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Electrical Measurements and Measuring Instruments

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MEASURING INSTRUMENTS

Chapter

1

1.1 INTRODUCTION

Instrumentation is a technique of measurement which serves not only science but all branches of engineering, medicine and almost every human endeavour. The knowledge of any parameter largely depends on the measurement. The major problem encountered with any measuring instrument is the error. Therefore, it is necessary to select suitable instrument and also the method which minimise the error. Errors can be minimised in any experimental work by careful planning, execution and evaluation of the experiment.

1.2 CLASSIFICATIONS OF MEASURING INSTRUMENTS

1.2.1 Analog and Digital Instruments

The instruments are classified as either analog instruments or digital instruments based on the method of display of the measuring quantity. An analog instrument is one in which magnitude of the measured electrical quantity is indicated by the movement of a pointer across the face of a scale. The indication on a digital instrument is in the form of a series of numbers displayed on a screen. The choice of the type of the instrument depends on the application.

1.2.2 Absolute and Secondary Instruments

Instruments are classified based on the method of calibration.

1.2.2.1 Absolute instruments

These instruments are rarely used except in standard laboratories and for scientific work. The quantity to be measured will be given in terms of deflection and constant of the instrument. No calibration is needed in this type of instruments. Division on the graduated scale will not have any value marked on it.

Example : Tangent galvanometer and Raleigh current balance.

The tangent galvanometer gives the value of current (I) in terms of the tangent of deflection produced ($\tan \theta$) by the current, the radius (r), the number of turns (N) of the galvanometer and the horizontal component of earth's field (H).

$$I = \frac{Hr}{2\pi N} \tan \theta \quad (1.1)$$

1.2.2.2 Secondary instruments

In this type, the quantity to be measured will be obtained in terms of deflection of pointer because it will be calibrated by comparison with standard instrument or absolute instrument. Unlike in the previous case, the divisions on the graduated scale will have numerical values. These classes of instruments are most generally used in laboratories, industries and power stations.

1.2.3 Indicating, Recording and Integrated Instruments

Instruments are classified based on the method of display.

1.2.3.1 Indicating instruments

Indicating instruments are those which indicate the magnitude of the quantity being measured at that time. These indications are given by pointers moving over calibrated scales. Instruments like ammeters, voltmeters, wattmeters, etc., belong to this class.

1.2.3.2 Recording instruments

Recording instruments are those which give a continuous record of variation of the quantity, such as current voltage or power over a selected period of time. The moving system of the instruments carries an ink pen which rests lightly on a chart or graph sheet carried by a revolving drum. The drum moves at a uniform speed in a direction perpendicular to the direction of the deflection of the pen. The path traced out by the pen on the sheet of paper gives a continuous record of the variations in the quantity being recorded. Recording voltmeters are in common use to record the variation of voltage by suppliers at the terminals of the consumers during 24 hours in case of their complaints of low voltage.

Example : Demand meters, Barometer.

1.2.3.3 Integrated instruments

Instruments register by a set of dials and pointers either total ampere hours or the total amount of electrical energy (kWh) supplied to a circuit in a given time. Household energy meter is an integrating instrument. Ampere hour meter is another example of integrating meter.

$$\text{Energy} = \int_0^t P dt \quad (1.2)$$

Variation of power with time is shown in Fig. 1.1.

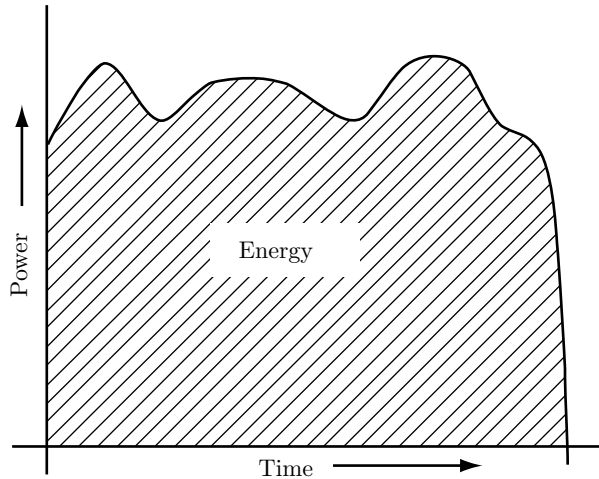


Fig. 1.1 Energy measurement by integration.

1.3 EFFECTS USED IN MEASURING INSTRUMENTS

The operation of the secondary instruments depends on one of the following effects for producing deflecting torque.

1. *Electromagnetic Effect* : Using this effect, we can produce ammeters, wattmeters and energy meters
2. *Heating Effect* : Using this effect we can produce ammeters and voltmeters
3. *Chemical Effect* : Using chemical effect, we can produce D.C. ampere hour meters.
4. *Electrostatic Effect* : Using electrostatic effect one can produce voltmeters (indirectly ammeters and watt-hour meters)
5. *Induction Effect* : Using induction effect, we can produce voltmeters, ammeters, watt-hour meters and energy meters.

1.4 INDICATING INSTRUMENTS

Electrical instruments, such as ammeters, voltmeters, wattmeters, etc., are called indicating instruments since they indicate with a pointer on a graduated scale the value of the quantity being measured at a particular instant. Indicating instruments possess three essential features:

- (a) Device for deflecting the pointer over the scale,
- (b) Device for controlling the movement of the pointer, and

- (c) Device to ensure that the pointer comes to rest quickly at its correct reading position without excessive oscillation and in a short time.

1.4.1 Deflecting Device

The device used for deflecting the pointer over the scale is called the deflecting device. The torque needed to obtain the deflection is known as deflecting torque or operating torque. The production of deflecting torque is dependent upon the quantity to be measured and the type of the instrument.

1.4.2 Control Device

The device used for controlling the movement of the pointer over the scale is called the control device. It ensures that

- the pointer comes to its correct position on the application of the deflecting torque.
- the pointer returns to the zero position when the deflecting torque is removed. The torque which controls the movement of the pointer is called the control torque. It opposes the deflecting torque and increases as the deflection increases. To obtain a stable position of the pointer, the control torque must be equal to the deflecting torque. Two methods may be used to obtain control torque, namely, spring control and gravity control.

1.4.2.1 Spring control

The control torque is obtained by either two spiral wound springs or a twisted suspension wire. In spring control the two hair springs are made of non-magnetic alloy such as phosphor-bronze or beryllium-copper. The spring material should have low values of specific resistance and temperature coefficient of resistance and should not be subjected to fatigue. The two springs S_1 and S_2 would be in opposite directions on the spindle S of the moving system so that when the moving system is deflected one spring opens while the other closes as shown in Fig. 1.2. This minimises the effect of temperature change on the restraining torque of the springs. The control torque is due to the combined torsions of the two springs.

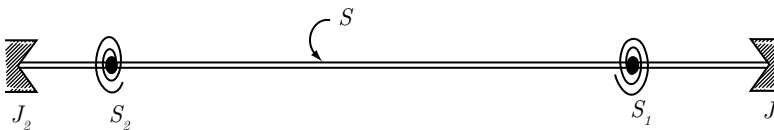


Fig. 1.2 Control springs on the moving system of an instrument.

Since the torsional torque of a spiral spring is proportional to the angle of twist, the control torque is directly proportional to the angular deflection of the pointer

If T_c = control torque
 θ = angular deflection of the pointer

$$T_c \propto \theta$$

$$T_c = k_s \theta \quad (1.3)$$

where k_s is the spring constant. It depends upon the material and geometry of the spring and it is expressed in Newton metres (Nm) per unit deflection.

1.4.2.2 Gravity control

In gravity controlled instruments, a small adjustable weight W_c is attached to the moving system as shown in Fig. 1.3. In order to counterbalance the weight of the moving system, another weight W_b (called the balance weight) is also attached to the moving system. In the zero position of the pointer, the control weight is vertical. When the pointer is deflected through an angle θ , the control weight W_c has a new position shown dotted in Fig. 1.3. The control weight tends to come to its original vertical position due to gravity. The restoring force or control force is $W_c \sin \theta$ and the restoring torque or control torque T_c is $W_c l \sin \theta$. Here l is the distance of the centre of gravity of the controlling arm for pivot. In case of an instrument in which the deflecting torque is directly proportional to current that is a PMMC instrument ($T_d \propto I$) and for gravity control $T_c \propto \sin \theta$. For equilibrium position

$$T_d = T_c$$

$$I \propto \sin \theta$$

$$I = k \sin \theta \quad (1.4)$$

Since current is proportional to sine of angle of deflection, the scale of a gravity controlled instrument is not uniform. It is cramped or crowded at its lower end. Another disadvantage of such instrument is that it should be kept in vertical position.

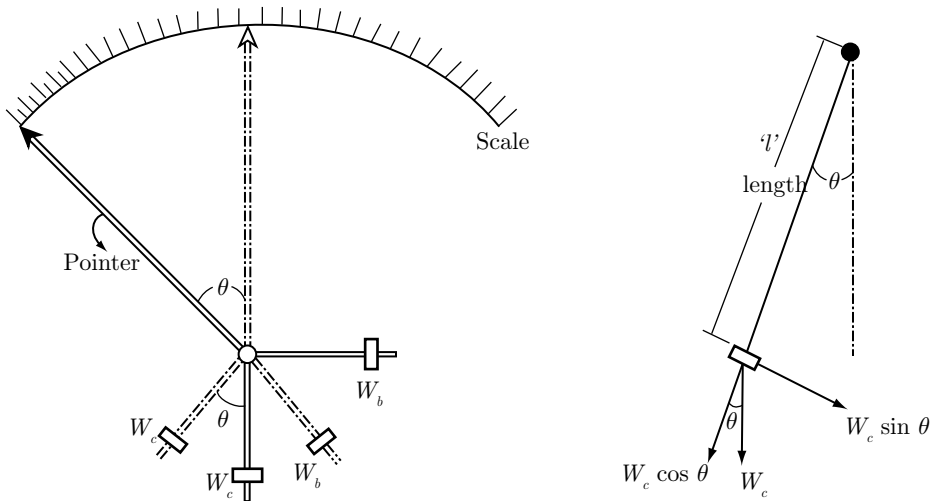


Fig. 1.3 Gravity control.

However, gravity control has the following advantages:

- It is cheaper than spring controlled instrument.
- It is unaffected by temperature variations.
- It is not subjected to fatigue.

1.4.3 Damping Devices

When the pointer changes its position due to variation of current, its momentum carries it beyond its new position. It then starts oscillating about its new position due to inertia. For satisfactory operations, the pointer should settle down to its new position quickly. Damping is the prevention of the oscillation of the pointer to reduce its settling time. The torque applied to damp out the oscillation is called the damping torque, and the device used for this purpose is known as a damping device. The damping torque is proportional to the angular velocity of the moving system, and thus it acts only when the system is in motion.

The degree of damping decides the behaviour of the moving system. The effect of damping on the variation of position with time of the moving system of the instrument is shown in the Fig. 1.4.

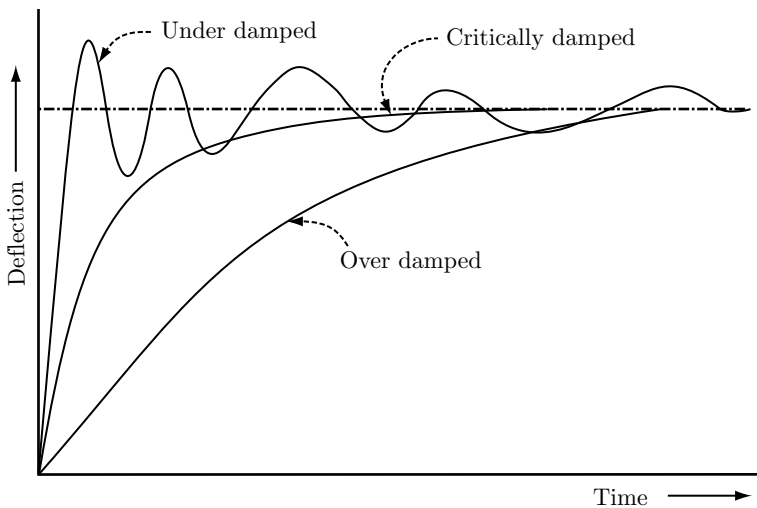


Fig. 1.4 Effect of damping on settling time of the pointer.

If the instrument is under damped, the pointer will oscillate about its final deflected position before coming to rest. If the instrument is over damped, the moving system rises slowly for zero to its final position. When the pointer reaches its final position quickly without oscillations, the damping is said to be critical, and the instrument is said to be dead beat or critically damped. In practice, it is found that best results are obtained when the damping is slightly less than the critical value.

The methods commonly used for damping oil are

- (a) Eddy current damping
- (b) Air friction damping
- (c) Fluid friction damping.

1.4.3.1 Air friction damping

1st Method:

Damping force is produced by moving movement of aluminium piston in an air chamber as shown in Fig. 1.5(a). The gap between the piston and the chamber, will be $1/1000$ th of an inch. When the piston is moving into the chamber the air will be compressed; this compressed air will oppose the movement of the piston.

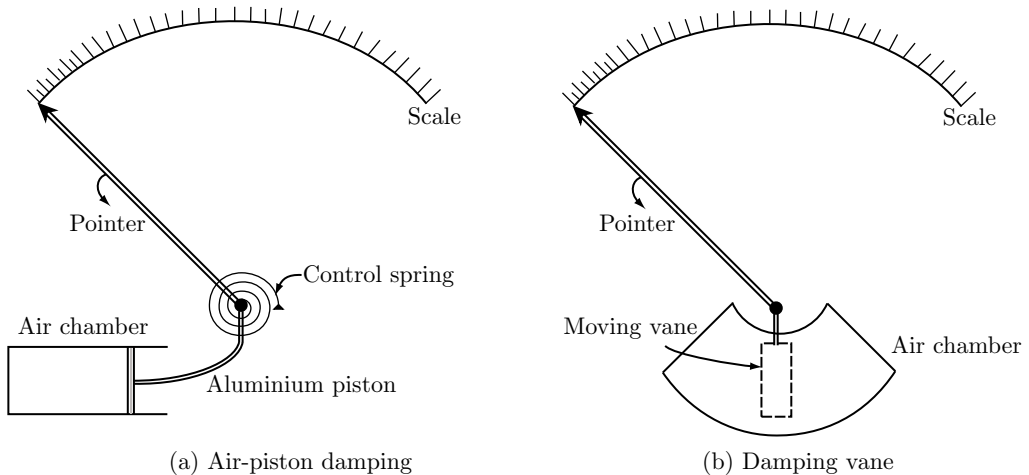


Fig. 1.5 Air friction damping.

When the movement of the piston is out of the chamber, the pressure inside the chamber will fall, below the external value. The difference in the pressure will act on the piston and thereby try to arrest the movement of the piston when it is moving outwards. Damping force comes into act only when there is a movement of piston.

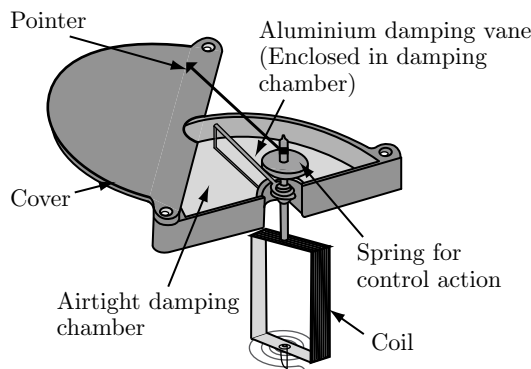


Fig. 1.6 Air friction damping.

2nd Method:

This method utilises a vane, mounted on the spindle of the moving system. The vane is of thin aluminium sheet and moves in a closed sector shaped box as shown in Fig. 1.5(b).

1.4.3.2 Fluid friction damping**1st Method:**

A light vane is attached to the spindle of the moving system; is dipped into a pot containing damping oil and is completely submerged in the oil as shown in Fig. 1.7(a).

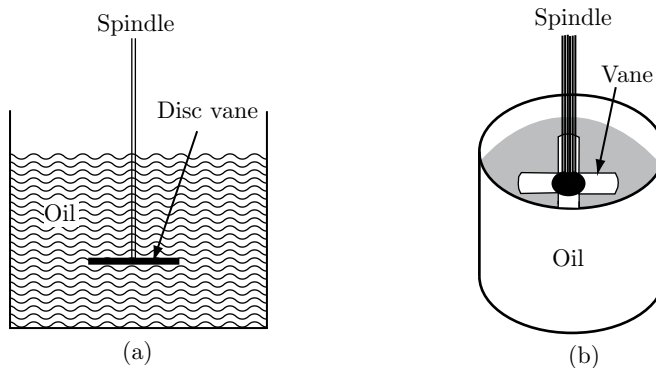


Fig. 1.7 Fluid friction damping.

Damping force is provided by surface tension between the vane and the oil, acts opposite to the direction of the motion of the vane. No damping force comes into picture when the spindle is stationary.

2nd Method:

In this method, the section of the moving vane produces more damping force as in the Fig. 1.5.(b). The damping oil should possess the following properties:

- (a) It should not evaporate quickly.
- (b) It should be a good insulator.
- (c) Its viscosity should not be affected by temperature.
- (d) It should not have any chemical reactions on the spindle.

Disadvantages:

- (a) One cannot keep the disk in any position.
- (b) Oozing of the oil is exhibited if there is any slight leakage.

1.4.3.3 Eddy current damping

Eddy current damping is shown in Fig. 1.8. As its spindle rotates, the part of the material under the magnet will cut the lines of force of permanent magnet and emf will be induced along the radial direction of the disc. This induced emf drives current in such a way according to Lenz's law, the force on part of the disc under the magnet is always directed opposite to the direction of motion.

$$\begin{aligned}
 \text{Damping force} &\propto I_e; & I_e &\propto N\phi; & \text{emf} &\propto \phi N; & I_e &\propto \text{emf} \\
 \text{Damping force} &\propto N\phi \quad (\text{since } \phi \text{ is constant}) \\
 \text{Damping force} &= KN\phi
 \end{aligned} \tag{1.5}$$

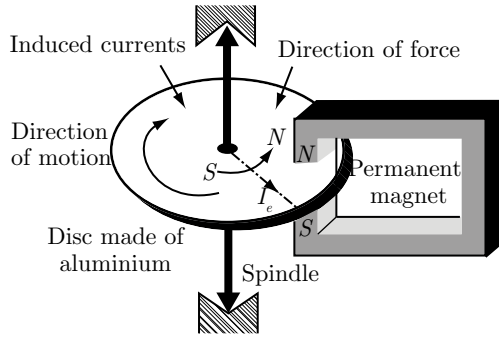


Fig. 1.8 Eddy current damping.

There can be no damping force when the speed of the disc is zero, i.e., when the pointer reads steady value.

Out of three types, Eddy current damping is most efficient (provided introduction of magnets will not produce distortion of an existing magnetic field used for deflection which involves an error).

Example 1.1 *If the deflecting torque of an instrument is directly proportional to the current to be measured and the maximum current produces a deflection 90° , compare the deflection in a spring controlled instrument with a similar instrument having gravity control for a current equal to half the maximum value.*

Solution

$$T_D = \text{Deflecting torque} = kI$$

$$\text{In spring control, } T_C = \text{Controlling torque} = C\theta$$

$$\text{Under steady conditions of reading } T_D = T_C$$

$$I = k_1\theta$$

$$I_{max} = k_1 90 \tag{1.6}$$

$$\frac{I_{max}}{2} = k_1\theta \tag{1.7}$$

$$\text{From (1)/(2)} \quad 2 = \frac{90}{\theta} = 45^\circ$$

Hence, deflection will be 45° only when flux is maximum.

Gravity control

$$T_C = K \sin \theta$$

$$I = K_2 \sin \theta$$

$$I_{max} = K_2 \sin 90^\circ \tag{1.8}$$

$$\frac{I_{max}}{2} = K_2 \sin \theta \tag{1.9}$$

From (3)/(4) $2 = \frac{1}{\sin \theta}$ $\theta = 30^\circ$.

Hence, corresponding deflection will be only 30° for half the current.

1.5 CONSTRUCTIONAL DETAILS OF INDICATING INSTRUMENTS

1.5.1 Balancing

Control mechanisms are shown in Fig. 1.9. In order that the deflection of a spring controlled instrument shall be independent of its position and also that the wear and tear on the bearing is small and uniform, it is essential that the centre of gravity of the moving system must coincide with the axis of rotation. For this reason one or more balancing weights are added to the moving system.

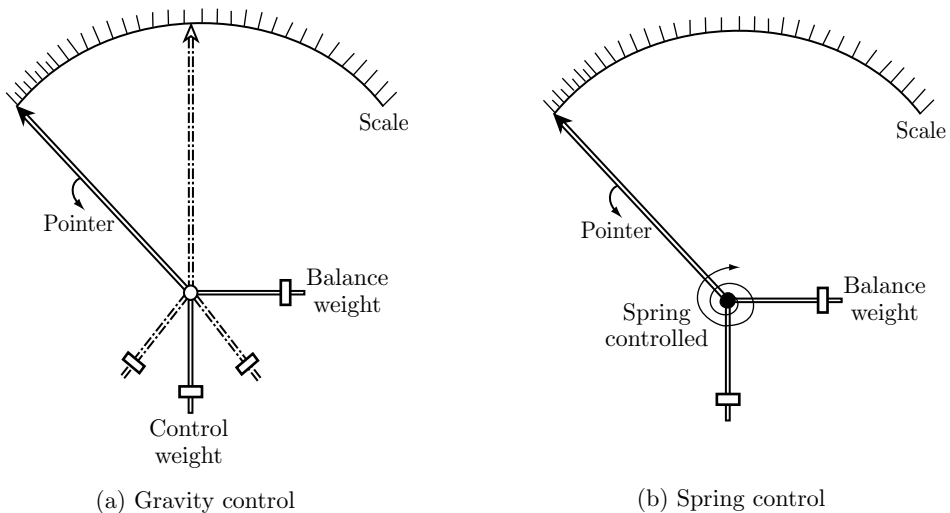


Fig. 1.9 Control mechanism for indicating instruments.

In gravity control, both the weights will control the pointer; the weight of the system is increased by balancing. The gravity control and spring control were shown in Fig. 1.7.

Disadvantages of balancing:

- (a) Wear and tear on the bearing will be more because of increase in weight.
- (b) It requires more deflecting torque since the frictional torque is increased due to increase of pressure on the bearings.

- (c) We can reduce the weight of the moving system by reducing the balance weight and increasing the length of the arm. But it will increase the inertia of the system which necessitates a large damping force.

1.5.2 Torque and Weight Ratio

The weight of the moving parts must be small to reduce the frictional torque and also to reduce wear on the bearings. For this

$$\frac{\text{Deflecting torque at full scale}}{\text{Weight of the moving system}} \leq 0.01 \text{ N-m/kg}$$

This relation is influenced by whether the area of moving system is vertical or horizontal. Frictional error will be reduced by employing high T_D/w ratio and sensitivity is increased.

1.5.3 Methods of Supporting Moving System

There are two methods of supporting the moving system:

- (a) By pivoting
- (b) By thread suspension.

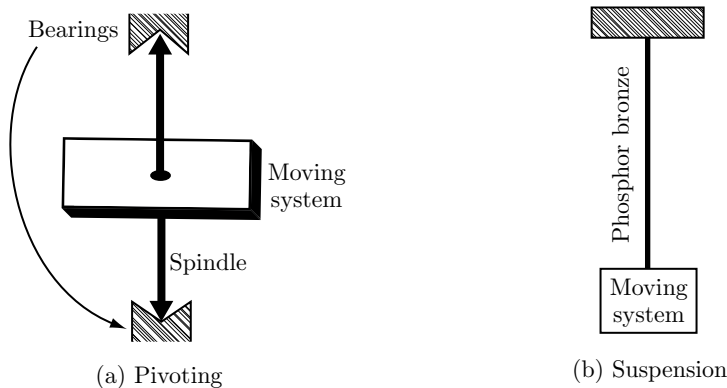


Fig. 1.10 Methods of supporting moving system.

Pivoting:

If the ends of the spindle are conical, the bearing friction will be more. To reduce the bearing friction the bearing is slightly rounded off to reduce the contact area which will reduce the bearing friction but the pressure on the ends of the spindle will exceed 80 T/m^2 when the ends are very sharp. To reduce the pressure on the ends, the pivot is slightly rounded off. Materials used are sapphire, jewels (for bearings).

Thread suspension:

Thread suspension is advantageous when the operating forces are small compared to the weight of the system. This type completely eliminates bearing friction. Thread suspension also provides controlling torque in addition to supporting.

1.5.4 Permanent Magnets used in Indicating Instruments

Properties: The strength of the magnet should not be reduced with time. Materials for permanent magnets

- 1) Hard steel with tungsten as small percentage
- 2) ALNICO or ALCOMAX. (Aluminium 8% + Nickel 14% + Cobalt 24% + Copper 3% and rest hard steel).

Moving coil permanent magnet type is shown in the Fig. 1.11.

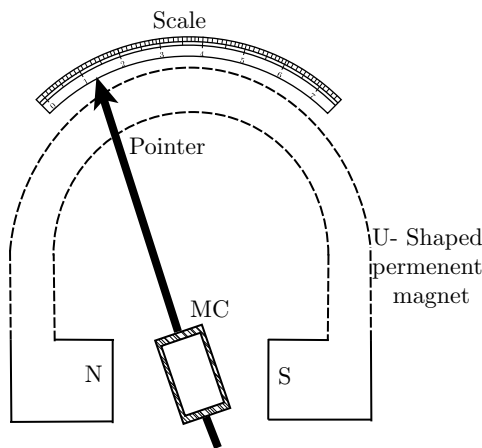


Fig. 1.11 Permanent magnets used in indicating instruments.

1.5.5 Pointers and Scales

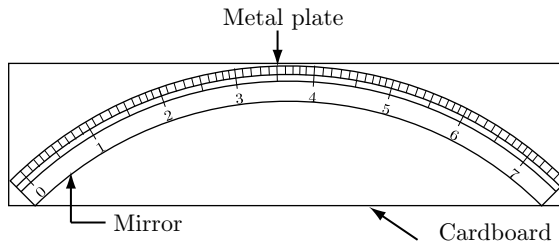


Fig. 1.12 Scale.

The weight of the pointer must be reduced as far as possible. It will reduce bearing friction and also the damping force employed if the pointer is light. The pointer will have different shapes. Aluminium is usually preferred for pointers.

Scale: A stiff cardboard mounted on a metal sheet is used for scales. To avoid parallax error a small strip of mirror is fixed with cardboard. For accurate reading the width of the pointer must be as small as possible.

1.5.6 Casting for Meters

Materials used for casting of meters to protect the system from dust and moisture are

- 1) Hard wood
- 2) Brass
- 3) Cast iron
- 4) Pressed steel
- 5) Plastics.

Steel covering is preferred to avoid the effect of extraneous magnetic fields on the deflecting system since it acts as a screen. For meters it is an advantage since the effect of extraneous magnetic field on the moving system is nil. Covering also eliminates the possibility of dust and moisture coming in contact with the moving system.

1.6 CLASSIFICATION OF INDICATING INSTRUMENTS ACCORDING TO LIMITING ERROR

According to the B.B.S. No. 89, 1937; the indicating instruments are divided into the categories

- (a) Substandard type
- (b) First Grade type.

Table 1.1 Errors allowed in the instruments

S.No.	Type of the instrument	Single range voltmeter or ammeter	Multi range voltmeter or ammeter
1.	Permanent magnet type	0.2%	0.6%
2.	Electrodynamic type	0.3%	0.5%
3.	Wattmeters	0.25%	0.6%
4.	First grade type	1 to 3.5%	-

The errors specified in the above table are given in terms of full-scale readings.