CHAPTER

2

Indicators and Display Devices

2.1 INTRODUCTION

Analogue ammeters and voltmeters are classified together, since there is no basic difference in their operating principles. The action of all ammeters and voltmeters, except those of the electrostatic variety, depends upon a deflecting torque produced by an electric current. In an ammeter this torque is produced by the current to be measured, or by a definite fraction of it. In a voltmeter it is produced by a current that is proportional to the voltage to be measured. Hence both voltmeters and ammeters are essentially current measuring devices.

The essential requirements of a measuring instrument are (a) that its introduction into the circuit where measurements are to be made, should not alter the circuit conditions, and (b) the power consumed by it be small.

2.1.1 Types of Instrument

The following types of instrument are mainly used as ammeters and voltmeters.

1. PMMC
2. Moving Iron
3. Electrodynamometer
4. Hot wire
5. Thermocouple
6. Induction type
7. Electrostatic
8. Rectifier

Of these, the PMMC type can be used for dc measurements only, and the induction type for ac measurements only. The other types can be used for both.

The moving coil and moving iron types depend upon the magnitude effect of current. The latter is the most commonly used form of indicating instrument, as well as the cheapest. It can be used for both ac and dc measurements and is very accurate, if properly designed.

The PMMC instrument is the most accurate type for dc measurement. Instrument of this type are frequently constructed to have substandard accuracy.

The calibration of the electrodynamometer type of instrument is the same for ac and dc. The same situation prevails for thermal instruments. These are particularly suitable for ac measurements, since their deflection depends directly upon the heating effect of the ac, i.e. upon the rms value of the current. Their readings are therefore independent of the frequency.

Electrostatic instruments used as voltmeters have the advantage that their power consumption is exceedingly small. They can be made to cover a large range of voltage and can be constructed to have sub-standard accuracy.

The induction principle is most generally used for Watt-hour meters. This principle is not preferred for use in ammeters and voltmeters because of the comparatively high cost and inaccuracy of the instrument.

BASIC METER MOVEMENT

The action of the most commonly dc meter is based on the fundamental principle of the motor. The motor action is produced by the flow of a small current through a moving coil, which is positioned in the field of a permanent magnet. This basic moving coil system is often called the D'Arsonval galvanometer.

The D'Arsonval movement shown in Fig. 2.1 employs a spring-loaded coil through which the measured current flows. The coil (rotor) is in a nearly homogeneous field of a permanent magnet and moves in a rotary fashion. The amount of rotation is proportional to the amount of current flowing through the coil. A pointer attached to the coil indicates the position of the coil on a scale calibrated in terms of current or voltage. It responds to dc current only, and has an almost linear calibration. The magnetic shunt that varies the field strength is used for calibration.

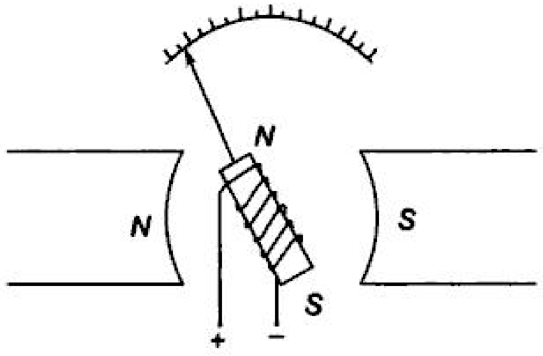

Fig. 2.1 ■ D'Arsonval Principle

2.2.1 Permanent Magnetic Moving Coil Movement

In this instrument, we have a coil suspended in the magnetic field of a permanent magnet in the shape of a horse-shoe. The coil is suspended so that it can rotate freely in the magnetic field. When current flows in the coil, the developed (electromagnetic) torque causes the coil to rotate. The electromagnetic

(EM) torque is counterbalanced by a mechanical torque of control springs attached to the movable coil. The balance of torques, and therefore the angular position of the movable coil is indicated by a pointer against a fixed reference called a scale. The equation for the developed torque, derived from the basic law for electromagnetic torque is

$$\tau = B \times A \times I \times N$$

where τ = torque, Newton-meter
B = flux density in the air gap, Wb/m^2
A = effective coil area (m^2)
N = number of turns of wire of the coil
I = current in the movable coil (amperes)

The equation shows that the developed torque is proportional to the flux density of the field in which the coil rotates, the current coil constants (area and number of turns). Since both flux density and coil constants are fixed for a given instrument, the developed torque is a direct indication of the current in the coil. The pointer deflection can therefore be used to measure current.

Example 2.1 A moving coil instrument has the following data.

Number of turns = 100
Width of the coil = 20 mm
Depth of the coil = 30 mm
Flux density in the gap = 0.1 Wb/m^2

Calculate the deflecting torque when carrying a current of 10 mA. Also calculate the deflection, if the control spring constant is 2×10^{-6} Nm/degree.

Solution The deflecting torque is given by

$$\begin{aligned} \tau_d &= B \times A \times N \times I \\ &= 0.1 \times 30 \times 10^{-3} \times 20 \times 10^{-3} \times 100 \times 10 \times 10^{-3} \\ &= 600 \times 1000 \times 0.1 \times 10^{-9} \\ &= 600 \times 1000 \times 10^{-10} \\ &= 60 \times 10^{-6} \text{ Nm} \end{aligned}$$

The spring control provides a restoring torque, i.e. $\tau_c = K\theta$, where K is the spring constant

As deflecting torque = restoring torque

$$\therefore \quad \tau_c = 6 \times 10^{-5} \text{ Nm} = K\theta, \ \therefore \theta = \frac{6 \times 10^{-5}}{2 \times 10^{-6}} = 3 \times 10 = 30^\circ$$

Therefore, the deflection is 30°.

2.2.2 Practical PMMC Movement

The basic PMMC movement (also called a D'Arsonval movement) offers the largest magnet in a given space, in the form of a horse-shoe, and is used when a large flux is required in the air gap. The D'Arsonval movement is based on the principle of a moving electromagnetic coil pivoted in a uniform air gap between the poles of a large fixed permanent magnet. This principle is illustrated in Fig. 2.1 With the polarities as shown, there is a repelling force between like poles, which exerts a torque on the pivoted coil. The torque is proportional to the magnitude of current being measured. This D'Arsonval movement provides an instrument with very low power consumption and low current required for full scale deflection (fsd).

Figure 2.2 shows a permanent horse-shoe magnet with soft iron pole pieces attached to it. Between the pole pieces is a cylinder of soft iron which serves to provide a uniform magnetic field in the air gap between the pole pieces and the cylindrical core.

The coil is wound on a light metal frame and is mounted so that it can rotate freely in the air gap. The pointer attached to the coil moves over a graduated scale and indicates the angular deflection of the coil, which is proportional to the current flowing through it.

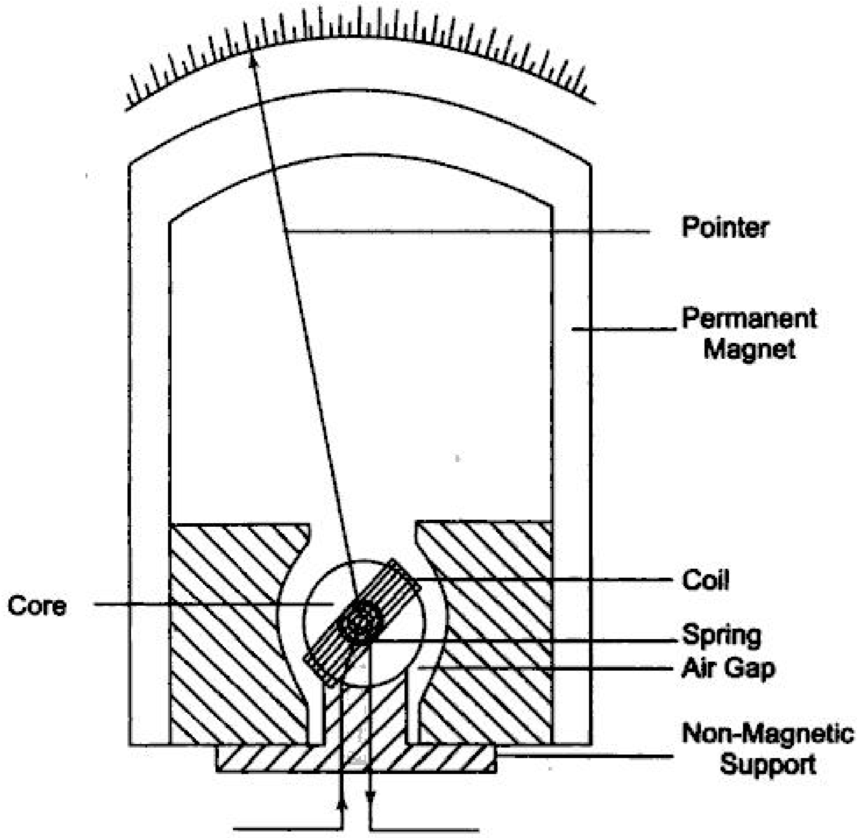

Fig. 2.2 ■ Modern D'Arsonval Movement

The Y-shaped member shown in Fig. 2.3 is the zero adjust control, and is connected to the fixed end of the front control spring. An eccentric pin through the instrument case engages the Y-shaped member so that the zero position of the pointer can be adjusted from outside. The calibrated force opposing the moving torque is provided by two phosphor-bronze conductive springs, normally equal in strength. (This also provides the necessary torque to bring the pointer back to its original position after the measurement is over.)

The accuracy of the instrument can be maintained by keeping spring performance constant. The entire moving system is statically balanced at all positions by three (counterweights) balance weights. The pointer, springs, and pivots are fixed to the coil assembly by means of pivot bases and the entire movable coil element is supported by jewel bearings.

PMMC instruments are constructed to produce as little viscious damping as possible and the required degree of damping is added.

In Fig. 2.4, Curve 2 is the underdamped case; the pointer attached to the movable coil oscillates back and forth several times before coming to rest. As in curve 1, the overdamped case, the pointer tends to approach the steady state position in a sluggish manner. In Curve 3, the critically damped case, the pointer moves up to its steady state position without oscillations. Critical damping is the ideal behaviour for a PMMC movement.

In practice, however, the instrument is usually slightly underdamped, causing the pointer to overshoot a little before coming to rest.

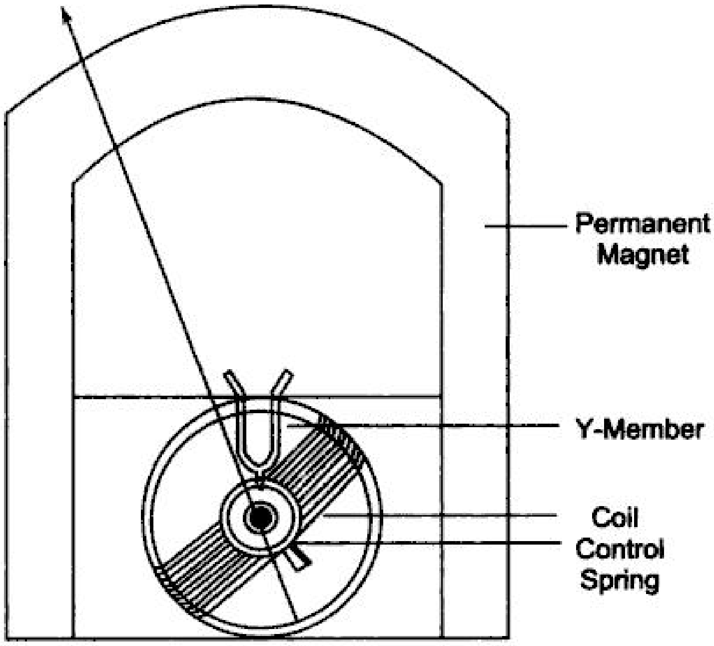

Fig. 2.3 ▬ Simplified Diagram of a PMMC Movement Showing the Y-member

The various methods of damping are as follows.

One of the simplest methods is to attach an aluminium vane to the shaft of the moving coil. As the coil rotates, the vane moves in an air chamber, the amount of clearance between the chamber walls and the air vane effectively controlling the degree of damping.

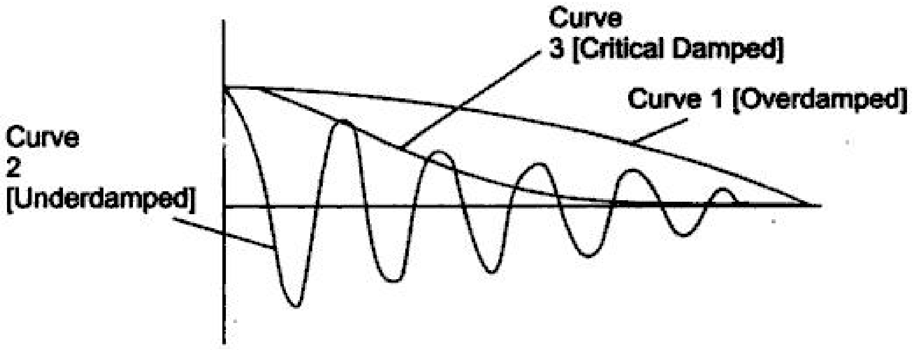

Fig. 2.4 Degree of Damping

Some instruments use the principle of electromagnetic damping (Lenz's law), where the movable coil is wound on a light aluminium frame. The rotation of the coil in the magnetic field sets up a circulating current in the conductive frame, causing a retarding torque that opposes the motion of the coil.

A PMMC movement may also be damped by a resistor across the coil. When the coil rotates in the magnetic field, a voltage is generated in the coil, which circulates a current through it and the external resistance. This produces an opposing or retarding torque that damps the motion. In any galvanometer, the value of the external resistance that produces critical damping can be found. This resistance is called critically damping external resistance (CDRX). Most voltmeter coils are wound on metal frames to provide Electro-Magnetic damping. The metal frames constitute a short-circuit turn in a magnetic field.

Ammeters coils, are however wound in a non-conductive frame, because the coil turns are effectively shorted by the ammeter shunt. The coil itself provides the EM damping.

If low frequency alternating current is applied to the movable coil, the deflection of the pointer would be upscale for half the cycle of the input waveform and downscale (in the opposite direction) for the next half. At power line frequency (50 Hz) and above, the pointer cannot follow the rapid variations in direction and quivers slightly around the zero mark, seeking the average value of the ac (which equals zero). The PMMC instrument is therefore unsuitable for ac measurements, unless the current is rectified before reaching the coil.

Practical coil areas generally range from 0.5 – 2.5 cm^2.

The flux density for modern instruments usually ranges from 1500 – 5000 Wb/cm^2.

The power requirements of D'Arsonval movements are quite small, typically from 25 – 200 μW.

The accuracy of the instrument is generally of the order of 2 – 5% of full scale deflection.

The permanent magnet is made up of Alnico material.

Scale markings of basic dc PMMC instruments are usually linearly spaced, because the torque (and hence the pointer deflection) is directly proportional to the coil current. The basic PMMC instrument is therefore a linear-reading device.

The advantages and disadvantages of PMMC are as follows.

Advantages

1. They can be modified with the help of shunts and resistance to cover a wide range of currents and voltages.
2. They display no hystersis.
3. Since operating fields of such instruments are very strong, they are not significantly affected by stray magnetic fields.

Disadvantages

1. Some errors may set in due to ageing of control springs and the permanent magnet.
2. Friction due to jewel-pivot suspension.

TAUT BAND INSTRUMENT

The taut band movement utilises the same principle as the D'Arsonval movable coil and fixed magnet. The primary difference between the two is the method of mounting the movable coil.

The taut band movement has the advantage of eliminating the friction caused by a jewel-pivot suspension. The meter has a coil mounted in a cradle and surrounded by a ring-bar magnet, as shown in Fig. 2.5. The cradle is secured to a support bracket, which in turn is suspended between two steel taut bands (ribbon), i.e. the movable coil is suspended by means of two taut torsion ribbons. The ribbons are placed under sufficient tension to eliminate any sag. This tension is provided by the tension spring, so that the instrument can be used in any position.

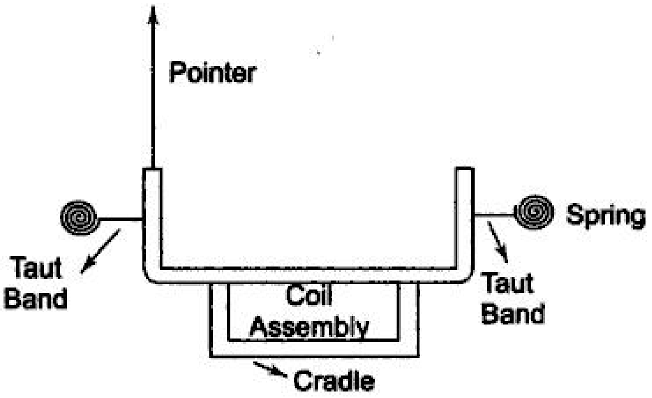

Fig. 2.5 ▬ (a) Taut Band Instrument (Side View)

The current to be measured is passed through the coil, thereby energising it. The interaction of the magnetic fields deflects the cradle to one side and moves the pointer along the scale.

The movement of the cradle exerts a twisting force on the steel bands. These twisted bands supply the torque to return the pointer to zero, when no current flows. There are no bearings, and there is a constant level of sensitivity throughout the range of movement.

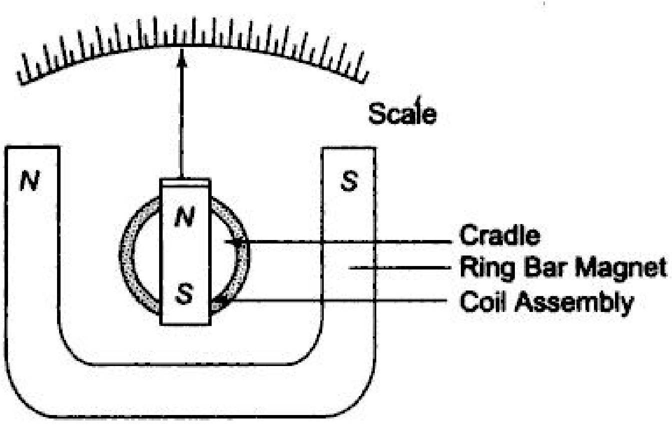

Fig. 2.5 (b) Taut Band Instrument (Top View)

Taut band instruments have a higher sensitivity than those using pivots and jewels. In addition taut band instruments are relatively insensitive to shock and temperature and are capable of withstanding greater overloads than PMMC or other types.

ELECTRODYNAMOMETER

The D'Arsonval movement responds to the average or dc value of the current flowing through the coil.

If ac current is sought to be measured, the current would flow through the coil with positive and negative half cycles, and hence the driving torque would be positive in one direction and negative in the other. If the frequency of the ac is very low, the pointer would swing back and forth around the zero point on the meter scale.

At higher frequencies, the inertia of the coil is so great that the pointer does not follow the rapid variations of the driving torque and vibrates around the zero mark.

Therefore, to measure ac on a D'Arsonval movement, a rectifier has to be used to produce a unidirectional torque. This rectifier converts ac into dc and the rectified current deflects the coil. Another method is to use the heating effect of ac current to produce an indication of its magnitude. This is done using an electrodynamometer (EDM).

An electrodynamometer is often used in accurate voltmeter and ammeters not only at power line frequency but also at low AF range. The electrodynamometer can be used by slightly modifying the PMMC movement. It may also serve as a transfer instrument, because it can be calibrated on dc and then used directly on ac thereby equating ac and dc measurements of voltage and current directly.

A movable coil is used to provide the magnetic field in an electrodynamometer, instead of a permanent magnet, as in the D'Arsonval movement. This movable coil rotates within the magnetic field. The EDM uses the current under measurement to produce the required field flux. A fixed coil, split into two equal halves provides the magnetic field in which the movable coil rotates, as shown in Fig. 2.6 (a). The coil halves are connected in series with the moving coil and are fed by the current being measured. The fixed coils are spaced far apart to allow passage for the shaft of the movable coil. The movable coil carries a pointer, which is balanced by counterweights. Its rotation is controlled by springs, similar to those in a D'Arsonval movement.

The complete assembly is surrounded by a laminated shield to protect the instrument from stray magnetic field which may affect its operation.

Damping is provided by aluminium air vanes moving in a sector shaped chamber. (The entire movement is very solid and rigidly constructed in order to keep its mechanical dimensions stable, and calibration intact.)

The operation of the instrument may be understood from the expression for the torque developed by a coil suspended in a magnetic field, i.e.

$$\tau = B \times A \times N \times I$$

indicating that the torque which deflects the movable coil is directly proportional to the coil constants (A and N), the strength of the magnetic field in which the coil moves (B), and the current (I) flowing through the coil.

In an EDM the flux density (B) depends on the current through the fixed coil and is therefore proportional to the deflection current (I). Since the coil constants are fixed quantities for any given meter, the developed torque becomes a function of the current squared (I^2).

If the EDM is used for dc measurement, the square law can be noticed by the crowding of the scale markings at low current values, progressively spreading at higher current values.

For ac measurement, the developed torque at any instant is proportional to the instantaneous current squared (i^2). The instantaneous values of i^2 are always positive and torque pulsations are therefore produced.

The meter movement, however, cannot follow rapid variations of the torque and take up a position in which the average torque is balanced by the torque of the control springs. The meter deflection is therefore a function of the mean of the squared current. The scale of the EDM is usually calibrated in terms of the square root of the average current squared, and therefore reads the effective or rms value of the ac.

The transfer properties of the EDM become apparent when we compare the effective value of the alternating current and the direct current in terms of their heating effect, or transfer of power.

(If the EDM is calibrated with a direct current of 500 mA and a mark is placed on the scale to indicate this value, then that ac current which causes the pointer to deflect to the same mark on the scale must have an rms value of 500 mA.)

The EDM has the disadvantage of high power consumption, due to its construction. The current under measurement must not only pass through the movable coil, but also provide the necessary field flux to get a sufficiently strong magnetic field. Hence high mmf is required and the source must have a high current and power.

In spite of this high power consumption the magnetic field is still weaker than that of the D'Arsonval movement because there is no iron in the path, the entire flux path consisting of air.

The EDM can be used to measure ac or dc voltage or current, as shown in Figs. 2.6 (a) and (b).

Typical values of EDM flux density are in the range of approximately 60 gauss as compared to the high flux densities (1000 – 4000 guass) of a good D'Arsonval movement. The low flux density of the EDM affects the developed torque and therefore the sensitivity of the instrument.

The addition of a series multiplier converts the basic EDM into a voltmeter [Fig. 2.6 (b)] which can be used for ac and dc measurements. The sensitivity of the EDM voltmeter is low, approximately 10 – 30 Ω/V, compared to 20 kΩ/V of the D'Arsonval movement. It is however very accurate at power line frequency and can be considered as a secondary standard.

The basic EDM shown in Fig. 2.6 (a) can be converted into an ammeter (even without a shunt), because it is difficult to design a moving coil which can carry more than approximately 100 mA.

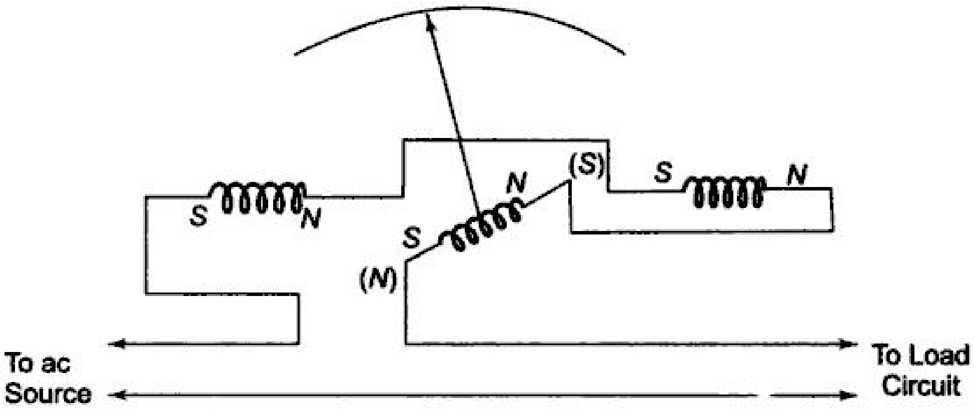

Fig. 2.6 ■ (a) Basic EDM as an Ammeter

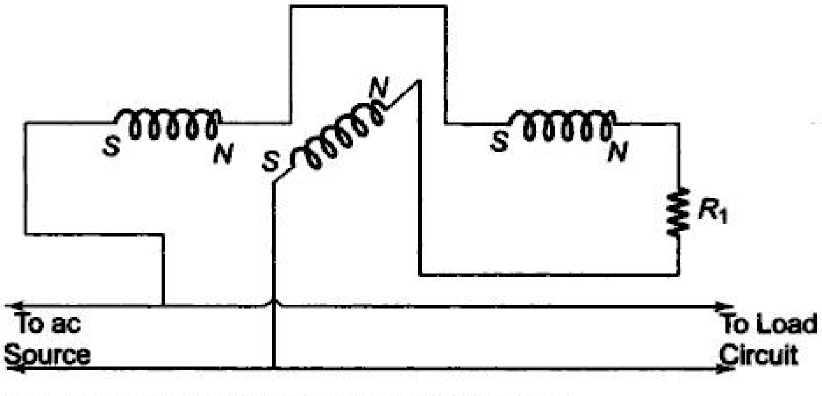

Fig. 2.6 ■ (b) Basic EDM as a Voltmeter

The EDM movement is extensively used to measure power, both dc and ac, for any waveform of voltage and current.

An EDM used as a voltmeter or ammeter has the fixed coils and movable coil connected in series, thereby reacting to I^2.

When an EDM is used as a single phase wattmeter, the coil arrangement is different, as shown in Fig. 2.7.

The fixed coils, shown in Fig. 2.7 as separate elements, are connected in series and carries the total line current. The movable coil located in the magnetic field of the fixed coils is connected in series with a current-limiting resistor across the power line, and carries a small current.

The deflection of the movable coil is proportional to the product of the instantaneous value of current in the movable coil and the total line current. The EDM wattmeter consumes some power for the maintenance of its magnetic field, but this is usually small compared to the load power.

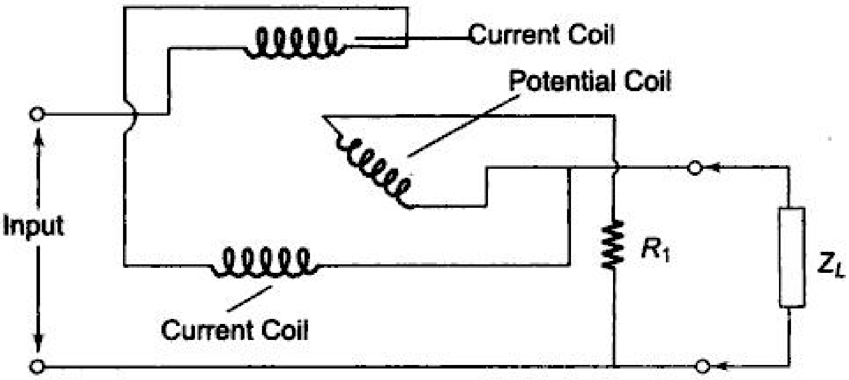

Fig. 2.7 ■ EDM as a Wattmeter

2.5 MOVING IRON TYPES INSTRUMENT

Moving iron instruments can be classified into attraction and repulsion types. Repulsion type instruments are the most commonly used.

Iron vane ammeters and voltmeters depend for their operations on the repulsion that exists between two like magnetic poles.

The movement consists of a stationary coil of many turns which carries the current to be measured. Two iron vanes are placed inside the coil. One vane is rigidly attached to the coil frame, while the other is connected to the instrument shaft which rotates freely. The current through the coil magnetises both the vanes with the same polarity, regardless of the instantaneous direction of current. The two magnetised vanes experience a repelling force, and since only one vane can move, its displacement is an indicator of the magnitude of the coil current. The repelling force is proportional to the current squared, but the effects of frequency and hysteresis tend to produce a pointer deflection that is not linear and that does not have a perfect square law relationship.

Figure 2.8 shows a radial vane repulsion instrument which is the most sensitive of the moving iron mechanisms and has the most linear scale. One of these like poles is created by the instrument coil and appears as an iron vane fixed in its position within the coil, as shown in Fig. 2.8. The other like pole is induced on the movable iron piece or vane, which is suspended in the induction field of the coil and to which the needle of the instrument is attached. Since the instrument is used on ac, the magnetic polarity of the coil changes with every half cycle and induces a corresponding amount of repulsion of the movable vane against the spring tension. The deflection of the instrument pointer is therefore always in the same direction, since there is always repulsion between the like poles of the fixed and the movable vane, even though the current in the inducing coil alternates.

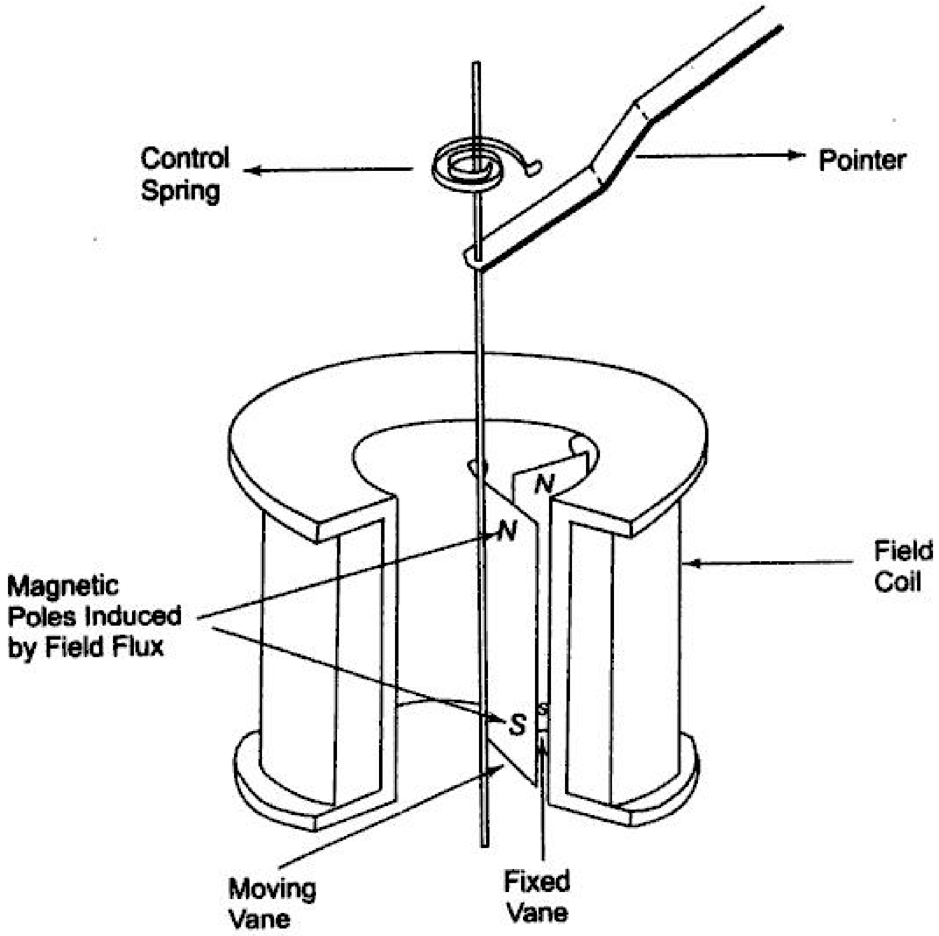

Fig. 2.8 Repulsion Type AC Meter (Radial Vane Type)

The deflection of the pointer thus produced is effectively proportional to the actual current through the instrument. It can therefore be calibrated directly in amperes and volts.

The calibrations of a given instrument will however only be accurate for the ac frequency for which it is designed, because the impedance will be different at a new frequency.

The moving coil or repulsion type of instrument is usually calibrated to read the effective value of amperes and volts, and is used primarily for rugged and inexpensive meters.

The iron vane or radial type is forced to turn within the fixed current carrying coil by the repulsion between like poles. The aluminium vanes, attached to the lower end of the pointer, acts as a damping vane, in its close fitting chamber, to bring the pointer quickly to rest.

CONCENTRIC VANE REPULSION TYPE (MOVING IRON TYPE) INSTRUMENT

A variation of the radial vane instrument is the concentric vane repulsion movement. The instrument has two concentric vanes.

One vane is rigidly attached to the coil frame while the other can rotate coaxially inside the stationary vane, as shown in Fig. 2.9. Both vanes are magnetised by the current in the coil to the same polarity, causing the vanes to slip laterally under repulsion. Because the moving vane is attached to a pivoted shaft, this repulsion results in a rotational force that is a function of the current in the coil. As in other mechanisms the final pointer position is a measure of the coil current. Since this movement, like all iron vane instruments, does not distinguish polarity, the concentric vane may be used on dc and ac, but it is most commonly used for the latter.

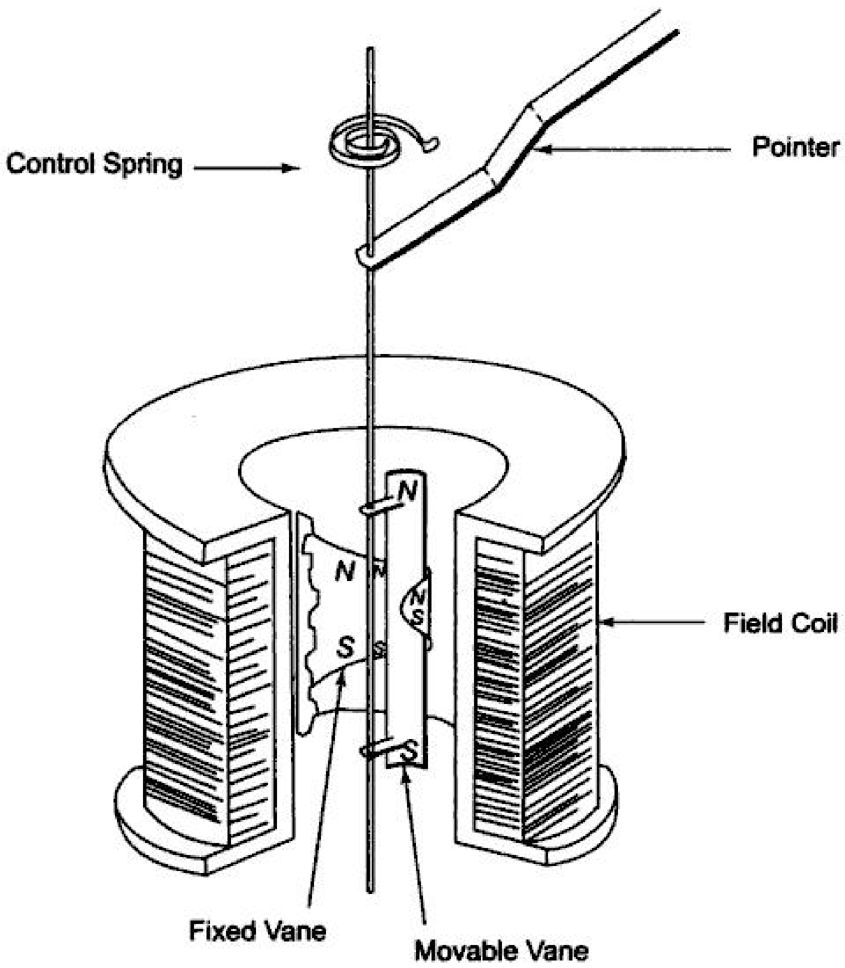

Fig. 2.9 ▬ Concentric Iron Vane (Repulsion Type)

Damping is obtained by a light aluminium damping vane, rotating with small clearance in a closed air chamber. When used on ac, the actual operating torque is pulsating and this may cause vibration of the pointer. Rigid (trussed) pointer construction effectively eliminates such vibration and prevents bending of the pointer on heavy overloads. The concentric vane moving iron instrument is only moderately sensitive and has square law scale characteristics. The accuracy of the instrument is limited by several factors: (i) the magnetisation curve of the iron vane is non-linear. (ii) at low current values, the peak to peak of the ac produces a greater displacement per unit current than the average value, resulting in an ac reading that may be appreciably higher than the equivalent dc reading at the lower end of the scale. Similarly, at the higher end of the scale, the knee of the magnetisation curve is approached and the peak value of the ac produces less deflection per unit current than the average value, so that the ac reading is lower than the equivalent dc value.

(Hysteresis in iron and eddy currents in the vanes and other metal parts of the instrument further affect the accuracy of the reading.) The flux density is very small even at full scale values of current, so that the instrument has a low current sensitivity. There are no current carrying parts in the moving system, hence the iron vane meter is extremely rugged and reliable. It is not easily damaged even under severe overload conditions.

Adding a suitable multiplier converts the iron vane movement into a voltmeter; adding a shunt produces different current ranges. When an iron vane movement is used as an ac voltmeter, the frequency increases the impedance of the instrument and therefore a lower reading is obtained for a given applied voltage. An iron vane voltmeter should therefore always be calibrated at the frequency at which it is to be used. The usual commercial instrument may be used within its accuracy tolerance from 25–125 Hz.

DIGITAL DISPLAY SYSTEM AND INDICATORS

The rapid growth of electronic handling of numerical data has bought with it a great demand for simple systems to display the data in a readily understandable form. Display devices provide a visual display of numbers, letters, and symbols in response to electrical input, and serve as constituents of an electronic display system.

CLASSIFICATION OF DISPLAYS

Commonly used displays in the digital electronic field are as follows.

1. Cathode ray tube (CRT)
2. Light emitting diode (LED)
3. Liquid crystal display (LCD)
4. Gas discharge plasma displays (Cold cathode displays or Nixies)
5. Electro-luminescent (EL) displays
6. Incandescent display
7. Electrophoretic image displays (EPID)
8. Liquid vapour display (LVD)