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Measurement of Resistance

Classification of Resistance

1. **Low resistance:** All resistance of the order of 1 Ω and below.
   Example: Winding coils of electrical motors, generators and transformers.
2. **Medium resistance:** Resistances from 1 Ω upwards to about 0.1 MΩ
   Example: Resistance of heaters, potentiometers.
3. **High resistance:** All resistances of the order of 0.1 MΩ and above.
   Example: Insulation of electrical cable and windings, insulation of motors generators and transformers.

Measurement of Medium Resistance

The different methods employed are:

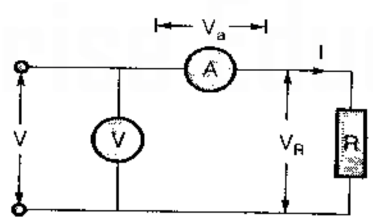
(i) Ammeter-voltmeter method
(ii) Wheatstone bridge method
(iii) Ohmmeter method
(iv) Substitution method

1. Ammeter Voltmeter Method

$$R_m = \frac{\text{voltmeter reading}}{\text{ammeter reading}} = \frac{V}{I}$$

where, R_m = measured value of resistance

(a) Circuit for higher resistance



❑ True value of resistance

$$R = R_{m_1} - R_a$$

$$R_m = R_{m1}\left(1 - \frac{R_a}{R_{m1}}\right)$$

where, R_{m_1} = Measured value of resistance

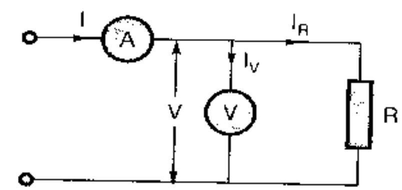
R_a = Resistance of ammeter

❑ Relative error

$$\epsilon_r = \frac{R_{m1} - R}{R} = \frac{R_a}{R}$$

- To get minimum error, the test resistance should be more than the ammeter resistance so that this adjustment is suitable for measurement of high resistance.

(b) Circuit for lower resistance



❑ True value of resistance

$$R = \frac{R_{m_2} R_v}{R_v - R_{m_2}}$$

where, R_{m_2} = Measured value of resistance

R_v = Resistance of voltmeter

For $R_v >> R_{m_2}$

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

❑ Relative error

$$\epsilon_r = \frac{R_{m2} - R}{R} = \frac{-R_{m2}^2}{R_v R}$$ [For $R_v >> R_{m_2}$]

- Approximate relative error

$$\boxed{\epsilon = -\frac{R}{R_v}} \qquad \left[\text{For } R_{m_2} \approx R\right]$$

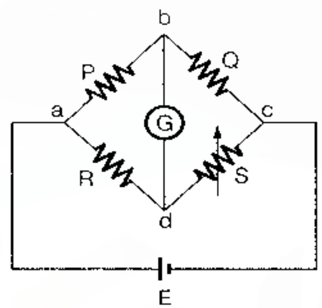
- This circuit is suitable for measurement of low resistance under medium scale range to get minimum error.

Note:

Relative errors for above two cases are equal when true value of resistance,

$R = \sqrt{R_a R_v}$

2. Wheatstone Bridge



- At balance

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

- Sensitivity of Wheatstone bridge

$$\boxed{S_B = \frac{\theta}{\Delta R/R} = \frac{S_v ESR}{(R+S)^2}} \text{ ; mm}$$

$$\boxed{S_B = \frac{S_v E}{\frac{P}{Q} + 2 + \frac{Q}{P}}}$$

where, S_v = Voltage sensitivity of galvanometer, mm/volt

E = Bridge voltage

P, Q = Branch resistances

θ = Deflection of galvanometer, mm

- For a bridge with equal arms

$$\boxed{S_B = \frac{S_v E}{4}}$$

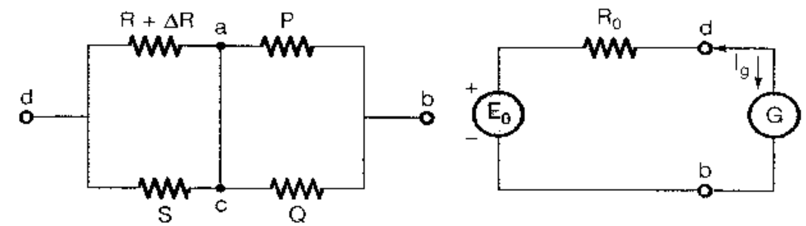
Note:

- For maximum bridge sensitivity

$$\frac{P}{Q} = \frac{R}{S} = 1$$

- Sensitivity of bridge is most important parameter as compared to accuracy, precision and resolution.

Equivalent circuit of Wheatstone bridge



- Galvanometer current

$$\boxed{I_g = \frac{E_0}{R_0 + G}}$$

where E_0 = Thevenin's or open circuit voltage appearing between terminals b and d with galvanometer circuit open circuited.

G = Resistance of the galvanometer circuit

$$\boxed{E_0 = E\left[\frac{R+\Delta R}{2R+\Delta R} - \frac{1}{2}\right] \approx E\left(\frac{\Delta R}{4R}\right)} \text{ as DR << R}$$

ΔR = Change in resistance R

- Thevenin equivalent resistance of bridge

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

- Galvanometer deflection

$$\theta = \frac{S_v\, ES\, \Delta R}{(R+S)^2} = \frac{S_i\, E\, S\Delta R}{(R_0 + G)\,(R+S)^2}$$

where, S_i = Current sensitivity of galvanometer

- Bridge sensitivity

$$S_B = \frac{\theta}{\Delta R / R} = \frac{S_i\, E\, SR}{(R_0 + G)\,(R+S)^2}$$

- Current Sensitivity

$$S_i = \frac{\theta}{I_g};\ \text{mm}/\mu\text{A}$$

θ = Deflection in galvanometer

I_g = Current in galvanometer

- Voltage Sensitivity

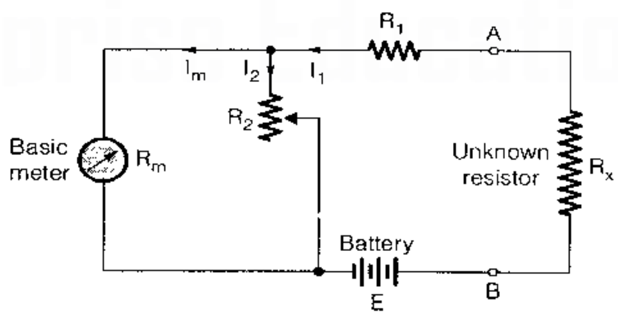
$$S_v = \frac{\theta}{V_{Th}};\ \text{mm/V}$$

V_{Th} = Voltage across galvanometer

Note: In Wheatstone bridge method, the effect of lead resistance is not eliminated hence it is not suitable for measurement of low resistance.

3. Ohmmeters

(a) Series Type Ohmmeter



- Half scale resistance

$$R_h = R_1 + \frac{R_2\, R_m}{R_2 + R_m}$$

- Meter current

$$I_m = \frac{ER_2}{(R_h + R_x)\,(R_2 + R_m)}$$

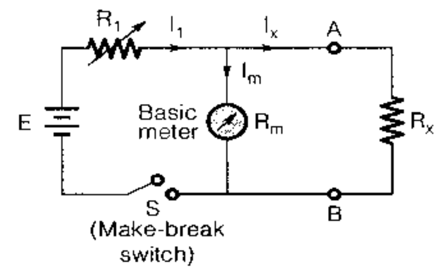
- Full scale deflection current

$$I_{fs} = \frac{ER_2}{R_h(R_2 + R_m)}$$

- Friction of full scale reading

$$s = \frac{I_m}{I_{fs}} = \frac{R_h}{R_x + R_h}$$

(b) Shunt Type Ohmmeter



- Half scale reading of unknown resistance R_x is

$$R_h = \frac{R_1\, R_m}{R_1 + R_m}$$

- Half scale reading of the meter

$$I_h = 0.5\, I_{fs} = \frac{ER_h}{R_1 R_m + R_h(R_1 + R_m)}$$

where, R_m = Internal resistance of meter

R_1 = Adjustable resistor (as shown in figure)

E = Supply voltage

Measurement of low Resistance

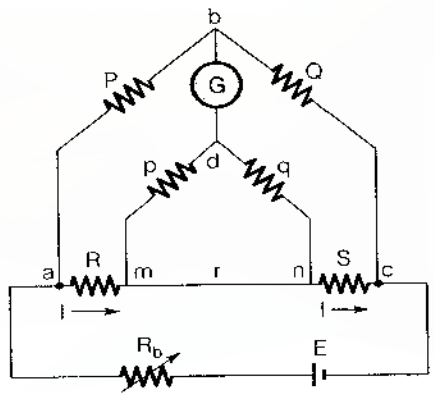
The different methods employed are:

(i) Kelvin's double bridge method

(ii) Ammeter voltmeter method

(iii) Potentiometer method

Kelvin's Double Bridge Method



- For zero galvanometer deflection

$$E_{ab} = E_{amd}$$

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

- If $\frac{P}{Q} = \frac{p}{q}$

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

Note:

Accuracies by Kelvin double bridge method

(i) From 1000 μΩ to 1.0 Ω : 0.05%

(ii) From 100 μΩ to 1000 μΩ : 0.5% to 0.05%

(iii) From 10 μΩ to 100 μΩ : 0.5% to 0.2%

Measurement of High Resistance

The differenece methods employed are:

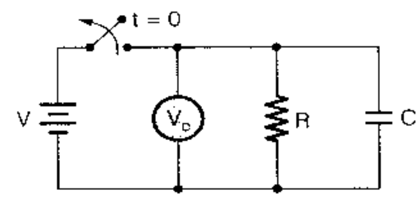
(i) Loss of charge method

(ii) Meggar

(iii) Direct deflection method

(iv) Megohm bridge

1. Loss of Charge Method



$$R = \frac{0.4343\,t}{C \log_{10}\left(\frac{V}{V_c}\right)}$$

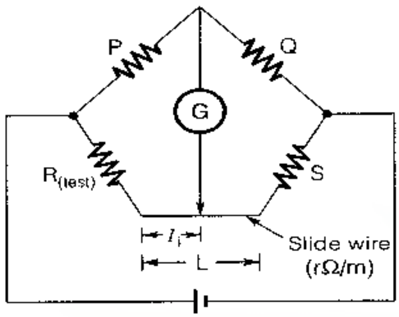
2. Meggar

- Meggar works on the principle of electrodynamometer.
- Meggar is used to measure the insulation resistance of cable, motor and generator, etc.
- Deflecting torque angle is proportional to the resistance of the insulator, which is under test.
- It is also used to check the continuity of cable.
- No external control torque provided.
- Air friction damping is used.
- No need of external power supply.

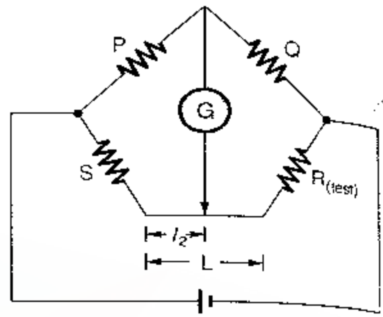
Note:

High resistance have a guard terminal which is used to avoid leakage current.

Carry Foster Slide Wire Bridge



(Bridge-1)



(Bridge-2)

From bridge (1)

$$\frac{P}{Q}+1=\frac{R+S+Lr}{S+(L-l_1)r} \quad \cdots(i)$$

From bridge (2)

$$\frac{P}{Q}+1=\frac{R+S+Lr}{R+(L-l_2)r} \quad \cdots(ii)$$

Equating equation (i) and (ii)

$$\boxed{R-S=(l_2-l_1)r}$$

Note: ....

Carry Foster bridge method is used for medium resistance measurement by comparing with standard resistance.

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