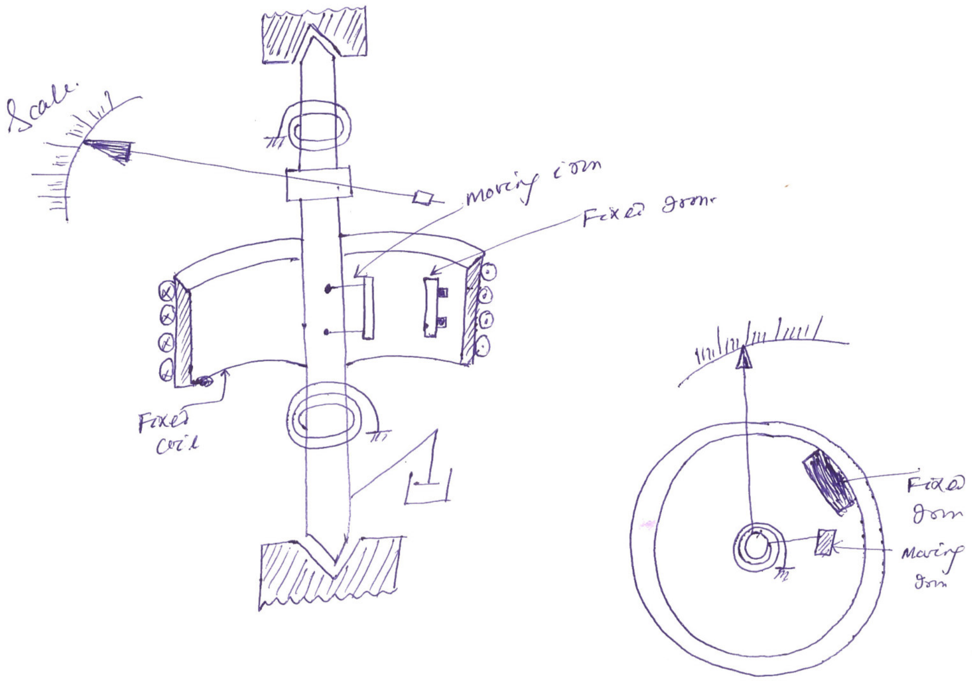

Fig. 1.12

1.9 Dynamometer (or) Electromagnetic moving coil instrument (EMMC)

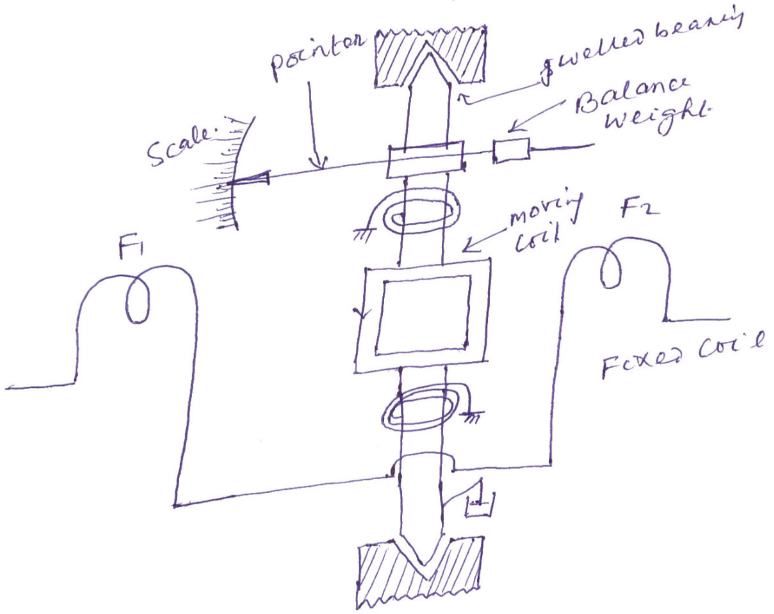

Fig. 1.13

This instrument can be used for the measurement of voltage, current and power. The difference between the PMMC and dynamometer type instrument is that the permanent magnet is replaced by an electromagnet.

Construction: A fixed coil is divided in to two equal half. The moving coil is placed between the two half of the fixed coil. Both the fixed and moving coils are air cored. So that the hysteresis effect will be zero. The pointer is attached with the spindle. In a non metallic former the moving coil is wounded.

Control: Spring control is used.

Damping: Air friction damping is used.

Principle of operation:

When the current flows through the fixed coil, it produced a magnetic field, whose flux density is proportional to the current through the fixed coil. The moving coil is kept in between the fixed coil. When the current passes through the moving coil, a magnetic field is produced by this coil.

The magnetic poles are produced in such a way that the torque produced on the moving coil deflects the pointer over the calibrated scale. This instrument works on AC and DC. When AC voltage is applied, alternating current flows through the fixed coil and moving coil. When the current in the fixed coil reverses, the current in the moving coil also reverses. Torque remains in the same direction. Since the current i_1 and i_2 reverse simultaneously. This is because the fixed and moving coils are either connected in series or parallel.

Torque developed by EMMC

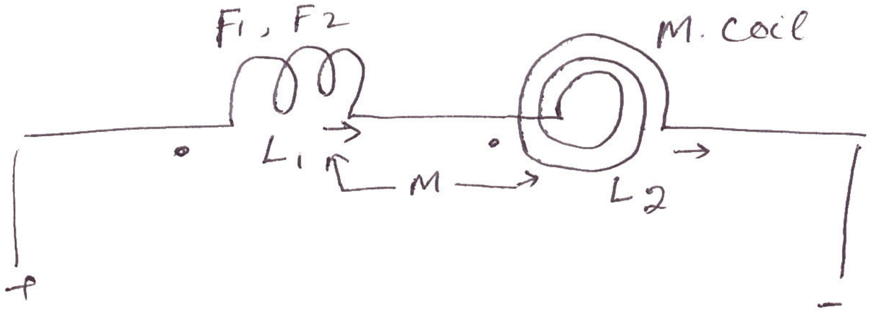

Fig. 1.14

Let

L_1=Self inductance of fixed coil

L_2= Self inductance of moving coil

M=mutual inductance between fixed coil and moving coil

$i_{1=}$current through fixed coil

i_2=current through moving coil

Total inductance of system,

$$L_{total} = L_1 + L_2 + 2M \tag{1.33}$$

But we know that in case of M.I

$$T_d = \frac{1}{2} i^2 \frac{d(L)}{d\theta} \tag{1.34}$$

$$T_d = \frac{1}{2} i^2 \frac{d}{d\theta}(L_1 + L_2 + 2M) \tag{1.35}$$

The value of L_1 and L_2 are independent of 'θ' but 'M' varies with θ

$$T_d = \frac{1}{2} i^2 \times 2 \frac{dM}{d\theta} \tag{1.36}$$

$$T_d = i^2 \frac{dM}{d\theta} \tag{1.37}$$

If the coils are not connected in series $i_1 \neq i_2$

$$\therefore T_d = i_1 i_2 \frac{dM}{d\theta} \tag{1.38}$$

$$T_C = T_d \tag{1.39}$$

$$\therefore \theta = \frac{i_1 i_2}{K} \frac{dM}{d\theta} \tag{1.40}$$

Hence the deflection of pointer is proportional to the current passing through fixed coil and moving coil.

1.9.1 Extension of EMMC instrument

Case-I Ammeter connection

Fixed coil and moving coil are connected in parallel for ammeter connection. The coils are designed such that the resistance of each branch is same.

Therefore

$I_1 = I_2 = I$

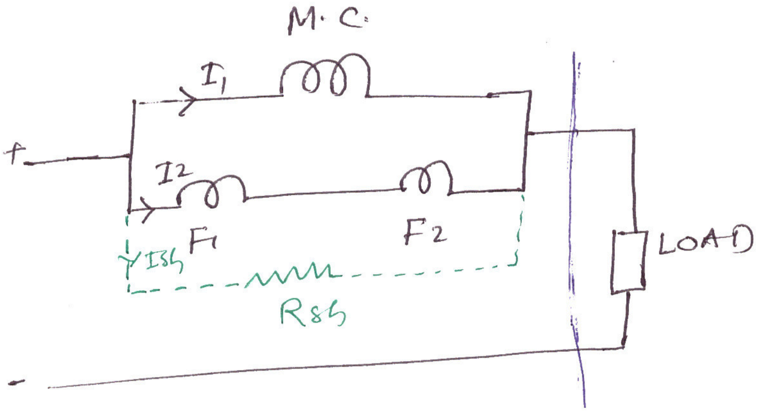

Fig. 1.15

To extend the range of current a shunt may be connected in parallel with the meter. The value R_{sh} is designed such that equal current flows through moving coil and fixed coil.

$$\therefore T_d = I_1 I_2 \frac{dM}{d\theta} \tag{1.41}$$

$$\text{Or } \therefore T_d = I^2 \frac{dM}{d\theta} \tag{1.42}$$

$$T_C = K\theta \tag{1.43}$$

$$\theta = \frac{I^2}{K}\frac{dM}{d\theta} \tag{1.44}$$

$$\therefore \theta \propto I^2 \text{ (Scale is not uniform)} \tag{1.45}$$

Case-II Voltmeter connection

Fixed coil and moving coil are connected in series for voltmeter connection. A multiplier may be connected in series to extent the range of voltmeter.

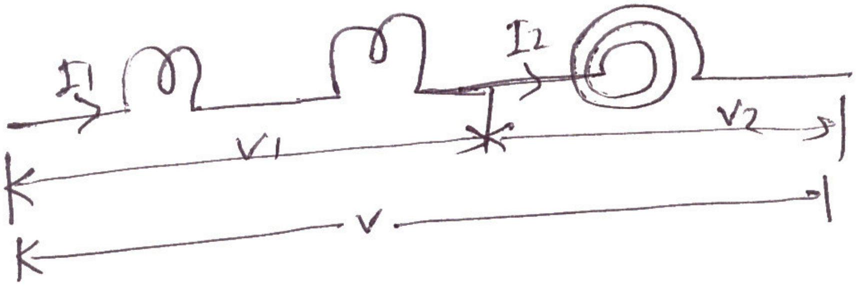

Fig. 1.16

$$I_1 = \frac{V_1}{Z_1}, I_2 = \frac{V_2}{Z_2} \quad (1.46)$$

$$T_d = \frac{V_1}{Z_1} \times \frac{V_2}{Z_2} \times \frac{dM}{d\theta} \quad (1.47)$$

$$T_d = \frac{K_1 V}{Z_1} \times \frac{K_2 V}{Z_2} \times \frac{dM}{d\theta} \quad (1.48)$$

$$T_d = \frac{KV^2}{Z_1 Z_2} \times \frac{dM}{d\theta} \quad (1.49)$$

$$T_d \propto V^2 \quad (1.50)$$

$$\therefore \theta \propto V^2 \text{ (Scale in not uniform)} \quad (1.51)$$

Case-III As wattmeter

When the two coils are connected to parallel, the instrument can be used as a wattmeter. Fixed coil is connected in series with the load. Moving coil is connected in parallel with the load. The moving coil is known as voltage coil or pressure coil and fixed coil is known as current coil.

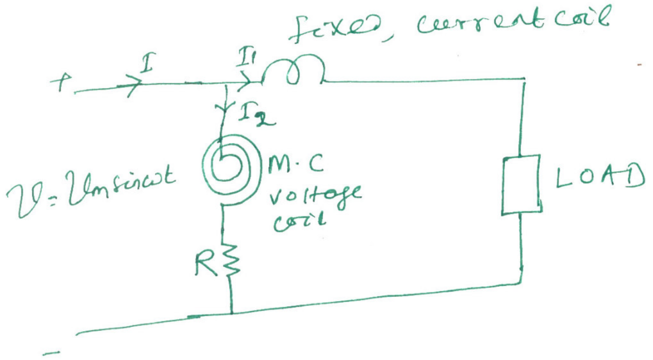

Fig. 1.17

Assume that the supply voltage is sinusoidal. If the impedance of the coil is neglected in comparison with the resistance 'R'. The current,

$$I_2 = \frac{v_m \sin wt}{R} \quad (1.52)$$

Let the phase difference between the currents I$_1$ and I$_2$ is ϕ

$$I_1 = I_m \sin(wt - \phi) \quad (1.53)$$

$$T_d = I_1 I_2 \frac{dM}{d\theta} \quad (1.54)$$

$$T_d = I_m \sin(wt - \phi) \times \frac{V_m \sin wt}{R} \frac{dM}{d\theta} \quad (1.55)$$

$$T_d = \frac{1}{R}(I_m V_m \sin wt \sin(wt - \phi)) \frac{dM}{d\theta} \quad (1.56)$$

$$T_d = \frac{1}{R} I_m V_m \sin wt . \sin(wt - \phi) \frac{dM}{d\theta} \quad (1.57)$$

The average deflecting torque

$$(T_d)_{avg} = \frac{1}{2\Pi} \int_0^{2\Pi} T_d \times d(wt) \quad (1.58)$$

$$(T_d)_{avg} = \frac{1}{2\Pi} \int_0^{2\Pi} \frac{1}{R} \times I_m V_m \sin wt . \sin(wt - \phi) \frac{dM}{d\theta} \times d(wt) \quad (1.59)$$

$$(T_d)_{avg} = \frac{V_m I_m}{2 \times 2\Pi} \times \frac{1}{R} \times \frac{dM}{d\theta} \left[\int \{\cos\phi - \cos(2wt - \phi)\} dwt \right] \quad (1.60)$$

$$(T_d)_{avg} = \frac{V_m I_m}{4\Pi R} \times \frac{dM}{d\theta} \left[\int_0^{2\Pi} \cos\phi . dwt - \int_0^{2\Pi} \cos(2wt - \phi) . dwt \right] \quad (1.61)$$

$$(T_d)_{avg} = \frac{V_m I_m}{4\Pi R} \times \frac{dM}{d\theta} \left[\cos\phi [wt]_0^{2\Pi} \right] \quad (1.62)$$

$$(T_d)_{avg} = \frac{V_m I_m}{4\Pi R} \times \frac{dM}{d\theta} [\cos\phi (2\Pi - 0)] \quad (1.63)$$

$$(T_d)_{avg} = \frac{V_m I_m}{2} \times \frac{1}{R} \times \frac{dM}{d\theta} \times \cos\phi \quad (1.64)$$

$$(T_d)_{avg} = V_{rms} \times I_{rms} \times \cos\phi \times \frac{1}{R} \times \frac{dM}{d\theta} \quad (1.65)$$

$$(T_d)_{avg} \propto KVI\cos\phi \qquad (1.66)$$

$$T_C \propto \theta \qquad (1.67)$$

$$\theta \propto KVI\cos\phi \qquad (1.68)$$

$$\theta \propto VI\cos\phi \qquad (1.69)$$

Advantages

- ✓ It can be used for voltmeter, ammeter and wattmeter
- ✓ Hysteresis error is nill
- ✓ Eddy current error is nill
- ✓ Damping is effective
- ✓ It can be measure correctively and accurately the rms value of the voltage

Disadvantages

- ✓ Scale is not uniform
- ✓ Power consumption is high(because of high resistance)
- ✓ Cost is more
- ✓ Error is produced due to frequency, temperature and stray field.
- ✓ Torque/weight is low.(Because field strength is very low)

Errors in PMMC

- ✓ The permanent magnet produced error due to ageing effect. By heat treatment, this error can be eliminated.
- ✓ The spring produces error due to ageing effect. By heat treating the spring the error can be eliminated.
- ✓ When the temperature changes, the resistance of the coil vary and the spring also produces error in deflection. This error can be minimized by using a spring whose temperature co-efficient is very low.

1.10 Difference between attraction and repulsion type instrument

An attraction type instrument will usually have a lower inductance, compare to repulsion type instrument. But in other hand, repulsion type instruments are more suitable for economical production in manufacture and nearly uniform scale is more easily obtained. They are therefore much more common than attraction type.

1.11 Characteristics of meter

1.11.1 Full scale deflection current(I_{FSD})

The current required to bring the pointer to full-scale or extreme right side of the instrument is called full scale deflection current. It must be as small as possible. Typical value is between 2 μ A to 30mA.

1.11.2 Resistance of the coil(R_m)

This is ohmic resistance of the moving coil. It is due to ρ , L and A. For an ammeter this should be as small as possible.

1.11.3 Sensitivity of the meter(S)

$$S = \frac{1}{I_{FSD}}(\Omega / volt), \uparrow S = \frac{Z \uparrow}{V}$$

It is also called ohms/volt rating of the instrument. Larger the sensitivity of an instrument, more accurate is the instrument. It is measured in Ω/volt. When the sensitivity is high, the impedance of meter is high. Hence it draws less current and loading affect is negligible. It is also defend as one over full scale deflection current.

1.12 Error in M.I instrument

1.12.1 Temperature error

Due to temperature variation, the resistance of the coil varies. This affects the deflection of the instrument. The coil should be made of manganin, so that the resistance is almost constant.

1.12.2 Hysteresis error

Due to hysteresis affect the reading of the instrument will not be correct. When the current is decreasing, the flux produced will not decrease suddenly. Due to this the meter reads a higher value of current. Similarly when the current increases the meter reads a lower value of current. This produces error in deflection. This error can be eliminated using small iron parts with narrow hysteresis loop so that the demagnetization takes place very quickly.

1.12.3 Eddy current error

The eddy currents induced in the moving iron affect the deflection. This error can be reduced by increasing the resistance of the iron.

1.12.4 Stray field error

Since the operating field is weak, the effect of stray field is more. Due to this, error is produced in deflection. This can be eliminated by shielding the parts of the instrument.

1.12.5 Frequency error

When the frequency changes the reactance of the coil changes.

$$Z = \sqrt{(R_m + R_S)^2 + X_L^2} \tag{1.70}$$

$$I = \frac{V}{Z} = \frac{V}{\sqrt{(R_m + R_S)^2 + X_L^2}} \tag{1.71}$$

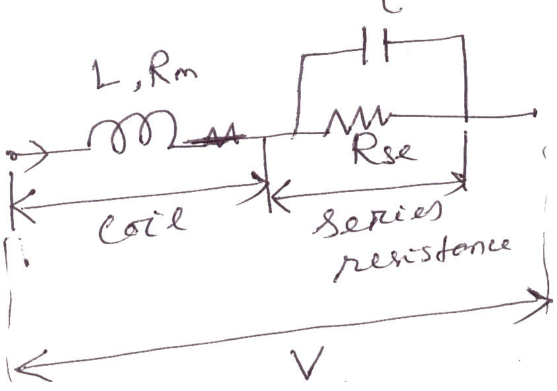

Fig. 1.18

Deflection of moving iron voltmeter depends upon the current through the coil. Therefore, deflection for a given voltage will be less at higher frequency than at low frequency. A capacitor is connected in parallel with multiplier resistance. The net reactance, $(X_L - X_C)$ is very small, when compared to the series resistance. Thus the circuit impedance is made independent of frequency. This is because of the circuit is almost resistive.

$$C = 0.41 \frac{L}{(R_S)^2} \tag{1.72}$$

1.13 Electrostatic instrument

In multi cellular construction several vans and quadrants are provided. The voltage is to be measured is applied between the vanes and quadrant. The force of attraction between the vanes and quadrant produces a deflecting torque. Controlling torque is produced by spring control. Air friction damping is used.

The instrument is generally used for measuring medium and high voltage. The voltage is reduced to low value by using capacitor potential divider. The force of attraction is proportional to the square of the voltage.

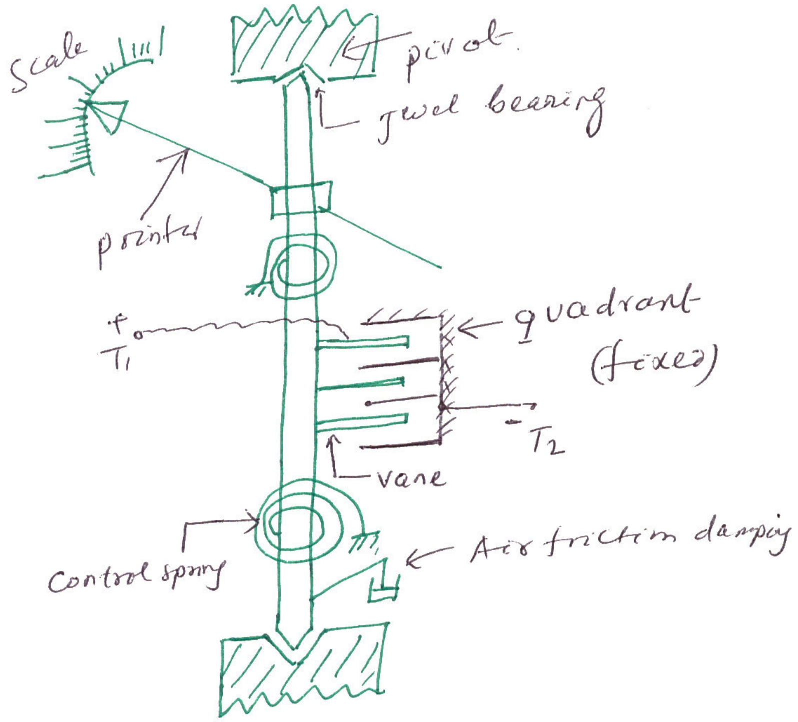

Fig. 1.19

Torque develop by electrostatic instrument

V=Voltage applied between vane and quadrant

C=capacitance between vane and quadrant

Energy stored=$\frac{1}{2}CV^2$ (1.73)

Let 'θ' be the deflection corresponding to a voltage V.

Let the voltage increases by dv, the corresponding deflection is'$\theta + d\theta$'

When the voltage is being increased, a capacitive current flows

$$i = \frac{dq}{dt} = \frac{d(CV)}{dt} = \frac{dC}{dt}V + C\frac{dV}{dt} \quad (1.74)$$

$V \times dt$ multiply on both side of equation (1.74)

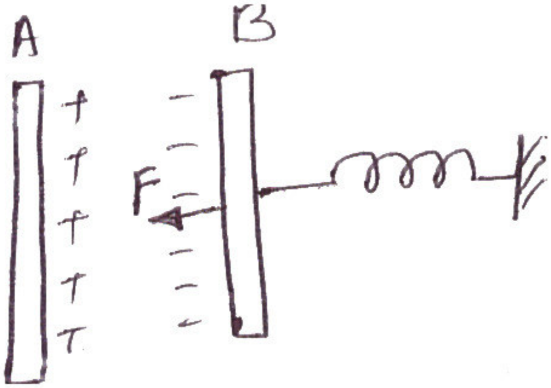

Fig. 1.20

$$Vidt = \frac{dC}{dt}V^2dt + CV\frac{dV}{dt}dt \tag{1.75}$$

$$Vidt = V^2dC + CVdV \tag{1.76}$$

Change in stored energy$= \frac{1}{2}(C+dC)(V+dV)^2 - \frac{1}{2}CV^2$ (1.77)

$$= \frac{1}{2}\left[(C+dC)V^2 + dV^2 + 2VdV\right] - \frac{1}{2}CV^2$$

$$= \frac{1}{2}\left[CV^2 + CdV^2 + 2CVdV + V^2dC + dCdV^2 + 2VdVdC\right] - \frac{1}{2}CV^2$$

$$= \frac{1}{2}V^2dC + CVdV$$

$$V^2dC + CVdV = \frac{1}{2}V^2dC + CVdV + F \times rd\theta \tag{1.78}$$

$$T_d \times d\theta = \frac{1}{2}V^2dC \tag{1.79}$$

$$T_d = \frac{1}{2}V^2\left(\frac{dC}{d\theta}\right) \tag{1.80}$$

At steady state condition, $T_d = T_C$

$$K\theta = \frac{1}{2}V^2\left(\frac{dC}{d\theta}\right) \tag{1.81}$$

$$\theta = \frac{1}{2K}V^2\left(\frac{dC}{d\theta}\right) \tag{1.82}$$

Advantages

- ✓ It is used in both AC and DC.
- ✓ There is no frequency error.
- ✓ There is no hysteresis error.
- ✓ There is no stray magnetic field error. Because the instrument works on electrostatic principle.
- ✓ It is used for high voltage
- ✓ Power consumption is negligible.

Disadvantages

- ✓ Scale is not uniform
- ✓ Large in size
- ✓ Cost is more

1.14 Multi range Ammeter

When the switch is connected to position (1), the supplied current I_1

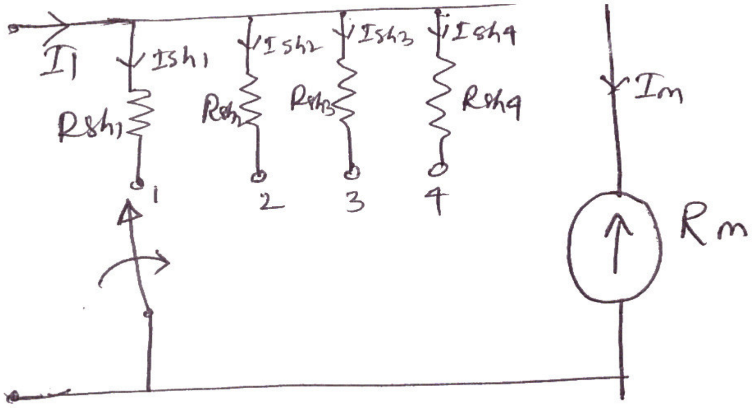

Fig. 1.21

$$I_{sh1}R_{sh1} = I_m R_m \qquad (1.83)$$

$$R_{sh1} = \frac{I_m R_m}{I_{sh1}} = \frac{I_m R_m}{I_1 - I_m} \qquad (1.84)$$

$$R_{sh1} = \frac{R_m}{\frac{I_1}{I_m} - 1}, R_{sh1} = \frac{R_m}{m_1 - 1}, m_1 = \frac{I_1}{I_m} = \text{ Multiplying power of shunt}$$

$$R_{sh2} = \frac{R_m}{m_2 - 1}, m_2 = \frac{I_2}{I_m} \quad (1.85)$$

$$R_{sh3} = \frac{R_m}{m_3 - 1}, m_3 = \frac{I_3}{I_m} \quad (1.86)$$

$$R_{sh4} = \frac{R_m}{m_4 - 1}, m_4 = \frac{I_4}{I_m} \quad (1.87)$$

1.15 Ayrton shunt

$$R_1 = R_{sh1} - R_{sh2} \quad (1.88)$$

$$R_2 = R_{sh2} - R_{sh3} \quad (1.89)$$

$$R_3 = R_{sh3} - R_{sh4} \quad (1.90)$$

$$R_4 = R_{sh4} \quad (1.91)$$

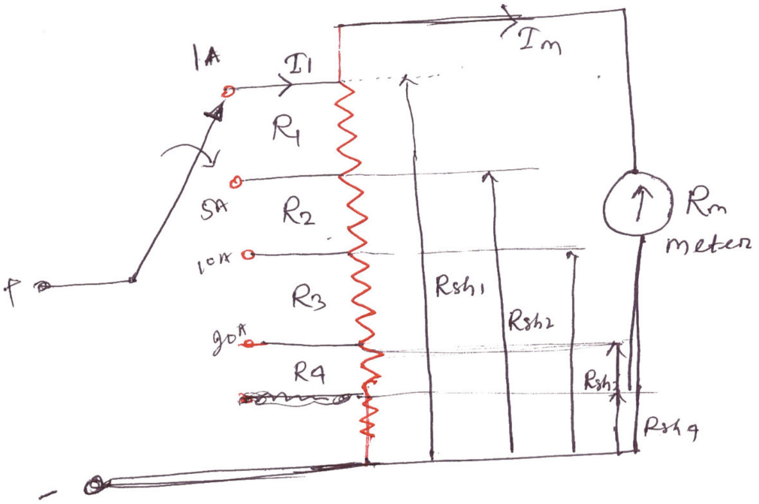

Fig. 1.22

Ayrton shunt is also called universal shunt. Ayrton shunt has more sections of resistance. Taps are brought out from various points of the resistor. The variable points in the o/p can be connected to any position. Various meters require different types of shunts. The Aryton shunt is used in the lab, so that any value of resistance between minimum and maximum specified can be used. It eliminates the possibility of having the meter in the circuit without a shunt.

1.16 Multi range D.C. voltmeter

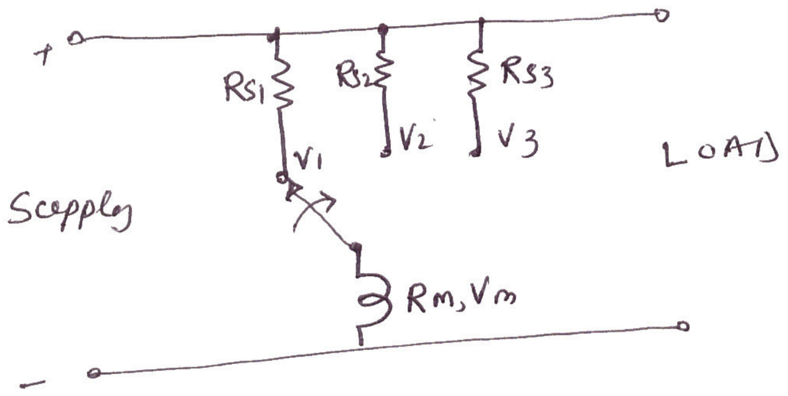

Fig. 1.23

$$R_{s1} = R_m(m_1 - 1)$$
$$R_{s2} = R_m(m_2 - 1) \tag{1.92}$$
$$R_{s3} = R_m(m_3 - 1)$$

$$m_1 = \frac{V_1}{V_m}, m_2 = \frac{V_2}{V_m}, m_3 = \frac{V_3}{V_m} \tag{1.93}$$

We can obtain different Voltage ranges by connecting different value of multiplier resistor in series with the meter. The number of these resistors is equal to the number of ranges required**.**

1.17 Potential divider arrangement

The resistance R_1, R_2, R_3 and R_4 is connected in series to obtained the ranges V_1, V_2, V_3 and V_4

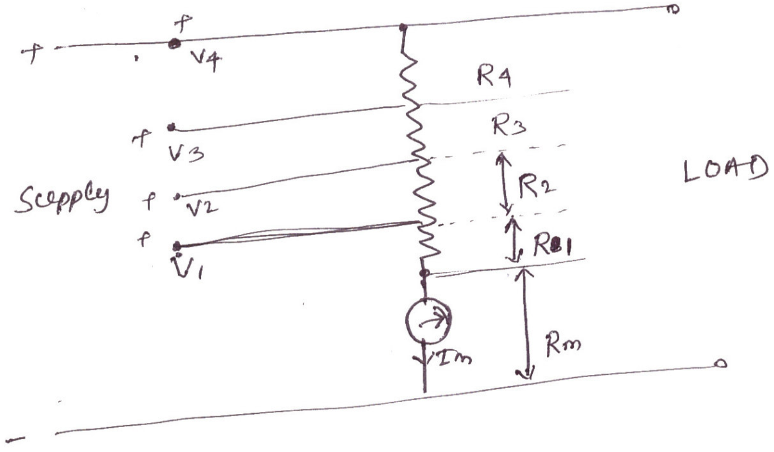

Fig. 1.24

Consider for voltage V₁, $(R_1 + R_m)I_m = V_1$

$$\therefore R_1 = \frac{V_1}{I_m} - R_m = \frac{V_1}{(\frac{V_m}{R_m})} - R_m = \left(\frac{V_1}{V_m}\right)R_m - R_m \tag{1.94}$$

$$R_1 = (m_1 - 1)R_m \tag{1.95}$$

For V₂, $(R_2 + R_1 + R_m)I_m = V_2 \Rightarrow R_2 = \frac{V_2}{I_m} - R_1 - R_m$ (1.96)

$$R_2 = \frac{V_2}{\left(\frac{V_m}{R_m}\right)} - (m_1 - 1)R_m - R_m \tag{1.97}$$

$$R_2 = m_2 R_m - R_m - (m_1 - 1)R_m$$

$$= R_m(m_2 - 1 - m_1 + 1) \tag{1.98}$$

$$R_2 = (m_2 - m_1)R_m \tag{1.99}$$

For V₃ $(R_3 + R_2 + R_1 + R_m)I_m = V_3$

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

$$= \frac{V_3}{V_m}R_m - (m_2 - m_1)R_m - (m_1 - 1)R_m - R_m$$

$$= m_3 R_m - (m_2 - m_1)R_m - (m_1 - 1)R_m - R_m$$

$$R_3 = (m_3 - m_2)R_m$$