-6}$$

$\frac{\pi}{6} = \frac{1}{2}\frac{(100)}{K} \cdot \left(\frac{4\pi}{6} - 5\right)$

$\frac{\pi}{6} = \frac{50}{K}\left(\frac{4\pi}{6} + 5\right)$

$K \Rightarrow \frac{50 \times 6}{\pi}\left(\frac{4\pi}{6} + 5\right)$

$K \Rightarrow \frac{300}{\pi}(1.261)$

$K \Rightarrow 120.4$

$$\theta = \frac{25 \times 10^{-6}}{40}(10 - 4\theta)$$

$$\theta = \frac{25 \times 10^{-7}}{40} - \frac{25 \times 10^{-6} \times 4\theta}{40}$$

$$\cancel{40\theta/4}\;\theta \Rightarrow \frac{25}{40 \times 10^{-6}}(-4\theta + 10) \times 10^{-6}$$

$K = \frac{25 \times \pi}{2 \times 6}(1.26)$

$\Rightarrow$

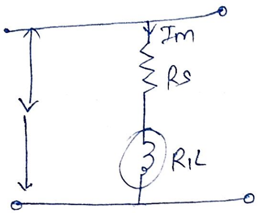
$$\frac{400}{25} + 4\theta = 10$$

$$\frac{1400}{25} = 10 \qquad \theta \Rightarrow \frac{250}{140} = 1.689$$

Ans

MULTIPLIERS FOR MOVING IRON INSTRUMENTS

25/08/2022



$$V = I_m \sqrt{R^2 + \omega^2 L^2}$$

$$V = I_m \sqrt{(R+R_s)^2 + \omega^2 L^2}$$

$$m = \frac{V}{v} = \frac{\cancel{I_m}\sqrt{(R+R_s)^2 + \omega^2 L^2}}{\cancel{I_m}\sqrt{R^2 + \omega^2 L^2}}$$

$$m = \frac{\sqrt{(R+R_s)^2 + \omega^2 L^2}}{\sqrt{R^2 + \omega^2 L^2}}$$

Q1) Calculate the Constant of M to extend the range of (0-5) A moving Iron Ammeter to (0-50) A. The instrument const. are $R = 0.09\Omega$, $L = 90\mu H$. If the shunt is made non inductive and the combination is correct on DC. Find the full scale error at 50 Hz.

Soln

$\cancel{f = \frac{\omega}{2\pi}}$, $\cancel{\omega = 100\pi}$

$$\frac{L}{R} = \frac{L_{sh}}{R_{sh}} \Rightarrow \frac{90\mu H}{0.09} = \frac{L_{sh}}{R_{sh}}.$$

$$\frac{I_{sh}}{I_m} = \frac{R}{R_{sh}} \Rightarrow \cancel{\frac{5}{50}} = \cancel{\frac{0.09}{R_{sh}}} \quad R_{sh} = 0.9\Omega$$

$$\cancel{\frac{90\mu H}{0.09} = \frac{L_{sh}}{0.9}}$$

$$\cancel{\frac{0.9 \times 90 \times 10^{-6}}{0.09}} = \cancel{L_{sh}}$$

$$900\mu H = L_{sh}$$

$I_m = 5A$

$I = 50A$

$$\frac{L}{R} = \frac{L_{sh}}{R_{sh}} \qquad \frac{I_{sh}}{I_m} = \frac{R}{R_{sh}}$$

$$I = I_{sh} + I_m$$

$$= \frac{R}{R_{sh}} I_m + I_m$$

$$\frac{I}{I_m} = \left(1 + \frac{R}{R_{sh}}\right) I_m$$

$$\frac{I}{I_m} = m = 1 + \frac{R}{R_{sh}}$$

$$I_{sh} = \frac{R}{R_{sh}} I_m$$

$$\therefore L_{sh} = \frac{L}{R} \times R_{sh}$$

$$= 10\mu H$$

$$R_{sh} = \frac{R}{m-1} = 0.01$$

for DC

$$I_m = I \times \frac{R_{sh}}{R + R_{sh}} \Rightarrow 50 \times \frac{0.01}{0.1} = 5A$$

$$\cancel{\frac{I_{sh}}{I_m} = \frac{R}{R_{sh}}}$$

2→3 → ~~Heat~~ Network
3→5 → Measurement

for AC

$$I_m = \frac{I \times R_{sh}}{\sqrt{(R+R_{sh})^2 + \omega^2 L^2}}$$

$$\Rightarrow \frac{50 \times 0.01}{\sqrt{(0.1)^2 + (50)^2 (90)^2 \times 10^{-12}}}$$

$$\Rightarrow \frac{50 \times 0.01}{\sqrt{0.01 + 2500 \times 8100 \times 10^{-12}}}$$

$$\Rightarrow \frac{0.5}{\sqrt{0.01 + 25 \times 81 \times 10^{-8}}}$$

$$\Rightarrow \frac{0.5}{\sqrt{0.01 + 0.000002025}}$$

$$\Rightarrow \frac{0.5}{0.100101199} = 4.99 \approx 4.01$$

Q 2) The inductance of a moving iron ammeter is given by the expression $L = (10 + 5\theta - 2\theta^2)\ \mu H$ where θ is the angular deflection in radian from zero position. Determine the angular deflection for a current of 10A, if the deflection for a current of 5A is 30°. Also determine the screen constant.

Soln $\frac{dL}{d\theta} = \frac{2K\theta}{I^2} \Rightarrow I = 5A,\ \theta = 30° \to \pi/6$

$$(5 - 4 \times \pi/6) \times 10^{-6} = \frac{2 \times K \times \pi/6}{25}$$

$$K = 69.36 \times 10^{-6}\ Nm/rad.$$

$I = 10\,A$
$\theta = ?$

$$\frac{dL}{d\theta} = \frac{2K\theta}{I^2} \Rightarrow (5 - 4\theta) \times 10^{-6} = \frac{2 \times 69.36 \times 10^{-6} \times \theta}{10^2}.$$

Q) The inductance of a moving Iron instrument is given by $L = (0.01 + K_1\theta)^2\ \mu H$, where θ is angular deflection in radians from zero position the instrument angular deflection, corresponding to current of 2A and 5A are 45° and 90° respectively, find the value of K_1.

Errors in Moving Iron Instruments

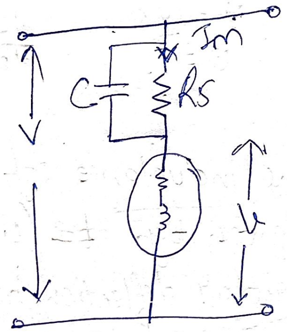
2022

Errors with both ac & dc

(i) Hysteresis Error
(ii) Temperature error
(iii) Strong Magnetic field.

Errors with Ac only.

Frequency error-



~~Eddy current~~

$$Z = R + j\omega L + \frac{R_s}{1 + j\omega C R_s}$$

$$= R + j\omega L + \frac{R_s(1 - j\omega C R_s)}{1 + \omega^2 C^2 R_s^2}$$

$$= R + j\omega L + \frac{R_s}{1 + \omega^2 C^2 R_s^2} - \frac{j\omega C R_s^2}{1 + \omega^2 C^2 R_s^2}$$

$$R + R_s = R + j\omega L + \frac{R_s}{1 + \omega^2 C^2 R_s^2} - \frac{j\omega C R_s^2}{1 + \omega^2 C^2 R_s^2}$$

$$R + R_s = R + \frac{R_s}{1 + \omega^2 C^2 R_s^2}$$

$$1 + \omega^2 C^2 R_s^2 = 1 \quad \text{if } \omega^2 C^2 R_s^2 << 1$$

$$L - \frac{C R_s^2}{1 + \omega^2 C^2 R_s^2} = 0$$

$$L = \frac{C R_s^2}{1 + \omega^2 C^2 R_s^2}$$

$$L = C R_s^2$$

$$\boxed{C = \frac{L}{R_s^2}} \qquad \boxed{C = 0.41 \frac{L}{R_s^2}}$$

Eddy Current-

M

$$I_e = \frac{\omega M I}{\sqrt{R_e^2 + \omega^2 L_e^2}} \qquad E_e = \omega M I \rightarrow I_e$$

$$I_e' = I_e \sin\theta_e$$

$$= \frac{\omega M I}{\cdots} \times \frac{\omega L_e}{\cdots} = \frac{\omega^2 M L_e I}{R_e^2 + \omega^2 L_e^2}$$

If $R_e >> \omega L_e$

$\omega L_e >> R_e$

$I_e' = \omega^2 M L_e I$

$I_e' = \frac{MI}{L_e}$

3.14×1

Q) A coil of a 300V Moving Iron Voltmeter, has a resistance of 500Ω and an Inductance of 0.8H, The instrument reads correctly at 50Hz ac supply and takes 100mA at full scale deflection, what is % error in the instrument when it is connected to 200V dc supply?

Soln $R_m = 500\Omega$

$L = 0.8H$

$f = 50Hz$

$I_m = 100mA = 0.1A$

$X_L = 2\pi f L$

$= 2 \times 3.14 \times 50 \times 0.8$

$= 251.2\Omega$

$V = 300V$

$Z = V/I$, $= \frac{300}{0.1} = 3000\Omega$.

$R = \sqrt{Z^2 - X_L^2}$

$= 2989.4\Omega$

200 V ac

$I = \frac{200}{Z} = \frac{200}{3000} = 0.06$

200 V dc

$I = \frac{200}{2989.4} = 0.0669$

$0.666 \rightarrow 200V$

$0.669 \rightarrow \frac{200 \times 0.6}{0.666}$

$\Rightarrow 200.9$

%

The operating coil of a 250V moving Iron voltmeter has a resistance of 500Ω and Inductance of 1H. The series resistance is 2000Ω. The instrument reads correctly when a direct voltage of 250V is applied what will it read when 250V at 50Hz is applied.

→ with what value of Capacitance must the series resistance be shunted to make the meter read correctly at 50Hz.

Soln $R_m = 500\Omega$

$R_s = 2000$

$L = 1H$

$f = 50Hz$

$\omega = 2\pi f$

$Z = \sqrt{(R+R_s)^2 + \omega^2 L^2}$

$= \sqrt{(2500)^2 + (100\pi 1)^2}$

$= 2519.6\Omega$

$R_T = R + R_s$

$= 2000 + 500 = 2500$

for dc

$I_m = \frac{250}{2500} \Rightarrow 0.1A$

for AC

$$I_m = \frac{250}{2519.6} = 0.099$$

0.1 —— $250V$

$0.099 \longrightarrow \frac{250}{0.1} \times 0.099$

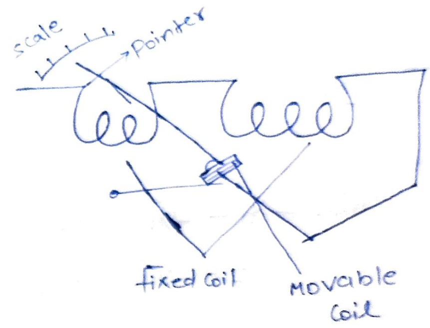
$\Rightarrow 247.5$

$$\%error = \frac{247.5-250}{250} \times 100 = (-1\%)$$

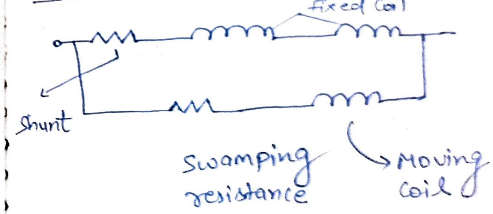
$$C = 0.41 \times \frac{1}{2000^2}$$

06 | 09 | 202

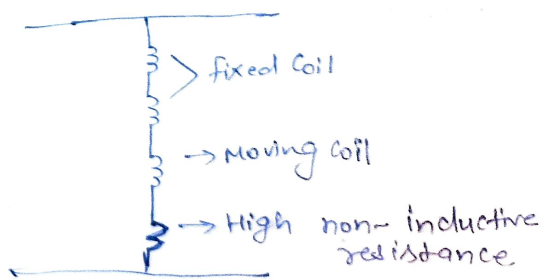
ELECTRODYNAMOMETER TYPE INSTRUMENTS



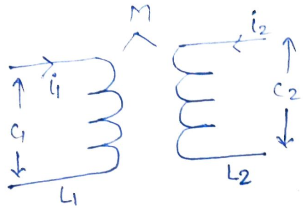
Dynamometer type Ammeter



Dynamometer type Voltmeter



Torque equation:-



Flux linkage in coil 1 $\psi_1 = L_1 i_1 + M i_2$

" " " " 2 $\psi_2 = L_2 i_2 + M i_1$

$$e_1 = \frac{d\psi_1}{dt}, \quad e_2 = \frac{d\psi_2}{dt}$$

$\therefore$ electrical input energy $= e_1 i_1 dt + e_2 i_2 dt$

$$= \frac{d\psi_1}{dt} \times i_1 \times dt + \frac{d\psi_2}{dt} \times i_2 \times dt$$

$$\Rightarrow d(L_1 i_1 + M i_2) \times i_1 + d(L_2 i_2 + M i_1) \times i_2$$

$$\Rightarrow i_1 L_1 di_1 + i_1^2 dL_1 + i_1 M di_2 + i_1 i_2 dM$$
$$+ i_2^2 dL_2 + i_2 L_2 di_2 + i_2 M di_1 + i_2 i_1 dM$$

$\therefore$ Stored energy $= \frac{1}{2} i_1^2 L_1 + \frac{1}{2} i_2^2 L_2 + i_1 i_2 M$

change in stored energy:-

$$= d\left(\frac{1}{2} i_1^2 L_1 + \frac{1}{2} i_2^2 L_2 + i_1 i_2 M\right)$$

$$\Rightarrow \frac{1}{2} i_1^2 dL_1 + \frac{2}{2} \times L_1 di_1 \times i_1 + \frac{1}{2} i_2^2 dL_2 + \frac{2}{2} \times i_2 \times di_2 L_2$$
$$+ i_2 i_1 dM + i_1 M di_2 + M i_2 di_1$$

$$\Rightarrow \frac{1}{2} i_1^2 dL_1 + i_1 L_1 di_1 + \frac{1}{2} i_2^2 dL_2 + i_2 L_2 di_2 + i_1 M di_2 + i_2 M di_1$$
$$+ i_1 i_2 dM$$

Principle of conservation of energy elec. i/p energy

= change in stored energy + Mech. work done.

$$i_1 L_1 di_1 + i_1^2 dL_1 + i_1 M di_2 + i_1 i_2 dM + i_2^2 dL_2 + i_2 L_2 di_2$$
$$+ i_2 M di_1 + i_2 i_1 dM = \frac{1}{2} i_1^2 dL_1 + i_1 L_1 di_1 + \frac{1}{2} i_2^2 dL_2$$
$$+ i_2 L_2 di_2 + i_1 M di_2 + i_2 M di_1 + i_1 i_2 dM$$
$$+ T_d \cdot d\theta$$

$$\frac{1}{2} i_1^2 dL_1 + \frac{1}{2} i_2^2 dL_2 + i_1 i_2 dM = T_d \cdot d\theta.$$

If self inductance is constant then, dL_1 and $dL_2 = 0$

$$i_1 i_2 dM = T_d \cdot d\theta.$$

$$\boxed{T_{d_{inst}} = i_1 i_2 \frac{dM}{d\theta}}$$

For DC

I_1 = Ct through the fixed coil

I_2 = Ct through the moving coil.

$$T_d = I_1 I_2 \frac{dM}{d\theta}$$

$$T_c = K\theta$$

$$K\theta = I_1 I_2 \frac{dM}{d\theta}$$

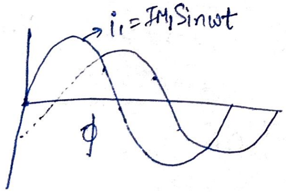
$$\boxed{\theta = \frac{I_1 I_2}{K} \frac{dM}{d\theta}}$$

For AC

$$T_i = i_1 i_2 \frac{dM}{d\theta}$$

Avg. torque over whole cycle

$$T_d = \frac{1}{T}\int_0^T i_1 i_2 \frac{dM}{d\theta}$$



∴ Avg. torque.

$$T_d = \frac{1}{2\pi}\int_0^{2\pi} I_{m_1} \sin wt \times I_{m_2} \sin(wt - \phi) \frac{dM}{d\theta} \cdot d(wt)$$

$$T_d = \frac{I_{m_1} I_{m_2} \times \cos\phi}{2} \frac{dM}{d\theta}$$

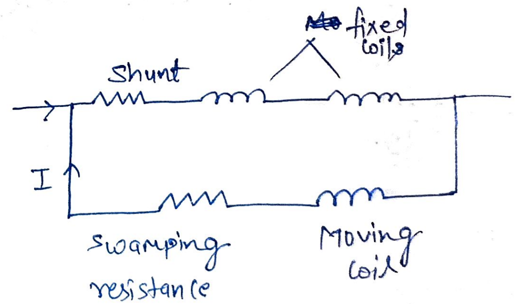
$$= \frac{I_{m_1}}{\sqrt{2}} \times \frac{I_{m_2}}{\sqrt{2}} \cos\phi \frac{dM}{d\theta}$$

$$\boxed{T_d = I_1 \times I_2 \cos\phi \frac{dM}{d\theta}.}$$

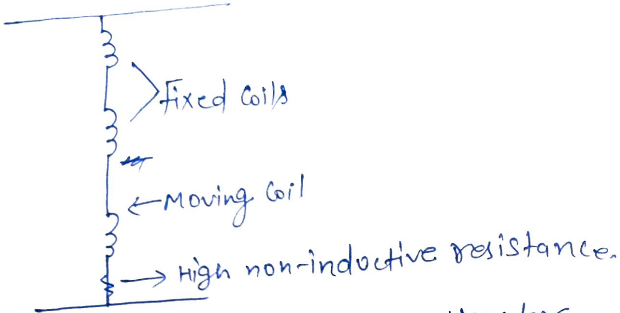
$$K\theta = I_1 I_2 \cos\phi \frac{dM}{d\theta}$$

$$\boxed{\theta = \frac{I_1 I_2}{K} \cos\phi \frac{dM}{d\theta}}$$

07/09/2022

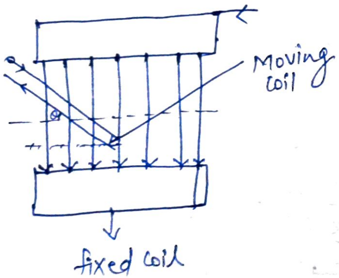


Dynamometer Ammeter



Dynamometer type voltmeter

Shape of Scale



Errors

1. low torque/weight ratio
2. frequency.
3. Eddy Currents
4. External magnetic fields.
5. Temp. change

$$\theta = \frac{I_1 I_2 \cos\phi}{K} \frac{dM}{d\theta}.$$

$$I_1 = I_2 = I$$

$$\phi = 0$$

$$\therefore \boxed{\theta = \frac{I^2}{K} \frac{dM}{d\theta}}$$

$\theta = 0^\circ$

$M = -M_{max}$

Mutual inductance for angle $\theta \Rightarrow$

$$M = -M_{max} \cos\theta$$

$$\frac{dM}{d\theta} = M_{max} \sin\theta$$

$$\therefore \theta = \frac{I_1 I_2}{K} \cos\phi \, M_{max} \sin\theta$$

$$\theta = \frac{V^2}{KZ^2} \frac{dM}{d\theta}$$

$$\uparrow Z = \sqrt{R^2 + (2\pi f L)^2} \simeq R$$

$R_1 L_1 Z_1$; $I_1 Z_1 = I_2 Z_2$

$R_2 L_2 Z_2$; $\frac{I_2}{I_1} = \frac{Z_1}{Z_2} = \frac{\sqrt{R_1^2 + (2\pi f L_1)^2}}{\sqrt{R_2^2 + (2\pi f L_2)^2}}$

$$\therefore \frac{I_1}{I_2} = \frac{R_1 \sqrt{1 + (2\pi f)^2 (L_1/R_1)^2}}{R_2 \sqrt{1 + (2\pi f)^2 \left(\frac{L_2}{R_2}\right)^2}}$$

for AC

$$\frac{I_2}{I_1} = \frac{R_1}{R_2}$$

for DC

$$\frac{I_1}{I_2} = \frac{R_2}{R_1}$$

Q The inductance of a 25Amp electrodynamic ammeter changes uniformly at the rate of 0.0035 μH/degree. The spring constant is ~~10~~ 10^{-6} NM/Degree. Determine the Angular deflection full scale.

$$\theta = \frac{I_1 I_2 \cos\phi}{K} \frac{dM}{d\theta}$$

Soln

$$= \frac{I^2}{K}\frac{dM}{d\theta} = \frac{(25)^2}{10^{-6}}(35\times10^{-10})$$

$\Rightarrow 625 \times 35 \times 10^{-4}$

$\Rightarrow 21875 \times 10^{-4}$

$\Rightarrow 2.1875$ rad

$$I = \frac{2.1875 \times 180}{\pi} = 125.33 \text{ degree}$$

Q In a Particular instrument the ~~total~~ voltage coil is 8200Ω and Mutual Inductance and Mutual inductance changes uniformly from −173μH at 0 ~~degree~~ deflection to +175μH at full scale. The angle of full scale being 95°. If a P.D of a 100V is applied across the voltage circuit and a current of 3A at a power factor of 0.75 is passed through the current coil, what will the deflection if the spring constant is 4.63×10^{-6} NM/rad.

Soln

$$\theta = \frac{I_1 I_2}{K}\cos\phi \frac{dM}{d\theta}$$

$$I = \frac{V}{R} = \frac{100}{8200} \Rightarrow \frac{1}{82}$$

$$= \frac{\frac{1}{82}\times 3 \times \frac{75}{100} \times 210\times10^{-6}}{4.63\times10^{-6}\times\frac{\pi}{180}}$$

$$\frac{dM}{d\theta} = \frac{175+173}{95} \Rightarrow \frac{348}{95}$$

$$\frac{dM}{d\theta} = 2.61$$

$$\frac{dM}{d\theta} = 210$$

$$\Rightarrow \frac{3\times210\times\frac{1}{82}\times\frac{3}{4}\times180\times10^{-6}}{4.63\times10^{-6}\times\pi}$$

$$\Rightarrow \frac{3\times210\times3\times180}{4.63\times\pi\times82\times4} = 71.3$$

Measurement of Power

11/10/22

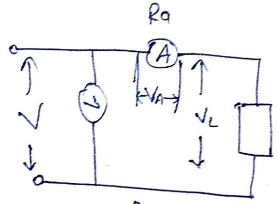


fig.1

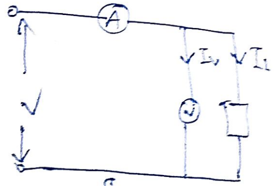
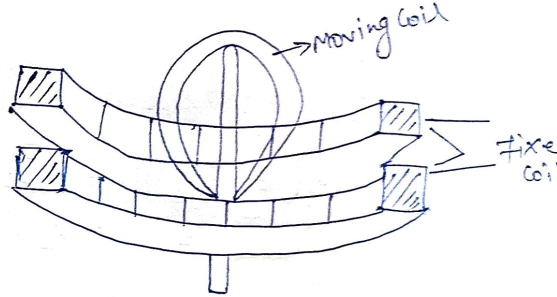
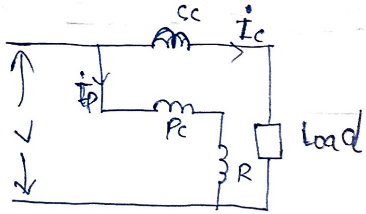


fig.2

Electrodynamometer Wattmeter





For fig.1 ⇒ $P = V \times I$ $\quad \because V = V_a + V_L$

$V_a = I R_a$ $\quad V_L = V - V_a$.

Power consumed by load $= I V_L$

$= I(V - V_a)$

$\Rightarrow$ Power indicated by instrument − Power loss in ammeter $= VI - V_a I$

For fig. 2 :→

Power indicated by inst − Power Consumed by load + Power loss in voltmeter

$I_v = \frac{V}{R_a}$

$I = I_v + I_L$

$I_L = I - I_v$

$\therefore$ Power Consumed by load $= VI_L$

$= V(I - I_v)$

$= VI - \frac{V^2}{R}$

for AC circuit

$P = Vi$

$V = V_m \sin wt$

$i = I_m \sin(wt - \phi)$ | $\theta = wt$

$\therefore P = V_m \sin wt \; I_m \sin(wt - \phi)$

$= V_m I_m \sin\theta \sin(\theta - \phi)$

$= \frac{V_m I_m}{2}\left[\cos\phi - \cos(2\theta - \phi)\right]$

$\therefore$ Avg Power over whole Cycle.

$P = \frac{1}{2\pi}\int_0^{2\pi} \frac{V_m I_m}{2}\left[\cos\phi - \cos(2\theta - \phi)\right] d\theta$

$= \frac{V_m I_m}{2} \cos\theta$

$= \frac{V_m}{\sqrt{2}} \times \frac{I_m}{\sqrt{2}} \times \cos\phi$

$\boxed{P = VI\cos\phi}$

Torque equation−

$T_i = i_1 i_2 \frac{dM}{d\theta}$ and $i_c = \sqrt{2} I(\sin(wt + \phi))$

$= \sqrt{2} I \sin(wt - \phi)$

$\because v = V_m \sin wt = \sqrt{2} V \sin wt$

$i_p = \frac{v}{R_p}$

$V_{rms} = \frac{V_m}{\sqrt{2}}$

$I_p, = \frac{\sqrt{2} V \sin wt}{R_P}$

$$T_i = \frac{\sqrt{2}V\sin\omega t}{R_P} \times \sqrt{2} I \sin(\omega t - \phi)\frac{dM}{d\theta}$$

$$= \sqrt{2} I_p \sin\omega t \times \sqrt{2} I \sin(\omega t - \phi)\frac{dM}{d\theta}$$

$$= 2 I_p I \sin\omega t \sin(\omega t - \phi)\frac{dM}{d\theta}$$

$$= I_p I\left[\cos\phi - (\cos 2\omega t - \phi)\right]\frac{dM}{d\theta}$$

∴ Avg torque over whole cycle:

$$T_d = \frac{1}{T}\int_0^T I_p I\left[\cos\phi - \cos(2\omega t - \phi)\right]\frac{dM}{d\theta}\, d\omega t$$

$$= I_p I\cos\phi\frac{dM}{d\theta}$$

$$T_d = \frac{V}{R_p} I\cos\phi\frac{dM}{d\theta}$$

$$T_c = K\theta$$

At balance

$$K\theta = \frac{V}{R_p} I\cos\theta\frac{dM}{d\theta}$$

$$\theta = \frac{V}{R_pK} I\cos\phi\frac{dM}{d\theta} \rightarrow P.$$

$$\frac{1}{R_pK} = K_1$$

$$\theta = K_1 V I\cos\phi\frac{dM}{d\theta}$$

$$\theta = K_1 \times P \times \frac{dM}{d\theta}$$

$$\therefore \boxed{\theta \propto P}$$

12/10/2022

Errors Caused because of Correction –

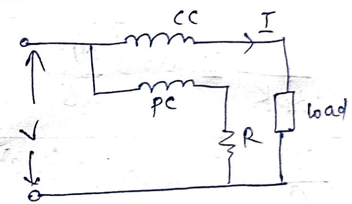


fig-a

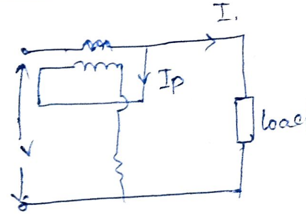
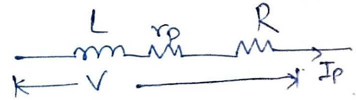
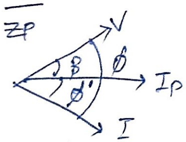


fig-b

Wattmeter errors

Pressure Coil inductance $I_p = \frac{V}{Z_P}$



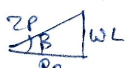


$\phi' = \phi - \beta$

$R_p = r_p + R$

$Z_p = \sqrt{(r_p+R)^2 + \omega^2 L^2}$

∴ Actual wattmeter Reading →



$R_p = Z_p\cos\beta$ $Z_p = R_p/\cos\beta$

$$= \frac{I_p I \cos\phi}{K} \frac{dM}{d\theta}$$

$$= \frac{I_p I}{K} \cos(\phi - \beta) \frac{dM}{d\theta}$$

$$= \frac{V}{Z_p K} I \cos(\phi - \beta) \frac{dM}{d\theta}$$

$$= \frac{V}{\frac{R_p}{\cos\beta} K} I \cos(\phi - \beta) \frac{dM}{d\theta}$$

$$\Rightarrow \frac{VI}{R_p K} \cos\beta \cos(\phi - \beta) \frac{dM}{d\theta}$$

$Z_p \approx Z_p \quad \beta = 0$

$\therefore$ True Power

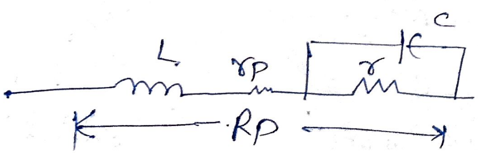
$$= \frac{I_p I \cos\phi}{K} \frac{dM}{d\theta}$$

$$= \frac{V}{R_p K} I \cos\phi \frac{dM}{d\theta}$$

$$\Rightarrow \frac{\text{True power}}{\text{Actual wattmeter reading}} = \frac{\frac{V}{R_p K} I \cos\phi \frac{dM}{d\theta}}{\frac{V}{R_p K} I \cos\beta \cos(\phi - \beta) \frac{dM}{d\theta}}$$

$$\text{True Power} = \underbrace{\frac{\cos\phi}{\cos\beta \cos(\phi - \beta)}}_{\text{Correction factor.}} \times \text{Actual wattmeter reading.}$$

#



$r_p = R_p - r$

$$Z_p = j\omega L + (R_p - r) + \frac{r}{1 + j\omega c r}$$

$$= j\omega L + (R_p - r) + \frac{r(1 - j\omega c r)}{1 + \omega^2 c^2 r^2}$$

if, $\omega^2 c^2 r^2 \ll 1$

$$Z_p \approx j\omega L + R_p - r + r - j\omega c r^2$$

$$\approx R_p + j\omega[L - cr^2]$$

If we make, $L = cr^2$

$Z_p \approx R_p \quad , \beta = 0.$

for fig. 1

Power indicated by wattmeter

= Power Consumed by load + Power loss instru...

= Power Consumed by load + $I^2 R_c$

for fig. 2

Power indicated by wattmeter

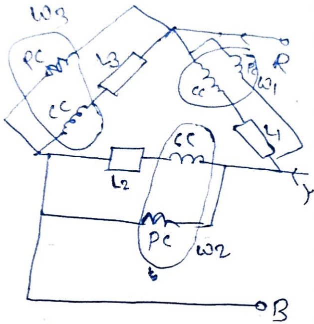
= Power Consumed by load + Power loss in R_c

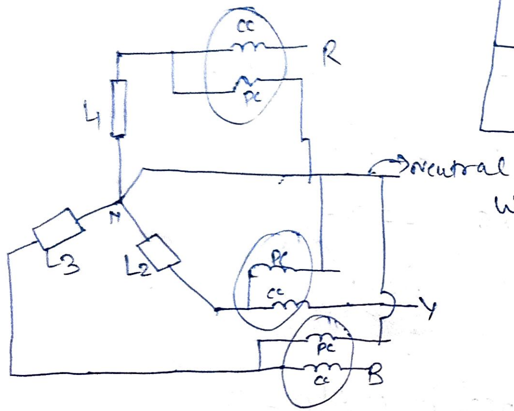
$$\downarrow$$

$$\frac{V^2}{R_p}$$

Measurement of 3-ϕ power

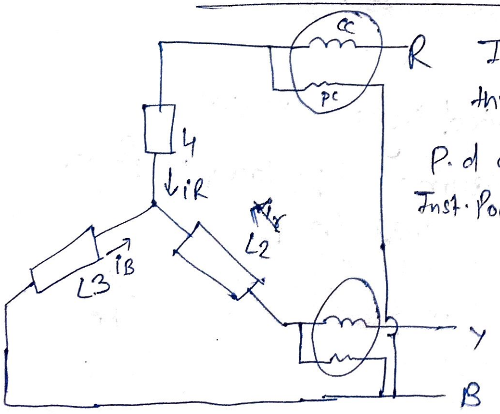
1. Three wattmeter method.
2. Two wattmeter method.
3. One wattmeter method.





$W_1 + W_2 + W_3 =$ Total Power of load

Two wattmeter method for balanced / unbalanced load.



Inst. value of ct through $W_1 = i_R$

P.d across $W_1 = e_{RB} = (e_R - e_B)$

Inst. Power Read by W_1

$= i_R(e_R - e_B)$

Inst. value of ct through $W_2 = i_Y$

p.d across $W_2 = e_{YB} = (e_Y - e_B)$

Inst. Power read by $W_2 = i_Y(e_Y - e_B)$

$$W_1 + W_2 = i_R(e_R - e_B) + i_Y(e_Y - e_B)$$

$$= i_R e_R - i_R e_B + i_Y e_Y - i_Y e_B$$

$$= i_R e_R + i_Y e_Y - e_B(i_R + i_Y)$$

$$= \underbrace{i_R e_R}_{P_1} + \underbrace{i_Y e_Y}_{P_2} + \underbrace{e_B i_B}_{P_3}$$

$$\text{Avg. Power} = \frac{1}{T}\int_0^T i_R e_{RB}\,dt + \frac{1}{T}\int_0^T i_Y e_{YB}\,dt.$$

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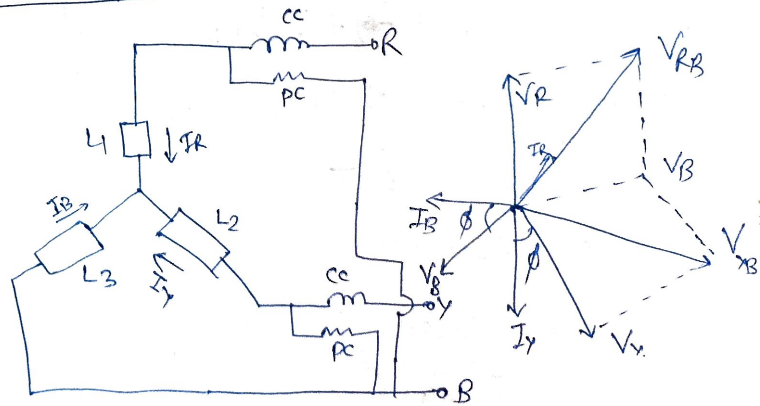
Two wattmeter method (Balanced load)



Ct through $W_1 = I_R$

P.d across $W_1 = V_{RB} = V_R - V_B$

↳ vectorially

Phase diff between I_R & $V_{RB} = (30 - \phi)$

Reading of $W_1 = I_R V_{RB} \cos(30-\phi)$

Ct through $W_2 = I_Y$

P.d across $W_2 = V_{YB}$

Phase difference betn I_Y & $V_{YB} = (30+\phi)$

$\therefore$ Reading of $W_2 = I_Y V_{YB} \cos(30+\phi)$

$V_{RB} = V_{YB} = V_L$

$I_R = I_Y = I_L$

$W_1 + W_2$

$= I_R (V_{RB}) \cos(30-\phi) + I_Y V_{YB} \cos(30+\phi)$

$= V_L I_L \cos(30-\phi) + V_L I_L \cos(30+\phi)$

$= V_L I_L [\cos(30-\phi) + \cos(30+\phi)]$

$= \sqrt{3} V_L I_L \cos\phi$

Total power of load

$W_1 + W_2 = \sqrt{3} V_L I_L \cos\phi$ — (i)

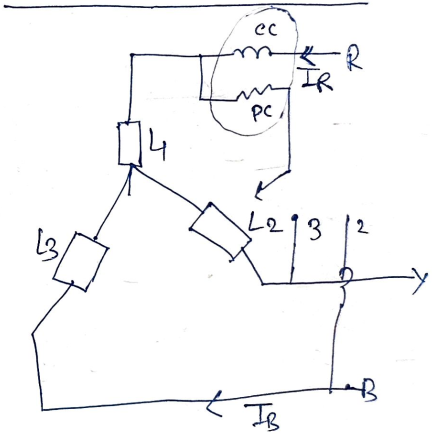
$W_1 - W_2 = V_L I_L \sin\phi$ — (ii)

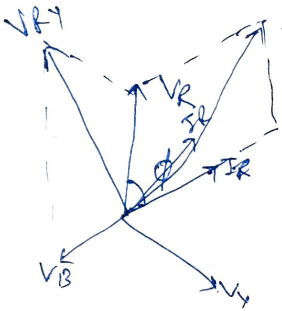
$$\tan\phi = \frac{\sqrt{3}(W_1 - W_2)}{W_1 + W_2}$$

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

$\cos\phi$

One Wattmeter Method.





For position – 2

Ct through $W_1 = I_R$

P.d across $W_1 = V_{RB}$

Ph. diff b/w V_{RB} & $I_R = (30 - \phi)$

$\Rightarrow V_{RY} = V_{RB} = V_L$

$I_R = I_L$

$\Rightarrow V_L I_L \cos(30-\phi) + V_L I_L (30+\phi) = \sqrt{3} V_L I_L \cos\phi$.

For position - 3

Ct through $W_1 = I_R$

P.d across $W_1 = V_{RY}$

$\therefore$ Ph. diff b/w I_R & V_R $= (30+\phi)$

Q: Each phase of a 3-phase delta connected load consist of an impedance $Z = 20\angle 60^\circ$ the line voltage is 440V at 50Hz. Compute power consumed by each phase impedence and the total power. What will be the reading of two wattmeter connected.

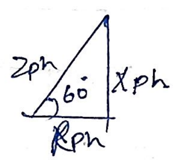
Soln

$Z = 20\angle 60^\circ$

$V_{ph} = V_L = 440V$

$Z = 20\Omega$.

$I_{ph} = \frac{440}{20} = 22A$



$R_{ph} = Z_{ph}\cos 60^\circ$

$= 20 \times \frac{1}{2}$

$= 10\Omega$

$\therefore$ Power/phase $= I_{ph}^2 \times R_{ph}$

$= 22^2 \times 10$

$= 4840.$

Total power $= 3 \times 4840 = 14520W.$

$\cancel{440 \times \sqrt{3} \times 22 \times \frac{\sqrt{3}}{2}}$

$\cancel{440}^{22} \times 22 \times \frac{1}{2}$

$\Rightarrow 4840$

$\sqrt{3} V_L I_L \cos\phi$

$= 14520W$

$W_1 = V_L I_L \cos(30-\phi) =$

$W_2 = 0$

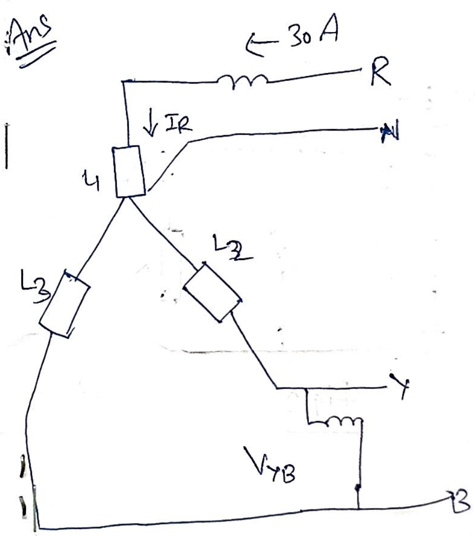
Q: Three identical coil each having a reactance of 20Ω are connected in ① star ② Delta across a 440V 3 phase line. Calculate for each method of connection the line current and the reading on each of the two-wattmeter connected to measure the power.

MEASUREMENT AND MEASURING INSTRUMENTS

10/10/2022

1) A wattmeter reads 5.454KW when its current coil is connected in the red phase and its voltage coil is connected between neutral and red phase of a symmetrical 3-phase system supply in a balanced load of 30A at 400V. What will be the reading of the instrument, if the CC remains unchanged and the voltage coil be connected b/w blue and yellow phase. The phase sequence R, Y, B what does this fig. represent

Ans



$V_P = \frac{V_L}{\sqrt{3}} = \frac{400}{\sqrt{3}}$

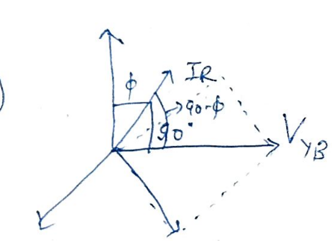
$I_P = I_L = 30A$

Reading $= 5.54 \times 10^3 W$

$V_P I_P \cos\phi = 5.54 \times 10^3$

$\cos\phi = \frac{5540 \times \sqrt{3}}{400 \times 30}$

$\cos\phi = 0.799$



ph. diff betn V_{YB} & $I_R = (90 - \phi)$

Reading $= V_{YB} I_R \cos(90-\phi)$

$= V_{YB} I_R \sin\phi$

$= \sqrt{3} \times V_P \times I_P \times \sin\phi$

$= 7.2 KVAR$

MEASUREMENT OF RESISTANCE

1) Low resistance $< 1\Omega$

II) Medium resistance = 1 ohm upwards to 0.1 MΩ

III) High resistance − 0.1 MΩ & upwards.

Measurement of medium resistance

(i) Ammeter-Voltmeter Method

(ii) Substitution Method

(iii) Wheatstone bridge Method

(iv) Ohmmeter Method.

1) Ammeter-voltmeter Method :-

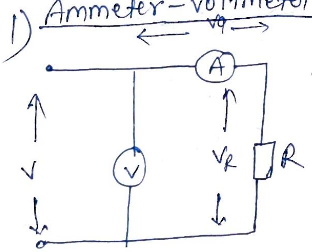


Fig. 1

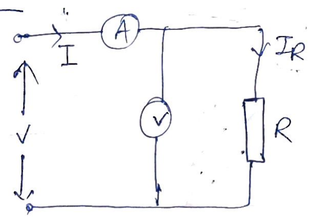


Fig. 2

$V_a = IR_a$

$$R_{m_1} = \frac{V}{I} = \frac{V_a + V_R}{I} = \frac{IR_a + IR}{I}$$

$$R = R_{m_1} - R_a \quad \because R_{m_1} = R_a + R$$

$$= R_{m_1}\left(1 - \frac{R_a}{R_{m_1}}\right) \Rightarrow R_{m_1} - R = R_a$$

$$\downarrow \varepsilon_r = \frac{R_{m_1} - R}{R} = \frac{R_a}{R} \uparrow$$

Fig. 2 $\quad \varepsilon = \frac{M-T}{T} \times 100\%$

$$R_{m_2} = \frac{V}{I} = \frac{V}{I_R + I_V} = \frac{V}{\frac{V}{R} + \frac{V}{R_V}} = \frac{RR_V}{R + R_V} = \frac{RR_V}{R_V\left(1 + \frac{R}{R_V}\right)} = \frac{R}{1 + \frac{R}{R_V}}$$

$$R_{m_2} = \frac{R}{1 + \frac{R}{R_V}}$$

$$R_{m_2}\left(1 + \frac{R}{R_V}\right) = R$$

$$R_{m_2}R_V + RR_{m_2} = RR_V$$

$$RR_V - RR_{m_2} = R_{m_2}R_V$$

$$R(R_V - R_{m_2}) = R_{m_2}R_V \Rightarrow R = \frac{R_{m_2}R_V}{R_V - R_{m_2}}$$

$$= \frac{R_{m_2}R_V}{R_V\left(1 - \frac{R_{m_2}}{R_V}\right)}$$

$$R = R_{m_2}\left(\frac{1}{1 - \frac{R_{m_2}}{R_V}}\right)$$

if $R_V >>> R_{m_2}$

$R \approx R_{m_2}$

$$R = R_{m_2}\left(1 + \frac{R}{R_V}\right) \qquad R_V >>> R_{m_2}, \quad R \approx R_{m_2}$$

$$= R_{m_2}\left(1 + \frac{R_{m_2}}{R_V}\right)$$

$$R_{m_2} - R = -\frac{R_{m_2}^2}{R_V}$$

$$\downarrow \%\varepsilon_r = \frac{R_{m_2} - R}{R} = \frac{-R_{m_2}^2}{RR_V} = \frac{-R^2}{RR_V} = \frac{-R}{R_V}\downarrow$$

ii) Substitution Method:

r → ammeter
R → unknown resistance
S → standard resistance

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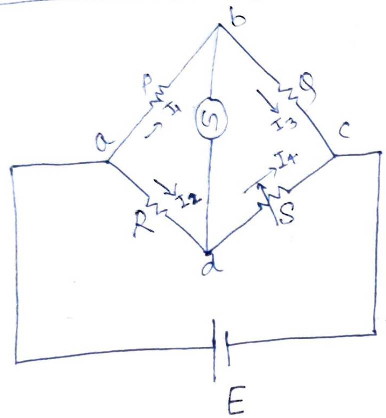
iii) Wheatstone bridge



At balance.

$I_1 = I_3$

$I_2 = I_4$

$\therefore I_1 P = I_2 R$

$I_1 = \frac{E}{P+Q}$, $I_2 = \frac{E}{R+S}$

$\frac{E}{P+Q} P = \frac{E}{R+S} R$

$\frac{P}{P+Q} = \frac{R}{R+S}$

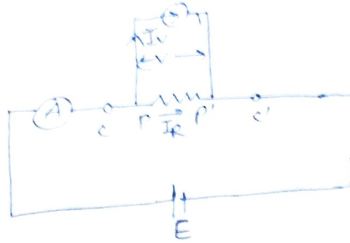
$\boxed{R = \frac{P}{Q} \cdot S}$

Measurement of low resistance :-

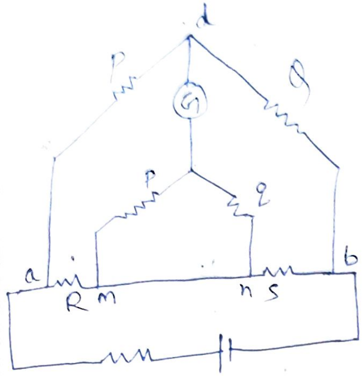
i) Ammeter Voltmeter Method

ii) Kelvin's double bridge Method

iii) Potentiometer Method



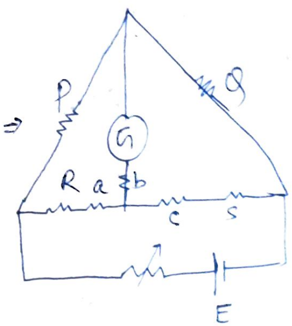
Ammeter voltmeter Method.



Kelvin's double bridge.

$$\boxed{\frac{P}{Q} = \frac{p}{q}}$$

⇒



$\frac{P}{Q} = \frac{R+a}{c+S}$

$b = \frac{pq}{p+q+r}$

$a = \frac{pr}{p+q+r}$

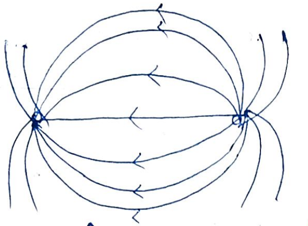
$c = \frac{qr}{p+q+r}$

$R = \frac{P}{Q}(c+S) - a$

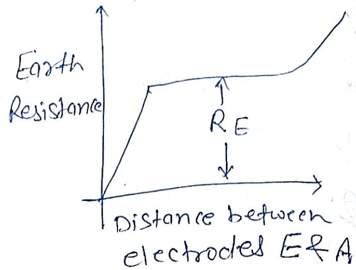
$= \frac{P}{Q} S + \frac{P}{Q} \times \frac{qr}{p+q+r} - \frac{pr}{p+q+r}$

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

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

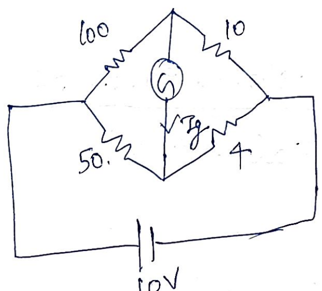


flow of ground current



H.W High resistance (Megger)

Q



G1. I_g ?

$$\frac{1}{R_0} = \frac{1}{100} + \frac{1}{10} + \frac{1}{50}$$

$$R_0 \Rightarrow \frac{1000}{110} + \frac{200}{54}$$

$$R_0 \Rightarrow 9.09 + 3.7$$

$$R_0 = 12.793$$

$$\cancel{R_0 + g = \frac{E_0}{I_g}}$$

$$\cancel{10 + 12.793 = \frac{10}{I_g}}$$

$$\cancel{I_g = \frac{10}{22.793} = 0.438 \text{ Amp}}$$

p.d of b w.r.t c

$$= 10 \times \frac{10}{110} = 0.909$$

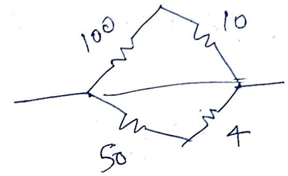
p.d of d w.r.t c

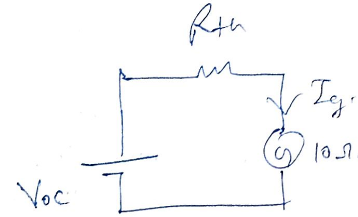
$$= 10 \times \frac{4}{54} = 0.74$$

$$\therefore V_{oc} = V_b - V_d$$

$$= 0.909 - 0.74$$

$$= 0.17$$





$$R_{th} = (100 \parallel 10) + (50 \parallel 4) = 12.79$$

$$I_g = \frac{V_{oc}}{R_{th} + 10} = \frac{0.17}{12.79 + 10} = 7.45\,mA$$

Q) Three identical coils each having a reactance of 20Ω and resistance of 20Ω are connected in
1) Star
2) Delta
across a 440V, 3phase line. Calculate for each method of connection the line current and reading each of two wattmeter connected to measure power.

→ ~~$W_1 = 3kW$~~
~~$W_2 =$~~

$V_p = \frac{V_L}{\sqrt{3}} = \frac{440}{\sqrt{3}}$

$I_p = I_L$

$I_p = \frac{V_p}{Z_p}$

$I_p = \frac{\frac{440}{\sqrt{3}}}{\sqrt{(20)^2+(20)^2}}$

$I_p = 8.98$ Amp.

Total power $= \sqrt{3} V_L I_L \cos\phi$

$= \sqrt{3} \times 440 \times 8.98 \times \frac{20}{20\sqrt{2}}$

$= 4839.21$ Watt

$W_1 = V_L I_L \cos(30-\phi)$

$= 440 \times 8.98 \times (0.965) = 3816.566\,W$

$W_2 = V_L I_L \cos(30+\phi) = 1022.64\,W$

for delta

$I_p = \frac{I_L}{\sqrt{3}}$

$V_p = V_L = 440$

$I_p = \frac{V_p}{Z_p} = \frac{V_L}{Z_p} = \frac{4}{5}$

$I_p = 15.55$ Amp.

$I_L = \sqrt{3} I_p = 26.9$

Total power $= \sqrt{3} V_L I_L \cos\phi$

$= 14442.1915\,W$

$W_1 = V_L I_L \cos(30-\phi)$

$= 11390.19\,W$

$W_2 = 3051.99410\,W$ (14441.99) Sumation of $W_1 + W_2$

$W_1 = 782\,W$

$W_2 = 1980\,W$

$V_L = 416\,V$

$I_L = ?$ $C = ?$

$\tan^{-1}\left(\frac{W_1 - W_2}{W_1 + W_2}\right) = \phi$

$\tan\phi = -\sqrt{3}\left(\frac{1980-782}{1980+782}\right)$

$= -\sqrt{3}\left(\frac{1198}{2762}\right)$

$\tan\phi = -\sqrt{3}\left(\frac{1198}{2762}\right)$

~~$W = \sqrt{3} I_L V_L \cos\phi$~~

$W_1 = V_L I_L \cos(30-\phi)$

$\frac{782}{1980} = \frac{V_L I_L \cos(30-\phi)}{V_L I_L \cos(30+\phi)}$

$2.53 = \frac{\cos(30+\phi)}{\cos(30-\phi)}$

~~$2.53 = \cos 30 \cos\phi - \sin 30 \sin\phi$~~

$\cos\phi = 0.8$

$\phi = 36.9$

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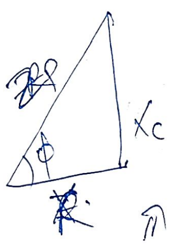
$W = \sqrt{3} V_L I_L \cos\phi$

$2762 = \sqrt{3} \times \cancel{V_L} \, 416 \times I_L \times 0.8$

$I_L = 4.79$ AMP

$I_P = \frac{V_P}{Z_P}$

$Z_P = \frac{V_P}{I_P} = \frac{240.17}{4.79}$



$Z_P = 50.14\,\Omega$

$\sin\phi = \frac{X_C}{Z_P}$

$0.6 = \frac{X_C}{50.14}$

$30.084 = X_C$

$\frac{1}{\omega C} = 30.08$

$\frac{1}{C} = 30.08 \times 314$

$C = \frac{1}{9445.12}$

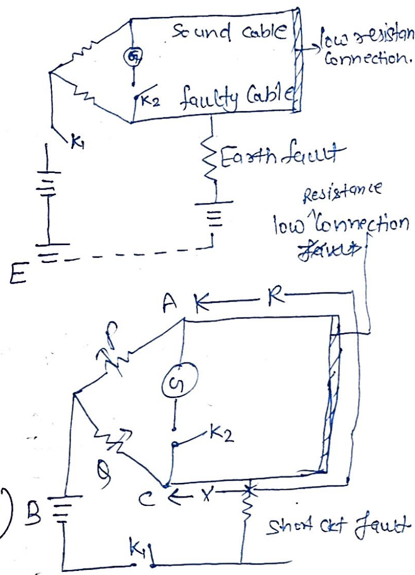
$C = 105.8 \times 10^{-5}$

Types of Cable faults

1) open circuit fault
11) Short circuit fault
111) Earth fault

Loop tests for location of faults in underground cable

(i) Murray loop test
(ii) Varley loop test



Murray loop test

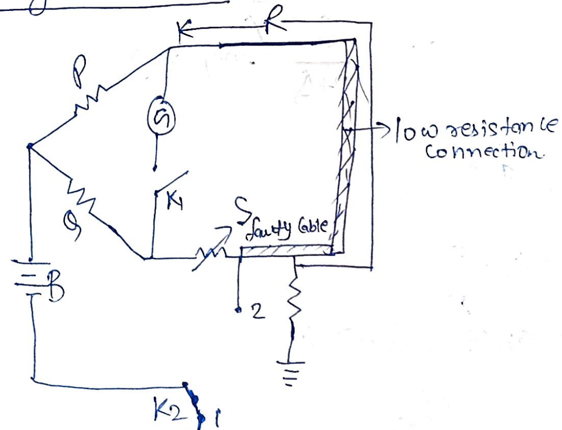
$\frac{P}{Q} = \frac{R}{X} \Rightarrow \frac{P}{Q} + 1 = \frac{R}{X} + 1$

$\Rightarrow \frac{P+Q}{Q} = \frac{R+X}{X}$

$\Rightarrow X = \frac{Q}{P+Q}(R+X)$

→ (next page)

Varley loop test



Murray loop test (Continued):

$$\therefore X = \frac{Q}{P+Q}(R+X)$$

r is the resistance of each cable

$R+X = 2r$

l is the length of each cable in m.

$\therefore$ resistance / m length $= r/l$

$$X = \frac{Q}{P+Q}(2r)$$

$\therefore$ distance of fault from the end

$$= \frac{X}{r/l} = \frac{Q}{P+Q} \times 2r \times \frac{l}{r}$$

$$d = \frac{Q}{P+Q}(2l)$$

$$d = \frac{Q}{P+Q}(\text{loop length})$$

Varley loop test

At position ①

At balance $S \rightarrow S_1$

$$\frac{P}{Q} = \frac{R}{X+S_1}$$

$$\frac{P}{Q}+1 = \frac{R}{X+S_1}+1$$

$$\frac{P+Q}{Q} = \frac{R+X+S_1}{X+S_1}$$

$$\frac{Q}{P+Q} = \frac{X+S_1}{P+X+S_1}$$

$$X = \frac{Q}{P+Q}(R+X+S_1) - S_1$$

$$X = \frac{QR+Q+\cancel{QS_1}-PS_1-\cancel{QS_1}}{P+Q}$$

$$\boxed{X = \frac{Q(R+X)-PS_1}{P+Q}}$$

At Position ②

At balance $S \rightarrow S_2$

$$\frac{P}{Q} = \frac{R+X}{S_2}$$

$$\therefore R+X = \frac{P}{Q}S_2$$

$$Q(R+X) = PS_2$$

$$\Rightarrow \boxed{X = \frac{P(S_2-S_1)}{P+Q}}$$

In a test by Murray loop method for a fault to R on 525m length of cable having a resistance of $1.1\Omega/1000m$, The faulty cable is looped with a sound cable of same length but having a resistance of $\frac{2.29\Omega}{1000m}$ the resistances of the other two arm of the testing network at balance are in the ratio of $2.7:1$. Calculate the distance of fault from testing end of cable.

Soln r_e of faulty Cable – $1.1/1000$

r_e of Sound Cable – $\frac{2.29}{1000}$

$$R+X = \left[\frac{1.1}{1000} + \frac{2.29}{1000}\right] 520$$

$$\Rightarrow \frac{3.39 \times 520}{1000} = 1.7628\,\Omega$$

$$X = \frac{Q}{P+Q}(R+X)$$

$$X = \frac{1}{\cancel{2.7}\ 4.1} \times 1.7628$$

$$X = 0.476\,\Omega$$

$$d = \frac{0.476}{\frac{1.1}{1000}}$$

≈ 433m

Q A short circuit fault is located by Varley ~~Vernier~~ loop test. The ratio arms are set at $P = 5\Omega$, $Q = 10\Omega$ and the values of variab resistance $S = 16\Omega$ for (P1) and 7Ω for (P2). The Sound and faulty Cable are identic and have a resistance of $0.4\Omega/km$. Deter the length of each Cable and the distanc

Soln

$$R+X = \frac{P}{Q}S_1$$

$$R+X = \frac{5}{10} \times 16 \Rightarrow 8\Omega$$

$$X = \frac{5(16-7)}{10+5} \Rightarrow \frac{9}{3} = 3\Omega$$

$$d = \frac{3}{0.4} = \frac{30}{4} = \frac{15}{2} = 7.5\text{km}$$

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

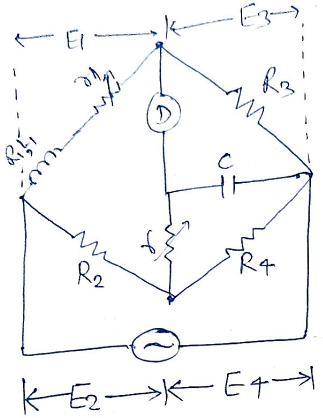
$$\cancel{X = S}\frac{(P)}{Q}$$

$$X = \frac{(16-7)5}{10+5} \Rightarrow 3\Omega$$

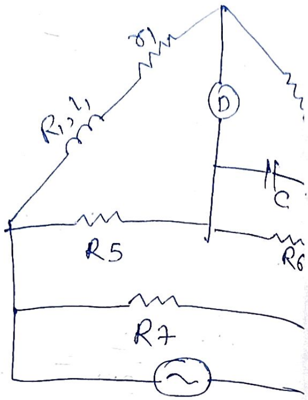
$$d = \frac{X}{0.4}$$

09|11|20

Anderson's bridge



$\Rightarrow$



$$R_5 = R_2 + r_4 + \frac{R_2 r}{R_4}$$

$$R_6 = R_4 + \cancel{r_2} + \frac{r R_4}{R_2}$$

$$R_7 = R_2 + R_4 + \frac{R_2 R_4}{r}$$

At balance.

$$\frac{(R_1 + r_1 + j\omega L_1) R_6}{1 + j\omega C R_6}$$

$$(R_1 + r_1) R_6 = R_5 R_3$$

$$(R_1 + r_1) \times \frac{(R_4 + R_2 + r R_2 + r R_4)}{R_2} = \frac{(R_2 R_4 + r R_4 + \dots}{R_2}$$

$$\frac{R_1 r_1}{R_2} = \frac{R_3}{R_4}$$

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

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

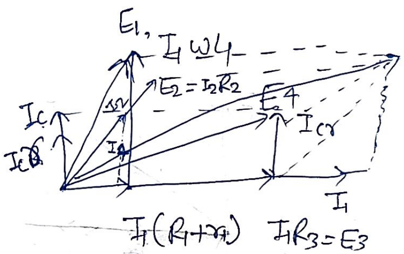
$$j\omega L_1 R_6 = j\omega C R_6 R_5 R_3$$

$$L_1 = C R_5 R_3$$

$$= C\left[\frac{R_2 R_4 + r R_4 + r R_2}{R_4}\right] R_3$$

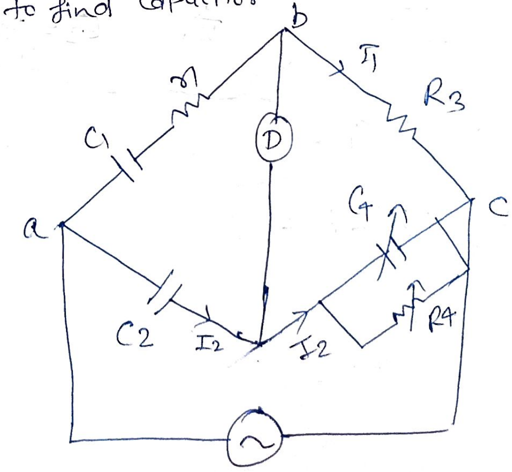
$$\boxed{L_1 = \frac{C R_3}{R_4}\left[r(R_2 + R_4) + R_2 R_4\right]}$$

Phasor diagram



Schering Bridge

, used to find Capacitor



$z_1 z_4 = z_2 z_3$

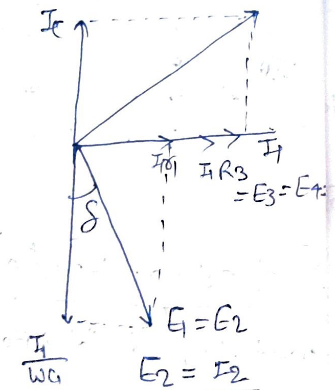
$$\left(r_1 + \frac{1}{j\omega C_1}\right)\left(\frac{R_4}{1 + j\omega C_4 R_4}\right) = \frac{R_3}{j\omega C_2}$$

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

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

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

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



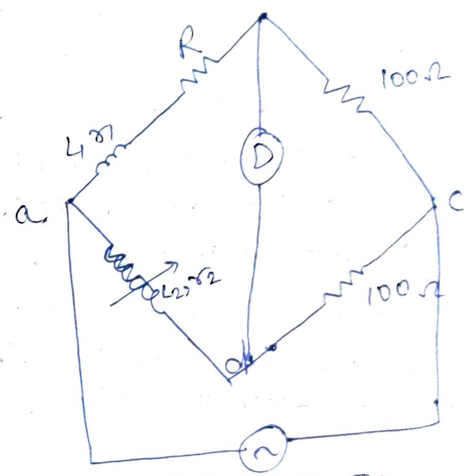
$$\tan\delta = \frac{I_1 r_1}{\frac{I_1}{\omega C_1}}$$

$\Rightarrow \omega C_1 r_1$

$$\boxed{D = \omega C_4 R_4}$$

1. The four arm of an AC bridge are as follows- The arm ab consist of a coil with inductance L_1 and resistance r_1 in series with a non-inductive resistance (R). Arm bc and cd are are each a non inductive resistance of 100Ω arm ad consist of standard variable ~~resistor~~ R inductor L_2 of resistor r_2 32.7Ω. Balance is obtained when $L_2 = 47.8$ mH and $R = 1.36$Ω. Find the resistance and inductance of coil in arm ab.

Sln



$z_1 z_4 = z_2 z_3$

$$(R_1 + j\omega L_1 + r_1)100 = (r_2 + j\omega L_2)100$$

$$R_1 + r_1 = r_2$$

$$r_1 = r_2 - R_1$$

$$= 37.7 - 1.36$$

$$= 31.54\Omega$$

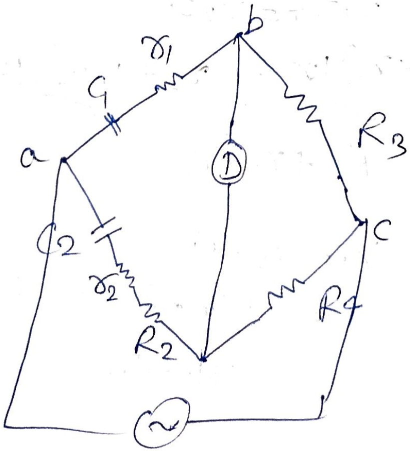
$j\omega L_1 = j\omega L_2$

$L_1 = L_2$

$L_1 = 47.8\,mH$

Q) The four arm of a bridge are –
Arm ab an imperfect capacitor with an equivalent resistor r_1, arm bc a non-inductive resistance R_3, arm cd non inductance resistan R_4 and arm ad an imperfect Cap C_2 with an equivalent series resistance r_2 in series with R_2. A supply of 450 Hz is given the terminal b/w a and c and the detector is connected between b and d. At balance $R_2 = 4.8\,\Omega$ and $R_3 = 2000\,\Omega$. $R_4 = 2850\,\Omega$, $C_2 = 0.$ $r_2 = 0.4\,\Omega$. Calculate the value of C_1 & r_1 and also find the dissipation factor.

Soln



$$\left(r_1 + \frac{1}{j\omega C_1}\right) R_4 = R_3\left(R_2 + r_2 + \frac{1}{j\omega C}\right)$$

$$r_1 R_4 + \frac{R_4}{j\omega C_1} = (R_2 + r_2) R_3 + \frac{R_3}{j\omega C_1}$$

$$r_1 R_4 = (R_2 + r_2) R_3$$

$$r_1 = (R_2 + r_2)\frac{R_3}{R_4} = 3.65\,\Omega$$

$$D = \omega C_1 r_1$$

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

$$\frac{C_1}{C_4} = \frac{C_2}{R_3} \quad C_1 = \frac{R_4}{R_3} C_2 = 0.7125\,\mu f$$

Q) Derive the balance equation of wien bridge and phasor diagram

A.K sahani book, exp – 16.5, 16.7, 16.12

Accuracy, Precision, sensitivity, Resolution, errors

10|11|20

1) Accuracy
2) Precision
3) sensitivity
4) Resolution
(smallest change in value of an instrument)

1) static error
2) relative static error
3) limiting error or Guarantee error

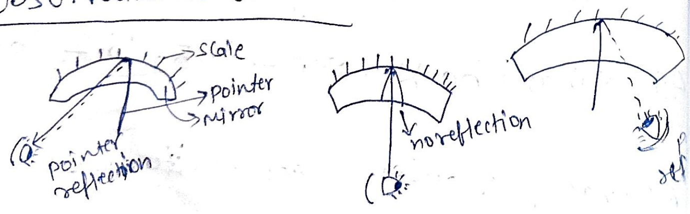
Types of errors
1) Gross error
2) Systematic error
3) Random error

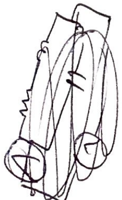
Systematic error

Instrumental error
Environmental error
observation error

These errors arises due to three main reasons-
1) Due to inherent short coming in the instrument
2) Due to misuse of the instrument
3) Due to loading effect

Observational error-



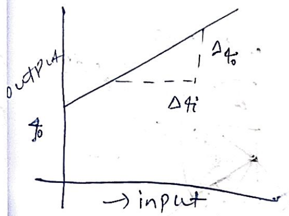


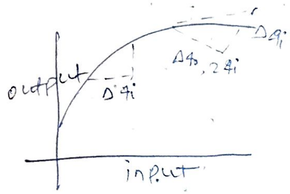
Accuracy can be expressed in the following ways-

1) Point accuracy
2) Accuracy as percentage of scale range
3) Accuracy as percentage of True value..

Acc- A1 ⇒100A, 100.1A, 100A, 100A, 100.1A
Sens-> A2 ⇒100A . 100.2A, 100.5A, 100.1A

sensitivity = $\frac{\text{mag. of output signal/response}}{\text{mag. of input signal/response.}}$





Measurement of Energy

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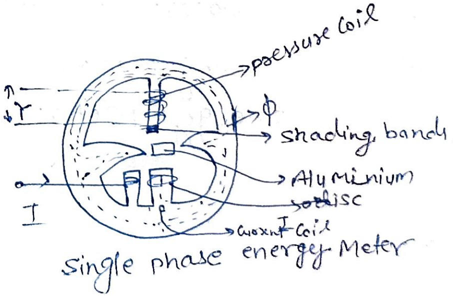
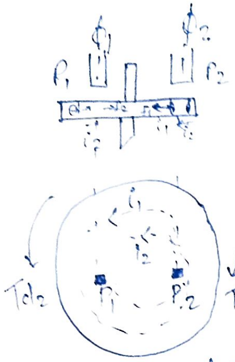
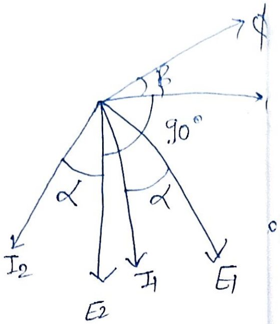


single phase energy Meter

Construction
(i) Driving system
(ii) Moving system
(iii) Braking system
(iv) Registering system

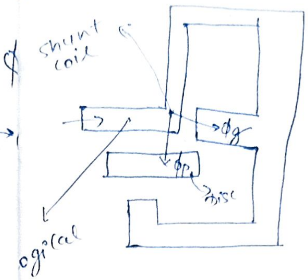


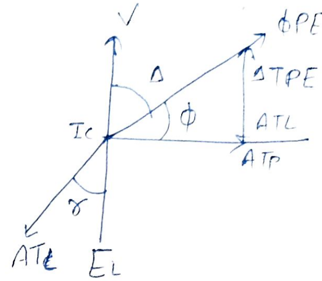
Working of an induction

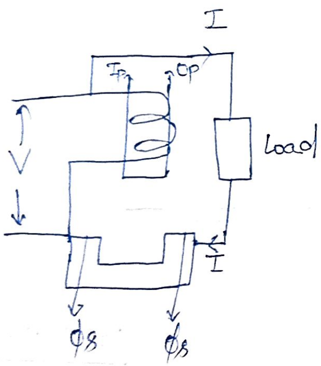


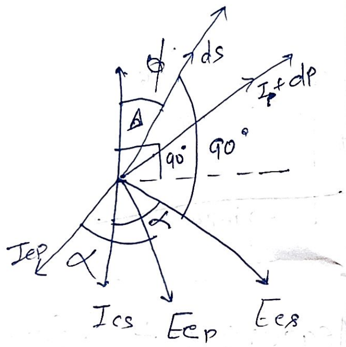
phasor diagram of an induction type meter

Lag Adjustment device

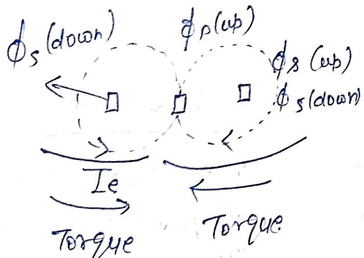








phasor diagram single phase energy meter



Working of single phase energy meter

1) A meter constant of 230V, 10A watthr meter is 1800 revolution/kWh. The meter is tested at half load and rated voltage and unity powerfactor. The meter is found to make 20 rev/n 138 sec. Determine the meter error at half load.

2) A 230 V single phase watt-hour meter has constant load of 4 Amp passing it for 6hr at unity power factor

If the Meter disc makes 2200 ... during this period what is the meter constant in revolution per kWhr. Calculate the power factor of the load if the no. of revol make by the meter are 1472 when opera at 230 V, 5 Amp for 4 hrs.

Sol-1)

meter const $= \frac{\text{No. of rev}}{\text{kWh}}$

$= 1000$

Actual energy consumed $= VI\cos\phi \times t \times 10^{-3}$

$= \frac{230 \times 5 \times 1 \times 138}{3600} \times 10^{-3}$

$= 44.08 \times 10^{-3}$ kWhr

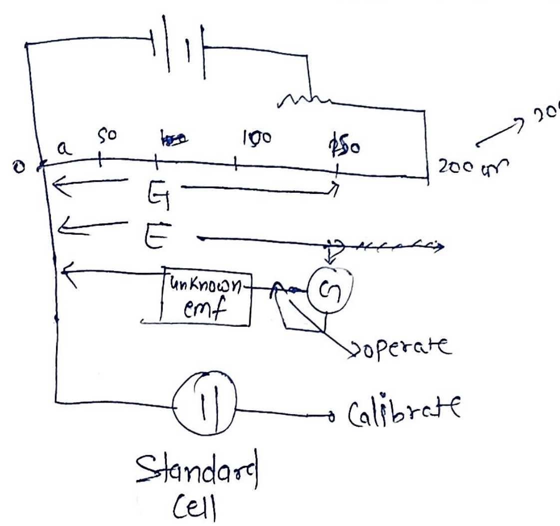
Energy recorded $= \frac{80}{1800} \Rightarrow 44.4 \times 10^{-3}$

% error $= \frac{44.4 - 44.08}{44.08} \times 100$

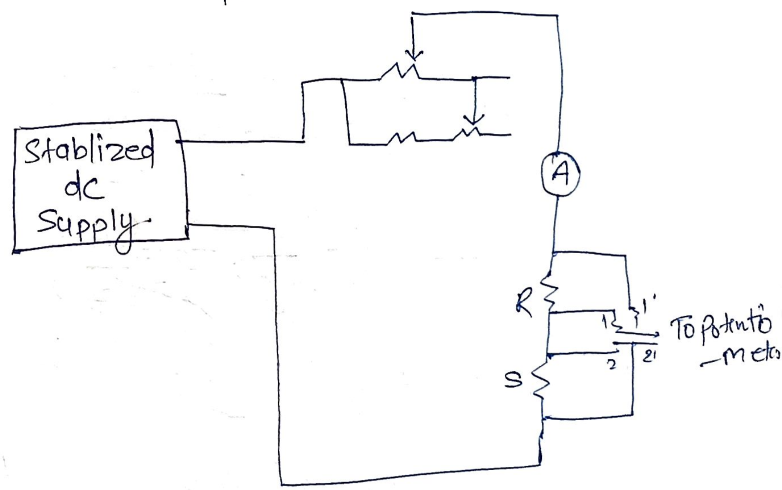
8004922015

1912

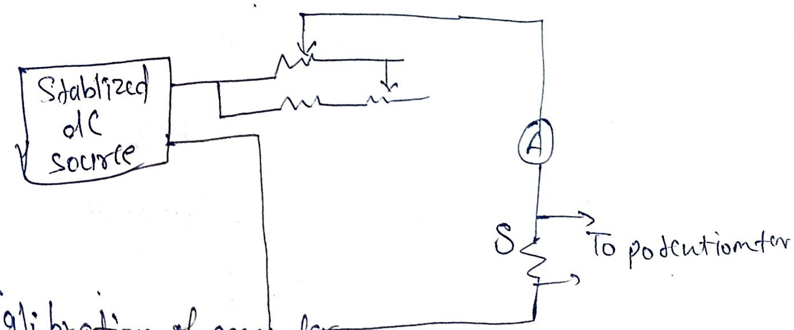
DC Potentiometer



Circuit diagram of basic slidewire potentiometer.



Measurement of resistance



→ Calibration of ammeter