SWAMI VIVEKANANDA SCHOOL OF ENGG AND TECHNOLOGY

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ELECTRICAL MEASUREMENT AND INSTRUMENTATION

Measuring Instruments

CH-1
EMI

Measurement :- Measurement is the process of measuring by which one parameter converted into physical parameters so that it gives a meaningful ~~ma~~ numbers.

→ There are two basic requirements gives the meaningful measurement results:

* The standard used for comparision purposes must be accurately defined and should be commonly accepted
* The apparatus used and the method adapted must be provable.

→ There are two methods of measurement

(i) Direct method
(ii) Indirect Method

(i) Direct method : It is a methods in which the unknown quantity is directly compared against a standard. The result is expressed as a numerical number and in units.

(ii) Indirect Method :- Measurement by direct methods are not always possible, feasible and practicable. these methods in most of the cases, are inaccurate because they involve human factors. They are less sensitiv

Basic Terms

1. **Accuracy**:- It is the closeness with which an instrument reading approaches the true value of quantity being measured.

:- Thus accuracy of a measurement means conformity of truth.

* **point accuracy**:-> this is the accuracy of the instrument only at one point on its scale. the specification of this accuracy does not give any information about the accuracy at other points on the scale. In other words it does not give any information about the general accuracy of the instrument.

* **Accuracy as "percentage of scale Range"**:->
-> when an instrument has uniform scale, its accuracy may be expressed in terms of scale range.

* **Accuracy as "Percentage of true value"**:->
-> the true value of the quantity is measured as with in ± 0.5% of true values.
-> Thus at 5% of full scale the accuracy of the instrument would be 20% better than that of an instrument, which is accurate to ± 0.5% of scale range.

i) <u>Precision</u>:- It is the degree of agreement with in a group of measurements or instruments. Precision is composed of two characteristics confirmity and the number of significant figure to which a measurement may be made.

→ The precision of an instrument is usually dependent upon many factors and requires many sophisticated techniques of analysis.

) <u>Resolution</u>:-

→ If the input is slowly increased from some arbitary (non-zero) input value, it will again be found that output doesnot change at all until a certain increment is exceeded.

→ This increment is called resolution or Discrimination, of the instrument.

→ Thus the smallest increament in input which can be detected with certainty by an instrument is its resolution.

→ So resolution defines the smallest measurable input change while the threshold defines the smallest measurable input.

(v) ERRORS :- Deviation from the true value of the measured variable is known as error.

Types of error :-

There are three types of error

a) Gross error

b) Systematic error

c) Random error.

a) gross error :- This error created by human mistakes in reading or using instruments and in recording and calculating measurement result.

b) Systematic error :-

This error is mainly divided into three differe categories.

* Instrumental error
* Environmental error
* Observational error

* Instrumental error :-

→ Instrumental error use errores inherent in measuring instrument because of their mechanica structure.

* environmental error :-

Environmental errores due to external to the measuring device, including conditions in the a surrounding the instrument such as the effect of changes in temperature, humidity, barometric pressure, or magnetic or electrostatic field.

* **observational errors :-**

There are many sources of observational errore.
example :- the pointer of a voltmeter resets slightly above the surface of the scale.
→ thus an error on account of PARALLAX will be incurred unless the line of vision of the observer is exactly above the pointer.

c. **Random Error :-**

→ This error are generated due to unknown causes and occur even when all systematic errors have been accounted for.
→ In well designed experiments few random errors usually occurs, but they become important in high accuracy work.

v) **Tolerance :-** Tolerance refers to the total allowable error with in an item.
→ This is typically represented as a +/- value of a nominal specification.

Classification of measuring Instruments :

★ Absolute and Secondary Instruments :-

The various instruments in very broad sense, are classified into two classes namely (i) Absolute instrumen (ii) Secondary instrument.

(i) Absolute Instrument :- The instrument of this type provi the magnitude of the quantity to be measured in terms instrument constant and its deflection.

→ Such instruments do not require any comparision w any other standard instrument.

eg:- tangent galvanometer.

(ii) Secondary Instrument :- These instruments are so designed that the measurand can only be measured observing the output indicated by the instrument.

→ These instruments are required to be calibrated comparision with an absolute instrument or another secondary instrument which has already been calibrated against the absolute instrument.

eg:- voltmeter, ammeter, wattmeter.

★ Direct Measuring and comparision Instruments

(i) Direct Measuring Instruments :- Direct measuring instruments convert the energy of the unknown quantity directly into energy that deflects the moving element of the instrument.

the value of the unknown quantity being measured by reading the resulting deflection.

→ eg :- Ammeter, voltmeter etc.

ii) Comparision instrument :- It measure the unknown quantity by comparing it with a standard that is often contained in the instrument case such as resistance measuring bridge.

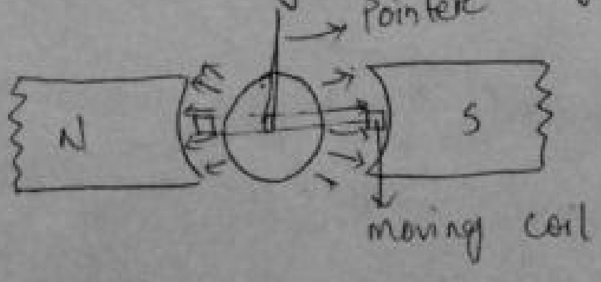
Deflection and null type instruments:

(i) Deflection type instruments :- The measurand produces some physical effect which deflects or produces a mechanical displacement of the moving system of the instrument.

→ An opposing effect is built in the instrument which tries to oppose the deflection or the mechanical displacement of the moving system.

→ The opposing effect is closely related to the deflection or mechanical displacement that can be directly observed.

→ eg :- Permanent magnet moving coil (PMMC) ammeter



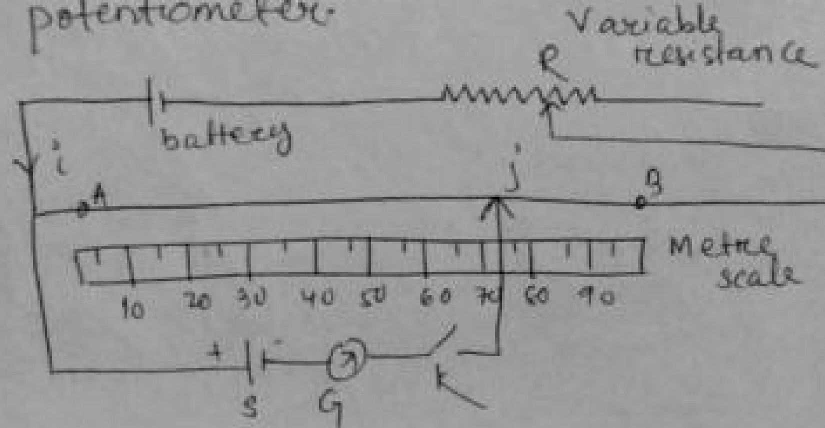
(ii) Null type Instruments :-

→ Null type Instrument attempts to maintain deflection at zero by suitable application of an effect opposing that generated by the measurand.

→ Necessary to such an operation are a detector of unbalance and a means of restoring balance

→ Since deflection is kept at zero, determination of numerical values requires accurate knowledge of magnitude of the opposing effect.

eg:- dc potentiometer.



★ Analog and digital instruments :-

(i) Analog Instruments :- Signals that vary in continuous fashion and take on an infinite number of values in given range are known as analog signal.

→ The device producing such signals are known as analog devices.

(ii) Digital Instruments :- The signal which vary in discrete steps and thus take up only ~~fit~~ finite different values in a given range are termed as digital signals

→ The devices producing such signals are called the digital devices.

Classification of secondary Instruments

1) Indicating Instruments: The instruments that supplies the information in the form of deflection of a pointer is known as an indicating instrument.

eg:- pointer of an ammeter indicates the current flowing through the circuit which is connected.

2) Recording Instruments :- Recording instruments are those which keep a continuous record of the variation of the magnitude of an unknown quantity to be observed over a definite period of time.

3) Integrating Instruments :- These are instruments which measure the total amount of either quantity of electricity or electrical energy supplied over a period of time.

→ The summation given by such an instrument is the product of time and an electrical quantity under measurement

→ eg:- Ampere-hour meter, energy meter etc.

Essentials of Indicating Instruments

Indicating instruments consist, essentially of a pointer moving over a calibrated scale and attached to the moving system pivoted on jewelled bearing.

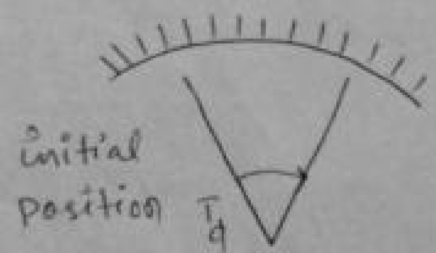
→ For satisfactory working of indicating instruments the torque required are

1. Deflecting torque 2. controlling torque 3 Damping torque.

1. <u>Deflecting torque</u>:- the deflecting torque is produced by making use of one of the magnetic, heating, chemical, electrostatic and electromagnetic induction effects of current or voltage.

→ this cause the moving system of the instrument to move from its zero position when the instrument is connected in an electrical circuit to measure the electrical quantity.

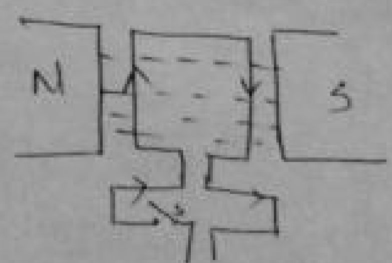
→ The method of producing this torque depends upon type of the instrument.



<u>Mechanism produce to deflecting torque</u>:

→ Force between permanent magnet and current carrying coil ⇒ $F = BIL\sin\theta$

$F \propto L$



~~→ Force betn~~

→ Force betn two current carrying coil.

→ Force betn current carrying coil and soft iron disc (moving iron)

2. <u>Controlling torque</u>: The magnitude of the movement of moving system would be somewhat indefinite under the influence of deflecting torque unless some controlling torque existed.

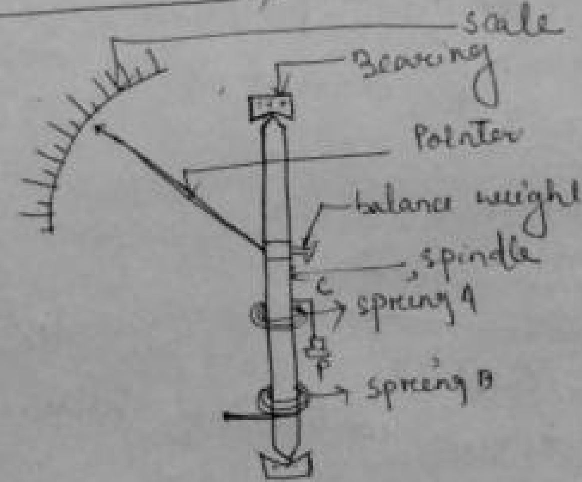
→ This torque opposes the deflecting torque and increases with the increase in deflection of the moving system.
→ Under the influence of controlling torque the pointer will return to its zero position on removing the source producing the deflecting torque.

At equilibrium

$$\boxed{T_d = T_c}$$

→ This torque can be developed by two method
a) spring control method
b) Gravity control method

a) <u>spring control method</u> :-



→ In this method a phosphor bronze spiral hair springs A and B coiled in opposite directions and acting one against the other are used in spring control.
→ One end of each spring attached to the spindle. The outer end of spring A is attached to a lever at point C pivoted at P while that of B is fixed.
→ Under the influence of deflecting torque when the pointer moves, one of the spring unwinds itself while the other gets twisted.

→ The twist produces ~~deflecting~~ controlling torque which is directly proportional to the angle of the deflection of the moving system

$T_c \propto \theta$

$\boxed{T_c = K\theta}$ K = Spring constant ——— (i)

→ when deflecting torque (T_d) and controlling torque (T_c) equal, the pointer comes to rest.

$\boxed{T_c = T_d}$ ——— (ii)

→ Since $T_c \propto \theta$ and $T_d \propto I$

from eqn (i) and (ii)

$\boxed{\theta = I}$ ——— (iii)

→ Since in spring controlled instrument the deflection directly propotional to the current ∴ these instruments have uniform scale.

Advantages of spring control :-

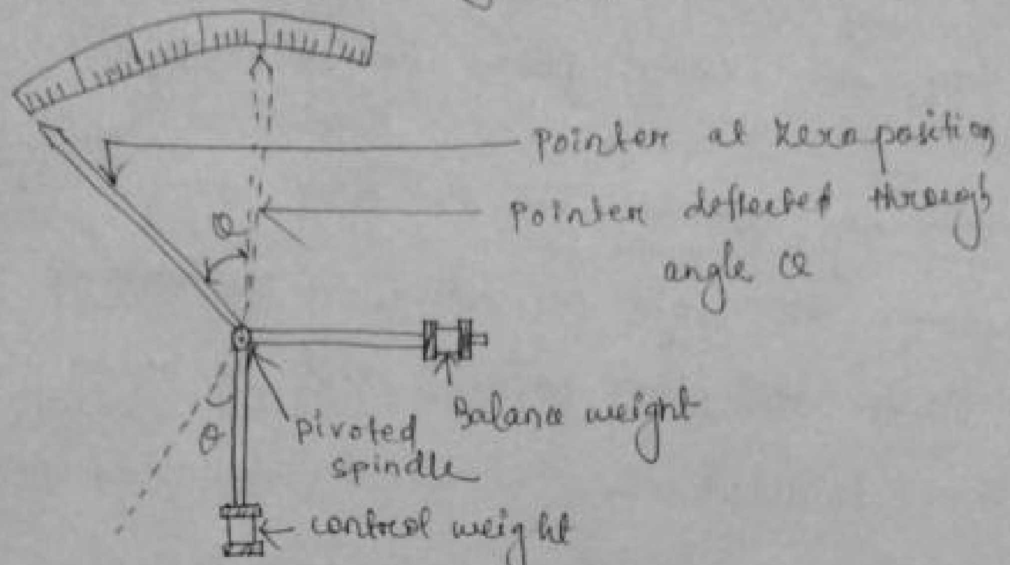
→ Linear output ($\theta \propto I$)

→ when place the spring controlling instrument both in horizontaly and vertically.

Disadvantages :- when temperature increases the stiffness of the spring decreases which produces less controlling torque and deflecting torque which results high reading.

b) Gravity Control method :- In gravity controlled instrument a small weight is attached to the moving system in such way that it produces a controlling torque, hen the moving system is in deflecting position.

The controlling torque can be varied quite easily by adjusting the position of the controlling weight up on the arm.



In zero position of the pointer the control weight is vertical. When the pointer is deflected through an angle Q from its zero position.

The control will be in a position shown dotted in the fig.

In deflecting ~~torque~~ position, the controlling torque is (T_c)

$T_c = wl\sin\theta$ where w = control weight
l = distance from the axis of deflection
θ = deflection

$T_c \propto \sin\theta$

If $T_d \propto I$

Then at final deflected position

$T_d = T_c$

or $I \propto \sin\theta$

$I = k\sin\theta$

$\theta = \sin^{-1} I/k$

Advantage :- It is very cheap.

→ There is no temperature errors.

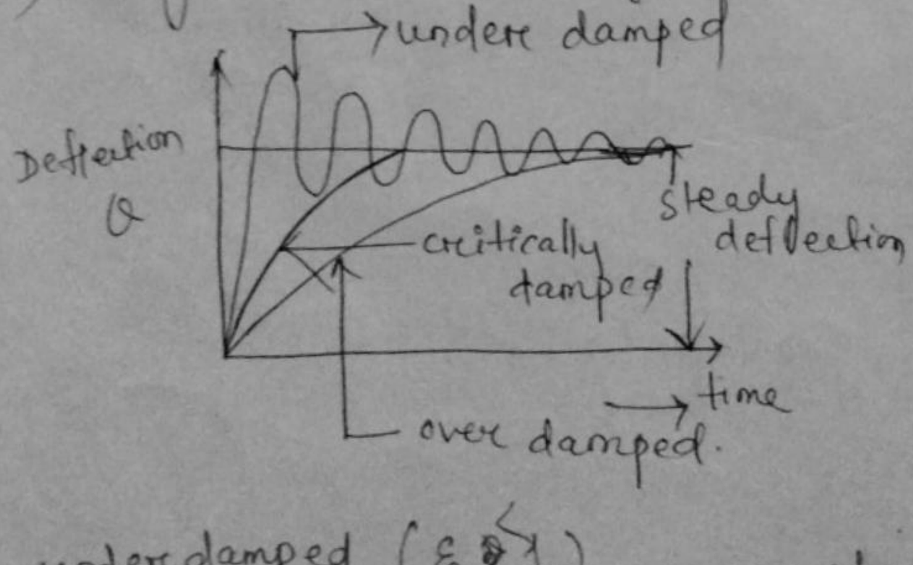
Disadvantage: → Non-linear rotation.

→ They are always placed in vertically.

3. **Damping torque**: The damping torque is also necessary to avoid oscillations of the moving system. about its final deflecting position and to bring the moving system to rest in its final deflected position quickly.

→ The damping torque must operate only while the moving system of the instrument is actually moving and always oppose its motion.

→ The various methods of obtaining damping are
a) air friction damping
b) fluid friction damping
c) Eddy current damping



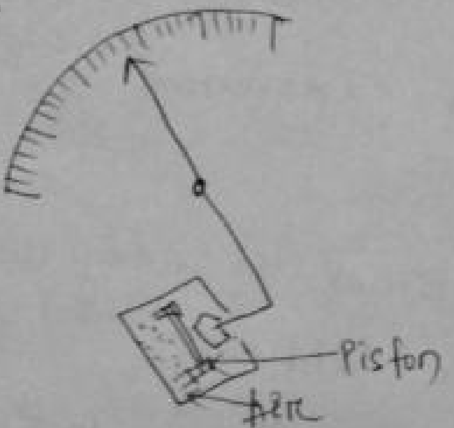
(i) underdamped ($\varepsilon_e < 1$)
(ii) undamped ($\varepsilon_e = 0$)
(iii) critically damped ($\varepsilon_e = 1$)
(iv) over damped ($\varepsilon_e > 1$)

where ε_e = damping coefficient

a) air friction damping :- In this type of damping system a light alluminium piston is attached to the moving system as the piston moves with a very small clearance in fixed air chamber closed at one end.

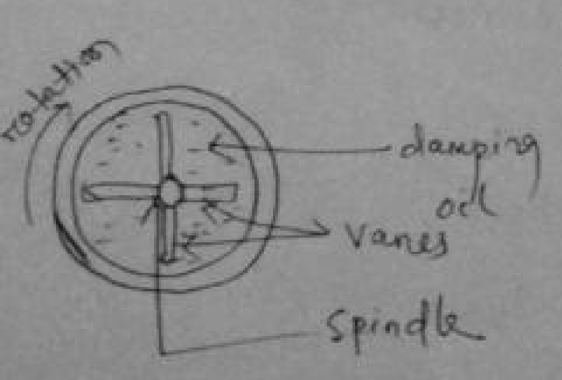
→ the fixed volume of air subjected to frictional force of compression and expansion. there by osilation are nullified

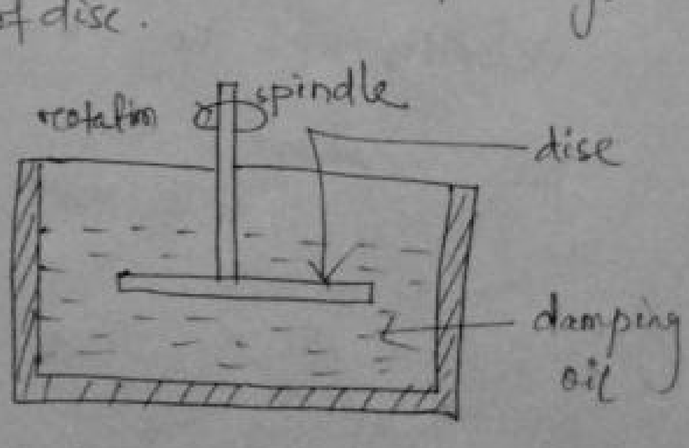
→ this method is adoptable for low and medium range equipments.



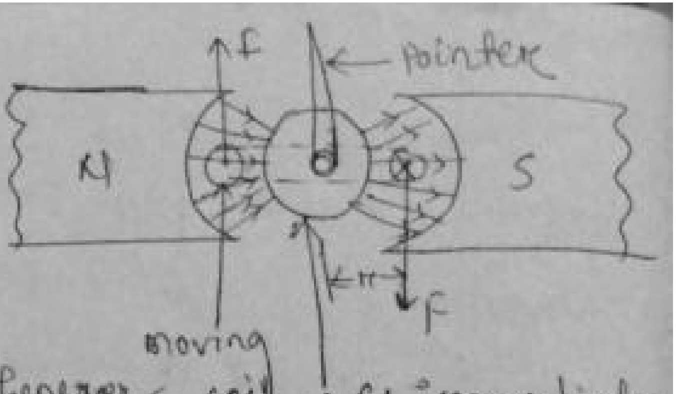
) fluid friction damping :- In this method of damping light vane or disc are attached to the spindle of the moving system. they move in a damping oil.

→ Oil employed must be good insulator, non-evaporating, non corrosive upon the metal of disc.





c) Eddy current damping :-



→ the eddy current damping is the most efficient and is based on the principle that whenever a sheet of conducting but nonmagnetic material like copper or aluminium mov[es in] a magnetic field, eddy current are set up in the sheet

→ Due to these eddy current a force opposing [the] motion of the sheets is experienced between them a[nd] the magnetic field

→ this force is propotional to eddy current and strength of the magnetic field.

→ The eddy currents are proportional to the velocity o[f] the moving system.

→ Hence the strength of the magnetic field is constant, the damping force is proportional to velocity of the moving system. and is zero whe[n] the moving system is at rest.

Calibreation :-

→ Calibreation is a compaerision between a known measurement (the standard) and the measurement using your instrument.

→ Calibreation refers to the act of evaluating and adjusting the precision and accuracy of measurement equipment.

→ The outcome of the comparison can result in one of the following

a) No significant error being noted on the device under test

b) A significant errore being noted but no adjustment made

c) An adjustment made to correct the error to an acceptable level.

Analog Ammeters And Voltmeters

Moving Iron type Instruments :-

There are two basic forms of these instruments i.e, the attraction type and the repulsion type.

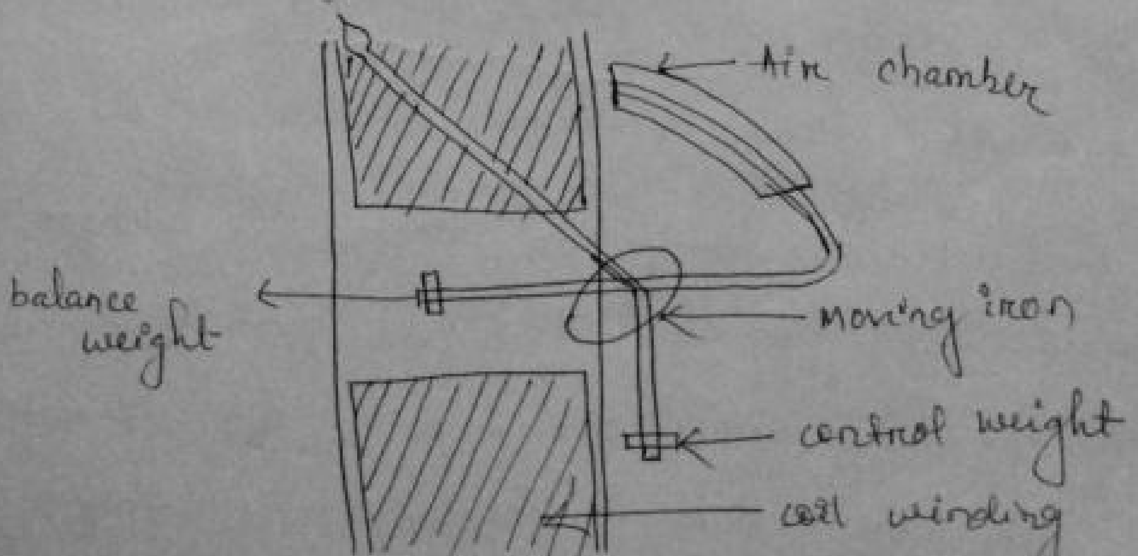
The operation of attraction type ~~depends on the repulsion of two~~ adjacent depends on the attraction of a single piece of soft iron into a magnetic field.

→ The repulsion type depends on the repulsion of two adjacent pieces of iron magnetized by the same magnetic field.

→ For both types of these instruments, the necessary magnetic field is produced by the ampere-turns of a current carrying coil.

→ In this case the instrument is to be used as an ammeter.

(i) Attraction type M.I. Instruments



→ In this instrument we used a solenoid and moving oval shaped soft iron pivoted eccentrically

→ To this iron a pointer is attached so that it may deflect along with the moving iron over a graduated scale.

→ The moving iron is drawn into the field of solenoid when current flows through it

→ The movement of iron is always from weaker magnetic field outside the coil into the stronger magnetic field inside the coil.

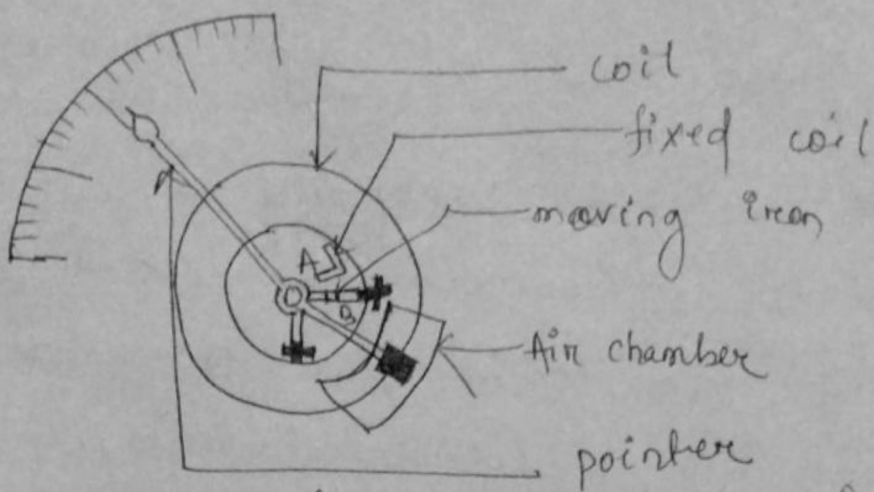
→ When the current to be measured is passed through the solenoid, a magnetic field is set up inside the solenoid, which in turn magnetises the iron.

→ Thus the iron is attracted in to the coil causing the spindle and the pointer to rotate.

→ Such as instrument has a scale cramped at lower end and greatly expanded at the upper end; operating torque is quite low when the moving iron is just entering the solenoid and increases rapidly as iron is drawn further.

→ The instantaneous deflecting torque is proportional to the square of the instantaneous current, hence the instrument is connected in a ac ckt it will indicate the rms value of current or voltage

Repulsion type M.I instrument :-



→ It consist of a fixed coil inside which are placed two shoft iron rood A and B ~~which~~ are parallel to one ~~anthe~~ another and along the axis of the coil.

→ One of them i.e. A is fixed and B which is moveable carries a pointer.

→ when the current is measured passed through the fixed coil, it sets up its own magnetic field. which magnetizes the two roods similarly i.e. the adjacent

→ similarly points on the length of the rods will have same magnetic ~~preoperty~~ polarity.

→ Hence they reepel each other with the result that the pointer is deflected against the controlling toreque of a spring or gravity.

→ The force of reepulsion is approximately proportional to the square of the current passing through the coil.

→ Moreover, whatever may be the direction of the cu[rrent] through the coil, the two rods will be magnetized similarly and hence will repel each other.

→ In order to achive uniformity of scale, two tongue shaped strips of iron are used instead of two rods.

→ the fixed iron consist of a tongue shaped sheet iron bent into a cylindrical form,

→ the moving iron also consist of another sheet o[f] iron or dic so mounted as to move parallel to t[he] fixed iron and towards its narrower.

Sources of error

a) Errores with dc and ac both

(i.) Error due to hysteresis :-

→ Because of hysteresis in the iron parts of the moving system, readings are higher for descen[ding] values but lower for ascending values.

→ This can be eliminated by using Mumetal a[nd] Perm-alloy, which have negligible hysteresis los[s].

(ii) Error due to stray fields :-

→ Unless shielded effectively from the effects of stray external fields, it will give wrong readi[ngs].

→ Magnetic shielding of the working part is obtain[ed] by using a covering case of cast iron.

(b) Errore with ac work only

(i) Change in the impedance of the coil.
(ii) change in the magnitude of the eddycurrent.

Advantages And Disadvantages

→ Such instruments are cheap and robust, give a reliable services and can be used both on ac and dc circuits.

→ It cannot be calibrated with a high degree of precision with d.c on account of the effect of hysteresis in the iron rods and vanes.
Hence they are usually calibrated by comparision with an alternating current standard.

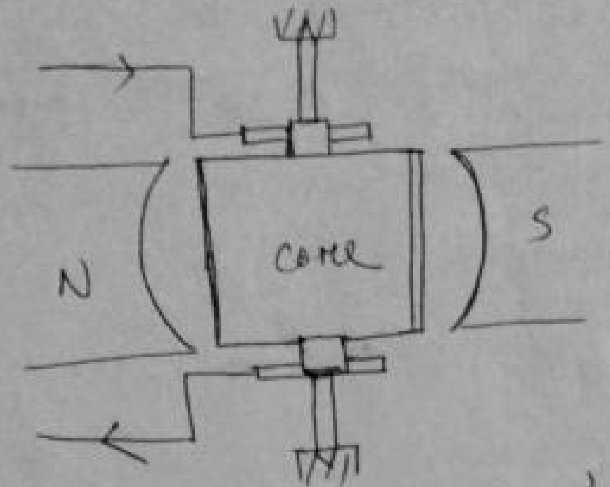
Moving coil Instruments (M.C.)

There are two kinds of such instruments
(i) Permanent magnet moving coil instrument
(ii) Dynamometer type instrument.

(i) Permanent magnet Moving coil (PMMC) Instrument

The operation of permanent magnet moving coil is based upon the principle that when a current carrying conductor is placed in a magnetic field, it is act upon by a force which tends to move it to one side and out of the field.

Construction:



→ As the name indicates, the instrument consists of a permanet magnet and a rectangular coil of many turns wound on a light aluminium or copper former inside which is an iron core.

~~→ the powerful U-shaped permanent magnet is m~~

→ the powerful U-shaped permanent magnet and has soft-iron end-pole pieces which are bored out cylindrically.

→ Between the magnetic poles is fixed a soft iron cylinder whose function is

(i) to make the field radial and uniform

(ii) to decrease the reluctance of the air path betn the poles and hence increase the magnetic flux.

→ Surrounding the core is a rectangular coil of many turns wound on a light aluminium frame which supported by delicate bearings and to which is attached a light pointer.

The aluminium frame is not only provides support for the coil but also provide damping by eddy current induced in it.

. The sides of the coil are free to move in the two air-gaps between the poles and core.

. Control of the coil movement is affected by two phosphor - bronze hair springs, in one above and one below, which additionally serve the purpose of leading the current and out of the coil.

. The two springs are spiralled in opposite directions in order to neutralise the effects of temperature changes.

Advantages :-

-> They have low power consumption.

-> Their scales are uniform and can be designed to extend over an arc of 270° or so.

-> They posses high (torque / weight) ratio.

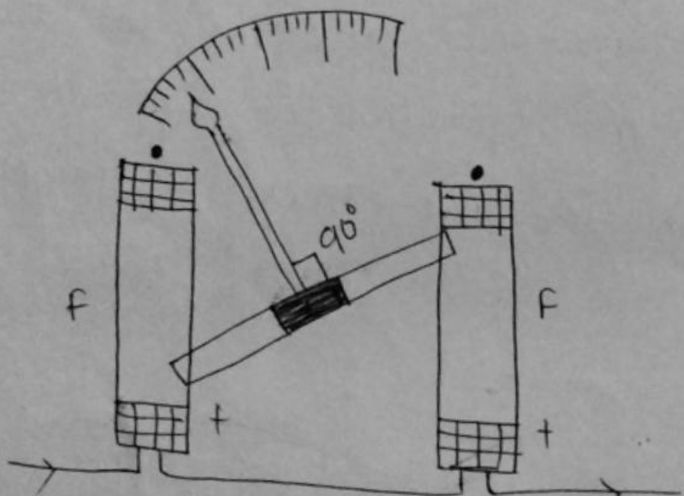
-> They can be modified with the help of shunts and resistances to cover a wide range of currents and voltages

-> They have no hysteresis loss.

Disadvantage :-> Due to delicate construction and the necessary accurate machining and assembly of var parts , such instruments are some what costlier as compared to moving - iron instruments .

-> Some errors are set in due to the ageing of control springs and the permanent magnet. such instruments are mainly used for d.c work onl

Electrodynamic or Dynamometer Type Instruments



-> An electrodynamic instrument is a moving coil instrument in which the operating field is produce not by a permanent magnet ~~bg~~ but by another fixed coil.

-> this instrument can be used both as amme and voltmeter. but is generally used as wattmeter.

-> the fixed coil is usually arranged in two equal section. F and F placed together and parallel to each other.

-> The two fixed coil are air cored to avoid hysteresis effects when used on a.c circuits.
-> This has the effect of making the magnetic field in which moves the moving coil M, more uniform.
-> The moving coil is spring-controlled and has a pointer attached to it.

Errors :-

-> Since the coils are air-cored, the operating field produced is small. For producing an appreciable deflecting torque, a large no. of turns is necessary for the moving coil.
-> The magnitude of the current is also limited because two control springs are used both for leading in and for leading out the current.
-> Both these factors lead to a heavy moving system resulting in frictional losses which are somewhat larger than in other types and so frictional errors tend to be relatively higher.

Advantage and Disadvantage :

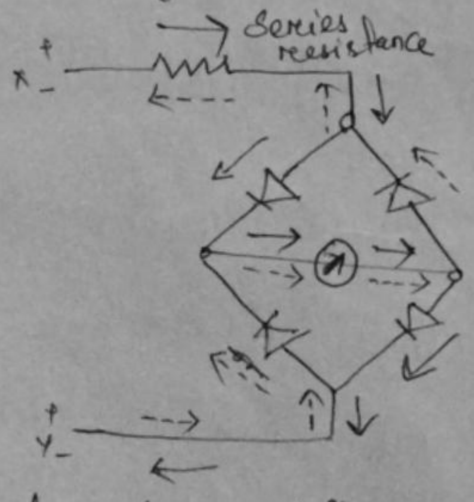
1. Such instruments are free from hysteresis and eddy current errors.
2. Since torque to weight ratio is small, such instrument is low sensitivity.

Rectifier type Instrument :-

⇒ A rectifier instrument is essentially, the comb of a permanent magnet moving coil instrument a semiconductor rectifier.

⇒ It is an easy matter to construct voltmeters having a resistance of 20K Ω per volt and to measure currents as low as 5 μA with indicati instrument.

⇒ The sensitivity of the rectifier type instrument is very high and power required for their operati is very small.



(Bridge rectifier circuit for voltmeter)

⇒ It is usual to employ rectifier consisting of fou elements arranged in the of a wheat stone bridge.

⇒ The arrows indicate the direction of flow of curr

⇒ It is obvious that the direction of flow of curr in the instrument is same for both conditions i.e when terminal X is positive and terminal Y i -ve and vice versa.

⇒ The PMMC instrument reads the mean value the instrument is calibrated to read the rms

⇒ For measurement of voltage a suitable series resistance is placed on the alternating circuit side of the rectifier as shown in the figure.

⇒ For current measurement they find their greatest use as milliammeters.

Factors affecting the performance of rectifier type instrument.

(i) Effect of wave form
(ii) Effect of temperature changes
(iii) Effect of rectifier capacitance
(iv) Decrease in sensitivity

Ranges :- (i) 0-100 μA ; upto 0 - 100 mA
(ii) 0-1.0V upto 0.230 V without external resistance
(iii) frequency range 20 - 20,000Hz

Merits :-

⇒ The instrument can be employed at frequencies well above the range of other ac instruments of the ordinary type

⇒ These instrument have a very low power consumption.

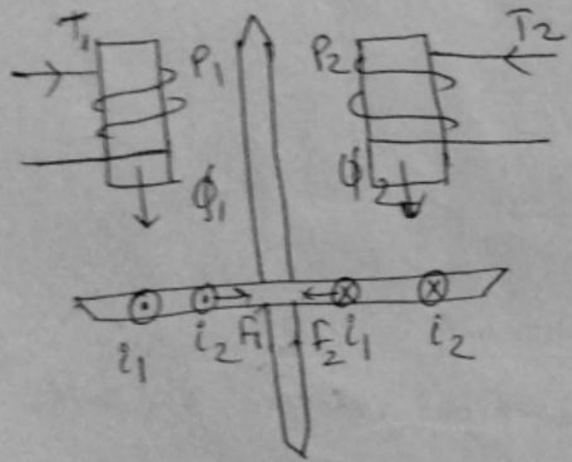
⇒ High Sensitivity

Induction Type Instruments :-

⇒ Induction type instruments are used only for a.c. measurements can be used either as ammeter, voltm or wattmeter.

⇒ In such instrument the deflecting torque is produced due to the reaction between the flux of an a.c magnet and the eddy currents induced by this fl

Principle :-



⇒ The operation of all induction instruments depen on the production of torqu due to the reaction betⁿ a flux ϕ_1 and eddy current induced in a metal disc by another flux ϕ_2.

⇒ Since the magnitude of eddy currents also depend on the flux producing them, the instantaneous valu of torque is propotional to the square of curren or voltage under measurement.

⇒ ~~And~~

⇒ Consider a thin alluminium or cu disc 'D' free rotate about an ~~axix~~ axis passing through its centre.

⇒ Two a.c magnet poles P_1 and P_2 Produce alternat flux ϕ_1 and ϕ_2 respectively.

→ Consider any portion of the disc around P_1 which will be linked by flux ϕ_1 and so an a.c emf e_1 be induced in it.

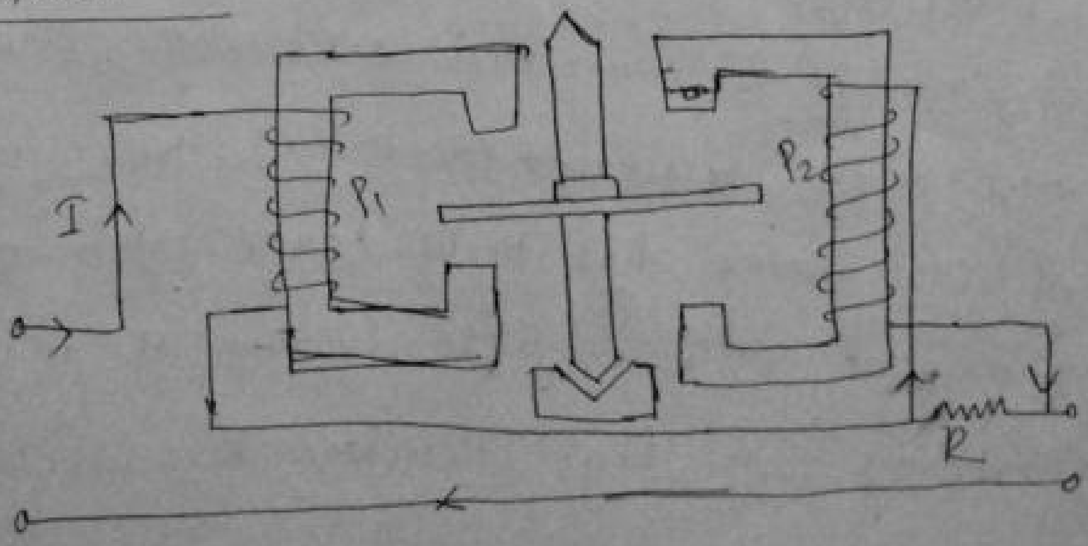
→ this emf will circulate an eddy current i_1 will pass under P_2.

→ Similarly ϕ_2 will induced and emf e_2 which will further induce an eddy current i_2 in an portion of the disc around P_2. This eddy current i_2 flows under pole P_1

→ Let us take the downword direction of fluxes as positive and further assume that at the instant under consideration both ϕ_1 and ϕ_2 are increasing.

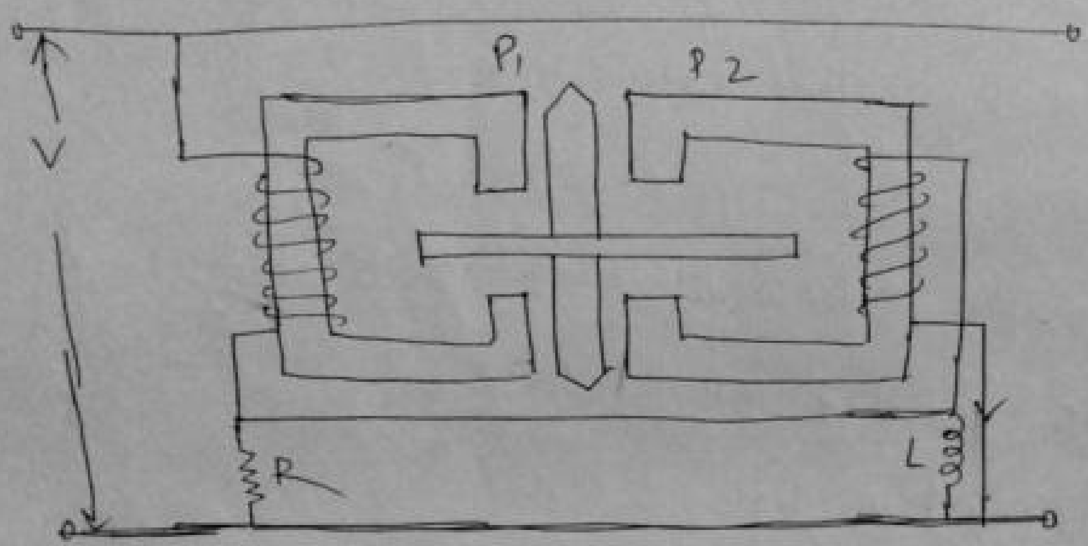
→ By applying Lenz's law the direction of induced current i_1 and i_2 can be found.

<u>Induction Ammeter</u> :-



-> The winding of two laminated a.c magnets P_1, P_2 are connected in series. But the winding of P_2 is shunted by a resistance R with the result that the current in this winding lags with respect to the total line current.

Induction Voltmeter



=> Its construction is similar to that of an ammeter except for the difference that its winding is wound with a large number of turns of fine wires

=> Since it is connected across the lines and carries very small current (5 - 100 mA), the number of turns of its wire has to be large in order to produce an adequate amount of m.m.f by connecting a high resistance R in series with

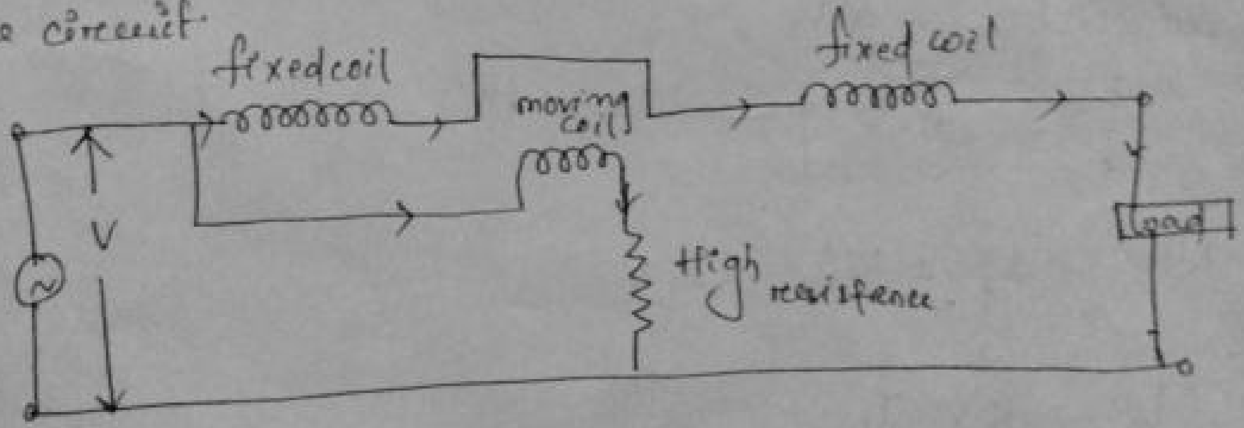
Wattmeters and measurement of Power

Dynamometer type Wattmeter :-

⇒ This instrument is similar in design and principle to the dynamometer type ammeter and voltmeter.

⇒ When the instrument of this type is used as wattmeter, the fixed coil which is divided into two equal portions in order to provide uniform field, is employed as current coil and the moving coil is used as a pressure coil.

⇒ The fixed coil carries the current flowing through the circuit and the moving coil carries the current proportional to the voltage across the circuit.



⇒ A high non inductive resistance is connected in series with the moving coil in order to limit the current in it.

⇒ The magnetic field of the fixed and moving coils react on one another causing the moving coil to turn about its axis.

⇒ Let the I_1 is the current flowing through the current coil and I_2 is the current flowing through the pressure coil.

⇒ Current I_2 is led into the moving coil which supply necessary controlling torque.

Deflecting torque:

Since coils are air cored, the flux density produced is directly proportional to the current.

$$B \propto I_1$$

$$\boxed{B = K_1 I_1} \quad \text{——— (i)}$$

current $I_2 \propto V$

$$\boxed{I_2 = K_2 V} \quad \text{——— (ii)}$$

Now $T_d = BI_2 \propto I_1 V$

$$T_d = KV \cdot I_1$$

$$\boxed{T_d = K \times \text{power}}$$

In d.c circuits, power is given by the product of voltage and current in amperes.

Hence torque is directly proportional to the power.

...re a.c supply the value of instantaneous torque ...s given by

$$T_{inst} \propto vi = Kvi$$

where v = instantaneous value of voltage across the moving coil.
i = instantaneous value of current across the fixed coil

⇒ The instrument indicates the mean or average power

Mean deflecting torque $T_m \propto$ average value of vi

Let $v = V_{max} \sin\theta$ and $i = I_{max} \sin(\theta - \phi)$

$$\therefore T_m \propto \frac{1}{2\pi} \int_0^{2\pi} V_{max} \sin\theta \times I_{max} \sin(\theta - \phi)\, d\theta$$

$$\Rightarrow T_m \propto \frac{V_{max} \cdot I_{max}}{2\pi} \int_0^{2\pi} \sin\theta \sin(\theta - \phi)\, d\theta$$

$$\Rightarrow T_m \propto \frac{V_{max} \cdot I_{max}}{2\pi} \int_0^{2\pi} \frac{\cos\phi - \cos(2\theta - \phi)}{2}\, d\theta$$

$$\Rightarrow T_m \propto \frac{V_{max} \cdot I_{max}}{4\pi} \left[\theta \cos\phi - \frac{\sin(2\theta - \phi)}{2} \right]_0^{2\pi}$$

$\Rightarrow T_m \propto \frac{V_{max}}{\sqrt{2}} \cdot \frac{I_{max}}{\sqrt{2}} \cos\phi$

$\Rightarrow T_m \propto VI\cos\phi$ where V and I are the rms values

So the deflection is proportional to the the power in the circuit.

Advantages and disadvantages:-

⇒ By careful design, such instruments can be built to give a very high degree of accura

⇒ they are equally accurate on dc as well a.c circuits.

⇒ At low power factor the inductance of the voltage coil causes serious error unless special precautions are taken.

Errors In dynamometer type Wattmeters

1. Error due to inductance of pressure coil:-

Inductance of pressure coil may cause an in the reading of the wattmeter, hence it essential to ~~studdy~~ study the effect of indu of pressure coil on wattmeter reading.

Errores due to pressure coil capacitance:-

the pressure coil circuit may have capacitance also in addition to inductance.

Due to capacitance of pressure coil circuits, the pressure coil current will tend to lead the supply voltage

If the capacitive reactance = Inductive reactance in the pressure coil circuit then the error will be completely eliminated and the instrument will give correct reading.

Errores due to eddy current:-

the alternating magnetic field of current coil induces eddy currents in the solid metal parts nearby the current coil.

These eddy currents set up their own magnetic field. Thus error is introduced in the instrument.

If the wattmeter current is designed for heavy currents, it should consist of standard conductors in order to minimise the eddy currents flowing in the conductors of the current coil itself.

4. Error due to power loss in pressure coil :-

=> The current coil carries the current equal to lo[ad]
current plus potential coil current.

=> Hence the wattmeter measures the load power plus
power lost in the pressure coil.

=> Compensating winding are used to overcome t[he]
error.

5. Error due to friction:

=> The frictional error becomes relatively impor[tant]
in wattmeters due to availability of small
deflecting torque.

=> In order to reduce friction error it becom[es]
necessary that the weight of the moving syste[m]
be reduced to the minimum possible on one
hand. and great care be taken in the pivot
on there hand.

6. Error due to heating: Heating Errore is m[ainly]
due to pressure circuit, which carries a curre[nt]
propotional to the potential difference across
its terminals and inversly proportional to i[ts]

impedence.

- the resistance of the circuit should remain sensibly constant at all temperatures with in the operating range
- This type of error is very small.
- It is necessary to reduce the inductive error by winding the pressure coil with as few turns as possible.

Errors due to ~~mutual~~ mutual inductance effect:-

- Errors are caused due to mutual inductance between current and potential coil of the instrument.
- These errors are quite small at power frequencies but increase and relatively significant with the increase in frequency.
- wattmeters have now been developed whose coil system are so arranged that they are always in zero position of mutual inductance. and thus are free from errors.

~~Errors caused~~

(8) Errors caused due to vibration of moving system

=> Such an error is prevalent in a.c. The torque on moving system varies cyclically with a frequency which is twice that of voltage.

=> Vibration not only make the pointer position difficult to read.

=> These vibrations are avoided by designing the instrument in such a way that the natural frequ[ency] of the moving system is very much different from twice the frequency of the system. on which the instrument is intended to be used.

(9) Error Due to stray fields:-

=> External field may cause serious errors in th[e] ordinary types of non-static dynamometer wattme[ters] unless shielded either by means of an iron case o[r] by a laminated shield.

=> The presence of such stray field may be easily detected by the deflection of the instrument

In order to reduce that the presence of the cover tends to increase the working fields and the instrument reads higher with it in position, and this fact must be taken into account in the final calibration.

If well carried out, the iron case appears to be enough capable of reducing the stray field.

Induction Wattmeters

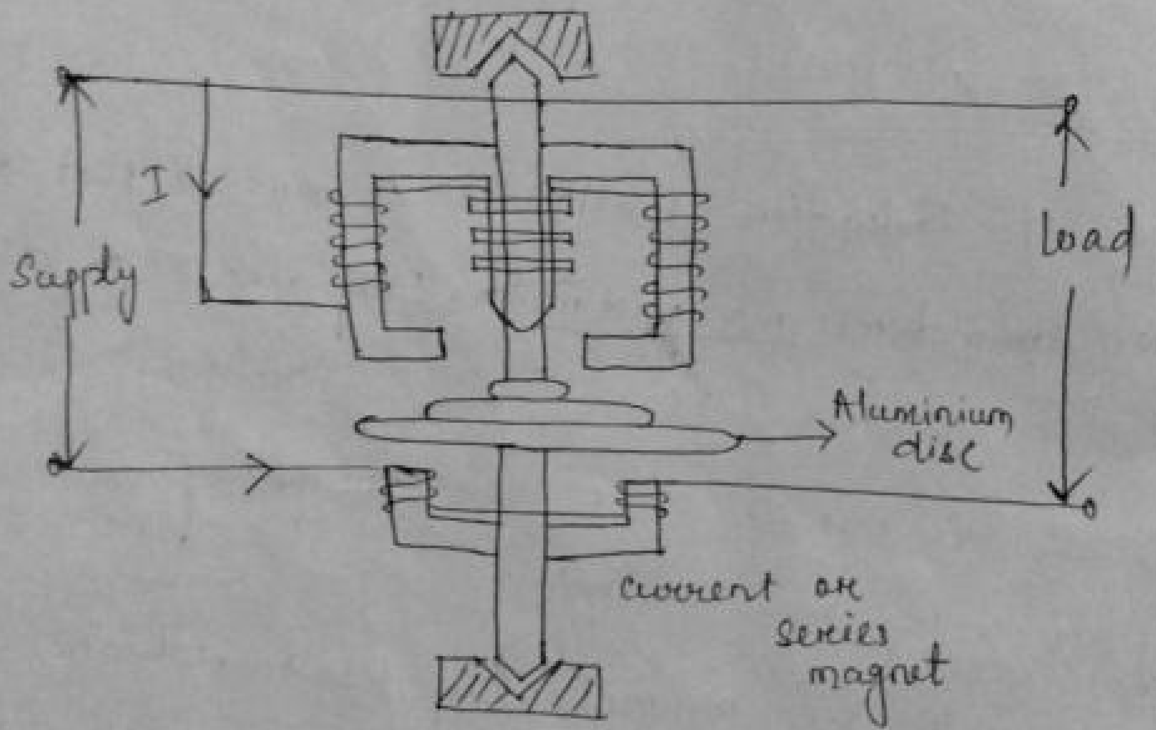
Principle of induction wattmeter is same as that of induction ammeters and voltmeters (Explained in CH-2)
⇒ They can be used on a.c supply only. Induction wattmeters are useful when the frequency and supply voltage are constant.
⇒ Two separate a.c. magnets are used, which produce two fluxes, which have the required phase difference.

Construction :-

⇒ The wattmeter has two laminated electromagnets one of which is excited by the current in the main circuit exciting winding being joined in series with the circuit, hence it is also called series magnet.

⇒ The other is excited by current which is proportional to the voltage of the circuit.

⇒ Its exciting coil is joined in parallel with the circuits hence this magnet is sometimes reffered to as shunt magnet.



⇒ A thin aluminium disc is so mounted that it cuts the fluxes of both the magnets. Hence two eddy currents are produced in the disc.

⇒ The deflection torque is produced due to the interaction of these eddy currents and the inducing fluxes.

Two or three copper rings are fitted on the central limb of the shunt magnet and can be so adjusted as to make the resultant flux in the shunt magnet lag behind the applied voltage by 90°.

In the fig. two pressure coils are joined in series and are so wound that both send the flux through the central limb in the same direction.

The series magnet carries two coils joined in series and so wound that they magnetise their respective cores in the same direction.

Correct phase ~~difference~~ displacement between the shunt and series magnet fluxes can be obtained by adjusting the position of the copper band.

Advantage :-

⇒ The wattmeter posses the advantage of fairly long scale.

⇒ They are free from the effects of stray field

⇒ Good damping

=> free from frequency error.

<u>Disadvantage :-</u>

=> They are subjected to series temperature error because the main effect of temperature is on the resistance of the eddy current paths.

Energy meter AND Measurement of Energy

CH-4
EMI-SONALI

Introduction :- Electrical energy is measured by means of energy meter (watt-hour meter).

→ Energy meter is an integrating instrument and takes into account both the quantities that is the power and time, the product of which gives energy.

→ An energy meter keeps a record of total energy consumed in a circuit during a particular period.

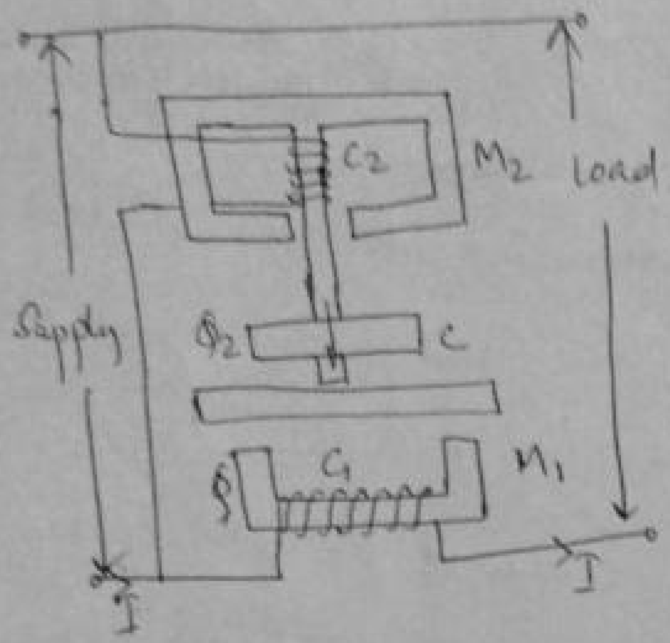
→ Energy meters are generally of three types
(i) electrolytic meter (ii) Motor meters (iii) clock meter.

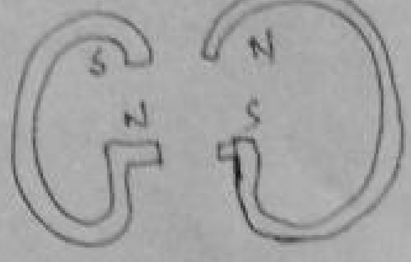
Single phase Induction type energy Meter :

Induction type meters are the most common from of a.c meters met with in everyday domestic and industrial installation.

→ These meters measure electric energy in kilo-watt hour
The principle is same as that of induction wattmeter.

Construction And working :





breaking magnet

→ Constrecctionally we use a breake magnet and spin

→ the breake magnet induce eddy current in the dis which revolves continuously instead of rotating through only a fraction of a revolution as in case of wattmeter.

→ The meter consist of two electromagnets. One of which is M_1 is excited by the line current I & known as series magnet.

→ The winding of other magnet M_2 called shunt magnet is connected across the supply line and carries current propotional to the supply voltage

→ the alternating flux ϕ_1 produced by it is propotional and in phase with the line current.

flux ϕ_2 produced by its ∝ proportional
the supply voltage v. and lags behind it by 90°,
which is obtained by adjusting the copper standing
bands 'C'.

Majore portion of ϕ_2 crosses the narrow gap betⁿ
the centre and side limbs of M_2 but a small amount,
which is ~~obtained~~ the useful flux, passes through the
disc 'D'.

The two fluxes ϕ_1 and ϕ_2 induce emfs in the
disc which further produce the circulatory eddy
currents.

The reaction betⁿ these fluxes and eddy current
produces the driving torque on the disc.

The breaking torque is produced by a pair of
magnets called breaking magnet. They are mounted
diametrically opposite to the magnets M_1 and M_2
This arrangement minimize the interaction
between the fluxes of M_1 and M_2 and that of the
breaking magnet.

Breaking Torque $T_B \propto \phi^2 \frac{N}{R}$

where ϕ = flux of breaking magnet

N = speed of the rotating disc

R = resistance of eddy current path

If ϕ & R is constant

$\Rightarrow T_B \propto N$.

<u>Theory</u>:-

driving torque $T_d \propto \omega \phi_{1m} \phi_{2m} \sin\alpha$

where ϕ_{1m} and ϕ_{2m} are the maximum fluxes p

produced by M_1 and M_2

α = angle between these fluxes

current through winding of $M_1 = I$

Current through winding of $M_2 = \frac{V}{WL}$

$\Rightarrow \alpha = 90 - \phi$, ϕ is the load p.f angle

$T_d \propto \omega \cdot \frac{V}{\omega L} \cdot I \cos(90-\phi) \propto VI \cos\phi$

Also $T_B \propto N$

$\rightarrow$ The disc achieves a steady speed N when the two torque are equal i.e when

$T_d = T_B$

$\therefore N \propto$ Power W

→ In a given period of time, the total number of revolution $\int_0^t N dt$ is proportional to $\int_0^t W dt$ i.e electric energy consumed.

Methods of Testing of Energy meters :-

There are three methods of testing of Energy meter.

1) Method-A - long Period Dial Test :-

→ In this method of testing energy meters, a rotating meter is employed to measure the amount of energy by passing through the meter under test during a given time.

→ The current coil of two meters are connected in series with each other and in series with the load circuit.

→ The voltage circuits of two meters are connected in parallel across the supply circuit.

→ The two meters are started simultaneously and after suitable time interval, stopped simultaneously.

→ the duration of the test must be long enough for the register of the meter to advance by at least 10 revolutions of the pointer on its lowest reading dial.

Percentage error of the meter under test can be calculated from the relation

$$\% \text{ error} = \frac{R-r}{r} \times 100$$

where R and r are the readings of the test and standa meter respectively.

Method B- Short period Test using a Rotating substandard :-

→ In this method of testing of energy meter, a sub-standard rotating meter of precision type is employe to measure the amount of energy passing through the meter under test for a stated number of revolution of the disc of the meter under test.

→ The scale of standard meter's largest dial is subdivided so that the position of its pointer can read to $\frac{1}{100}$ th of a revolution of the meter disc.

→ An arrangement is also fitted so that the register of the standard and test meters can b started and stopped instantaneously. The thr lowest reading pointers can be reset to zero.

→ After adjusting the load to the required value, t meter under test is allowed to make a certain number of revolution and the number of revoluti made by the standard in the same time are observed.

If the constants of both meters are the same, the error in the meter being tested can be obtained directly and if the constants of meters are different then the error of the meter under test can be found as follows.

Let K_x = no. of revolution per KWh for meter under test

K_s = no. of revolution per KWh for the standard

N_s = no. of revolution made by the standard during the time the meter under test takes to complete certain number of revolution (N)

Now energy supplied = Energy indicated by the standard

$$= \frac{N_s}{K_s} \text{ KWh}$$

Energy indicated by meter under test $= \frac{N_x}{K_x}$ KWh

$$\% \text{ error} = \frac{\frac{N_x}{K_x} - \frac{N_s}{K_s}}{\frac{N_s}{K_s}} \times 100$$

$$= \left(\frac{N_x K_s}{N_s K_x} - 1\right) \times 100$$

Method-C

Short period test Using a standard wattmeter :-

→ This is the alone method which is to be used for testing direct current motor meters.

→ In this method of testing of meters precision grade indicating instruments are employed as the standard of reference and are connected in the circuit with the meter under test

→ The time taken by the rotor test disc of the meter under test to complete three revolution. or number of revolution that will make the test period not less than 100 seconds is measured.

→ The current and voltage are maintained constant during the test

% error of meter under test is given by

$$\% \text{ error} = \frac{\frac{N_x}{K_x} - \frac{K_W \times t}{3,600}}{\frac{K_W \times t}{3600}} \times 100$$

$$= \left(\frac{N_x \times 3600}{K_x \times K_W \times t} - 1\right) \times 100$$