Lecture 5, 6, 7and 8

D.C indicating instrument, General theory of PMMC

3.1 Introduction

The electronic instruments generally have higher sensitivity, faster response and greater flexibility than mechanical or electrical instruments in indicating, recording and, where required, in controlling the measured quantity.

The deflection type instruments with a scale and movable pointer are called **analog** instruments. The deflection of the pointer is a function of (and, hence, analogous to) the value of the electrical quantity being measured.

In PMMC meter or (D'Arsonval) meter or galvanometer all are the same instruments, a coil of fine wire is suspended in a magnetic field produced by permanent magnet. According to the fundamental law of electromagnetic force, the coil will rotate in the magnetic field when it carries an electric current by electromagnetic (EM) torque effect.

A pointer is attached to the movable coil. This pointer will deflect according to the amount of current to be measured which is applied to the coil. The (EM) torque is counterbalanced by the mechanical torque of control spring attached to the movable coil also. When the torques are balanced, the moving coil will stop rotating and its angular deflection represent the amount of electrical current to be measured against a fixed reference, called a scale. If the permanent magnet field is uniform and the spring is linear, the pointer deflection will also be linear.

3.2 PMMC Meter

It is also called D' Arsonval meter movement or a permanent-magnet moving-coil (PMMC) meter movement. Since it is widely used in electronic instruments, it is worthwhile to discuss its construction and principle of operation.

The basic PMMC movement is often called the D'Arsonval movement, after its inventor. This design offers the largest magnet in a given space and is used when maximum flux in the air gap is required. It provides an instrument with very low power consumption and low current required for full-scale deflection. It can be used for D.C. measurements only.

1. Construction

As shown in Fig. 3.1, it consists of a permanent horse-shoe magnet with soft iron pole pieces attached to it. Between the two pole-pieces a cylinder-shaped soft iron core is situated. A coil of fine wire wound on a light metal frame moves around the cylinder-shaped soft iron core. The metal frame is mounted in jewel bearings so that it can rotate freely. A light pointer attached to the moving coil moves up-scale as the coil rotates when current is passed through it. The rotating coil is prevented from continuous rotation by a spring which provides restoring torque.

The moving coil movement described above is being increasingly replaced by tautband movement in which the moving coil and the pointer are suspended between bands of spring metal so that the restoring force is tensional. The bands perform two functions (*i*) to support the coil and (*ii*) to provide restoring torque thereby eliminating the pivots and jewels used with coil spring movement.

As compared to pivoted movement, the taut-band has the advantages of

1. Greater sensitivity i.e. small full-scale deflection current
2. Ruggedness,
3. Minimal friction,
4. Easy to manufacture.

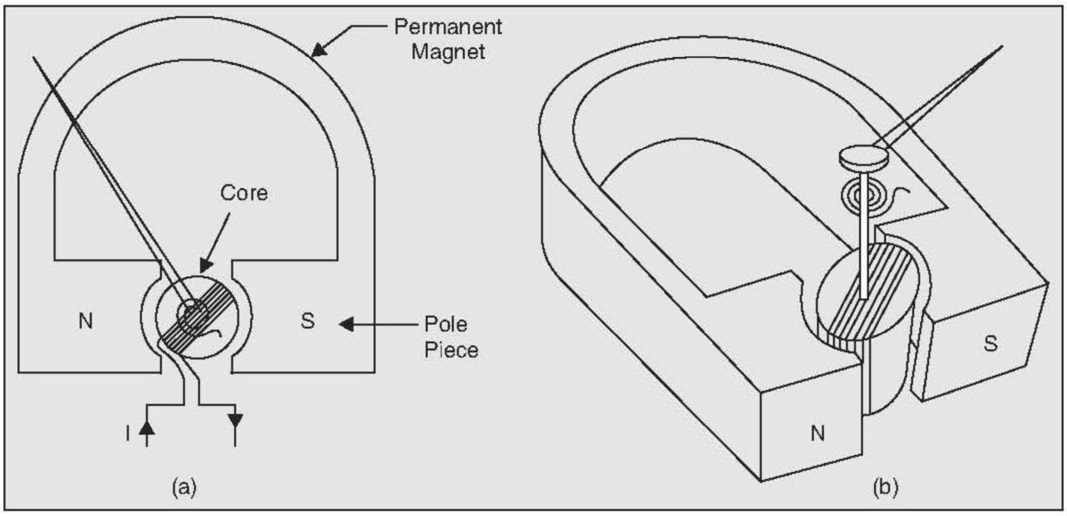

Fig. 3.1.

2. Principle of Operation

This meter movement works on the motor principle and is a current-responding device. The deflection of the pointer is directly proportional to the amount of current passing through the coil.

When direct current flows through the coil, the magnetic field so produced reacts with the field of the permanent magnet. The resultant force turns the coil alongwith its pointer. The amount of deflection is directly proportional to the amount of current in the coil. Hence, their scale is linear. With correct polarity, the pointer reads up-scale to the right whereas incorrect polarity forces the pointer off-scale to the left.

3. Deflecting Torque

If the coil is carrying a current of i A,

the force on a coil side = $BilN$

torque due to both coil sides = $(2r)(BilN)$

$= Gi$

$G = 2rBlN = NBA$

Where G = constant

$A = 2rl$ = area of the coil

N = no. of turns of the coil.

B = flux density in Wb/m^2.

l = length of the vertical side of the coil, m.

$2r$ = breadth of the coil, m

i = current in ampere.

4. Controlling Torque

The value of control torque depends on the mechanical design of the control device. For spiral springs and strip suspensions, the controlling torque is directly proportional to the angle of deflection of the coil.

$$\text{Control torque} = C\,\theta$$

Where, θ = deflection angle in radians

C = spring constant

3.3 Characteristics of Moving Coil Meter Movement

We will discuss the following three characteristics:

(*i*) full-scale deflection current (I_m),

(*ii*) internal resistance of the coil (R_m),

(*iii*) sensitivity (S).

1. Full-scale Deflection Current (I_m)

It is the current needed to deflect the pointer all the way to the right to the last mark on the calibrated scale. Typical values of Im for D' Arsonval movement vary from 2 μA to 30 mA.

It should be noted that for smaller currents, the number of turns in the moving coil has to be more so that the magnetic field produced by the coil is strong enough to react with the field of the permanent magnet for producing reasonable deflection of the pointer. Fine wire has to be used for reducing the weight of the moving coil but it increases its resistance. Heavy currents need thick wire but lesser number of turns so that resistance of the moving coil is comparatively less. The schematic symbol is shown in Fig. 3.2.

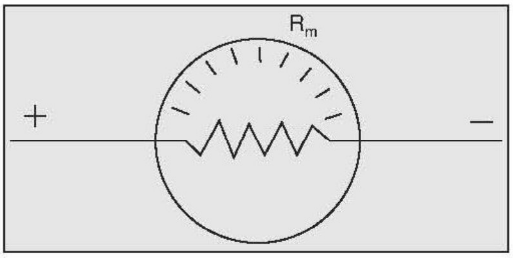

Fig. 3.2.

2. Internal Resistance (R_m)

It is the dc ohmic resistance of the wire of the moving coil. A movement with smaller I_m has higher R_m and *vice versa*. Typical values of R_m range from 1.2 W for a 30 mA movement to 2 kW for a 50 mA movement.

3. Sensitivity (S)

It is also known as **current sensitivity or sensitivity factor**. It is given by the reciprocal of full-scale deflection current I_m.

$$S = \frac{1}{I_m} \text{ ohm/volt.}$$

For example, the sensitivity of a 50-μA meter movement is

$$S = \frac{1}{50 \times 10^{-6}} \frac{\text{ohm}}{\text{volt}} = 20{,}000\ \Omega/\text{V} = 20\ \text{k}\Omega/\text{V}$$

The above figure shows that a full-scale deflection of 50 μA is produced whenever 20,000 W of resistance is present in the meter circuit for each volt of applied voltage. It also represents the ohms-per-volt rating of the meter. The sensitivity of a meter movement depends on the strength of the permanent magnet and number of turns in the coil. Larger the number of turns, smaller the amount of current required to produce full-scale deflection and, hence, higher the sensitivity. A high current sensitivity means a high quality meter movement. It also determines the lowest range that can be covered when the meter movement is modified as an ammeter or voltmeter.

3.4 Advantage of PMMC

Following are some of the advantages of PMMC which are important from the subject point of view:

1. It has uniform scale.
2. Operating current is small.
3. It has high sensitivity.
4. It consumes low power, of order of 25 W to 200 μW.
5. It has high accuracy.
6. Extension of instrument range is possible.
7. Not affected by eternal magnetic fields called stray magnetic fields.

3.5 Disadvantage of PMMC

PMMC has some disadvantages too. These are given below :

1. Used only for D.C measurements. The torque reverse if the current reverses. If the instrument is connected to A.C., the pointer cannot follow the reversals and the deflection corresponds to mean torque, which is zero, hence it cannot be used for A.C.
2. The cost of the instrument is high.

3.6 Galvanometer

A moving coil galvanometer is an instrument used for detection and measurement of small electric currents.

A **galvanometer** is a type of ammeter, an instrument for detecting and measuring electric current. It is an analog electromechanical transducer that produces a rotary deflection of some type of pointer in response to electric current flowing through its coil.

The Galvanometer is an electromechanical instrument which is used for the detection of electric currents or voltage through electric circuits. Being a sensitive instrument, Galvanometer cannot be used for the measurement of heavy currents.

However we can measure very small currents or voltages by using galvanometer but the primary purpose of galvanometer is the detection of electric current not the measurement of current.

The Galvanometer may be classified into three categories

1. DC Galvanometers

There are two types of galvanometer: (*i*) moving-magnet galvanometer and (*ii*) moving coil galvanometer.

(i) In ***moving-magnet galvanometer*** the magnet moves due to the magnetic field set up by the flow of current through a fixed coil. The damping in this galvanometer is poor but may be improved by using conducting plates near the moving magnets. Tangent galvanometer is the example of moving-magnet galvanometer.

(ii) In ***moving coil galvanometer*** a magnetic coil moves in the field of permanent magnet. The current to be detected is passes through the coil. ***D' Arsonval galvanometer*** is the example of ***moving coil galvanometer***.

2. AC Galvanometers

The AC Galvanometers is used for measuring the effective or rms value of small current or in most case null detectors in bridge and potentiometer circuits. There are two types of ac galvanometers: (*i*) phase sensitive and (*ii*) frequency sensitive galvanometer.

The phase sensitive is a dynamometer type galvanometer and the frequency sensitive is a tuned detector or vibration type galvanometer. It is important type of galvanometer for frequencies below 200 Hz.

3. Ballistic Galvanometers

It is used for the measurement of charge or quantity of electricity passed through it. This quantity of electricity in magnetic measurements is due to the induced emf or change in magnetic flux in the coil. It is used in almost all the dc magnetic measurements.

3.7 D' Arsonval or Moving Coil Galvanometer

Galvanometer is an instrument used to indicate the presence, direction, or strength of a small electric current. A typical Galvanometer is a sensitive instrument used in laboratory, mainly to detect and compare currents. It makes use of the fact that an electric current flowing through a wire sets up a magnetic field around the wire. This is based on the principle, discovered in 1820 by Hans Christian Oersted when he observed that a magnetic needle could be deflected by an electric current. The first galvanometer was made in 1820 by Johann Schweigger.

Fig. 3.3 shows the D'Arsonval galvanometer type. The description of the different parts is given below:

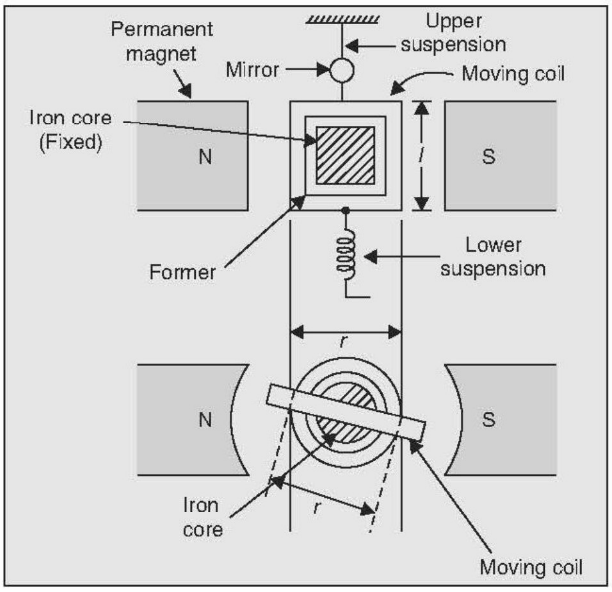

Fig. 3.3.

1. Moving Coil

The moving coil is the current carrying element. It is rectangular or circular in shape and consists of a number of turns of fine wire. It is arranged in a uniform, radial, horizontal magnetic field in the air gap between pole pieces of a permanent magnet and iron core. This coil is suspended so that it is free to turn about its vertical axis of symmetry.

2. Damping

The damping(or more precisely eddy current damping) is obtained by connecting a low resistance across the galvanometer terminals. Damping torque depends upon the resistance and we obtain critical damping by adjusting the values of resistance.

3. Suspension

The coil is supported by a flat ribbon suspension which also carries current to the coil. This is called the lower suspension and has a negligible torque.

The upper suspension consists of gold or copper wire of nearly 0.0125 or 0.025 mm diameter rolled into the form of a ribbon. This is mechanically not strong, so that galvanometer must be handled carefully without jerks. Sensitive galvanometer provided with coil clamps to take the strain from suspension.

4. Indication

The suspension carries a small mirror upon which a beam of light is cast. This beam of light is reflected on to a scale upon which the deflection is r [illegible] 1 meter away from the instrumentation.

5. Zero Setting

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

3.8 Torque Equation of Galvanometer

Galvanometer works on the principle of conversion of electrical energy into mechanical energy. When a current or voltage flows in a magnetic field it experiences a magnetic torque. If it is free to rotate under a controlling torque, it rotates through an angle proportional to the current flowing through it.

Fig. 3.4. shows the quantities that enter the torques equation of a galvanometer.

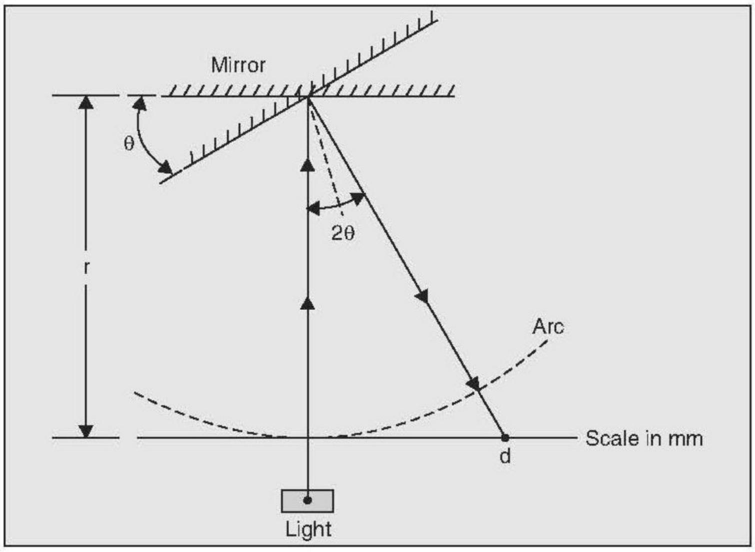

Fig. 3.4.

Where l, r = length of respectively vertical and horizontal side of coil

N = number of turns in the coil

B = flux density in the air gap

i = current through moving coil

K = spring constant of suspension

θ_F = final steady state deflection of moving coil

We know that the force on the coil is given by,

$$F = NBil \sin \alpha$$

where α = angle between direction of magnetic field and conductor.

When the field is radial, $\alpha = 90°$, then the force is given by

$$F = NBil$$

The deflecting torque is given by

$$T_d = \text{force} \times \text{distance} = NBilr$$
$$= NBAi$$

where $A = lr$ = area of coil

1. Deflection torque

$$T_d = Gi$$

where G is called the displacement constant of the galvanometer. It's value is given by

$$G = NBA = NBlr$$

2. Controlling torque

Controlling torque exerted by the suspension at deflection θF

$$T_c = K\theta_F$$

In steady state deflection

$$T_c = T_d$$
$$K\theta_F = G_i$$
$$\theta_F = \frac{Gi}{K}$$

For small deflection, the radius of arc and angle of turning, decide the deflection. If the mirror is turned through θ_F the angle through which the beam gets reflected is $2\theta_F$.

$$d \text{ in mm} = 2\ \theta_F \times r$$
$$d = \frac{2\ Gir}{K} \text{ mm}$$

where r = 1m = 1000 mm for the galvanometer.

3.9 Use of Galvanometer

There are many uses of galvanometer. Some of the important ones are as given below :

1. Galvanometer instrument used to determine the presence, direction, and strength of an electric current in a conductor.
2. A major early use for galvanometers was for finding faults in telecommunications cables. They were superseded late in the 20th century by time-domain reflectometers.
3. Used in positioning and control systems.
4. Mirror galvanometer systems are used as beam positioning elements in laser optical systems.
5. An automatic exposure unit from an 8 mm movie camera, based on a galvanometer mechanism (center) and a CdS photoresistor in the opening at left.

3.10 Variations of Basic Meter Movement

The basic moving-coil system can be converted into an instrument to measure dc as well as ac quantities like current, voltage and resistance etc. Without any modification, it can carry a maximum current of Im can withstand a maximum dc voltage $v = I_m R_m$.

DC instruments

(*a*) it can be made into a dc ammeter, milliammeter or micrommeter by adding a suitable shunt resistor R_{sh} in parallel with it as shown in Fig. 3.5(*a*),

(*b*) it can be changed into a dc voltmeter by connecting a multiplier resistor Rmult in series with it as shown in Fig. 3.5(*b*), (*c*) it can be converted into an ohmmeter with the help of a battery and series resistor *R* as shown in Fig. 3.5(*c*).

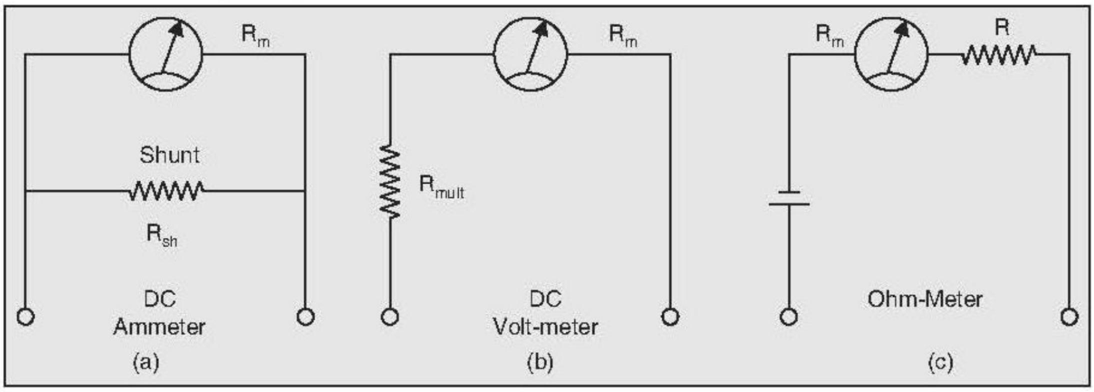

Fig. 3.5.

D.C. Instruments

(*a*) D.C. ammeter: by using a shunt resistor.

(*b*) D.C. voltmeter: by using series multiplier resistor.

(*c*) Ohmmeter: by using battery and series resistor.

3.11 D.C. Ammeter

The D'Arsonval galvanometer is a **moving coil** ammeter. It uses magnetic deflection, where current passing through a coil causes the coil to move in a magnetic field. The voltage drop across the coil is kept to a minimum to minimize resistance across the ammeter in any circuit into which it is inserted.

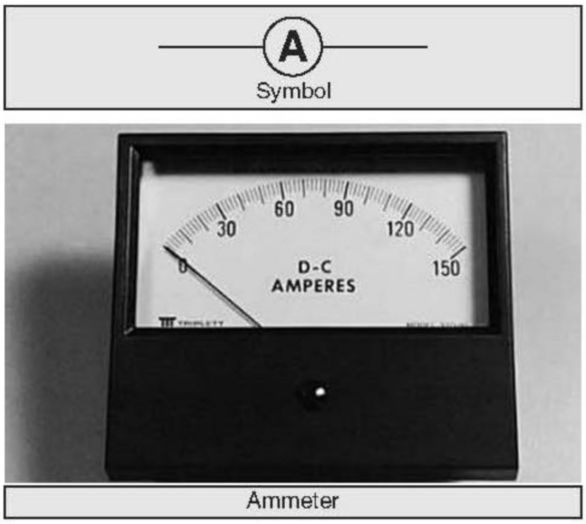

Fig. 3.6.

Ammeter Shunt Resistor

The basic movement of a dc ammeter is a PMMC D'Arsonval galvanometer. The coil winding of a basic movement is very small and light it can carry very small value of currents. When the large currents are to be measured it is necessary to bypass the major part of the current through a low resistance called shunt resistor. The shunt resistor is connected parallel with D'Arsonval movement. The ammeter is always connected in series with the load in the circuit.

The dc ammeter is shown in Fig. 3.7. The resistance of the shunt can be calculated by circuit analysis.

Where R_m = internal resistance of the movement coil

R_{sh} = resistance of the shunt

I_m = I_{fsd} = full scale deflection current

I_{sh} = shunt current

I = current to be measured

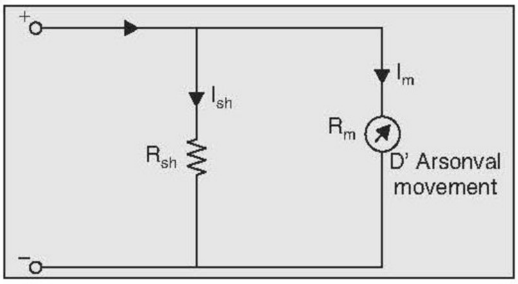

Fig. 3.7. DC Ammeter

Since the shunt resistance is in parallel with the meter movement, the voltage drop across the shunt and movement is the same.

$$V_{\text{shunt}} = V_{\text{movement}}$$

$$I_{sh} R_{sh} = I_m R_m$$

and

$$R_{sh} = \frac{I_m R_m}{I_{sh}}$$

We know that $I_{sh} = I - I_m$, so we can write

$$R_{sh} = \frac{I_m R_m}{I - I_m}$$

Rearranging the above equation we get,

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

The ratio of total current to the movement current is known as multiplying power of shunt.

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

$$R_{sh} = \frac{R_m}{(m-1)}$$

3.12 Properties of shunt resistor

Main properties of shunt resistor are given below:

1. Resistance of the shunt should not vary with time.
2. Temperature co-efficient of shunt and instrument should be low and should be same.

Example 1. *A 1 mA meter movement with an internal resistance of 100 Ω is to be converted into 0–100 mA. Calculate the value of shunt resistance required.*

Solution. Given: R_m = 100 Ω, I_m = 1 mA and I = 100 mA

We know that the value of shunt resistance,

$$R_{sh} = \frac{I_m R_m}{I - I_m}$$

$$= \frac{1\,\text{mA} \times 100\,\Omega}{100\,\text{mA} - 1\,\text{mA}} = \frac{100\,\text{mA}\,\Omega}{99\,\text{mA}} = 1.01\,\Omega \textbf{ Ans.}$$

3.13 Multi-range Ammeter

The current range of the dc ammeter is further extended by a number of shunts, selected by a range switch. This type of meter is called a multi-range ammeter.

Fig. 3.8 shows the multi-range ammeter and circuit diagram is shown in Fig. 3.9. It has four shunts (R_{sh1}, R_{sh2}, R_{sh3}, R_{sh4}) parallel with the meter movement and gives four different current ranges (I_1, I_2, I_3, I_4).

If m_1, m_2, m_3 and m_4 be the shunt multiplying powers for currents I_1, I_2, I_3 and I_4 then,

$$R_{sh1} = \frac{R_m}{(m_1 - 1)}$$

$$R_{sh2} = \frac{R_m}{(m_2 - 1)}$$

$$R_{sh3} = \frac{R_m}{(m_3 - 1)}$$

and

$$R_{sh4} = \frac{R_m}{(m_4 - 1)}$$

Fig. 3.8. Multi-range Ammeter

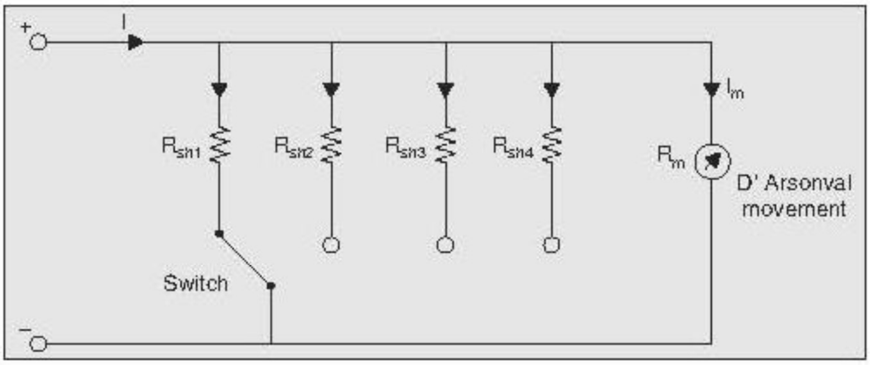

Fig. 3.9. Multi-range Ammeter

Ammeter uses a multiposition make-before-break switch. This type of switch is essential in order that the meter movement is not damaged when it change from one resistor to other resistor. If we used ordinary switch the meter remain without shunt when we change from one resistor to other resistor, this may damage the ammeter.

This ammeter used for ranges 1 – 50 A. While using the multi-range ammeter we use the highest current range first then decrease the current range.

Example 3.2. *Design a multi-range DC milli-ammeter with a basic meter having a resistance 75 Ω and full scale deflection for the current of 2 mA. The required ranges are 0-10 mA, 0-50 mA and 0-100 mA.*

Solution. Given: I_m = 10 mA; R_m = 75 Ω; I_1 = 10 mA; I_2 = 50 mA and I_3 = 100 mA.

For current range 0-10 mA

We know that for multi-range DC ammeter,

$$R_1 = \frac{I_m R_m}{(I_1 - I_m)}$$

$$= \frac{2 \times 75}{(10-2)} = 18.75\ \Omega$$

For current range 0-50 mA

We know that for multi-range DC ammeter,

$$R_2 = \frac{I_m R_m}{(I_2 - I_m)}$$

$$= \frac{2 \times 75}{(50-2)} = 3.125\ \Omega$$

For current range 0-100 mA

We know that for multi-range DC ammeter,

$$R_3 = \frac{I_m R_m}{(I_3 - I_m)}$$

$$= \frac{2 \times 75}{(100-2)} = 1.53\ \Omega$$

The design of multi-range ammeter is shown in Fig. 3.10.

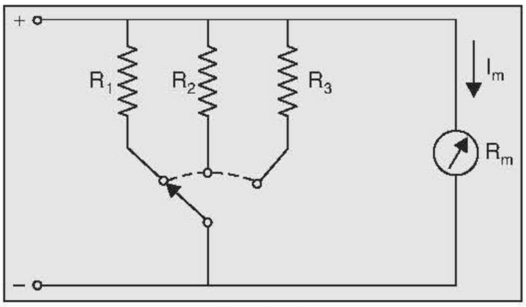

Fig. 3.10

3.14 Universal or Ayrton Shunt

We can use universal shunt in the multi-range ammeter. Fig. 3.11 shows the multi-range ammeter with universal shunt. The advantage of using universal shunt is that it eliminates the possibility of meter being in the circuit without shunt.

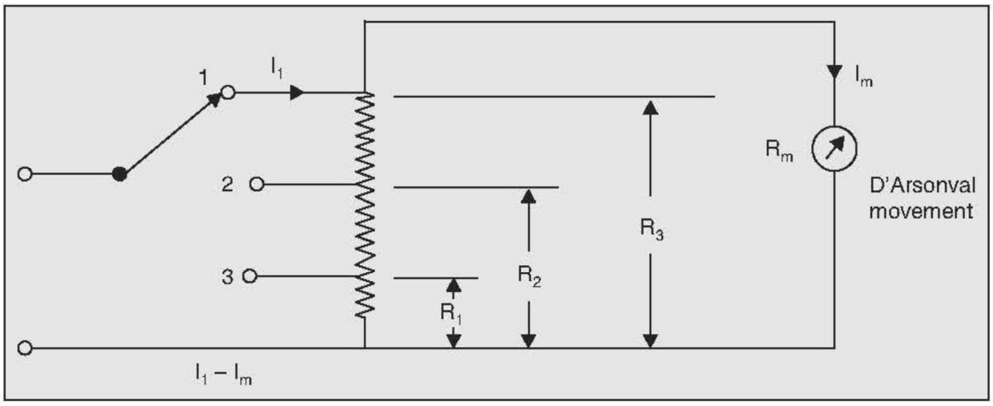

Fig. 3.11. Ammeter with universal shunt

When the switch is in position 1 then

$$I_m R_m = (I_1 - I_m)R_1$$

In position 2, then,

$$I_m (R_1 - R_2 + R_m) = (I_2 - I_m)R_2$$

In position 3, then,

$$I_m (R_1 - R_3 + R_m) = (I_3 - I_m)R_3$$

Precautions when using ammeter in measurement work,

1. Never connect an ammeter across a source of EMF. Because of its low resistance it draws damaging high currents and destroys the delicate movement. It is always connected in series with a load.