UNIT-I

MEASURING INSTRUMENTS

Introduction:-

The measurement of a given quantity to the result of Comparision between the quantity to be measured and a definite standard. The instruments which are used for such measurement are called measuring instruments. The three basic quantities in the electrical measurements are current, voltage and power.

→ The instrument which measured the current flowi in the circuit is called Ammeter.

→ The instrument which measured the voltage across any two points of a circuit is called Voltmeter.

→ The instruments which are used to measure the power are called power meters or wattmeter.

The action of almost all the analog ammeter and voltmete depends on the deflecting torque produced by an electric current. In ammeters such a torque is proportional to the curren measured In voltmeter torque is decided by a current whic is propotional to the voltage to be measured. Thus all the analog ammeters and voltmeter are basically current measuri devices.

The necessary requirements for any measuring instruments are

1. with the introduction of the instrument in the circuit, th circuit condition should not be altered. Thus the quantity to

be measured should not get affected due to the instrumen used.

2) The power consumed by the instruments for their opera on should be as small as possible.

⇛ measuring instruments are classified as:-

i) Absolute instruments
ii) Secondary instruments.

Classification of measuring instruments :-

(a) Indicating Instruments:-

Thus instruments make use of a dail and points are showing or indicating magnitude of unknown quantity. The Examples are ammeters, voltmeter etc. and also speedom

(b) Recording Instruments:-

These instruments give a continuous record of the given electrical quantity which is being measured over a specific period. Examples are various types of recordes. In such r rding instruments. The readings are recorded by drawing the graph Ex:- ECG, Seismic graphs

measured and records details of Earth quakes i.e. su as for and duratic.

(c) Integrating Instruments:-

These instruments measure the total quantity of ele city delivered over a period of time.

Ex:- House hold Energy meter.

Essential Requirements of an instrument :-

In case of measuring instruments the effect of quantity is converted into transmitted to the pointer which moves over a calibrated, scale. For satisfactory operation of any indicating instruments following system must be present in a instrument.

1. Deflecting system producing deflecting torque Td.
2. Controlling system producing controlling torque Tc
3. Damping system producing damping torque.

Absolute:-

Gives the magnitude and the quantity measured in terms of the deflection obtained during the measurment.

Ex:- Tangent galvanometer.

Secondary:- It does not need any calitration

Ex:- Ammeter, voltmeter, wattmeter.

Deflecting system:-

In most of the indicating instruments the mechanica force propotional to the quantity to be measured is generate This force or torque deflects the pointer. The system which produces such a deflecting torque is called deflecting system and the torque is dinoted as Td the deflecting torque over comes.

① The inertia of the moving system.

② The controlling torque provided by controlling system

③ The damping torque provided by damping system.

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

① magnetic Effect:-

When a current carrying conductor to placed in uniform magnetic field, it experiences a force which causes to move it. This effect is mostly used in many instrumen like moving iron attraction & repulsion type, permanent magnet moving coil instruments Etc.

② Thermal Effect:-

The current to be measured in passed through a small element which heats it to cause rise in temperature which is converted to an Emf by a there couple attach to it. when two dissimilar metals are connected End to En to form a closed loop and the two junctions formed are maintained at different temperature's then E.m.f is induced whi causes the flow of current through the closed circuit which is called a thermo couple

③ Electrostatic Effects:-

when two plates are charged, there to a force exerted b/w them, which moves one of the plates. The Effects is used in Electrostatic instruments which are normally voltmeters.

④ Induction Effect:-

when a non magnetic conducting disc is placed in a magnetic field produced by electro magnetic. which are Exictid by alternating currents an Emf is induced in it.

If a closed path is provided there is a flow of cur in the disc. The interaction b/w induced current of the alternating magnetic fields. exerts a force on the disc. which causes to more it. This interaction is called an induc Effect. This principle is mainly used in Energy meters.

⑤ Hall Effect:-

If a bar of semi conducting material is placed in uniform magnetic field and if the bar carrier current, then an E.m.f is magnetic field, current passing through the conducting bar and hall effect co-efficient, which is constant for a given Semi conductor. This Effect is mainly used in flux meters.

Controlling Systems:-

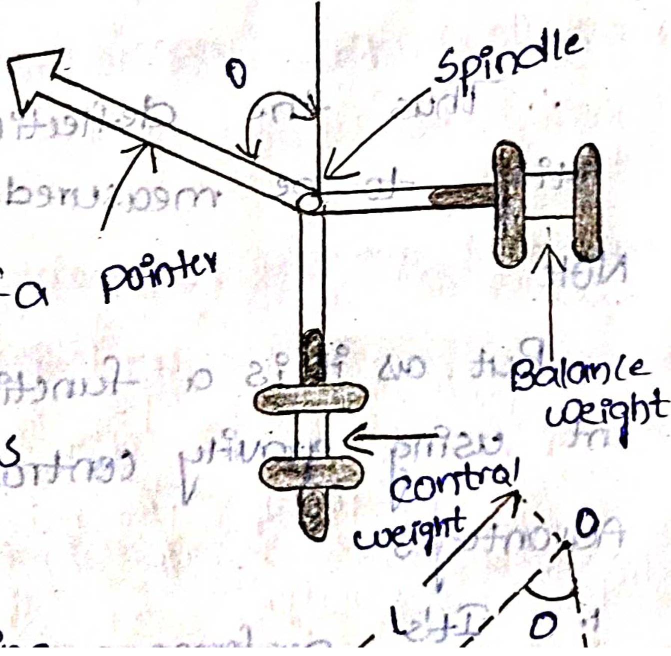
This system should provide a force so that current or any other Electrical quantity will produce deflection of the pointer proportional to its magnitude. The important tuns of this stystem are.

① It produces a force Equal and 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 and deflection will become indefinite.

② It brings the moving system back to zero position when the force which causes the movements of the moving system is removed It ~~force which Causes the~~ will never come back to its zero position in the absence of controlling system.

Gravity control:-

→ This type of control Consists of a pointer small weight attached to this assuming stystem where position is a Effectable.



of the weight in the fig2.

→ If the system deflects, the weight position also chang as shown in figure 8.

→ The system deflects through an angle θ is the cont

weight acts at a discharge its from the centre.

→ The component as sinθ of this weight tries to rest the pointer back to the zero position. This ~~the~~ is noth but the controlling torque Tc. T = Force displacement

Thus controlling torque $\boxed{T_c = w\sin\theta/s}$

$K\sin\theta$

where $k = ws$ = gravity control constant

Now generally all meters are current sensing meters

where, Deflecting torque $\boxed{T_d = K_t I}$

where K_t = another constant

In equilibrium position, $T_d = T_c$

$K_t I = K\sin\theta$

$$\boxed{I \propto \sin\theta}$$

∴ Thus the deflection is proportional to current i.e qu ntity to be measured.

Note:-

But as it is a function of sinθ, the scale for the instr ent using gravity control is not uniform.

Advantages:-

1. It's performance is not time dependent.
2. It is a simple and cheap.
3. The controlling torque can be varied by adjusting position of the control weight.
4. It's performance is not temperature depend

1. The scale is non uniform causing problems to ~~reduce~~ record accurate readings.

2. The system must be used in vertical position only and must be properly levelled. Otherwise it may cause serious errors in the measurements.

Spring controls:-

→ Two hair springs are attached to the moving system which exerts controlling torque. To empty spring control to an instrument, following requirements are essential.

1. The spring should be non- magnetic.
2. The spring should be free from mechanical stress.
3. The spring should have a small resistance, sufficient cross - sectional area.
4. It should have low resistance temperature co-efficient

The arrangement of the springs is shown in the fig.

→ The springs are made up of non-magnetic materials like silicon, bronze, hard rolled silver or copper, platinum silver and german silver.

** Spiral springs → Space required is less than other types.

→ For most of the instruments phosphor bronze spiral springs are provided.

** Flat spiral springs are used in almost all indicating instruments.

→ The inner end of the spring is attached to the spindle while the outer end is attached to a lever or arm which to actuated by a set of screw mounted

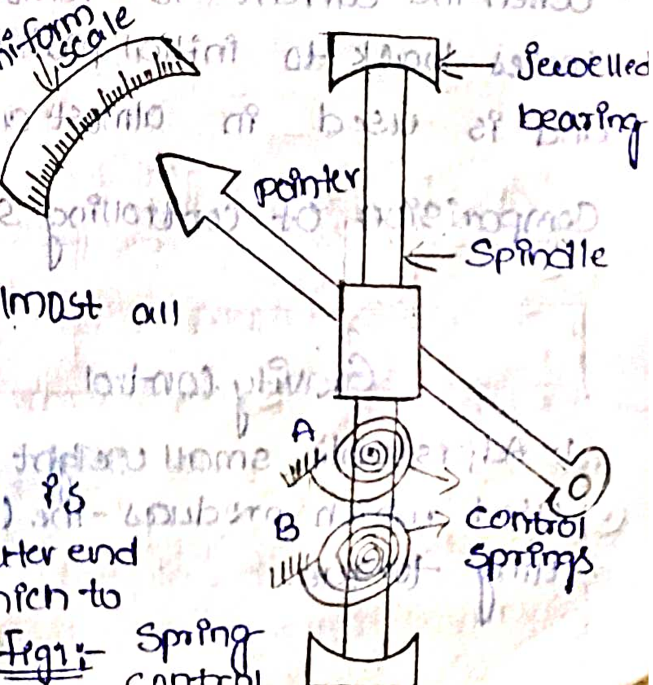


Fig1:- Spring control

at the front of the instrument so zero setting can be done.

→ The Controlling torque provided by the instrument is di proportional to the angular deflection of the pointer.

The Controlling torque produced by Spiral Spring is given

$$\boxed{T_c = \frac{Ebt^3}{12L}\theta = K_S\theta}$$

$$\boxed{T_c \propto \theta}$$

where t= thickness in meters

E= young's modulus of spring material N/

b= depth in meters

L= Length in meters.

Now deflecting torque is proportional to current

$$\boxed{T_d \propto I}$$

K_S = Spring Constant

At Equilibrium $T_d = T_c = \frac{Ebt^3}{12L}$

$$\boxed{I \propto \theta}$$

Note:- Thus the deflection is proportional to the Current. Hence the scale of the instrument using spring control is uniform.

When the current is removed, due to spring force the poi comes back to initial position. The spring control is very pop and is used in almost all indicating instruments.

Comparision of Controlling systems :-

Gravity Control	Spring Control
1. Adjustable small weight is used which produces the controlling torque.	Two hair springs are used which exert controlling torque.

2. Controlling torque can be varied.	Controlling torque is fixed.
3. The performance is not temperature dependent	The performance is temperature dependent.
4. The scale is non uniform	The scale is uniform.
5. The controlling torque is proportional to $\sin\theta$	The controlling torque is proportional to θ.
6. The readings can not be taken accurately.	Readings can be taken very accurately.
7. The system must be used in vertical position only	The system need not be necessarily in vertical position.
8. proper levelling is required as gravity control	The levelling is not required.
9. Simple, Cheap but delicate	Simple, rigid but costlier compared to gravity control.
10. Rarely used for indicating and portable instruments	Very popularly used is most of the instruments.

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 oscilates due to inertia, about the equilibrium position unless pointe comes to rest final readings cannot be obtained.

→ So to bring the pointer to rest within short time damping system is required.

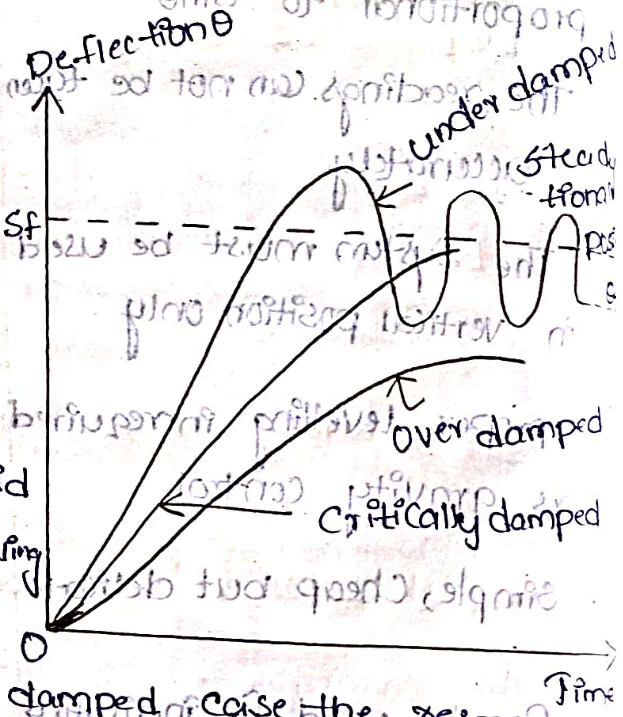
→ The system should provide damping torque only when the moving system is in motion.

→ Damping torque is proportional to velocity of the moving system.

→ The quickness with which the moving system settles to the final steady position depends on relative damping.

→ If the moving system reaches to its final position rapidly but smoothly without oscillations the instrument is said to be critically damped.

→ If the instrument to under damped the moving system will oscillated about the final steady position with a decreasing amplitude and will take some time to come to rest.



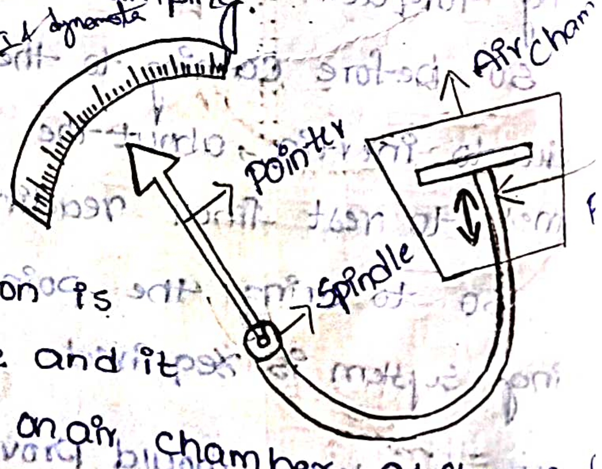
→ while the instrument is said to be over damped if the moving system moves slowly to its final steady position. In over damped case the response of the system is very slow. In praticert slightly under damp system are preffered.

The following methods are used to produce damping torque

⇒ ① Air friction damping ② Fluid friction damping

③ Eddy current damping.

① Air friction damping. eg: MI & dynamometa



→ In this method of obtaining damping, a light aluminium piston is rigidly attached to the spindle and it is made to reciprocate inside an air chamber as shown in f

→ The piston moves to & fro in the camber when the spindle rotates with small clearance b/w itself so the walls of the chamber which is closed at one end.

→ when the pointer moves clockwise i.e upscale, the piston moves down wards. The air in the closed portion of the chamber expands of its pressure falls.

→ The pressure in the open portion of the chamber forces the piston upwards.

→ If the ~~piston~~ pointer moves anticlockwise, the piston moves upwards compressing the air above it. The increased air pressure forces the piston downwards.

→ Thus the motion of the pointer is opposed in either direction, with the result that oscillations of the pointer lie down, and the mean deflected position can be instaneously noted.

Advantages:-

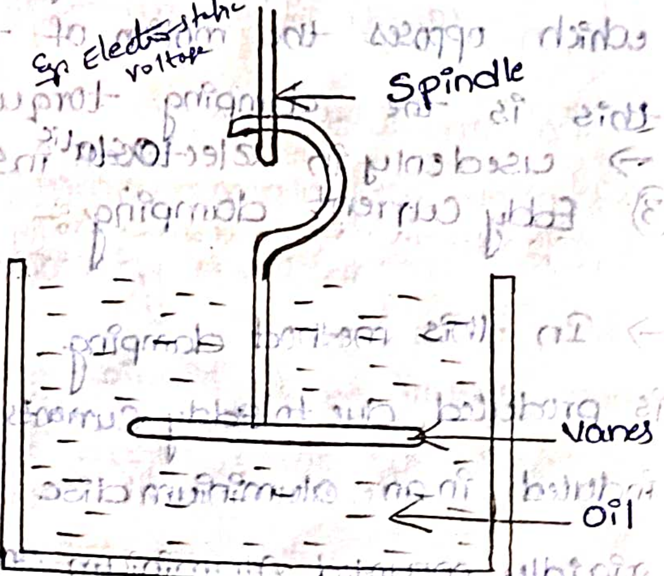
→ simple and cheap

→ no use of permanent magnets

→ used for MI and dynamometer type Instruments.

⑥ fluid friction damping:-

Eg: Electrostatic voltmeter



→ Due to more viscosity of fluid more damping is provided.

Advantages:-

oil can be used for insulation purposes, Due to the up through of oil, the Load on bearings are reduced thus reducing frictional error.

Disadvantages:-

→ can be used for instruments which are in vertical Posi

~~Becausing~~ Because of Craping of oil, instruments canno be kept clean.

→ In this method damping to brought about by th motion of metallic vanes inside a highly viscous Liquid. The arrangement is as shown in fig.

→ Thin metallic vanes which are suitably shaped are susp ded from the spindle and they are kept immersed in a highly viscous oil contained in a suitable vessel.

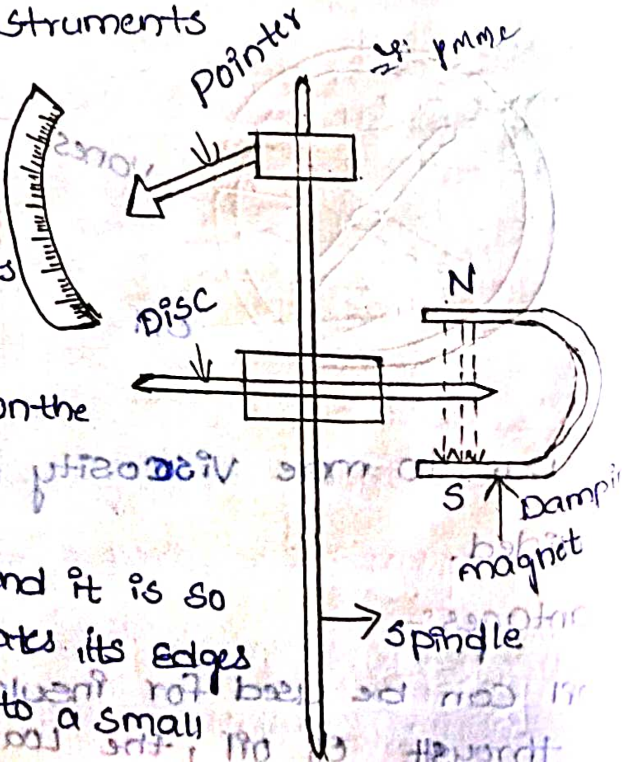
→ when the spindle rotates, the metallic vanes also move through the oil.

→ The frictional force b/w oil and the vanes is used to produce the damping torque.

→ However due to the high viscosity of the oil a torque which opposes the motion of the spindle is brought into pla this is the damping torque.

→ used only in electrostatic instruments

③ Eddy current damping:-



→ In this method damping is produced due to eddy currents induced in an aluminium disc rigidly mounted Aluminium on the spindle as shown in fig.

→ The disc to circular and it is so positioned that, when it rotates its edges cut across the flux due to a small

→ when the spindle rotates, the aluminium disc also rotates along with it. Due to the flux of the magnet being cut across by the edge of the disc, eddy currents are induced in the disc.

→ Due to interaction b/w these eddy current of the flux producing them, a torque is set up.

→ According to lenz's law the direction of this torque is such as to oppose the motion of the spindle hence it brings about damping.

Advantage:-

electromagnetic damping:
Flux meter

→ most effective and efficient method.

Drawback:-

→ cannot be used in MI and dynamometer type instrument

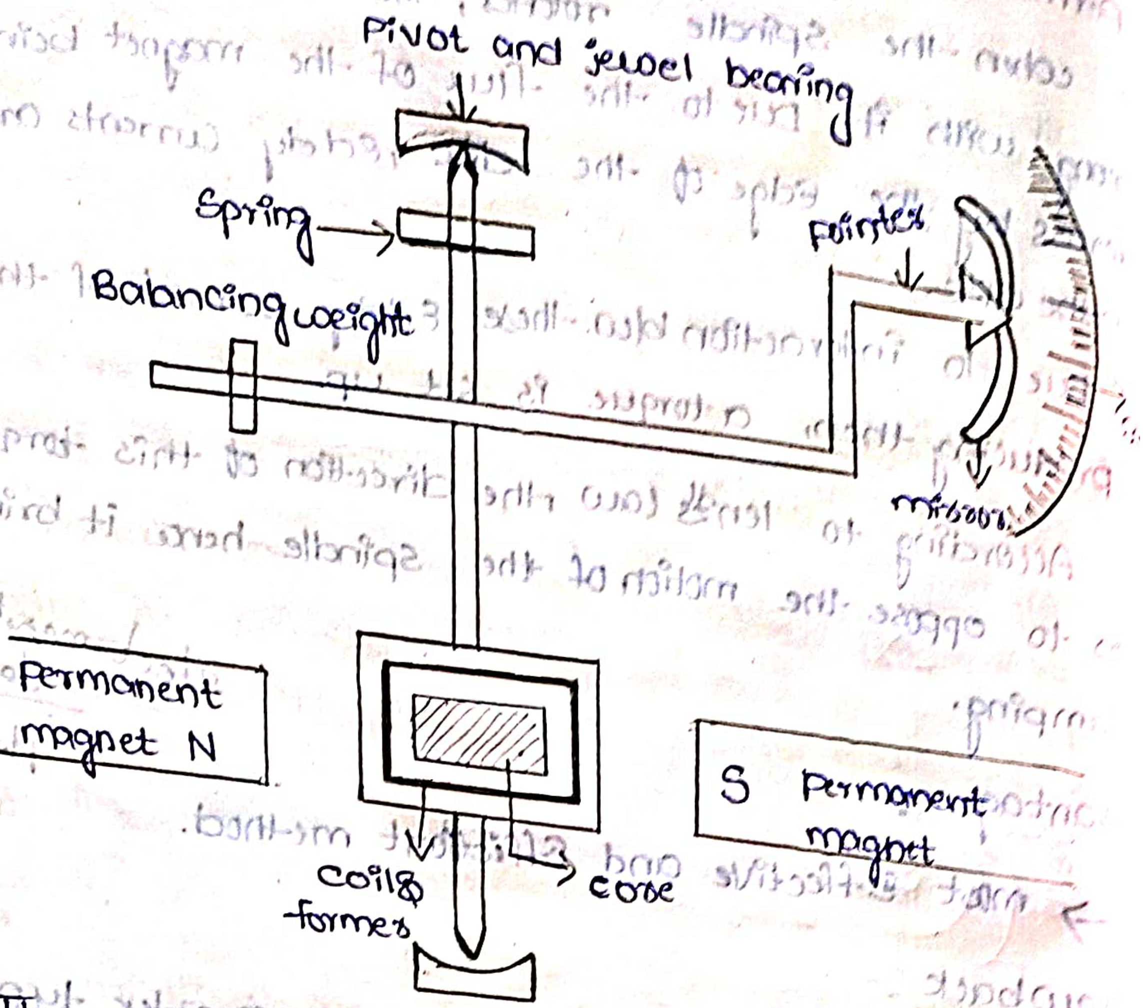
1st Parmanent magnet moving coil Instruments:- (PMMC)

→ The parmanent magnet moving coil instruments are most accurate type of dc measurements. The action of these instrument is based on the motoring principle.

→ When a current carrying coil is placed in the magnetic field produced by permanent magnet, the coil experiences a forced moves.

→ As the coil is moving and the magnet is permanent the instrument is called permanent magnet moving coil instrument

→ This basic principle is called D Arsonval principle. The amount of force experienced by the coil is proportional to the current through the coil.



→ The moving coil is Either reactangular or circular shape.

→ It has no of turns of fine wire.

→ The coil is suspened so that it is free to turn about its vertical axis.

→ The coil is placed uniform, horizontal and radial m netic field of a permanent magnet in the shape a horse-shoe.

→ The iron code is spherical if the coil is circul and is cylindrical if the coil is reactangular.

→ Due to iron core, The deflecting torque increases. easing the sensitivity of the instrument.

→ The controlling torque is provided by two Eddy c Phosphor bronze hair springs.

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

→ The pointer is carried by the spindle and it moves over a graduated scale. The pointer has ~~high~~ Light weight so that it can deflect rapidly.

→ The mirror is placed below the pointer to get the accurate reading by removing the paralax.

→ The weight of the instrument is normally counter balanced by the weights situated diametrically opposite and rigidly connected to it.

→ The scale markings of the basic d.c pmmc instruments are usually linearly spaced as the deflecting torque, and hence the pointer deflection are directly propotional to the current passing through the coil.

Torque Equation:-

The Equation for the developed torque can be obtained from the basic law of the electromagnetic torque. The deflecting torque is given by.

$$\boxed{T_d = NBAI}$$

T_d = Force x distance force on each side of coil $= NBiL$

$T_d = NBiL \times d = NBiA$

Where T_d = deflecting torque in N-m

B = flux density in air gap, wb/m²

N = No. of turns of the coil

A = Effective coil area m²

I = Current in the moving coil, Amperes.

$$\boxed{T_d = GI}$$

$$G = NBA = \text{constants}$$

The controlling torque is provided by the springs and is propotional to the angular deflection of the pointer.

$$T_c = k\theta$$

where T_c = controlling torque

k = Spring constant, Nm/rad (or) Nm/deg

θ = Angular deflection.

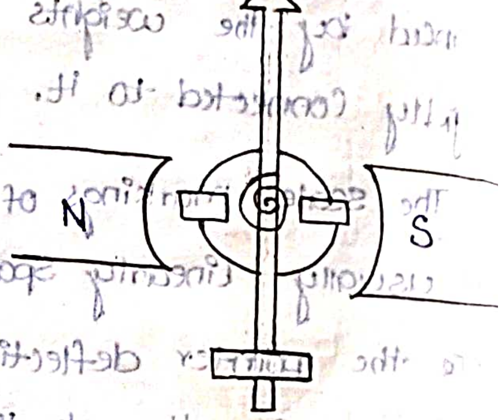
For the final steady state position,

$$T_d = T_c$$

$$GI = k\theta$$

$$\theta = \left(\frac{G}{K}\right)I$$

(or) $\boxed{I = \left(\frac{K}{G}\right)\theta}$



Note:- ① Thus the deflection is directly propotional to the current passing through the coil.

② As the direction of the current through the coil ch the direction of the deflection of the pointer also changes. Hence such instruments are well suited for the d.c measurements.

③ In the micro ammeters and milliammeters upto ab 20mA, the entire current to be measured is passed through the coil. The springs carry current to the coil. Thus the current carrying capacity of the springs. Li the currents which can be safely carried.

④ Most dc voltmeters are designed to produce full deflection with a current of 20, 10, 5 or 1mA

⑤ The power requirement of pmmc instrument is very small typically of the order of 25mW to 200mW. Accuracy is generally of the order of 2 to 5% of the full scale reading.

Advantages:-

1. It has uniform scale
2. with a powerful magnet, its torque to weight ratio is very high so operating current is small.
3. The sensitivity is high.
4. It consumes low power of the order and 25w to 200mw
5. It has high accuracy.
6. Instrument is free from hysteresis Error.
7. Extension of instrument range is possible.
8. Not affected by external magnetic fields called stray magnetic fields.

Disadvantages:-

1. Suitable for dc measurements only.
2. Ageing of permanent magnet, is the control springs introduces machining.
3. The coil is high due to delicate construction and accurate machining.
4. The friction due to jewel - pivot suspension.

End

Error in pmmc Instrument:-

→ The basic sources of Errors in pmmc instruments are friction temperature and aging of various parts. To reduce the frictional errors of torque to weight is made very high.

→ The most Serious Errors are produced by the heat generated or by changes in the temperature. This change the resistance of the working coil, causing large errors.

→ The aging or permanent magnent and control springs also cause Errors. The weakening of magnet and springs cause opposite errors.

→ The weakening of magnet cause let's deflection while weakeaing of the control springs cause large deflecti for a particular value of current.

→ The proper use of material and preageing during ma facturing can reduce the errors due to weakening of the control springs.

2nd Moving Iron Instruments:-

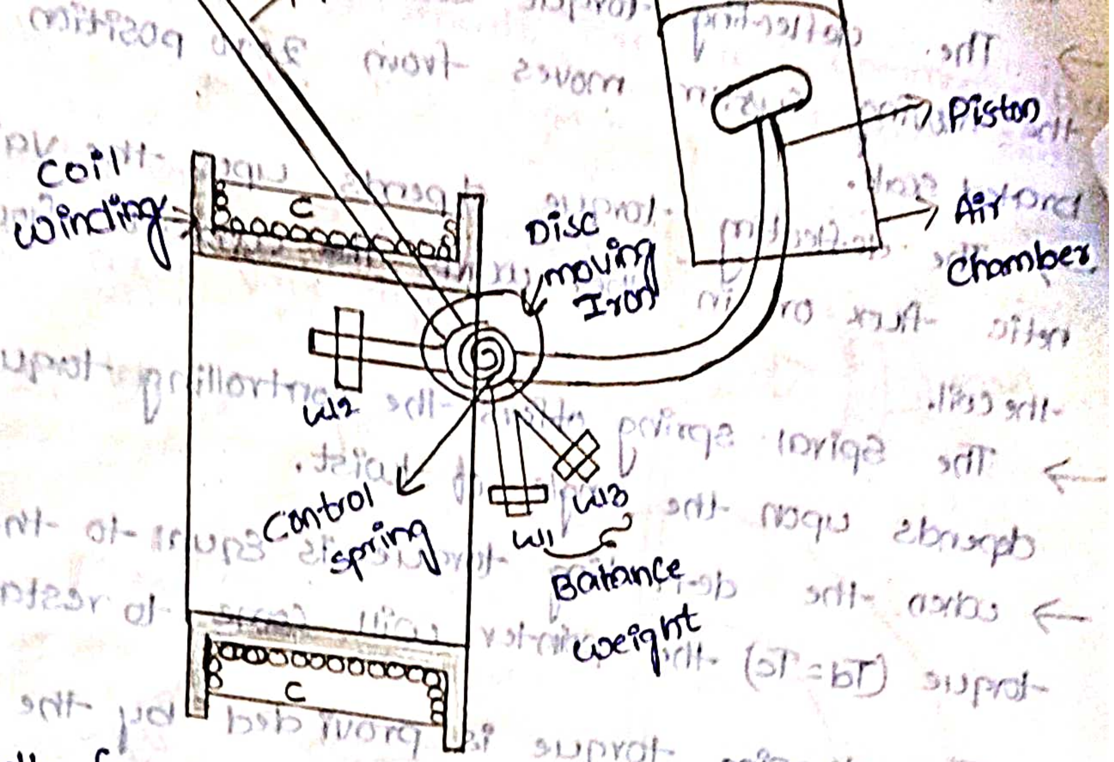
In this type of Instruments [Ammeters and Voltmeters the current carrying coil is stationary, but the iron core rotates hence it is called as moving iron (MI) instruments. These instruments are mostly used to measure the curre and voltage in an alternating and direct current circuit. These are two types of moving iron instruments. **Attractive Type:** These operate on the principle of attraction of a single of soft iron into a magnetic field.

Repulsion type:- These operate on the principle of repulsion two adjacent iron pieces magnetized by the same magnetic field.

The Attraction type MI instruments.

construction:-

→ A MI instrument of the attraction type is shown in fig. It consists a fixed coil "C" of a copper wire is mounted on a bobbin B.



→ The Sindle [or moving system] has a suitably shaped soft iron piece rigidly fixed to it, and it is mounted eccentrically with respect to the fixed coil as shown →A pointer rigidly attached to the spindle can move over a graduated scale.

→ controlling torque is provided by the spring sp and damping is obtained by the to and fro motion of the piston Ps inside the air chamber.

Working:-

→ The operation of MI instruments depends upon the magnetic effect of electric current.

→ when the instrument is connected in the circuit to measure current or voltage, the operating current flows through the coil.

→ when every current flows through the coil, the electromagnetic field is set up along its axis. In other words the coil behaves like a magnet and therefore it attracts the soft iron piece towards it, Thus providing the deflecting torque(T_d).

→ The deflecting torque causes the pointer attached the moving system moves from zero position over a c brated scale.

→ The deflecting torque depends upon the value and m netic flux or in other words the current flowing throu the coil.

→ The spiral spring offers the controlling torque (T_c) whic depends upon the angle of twist.

→ when the deflecting torque is equal to the controll torque ($T_d = T_c$) the pointer will come to restat a positio

→ The damping torque is provided by the air frict A light aluminium piston is attached to the moving sys 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 mov system.

→ The operating magnetic field in moving iron ins -ments is very weak. Hence eddy current damping not used since it requires a permanent magnet which would affect or distort the operating field.

Repulsion type MI instrument:-

→ These instruments have two vanes inside the coil, the one is fixed and other is movable.

→ when the current flows in the coil, both the va are magnetized with like polarities induced on the same side.

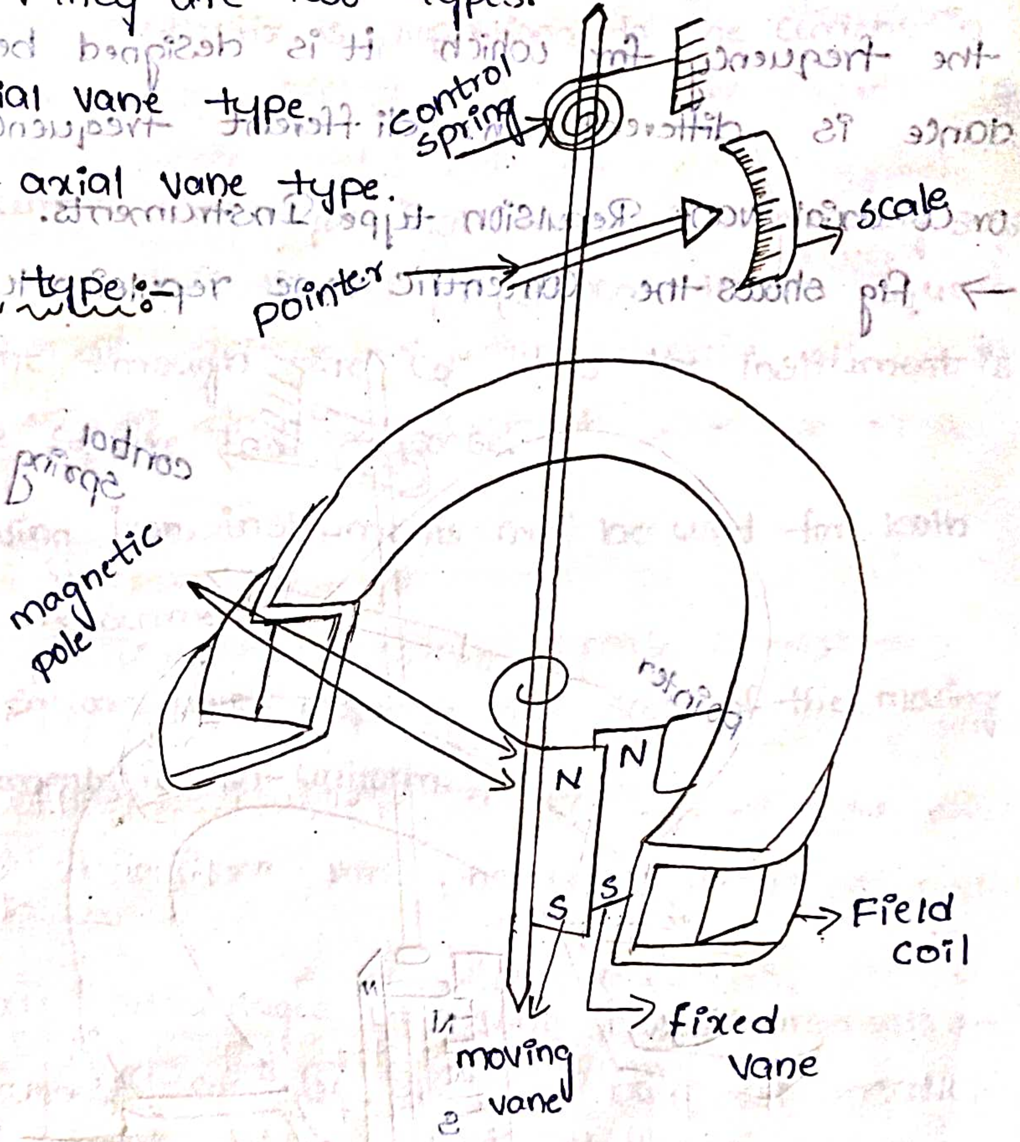
→ Hence due to the repulsion of like polarities, the is a force of repulsion b/w the two vanes causing the movements of the moving vane.

→ Repulsion type instruments are most commonly used instruments. They are two types.

(i) Radial vane type.

(ii) co-axial vane type.

Radial vane type:-



→ Fig above shows the radial vane repulsion type instrument. out and the other moving iron mechanisms, This is the most sensitive and has most Linear scale.

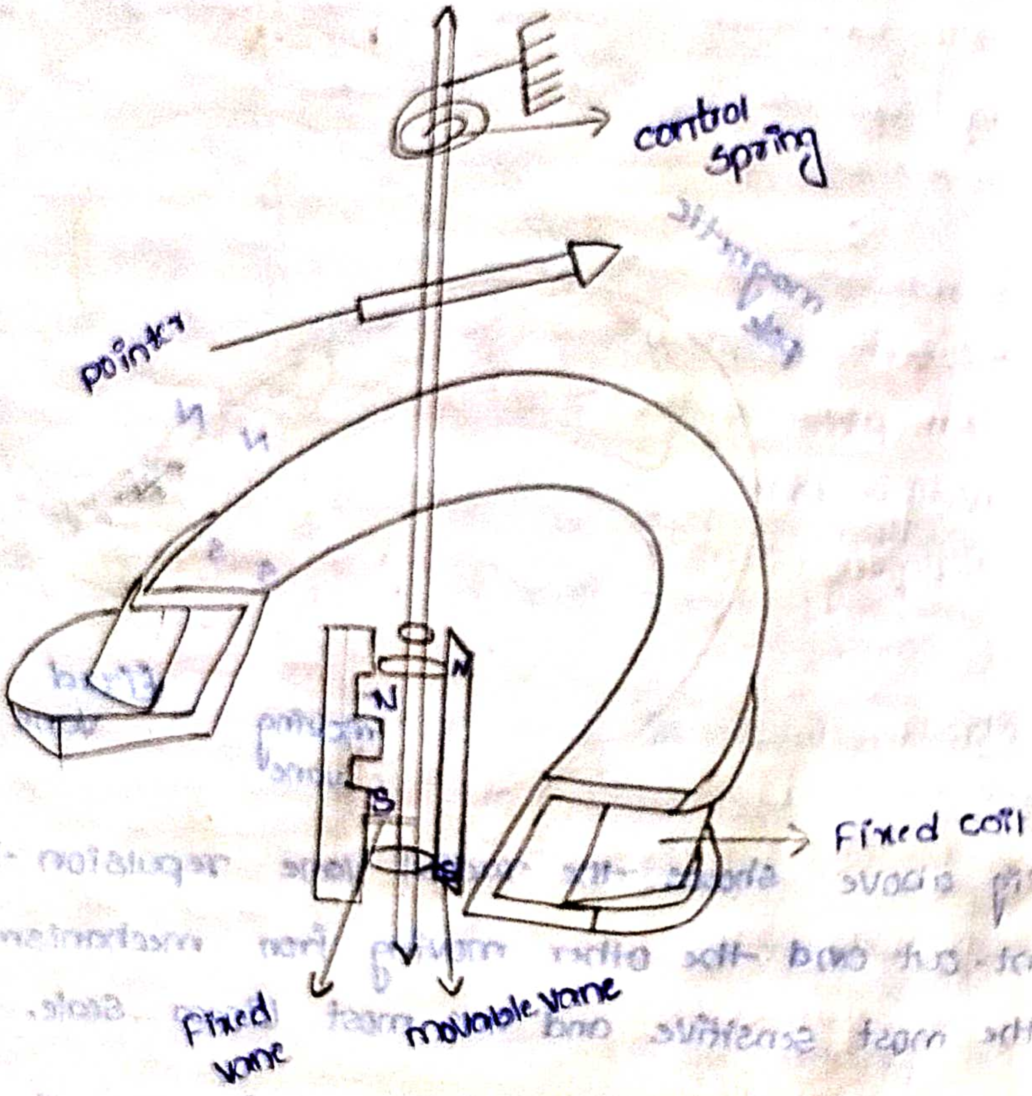
→ The two vanes are radial strip of iron. the fixed vane is attached to the coil.

→ The movable vane is attached to the spindle and suspended in the induction field of the coil. The needle of the instrument is attached to this vane.

→ Even though the current through the coil is alternating, there is always repulsion b/w the like poles of the fixed and the movable vane.

→ Hence the deflection Effectively proportional to
actual current and hence the scale is calibrated directly
read amperes or volts. The calibration is accurate only
the frequency for which it is designed because the
dance is different for different frequencies Concentric
or Co-axial vane Repulsion type Instruments.

→ Fig shows the concentric vane repulsion type instrum



→ The instrument has 2 concentric vanes one is atta
to the coil frame rigidly while the other can rotate
ally inside the stationary vane.

→ Both the vanes are magnetised to the same polarity
the current in the coil.

→ Thus the movable vane rotates under the repulsive

→ As 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.

→ The concentric vane type instruments is moderately sensitive and the deflection is proportional to the square of the current through the coil. Thus the instrument is said to have square law response.

→ Hence moving iron instruments can be used for both AC and DC measurements.

→ Due to square law response, the scale of the moving iron instrument is non-uniform.

ADVANTAGES:-

→ The various advantages of moving iron instruments are

1) The instruments can be used for both a.c and d.c measurments.

* The MI Instruments are upolorised instruments i.e they are independent of direction of current.

2) As the torque to weight ratio is high, errors due to the friction are very less.

3) These are capable of giving good accuracy.

4) The range (and) of instruments can be extended.

5) These are no current carying parts in the moving system. Hence these meters are extremly rugged and reliable.

1) The scale of the moving iron instrument is not uni accurate readings are not possible at this End.

2) These are serious errors due to hysteresis, frequency changes and stray magnetic field.

3) Power consumption is on higher side.

4) The increase in temperature increases the resis ance of coil, decreases stiffness of the springs.

Torque Equation of moving Iron Instruments :-

Consider a small increment in current supplied to the coil of the instrument. Due to this current let dθ be the deflection under the deflecting Torque T Due to such deflection. Some mechanical work will be do

$$\text{mechanical work} = T_d \, d\theta$$

There will be a change in the energy stored in the magnetic field due to the change in inductance. This is because the vane tries to occupy the position of m mum reflectance hence the force is always in such direction so as to increase the inductance of coil. The inductance is inversely proportional to the reluctance the magnetic circuit of coil.

Let I = Initial Inductance

L = Instrument Inductance

θ = Deflection

dI = Increase in current

$d\theta$ = change in deflection

In order to effect an increment dI in to current, these must be an increment in the applied voltage given by.

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

$$= I\frac{dL}{dt} + L\frac{dI}{dt}$$

As both I & L are changing

The electrical energy supplied is given by,

$$eIdt = \left(I\frac{dL}{dt} + L\frac{dI}{dt}\right)Idt$$

$$= I^2dL + ILdI$$

The stored energy increases from $\frac{1}{2}LI^2$ to $\frac{1}{2}(L+dL)(I+dI)$

Hence the change in the stored Energy

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

Neglecting higher order turns, this becomes, $I+dI+\frac{1}{2}I^2d$

The energy supplied ~~to~~ is nothing but increase in stand energy plus required for mechanical work done.

$$\therefore \quad I^2dL + ILdI = ILdI + \frac{1}{2}I^2dL + T_d \cdot d\theta$$

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

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

While the controlling torque is given by

$$T_c = k\theta$$

Where k = spring constant

$$T_c = T_d$$

$$k\theta = \frac{1}{2}I^2\frac{dL}{d\theta} \quad \text{under Equilibrium}$$

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

Thus the deflection is proportional to the square to th
Current through the coil. And the instrument gives squar
Law response.

Errors in moving Iron Instruments

Errors with Both DC and AC :-

1. Hysteresis Error:-

This Error occurs as the value of flux density is diff
ent for the same current for ascending so descending values.

This Error can be minimized by making the iron parts small so that they demagnetic themselves quickly. Hysteresis may produce 2 to 3%. Error. with the use of nickel iron alloys it is reduced to 0.05%.

2. Temperature Error:-

The Effect and temperature changes on moving iron inst
ments arises from the temperature co-efficient of sprin
In voltmeter error are caused due to self-heating of coil series resistance.

This is reduced by series resistance made by mang

3. Stray magnetic fields:-

The errors due to stray magnetic fields may be ap
-ciable as the operating magnetic field in weaks.

These errors can be minimized by using an iron cas
of a thin iron shield over the working parts..

Errors with A.C only

1. Frequency Errors:- If the deflectio

decreases and deflection decreases then frequency increases.

To reduce this frequency error a Capacitor is placed in parallel with ammeter.

Errors in MC Instruments:-

1. Frictional Error:-

The Error due to friction at the pivot in the field of PMMC instrument.

The Error due to friction at the pivot can be reduce with proper and balancing. The machanical friction b/w coil and core be avoided by carefully winding the coil.

2. Temperature Error:-

The heat produced due to I^2R loss in the coil is known as "Temperature Error". This increases resistance in temperature. This increases the change in operating current.

This Error can be minimised by designing the inst -ent by providing proper Ventilation and Cooling.

3. Error due to weakening of permanent magnet:-

The weakening of permanent magnet with the time of usag causes the error in the reading.

This Error can be minimised by proper againg of magnet at the time of manufacturing.

4. Error due to stray magnetic fields:-

Due to the presence of Iron core in the working par the effects of External magnetic fields is increased.

This error can be minimised by proper ageing of the magn
at the time of manufacture.

4. Error due to stray magnetic fields:-

~~Due to the presence of iron core in the working par~~
~~the effects of~~ External magnetic fields ~~fied~~

5. Thermo-electric Error:-

The Error due thermo-electric emf's is known as "therm electric error". This mainly occurs in shunted ammeters and in due to unevent temperature distribution in the shunts.

This Error can be minimized by using a material having a low-thermo-electric emf such as manganine etc.

Extension of Range:-

Any instruments whether it is MI or MC have a limita tion of measuring capacity and to extend the capaci to higher ranges it is necessary to are shunts and multiples.

Shunts:-

The range of an ammeter can be extended by connecting a low resistance called shunts is parallel with amme The shunts by passes the extra current and allows only safe current to flow through the ammeter.

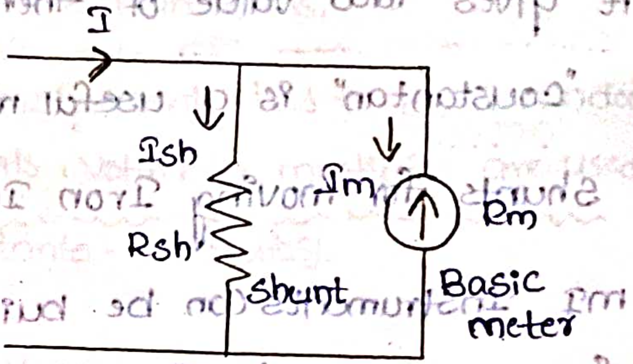
Properties:-

1. Low temperature Coefficient.
2. Low thermal e.m.f with copper.
3. The resistance of shunts should not

→ when heavy currents are to be measured, the major part of the ~~act~~ is by passed through a low resistance called a "Shunt".

Extension of Ammeter:-

Let "I" be the total current to be measured



Rm = Internal resistance of coil (Ω)

Rsh = Shunt Resistance (Ω)

Im = Full scale deflection current (A)

Ish = Shunt current (A)

Since the two resistance Rsh and Rm are in parallel, the voltage drop across them is same.

$$I_{sh}R_{sh} = I_mR_m$$

$$R_{sh} = \frac{I_mR_m}{I_{sh}}$$

but $I_{sh} = I - I_m$

$$\therefore R_{sh} = \frac{I_mR_m}{(I-I_m)}$$

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

$$\frac{I(\frac{I}{I_m})R_m}{I - I(\frac{I}{I_m})}$$

$$\frac{\frac{I^2}{I_m}R_m}{I - \frac{I^2}{I_m}}$$

$$\frac{\frac{I^2 R_m}{I_m}}{\frac{I I_m - I^2}{I_m}}$$

m - multiplying power → ratio of total current to the current through the coil.

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

Thus the (resistance) increase the range of amme

the shunt resistance required is $1/(m-1)$ times the ba

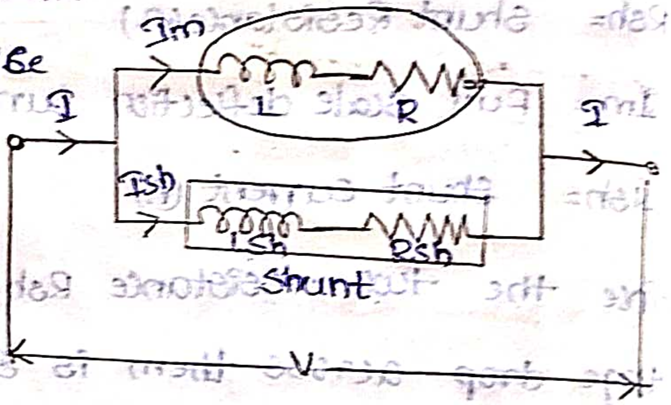
meter resistance.

"manganin" is usually used for shunts of d.c instruments a

it gives low value of thermal Emf with copper.

"coustantan" is a useful material for A.c circuits.

Shunts for moving Iron Instruments:



MI Instruments can be built for a range upto 50A since in the these instruments moving parts do not carry any current Hence shunt are not necessary except for every large currents. If a shunt is required to u used the inductances of both meter coil and shunt mu be considered.

The current in meter and shunt are in inverse ratio their impedance.

$$\frac{I_{sh}}{I_m} = \sqrt{\frac{(R_m)^2+(\omega L)^2}{(R_{sh})^2+(\omega L_{sh})^2}} \rightarrow ①$$

From above Equation it is clear that the ratio of t currents depends upon frequency.

In order to have same division of current through m and shunt for all frequencies. The ratio of impedanc must remain constant.

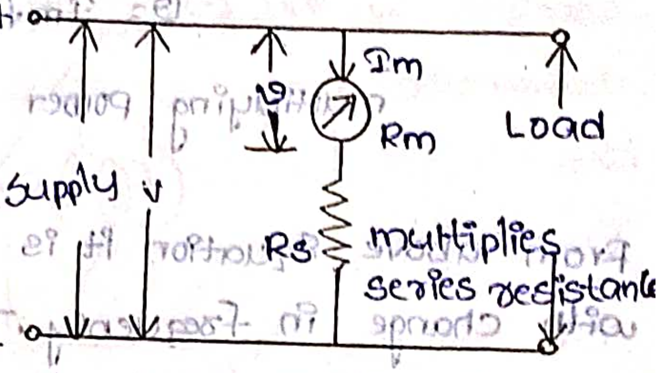
In order to make readings independent of the freq the time constant of meter and shunt should be Equal.

$$\boxed{\frac{L_{sh}}{R_{sh}} = \frac{L}{R}}$$

The Range of moving Iron am meters for A.C applications can be Extended through use of Current transforms.

→ when the range of the instrument has to be Extended for high voltage measurements, voltmeter multiplies are used. [A highly non inductive resistance - multiplies].

Voltmeter multiplies:-



A basic meter voltmeter is converted into a voltmeter by connecting a series resistance with it. This series resistance is known as a multiplies.

Let I_m = Full Scale deflection current of meter.

R_m = Internal resistance of meter movements.

R_s = multiplier resistance.

v = voltage across the meter for current I_m.

V = Full range voltage of instrument.

for the circuit $v = I_m R_m$

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

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

Interms of multiplying factor

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

∴ Resistance of multiplies $\boxed{R_s = (m-1) R_m}$

Essential requirements of multiplies:

1. Resistance should not change with time.
2. The change in their resistance with temperature should be small.
3. They should be non-inductively wound for A.c meter.

For A.c operation, the inductance has to be taken into accounts.

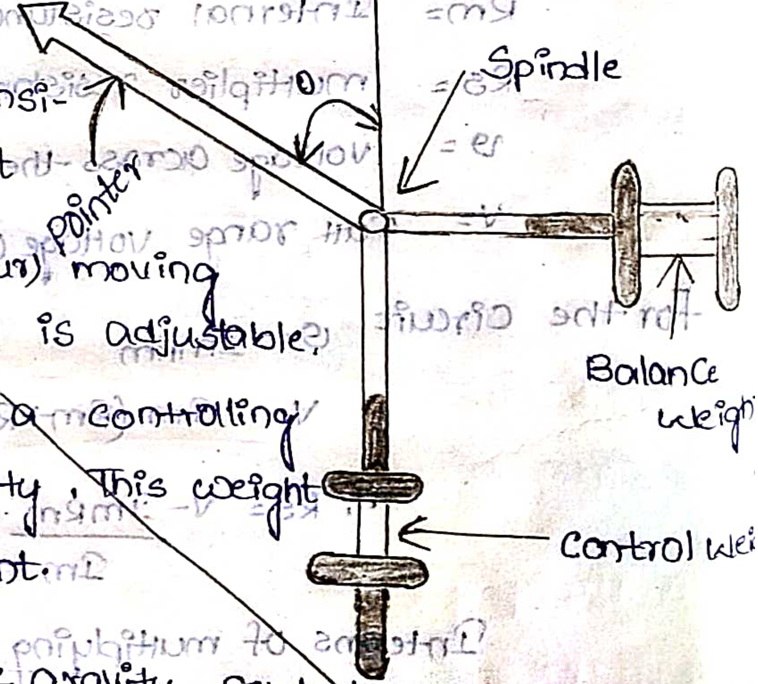
Then $I_m = \frac{V}{\sqrt{(R_s+R_m)^2+\omega^2L^2}}$

$$v = I_m\sqrt{R_m^2+\omega^2L^2}$$

multiplying power $m = \frac{V}{v} = \frac{\sqrt{(R_s+R_m)^2+\omega^2L^2}}{\sqrt{R_m^2+\omega^2L^2}}$

From above Equation it is Equident that m will change th with change in frequency. The multiplies may be shunted by a capacitor, inorder to compensate error caused by change of "m" with change of frequency.

Gravity Control:-

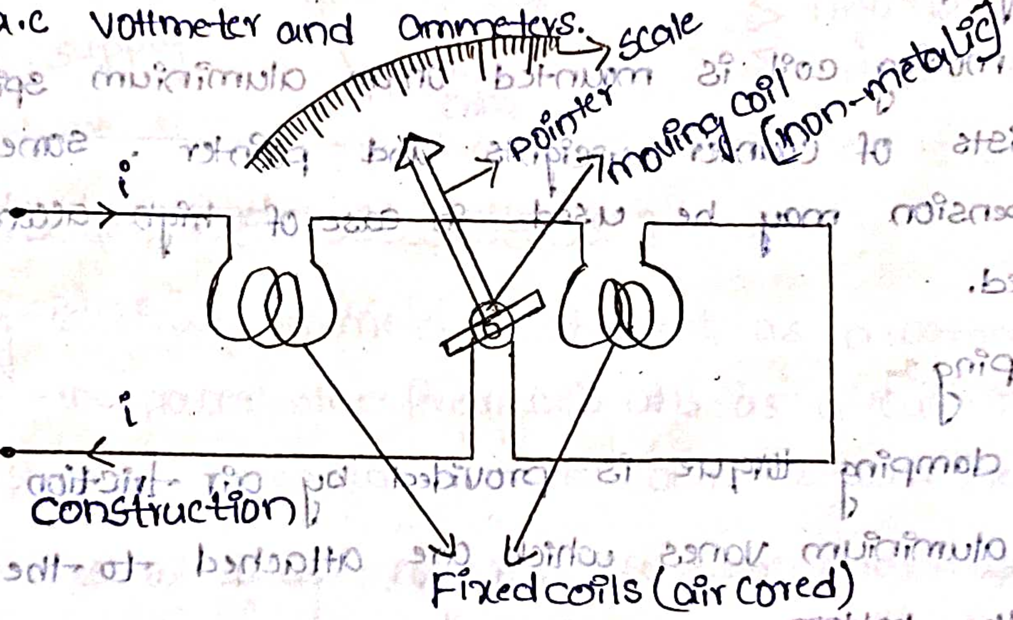


The type of control consists of a small weight attached to the (measur) moving system, whose position is adjustable. This weight produces a controlling torque due to gravity. This weight as called control weight.

The figure shown the gravity control system, At the ze position of the pointer, the controlling torque is ze The position is shown as position A of the weight in th figure.

3) Electrodynamometer Type Instruments :-

The electrodynamometer type instruments is a transfer instrument. A transfer instrument is one which is calibrated with a d.c source and used without any modifications for A.C measurements such a transfer instrument has same accuracy for a.c and D.c measurements. The electrodynamometer type instruments are often used in accurate a.c voltmeter and ammeters.



construction

The various parts of the electrodynamometer type instrument

Fixed coils:-

The necessary field required for the operation of the instrument is produced by the fixed coils. A uniform field is obtained near the centre of coil due to division of coil in two sections. These coils are air cored. Fixed coils are wound with fine wire for using as voltmeter, while for ammeters and wattmeter it is wound with heavy wire.

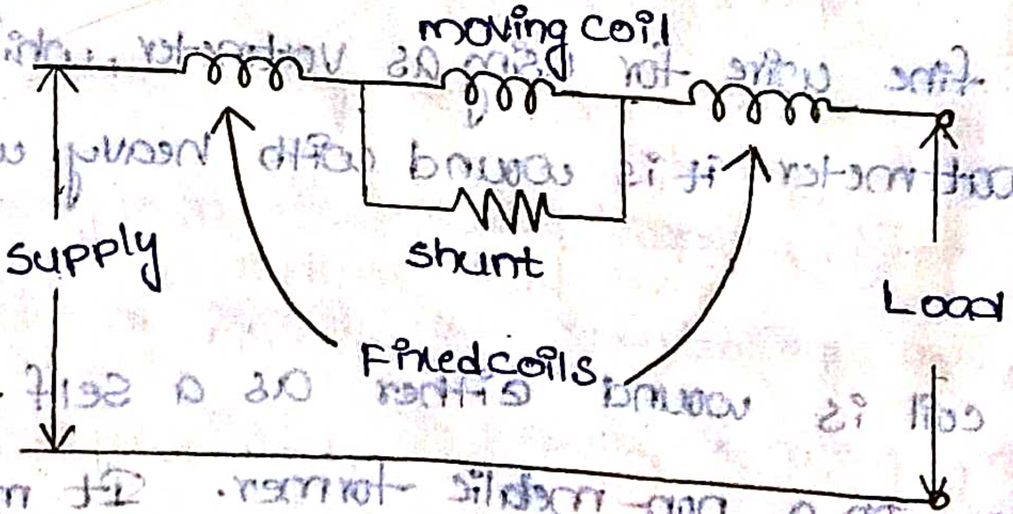
moving coil:-

The moving coil is wound either as a self-sustaning coil or else on a non-metalic former. It matalic forme

The damping torque is provided by air friction by a pai of aluminium vanes which are attached to the Spindle at the bottom.

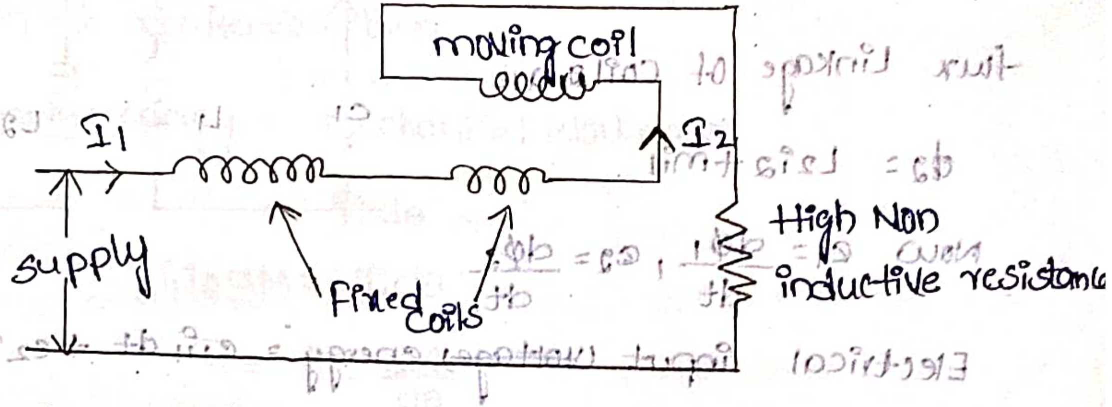
(ii) Electrodynamometer as Ammeter:-

For using electrodynamometer instrument as Amm fixed and moving coils are connected in series and con the same ~~about~~ current. A suitable shunt is conne to these coils to limit current through them upto desi Limit.



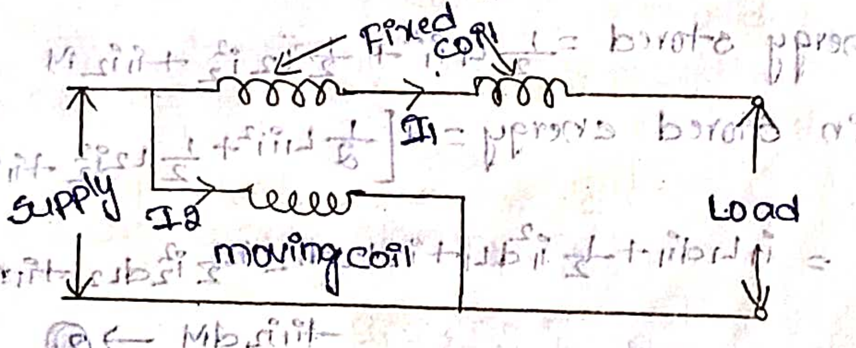
② Electrodynamometer as Voltmeter :-

The electrodynamometer instruments can be used as a voltmeter by connecting the field and moving coils in most accurate type of voltmeter.



③ Electrodynamometer as wattmeter :-

(i) using electrodynamometer instrument as a wattmeter to measure the power, the fixed coils acts as a current coil and must be connected in series with the load. The moving coil acts as a voltage coil or pressure coil and must be connected across the supply terminals.



Torque Equation :-

Let i_1 = Instantaneous value of current in fixed coil.

i_2 = Instantaneous value of current in moving coil.

L_1 = Self Inductance of fixed coils.

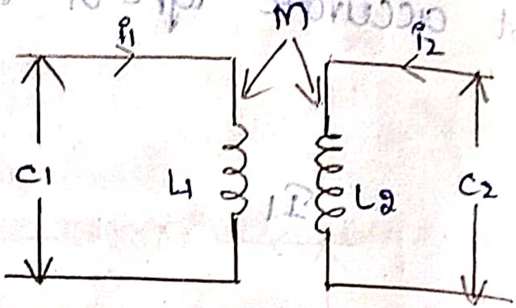
L_2 = Self inductance of moving coil.

M = mutual inductance b/w fixed and moving coils.

The electrodynamometer instrument can be represented an Equivalent circuit as shown.

The flux Linkage of Coil 1

$\phi_1 = L_1 i_1 + m i_2$



flux Linkage of coil 2 are

$\phi_2 = L_2 i_2 + m i_1$

Now $e_1 = \frac{d\phi_1}{dt}$, $e_2 = \frac{d\phi_2}{dt}$

Electrical input ~~(voltage)~~ energy $= e_1 i_1 \, dt + e_2 i_2 \, dt$

$= i_1 d\phi_1 + i_2 d\phi_2$ $\left[\frac{d\phi_1}{\cancel{dt}} i_1 \cancel{dt}\right.$

$= i_1 d\left[L_1 i_1 + m i_2\right) + i_2 d\left(L_2 i_2 + m i_1\right)$ $\frac{d\phi_2}{dt}$

$= i_1 L_1 di_1 + i_1^2 dL_1 + i_1 i_2 dm + i_1 m di_2 + i_2 L_2 di_2 + i_2^2 dL_2 + i_2 l_2$

$+ i_2 m di_1 \rightarrow$ ①

The energy stored in magnetic field due to L_1, L_2 and

is given by.

Energy stored $= \frac{1}{2} L_1 i_1^2 + \frac{1}{2} L_2 i_2^2 + i_1 i_2 M$

change in stored energy $= d\left[\frac{1}{2} L_1 i_1^2 + \frac{1}{2} L_2 i_2^2 + i_1 i_2 M\right]$

$= i_1 L_1 di_1 + \frac{1}{2} i_1^2 dL_1 + i_2 L_2 di_2 + \frac{1}{2} i_2^2 dL_2 + i_1 m di_2 + i_2$

$+ i_1 i_2 dM \rightarrow$ ②

From the principle of conservation of energy

Energy input = Energy stored + mechanical energy

mechanical Energy = Energy stored - Energy input.

Substracting Eq ② from Eq ①

mechanical energy $= \frac{1}{2} i_1^2 dL_1 + i_2^2 dL_2 + i_1 i_2 dM$

due are zero.

$\therefore$ Mechanical energy $= i_1 i_2 dM$

If T_i is the instantaneous deflecting torque $d\theta$ is the change in the deflection then.

mechanical energy = mechanical workdown

$$= T_i d\theta$$

$$i_1 i_2 dM = T_i d\theta$$

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

This is the expression for the instantaneous deflecting torque operation of deflecting torque in a.c and d.c

Dc operation:-

For dc currents of I_1 and I_2

$$Td = I_1 I_2 \frac{dm}{d\theta}$$

provided

The controlling torque is ~~providing~~ by springs hence.

$$Tc = k\theta$$

In steady state $Td = Tc$

$$I_1 I_2 \frac{dm}{d\theta} = k\theta$$

$$\theta = \frac{I_1 I_2}{k} \frac{dm}{d\theta}$$

Thus the deflection is proportional to the product of the two currents and the rate of change of mutual inductance.

In a.c operation, the total deflecting torque over a cycle must be obtained by integrating Ti over one period.

Average deflecting torque over one cycle is

$$T_d = \frac{1}{T}\int_0^T T_i\,dt$$

$$T_d = \frac{dm}{d\theta}\cdot\frac{1}{T}\int_0^T i_1 i_2\,dt$$

Now if the two currents are sinusoidal and displaced by a phase angle ø then.

$$i_1 = I_{m1}\sin\omega t$$

$$i_2 = I_{m2}\sin(\omega t - \phi)$$

$$T_d = \frac{dm}{d\theta}\cdot\frac{1}{2\pi}\int_0^{2\pi} I_{m1}\sin\omega t\cdot I_{m2}\sin(\omega t - \phi)\,d(\omega t)$$

$$= \left(\frac{I_{m1} I_{m2}}{2}\right)\cos\phi\,\frac{dm}{d\theta}$$

$$= I_1 I_2 \cos\phi\,\frac{dm}{d\theta}$$

where I_1, I_2 are the rms values of the two currents as

$$I_1 = \frac{I_{m1}}{\sqrt{2}} \;\&\; I_2 = \frac{I_{m2}}{\sqrt{2}}$$

$$T_c = k\theta$$

Henle steady state $T_c = T_d$

$$I_1 I_2 \cos\phi\,\frac{dm}{d\theta} = k\theta$$

$$\boxed{\theta = \frac{I_1 I_2}{k}\cos\phi\,\frac{dm}{d\theta}}$$

Thus the deflection is decided by the product of r.m values of two currents, cosine of the phase angle (power-factor) and rate of change of mutual inductance.

Advantages:-

1. They have a precision grade accuracy.
2. used for both a.c and d.c, they are also used as transfer instruments.
3. Free from hysterisis Error.
4. Low power consumption.
5. Light in weight.

Disadvantages:-

1. They are more expensive.
2. They have a non-uniform scale.
3. These instruments have low sensitivity due to a low torque to weight ratio.
4. These instruments are sensitive to overloads and mechanical inputs.

Errors in Electrodynamometer

1. **Torque to weight ratio:-**

To have reasonable deflecting torque, mmf of the moving coil must be large enough. Thus mmf = NI hence current through moving coil should be high. no.of turns should be large. current can not be heigh because it cause excessive heatings and springs large no.of turns in this only option. This reduces torque

2. **Frequency errors:-**

The changes in the frequency causes to changes self inductances of moving coil and fixed coil. This causes th error in reading. This can be reduced by having Equa time constants for both fixed and moving coil circuits.

3. Eddy current Errors:-

In metal parts of the instrument the eddy current intreact with the instruments current, to cause chan in the deflecting torque, to cause error. Hence meta parts should be kept as minimum as possible.

4. Stray magnetic field error:-

operating field in electrodynamometeric instrument very weak. Hence External magnetic field can interact with the operating field to cause change in the deflection causing the error. To reduce this error, the shields must be used for the instruments.

5. Temperature Error:-

The temperature errors are caused due to the Se heating of the coil, which causes Changes in the ~~compensating~~ ~~resi~~ resis of the coil. Thus temperature compensating resistor can be used in the precise instrument to Elimin te the temperature errors.

End

UNIT-II

MEASUREMENT OF POWER AND ENERGY

Syllabus:-

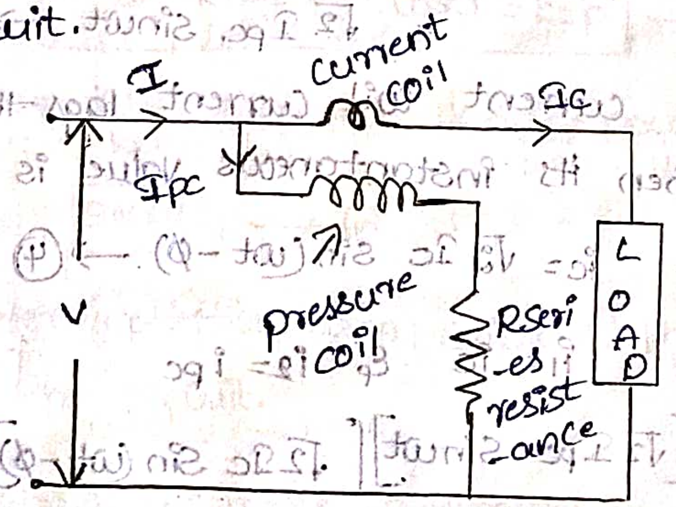
Principal of operation of EDM-type wattmeters - Errors and compensation - LPF and UPF types - measurment of three phas power by two and three wattmeters - single phase induction type Energymeter - principle of operation - Errors and compen sations in energymeters - Three phase Energy meter.

Single phase Electrodynometer type wattmeter

→ An electrodynamometer type wattmeter is used to measu -e power.

→ It has two coils, fixed coil which is current coil and moving coil which is pressure coil or voltage coil.

→ The current coil carriers the current of the circuit while pressure coil carriers current proportional to the voltage in the circuit. This is achieved by connecting a series resistance in voltage circuit.



. Electrodynamometer Voltmeter

Let I_c = Current through Current Coil

I_{pc} = current through pressure coil

R = Series resistance

V = Rms value of supply voltage

I = Rms value of current

Torque Equation:-

According to theory of electrodynamometer in

$$T_i = i_1 i_2 \frac{dm}{d\theta} \rightarrow ①$$

Let v = Instantaneous voltage

$$= V_m \sin\omega t$$

$$= \sqrt{2} V \sin\omega t \rightarrow ②$$

Due to high series resistance, pressure coil is be purly resistive.

Therefore the current I_{pc} is in phase with "v". coil is purely resistive.

$$I_{pc} = \text{Instantaneous value}$$

$$= \frac{v}{R_p} \quad \text{where } R_p = r_{pc} + R$$

$$\therefore I_{pc} = \frac{\sqrt{2} V}{R_p} \sin\omega t$$

$$= \sqrt{2} I_{pc} \sin\omega t \rightarrow ③$$

If the current coil current lags the voltag angle ϕ then its instantaneous value is

$$i_c = \sqrt{2} I_c \sin(\omega t - \phi) \rightarrow ④$$

$$i_1 = i_c \quad \& \quad i_2 = i_{pc}$$

$$T_i = [\sqrt{2} I_{pc} \sin\omega t][\sqrt{2} I_c \sin(\omega t - \phi)] \frac{dm}{d\theta}$$

$$= 2 I_c I_{pc} \sin(\omega t) \sin(\omega t - \phi) \frac{dm}{d\theta}$$

$$= I_c I_{pc} [\cos\phi - \cos(2\omega t - \phi)] \frac{dm}{d\theta} \rightarrow ⑤$$

Thus instantaneous torque has a component of pow which varies as twice the frequency of current & voltage

T_d = Average deflecting Torque

$$= \frac{1}{T}\int_0^T T_i \, d(\omega t)$$

$$= \frac{1}{T}\int_0^T I_c I_{pc}\left[\cos\phi - \cos(2\omega t-\phi)\right]\frac{dm}{d\theta}\, d(\omega t)$$

$$T_d = I_c I_{pc}\cos\phi \frac{dm}{d\theta} \rightarrow ⑥$$

where $I_{pc} = \frac{V}{R_p}$

For Spring control system $\boxed{T_c = k\theta} \rightarrow ⑦$

Let $T_d = T_c$ [At Equilibrium]

$$I_c I_{pc}\cos\phi \frac{dm}{d\theta} = k\theta$$

$$\theta = \frac{1}{k} I_c I_{pc}\cos\phi \frac{dm}{d\theta}$$

$$= k_1 I_c I_{pc}\cos\phi \rightarrow ⑧$$

where $k_1 = \frac{1}{k}\frac{dm}{d\theta}$

$$\boxed{\therefore\ \theta = k_1 I_c \frac{V}{R_p}\cos\phi = k_2 P} \rightarrow ⑨$$

where $k_2 = \frac{k_1}{k_p}$ & $P = V I_c \cos\phi$ = power

$$\boxed{\theta \propto P} \rightarrow ⑩$$

Thus wattmeter deflection when calibrated gives the power consumption of the circuit.

Errors in Electrodynamometer wattmeter :-

1. Error due to pressure coil inductance:

Let r_p = resistance of pressure coil

L = Inductance of pressure coil.

R_p = Total resistance of pressure coil.

$= r_p + z$

V = voltage applied to pressure coil Circuit Current

I = current in the current coil circuit

I_p = current in pressure coil circuit.

Z_p = Impedance of pressure coil circuit

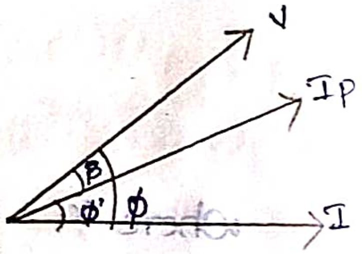
$$= \sqrt{(R+r_p)^2 + (\omega L)^2}$$

→ In an ideal wattmeter that the current in the pressure coil is in phase with applied voltage.

→ If the pressure coil of wattmeter has an inductance the current in it will lag voltage by an angle β

$$\beta = \tan^{-1}\left(\frac{\omega L}{R_p}\right)$$

$$= \tan^{-1}\left(\frac{\omega L}{R+r_p}\right)$$



→ For the lagging p.f. the angle b/w current coil current in the pressure coil circuit is less than φ.

→ The angle b/w pressure coil current & current coil current is $\phi' = \phi - \beta$

Actual wattmeter reading $= \left(\frac{I I_p}{K}\right)\cos\phi' \frac{dm}{d\theta}$

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

$$= \frac{V \cdot I}{K \cdot \left(\frac{R_p}{\cos\beta}\right)}\cos(\phi-\beta)\frac{dm}{d\theta}$$

$$= \frac{V \cdot I}{K \cdot R_p}\cos(\phi-\beta)\cos\left(\frac{dm}{d\theta}\right)$$

If the inductance is zero i.e $Z_p = R_p$ & $\beta = 0$ then its wattmeter will read true power.

$$\text{True power} = \frac{I_p . I}{K} \cos\phi \frac{dm}{d\theta}$$

$$= \frac{VI\cos\phi}{(KR_p)} \frac{dm}{d\theta}$$

$$\frac{\text{true power}}{\text{wattmeter Reading}} = \frac{VI\cos\phi}{K \cdot R_p} \cdot \frac{dm}{d\theta} \times \frac{K \cdot R_p}{VI\cos(\phi-\beta)\cos\beta \frac{dm}{d\theta}}$$

$$= \frac{\cos\phi}{\cos(\phi-\beta)\cos\beta}$$

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

$$\text{Correction factor} = \frac{\cos\phi}{\cos(\phi-\beta)\cos\beta} \text{ for lagging p.f}$$

→ From the vector diagram for the lagging loads. wattmeter will read high due to the Effect of pressure coil inductance.

→ For leading Load, wattmeter will read low value due to effect and pressure coil inductance.

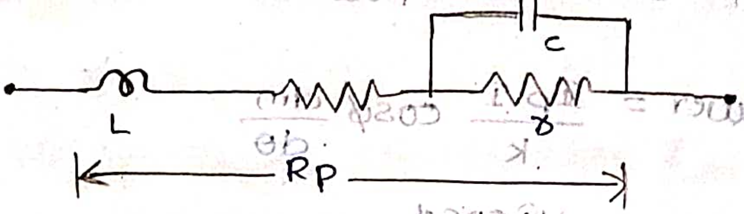
$$\text{Correction factor for leading load} = \frac{\cos\phi}{\cos\beta \cdot \cos(\phi+\beta)}$$

$$\text{Error} = \tan\phi\tan\beta \times VI\cos\phi = VI\sin\phi\tan\beta$$

→ From the above it is clear that error is serious at low power factor.

compensation:-

many wattmeter are compensated for inductance of pressure coil current by connecting a capacitor in parallel to a portion of series resistance as shown in figure.



Total impedance $= Z_p = (R_p - r) + j\omega L + \dfrac{r - j\omega C r^2}{1 + \omega^2 C^2 r^2}$

If the value of circuit constants are chosen as $\omega^2 C^2 r^2 << 1$

then $Z_p \approx R_p - r + j\omega L + r - j\omega C r^2 \approx R_p + j\omega (L - C r^2)$

If we make $L - Cr^2 = 0$ then $Z_p \approx R_p$ & $\beta = 0$

Hence error due to pressure coil is almost eliminated

② Errors caused by stray magnetic fields :-

The dynamometer wattmeter is particulary capable t the influence of stray magnetic fields. Hence the instrum nt is effectively shielded magnetically so, that the opera system in free from adverse effects due to external mag tic fields.

③ Errors caused by mutual inductance :-

The mutual inductance b/w current coil and voltage coil also causes errors, but these are negligible at low frequency.

This is minimised by properly designing the coil sy such that the coils are always in a position of zero mutual inductance.

④ Errors due to Eddy currents:-

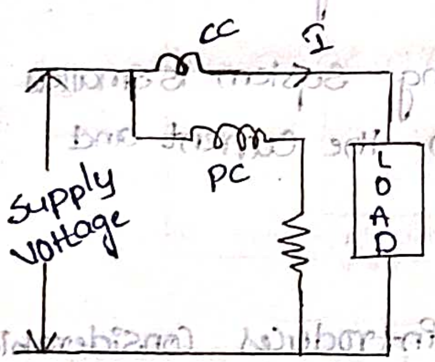
When the current coil carries alternating current an alternating flux is set up and this induces Eddy curren in solid metal parts of the operating system and also in the conductors of the current coil, due to this errors get introduced.

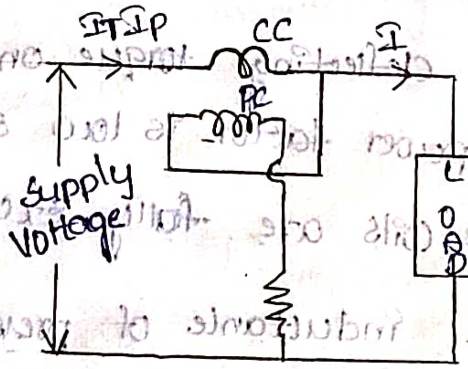
This can be minimised by avoiding solid metal parts & i having standard conductors.

⑤ Errors caused by capacitance of potential coil:-

Since a high series resistance is incorporated in the voltage coil circuit, this resistor has inter-turn capacitance is opposite to that of the voltage coil inductance, and if the two effects off set each other, that net error may be zero.

⑥ Error due to method of connection:-





Because of the power loss in the current and pressure coils, error is introduced in the measurment of power.

→ In fig (1) pressure coil is connected on the supply side and therefore the voltage applied to the pressure coil is the voltage across the load plus voltage drop across current coil. Thus wattmeter measure power loss in its current coil is addition to power consumed by load.

∴ power indicated by wattmeter = power consumed by load + power loss in current coil (I^2R_c)

→ If the wattmeter connections are shown in fig ② the current coil is on supply side and hence it carries pressure coil current plus the load current. Thus wattmeter reads in addition to power consumed in load, the power loss in pressure coil.

$$\text{power indicated by wattmeter} = \text{power consumed by load} + \text{power loss in pressure coil circuit} \left(\frac{V^2}{R_P}\right)$$

Low power factor meter :-

If any circuit is operating at low power factor then power in that circuit is difficult to measure with ordinary electrodynamometer wattmeter. The reading of wattmeter is accurate an account of following reasons.

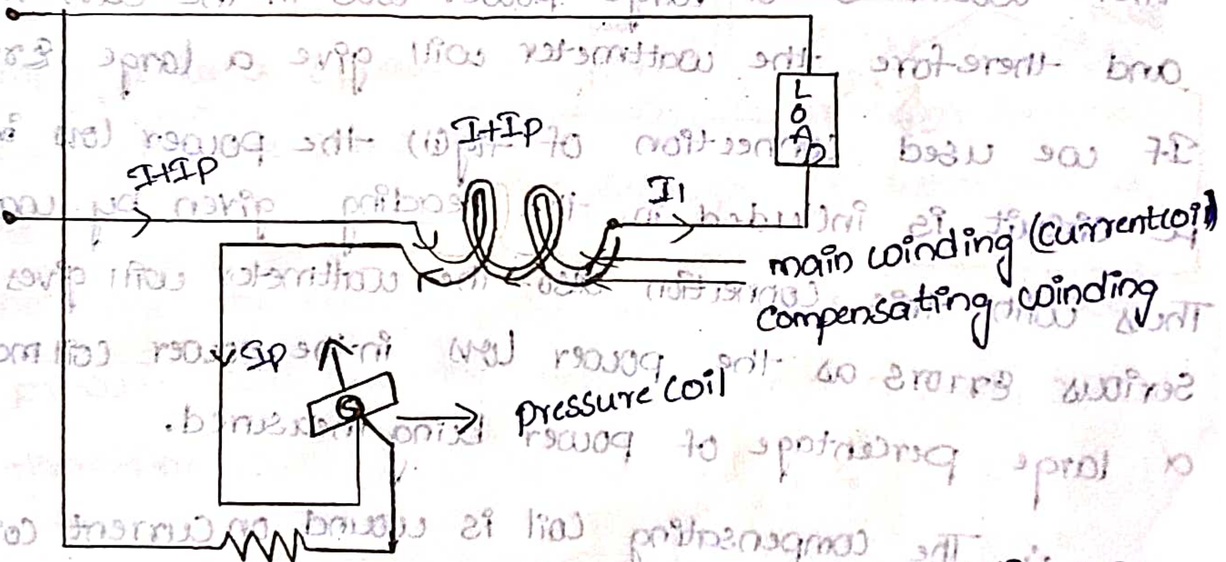
1) The deflecting torque on the moving system is small as the power factor is low Even though the current and pressure coils are fully excited.

2) The inductance of pressure coil introduces considerable error at low power factor.

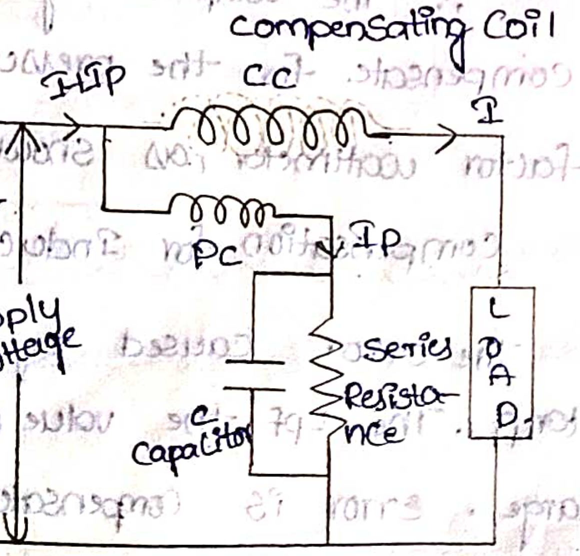
In order to get accurate reading from the wattmeter when it is measuring low power, extra adjustments are required to be made so that there will be compensation of the errors.

when the power to be measured is low then the current in the circuit is high as the power factor is low. Thus, in this case pressure coil cannot be connected to supply side otherwise large error will be produced because of large currents flowing in current coil and corresponding power lo in current coil circuit is measured by wattmeter.

If the pressure coil is connected to load side power consumed by pressure in comperision with power to be measured which is small. Hence it is necessary to compensate for pressure coil current in low power factor wattmeter. The compensated wattmeter is shown in figure (1).



1) pressure coil current:-



PF wattmeter

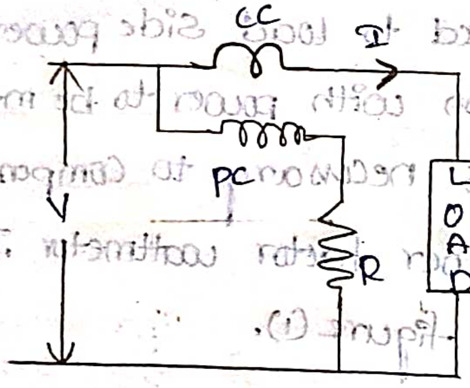
→ The pressure coil circuit is designed to have low value of resistance.

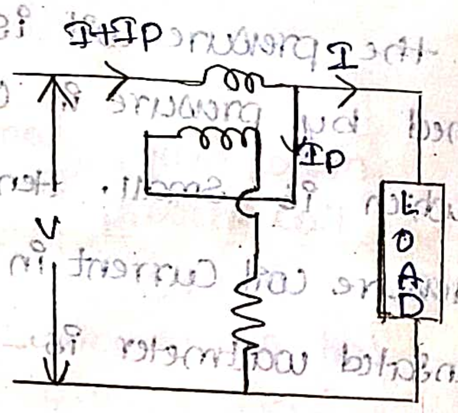
→ So that the current flowing through it is increased to an increased operating torque.

→ The pressure coil current in a low power factor wattmeter may be as much as 10 times the value employed for high power factor.

② Compensation for pressure coil current :-

The power being measured in a LPF circuit is small and current is high on account of LPF, connecting fig (1) cannot be used because owing to large load current.





There would be a large power loss in the current coil and therefore the wattmeter will give a large error. If we used connection of fig (ii) the power loss in the pc circuit is included in the reading given by wattmeter. Thus with this connection also the wattmeter will gives a serious errors as the power loss in the power coil may be a large percentage of power being measured.

∴ The compensating coil is wound on current coil to compensate for the pressure coil current in a low power factor wattmeter, as shown in fig (2).

③ Compensation for Inductance of pressure coil :-

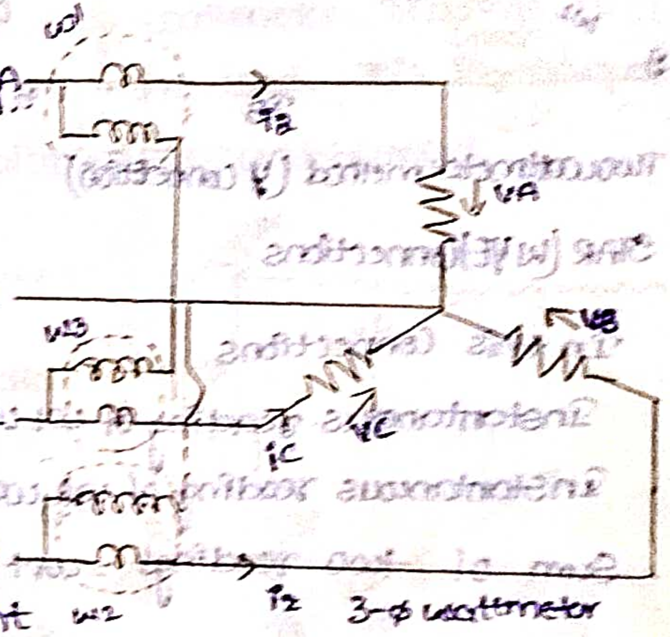
The error caused by pressure coil inductance is $VI \sin\phi \tan\beta$. The LPF, the value of ϕ is large, therefore error is large. error is compensated by connecting capacitor across a part of series resistance in the pressure coil circuit as shown in fig (3).

③ Small control torque:-

LPF wattmeter are designed with to have a small control torque so that they give full scale deflection for power factor as low as 0.1.

measurement of power in three phase circuits:-

There are three methods power in three phase circuits. They are
i) Three wattmeter method.
ii) Two wattmeter method.
iii) One wattmeter method.



i) Three wattmeter method:-

The three wattmeter method is employed for a 3 phase 4 wire system are shown in figure.

In this case the common point N of pressure coils and the neutral 0 of the load, coincide and there fore.

$V=0$

And $VA = VA'$; $VB = VB'$; $VC = VC'$

Instantanious power of the load

$$\boxed{P = VAiA + VBiB + VCiC}$$

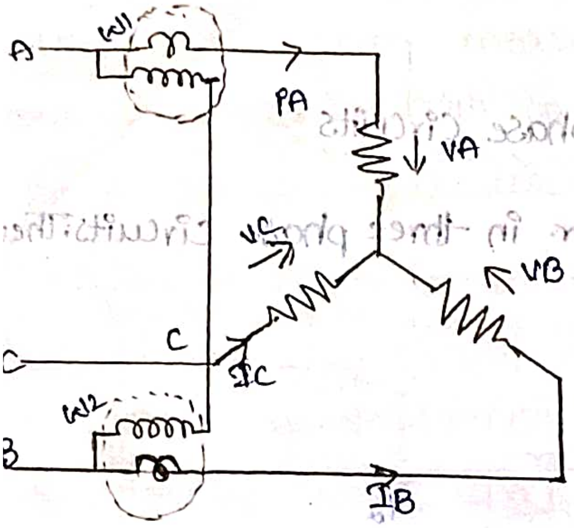
Hence these three wattmeter measure the power of the load.

ii) Two wattmeter method:-

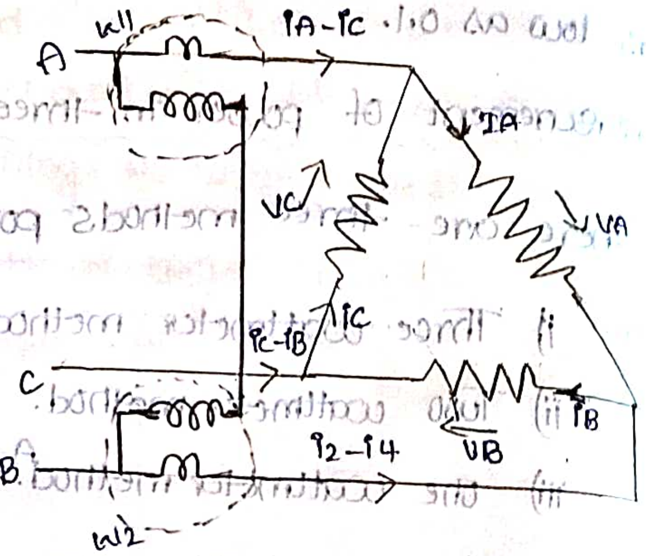
In a three wire system we requires 3 elements. But if we make the common points of the pressure coils coincide with of the lines then we will require only n-1 = 2 element

Instantanious power consumed by load = $V_A i_A + V_B i_B + V_C i_C$

Let us consider two wattmeter connected to measure power in 3 phase circuits as shown bellow.



Two wattmeter method (Y connection)



Two wattmeter method. (Delta connection)

STAR (WYE) Connections :-

In this Connections

Instantaneous reading of W1 wattmeter $W_1 = i_A (V_A - V_C)$

Instantaneous reading of W2 wattmeter $W_2 = i_B (V_B - V_C)$

Sum of two readings $= W_1 + W_2 = i_A(V_A - V_C) + i_B(V_B - V_C)$

$$= V_A i_A + V_B i_B - V_C (i_A + i_B)$$

From fig ①

Applying Kirchoff's law

$$i_A + i_B + i_C = 0 \text{ (or) } i_C = -(i_A + i_B)$$

$$\therefore \boxed{W_1 + W_2 = V_A i_A + V_B i_B + V_C i_C}$$

Therefore the sum of the two wattmeter reading is equal the power consumed by the load. this is irrespective of load whether it is balanced or unbalanced.

DELTA CONNECTION:-

Instantaneous reading of W1 wattmeter $W_1 = -V_C (i_A - i_C)$

Instantaneous reading of W2 wattmeter $= W_2 = V_B (i_B - i_A)$

Sum of two readings $W_1+W_2 = -V_C(I_A+I_C)+V_B(I_B-I_A)$

$= V_B I_B + V_C I_C - I_A(V_B+V_C)$

From fig 3

Applying Kirchoff's Voltage law

$V_A+V_B+V_C=0$

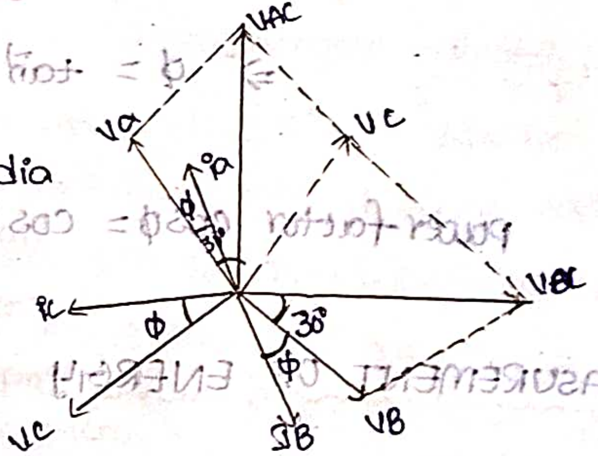
$V_A = -(V_B+V_C)$

$$\boxed{\therefore (W_1+W_2) = V_A I_A + V_B I_B + V_C I_C}$$

There fore the sum of the two wattmeter readings is Equal to the power consumed by the load. This is irrespective of load whether it is balanced or un-balanced.

FOR BALANCED LOAD:-

The figure shows the phasor diagram for a balanced star connected load.



Let VA, VB, VC be the rms values of phase voltage and IA, IB, IC the rms values of current

The load is balanced therefore phase voltages $V_A=V_B=V_C=\frac{V_L}{\sqrt{3}}$

Line voltage $V_{AC}=V_{BC}=V_{AB}=V_L$

Line Currents $I_A=I_B=I_C=I$ = phase currents.

power factor $=\cos\phi$.

The Current through wattmeter W_1 is I_A and Voltage across its pressure coil is V_{AC}. it leads V_{AC} by an angle $(30°-\phi)$

Reading of W_1 wattmeter $W_1 = V_{AC} I_A \cos(30°-\phi) = V_L I_L \cos(30-\phi)$

The current through wattmeter W_2 is I_B and voltage across presure Coil is V_{BC} it leads V_{BC} by an angle $(30°+\phi)$:

Total power Consumed by loads $= W = W_1 + W_2$

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

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

Diff b/w wattmeter readings

$$W_1 - W_2 = V_L I_L \cos(30-\phi) - V_L I_L \cos(30+\phi)$$

$$= V_L I_L \sin\phi$$

$$\frac{W_1 - W_2}{W_1 + W_2} = \frac{V_L I_L \sin\phi}{\sqrt{3} V_L I_L \cos\phi}$$

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

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

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

MEASUREMENT OF ENERGY

Introduction:-

The energy is defined as the power delivered over a time interval.

Energy = power X Time

The electrical energy is defined as the workdone over a time interval t and mathematically expressed as.

$$E = \int_0^t (\text{power})\, dt = \int_0^t vi\, dt.$$

The energy is measured as joules (J) (or) Watt-Sec (or), watt hour (or) kilo watt-hour (kwh)

3rd/ SINGLE PHASE INDUCTION TYPE ENERGY METER:-

most commonly used energy meters are induction type instruments. Energy meter is an integrating instrument which measure quantity of electricity. These meters record the energy in kilowatt-hours (kWh).

* The working principle of induction type Em is induction is on the production of Eddy currents in the moving system by the alternating fluxes. The interaction of produced eddy currents in the moving system produces a driving torque, due to this rotate to record the energy. This Energy meter there is no controlling torque. due to this the disc is continiously rotates.

Construction:-

There are four main parts

1. Driving system
2. moving system
3. Braking system
4. Registering system.

1. Driving System:-

The driving system consists of two electromagnets. This electromagnets core is made up of silicon steel laminations.

The one electromagnets is series coil called current coil, is exicted by load current.

The another electromagnet is connected across the supply and it carries current proportional to supply voltage. This is called pressure coil.

These coil called series and shunt magnets respectively.

moving system:-

Light aluminium disc mounted in a light alloy shaft is the main part of moving system. This positioned in b/w series and shunt magnets. It supported b/w jewel bearings and runs o hardened steel pivot. there there is no springs and controlli ng torque.

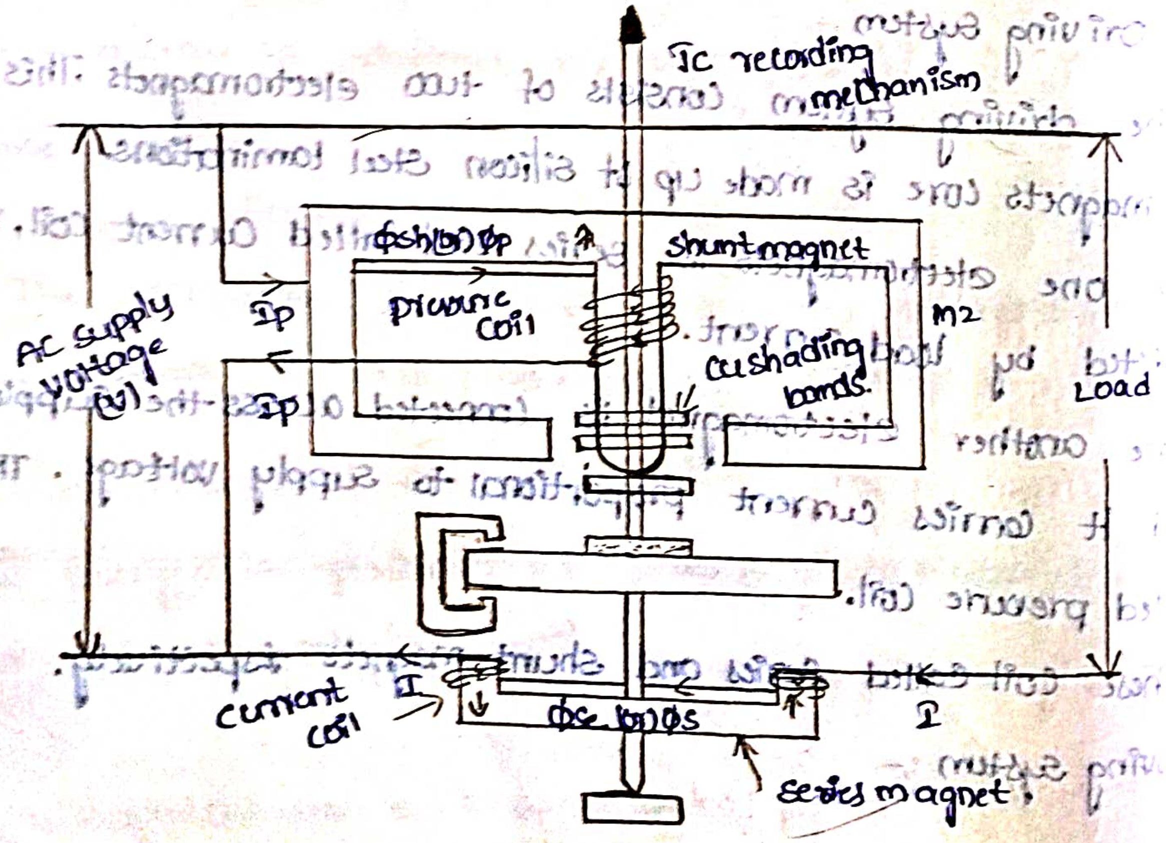
3. Braking system:-

A permenent magnet is placed near the aluminium disc for braking mechanisum. It produces own fields, when disc moves in this field the braking torque is obtained. The position of magnet is adjustable for different radial positions. So this magnet is called braking magnet.

4. Registering mechanism:-

It records continuously a number which is proportional to the revolutions made by the aluminium disc. For suitable system gears and pointers. These pointers are rotate on round dials which are equally marked with equal divisions.

In generally pointer type registering mechanism is used. These are all shown in bellow figure.



Operation :-

The shunt magnet m_2 which is connected across the supply, it carries current proportional to the voltage. Series magnet m_1 carries current coil which carries the load current. Both these coils produce alternating fluxes ϕ_{sh} and ϕ_{se} respectively. These fluxes are propotional is currents in their coils. These fluxes link with the disc and induces emf in it.

Due to these emfs eddy currents are induced in the disc. Due to the eddy currents in one coil to flux in another coil. Thus the portion of the disc experiences a mechanical force and due to motor action disc rotates the speed of the disc is controlled by the c, shapped magnet calling braking magnets

Torque Equation :-

Let V = supply voltage

I = Load current

= current coil current

I_p = pressure coil current

Δ = phase angle b/w V and I_p

$\Delta \simeq 90^\circ$

E_{ep} = Eddy emf induced due to ϕ_p

E_{es} = Eddy emf induced due to ϕ_s

α = phase angle of eddy currents.

I_{ep} = Eddy current due to E_{ep}

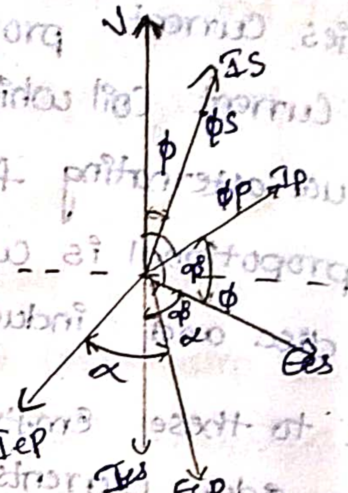
I_{es} = Eddy current due to E_{es}

Here the current I_p lags V by Δ and Δ is made 90° using the copper shading bands, the currents I lags by ϕ which depends on the loads. the flux ϕ_{sh} and I are inphase. the E_{ep} lags ϕ_p and E_{es} lags ϕ_s by 90° respectively. The Eddy current I_{es} and I_{ep} lags and E_{ep} respectively by the angle α.

The interaction b/w ϕ_p and I_{es} produces torque T_1.

And the interaction b/w ϕ_s and I_{ep} produles torque T_2.

Phasor diagram for 1-φ Induction type energy meter.



$$T_1 \propto \phi_p I_{es} \cos(\phi_p \hat{} I_{es})$$

$$T_2 \propto \phi_s I_{ep} \cos(\phi_s \hat{} I_{ep})$$

From phasor diagram $\phi_p \hat{} I_{es} = \alpha + \phi$

$$\phi_s \hat{} I_{ep} = 180 - \phi + \alpha$$

∴ Deflecting torque $T_d \propto T_1 - T_2$ [∵ By Δ made to 90°]

$$T_d \propto \{ [\phi_p I_{es} \cos(\alpha+\phi)] - \phi_s I_{ep} \cos[(180-\phi+\alpha)] \}$$

Now $\phi_p \propto V$ $\phi_s \propto I$ $I_{es} \propto \phi_s \propto I$ $I_{ep} \propto \phi_p \propto V$

$$T_d \propto VI [\cos(\alpha+\phi) - \cos(180-\phi+\alpha)]$$

$$\propto VI [(\cos\alpha\cos\phi - \sin\alpha\sin\phi) - (\cos(180-\phi)\cos\alpha - \sin(180-\phi)\sin\alpha)]$$

$$\propto VI [\cos\alpha\cos\phi - \cancel{\sin\alpha\sin\phi} + \cos\alpha\cos\phi + \cancel{\sin\alpha\sin\phi}]$$

$\cos\alpha\cos\phi$

$$T_d \propto VI \cos\alpha \cos\phi$$

$$T_d = K_1 VI \cos\phi \quad [∵ \cos\alpha \text{ is constant}]$$

Thus the deflecting torque is proportional to the true power in the circuit.

The braking torque is due to eddy currents induced in the alluminum disc, the magnetude of the currents is proportional to the speed N of the disc, Here the braking torque T_b is also proportional to this speed N.

$$T_b \propto N \quad \text{i.e} \quad T_b = K_2 N$$

For Study Speed of rotation $T_d = T_b$.

$K_1 V I \cos\phi = K_2 N$

$N = K\, V I \cos\phi = K\,[\text{power}]$

The total No. of revolution $= \int_0^t N dt = \int_0^t K\,(\text{power})dt$

Total No. of revolution $= K \int_0^t P dt = K$ energy.

Thus, the no. of revolutions of the disc in a given time is the energy consumption by the circuit in that time.

$K = \text{meter constant} = \frac{N'}{\text{energy}} = \frac{\text{No. of revolutions}}{\text{kwh}}$

Thus the no. of revolutions of the disc per kwh of Energy consumption is called meter constant.

Advantages of Induction type energy meter :-

1. It's construction is simple and strong
2. It is cheap in cost.
3. It has high torque to weight ratio, so frictional Error are less and we can get accurate reading.
4. It has more accuracy.
5. It requires less maintanance.
6. It's range can be extended with the help of instrumen transformer's

Disadvantages :-

1. It can be used only for a.c circuits.
2. The creeping can cause Errors.
3. Lack of symmetry in magnetic circuit may cause Errors.

Errors and their Compensations in 1-ϕ Energy meter:-

1. Phase Error:-

It is necessary that the energy meter should give correct reading on all power factors, which is only possible when the field set up by shunt magnet lags behind the applied voltage by 90°. But the flux due to shunt magnet does not lag behind the applied voltage exactly by 90° because ~~of~~ of winding resistance and iron losses.

Compensation:-

The flux in the shunt magnet can be made to lag behind the supply voltage by exactly 90° by adjusting the position of shading band placed round the lower end of the shunt magnet.

This adjustment is known as lag compensation or power factor compensation.

2. Speed Error:-

Some-times the speed of the meter is either fast or slow, resulting in the wrong recording of energy consumption.

Compensation:-

An error in the speed of the meter when tested on non-inductive load can be eliminated by correctly adjusting the position of the brake magnet. Movement of the brake magnet in the direction of the spindle will reduce the braking torque and vive-versa.

3. Friction Compensation (or) Friction Error:-

Frictional forces at the rotor bearings in the counting (or register) mechanism cause noticable error especially at high load. At light loads, the torque due to friction adds considerably to the braking torque ~~Can be~~ on the disc rotor sinc friction torque is not proportional to the speed but is roughly constant it can cause considerable error in meter reading.

Compensation:-

This Error Can be reduced to an unimportant Level by making the ratio of the shunt magnet flux ϕ_2 and series magnet flux ϕ_1 Large with the help of two Sharding bands. These bands Embrace the flux Contained in the two outer limbs of the shunt magnet and thus Eddy Currents are induced in them which cause a phase displacement b/w the enclosed flux of the main gap flux. As a result, a small driving torque is exerted on the disc rotor, this torque being adjusted by variation of the positions of these bands to Compensate for friction in the instrument. Correctness of friction Compensation is achieved by running the meter at high load of about 8 to 10% of full load when the disc should rotate Correctly. Over Compensation Loads to creep. This Compensation is known as Light load Compensation.

4. Creeping:-

Sometimes the disc of the energy meter make slow but Co nuous rotation at no load i.e., when the potential Coil is Excit but with no current flowing in the load. This is Called Creeping. This error may be caused due to over Compensation fi friction, excessive supply voltage, vibrations, stray magnetic fields etc.

Compensation:-

In order to prevent this creeping on no Load two holes or slots are drilled in the disc on opposite sides a the spindle. This causes sufficient distaction of the field. The result is that the disc tends to remain stationary when one of the holes comes under one of the shunt magnet.

5. Temperature Errors:-

The error due to variation in temperature are very small, because the various effects produce tend to neutralise one another.

The resistance of the disc of the potential coil and characteristics of magnetic circuit of the strength of break magnet are affected by the changes in temperature. Therefore great care is exercised in the design of the meter to eliminate the errors due to temperature variations.

Frequency variations:-

The meter is designed to give minimum error at a particular frequency (gen 50Hz) if the supply frequency changes, the reactance of the coils also changes, resulting in small error

Voltage Variations:-

The error due to variation voltage is very small [usually 0.8% to 0.3%] This can be eliminated by the proper design of the magnetic circuit of the shunt magnet.

Three phase Energy meter:-

→ In a three phase, four wire system, the measurement of energy is to be carried out by a three phase energy meter.

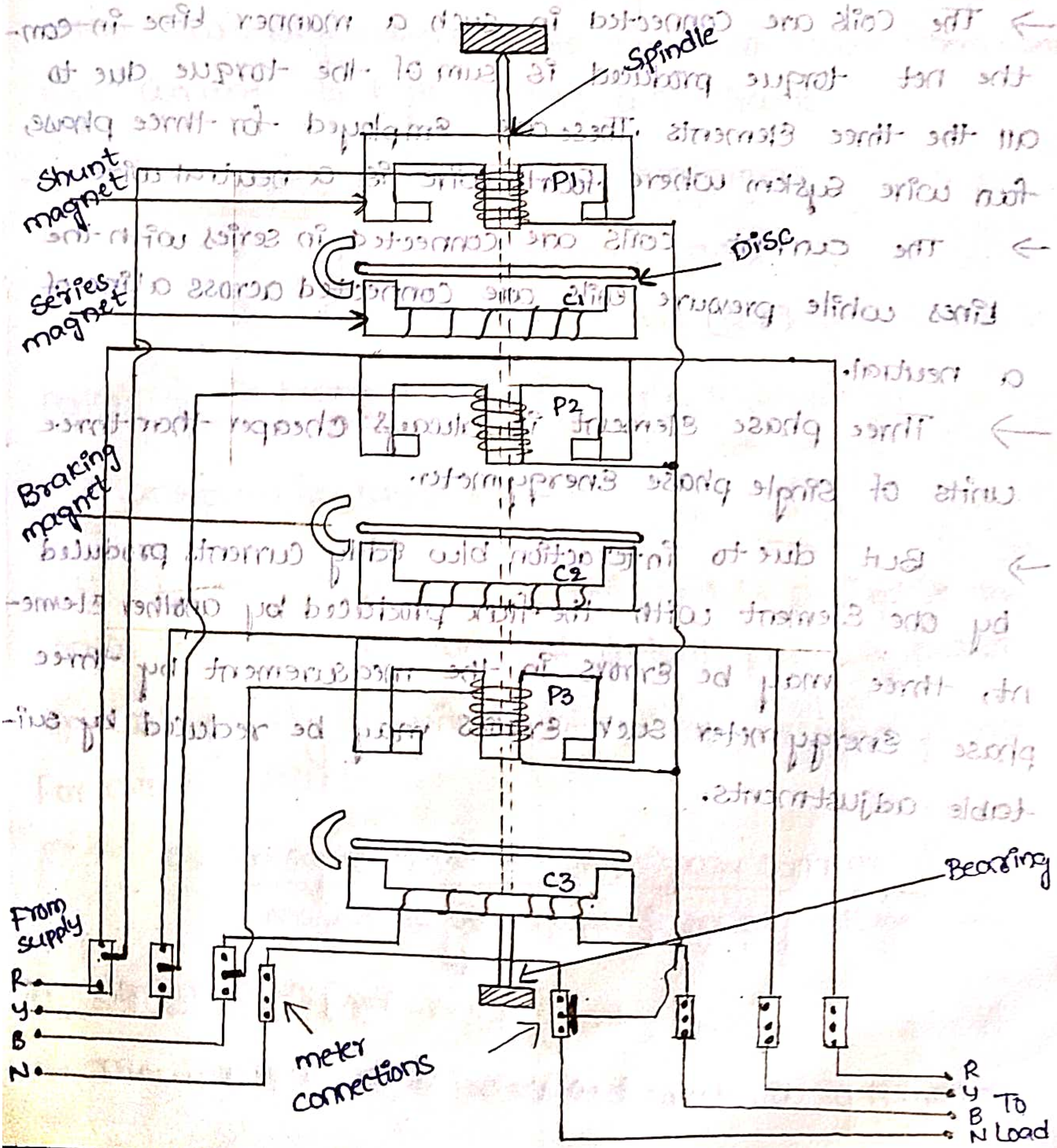
→ For a three phase, three wire system, the energy measure-can be carried out by two Element Energy meter, the connections of which are similar to the connections of two watt-meter for power measurement in the three phase, three wire system.

→ These meter are classified as

(i) three Element Energymeter.

(ii) two Element energymeter.

Three Element Energymeter:-



→ This meter consists of three elements. The construction of an individual element is similar to that of a single phase energymeter.

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

→ All the elements are mounted in a vertical line in common case and have a common spindle, gearing and registering mechanism.

→ The coils are connected in such a manner ~~line in com~~ the net torque produced is sum of the torque due to all the three elements. These are employed for three phase, four wire system where fourth wire is a neutral wire.

→ The current coils are connected in series with the lines while presure coils are connected across a line of a neutral.

→ Three phase element is always cheaper than three units of single phase energymeter.

→ But due to interaction b/w eddy currents produced by one element with the flux produced by another elem

nt, three may be errors in the measurem

phase energymeter such errors

table adjustments.

UNIT-3

Instrument Transformer

Introduction :-

→ For measurement of high current and high voltage's instrument Transformers are used.

→ They can be used for irrespective of the voltage and current ratings of the a.c circuits.

→ These Transformers not only extend the range of the low range instruments but also isolate them from high current to high voltage a.c circuits.

→ Two types of instruments Transformers

1. current transformers (C.T).
2. potential transformers (P.T)

Ratio's of instrument transformers :-

1. Transformation Ratio [R] :-

It is also called as Actual ratio and is defined as the ratio of the magnitude of actual primary phasor to the corresponding magnitude of actual secondary phasor.

For C.T

$$R = \frac{\text{magnitude of actual primary current}}{\text{magnitude of actual secondary voltage}}$$

2. Nominal Ratio [kn] :-

- The nominal ratio is defined as the ratio of rated

primary quantity to the rated secondary quant
Either current or voltage for I.T.

For C.T

$$k_n = \frac{\text{Rated primary current}}{\text{Rated secondary current}}$$

For P.T

$$k_n = \frac{\text{Rated primary current}}{\text{Rated secondary current}}$$

3. Turns Ratio[n]:-

For C.T

$$n = \frac{\text{No. of turns of secondary winding}}{\text{No. of turns of primary winding}}$$

For P.T

$$n = \frac{\text{No. of turns of primary winding}}{\text{No. of turns of secondary winding}}$$

4. Ratio Correction Factor [RCF]:-

It is the ratio of transformation to ratio of nom

$$\boxed{RCF = \frac{R}{k_n}}$$

5. Burden of an Instrument Transformer:-

Total secondary winding Burden = [secondary wind currents]^2 × [Total impedance of secondary circuit incl load and winding]

It is convenient to express load across th secondary winding terminals as the output in vo ampere at the rated secondary winding voltage.

Current Transformers:-

The current transformers consists of primary windings and secondary windings. In this the primary winding consists of few no. of turn's and secondary windings consists of lardge no. of turns. This is shown in figure and its equavaent circuit is shown in figure.

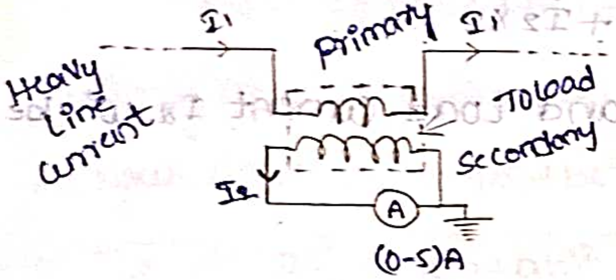


Fig:-1 Current transformer

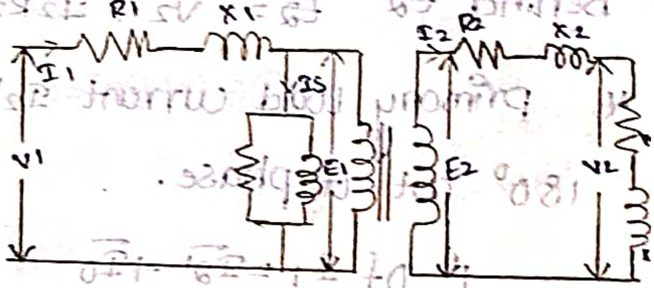


Fig:-2 Equivalent circuit of current transformer

Terms belongs to current transformer:-

V_1 = Supply voltage (or) transformer primary winding applyed voltage.

R_1 = Resistance of primary winding.

X_1 = Reactance of primary winding.

E_1 = Primary induced voltage

N_1 = No. of turns in primary winding.

V_2, R_2, X_2, E_2, N_2 are the corresponding values of secondary

I_μ = magnetising component of exciting current

I_w = working (or) loss component of exciting current.

α = Angle b/w exciting current I_0 and working flux ϕ.

δ = Angle b/w secondary induced voltage and secondary current

Δ = Angle b/w secondary terminal " " "

θ = phase Angle of transformer is angle b/w " "

The turns ratio of current transformer $K = \frac{\text{No. of secondary winding turns}}{\text{No. of primary winding turns}}$

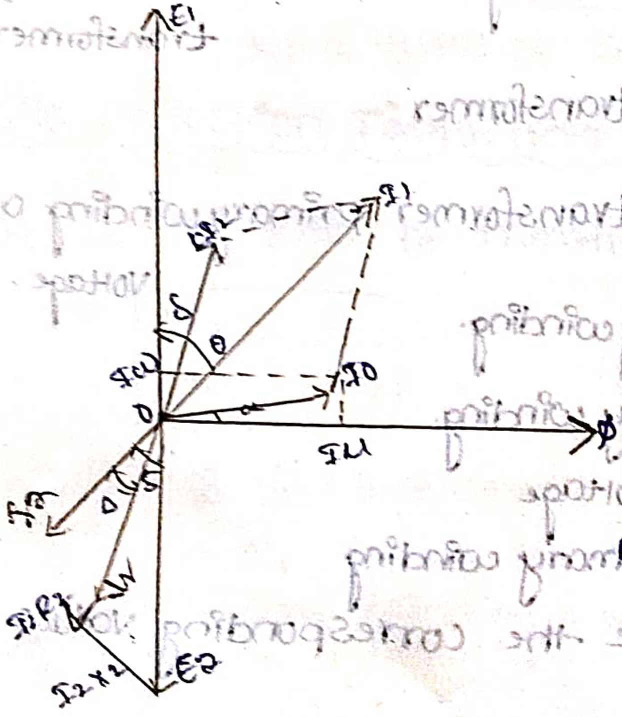
Consider the phasor diagram for current transformers for inductive loads is shown in figure.

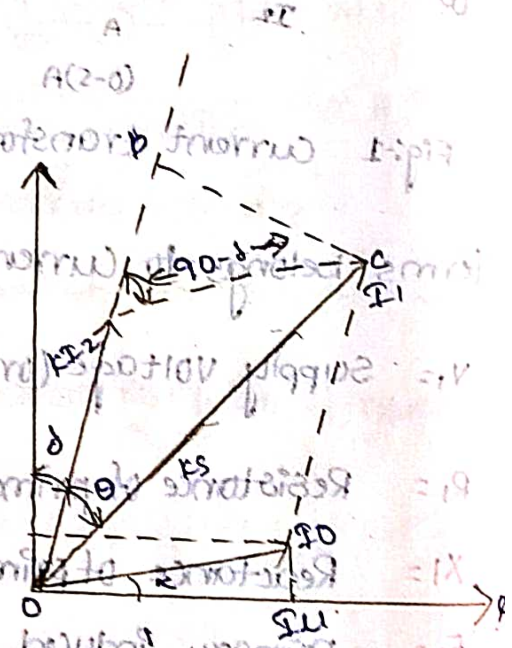
* ϕ is common for both 1° and 2° it is taken as reference

* Due to secondary voltage drop $[I_2(R_2+jX_2)]$ V_2 lags behind E_2 $\bar{E_2} = V_2 + \bar{I_2}\bar{R_2} + \bar{I_2}X_2$

* primary load current I_2' and load current I_2 will be 180° out of phase.

1^0 of $I_1 = \bar{I_2}' + \bar{I_0}$





A section of phasor diagram of a C.T.

phasor diagram of a current transformer

Transformation Ratio (R):-

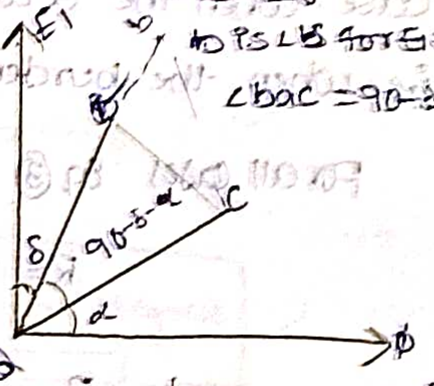
Consider a small section of the phasor diagram as shown in fig4; we have

$\angle bac = 90 - \delta - \alpha$

$ac = I_0$

$oa = kI_2$

$oc = I_1$



Here

$ac = I_0$

I_0 is ∠B for E1 so

$\angle bac = 90 - \delta - \alpha$

For right angle triangle abc

$$\sin(90-\delta-\alpha) = \frac{bc}{ac}$$

$$\Rightarrow bc = I_0 \sin(90-\delta-\alpha) \quad [\because ac = I_0]$$

$$= I_0 \sin[90 - (\delta+\alpha)]$$

$$bc = I_0 \cos(\delta+\alpha) \rightarrow ①$$

$\sin(90-\theta) = \cos\theta$

$\cos(90-\theta) = \sin\theta$

$\sin = \text{Opp} / \text{Hyp}$

$\cos\theta = \text{Adj} / \text{Hyp}$

$\tan\theta = \text{Opp} / \text{Adj}$

Similarly $ab = I_0 \cos(90-\delta-\alpha) = I_0 \sin(\delta+\alpha) \rightarrow ②$

Now Δabc, $oc^2 = ob^2 + bc^2$

$$oc^2 = (oa+ab)^2 + bc^2$$

$$I_1^2 = \left(I_0 \sin(\delta+\alpha) + kI_2\right)^2 + I_0^2 \cos^2(\delta+\alpha)$$

$$= I_0^2 \sin^2(\delta+\alpha) + k^2 I_2^2 + 2kI_2 I_0 \sin(\delta+\alpha) + I_0^2 \cos^2(\delta+\alpha)$$

$$= I_0^2 \left[\sin^2(\delta+\alpha) + \cos^2(\delta+\alpha)\right] + k^2 I_2^2 + 2kI_2 I_0 \sin(\delta+\alpha)$$

$$I_1^2 = I_0^2 + k^2 I_2^2 + 2kI_2 I_0 \sin(\delta+\alpha) \quad [\because \sin^2\theta + \cos^2\theta = 1]$$

Now in a well designed current transformer $I_0 < kI_2$ so I_0^2 is small. So simply replace I_0^2 by $I_0^2 \sin^2(\delta+\alpha)$ for our simplicity.

$$I_1^2 = I_0^2 \sin^2(\delta+\alpha) + k^2 I_2^2 + 2I_0 kI_2 \sin(\delta+\alpha)$$

$$\Rightarrow I_1^2 = \left(I_0 \sin(\delta+\alpha) + kI_2\right)^2$$

$$\Rightarrow \boxed{I_1 = kI_2 + I_0 \sin(\delta+\alpha)}$$

The transformation ratio of current transformer is given as

$$R = \frac{I_1}{I_2} = \frac{kI_2 + I_0 \sin(\delta+\alpha)}{I_2}$$

$$= k + \frac{I_0}{I_2} \sin(\delta+\alpha) \rightarrow ③$$

Although only approximate Eq 3 is sufficiently accurate for pratically all purpose. The above theory is applicable to case when the secondary burden has a lagging powerfactor i.e, when the burden is inductive which is normally the case.

For all cases Eq ③ further Expanded as

$\sin(a+b) = \sin a\cos b + \cos a \sin b$

$$R = K + \frac{I_0}{I_2}\left[\sin\delta\cos\alpha + \cos\delta\sin\alpha\right]$$

$$\boxed{R = K + \frac{I_\mu \sin\delta + I_w\cos\delta}{I_2}}$$

Here $I_\mu = I_0\cos\alpha$

$I_w = I_0\sin\alpha$

Phase angle (θ):-

The phase angle θ is also called as phase angle of transformer and it is defined as the angle b/w primary current and reversed secondary currents.

This angle is generally taken as +ve for the reversed secondary current leads the primary current -ve for the reversed secondary current lags the primary current.

Here the angle b/w reversed I_2 and I_1 is θ. so phase angle of the transformer is θ.

From phasor diagram $\tan\theta = \frac{bc}{ob} = \frac{bc}{oa+ob} = \frac{I_0\cos(\delta+\alpha)}{KI_2 + I_0\sin(\delta+\alpha)}$

$\boxed{\text{As } \theta \text{ is very small, } \tan\theta \simeq \theta}$

$$\theta = \frac{I_0\cos(\delta+\alpha)}{KI_2 + I_0\sin(\delta+\alpha)}$$

Now I_0 is very small when compared to KI_2 so $I_0\sin(\delta+\alpha)$ is neglected.

Ratio error

$\frac{\text{nominal ratio} - \text{Actual ratio}}{\text{actual ratio}} \times 100$

$R = K_t + \frac{I_w}{I_s}$

$\% = \frac{K_n - R}{R} \times 100$

phase angle error

$\theta = \frac{180}{\pi}\left[\frac{I_m \cos\delta - I_w \sin\delta}{K I_s}\right]$ degrees

$$\therefore \theta = \frac{I_0}{K I_2}(\cos(\delta + \alpha))$$

$$= \frac{I_0 \cos\delta \cos\alpha - I_0 \sin\delta \sin\alpha}{K I_2}$$

$$\theta = \frac{I_\mu \cos\delta - I_w \sin\delta}{K I_2} \text{ radians}$$

$$\boxed{\theta = \frac{180}{\pi}\frac{(I_\mu \cos\delta - I_w \sin\delta)}{K I_2} \text{ degrees}}$$

$\cos(a+b) = \cos a \cos b - \sin a \sin b$

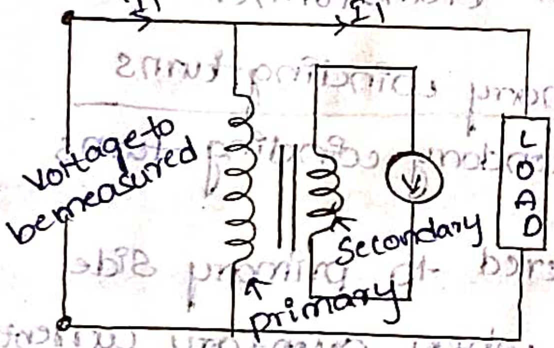
$I_0 \cos\alpha = I_\mu$

$I_0 \sin\alpha = I_w$

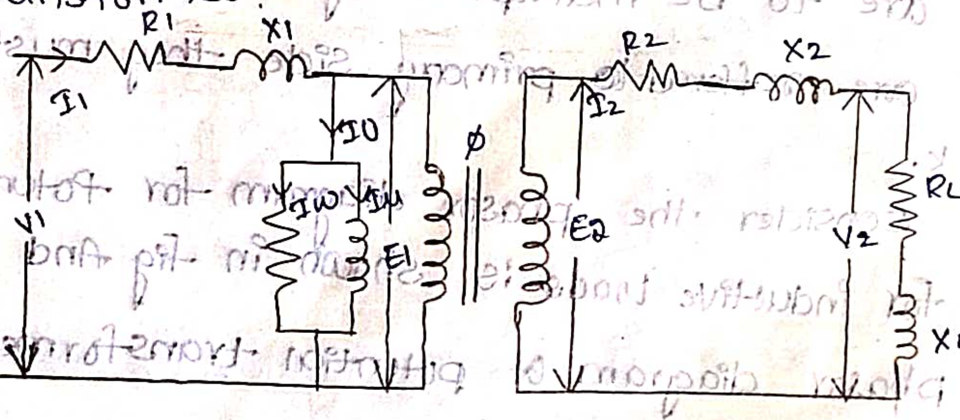
$1 \text{ radian} = \frac{180}{\pi}$ degrees

2nd Potential Transformers:

The current transformer consists of primary windings and secondary windings. In similarly potential transformers are also consist primary and secondary windings. In the potential transformer primary winding consist large no. of turns. And secondary winding consist of new no. of turns. The potential transformer is shown in fig and it is equivalent circuit is shown in fig.



Potential transformer:



Equivalent circuit of potential transformer

Terms belongs to potential transformer :-

V_1 = primary voltage or supply voltage.

R_1 = Resistance of primary winding

X_1 = Reactance " "

E_1 = primary induced voltage

N_1 = No. of turns in primary windings

V_2, R_2, X_2 & N_2 are corresponding values of secondary

I_0 = exciting current

I_μ = magnetising component of exciting current

I_w = working (or) loss component of exciting current

α = Angle b/w exciting current I_0 and working flux ϕ

Δ = Angle b/w secondary terminal voltage and secondary current

β = Angle b/w I_1 and reversed V_2

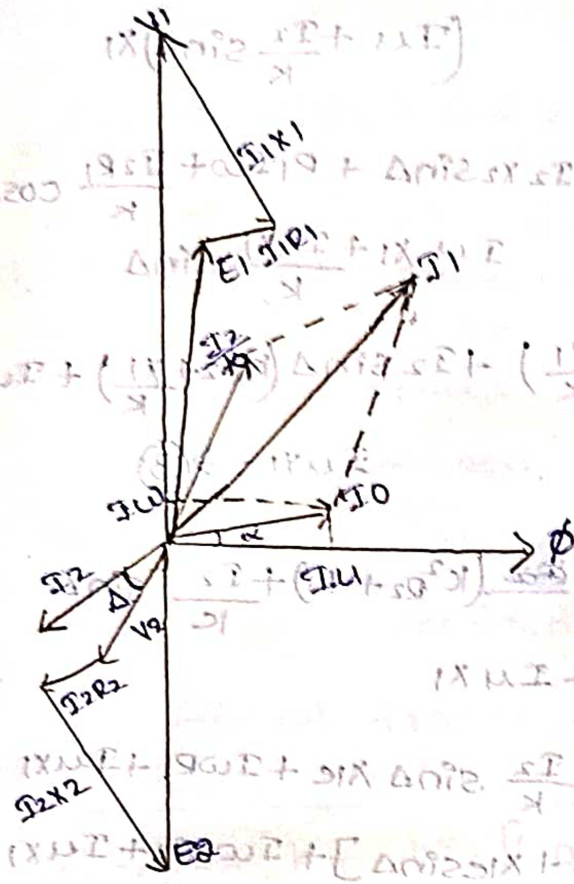
θ = phase angle of transformer i.e Angle b/w primary and reversed secondary voltage.

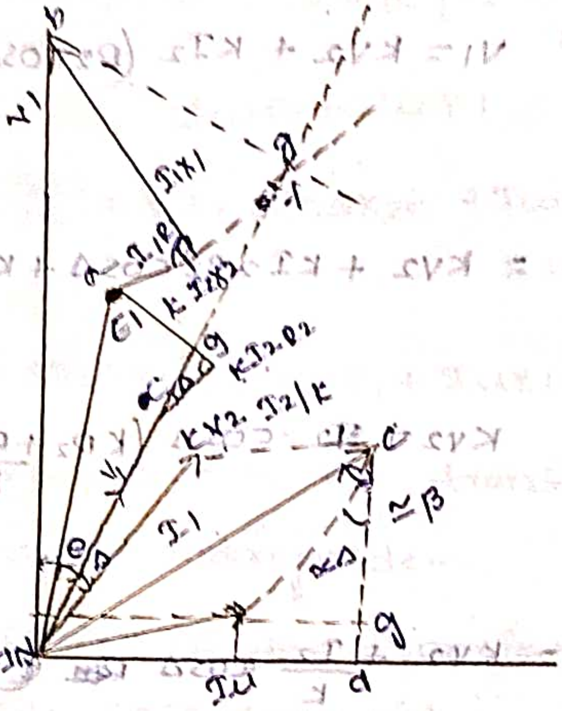
The turns ratio of potential transformer

$$K = \frac{\text{no. of primary winding turns}}{\text{No. of secondary winding turns}}$$

Secondary voltage when refered to primary side are to be multiplied by k. when secondary currents are reffered to primary side they must be divided by k.

Consider the phasor diagram for potential transformer for inductive loads is shown in fig And enlarged consise phasor diagram of potential transformer is shown in figure.





Enlarged concise phasor diagram of PT

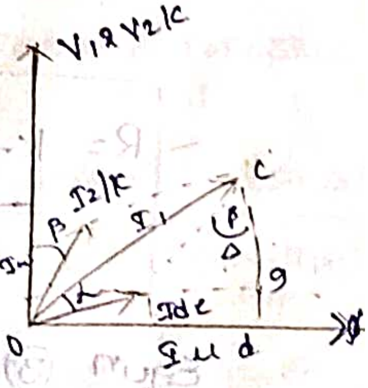
phasor diagram for PT

From Fig $\cos\theta = \frac{oa}{ob} \Rightarrow oa = V_1\cos\theta \rightarrow$ ①

From Fig oa can be written as

$$oa = KV_2 + KI_2R_2\cos\Delta + KI_2X_2\sin\Delta + I_1R_1\cos\beta + I_1X_1\sin\beta \rightarrow ②$$

Phase angle is very small i.e $\theta<1$ $\cos\theta=1$ and there-for both V_1 and reversed V_2 can be taken perpendicular to ϕ and it is shown in fig



From fig $\angle oca \simeq \beta$, $\angle ocg \simeq \Delta$

From this $I_1\cos\beta = cg + gd$

$I_1\cos\beta = \frac{I_2}{K}\cos\Delta + I_{\omega}$

Δecg $I_1\sin\beta = I_\mu + \frac{I_2}{K}\sin\Delta$

Substituting the above values in Eq ② we get

$$V_1 = KV_2 + KI_2(R_2\cos\Delta + V_2\sin\Delta) + R_1\left(I_\omega + \frac{I_2}{K}\cos\Delta\right) + \left(I_\mu + \frac{I_2}{K}\sin\Delta\right)X_1$$

$$= KV_2 + KI_2R_2\cos\Delta + KI_2X_2\sin\Delta + R_1I_\omega + \frac{I_2R_1}{K}\cos\Delta + I_\mu X_1 + \frac{I_2X_1}{K}\sin\Delta$$

$$= KV_2 + I_2\cos\Delta\left(KR_2 + \frac{R_1}{K}\right) + I_2\sin\Delta\left(KX_2 + \frac{X_1}{K}\right) + I_\omega R_1 + I_\mu X_1 \rightarrow ③$$

$$= KV_2 + \frac{I_2}{K}\cos\Delta\ \cancel{R_{ee}}\ \cancel{R_2}(K^2R_2 + R_1) + \frac{I_2}{K}\sin\Delta(K^2X_2 + X_1) + I_\omega R_1 + I_\mu X_1$$

$$\therefore V_1 = KV_2 + \frac{I_2}{K}\cos\Delta\, R_{1e} + \frac{I_2}{K}\sin\Delta\, X_{1e} + I_\omega R_1 + I_\mu X_1$$

$$V_1 = KV_2 + \frac{I_2}{K}\left[R_{1e}\cos\Delta + X_{1e}\sin\Delta\right] + I_\omega R_1 + I_\mu X_1$$

Here R_{1e} = Equivalent resistance of the transformer referred to the primary side.

X_{1e} = Equivalent reactance of the transformer referred to the primary side.

∴ Actual transformation ratio, $R = \frac{V_P}{V_S} = \frac{V_1}{V_2}$

$$\therefore R = KV_2 + \frac{I_2}{K}\left[R_{1e}\cos\Delta + X_{1e}\sin\Delta\right] + I_\omega R_1 + I_\mu R_1$$

$$\boxed{R = \frac{K + \frac{I_2}{K}\left[R_{1e}\cos\Delta + X_{1e}\sin\Delta\right] + I_\omega R_1 + I_\mu X_1}{V_2}}$$

Equn ③ also be written as

$$V_1 = KV_2 + I_2 \cos\Delta\, K \left[R_2 + \frac{R_1}{K^2}\right] + I_2 \sin\Delta\, K \left[X_2 + \frac{X_1}{K^2}\right] + I_w R_1 + I_\mu X_1$$

$$= \left[KV_2 + KI_2 \cos\Delta R_{2e} + KI_2 \sin\Delta X_{2e} + I_w R_1 + I_\mu X_1\right.$$

$$V_1 = KV_2 + KI_2 \left[\cos\Delta R_{2e} + \sin\Delta X_{2e}\right] + I_w R_1 + I_\mu X_1$$

Here R_{2e} = Equavalent resistance of the transformer refered to secondary side.

X_{2e} = Equavalent reactance of the transformer refered to secondary side.

∴ Actual transformation ratio $R = \frac{V_1}{V_2}$

$$\boxed{\therefore R = K + \frac{KI_2\left[(\cos\Delta) \times R_{2e} + X_{2e} \sin\Delta\right] + I_w R_1 + I_\mu X_1}{V_2}}$$

Phase angle (θ):-

The phase angle θ is also called as phase angle of transformer and it is defined as the angle b/w primary voltage and reversed secondary voltage.

From phasor diagram $\tan\theta = \frac{ab}{oa}$

$$ab = I_1 X_1 \cos\beta - I_1 R_1 \sin\beta + KI_2 X_2 \cos\Delta - KI_2 R_2 \sin\Delta$$

$$\tan\theta = \frac{I_1 X_1 \cos\beta - I_1 R_1 \sin\beta + KI_2 X_2 \cos\Delta - KI_2 R_2 \sin\Delta}{KV_2 + KI_2 R_2 \cos\Delta + KI_2 X_2 \sin\Delta + I_1 R_1 \cos\beta + I_1 X_1 \sin\beta}$$

The terms in denominator involving I_1 and I_2 are small so they are neglected as compared with KV_2.

$$\tan\theta = \frac{I_1X_1\cos\beta - I_1R_1\sin\beta + kI_2X_2\cos\Delta - kI_2R_2\sin\Delta}{kV_2}$$

$$= \frac{X_1\left[I_\omega + \frac{I_2}{R}\cos\Delta\right] = R_1\left[I_\mu + \frac{I_2}{R}\sin\Delta\right] + kI_2X_2\cos\Delta. \quad kI_2R_2\sin\Delta}{kV_2}$$

$$= \frac{I_2\cos\Delta\left(\frac{X_1}{k} + kX_2\right) - I_2\sin\Delta\left(\frac{R_1}{k} + kR_2\right) + I_\omega X_1 - I_\mu R}{kV_2}$$

$$\tan\theta = \frac{I_2\cos\Delta \cdot \frac{1}{k}\left(X_1 + k^2X_2\right) - I_2\sin\Delta \cdot \frac{1}{R}\left(R_1 + k^2R_2\right) + I_\omega X_1 - I_\mu R_1}{kV_2}$$

$$\tan\theta = \frac{\frac{I_2}{K}\cos\Delta X_{1e} - \frac{I_2}{k}\sin\Delta R_{1e} + I_\omega X_1 - I_\mu R_1}{kV_2}$$

$$\tan\theta = \frac{\frac{I_2}{k}\left[X_{1e}\cos\Delta - R_{1e}\sin\Delta\right] + I_\omega X_1 - I_\mu R_1}{kV_2}$$

For small θ values $\tan\theta = \theta$

$$\boxed{\text{Phase angle } \theta = \frac{\frac{I_2}{K}\left[X_{1e}\cos\Delta - R_{1e}\sin\Delta\right] + I_\omega X_1 - I_{\mu R}}{kV_2}}$$

Similarly we get θ value in resistance and reactance with referred secondary.

$$\boxed{\theta = \frac{I_2}{V_t}(X_{2e}\cos\Delta - R_{2e}\sin\Delta) + \frac{I_w X_1 - I_\mu R_1}{n V_s}}$$ radians

Thes θ values in degrees just multiplied by $\left(\frac{180}{\pi}\right)$.

Power Factor meter:-

The power in single phase A.C Circuit is given by $\boxed{P = VI\cos\phi}$

$\cos\phi$ - power factor of the circuit.

→ By using precise Voltmeter, Ammeter and wattmeter in the circuit, the readings of V, I and P can be obtained then power factor can be calculated as $\boxed{\cos\phi = \frac{P}{VI}}$

→ But this method is, not accurate. The errors in all the meters together cause the error in powerfactor. calculation. The meter which indicates the instrantanuons power factor of the circuit is called power-factor meter.

→ Basic construction of power-factor meter is similar to a wattmeter. It has two circuits.

① The current circuit carries current or fraction of current in the circuit whose power factor is to be measured.

② The voltage circuit in which voltage coil is split into two parallel paths, one inductive and one non-inductive. The currents in the two paths are propotional to the voltage of the circuit.

→ Thus the deflection depends upon the phase difference b/w the main current through current circuit the currents in the two branches of the circuit.

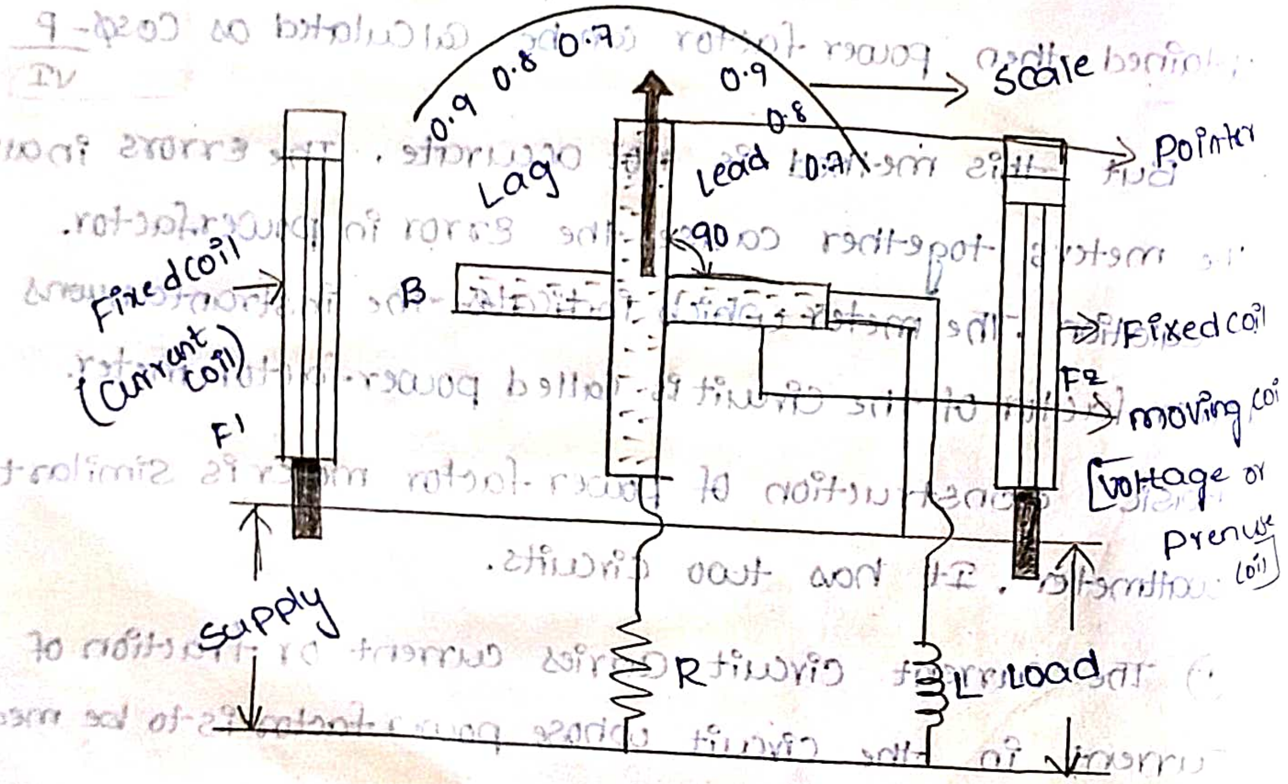
There are two types of power factor meters.

① Electrodynamometers' type

② moving Iron type

Single phase Electrodynamometer type power factor meter:

→ The construction of electrodynamometer type power factor meter is similar to the construction of electrodynamometer type.



→ The F1 - F2 are two fixed coils which are connected in series.

→ The A-B are the two moving coils which are rigidly connected to each other. So that their axes are at 90° to each other. They move together & carry the pointer which indicates the power factor of the circuit.

→ The fixed coils F_1-F_2 carry the main current in the circuit. The fraction of the current is passed through the fixed coils. Thus the magnetic field produced by the fixed coils is proportional to the main current.

→ The moving coils A-B are identical and are connected in parallel across the supply voltage and hence called pressure coil or voltage coil. The currents through the coils A to B are propostional to the supply voltage.

→ The coil A has a non-inductive resistance R in series with it while the coil B has an inductance L in series with it.

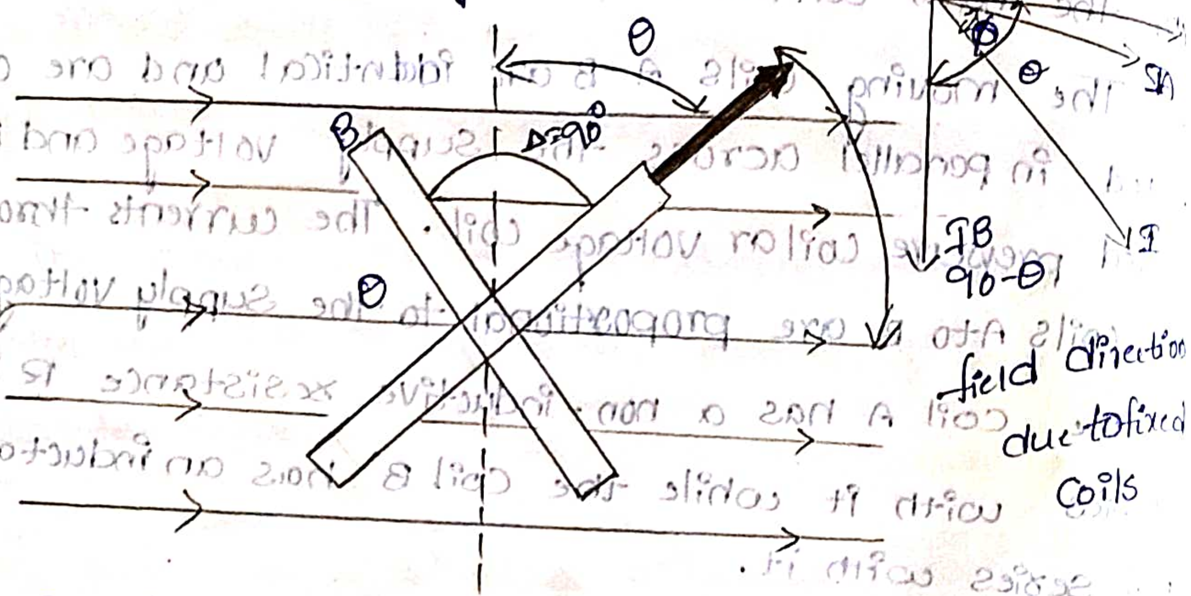
⇒ The values of R and L are so adjusted that the coils A and B carry equal currents at normal frequency so that normal frequency R=ωL

→ The current through coil A is in phase with the supply voltage while the current through coil "B" lags the supply voltage by nearly 90° due to highly inductive nature of the circuit.

→ Due to 'L' current through coil "B" is frequency dependent while current through coil "A" is frequency independent.

→ The current is the coils A and B are equal and produce the magnetic fields ~~and~~ of equal strength, which have phase difference of 90°, b/n them. The coils are also mutually perpendicular to each other.

→ The controlling torque is absent. The contacts to the moving coils are made with the help of extremely fine ligaments which give no controlling effect on the moving coil.



→ Consider the position of the moving system as shown in fig.

→ Assume that the current through coil "B" lags the voltage exactly by 90° and also assume that the field produced by the fixed coils is uniform & in the direction X-X as shown in fig.

→ Due to the interaction of the fields produced by the current through various coils, both coils A & B experience a torque.

→ The windings are arranged in such a manner that the torques experienced by coil A and B are opposite to each other. Hence the pointer attains an equilibrium position when these two torques are equal.

→ The torque on each coil, for a given coil current will be maximum when the coil is parallel to the field produced by $F_1 - F_2$ i.e direction X – X.

→ Let ϕ = power factor angle

θ = Angle of deflection

→ "θ" is measured from the vertical axis in the Equilibrium position. Similar to a dynamometer type wattmeter, torque on coil "A" is given by

$$T_A = KVI \cos\phi \cos(90-\theta) \quad K = \text{constant}.$$

→ The current through coil A is inphase with system voltage "V" and it moves in a magnetic field, which is proportional constant for radial field is not constant for parallel field & is proportional to $\cos(90-\theta)$.

Similarly current in coil "B" lags the supply voltage by 90° & it moves in same field. Hence the torque on B is proportional to $\cos(90-\phi)$ i.e $\sin\phi$ and $\cos\theta$.

$$T_B = KVI \sin\phi \cos\theta$$

In Equilibrium position $T_A = T_B$

$$\cos\phi \cos(90-\theta) = \sin\phi \cos\theta$$

$$\cos\phi \sin\theta = \sin\phi \cos\theta$$

$$\sin\theta = \frac{\sin\phi}{\cos\phi} \cos\theta$$

$$\sin\theta = \tan\phi \cos\theta$$

$$\frac{\sin\theta}{\cos\theta} = \tan\phi$$

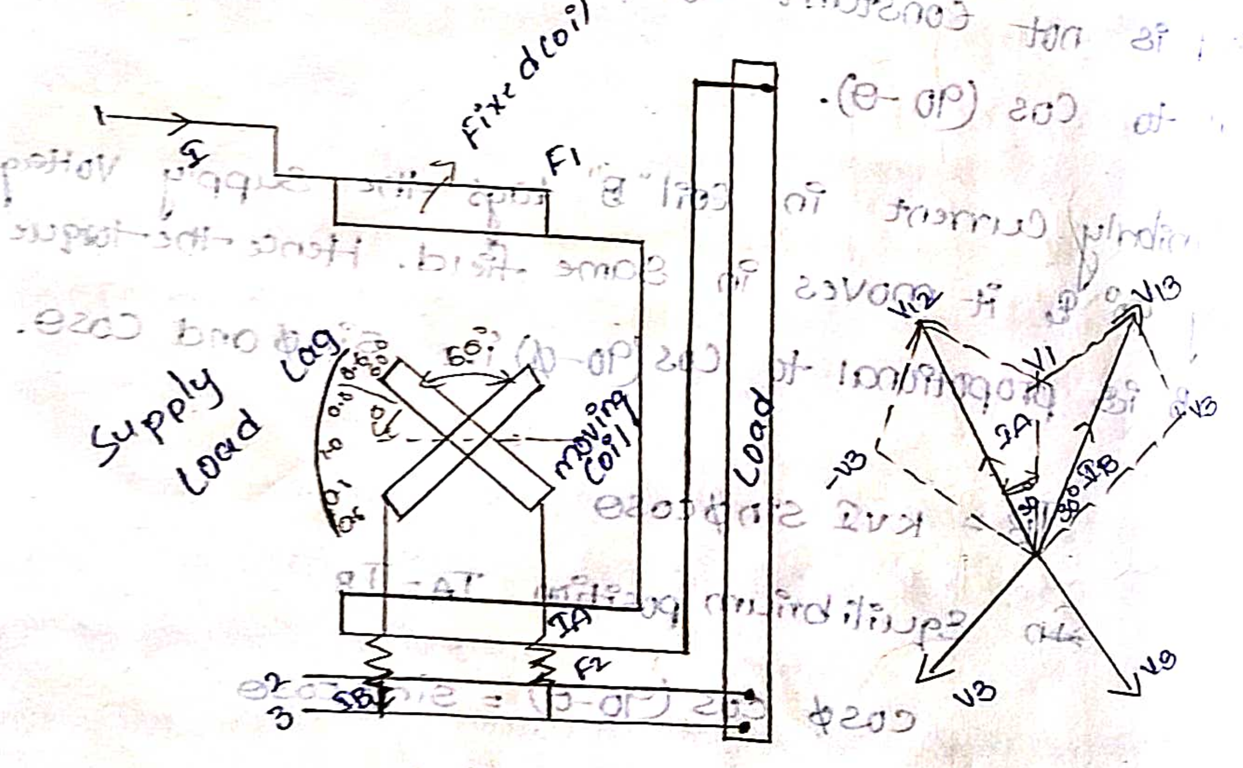
$$\tan\theta = \tan\phi$$

$$\boxed{\theta = \phi}$$

Thus the angular position taken up by the movi coils is equal to the system power factor angl The scale of the instrument can then be calibrated interms of power factor values.

The operation of the instrument is dependent on the specific supply frequency.

Three phase Electrodynamometer power factor meter:-



→ Fig shows the construction and connections of 3 phase Electrodynamometer type power factor met

→ This meter is only useful for balanced loads.

→ The two moving coils are so placed that the angle b/w. their planes is 120°.

→ They are connected across two different phases of the supply circuit.

→ Each coil has a series resistance.

→ There is no necessity for phase splitting by artifical means.

→ Since the required phase displacement b/w current I_A and I_B in the two moving coils be obtained from the supply itself as shown.

Voltage applied across coil A is V_{12} and as the its circuit is resistive, current I_A is in phase with V_{12}.

Voltage applied across coil is V_{13} and current is in phase with V_{13} as the circuit of coil is resistive.

Let ϕ = phase angle of the circuit

θ = Angular deflection from the plane of difference

$$V_1 = V_2 = V_3 = V$$

Torque acting on coil A is:

$$T_A = K_{12}\, I_{max} \cos(30° + \phi) \sin(60° + \theta)$$

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

Torque acting on coil B is

$$T_B = K V_{13} I_{max} \cos(30^\circ - \phi) \sin(120^\circ + \theta)$$

$$= \sqrt{3}\, K V I_{mmax} \cos(30^\circ - \phi) \sin(120^\circ + \theta)$$

Torques TA and TB act in the opposite directions of the moving system takes up on a position where TA = TB

$$\therefore \cos(30^\circ + \phi) \sin(60^\circ + \theta)$$

$$\cos(30^\circ - \phi) \sin(120^\circ + \theta)$$

Solving the above exp, we have $\theta = \phi$

Thus angular deflection is equal to the phase angle of the circuit to which the meter is connected.

The 3-φ power factor gives indications which are indipendent of wave form of freq of supply, since the currents in the two moving coils are equally effected by any change of frequency.

For measurement of power factor in 3phase unbalanced system a two element power factor meter has to be used.

moving Iron power factor meter:-

The advantages of moving iron power factor meter over the dynamometer type are.

1. The working forces in moving iron are layer.
2. All coils in moving iron are fixed so roligaments are required.
3. A scale Extends over 360°

But due to the loss in the iron parts the accuracy of moving iron power factor meter is much less than Electrodynamometer type. Two types of moving Iron pf meter.

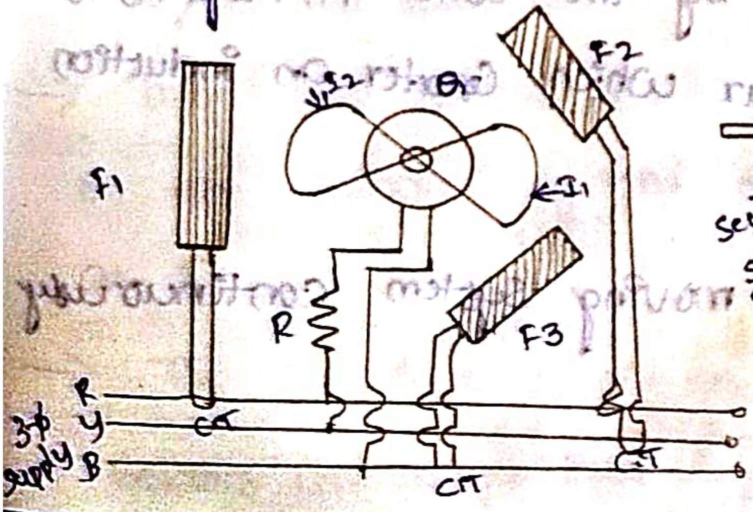
According to whether the operation of the instrument depends upon a rotating field (or) no. of alternating fields.

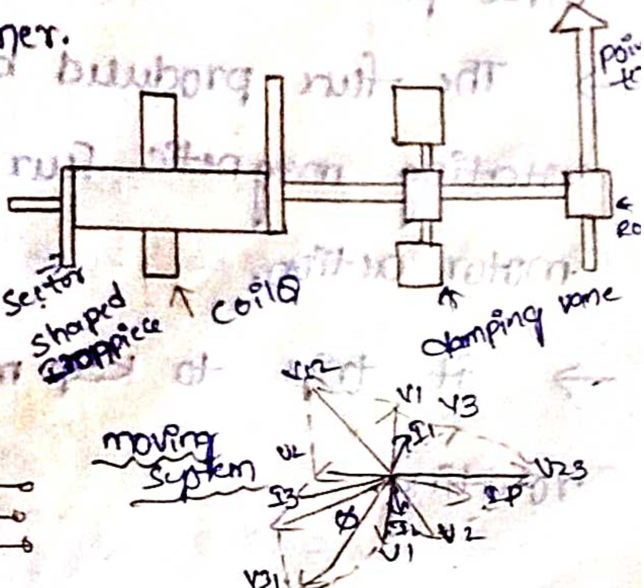
1. Rotating field type
2. Alternating field type.

Rotating field type moving Irom power factor meter:-

→ There are 3-fixed F1, F2 & F3 whose axes are displaced from each other by 120°.

→ The coils are suppiled from a three phase supply through current transformer.





→ The coil F_1 is supplied from phase R, F2, from F3 from B.

→ The coil Q is placed at the Centre of the three fixed Coil and is connected across any two Lines the supply through a series resistance.

→ Inside coil Q, there is a short pivoted iron rod The rod carries two sector shaped vanes F1 & at its ends.

→ The same rod carries damping vane of a Pointer the control springs absent.

→ The coil Q and the Iron system produces an alternating flux with interacts with the flux produced by the fixed Coils F1, F2 and F3.

→ Due to resistance R, the current in coil Q is in phase with the supply voltage.

→ So the deflection of the moving system is app -ximately equal to the power factor angle of the three phase circuit.

→ The flux produced by the coils F1, F2 & F3 is rotating magnetic flux which Creates an induction motor action.

→ It tries to keep moving system continuous rotating.

→ But it sets moving system in a definite position due to use of high resistivity iron parts. Such high resistive parts reduce the induced currents and stops the continuous rotation.

→ The meter can be used for balanced loads. It is also called westing house power factor meter.

→ It is calibrated at the normal supply frequency and can cause serious error is used at any other frequency.

Alternating field type moving Iron power factor meter

→ This instrument consists of three moving iron and vanes, which are fixed to the common spindle. Spindle carries damping vanes and of the pointer.

→ The moving iron vanes are sector shaped similar to those used in the rotating field type meter.

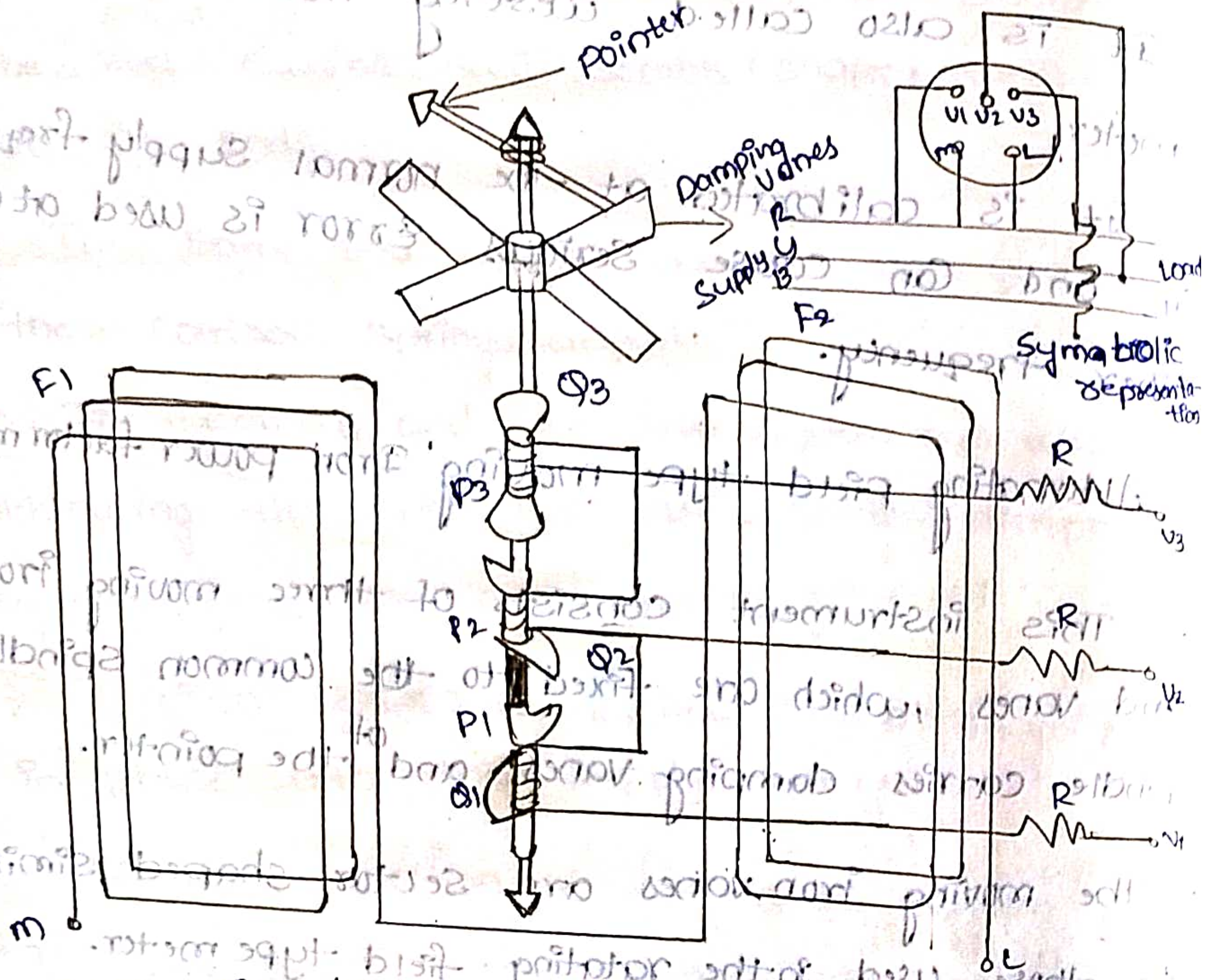
→ The ares of these section have an angle 120° with respect to each other.

→ These iron sectors are separated from each other on the spindle by the non-magnetic pieces denoted as S.

→ The Q_1, Q_2 & Q_3 are the iron sectors. These iron sectors are maghetized by the coils P_1, P_2 & P_3.

these are voltage coils.

→ These coils are connected across the three phase thus the current through them are proportional to the phase voltage of the three phase system.



Alternating field type moving iron power factor meter

→ The current coil is divided into two equal part F1 and F2 parallel to each other. The current coi carries one of the three line currents

→ one part F1 of the current coil is on on side of the moving system and other F2 the other side.

→ when connected in the circuit coil is [on one side of the moving system and other F2 on the other side.]

⇒ moving system moves & attains such a position in which mean torque on one of the iron pieces gets neutralized by the torque produced by the other two iron pieces.

→ In this position, the deflection of the pointer is Equal to phase angle b/w the current and voltages of the three phase system.

→ The instrument is used for the balanced loads but can be modified for unbalanced loads. The voltage coils are at different levels hence the resultant flux is not rotating but alternating.

→ This instrument is also called po
Power factor meter.

UNIT - IV

Potentiometer

Introduction:-

→ A Potentiometer is an instrument designed to measure an unknown voltage by comparing it with a known voltage. The known voltage may be supplied by a standard cell or any other known voltage reference source.

→ Advantage of the potentiometer is that it makes use of a balance or null condition no current flows and hence no power is consumed in the circuit.

→ potentiometer is extensively used for a calibration of voltmeter and ammeters and has infact become the standard for the calibration of these instruments.

→ Since Potentiometer measures voltage, it can also be used to determine currents simply by measuring the voltage drop produced by the unknown current passing through a known standard resistance.

→ potentiometer are of two types

* DC potentiometer, not only measure the unknown emf but also currents and resistance can be measured. Also ammeter and voltmeter and wattmeter can be calibrated.

* AC Potentiometer finds application in the measurement of unknown emf power supplied to a load, and self inductance of a coil.

Principle of mean potentiometer :-

The potentiometer works on the principle of opposing t unknown E.m.f by a known E.m.f with the negati terminals of both the E.m.f connected together, while the positive terminals connected together through galvanometer as shown in fig.

When the E.m.f are of same values, there is no deflection on galvanometer. Thus to measure the unknown E.m.f by using the above method, the known E.m.f used must be variable. Another important requirement is that known E.m.f should be varied to give a large no. of known values but it is pratically very difficult.

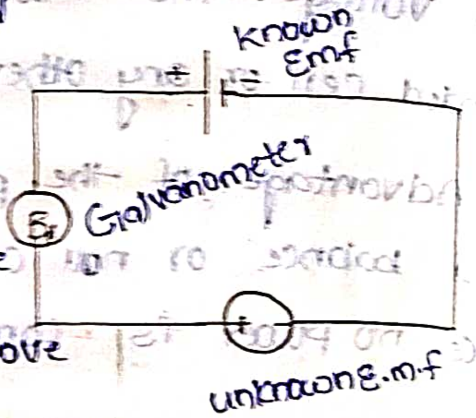


Fig:- Representation of method of balancing E.m.f.

Hence alternatively the known E.m.f is connected in parallel with and in opposition to a voltage drop measu across the resistor is shown in fig below.

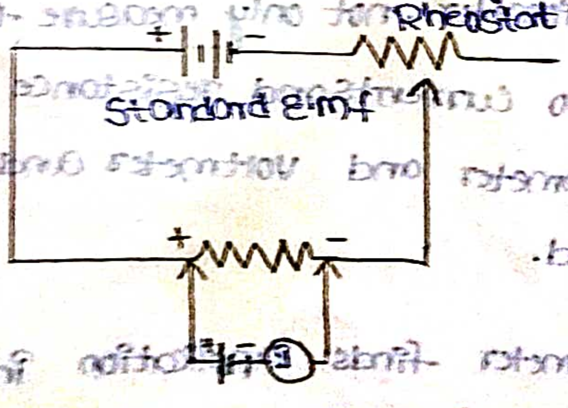
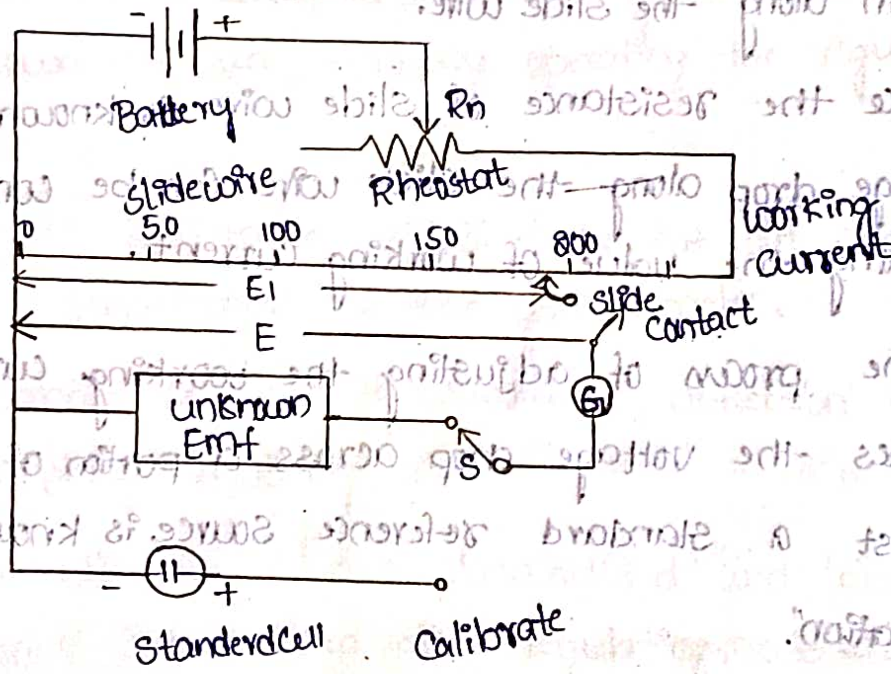


fig:- Alternative method of balancing E.m.f

The main advantage of this method is that the current in the resistor can be varied easily to obtain any desired voltage with very fine adjustment. The voltage drop cross resistor can be determined by calibrating the resistor with standard cell.

Basic Potentiometer circuit (or) slide wire potentiometer:-

→ The principle of operation of all potentiometer is based on the circuit shown below. which is also basic slide wire potentiometer.



1) with switch "S" in the operate position and galvanometer "K" open the battery supplies the working current through reastat "R" of the slide wire.

2) The working current in slide wire may be varied by changing the rheostat setting.

3) The method of measuring the unknown voltage "E" depend open finding a position for the sliding contact.

4) When the galvanometer K is closed and the sliding contact is moved along the slide wire, untill the galvanometer shows zero deflection.

5) Then the unknown voltage "E" is Equal to the voltage drop E₁ across portion of ac of slide wire.

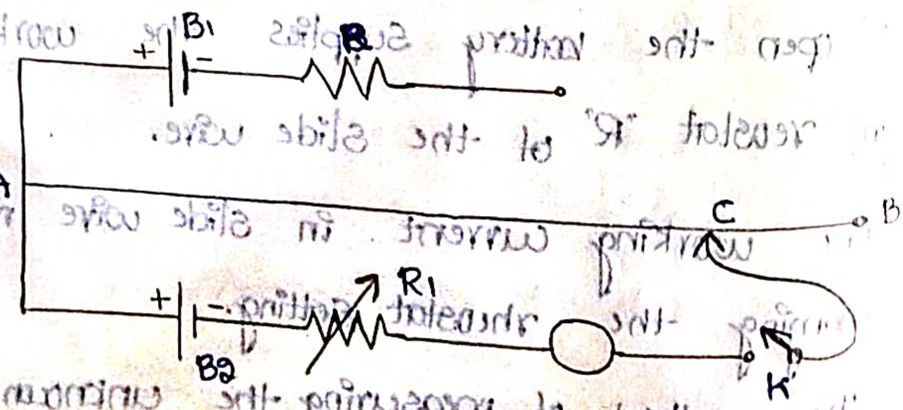
6) The slide wire has a uniform cross-section and hence uniform resistance along its entire length.

7) A calibrated scale is placed along the slide wire so the sliding contact can be placed accurately at any desired position along the slide wire.

8) Since the resistance of slide wire is known accurately the voltage drop along the slide wire can be controlled by adjusting the value of working current.

9) The process of adjusting the working current so as to makes the voltage drop across a portion of sliding wire against a standard reference source is known as "standardisation".

Procedure for standardisation:-



→ The procedure for standardisation is shown by above fig.

→ Here the B₁ is a battery with a ample capacity and 'R' is a regulating resistance.

→ B₂ is a standard Cell- usually it is Weston Standared cell with emf of 1·0186 volts and R' is series resistance

→ G is a sensitive galvanometer.

→ The key "K" is closed and with the series resistance R' folly cut-in the sliding contact "c" is set against the division ~~measured~~ marked as 1·0186 volts on the scale.

→ A deflection is obtained in the galvanometer. This is brought down to near zero by operating the regulating resistance R.

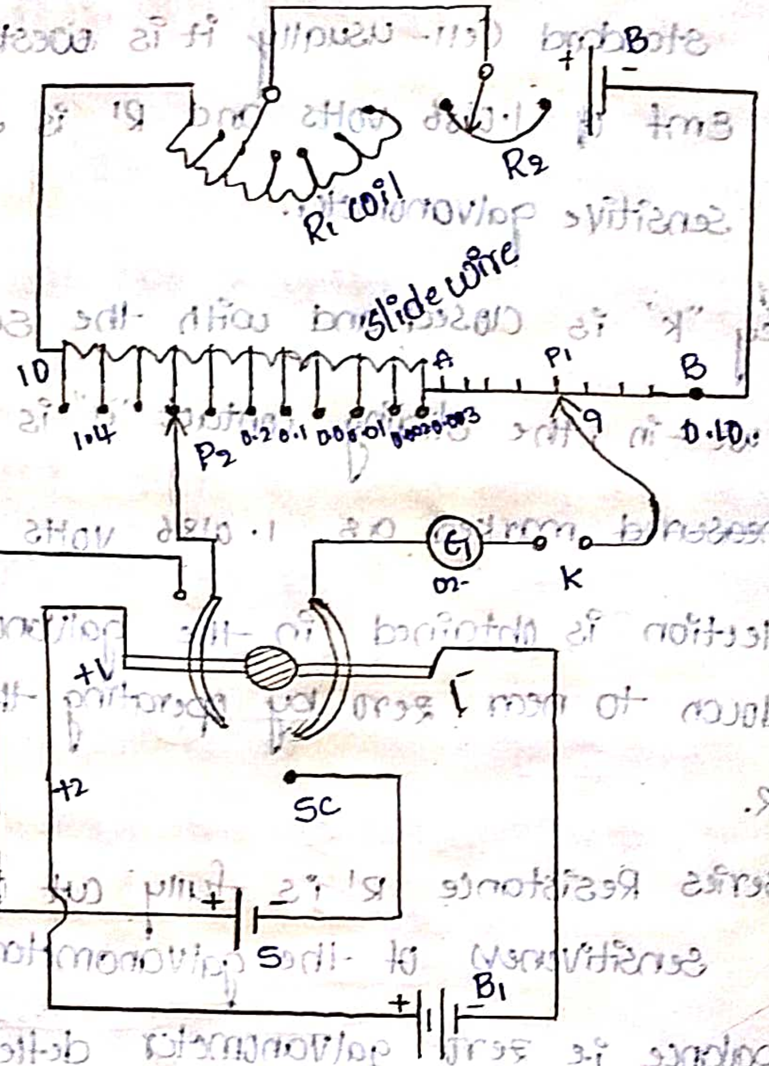
→ The series Resistance R' is fully cut out so as to increase the sensitiveness of the galvanometer.

→ perfect balance i.e zero galvanometer deflection is obtained by properly adjusting R.

→ The potentiometer is now standardised and it is direc reading once standardised the regulating resistance "R" should be left undistributed.

⑦ crompton D.C potentiometer:-

Imp



→ A pratical form of dc potentiometer which is very wide used is the crompton potentiometer.

→ The potentiometer consists of a short slide wire AB o uniform cross section in series with a no of resistance c (15) . The resistance of each coil being equal to the resiston of the slide wire.

→ There are two sliding contacts P₁ and P₂ , P₁ can slide over the slide wire and P₂ can move over the studs of resistance coils.

→ The regulating resistance in the form of two variabl resistor R₁ and R₂ joined in series.

→ R_1 taking the form of a no.of coils of R_2 taking the form of a slide wire.

→ There is a battery "B" ~~of~~ the ample capacity which supplies the slide wire current.

→ There is a change-over or multiple circuit switches(S with 6 terminals, A standard weston cell is connected acros terminals marked as SC [standardisation circuit].

→ The battery whose E.m.f is to be measured is connected across terminals 1,1 (OR) 2,2 with due regard to polarity.

→ "G" is a sensitive galvanometer which is connected to the switch and the sliding contacts P_1 and P_2 through a key "K" as shown.

→ To unbalance current initally a resistance is connected in series with the galvanometer.

Operation:-

→ The potentiometer is standardised as the change-over switch is through to terminals SC, SC across which the standard cell is connected.

→ The sliding contact P_2 is set at 1.0 and P_1 is set at 0.0186 reading. The key "K" is closed and null deflection is obtained by adjusting resistances R_1 and R_2.

→ The potentiometer is now standardised and it is direct reading. Resistor R_1 and R_2 are left undisturbed there after.

→ The change-over switch is moved to 1,1 position, if the battery whose X emf is to be measured is connected across

1.1 The potentiometer is again balanced i.e null deflection i obtained by adjusting the positions of P_1 and P_2.

→ The unknown e.m.f is directly read off from the sca

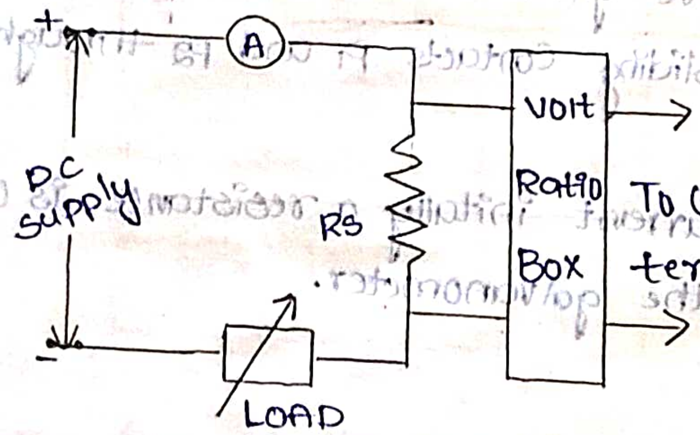
Example:-

If P_2 is at 1.2 and P_1 is at 0.07 the measured value of the e.m.f is 1.27 volts.

Application of d.c potentiometer:-

1. Calibration of Ammeter:-

An Ammeter can be calibrated by using d.c potentiometer.



Rs → Standard Resistance

A → Ammeter to be calibrated.

The ammeter to be calibrated is connected in series with a standard resistance of Rs of a variable load. supply is obtained form a suitabled d.c source. A small current is pa The voltage which develops across Rs is applied to a volt-ratio box. The o/p voltage of the V.R box is measured in the usual way using a d.c potentiometer. The ammeter is noted of repeated for different currents.

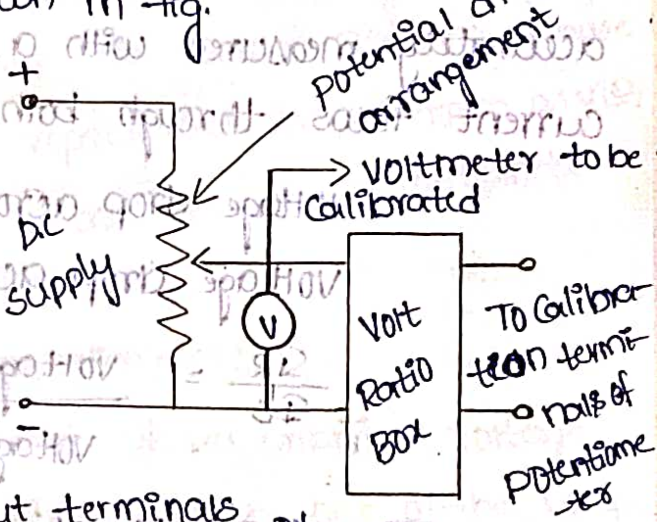
$$\text{Actual current } (I_{act}) = \frac{\text{Potentiometer Reading}}{\text{V.R box} \times \text{standard Resistance } R_S}$$

percentage error is calculated for each ammeter reading as

$$\% \text{ Error} = \frac{I_{ind} - I_{act}}{I_{ind}} \times 100$$

Calibrated of voltmeter:-

Voltmeter can be calibrated using d.c potentiometer. The necessary setup is shown in fig.



Any desired voltage with in the range of the voltmeter to be calibrated can be obtained, using the potential divider is shown in fig. This voltage is applied to the input terminals of a (VR) volt-ratio Box. The voltmeter to be calibrated is connected across these terminals. The o/p voltage of VR box is measured accurately with a d.c potentiometer.

The reading of the voltmeter is noted. This is the indicated voltage, Vind.

The test is repeated for several different voltages

$$\text{Actual Voltage}, V_{act} = \frac{\text{Potentiometer reading}}{\text{V.R box ratio}}$$

$$\% \text{ Error} = \frac{V_{ind} - V_{act}}{V_{ind}} \times 100$$

The calibration curve is obtained by plotting % Error against indicated voltage.

measurement of resistance:-

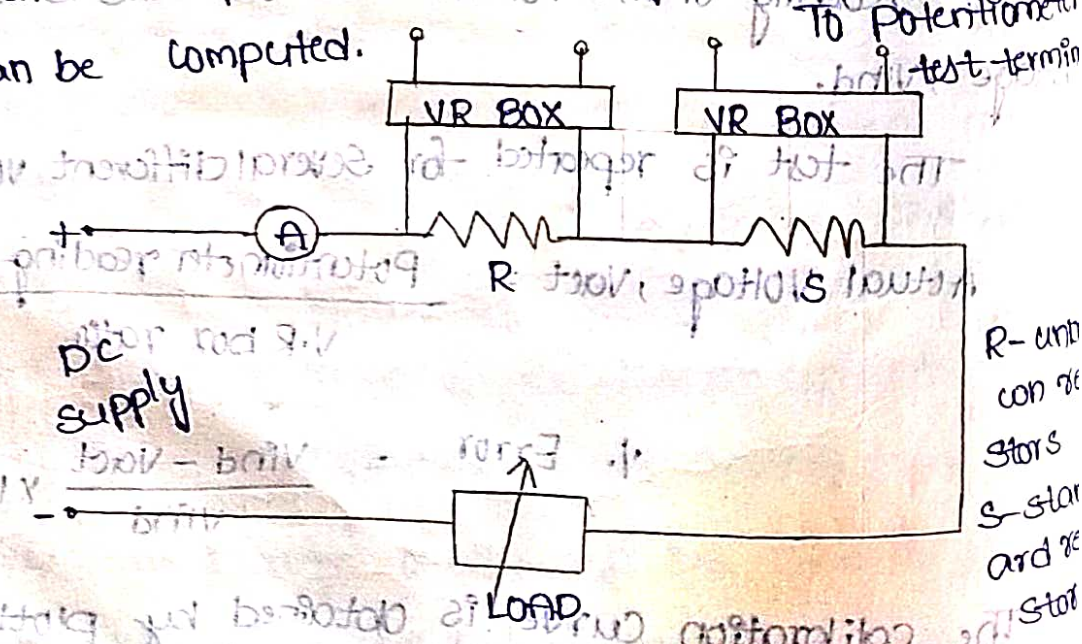
The unknown resistance 'R' is connected in series wi a standard resistance S, an ammeter of suitable range and variable load supply for the circuit is obtained from a sui ble d.c source. Different currents are passed through R and for each current, the voltages developing across 'R' and "S" a accurately measured with a d.c potentiometer. Since the sa current flows through both R & S, we have.

Voltage drop across R = IR volts

Voltage drop across S = IS volts

$$\frac{IR}{IS} = \frac{\text{voltage drop across R}}{\text{voltage drop across S}} = \frac{R}{S}$$

(or) $R = S \left\{ \frac{\text{Potentiometer Reading with R}}{\text{Potentiometer reading with S}} \right\}$ i.e. the V.R box, ratio is the same during both measurments. knowing S and the two potentiometer readings, the unknown resist nce R can be computed.



Ac potentiometer:-

→ In an AC potentiometer, the two voltages shou be balanced in magnitude as well as phase. A.c potentiomete are classified on the basis of method of measurement of unknown voltages.

These are two types of a.c potentiometer as.

(i) polar type a.c potentiometer:-

In which the magnitude and phase angle of unknown voltage are measured on different scales directly. The phase angle is measured with respect to some reference phase. As the voltage measured is represented in polar form as $V\angle\theta$; the a.c potentiometer is called polar type a.c potentiometer.

(ii) co-ordinate type of a.c potentiometer:-

In which the two component of an unknown voltage are measured on two different scales. One of the components measured is in phase component while remaining is quadrature component. Both the components are 90° out of phase each other. VA & VB are inphase and quadrature component then the magnitude & phase angle of an unknown voltage can be represented as given by.

$$V = \sqrt{VA^2 + VB^2} \text{ and}$$

$$\theta = \tan^{-1}\left(\frac{VB}{VA}\right)$$

As the two components of the unknown voltage represent reactangular form of voltage, the potentiometer is called co-ordinate type a.c potentiometer.