

Measurement:- The measurement of given quantity is the result of comparison between the quantity to be measured and a definite standard. The instruments which are used for such measurements are called measuring instruments.

In order that the result of the measurement are meaningful which are two basic requirements.

- (i) The standard used for comparison purpose must be accurately defined and should be commonly accepted.
- (ii) The apparatus used and the method adopted must be provable.

Classification of measuring instruments:-

These are two types

- (i) absolute instruments
- (ii) secondary instruments

(i) Absolute instruments:-

These instruments give the magnitude of the quantity under measurements in terms of deflection and physical constant of the instrument.

ex: Tangent Galvanometer.

(ii) Secondary instruments:-

These instruments give the magnitude of the quantity under measurements in terms of deflection only.

ex: Ammeter, voltmeter, etc.

The secondary instruments are again

classified into three types. These are.

- i) Indicating instrument
- ii) Recording instrument
- iii) Integrating instrument.

i) Indicating instruments :-

These instruments make use of dial & pointer showing (i) indicating magnitude of unknown quantity.

ex: Voltmeter, Ammeter.

ii) Recording instruments :-

These instruments give a continuous record of the given electrical quantity which is being measured over a specific period. Such recording instruments the readings are recorded by drawing the graph.

ex: X-Y plotter.

iii) Integrating instruments :-

These instruments measure the total quantity of electricity delivered over period of time.

For example a house hold energy meter registers numbers of revolutions made by the disc to give the total energy delivered.

ex: Energy meter.

Essential Requirements of Instruments:-

- (i) Deflecting System
- (ii) Controlling System
- (iii) Damping System

i) Deflecting System:-

In most of the indicating instruments the mechanical force proportional to the quantity to be measured is generated. This force deflects the pointer. The system which produces such a deflecting torque is called "deflecting system". The torque is denoted as T_d .

The deflecting system uses one of the following effects produced by current or voltage to produce deflecting torque.

- (i) magnetic effect
- (ii) Thermal effect
- (iii) electrostatic effect
- (iv) Induction effect
- (v) Hall effect

i) magnetic effect:- When a current carrying conductor is placed in uniform magnetic field, it experiences a force which causes move it. This effect used mostly in MISMB instruments.

ii) Thermal effect:- When two dissimilar metals are connected end to end to form a closed loop and the two junction formed are maintained at different temperatures, then e.m.f is induced which causes the flow of current through the closed path which is called a thermocouple.

iii) electrostatic effect:- When two plates are charged there is a force exerted between them which moves one of the plates this effect is used in electrostatic instruments which are normally voltmeters.

iv) Induction effect:- When a non-magnetic conducting disc is placed in a magnetic field produced by electromagnets which are excited by alternating currents an emf is induced in it. This induction is called an induction effect it is mainly used in energy meters.

v) Hall effect:- If a bar of semi-conducting materials is placed in uniform magnetic field and if the bar carries current, then an emf is produced b/w two edges of conductor. the magnitude of this emf depends on flux density of magnetic field. This effect is mainly used in flux meters.

vi) controlling system:-
This system should provide a force so that current (or) any other electrical quantity will produce deflection of the pointer proportional to its magnitude.

The important functions of this system are:

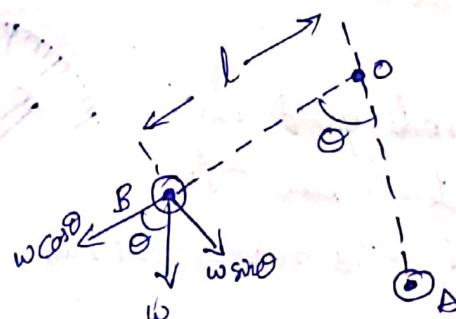
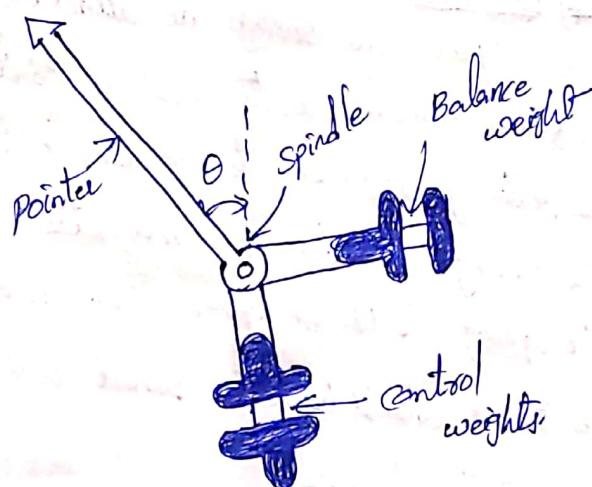
→ It produces a force equal & opposite to the deflecting force in order to make the deflection of pointer at a definite magnitude. If this system is absent, then the pointer will swing beyond its final steady position for the given magnitude of deflection will become indefinite.

→ It brings the moving system back to zero position when the force which causes the movement of the moving system is removed. It will never come back to its zero position in the absence of controlling system.

controlling torque is generally provided by spring & gravity control.

Gravity Control:-

This type of control consists of a small weight attached to the moving system whose position is adjustable. This weight produces a controlling torque due to gravity. This weight is called control weight.



The system deflects through an angle θ . The control weights act at a distance 'l' from the center. The component $w \sin \theta$ of this weight tries to restore the pointer back to the zero position. This is nothing but the controlling torque.

$$T_c = w \sin \theta \times l \Rightarrow K = w \times l \quad [K = \text{gravity control}]$$

$$T_c = K \sin \theta$$

generally Deflecting torque Θ

$$\Theta_d = kI$$

In equilibrium position

$$\Theta_d = \tau_c$$

$$kI = k \sin\theta$$

$$I d \sin\theta$$

→ Spring Control :-

Two hair springs are attached to the moving system which exerts (provides) controlling torque.

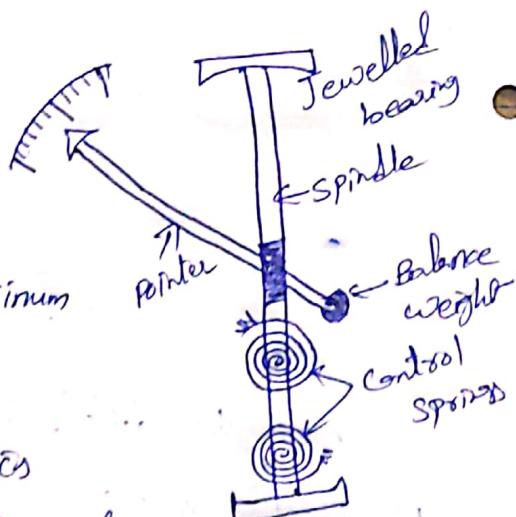
The following requirements are essential.

- The spring should be non-magnetic
- The spring should be free from mechanical stresses
- The spring should have a small resistance, sufficient cross-sectional area.

Springs are made up of non-magnetic materials like silicon-bronze, hard rolled silver; platinum silver & german silver.

The inner end of spring is attached to the spindle while outer end is attached to lever at the front of the instrument.

The controlling torque provided by the instrument is directly proportional to the angular deflection of the pointer.



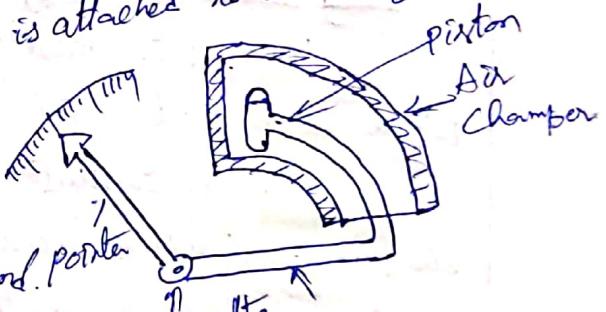
iii) Damping System:-

The deflecting torque provides some deflection and controlling torque acts in the opposite direction to that of deflecting torque so before coming to the rest pointer always oscillates due to inertia. unless pointer rest final reading can not be obtained so to bring the pointer to rest within short time damping system is required i.e. which damps the oscillation on pointer is called damping torque. the system should provide a damping torque only when moving system is in motion.

The following methods are used to produce damping

- i) Air friction damping
- ii) Fluid friction damping
- iii) Eddy current damping.

i) Air friction damping:- This arrangement consists of a light aluminium piston which is attached to the moving system. is shown below.



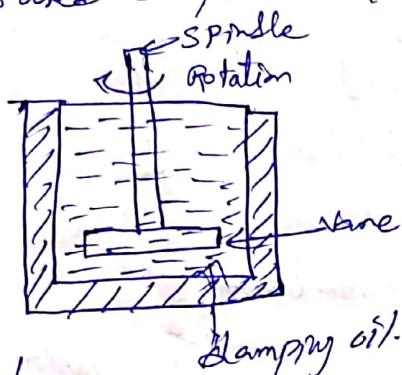
The piston moves in a fixed Air chamber. It is close to one end. pointer clearance b/w piston and well chamber is uniform and small piston reciprocates in the chamber when there are oscillations when piston moves into the chamber air inside is compressed and pressure of air developed due to friction opposes the motion of pointer. There is also opposition to motion of moving system when piston moves out of the chamber. thus the oscillations reduced due to motion of the piston in the chamber providing necessary damping torque.

This helps the pointer comes to rest its final position very quickly.

(i) Fluid friction damping:-

Fluid friction damping may be used in some instruments the method is similar to air friction damping. only air is replaced by working fluid. the friction between the disc and fluid is used for opposing motion damping force due to fluid is greater than that of air due to more viscosity.

It consist of a vane attached to the spindle which is completely dipped in the oil. the frictional force b/w oil & vane is used to produce the damping torque.

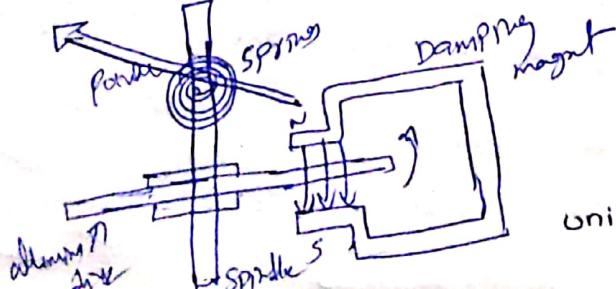


(ii) Eddy current damping:-

This is the most effective way of providing damping torque it is based on the "Faraday's Law" & "Lenz's Law"

when a conductor moves in a magnetic field cutting the flux emf gets induced in it and direction of this emf is so as to oppose the cause producing it.

The aluminium disc is connected to the spindle. The arrangement of disc is such that when it rotates, it cuts the magnetic flux lines of a permanent magnet. thus it produces an opposing torque so as to reduce the oscillations of pointer. This brings pointer to rest quickly.



Ammeters and voltmeters :-

The basic principle of the ammeters and voltmeters is the same. The action of all ammeters and voltmeters depends upon a deflecting torque produced by an electric current.

In ammeter deflecting torque is produced by a current to be measured.

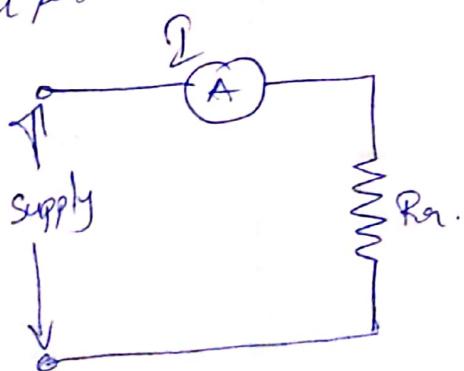
In voltmeters deflecting torque is produced by a current which is proportional to the voltage to be measured. Hence both are essentially current measuring devices.

Ammeter :- Ammeters are connected in series to the circuit whose current is to be measured. The power loss in an Ammeter is $I^2 R_A$.

I = current to be measured

R_A = ammeter resistance

The Ammeters should have a low resistance so that they cause a small voltage drop and consequently absorb small power.



Voltmeter :-

Voltmeters are connected in parallel with the circuit whose voltage is to be measured.

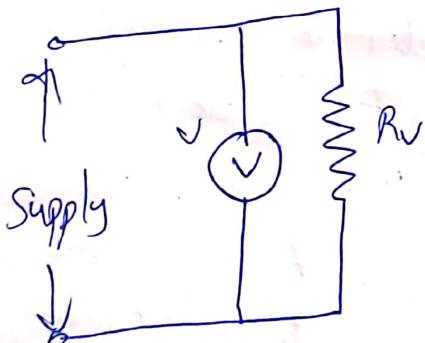
The power loss in voltmeter is $\frac{V^2}{R_v}$

V = voltage to be measured

R_v = Resistance of voltmeter.

The voltmeter should have high resistance in order to draw low current consequently the power consumed is small.

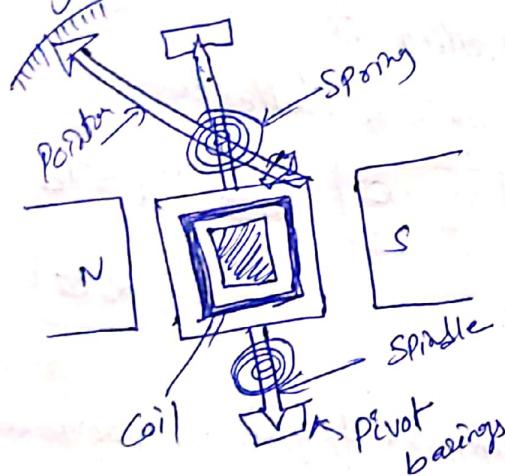
Small.



Permanent magnet moving coil [PMMC] :-

The PMMC instruments are most accurate type for D.C measurements the action of these instruments is based on the motoring principle i.e when a current carrying coil is placed in the magnetic field produced by permanent magnet, the coil experiences a force & moves.

In this the coil is moving and magnet is permanent. The basic principle is D'Arsonval principle i.e the amount of force experienced by the coil is proportional to the current passing through the coil.



The moving coil is either rectangular or circular in shape. It has number of turns of fine wire. The coil is suspended so that it is free to turn about its vertical axis. The coil is placed in uniform. The permanent magnet is in the shape of horse-shoe. The iron core is spherical or rectangular in shape.

Two phosphor-bronze hair springs are provided for controlling torque.

The pointer is carried by the spindle and it moves over a graduated scale. The pointer has light weight so that it can deflect rapidly. The mirror is placed below the pointer to get accurate reading by removing the parallax.

When some apply to the instruments the deflecting system produces deflecting torque hence the pointer deflections are directly proportional to the current passing through the coil.

$$T_d \propto I$$

Then two phosphor bronze hair spiral springs are provided for controlling torque. The controlling torque is proportional to angle of deflection.

$$T_c \propto \theta \Rightarrow T_d = T_c$$
$$T_c \propto \theta$$

Then the damping torque is provided by eddy current damping. It is obtained by movement of the aluminium former moving in the magnetic field of permanent magnet.

Moving Iron Type Instruments :-

Moving Iron Instruments are classified as

- i) moving iron attraction type instruments
- ii) moving iron Repulsion type instruments.

i) moving iron attraction type instruments :-

The basic working principle of these instruments is very simple that a soft iron piece is brought near the magnet gets attracted by magnet.

It consists of a fixed coil 'C' and moving iron piece 'D'

The coil is that and has a narrow slot like opening the moving iron is a flat disc which is eccentrically mounted on the spindle

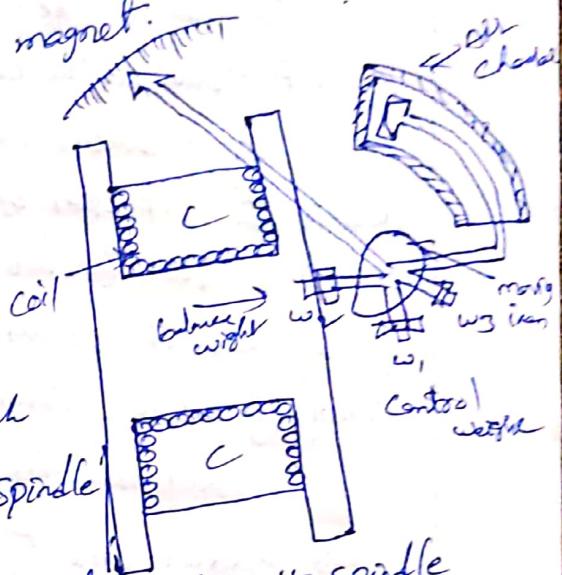
The spindle is supported by the jewel bearings the spindle carries a pointer which moves over a graduated scale. The deflection is proportional to current square

$$T_d \propto I^2$$

The controlling torque is provided by the springs but gravity control may also be used for vertically mounted panel type instruments.

The damping torque is provided by the air friction a light aluminium piston is attached to the moving system.

It moves in a fixed chamber.



The chamber is closed at one end. It can also be provided with the help of vane attached to the moving system.

$$T_C \propto \theta \Rightarrow T_d = T_C \\ \Rightarrow I^2 \propto \theta$$

Moving Iron Repulsion Type Instrument:-

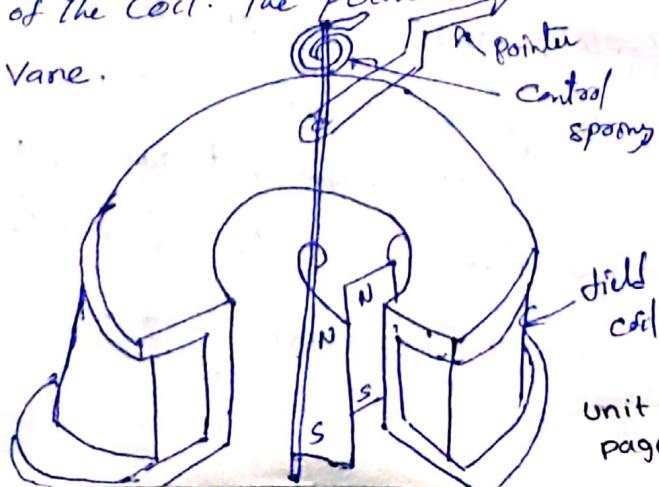
These instruments have two vanes inside the coil. One is fixed and other is movable, when the current flows in the coil, both the vanes are magnetized with like polarities induced on the same side. Hence due to the repulsion of like polarities, there is a force of repulsion b/w the two vanes causing the movement of the moving vane. The repulsion type instruments are the most commonly used instruments.

Repulsion type instruments are two types.

- Radial Vane type
- Co-axial Vane type

→ Radial Vane type:-

In this two vanes are radial strips of iron. The fixed vane is attached to the spindle & suspended in the induction field of the coil. The pointer of the instrument is attached to this vane.



when alternating current passes through the coil.

There is always Repulsion between the like poles of the fixed and movable vane hence the deflection of the pointer is always in the same direction. The deflection is effectively proportional to the actual current.

Controlling Torque is provided by Springs and damping torque is provided by air friction damping.

Here the deflecting torque is proportional to the force of repulsion the force of repulsion is directly proportional to the product of the pole strengths. If the two iron pieces having the same pole strength of m_1, m_2 respectively.

Then Deflecting torque is

$$T_d \propto m_1 m_2 I^2$$

$$T_d \propto I^2$$

$$T_c \propto \theta \Rightarrow T_c \propto I^2$$

(ii) co-axial type:- It has two concentric vanes. one is attached to the coil frame rigidly while the other can rotates coaxially inside the stationary vane.

Both the vanes are magnetised to the same polarity due to the current in the coil. Thus the movable vane rotates under the repulsive force the movable vane is attached to the pivoted shaft. The repulsion results in a rotation of the shaft. The pointer deflection is proportional to the current in the coil, and the deflection is proportional to the square of the current through the coil.

$$T_d \propto I^2$$

Controlling Torque is provided by springs & damping Torque is provided by air friction

$$T_c \propto \theta \Rightarrow T_c = T_d \Rightarrow \theta \propto I^2$$

Expression For Deflecting Torque & Controlling torque:-

The various parameters involved in torque eq?

l = length of coil

δ = width of coil

N = Number of turns of coil

B = flux density in air gap

i = current through the coil

K = spring constant

α = angle b/w plane of coil.

A = Area of coil in m^2 (lxr)

θ_f = deflection of coil

F = force on each side of coil

$$F = NBil \sin\alpha$$

$$T_d = \text{deflecting torque} = F \times d$$

$$T_d = NBil \sin\alpha (d)$$

$$T_d = NBil \sin\alpha (\delta)$$

$$T_d = NBi \sin\alpha (lxr)$$

$$(d = r)$$

$$\Rightarrow [lxr = A]$$

$$T_d = NBiA \sin\alpha$$

As the field is radial in nature, $\alpha = 90^\circ$, hence $\sin\alpha = 1$

$$T_d = NBiA \Rightarrow GI$$

$G = NB A$ = galvanometer constant

$$T_d = GI$$

The controlling torque is provided by the spring is directly proportional to the final deflection of the coil

$$T_c = K\theta_f$$

Final steady state position of coil

$$T_d = T_c \Rightarrow GI = K\theta_f$$

$$\theta_f = \frac{GI}{K}$$

Errors and compensations :-

basic errors of pmmc instruments are

- friction error
- temperature error
- aging of various parts.

To reduced the frictional errors ratio of torque to weight is made very high.

The most serious errors are produced by the heat generated by changes in the temperature this changes the resistance of working coil causing large errors. In case of voltmeters, large series resistance of very low temperature coefficient is used. this reduces temperature errors.

The aging of permanent magnet and control springs also cause errors. the weakening of magnet and springs cause opposite errors. The weakening of magnet cause less deflection while weakening of the control springs cause large deflection; for a particular value of current. the proper use of material and preageing of current during manufacturing can reduce the errors due to weakening of the control springs.

Errors in moving coil instruments are

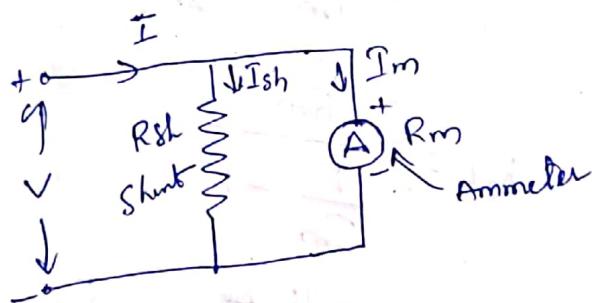
- Hysteresis error
- Temperature error
- Stray magnetic field error
- Frequency error
- Eddy current error.

Extension of range using shunts & series resistance:-

here the extending range of Ammeters by using shunt resistance and it is called "shunts". similarly the extending range of voltmeters by using series resistances and it is called "multiplier".

Ammeters [shunts]:- here shunts are used to extend the range of ammeter. the shunt is a low value resistance connected in parallel with the Ammeter.

The shunts by pass (avoid) the maximum line current and allows a small current through the meter. & it can handle without burning.



R_m = meter Resistance

R_{sh} = shunt Resistance

I_m = Full-scale deflection current.

I_{sh} = shunt current

I = line current to be measured.

voltage across the shunt = voltage across the Ammeter

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

$$I_{sh} R_{sh} = I_m R_m \quad \text{--- (1)}$$

here $I_{sh} = I - I_m$

$$(I - I_m) R_{sh} = I_m R_m$$

$$R_{sh} = \frac{I_m R_m}{I - I_m} \quad \text{--- (2)}$$

dividing the eqⁿ (2) with "I_m"

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

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

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

here $\frac{I}{I_m} = N$

$$R_{sh} = \frac{R_m}{N-1}$$

$$R_{sh}(N-1) = R_m$$

$$N-1 = \frac{R_m}{R_{sh}} \Rightarrow N = \frac{R_m}{R_{sh}} + 1$$

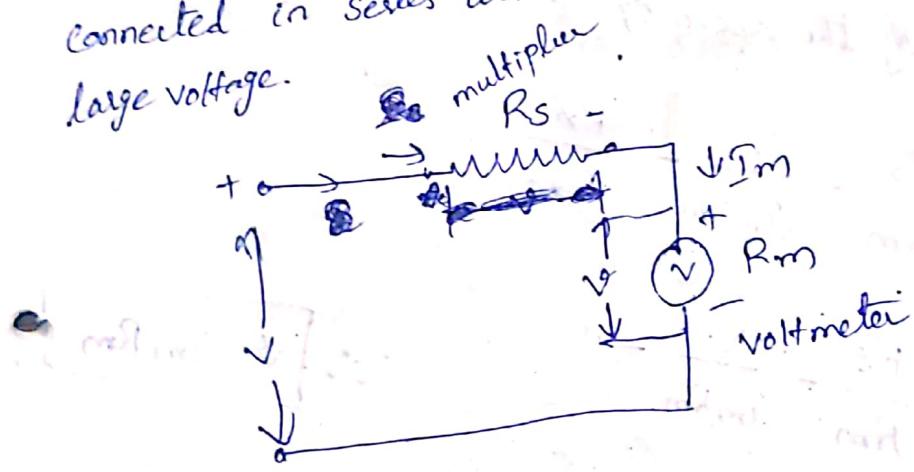
here $N = \frac{I}{I_m}$ is the multiplying factor

$$N = \frac{I}{I_m} = 1 + \frac{R_m}{R_{sh}}$$

Thus to increase the range of ammeter 'N' times
 The shunt resistance required is $\left[\frac{1}{N-1}\right]$ times the
 basic meter Resistance. This is nothing but extension
 of Range of an ammeter.

• voltmeters (multipliers):-

multipliers are used to extend the Range of voltmeters. The multiplier is a high value resistance is connected in series with the voltmeter in order to measure large voltage.



R_m = meter Resistance

R_s = Series Resistance

I_m = Full-scale deflection current

V = Full-scale potential drop across voltmeter

$$V = I_m R_m$$

The supply voltage

$$V = I_m (R_m + R_s)$$

$$= I_m R_m + I_m R_s$$

$$V - I_m R_m = I_m R_s$$

$$R_s = \frac{V - I_m R_m}{I_m}$$

$$R_s = \frac{V}{I_m} - \frac{I_m R_m}{I_m}$$

$$R_s = \frac{V}{I_m} - R_m$$

dividing the above eqⁿ on both sides by "R_m"

$$\frac{R_s}{R_m} = \frac{V}{I_m R_m} - \frac{R_m}{R_m}$$

$$\frac{R_s}{R_m} = \frac{V}{I_m R_m} - 1$$

$$\therefore V = I_m R_m$$

$$\frac{R_s}{R_m} = \frac{V}{V} - 1$$

$$\frac{V}{V} = 1 + \frac{R_s}{R_m}$$

$$\boxed{\frac{V}{V} = m}$$

$m = \frac{V}{V}$ is the multiplying factor

$$m = \frac{V}{v} = 1 + \frac{R_s}{R_m}$$

To increase the range of voltmeter 'm' times
The series resistance required is $(m-1)$ times the
basic meter resistance. This is nothing but extension of
range of voltmeters.

Electrostatic Instruments :-

Basically electrostatic instruments are all voltmeters.
The operation of all the electrostatic instruments is based on the principle that there exists a force between the two plates with opposite charges. This force can be obtained using the principle that the mechanical work done is equal to the stored energy if there is a relative motion of plates.

Consider two plates A & B where plate 'A' is fixed while 'B' is movable. Two plates are oppositely charged and plate 'B' is restrained by a spring connected to fixed point. Let the force of attraction between the two plates be 'F' newton. Let the capacitance between the two plates be 'C' farad.

The energy stored 'E' is given by

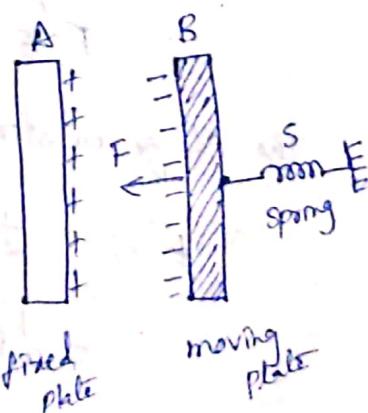
$$E = \frac{1}{2} C V^2 \quad (1)$$

when applied voltage increases by dV ,

The current flowing through capacitance also changes

and it is given by

$$i_s = \frac{dq}{dt} = \frac{d}{dt}(cv) \quad (2)$$



~~The input energy is given by~~

~~eqn ② multiplying with 'V'~~

$$Vi = C \frac{dV}{dt} + V \frac{dC}{dt}$$

$$i = C \frac{dV}{dt} + V \frac{dC}{dt} \quad -②$$

~~eqn ② multiplying with 'V' & the i/p energy is given by~~

$$Vi = CV \frac{dV}{dt} + V^2 \frac{dC}{dt}$$

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

$$Vi dt = CVdV + V^2 dC \quad -③$$

due to change in applied voltage by value ' dV ', The capacitance increases by ' dC ' because plate 'B' moves towards a fixed plate 'A' which decreases the distance of separation between two plates increasing net capacitance.

Thus the new energy stored is given by,

$$E' = \frac{1}{2} (C+dc) (V+dV)^2 \quad -④$$

The change in stored energy is given by,

$$E' - E = \frac{1}{2} (C+dc) (V+dV)^2 - \frac{1}{2} CV^2$$

$$= \frac{1}{2} (C+dc) (V^2 + dV^2 + 2VdV) - \frac{1}{2} CV^2$$

$$E' - E = \frac{1}{2} C(c+dc)(c^{\sqrt{v}} + 2vdv + dv^{\sqrt{v}}) - \frac{1}{2} Cv^{\sqrt{v}}$$

$$= \frac{1}{2} (Cv^{\sqrt{v}} + 2vdv c + dv^{\sqrt{v}} c + dc v^{\sqrt{v}} + 2vdv dc + dc dv^{\sqrt{v}})$$

$$= \frac{1}{2} Cv^{\sqrt{v}} + \frac{1}{2} v^{\sqrt{v}} dv c + \frac{1}{2} dv^{\sqrt{v}} c + \frac{1}{2} dc v^{\sqrt{v}} + \frac{1}{2} v^{\sqrt{v}} dv dc + \frac{1}{2} dc dv^{\sqrt{v}}$$

$$= \frac{1}{2} Cv^{\sqrt{v}} + \frac{1}{2} v^{\sqrt{v}} dv c + \frac{1}{2} dv^{\sqrt{v}} c + \frac{1}{2} dc v^{\sqrt{v}} + \frac{1}{2} v^{\sqrt{v}} dv dc + \frac{1}{2} dc dv^{\sqrt{v}}$$

$$= \frac{1}{2} Cv^{\sqrt{v}} + \frac{1}{2} v^{\sqrt{v}} dc + \frac{1}{2} dc v^{\sqrt{v}} + v^{\sqrt{v}} dv dc + \frac{1}{2} dc dv^{\sqrt{v}}$$

➡ Neglecting higher order terms of small quantities

such as dc & dv , we can write:

$$E' - E = \frac{1}{2} v^{\sqrt{v}} dc + Cv dv \quad \text{--- (5)}$$

From the principle of the conservation of energy we can write,

$$\text{input energy} = \text{increment in stored energy} + \text{mechanical work done}$$

$$Cv dv + v^{\sqrt{v}} dc = \left(\frac{1}{2} v^{\sqrt{v}} dc + Cv dv \right) + (F dx)$$

$$F dx = \frac{1}{2} v^{\sqrt{v}} dc$$

$$F = \frac{1}{2} v^{\sqrt{v}} \frac{dc}{dx} \quad \text{--- (6)}$$

From above expression it is clear that the force of attraction is directly proportional to square of the applied voltage v .

The above theory can be extended to the rotational motion, with the angular deflection θ .

$$T_d = \frac{1}{2} v^{\sqrt{v}} \frac{dc}{d\theta} \quad \text{--- (7)}$$

$$T_c = k\theta \Rightarrow T_d = T_c$$

$$\frac{1}{2} v^{\sqrt{v}} \frac{dc}{d\theta} = k\theta$$

$$\theta = \frac{1}{2} k^{\sqrt{v}} \frac{dc}{d\theta} \quad \text{unit-page.}$$

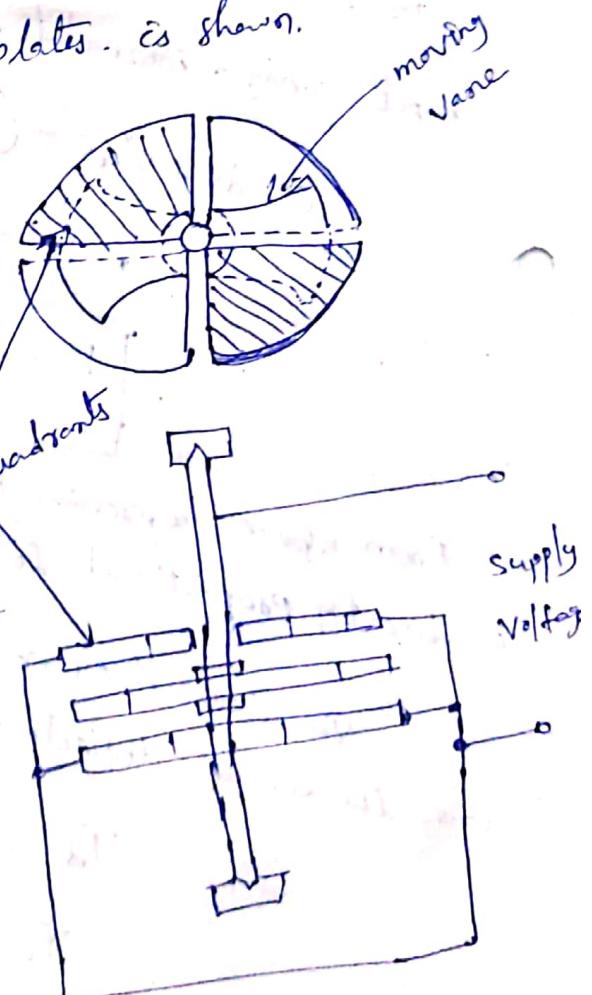
Types of electrostatic voltmeters:-

following are the two types of electrostatic voltmeter

- Quadrant type electrostatic voltmeter
- Attracted disc type electrostatic voltmeter.

i) Quadrant type electrostatic voltmeter:-

This instrument is used to measure voltages up to 10kV - 20kV. The instrument consists of four fixed metal double quadrants arranged such that there is a small air gap between the quadrants and the total assembly forms a shallow circular box. Inside this box a double sectored needle is suspended by means of a phosphor bronze thread. The needle is suspended such that it is placed equidistant from above & below quadrant plates. is shown.



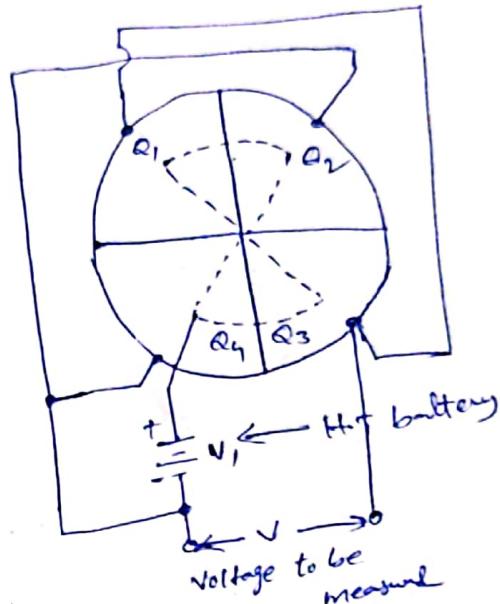
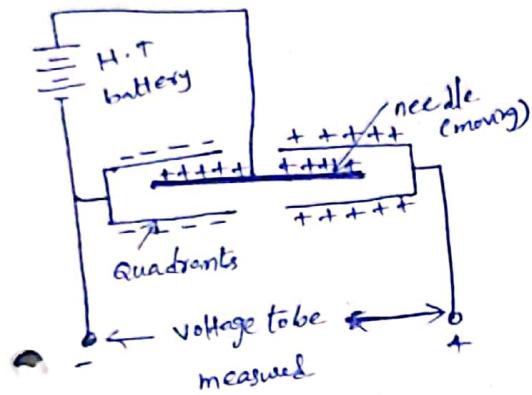
The fixed quadrants are connected together. The voltage to be measured either AC(DC) is connected b/w the fixed quadrants & moving needle. This needle rotates due to the electrostatic force set up due to charge accumulation on the quadrant plates.

This voltmeter has two types

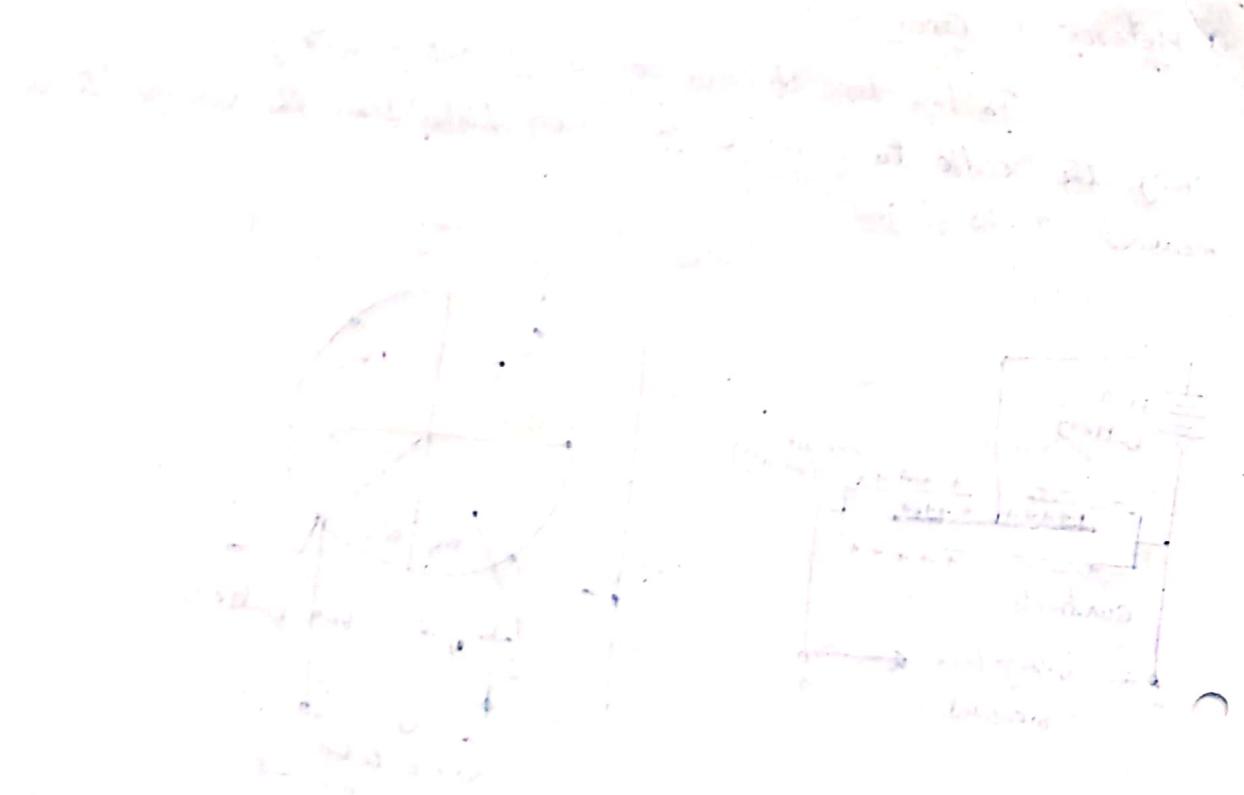
- Heterostatic connection
- Idiostatic connection.

Heterostatic connection:-

In This Type of connection a high voltage battery is used to charge the needle to a voltage considerably higher than the voltage to be measured. It is shown



In this connection, the quadrants are connected together in diagonally opposite pairs. The moving vane (needle) is positively charged due to battery. The deflecting force due to top and bottom quadrants on movable needle cancels each other on both sides. The only deflecting force responsible is force of attraction between left quadrant and right moving sector and force of repulsion between right quadrant and left moving sector.



植物细胞中具有双层膜的结构有：核膜、线粒体膜、叶绿体膜。植物细胞中具有单层膜的结构有：细胞膜、内质网膜、高尔基体膜、溶酶体膜、液泡膜。植物细胞中没有膜的结构有：细胞壁、细胞质、核糖体、中心体。

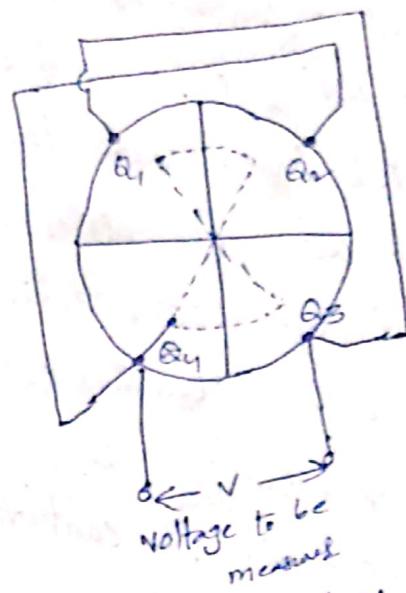
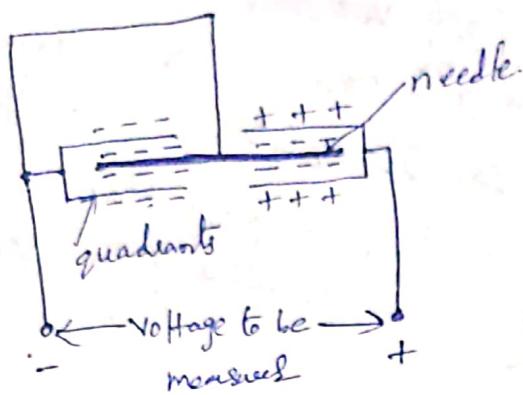
植物细胞中具有双层膜的结构有：核膜、线粒体膜、叶绿体膜。植物细胞中具有单层膜的结构有：细胞膜、内质网膜、高尔基体膜、溶酶体膜、液泡膜。植物细胞中没有膜的结构有：细胞壁、细胞质、核糖体、中心体。

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Idiostatic Connection :-

This connection generally used in commercial instruments.
In this type of connection, needle is connected to any one of the pairs of quadrant is shown.

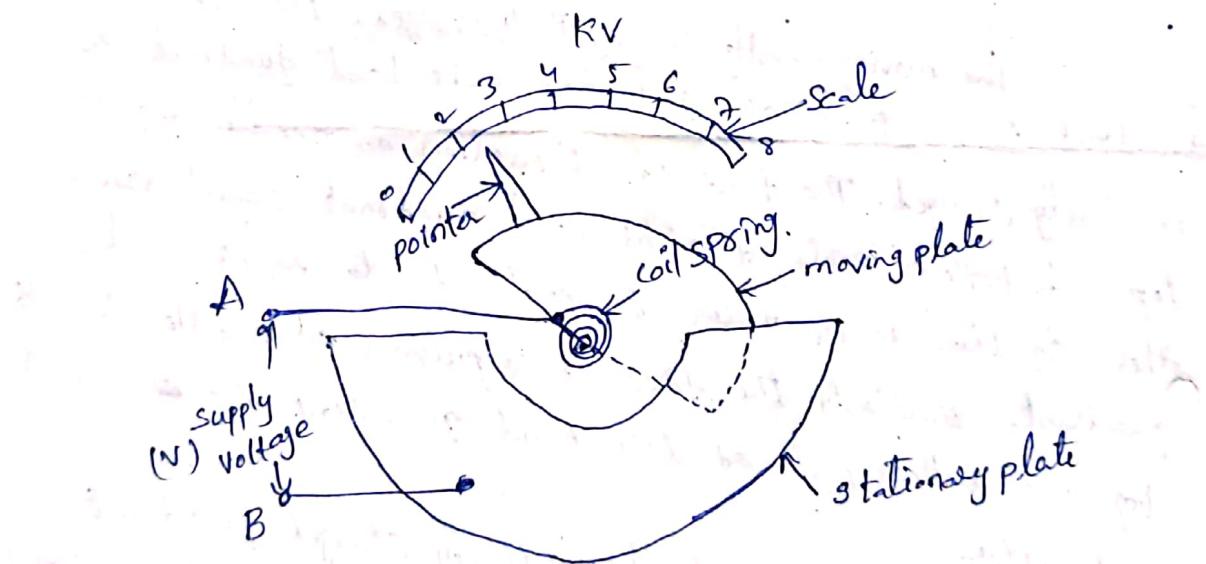


The moving needle is negatively charged, the left hand quadrant is negatively charged and right hand quadrant is positively charged. The force of attraction on needle due to top and bottom parts of right hand quadrant cancel each other. so there is no motion of needle due to right hand quadrant. similarly the force of repulsion on needle due to top and bottom parts of left hand quadrant also cancel each other.

Thus the right hand positively charged quadrant attracts the part of the needle near to left hand quadrant while the left hand negatively charged quadrant repels the part of the needle to right hand quadrant. This rotates the needle & hence the pointer.

Attracted disc Electrostatic voltmeter:-

The attracted disc type instruments are generally used for the measurement of voltages above 20 KV. The system consists of two plates such that one plate can move freely while other is fixed. Both the plates are perfectly insulated from each other. The voltage to be measured is applied across the plates as a supply voltage. Due to the supply voltage, electrostatic field gets produced which develops a force of attraction between the two plates. Due to the force of attraction, the movable plate gets deflected. In this mechanism the controlling torque is provided by a spring.



Advantages and disadvantages of Electrostatic Instruments:-

advantages:-

- They give correct measurement in both ac & dc circuits.
- They are most useful in high voltage measurements (10kV above).
- There are no frequency and waveform variations as the deflection is proportional to the square of voltage.
- There is no iron part in the working system of these instruments, they are free from errors due to eddy currents & hysteresis.
- The power loss in these instruments is very small.
- Costly resistance wires are not used in this instruments.
- The operating current is very small hence does not affect the performance of other circuits connected to the same supply.

disadvantages:-

- They are not suitable for low voltage measurements.
- These are large in size, bulky and not very robust.
- These are expensive instruments.
- The scale is not uniform.

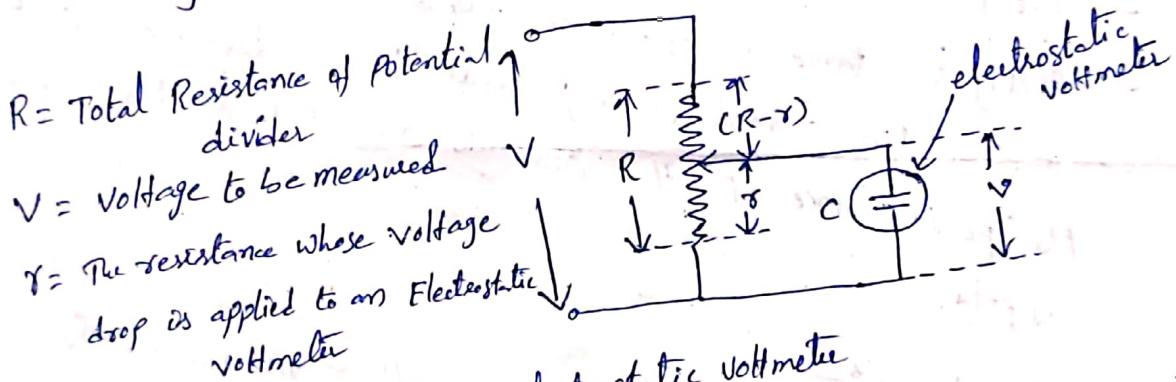
Extension range of electrostatic Instruments :-

The range of various instruments can be extended using multipliers. Similarly, the range of electrostatic instruments also extended by using multipliers. The multipliers used for electrostatic instruments are two types.

- i) Resistance potential divider
- ii) Capacitance multipliers.

i) Resistance potential divider :-

The use of resistance potential divider for extending the range of an electrostatic instruments is shown.



The resistance 'r' and capacitance 'C' forms a parallel circuit and the equivalent impedance is,

$$Z = r \parallel -jX_C \quad \text{where } X_C = \frac{1}{\omega C}$$

$$Z = \frac{r \times \frac{-j}{\omega C}}{r - \frac{j}{\omega C}}$$

$$Z = \frac{-jr}{\frac{r}{\omega C} - j}$$

$$\frac{R_1 \times R_2}{R_1 + R_2}$$

$$Z = \frac{-j\gamma}{\gamma w c - j}$$

(17)

The above eqⁿ is multiplying both sides by 'j'

$$Z = \frac{-j\gamma \times j}{(\gamma w c - j) \times j}$$

$$Z = \frac{-j^2 \gamma}{\gamma w c j - j^2}$$

$$Z = \frac{-j^2}{-j^2} \left[\frac{\gamma}{\gamma w c j + 1} \right]$$

$$Z = \left[\frac{\gamma}{1 + j\gamma w c} \right]$$

Thus the equivalent impedance across the voltage 'V' is

$$Z_T = R - \gamma + Z$$

$$Z_T = R - \gamma + \frac{\gamma}{1 + j\gamma w c}$$

$$Z_T = \frac{(R - \gamma)(1 + j\gamma w c) + \gamma}{(1 + j\gamma w c)}$$

$$Z_T = \frac{(R - \gamma) + (R - \gamma)(j\gamma w c) + \gamma}{1 + j\gamma w c}$$

$$= \frac{R - \gamma + (R - \gamma) j\gamma w c + \gamma}{1 + j\gamma w c}$$

$$Z_T = \frac{R + (R - \gamma) j\gamma w c}{1 + j\gamma w c}$$

The factor by which voltage is changed due to potential divider is called its multiplying power and given by.

$$m = \frac{V}{I} = \frac{Z_T}{Z} = \frac{\frac{R + (R-\gamma)j\omega c}{(1+j\omega c)}}{\frac{\gamma}{1+j\omega c}}$$

$$\begin{aligned} &= \frac{R + (R-\gamma)j\omega c}{\gamma} \\ &= \frac{R}{\gamma} + \frac{(R-\gamma)j\omega c}{\gamma} \\ &= \frac{R}{\gamma} + (R-\gamma)j\omega c \end{aligned}$$

The numerical value of multiplying power 'm' is

$$m = \sqrt{\left(\frac{R}{\gamma}\right)^2 + \omega^2 c^2 (R-\gamma)^2}$$

If ω, C, γ are very small then $\omega^2 c^2 \gamma^2 \leq 1$ and can be neglected.

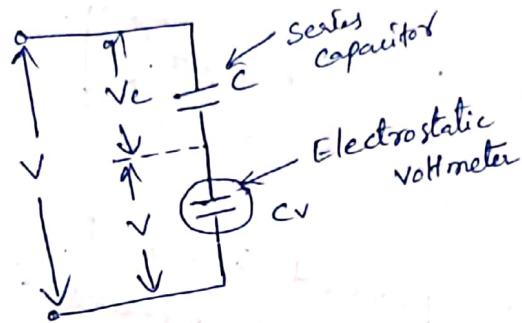
$$m = \frac{R}{\gamma} \sqrt{1 + \frac{\omega^2 c^2 \gamma^2 (R-\gamma)^2}{R^2}}$$

$$\boxed{m = \frac{R}{\gamma}}$$

(ii) Capacitance multipliers:-

The capacitance multiplier method is nothing but the use of capacitance potential divider. There are two methods of connecting capacitors for potential division.

Method 1 :- In first method, a single capacitor is connected in series with the voltmeter and the voltage to be measured is applied across the combination as shown.



Let C = Series capacitor

C_V = Capacitor of voltmeter

V = Voltage across voltmeter

V = Voltage to be measured.

The total capacitance across the supply is

$$C_t = \frac{C \times C_V}{C + C_V} \quad C \text{ & } C_V \text{ in series}$$

The total impedance across the supply is

$$Z_t = \frac{1}{j\omega C_t}$$

$$= \frac{1}{j\omega \left[\frac{C \times C_V}{C + C_V} \right]}$$

$$= \frac{1}{j\omega C C_V} \quad \frac{1}{C + C_V}$$

$$\Rightarrow Z_t = \frac{C + C_V}{j\omega C C_V}$$

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$$R_t = \frac{R_1 \times R_2}{R_1 + R_2}$$

The Impedance of voltmeter is

$$Z = \frac{1}{j\omega C V}$$

Thus the multiplying power of the multiplier is

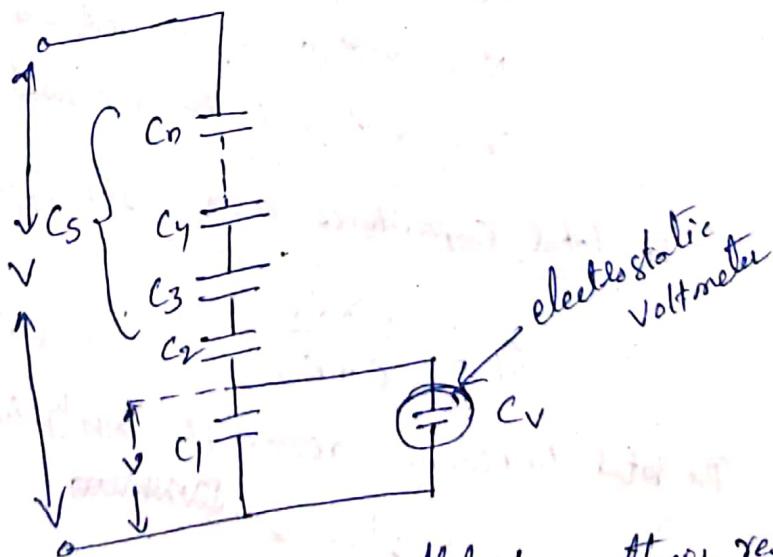
$$m = \frac{V}{v} = \frac{Z_t}{Z} = \frac{(C + Cv)}{\frac{1}{j\omega C V}}$$

$$m = \frac{C + Cv}{C} = 1 + \frac{Cv}{C}$$

$$\boxed{m = 1 + \frac{Cv}{C}}$$

method 2:-

In many practical cases a set of capacitors connected in series across the voltage to be measured is used. The voltmeter is connected across one of the suitable capacitors as shown.



The capacitors C_1 and C_V are in parallel hence their resultant is $C_1 + C_V$. while $C_2, C_3, C_4, \dots, C_n$ are in series and their equivalent is C_S where,

$$\frac{1}{C_S} = \frac{1}{C_1} + \frac{1}{C_2} + \dots + \frac{1}{C_n} \quad (3)$$

Thus C_S and $(C_1 + C_V)$ are in Series hence the resultant Capacitor across the voltage 'V' is

$$C_T = \frac{C_S(C_1 + C_V)}{C_S + C_1 + C_V}$$

$$Z_T = \frac{1}{j\omega C_T} \Rightarrow \frac{1}{j\omega \left[\frac{C_S(C_1 + C_V)}{C_S + C_1 + C_V} \right]}$$

$$Z_T = \frac{C_S + C_1 + C_V}{j\omega C_S(C_1 + C_V)}$$

while across the voltage 'V' the capacitor is $C_1 + C_V$
hence the impedance is

$$Z = \frac{1}{j\omega(C_1 + C_V)}$$

They multiplying power is

$$m = \frac{Z_T}{Z} = \frac{\sqrt{V}}{\sqrt{V}} = \frac{\frac{C_S + C_1 + C_V}{j\omega C_S(C_1 + C_V)}}{\frac{1}{j\omega(C_1 + C_V)}}$$

$$m = 1 + \left[\frac{C_1 + C_V}{C_S} \right]$$