

UNIT 2 ELECTRICAL MEASUREMENTS

Units of voltage and current - principle of operation of D'Arsonval Galvanometer - principle, operation, constructional details and comparison of the following: permanent magnet moving coil, permanent magnet moving iron, Dynamometer, Induction, thermal and rectifier type instruments, Power measurement - Voltmeter ammeter method, Ammeter voltmeter method, Electro-dynamic wattmeter - Low power factor wattmeter

Current

Current is the rate at which electric charge flows past a point in a circuit. Symbol is I and unit is A or amps

Voltage

Voltage is the electrical force that would drive an electric current between two points. And symbol is v units is volts or voltage

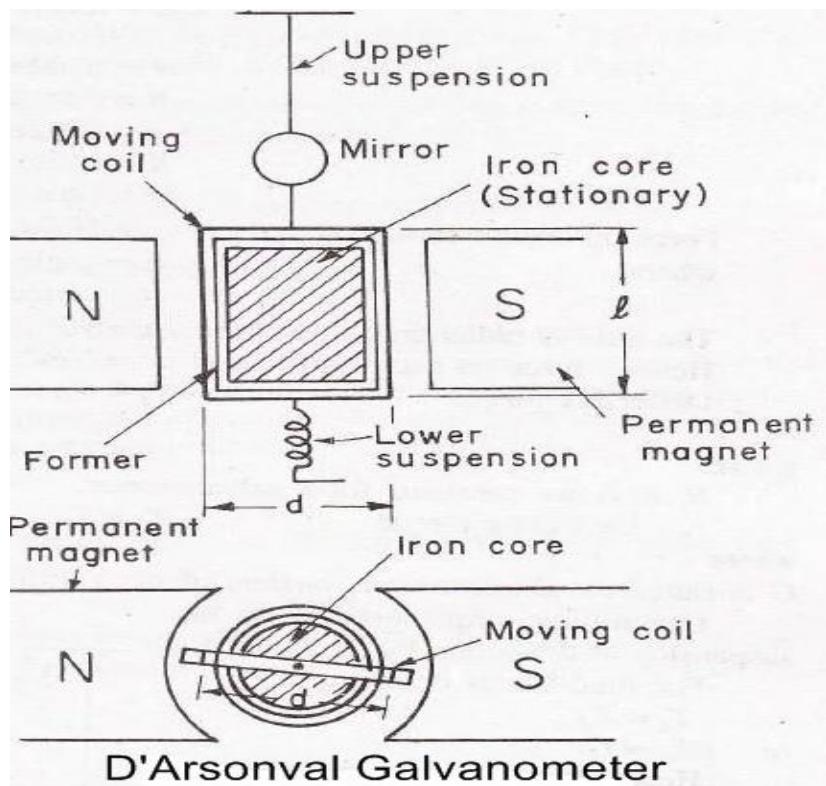
PRINCIPLE OF D'ARSONVAL GALVANOMETER

An action caused by electromagnetic deflection, using a coil of wire and a magnetized field. When current passes through the coil, a needle is deflected. Whenever electrons flow through a conductor, a magnetic field proportional to the current is created. This effect is useful for measuring current and is employed in many practical meters.

Moving Coil:

It is the current carrying element. It is either rectangular or circular in shape and consists of number of turns of fine wire. This coil is suspended so that it is free to turn about its vertical axis of symmetry. It is arranged in a uniform, radial, horizontal magnetic field in the air gap between pole pieces of a permanent magnet and iron core. The iron core is spherical in shape if the coil is circular but is cylindrical if the coil is rectangular. The iron core is used to provide a flux path of low reluctance and therefore to provide strong magnetic field for the coil to move in. this increases the deflecting torque and hence the sensitivity of the galvanometer. The length of air gap is about

1.5mm. In some galvanometers the iron core is omitted resulting in a decreased value of flux density and the coil is made narrower to decrease the air gap. Such a galvanometer is less sensitive, but its moment of inertia is smaller on account of its reduced radius and consequently a short periodic time.



2) Damping:

There is a damping torque present owing to production of eddy currents in the metal former on which the coil is mounted. Damping is also obtained by connecting a low resistance across the galvanometer terminals. Damping torque depends upon the resistance and we can obtain critical damping by adjusting the value of resistance.

3) Suspension:

The coil is supported by a flat ribbon suspension which also carries current to the coil. The other current connection in a sensitive galvanometer is a coiled wire. This is called the lower suspension and has a negligible torque effect. This type of galvanometer must be leveled carefully so that the coil hangs straight and centrally without rubbing the

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poles or the soft iron cylinder. Some portable galvanometers which do not require exact leveling have "taut suspensions" consisting of straight flat strips kept under tension for at the both top and at the bottom.

The upper suspension consists of gold or copper wire of nearly 0.012-5 or 0.02-5 mm diameter rolled into the form of a ribbon. This is not very strong mechanically; so that the galvanometers must be handled carefully without jerks. Sensitive galvanometers are provided with coil clamps to the strain from suspension, while the galvanometer is being moved.

4) Indication:

The suspension carries a small mirror upon which a beam of light is cast. The beam of light is reflected on a scale upon which the deflection is measured. This scale is usually about 1 meter away from the instrument, although $\frac{1}{2}$ meter may be used for greater compactness.

5) Zero Setting:

A torsion head is provided for adjusting the position of the coil and also for zero setting.

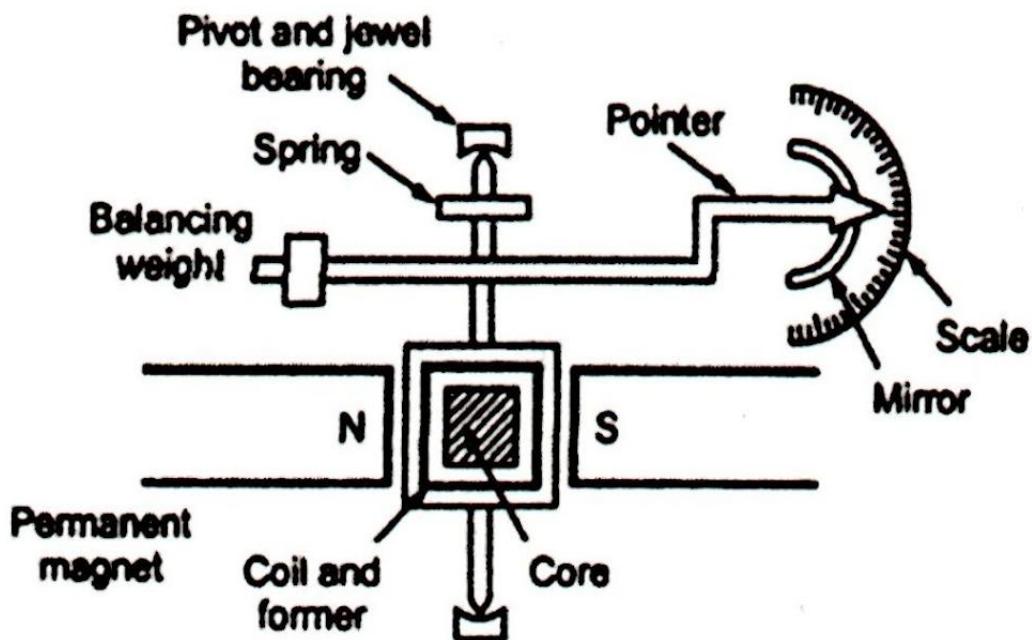
Operation

When a current flows through the coil, the coil generates a magnetic field. This field acts against the permanent magnet. The coil twists, pushing against the spring, and moves the pointer. The hand points at a scale indicating the electric current. Careful design of the pole pieces ensures that the magnetic field is uniform, so that the angular deflection of the pointer is proportional to the current. A useful meter generally contains provision for damping the mechanical resonance of the moving coil and pointer, so that the pointer settles quickly to its position without oscillation

PERMANENT MAGNET MOVING COIL INSTRUMENT

Principle of moving coil instrument

Moving coil instrument depends on the principle that when a current carrying conductor is placed on a magnetic field, mechanical force acts on the conductor. The coil placed on the magnetic field and carrying operating current is attached to the moving system. With the movement of the coil the pointer moves over the scale.



Construction of PMMC instrument

Moving coil instrument consists of a powerful permanent magnet with soft iron pieces and light rectangular coil of many turns of fine wire wound on aluminum former inside which is an iron core as shown in the figure. As it uses permanent magnets they are called "**Permanent magnet moving coil instrument**". The purpose of the coil is to make the field uniform. The coil is mounted on the spindle and acts as the moving element. The current is led into and out of the coil by means of the two control hair

springs, one above and the other below the coil. The springs also provides the controlling torque. damping torque is provide by eddy current damping.

Working of PMMC instrument

when the moving coil instrument is connected in the circuit, operating current flows through the coil. This current carrying coil is placed in the magnetic field produced by the permanent magnet and therefore, mechanical force acts on the coil. As the coil attached to the moving system, the pointer moves over the scale. It may be noted here that if current direction is reversed the torque will also be reversed since the direction of the field of permanent magnet is same. Hence, the pointer will move in the opposite direction, i.e it will go on the wrong side of zero. In other words, these instruments work only when current in the circuit is passed in a definite direction i.e. for d.c only. So it is called permanent magnet moving coil instruments because a coil moves in the field of a permanent magnet.

Torque Equation for PMMC

The equation for the developed torque of the PMMC can be obtained from the basic law of electromagnetic torque.

The deflecting torque is given by,

$$T_d = N B A I$$

Where, T_d = deflecting torque in N-m

B = flux density in air gap, Wb/m²

N = Number of turns of the coils

A = effective area of coil m²

I = current in the moving coil, amperes

Therefore, $T_d = G I$

Where, $G = N B A = \text{constant}$

The controlling torque is provided by the springs and is proportional 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

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For the final steady state position,

$$T_d = T_c$$

$$\text{Therefore } GI = K\emptyset$$

$$\text{So, } \emptyset = (G/K)I \text{ or } I = (K/G) \emptyset$$

Thus the deflection is directly proportional to the current passing through the coil. The pointer deflection can therefore be used to measure current.

Advantage of PMMC instrument

1. Uniform scale.
2. Very effective eddy current damping
3. Power consumption is low.
4. No hysteresis loss.
5. They are not affected by stray field.
6. Require small operating current.
7. Accurate and reliable.

Disadvantage of PMMC instrument

1. Only used for D.C measurement.
2. Costlier compared to moving iron instrument.
3. Some errors are caused due to the aging of the control springs and the permanent magnets.

MOVING IRON INSTRUMENT

There are classified in to two type

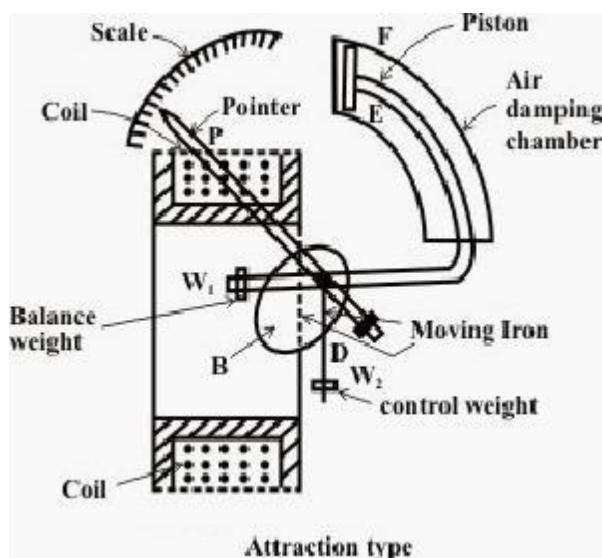
1. Attraction type moving iron instrument
2. Repulsion type moving iron instrument

Attraction type moving iron instrument

Principle of attraction type moving iron instrument

An “attraction type” moving-iron instrument consists of a coil, through which the test current is passed, and a pivoted soft-iron mass attached to the pointer. The resulting magnetic polarity at the end of the coil nearest the iron mass then induces the opposite magnetic polarity into the part of the iron mass nearest the coil, which is then drawn by attraction towards the coil, deflecting the pointer across a scale.

The coil is flat and has a narrow slot like opening. The moving iron is a flat disc or a sector eccentrically mounted. · When the current flows through the coil, a magnetic field is produced and the moving iron moves from the weaker field outside the coil to the stronger field inside it or in other words the moving iron is attracted in. · The controlling torque is provided by springs but gravity control can be used for panel type of instruments which are vertically mounted. · Damping is provided by air friction with the help of a light aluminium piston (attached to the moving system) which move in a fixed



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chamber closed at one end as shown in Fig. or with the help of a vane (attached to the moving system) which moves in a fixed sector shaped chamber a shown.

operation

The current to be measured is passed through the fixed coil. As the current is flow through the fixed coil, a magnetic field is produced. By magnetic induction the moving iron gets magnetized. The north pole of moving coil is attracted by the south pole of fixed coil. Thus the deflecting force is produced due to force of attraction. Since the moving iron is attached with the spindle, the spindle rotates and the pointer moves over the calibrated scale. But the force of attraction depends on the current flowing through the coil.

The force F , pulling the soft -iron piece towards the coil is directly proportional to;

- a) Field strength H , produced by the coil.
- b) pole strength „ m “ developed in the iron piece.

$$F \propto mH$$

Since, $m \propto H$,

$$F \propto H^2$$

Instantaneous deflecting torque $\propto H^2$

Also, the field strength $H = \mu i$

If the permeability(μ) of the iron is assumed constant,

Then, $H \propto i$

Where, i ® instantaneous coil current, Ampere

Instantaneous deflecting torque $\propto i^2$

Average deflecting torque, $T_d \propto$ mean of i^2 over a cycle.

Since the instrument is spring controlled,

$$T_c \propto \theta$$

In the steady position of deflection, $T_d = T_c$

$\theta \propto$ mean of i^2 over a cycle

$$\propto I^2$$

Since the deflection is proportional to the square of coil current, the scale of such instruments is non-uniform (being crowded in the beginning and spread out near the finishing end of the scale).

Moving iron repulsion type instrument

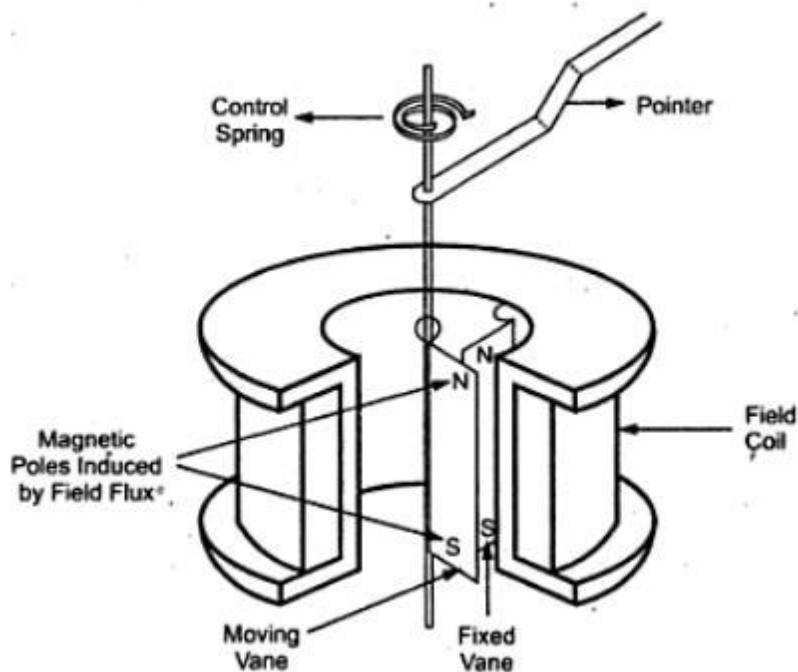
These instruments have two vanes inside the coil, the one is fixed and other is movable. When the current flows in the coil, both the vanes are magnetized with like polarities induced on the same side. Hence due to repulsion of like polarities, there is a force of repulsion between the two vanes causing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

The two different designs of repulsion type instruments are:

- i) Radial vane type and
- ii) Co-axial vane type

Radial vanes repulsion type instrument

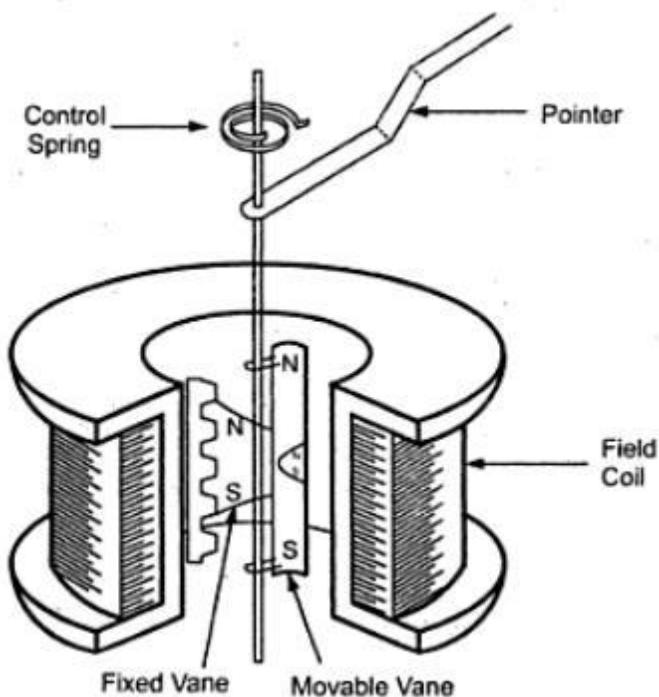
Out of the other moving iron mechanism, this is the most sensitive and has most linear scale. The two vanes are radial strips of iron. The fixed vane is attached to the coil. The movable vane is attached to the spindle and suspended in the induction field of the coil. The needle of the instrument is attached to this vane. Even though the current through the coil is alternating, there is always repulsion between the like poles of the fixed and the movable vane. Hence the deflection of the



pointer is always in the same direction. The deflection is effectively proportional to the actual current and hence the scale is calibrated directly to rad amperes or volts. The calibration is accurate only for the frequency for which it is designed because the impedance is different for different frequencies

Concentric vane repulsion type instrument

The instrument has two concentric vanes. One is attached to the coil frame rigidly while the other can rotate coaxially inside the stationary vane. Both the vanes are magnetized to the same polarity due to the current in the coil. Thus the movable vane rotates under the repulsive force. The movable vane is attached to the pivoted shaft, the repulsion results in a rotation of the shaft. The pointer deflection is proportional to the current in the coil. The concentric vane type instrument is moderately sensitive and the deflection is proportional to the square of the current through coil. Thus the instrument said to have square law response. Thus the scale of the instrument



is non-uniform in nature. Thus whatever may be the direction of the current in the coil, the deflection in the moving iron instruments is in the same direction. Hence moving iron instruments can be used for both a.c. and d.c. measurements. Due to square law response, the scale of the moving iron instrument is non-uniform.

Torque equation

The deflecting torque results due to repulsion between the similarly charged soft- iron pieces or vanes. If the two pieces develop pole strength of m_1 and m_2 respectively, then;

$$\text{Instantaneous deflecting torque } \propto m_1 m_2 \propto H^2$$

If the permeability of iron is assumed constant, then; $H \propto i$, where, i is the coil current

$$\text{Instantaneous deflecting torque } \propto i^2$$

Average deflecting torque, $T_d \propto \text{mean of } i^2 \text{ over a cycle.}$

Since the instrument is spring controlled, $T_c \propto \theta$

In the steady position of deflection, $T_d = T_c$

$\theta \propto \text{mean of } i^2 \text{ over a cycle.}$

$$\propto I^2$$

Thus, the deflection is proportional to the square of the coil current. The scale of the instrument is non- uniform; being crowded in the beginning and spread out near the finish end of the scale. However, the non- linearity of the scale can be corrected to some extent by the accurate shaping and positioning of the iron vanes in relation to the operating coil.

Advantages

- 1) The instruments can be used for both a.c. and d.c. measurements.
- 2) As the torque to weight ratio is high, errors due to the friction are very less.
- 3) A single type of moving element can cover the wide range hence these instruments are cheaper than other types of instruments.
- 4) There are no current carrying parts in the moving system hence these meters are extremely rugged and reliable.
- 5) These are capable of giving good accuracy. Modern moving iron instruments have a d.c. error of 2% or less.

- 6) These can withstand large loads and are not damaged even under sever overload conditions.
- 7) The range of instruments can be extended.

Disadvantages

- 1) The scale of moving iron instruments is not uniform and is cramped at the lower end. Hence accurate readings are not possible at this end.
- 2) There are serious errors due to hysteresis, frequency changes and stray magnetic fields.
- 3) The increase in temperature increases the resistance of coil, decreases stiffness of the springs, decreases the permeability and hence affect the reading severely.
- 4) Due to the non linearity of B-H curve, the deflecting torque is not exactly proportional to the square of the current.
- 5) There is a difference between a.c. and d.c. calibration on account of the effect of inductance of the meter. Hence these meters must always be calibrated at the frequency at which they are to be used. The usual commercial moving iron instrument may be used within its specified accuracy from 25 to 125 HZ frequency range.
- 6) Power consumption is on higher side.

Errors in moving iron instrument

1) Hysteresis error: Due to hysteresis effect, the flux density for the same current while ascending and descending values is different. While descending, the flux density is higher and while ascending it is lesser. So meter reads higher for descending values of current or voltage. So remedy for this is to use smaller iron parts which can demagnetise quickly or to work with lower flux densities.

2) Temperature error : The temperature error arises due to the effect of temperature on the temperature coefficient of the spring. This error is of the order of 0.02 % per oC change in temperature. Errors can cause due to self heating of the coil and due to which change in resistance of the coil. So coil and series resistance must have low temperature coefficient. Hence mangnin is generally used for the series resistance.

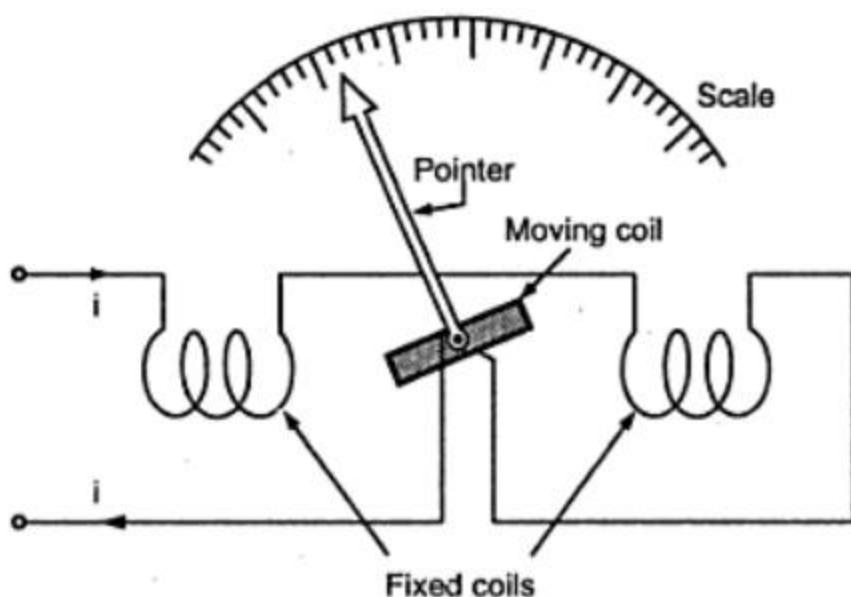
3) Stray magnetic Field Error : The operating magnetic field in case of moving iron instruments is very low. Hence effect of external i.e. stray magnetic field can cause

error. This effect depends on the direction of the stray magnetic field with respect to the operating field of the instrument.

4) Frequency Error : These are related to a.c. operation of the instrument. The change in frequency affects the reactance of the working coil and also affects the magnitude of the eddy currents. This cause error in the instrument.

5) Eddy Current Error : When instrument is used for a.c. measurements the eddy currents are produced in the iron parts of the instrument. The eddy current affects the instrument current causing the change in the deflection torque. This produce the error in the meter reading. As eddy current are frequency dependent, frequency changes cause eddy current error.

DYNAMAMOMETER



Construction

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 center 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 wattmeters it is wound with heavy

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wire. The coils are usually varnished. They are clamped in place against the coil supports. This makes the construction rigid.

Ceramic is usually used for mounting supports. If metal parts would have been used then it would weaken the field of the fixed coil.

Moving Coil : The moving coil is wound either as a self-sustaining coil or else on a non-metallic former. If metallic former is used, then it would induce eddy currents in it. The construction of moving coil is made light as well as rigid. It is air cored.

Controlling : The controlling torque is provided by springs. These springs act as leads to the moving coil.

Moving System : The moving coil is mounted on an aluminium spindle. It consists of counter weights and pointer. Sometimes a suspension may be used, in case a high accuracy is desired.

Damping : The damping torque is provided by air friction, by a pair of aluminium vanes which are attached to the spindle at the bottom. They move in sector shaped chambers. As operating field would be distorted by eddy current damping, it is not employed.

Shielding : The field produced by these instruments is very weak. Even earth's magnetic field considerably affects the reading. So shielding is done to protect it from stray magnetic fields. It is done by enclosing in a casing high permeability alloy.

Cases and Scales : Laboratory standard instruments are usually contained in polished wooden or metal cases which are rigid. The case is supported by adjustable levelling screws. A spirit level may be provided to ensure proper levelling.

For using electrodynamometer instrument as ammeter, fixed and moving coils are connected in series and carry the same current. A suitable shunt is connected to these coils to limit current through them upto desired limit.

The electrodynamometer instruments can be used as a voltmeter by connecting the fixed and moving coils in series with a high non-inductive resistance. It is most accurate type of voltmeter.

For 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 coils acts as a voltage coil or pressure coil and must be connected across the supply terminals. The wattmeter indicates the supply power.

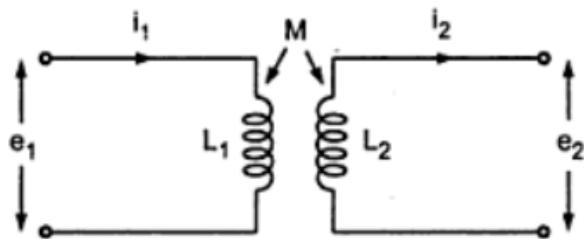
working

When current passes through the fixed and moving coils, both coils produce the magnetic fields. The field produced by fixed coil is proportional to the load current while the field produced by the moving coil is proportional to the voltage. As the deflecting torque is produced due to the interaction of these two fields, the deflection is proportional to the power supplied to the load.

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 coil L_2 = self inductance of moving coil M = Mutual inductance between fixed and moving coils

The electrodynamometer instrument can be represented by an equivalent circuit,



$$\text{Now } e_1 = \frac{d\phi_1}{dt}$$

$$\text{and } e_2 = \frac{d\phi_2}{dt}$$

$$\begin{aligned}
 \text{Electrical input energy} &= e_1 i_1 dt + e_2 i_2 dt \\
 &= i_1 \frac{d\phi_1}{dt} + i_2 \frac{d\phi_2}{dt} \\
 &= i_1 \frac{d}{dt} (L_1 i_1 + M i_2) + i_2 \frac{d}{dt} (L_2 i_2 + M i_1) \\
 &= i_1 L_1 d i_1 + i_1^2 d L_1 + i_1 i_2 d M + i_1 M d i_2 + \\
 &\quad i_2 L_2 d i_2 + i_2^2 d L_2 + i_1 i_2 d M + i_2 M d i_1 \quad \dots (1)
 \end{aligned}$$

The energy stored in the magnetic field due to L_1 , L_2 and M is given by,

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

$$\begin{aligned}
 \text{Change in stored energy} &= d \left[\frac{1}{2} L_1 i_1^2 + \frac{1}{2} L_2 i_2^2 + i_1 i_2 M \right] \\
 &= i_1 L_1 d i_1 + \frac{1}{2} i_1^2 d L_1 + i_2 L_2 d i_2 + \frac{1}{2} i_2^2 d L_2 + \\
 &\quad i_1 M d i_2 + i_2 M d i_1 + i_1 i_2 d M \quad \dots (2)
 \end{aligned}$$

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From the principle of conservation of energy,

Energy input=Energy stored + Mechanical energy

Mechanical energy=energy input-energy stored

Subtraction (2) from equation (1),

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

The self inductance L_1 and L_2 are constant and hence dL_1 and dL_2 are zero. Mechanical energy = $i_1 i_2 dM$

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

Mechanical energy = Mechanical work done

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

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

Advantage of Electrodynamometer instrument

- 1) As the coils are air cored, these instruments are free from hysteresis and eddy current losses.
- 2) They have a precision grade security.
- 3) These instruments can be used on both a.c. and d.c. They are also used as a transfer instruments.
- 4) Electrodynamometer voltmeter are very useful where accurate r.m.s values of voltage, irrespective of waveforms, are required.
- 5) Free from hysteresis errors.
- 6) Low power Consumption.
- 7) Light in weight.

Disadvantage of electrodynamometer instrument

- 1) These instruments have a low sensitivity due to a low torque to weight ratio. Also it introduces increased frictional losses. To get accurate results, these errors must be minimized.
- 2) They are more expensive than other type of instruments.
- 3) These instruments are sensitive to overload and mechanical impacts. Therefore care must be taken while handling them.
- 4) They have a nonuniform scale.
- 5) The operation current of these instruments is large due to the fact that they have weak magnetic field

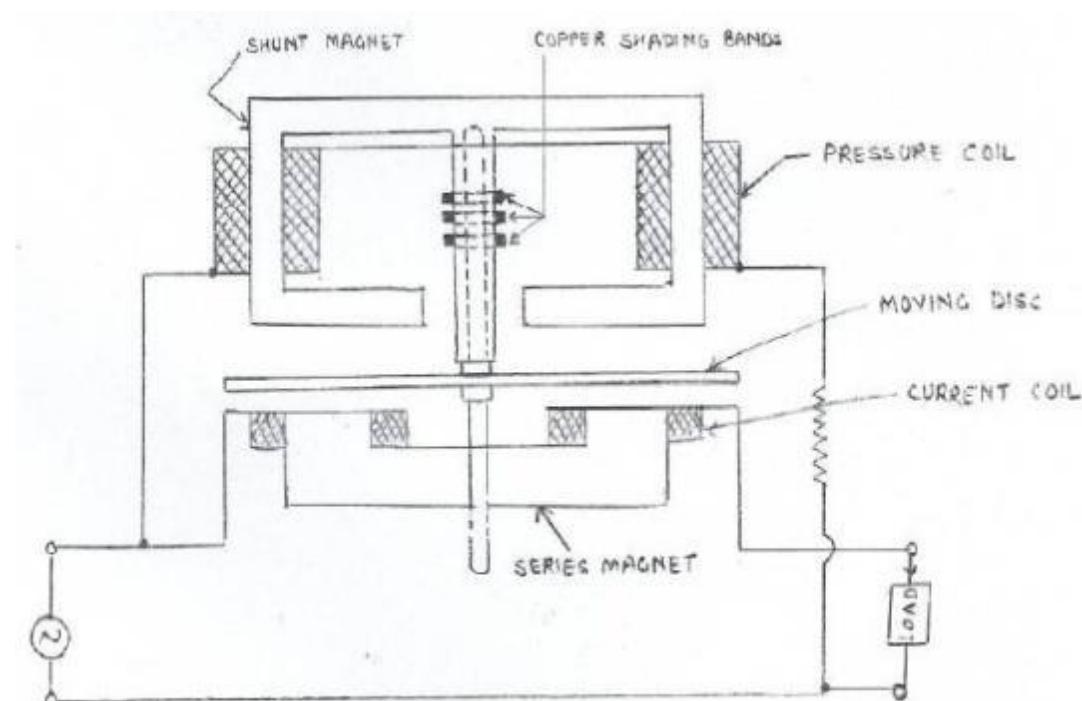
Error in electrodynamometer instrument

The various errors in electrodynamometer instruments are,

- 1. Torque to weight ratio :** To have reasonable deflecting torque, mmf of the moving coil must be large enough. Thus $m.m.f. = NI$ hence current through moving coil should be high or number of turns should be large. The current cannot be made very high because it may cause excessive heating of springs. Large number of turns hence is the only option but it increases weight of the coil. This makes the system heavy reducing torque to weight ratio. This can cause frictional errors in the reading
- 2. Frequency errors :** The changes in the frequency causes to change self inductances of moving coil and fixed coil. This causes the error in the reading. The frequency error can be reduced by having equal time constants for both fixed and moving coil circuits.
- 3. Eddy current errors :** In metal parts of the instrument the eddy current gets produced. The eddy current interacts with the instrument current, to cause change in the deflecting torque, to cause error. Hence metal parts should be kept as minimum as possible. Also the resistivity of the metal parts used must be high, to reduce the eddy currents.
- 4. Stray magnetic field error :** Similar to moving iron instruments the operating field in electrodynamometer instrument is very weak. Hence external magnetic field can interact with the operation field to cause change in the deflection, causing the error. To reduce the effect of stray magnetic field, the shields must be used for the instruments.

5. Temperature error : The temperature errors are caused due to the self heating of the coil, which causes change in the resistance of the coil. Thus temperature compensating resistors can be used in the precise instrument to eliminate the temperature errors.

INDUCTION TYPE INSTRUMENT



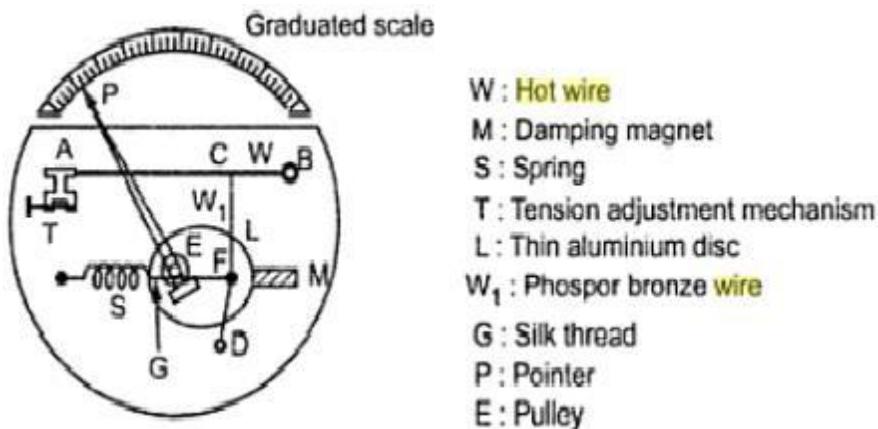
Induction Type Wattmeter

Induction type wattmeter consists of two laminate electromagnets known as shunt electromagnet and series electromagnet respectively. Shunt magnet is excited by the current proportional to the voltage across load flowing through the pressure coil and series magnet is excited by the current, proportional to the voltage across the load flowing through the pressure coil and series magnet is excited by the load current flowing through the current coil. A thin disc made of Cu or Al, pivoted at its centre, is placed between the shunt and series magnets so that it cuts the flux from both of the magnets. The deflection torque is produced by interaction of eddy current induced in the disc and the inducing flux in order to cause the resultant flux in shunt magnet to lag in

phase by exactly 90° behind the applied voltage, one or more copper rings, known as copper shading bond are provided on one limb at the shunt magnet. Correct disappointed between shunt and series magnet fluxes may be attained by adjusting the position of copper shading bonds. The pressure coil circuit of introduction type instrument is made

THERMAL TYPE INSTRUMENT

The hot wire instruments are based on the principle that length of wire increases due to heating effect when a current passed through it. It is a square law device with a non-linear relationship because increase in length of a wire is directly proportional to the square of current passing through wire. Note that the increase in the length of a wire is very small percentage of the total length of wire. Hence various mechanical linkages have been devised to expand this effect and convert it into motion of a point of a circular scale.



A hot working wire denoted by W in the Figure is made up of platinum-iridium alloy. The main advantages of using platinum-iridium alloy is that it can withstand high temperatures without deterioration of wire material caused by oxidation. The working wire W is very fine and its diameter is of the order of 0.1 mm. The wire W is stretched between two point A and B where point B is fixed point and point A is tension adjustment point at which tension adjustment mechanism is placed. One more wire W₁, made up of phosphor-bronze is connected to main hot wire W at point C while other end

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of wire W1 is connected to fixed point D. A fine thread of silk material represented by G is connected between spring S and point F. The thread G is wound around a pulley denoted by E. Both points F and spring S are fixed points. A point P used for indication and thin aluminium disc L are mounted on the spindle. The pulley system E is also mounted on the spindle.

When a current to be measured is passed through the wire, it gets expanded as a result of heating effect by current flowing through it. Because of heating effect, a sag is produced in the wire W. Now the sag in main working wire W causes sag in other wire W1. This sag is transferred to the spring S through a fine silk thread G. Thus the sag produced gets magnified and the spring activates pulley to rotate and pointer gets deflected indicating value of the current under measurement on a graduated scale.

The expansion of the wire is proportional to the heating effect of the current. As heat produced is in the form of power dissipated give $P = I^2R$, the expansion of the wire in hot wire instrument is proportional to the square of r.m.s. value of the current. A thin aluminium disc L rotates between poles of the permanent magnet M and it provides eddy current damping to the instrument. The base of the main instrument is made up of a material which is having coefficient of expansion same as that of hot wire. As base and hot wire, both have same coefficient of expansion, the errors due to uneven expansion between base of instrument and hot wire are minimized.

In early hot wire instruments, the hot wire used was made up of platinum-silver alloy. But the main drawback of early instruments was the low value of the full-scale operating temperature (about 135-150 °C). Because of very low operating temperature, even small variations in room temperature affects the position of the pointer. Today's hot wire instruments use wire made up of platinum-iridium alloy with which operating temperature range can be extended upto 300 to 500 °C. As the temperature range is increased, the effects due to room temperature variations are minimized. The hot wire is made very thin so that it can attain steady temperature quickly when current flows through wire. The size of wire is decided such that it can bare normal mechanical stresses developed in the instruments.

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The hot wire instrument can be used as ammeter over a range 0 to 1 A without a shunt, while 0 to 5 A with a shunt. It can be used as a voltmeter to measure voltage upto 400 V by using high value non-inductive resistance in series with instruments.

Advantages of hot wire type instrument

- (i) no stray magnetic field effect
- (ii) same calibration for dc as well as for ac
- (iii) fair accuracy
- (iv) simple construction
- (v) low cost
- (vi) negligible temperature error if suitably adjusted and
- (vii) suitability for measurement of currents at very high frequencies

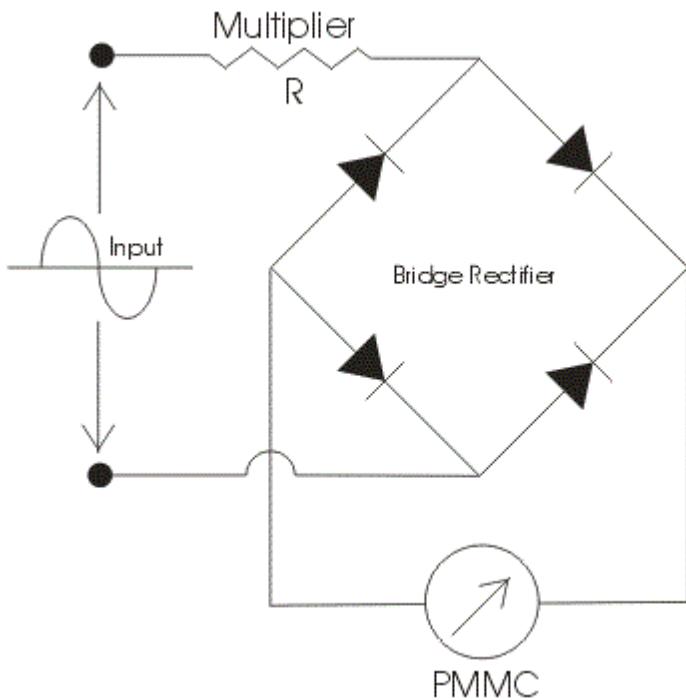
Disadvantages of hot wire type instrument

- (i) delicate construction
- (ii) relatively higher power consumption
- (iii) uneven scale
- (iv) incapability of taking over-load
- (v) sluggish in action
- (vi) need of frequent adjustment of zero position due to temperature variations and
- (viii) different deflections for ascending and descending values.

RECTIFIER TYPE INSTRUMENT

Rectifier type instrument measures the alternating voltage and current with the help of rectifying elements and permanent magnet moving coil type of instrument. However the primary function of rectifier type of instruments work as voltmeter.

We have used here a bridge rectifier circuit as shown. Again we divide our operation into two parts. In the first we analyze the output by applying the dc voltage and in another we will apply ac voltage to the circuit. A series multiplier resistance is connected in series with the voltage source which has the same function as described above.



Let us consider first case here we applying dc voltage source to the circuit. Now the value of full scale deflection current in this case is again $V/(R+R_1)$, where V is the root mean square value of the applied voltage, R is the resistance of the resistance multiplier and R_1 which is the electrical resistance of the instrument. The R and R_1 are marked in the circuit diagram. Now let us consider second case, in this case we will apply ac sinusoidal voltage to the circuit which is given $v=V_m \sin(\omega t)$ where V_m is the peak value of the applied voltage again if we calculate the value of full scale deflection current in this case by applying the similar procedure then we will get an expression of full scale current as $.9V/(R+R_1)$. Remember in order to obtain the average value of voltage we should integrate the instantaneous expression of voltage from zero to π . Thus comparing it dc output we conclude that the sensitivity with ac input voltage source is 0.9 times the as in the case of dc input voltage source.

Advantages of rectifier instruments:

1. The primary advantage of the rectifier voltmeter is that it is far more sensitive as compared to other types of voltmeter .suitable for measuring A.C. voltages.
2. Metal rectifiers can be incorporated in universal instruments, such as ammeter, thereby enabling a moving-coil milliammeter to be used in combination with shunt and series resistances to measure various ranges of D.C. and D.C. voltage, and in

combination with a bridge rectifier and suitable resistors to measure various ranges of A.C. and A.C. voltage.

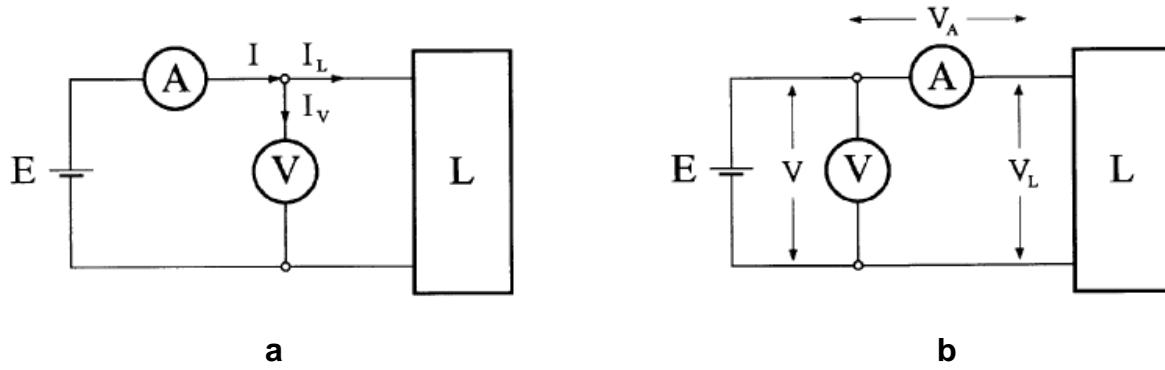
POWER MEASUREMENT

VOLTMETER AMMETER METHOD AND AMMETER VOLTMETER METHOD

Electrical Power dissipated by a load (L) fed by a dc power supply (E) is the product of the voltage across the load (V_L) and the current flowing in it (I_L)

$$P = V_L \times I_L$$

The power measurement in a dc circuit can be carried out using a voltmeter (V) and ammeter (A) as shown in the figure. In figure a the ammeter measures the current flowing in to the voltmeter, as well as that into the load; whereas in figure b the voltmeter measures the voltage drop across the ammeter in addition to that dropping across the load.



I – Current measured by ammeter

V – Voltage measured by voltmeter

R_V , R_A – Internal resistance of voltmeter and ammeter

R_L – Load resistance

I_V – Current flowing into the voltmeter

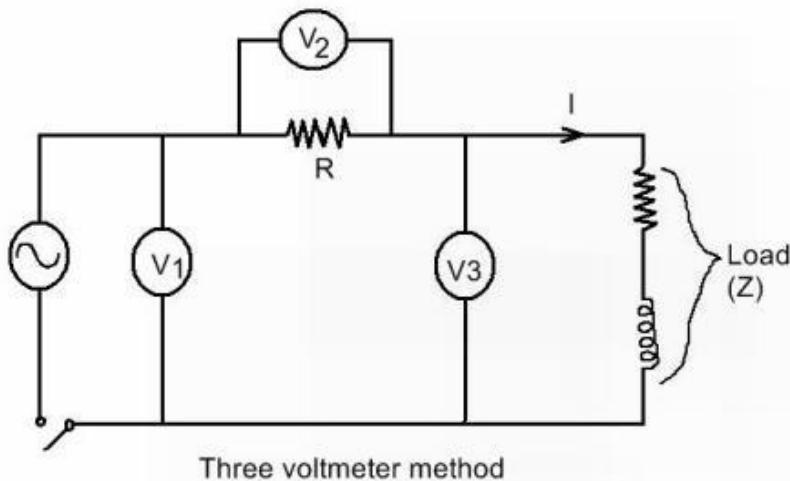
V_A – Voltage drop across the ammeter

$$P = V_L \times I_L = V \times I \times \left(\frac{R_V - R_L}{R_V} \right)$$

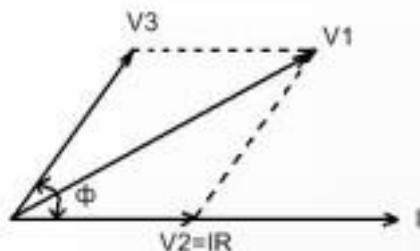
$$P = V_L \times I_L = V \times I \times \left(\frac{R_L - R_A}{R_L} \right)$$

THREE VOLTMETER METHOD

V_1 , V_2 and V_3 are the three voltmeters and R is a non-inductive resistance connected in series with the load as shown in figure.



Three voltmeter method



Phasor diagram

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From phasor diagram,

$$\begin{aligned}V_1^2 &= V_2^2 + V_3^2 + 2V_2V_3 \cos \phi \\&= V_2^2 + V_3^2 + 2(IR)V_3 \cos \phi \\&= V_2^2 + V_3^2 + 2R(V_3 I \cos \phi) \\&= V_2^2 + V_3^2 + 2PR\end{aligned}$$

...Since power in the inductive circuit, $P = V_3 I \cos \phi$

Or, power,

$$P = \frac{V_1^2 - V_2^2 - V_3^2}{2R}$$

Power factor of the circuit is given by:

$$\cos \phi = \frac{V_1^2 - V_2^2 - V_3^2}{2V_2V_3}$$

The assumptions are made that the current in the resistor R is same as the load current.

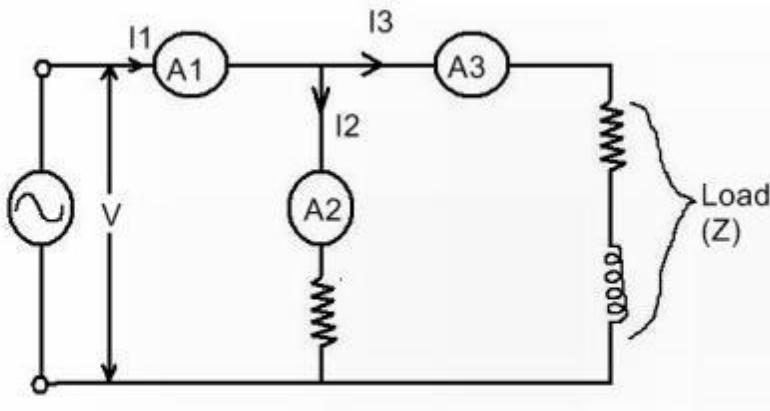
Disadvantages:

- Supply voltage higher than normal voltage is required because an additional resistance R is connected in series with the load Z (inductive circuit).
- Even small errors in measurement of voltages may cause serious errors in the value of power determined by this method.

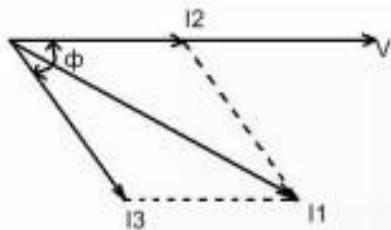
THREE AMMETER METHOD

Following figures shows the circuit diagram and phasor diagram of three ammeter method for measurement of power. The current measured by the ammeter A_1 , is the vector sum of the load current and that taken by the non-inductive resistor R, this latter being in phase with V.

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Three ammeter method



Phasor diagram

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From phasor diagram, we have:

$$I_1^2 = I_2^2 + I_3^2 + 2I_2 I_3 \cos\phi$$

But,

$$I_2 = \frac{V}{R}$$

$$I_1^2 = I_2^2 + I_3^2 + 2 \frac{V}{R} I_3 \cos\phi$$

Hence the power, $P = VI_3 \cos\phi$, is given by:

$$P = \frac{R}{2} (I_1^2 - I_2^2 - I_3^2)$$

Also,

$$\cos\phi = \frac{I_1^2 - I_2^2 - I_3^2}{2I_2 I_3}$$

Advantages:

- The advantage of this method is that the value of determined is independent of supply frequency and waveforms.
- The disadvantages of measurement of power by three voltmeter method are overcome in this method.

INDUCTION TYPE WATTMETER

These types of watt-meters operate on the same working principle on which the induction type ammeter and voltmeter operates. These instruments can only be used on ac supply while dynamo-meter type watt meters can be used on either ac or dc supply system. Induction type watt-meters are useful only when the supply and frequency remains constant. Since both the coils i.e. current coil and pressure coils are necessary in such instrument, it is not essential to use shaded pole principle. Because for producing a deflecting torque, two fluxes are essential with suitable phase angle and it would be available from these two coils.

A watt-meter has two laminated electromagnet, one of which is excited by load current or definite fraction of it, and is connected in series with the circuit, known as series magnet and the other is excited by the current proportional to the applied voltage or fraction of it and is always connected across the supply, known as shunt magnet. An aluminum disc is so mounted so that it cuts the fluxes produced by both the magnets. As a result of which, two e.m.f are produced which induces two eddy currents in the disc. C - Magnet is used to provide necessary damping torque to the pointer, to damp out the oscillations. Deflecting torque is produced due to interaction of these eddy currents and the inducing flux. Copper shading bands are provided either on central limb or on the outer 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. Both the watt-meters are provided with spiral springs A and B, for producing controlling torque to counter balance the deflecting torque. In Fig.a the spiral spring and damping magnet is omitted for simplicity. The scale of such type instruments is quite uniform and extends over an angle of 300. Currents up to 100 A can be handled by these watt-meters directly where as beyond this current transformers are used. Two types of induction type watt meters are available. Line diagrams of both of the types are detailed in Figures a and b.

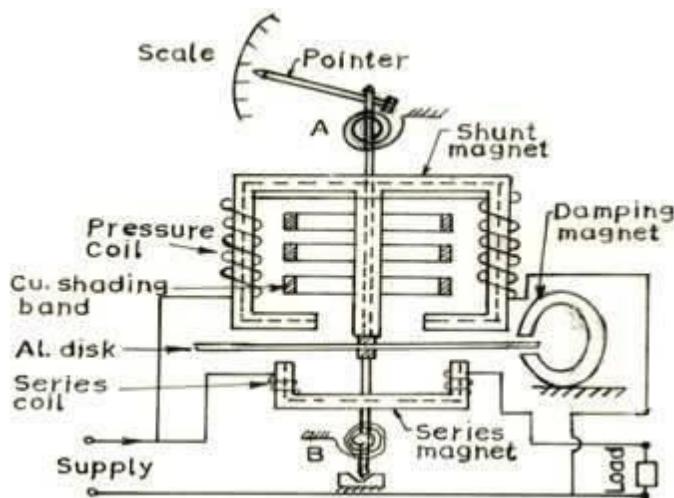


Figure a. Induction type Wattmeter

In the form of the instrument shown in Fig. a, two pressure coils are connected in series in such a way that both of them send flux through the central limb. The series magnet

also carries two small current coils connected in series and wound so that they magnetized their respective cores in the same direction. Correct phase displacement between the fluxes produced by series and shunt magnet is obtained by the adjustment of copper shading band on the central limb.

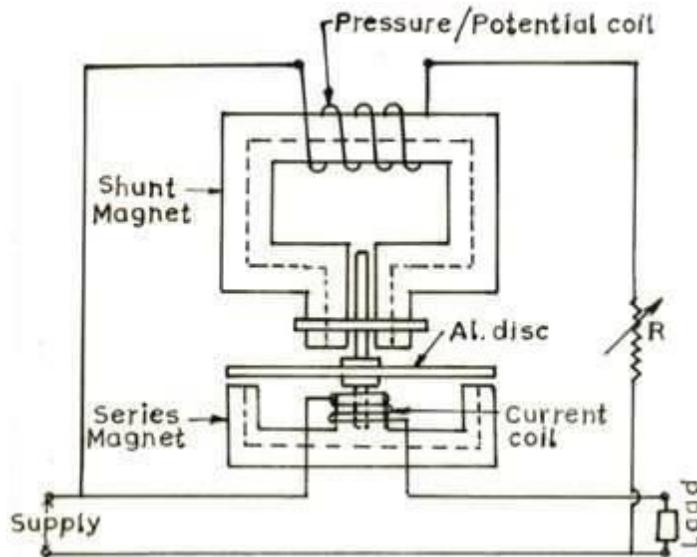


Figure b. Induction type Wattmeter

In Fig. b, there is only one pressure and one current coil. Two projecting poles of shunt magnet are surrounded by a copper shading band whose position can be adjusted for correcting the phase of the flux of this magnet with the applied voltage. The pressure coil circuit of induction type instrument is made as inductive as possible so that the flux of the shunt magnet may lag nearly by 90° behind the applied voltage.

Advantages

The advantages of induction watt meters are the same as those of induction ammeters long scale, freedom from effects of stray field, and have effective damping torque.

Disadvantages

Following are the disadvantages of the induction type instruments:

- Change in temperature causes variation in the resistance of the moving element, affects the eddy currents therein, and so the operating torque. The error due to this is in part offset by a balancing effect due to change in temperature of the windings.

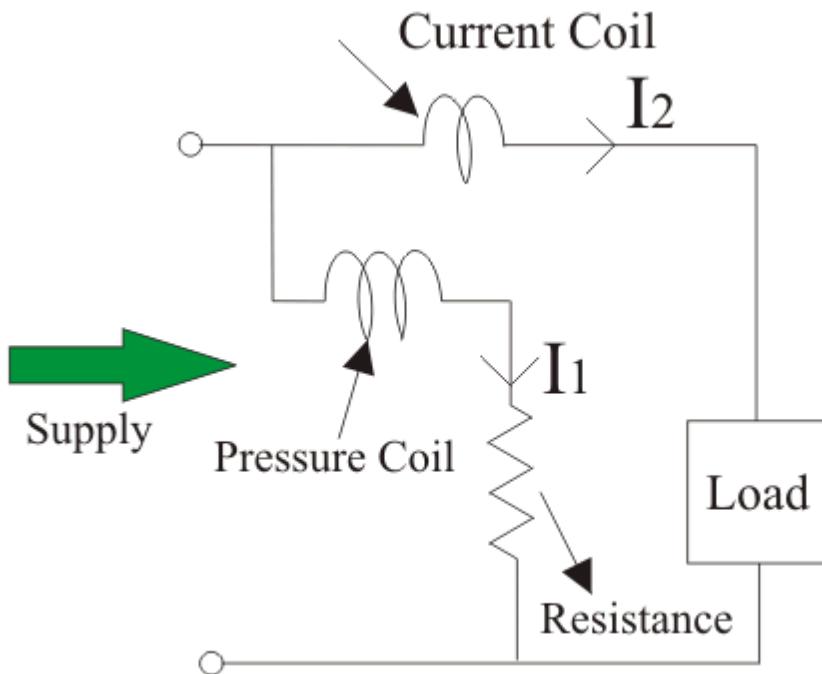
b) Change in frequency from that of the calibration value causes variations in both the reactance of the voltage coil circuit, which is highly inductive, and also in the amount of compensation from the phase compensating circuit. Within the limits of frequency variation met within practice on the mains, this last error is not important.

ELECTRODYNAMOMETER WATTMETER

Dynamometer type wattmeter works on very simple principle and this principle can be stated as "when any current carrying conductor is placed inside a magnetic field, it experiences a mechanical force and due to this mechanical force deflection of conductor takes place".

Construction and Working Principle

. It consists of following parts



There are two types of coils present in the electrodynamometer. They are :

(a) Moving coil : Moving coil moves the pointer with the help of spring control instrument. A limited amount of current flows through the moving coil so as to avoid

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heating. So in order to limit the current we have connect the high value resistor in series with the moving coil. The moving is air cored and is mounted on a pivoted spindle and can moves freely. In electrodynamometer type wattmeter, moving coil works as pressure coil. Hence moving coil is connected across the voltage and thus the current flowing through this coil is always proportional to the voltage.

(b) Fixed coil: The fixed coil is divided into two equal parts and these are connected in series with the load, therefore the load current will flow through these coils. Now the reason is very obvious of using two fixed coils instead of one, so that it can be constructed to carry considerable amount of electric current. These coils are called the current coils of electrodynamometer type wattmeter. Earlier these fixed coils are designed to carry the current of about 100 amperes but now the modern wattmeter are designed to carry current of about 20 amperes in order to save power.

(c) Control system: Out of two controlling systems i.e.

(1) Gravity control

(2) Spring control, only spring controlled systems are used in these types of wattmeter. Gravity controlled system cannot be employed because they will appreciable amount of errors.

(d) Damping system: Air friction damping is used, as eddy current damping will distort the weak operating magnetic field and thus it may leads to error.

(e) Scale: There is uniform scale is used in these types of instrument as moving coil moves linearly over a range of 40 degrees to 50 degrees on either sides.

Now let us derive the expressions for the controlling torque and deflecting torques. In order to derive these expressions let us consider the circuit diagram given

We know that instantaneous torque in electrodynamic type instruments is directly proportional to product of instantaneous values of currents flowing through both the coils and the rate of change of flux linked with the circuit.

Let I_1 and I_2 be the instantaneous values of currents in pressure and current coils respectively. So the expression for the torque can be written as:

$$T = I_1 \times I_2 \times \frac{dM}{dx}$$

where x is the angle.

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Now let the applied value of voltage across the pressure coil be

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

Assuming the electrical resistance of the pressure coil be very high hence we can neglect reactance with respect to its resistance. In this the impedance is equal to its electrical resistance therefore it is purely resistive.

The expression for instantaneous current can be written as $I_2 = v / R_p$ where R_p is the resistance of pressure coil.

$$I_2 = \sqrt{2} \times \frac{V \sin \omega t}{R_p}$$

If there is phase difference between voltage and electric current, then expression for instantaneous current through current coil can be written as

$$I_1 = I(t) = \sqrt{2}I \sin(\omega t - \phi)$$

As current through the pressure coil is very very small compare to current through current coil hence current through the current coil can be considered as equal to total load current.

Hence the instantaneous value of torque can be written as

$$\sqrt{2} \times \frac{V \sin \omega t}{R_p} \times \sqrt{2}I \sin(\omega t - \phi) \frac{dM}{dx}$$

Average value of deflecting torque can be obtained by integrating the instantaneous torque from limit 0 to T, where T is the time period of the cycle.

$$T_d = \text{deflecting torque} = \frac{VI}{R_p} \cos \phi \frac{dM}{dx}$$

Controlling torque is given by $T_c = Kx$ where K is spring constant and x is final steady state value of deflection.

Advantages of Electrodynamometer Type Wattmeter

Following are the advantages of electrodynamometer type wattmeters and they are written as follows:

- (a) Scale is uniform upto certain limit.
- (b) They can be used for both to measure ac as well dc quantities as scale is calibrated for both.

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Errors in Electrodynamometer Type Wattmeter

Following are the errors in the electrodynamometer type wattmeters:

- (a) Errors in the pressure coil inductance
- (b) Errors may be due to pressure coil capacitance
- (c) Errors may be due to mutual inductance effects
- (d) Errors may be due connections (i.e. pressure coil is connected after current coil)
- (e) Error due to Eddy currents
- (f) Errors caused by vibration of moving system
- (g) Temperature error
- (h) Errors due to stray magnetic field

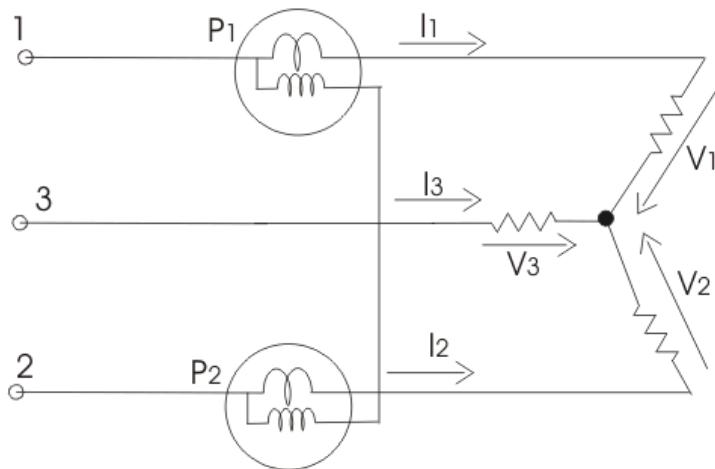
MEASUREMENT OF THREE PHASE POWER BY TWO WATTMETERS METHOD

In this method we have two types of connections

- (a) Star connection of loads
- (b) Delta connection of loads

When the star connected load, the diagram is shown in below- (c) Errors may be due to mutual inductance effects

- (d) Errors may be due connections (i.e. pressure coil is connected after current coil)
- (e) Error due to Eddy currents
- (f) Errors caused by vibration of moving system
- (g) Temperature error
- (h) Errors due to stray magnetic field



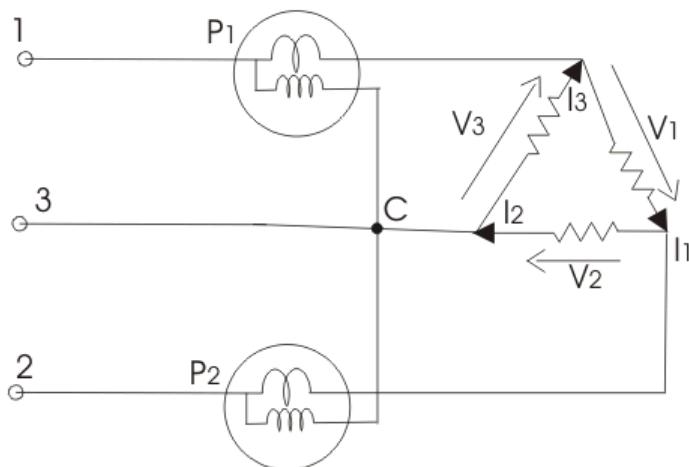
For star connected load clearly the reading of wattmeter one is product phase current and voltage difference (V_2-V_3). Similarly the reading of wattmeter two is the product of phase current and the voltage difference (V_2-V_3). Thus the total power of the circuit is sum of the reading of both the wattmeters. Mathematically we can write

$$P = P_1 + P_2 = I_1(V_1 + V_2) + I_2(V_2 - V_3)$$

but we have $I_1+I_2+I_3=0$, hence putting the value of $I_1+I_2=-I_3$

We get total power as $V_1I_1+V_2I_2+V_3I_3$

When delta connected load, the diagram is shown in below



The reading of wattmeter one can be written as

$$P_1 = -V_3(I_1 - I_3)$$

and reading of wattmeter two is

$$P_2 = -V_2(I_2 - I_1)$$

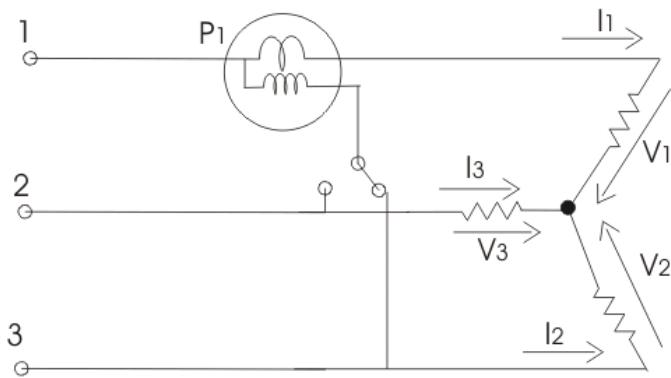
$$\text{Total power is } P = P_1 + P_2 = V_2I_2 + V_3I_3 - I_1(V_2 + V_3)$$

but $V_1 + V_2 + V_3 = 0$, hence expression for total power will reduce to $V_1I_1 + V_2I_2 + V_3I_3$

MEASUREMENT OF THREE PHASE POWER BY ONE WATTMETER METHOD

Limitation of this method is that it cannot be applied on unbalanced load. So under this condition we have $I_1 = I_2 = I_3 = I$ and $V_1 = V_2 = V_3 = V$

Diagram is shown below



Two switches are given which are marked as 1-3 and 1-2, by closing the switch 1-3 we get reading of wattmeter as

$$P_1 = V_{13}I_1 \cos(30^\circ - \phi) = \sqrt{3} \times VI \cos(30^\circ - \phi)$$

Similarly the reading of wattmeter when switch 1-2 is closed is

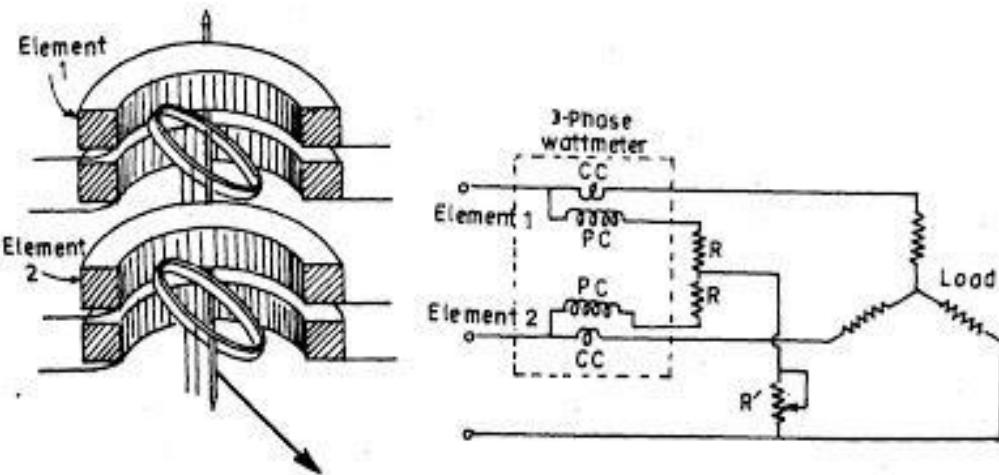
$$P_2 = V_{12}I_1 \cos(30^\circ + \phi) = \sqrt{3} \times VI \cos(30^\circ + \phi)$$

$$\text{Total power is } P_1 + P_2 = 3VI \cos \phi$$

THREE PHASE ELECTRODYNAMOMETER WATTMETER

A dynamometer type three-phase wattmeter consists of two separate wattmeter movements mounted together in one case with the two moving coils mounted on the same spindle.

- The arrangement is shown in Fig.
- There are two current coils and two pressure coils.
- A current coil together with its pressure coil is known as an element. Therefore, a three phase wattmeter has two elements.
- The connections of two elements of a 3 phase wattmeter are the same as that for two wattmeter method using two single phase wattmeter.
- The torque on each element is proportional to the power being measured by it.
- The total torque deflecting the moving system is the sum of the deflecting torque of the two elements.
- Hence the total deflecting torque on the moving system is proportional to the total Power.
- In order that a 3 phase wattmeter read correctly, there should not be any mutual interference between the two elements.
- A laminated iron shield may be placed between the two elements to eliminate the mutual effect



LOW POWER FACTOR ELECTRO-DYNAMOMETER TYPE WATTMETERS

Ordinary **electro-dynamometer wattmeter** is not suitable for measurement of power in low power factor circuits owing to

- Small deflecting torque on the moving system even when the current and pressure coils are fully excited and
- Introduction of large error due to inductance of pressure coil at low power factor.

The special features incorporated in an **electro-dynamometer type wattmeter** to make it suitable for measurement of power in low power factor circuits are given below.

1. Pressure coil Circuit. The pressure coil circuit is made of low resistance in order to make the pressure coil current large resulting in increased operating torque. The pressure coil current in a low pf wattmeter may be as much as 10 times the value used for ordinary wattmeters.
2. Compensation For Pressure Coil current
3. Compensation For Inductance of Pressure Coil. The error caused by pressure coil inductance is $(\sin\Theta)/\cos\Phi + \sin\Theta$ times the actual reading of wattmeter. Now with low pf, the value of Φ is large and, therefore, the error is large. The error caused by inductance of pressure coil is compensated by connecting a capacitor across a part of series resistance in the pressure coil circuit, as shown in fig

