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DEPARTMENT OF BIOMEDICAL ENGINEERING

III Semester

BM3301 SENSORS AND MEASUREMENTS

UNIT – 4

4.11 PMMC type Instruments

Permanent Magnet Moving Coil (PMMC) Type Instruments:

The permanent magnet moving coil instrument is the most accurate type for d.c. measurements. The working principle of these instruments is the same as that of the d'Arsonval type of galvanometers, the difference being that a direct reading instrument is provided with a pointer and a scale.

4.11.1 Construction of PMMC Instruments:

The general constructional features of this instrument are shown in Fig. 4.11.1

Frame:

The frame of the instrument provides structural support and houses all the components. It is typically made of non-magnetic material to prevent interference with the magnetic field.

Permanent Magnet:

A permanent magnet is mounted within the frame to create a static magnetic field. The magnet is usually a strong, permanent magnet, such as one made of Alnico (aluminum, nickel, cobalt) alloy.

Coil (Moving Coil):

The coil is mounted on a spindle and is free to rotate within the magnetic field. It is typically wound with a large number of turns of fine wire to increase sensitivity. The coil is usually made of copper or aluminum wire.

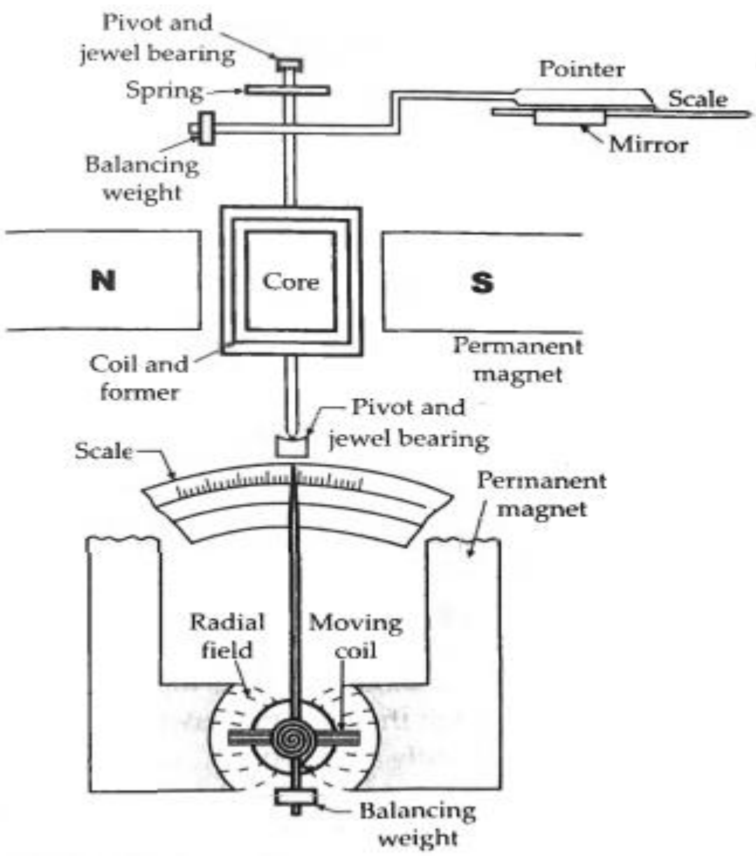

Fig. 4.11.1 Permanent magnet moving coil Instrument.

Suspension System:

The coil is suspended using a thin and flexible suspension system, often made of phosphor bronze or similar material. This suspension allows the coil to rotate freely while maintaining electrical contact.

Hair Spring:

A hair spring is used to control the movement of the coil. It acts as a restoring torque, ensuring that the coil returns to its zero position when no current is flowing through it. The hair spring is usually made of a thin, flat strip of phosphor bronze.

Pointer:

A pointer is attached to the coil and moves over a calibrated scale. The movement of the pointer indicates the value being measured.

Damping Mechanism:

To prevent the pointer from oscillating excessively and to make the reading stable, a damping mechanism is often employed. This could be in the form of air damping or fluid damping.

Scale:

The scale is marked with units corresponding to the quantity being measured (e.g., voltage or current). The pointer moves along this scale to indicate the measured value. The pointer is of light-weight construction and, apart from those used in some inexpensive instruments has the section over the scale twisted to form a fine blade. This helps to reduce parallax errors in the reading of the scale.

4.11.2 Working of PMMC Instruments:

The working of a Permanent Magnet Moving Coil (PMMC) instrument is based on the interaction between a magnetic field produced by a permanent magnet and the current flowing through a coil. The instrument is commonly used for measuring direct current (DC) in electrical circuits. Here are the key steps in the working of a PMMC instrument:

1. ***Static Magnetic Field***: A strong permanent magnet is mounted within the instrument's frame, creating a static magnetic field. The magnetic field is typically uniform and acts as a fixed reference.
2. ***Coil Placement***: A coil, often referred to as the moving coil, is mounted on a spindle and positioned within the static magnetic field. The coil is free to rotate about its axis.
3. ***Current Flow***: When a direct current (DC) flows through the coil, it becomes an electromagnet. The current-carrying coil generates its own magnetic field. The interaction between the magnetic field of the permanent magnet and the magnetic field produced by the current in the coil results in a torque.
4. ***Torque Generation***: The torque generated causes the coil to rotate within the magnetic field. The direction of rotation is determined by the right-hand rule, which states that if the thumb of the right-hand points in the direction of the current flow, and the fingers point in the direction of the magnetic field, the force (torque) on the conductor will be in the direction of the palm.

5. **Hair Spring**: The coil is connected to a hair spring, a thin, flat strip that provides a restoring torque. The purpose of the hair spring is to bring the coil back to its zero or equilibrium position when the current is removed.
6. ***Pointer Movement***: As the coil rotates, it moves the attached pointer across a calibrated scale. The scale is marked with units corresponding to the quantity being measured (e.g., voltage or current).
7. ***Damping Mechanism***: To prevent the pointer from oscillating excessively and to make the reading stable, a damping mechanism is often incorporated. This could be in the form of air damping or fluid damping, which provides resistance to the movement of the coil.
8. ***Reading Measurement***: The position of the pointer on the calibrated scale indicates the value of the current being measured. The scale is calibrated based on the known relationship between the current and the resulting torque.

4.11.3 Torque equation:

Deflecting torque Td = NB*l* dI

= GI where, G=NB*l* (d)

The spring control provides a restoring (controlling) torque

$$T_c = K\theta$$

where K -spring constant. For final steady deflection

$$T_c = T_d$$

$$GI = K\theta$$

$$Current\ I = \left(\frac{K}{G}\right)\ \theta$$

As the deflection is directly proportional to the current passing through the meter (K and G being constants) we get a uniform (linear) scale for the instrument.

4.11.4 Errors in PMMC Instruments:

The main sources of errors in moving coil instruments are due to :

(i) Weakening of permanent magnets due to ageing at temperature effects.
(ii) Weakening of springs due to ageing and temperature effects.
(iii) Change of resistance of the moving coil with temperature.

4.11.5 Advantages of PMMC Instruments:

1. Uniform scale.
2. High sensitivity.
3. Low power consumption.
4. No hysteresis loss.
5. Not much affected by stray magnetic fields.
6. Very effective and efficient eddy current damping.
7. High torque / weight ratio.
8. Very accurate and reliable.

4.11.6 Disadvantages of PMMC Instruments:

1. Can be used only for D.C measurements.
2. More costly than moving iron instruments.
3. Develop errors due to ageing of control springs and permanent magnets, and.
4. Develop also errors due to friction, mechanical unbalance, resistance temperature coefficient, etc.

4.11.7 Applications of PMMC Instruments:

1. It is used in the measurement of direct voltages and currents
2. Used to detect small currents in DC galvanometers.
3. It is used to measure the change in magnetic flux linkage in Ballistic galvanometers
4. It is used as an Ammeter
5. It is used as a Voltmeter
6. It is used as an Ohm meter
7. It is used as a Galvanometer.

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4.12 Moving Iron type Instruments

The most common ammeters and voltmeters for laboratory or switch-board use at power frequencies are the moving iron instruments. These instruments can be constructed to measure current and voltage to an accuracy needed in most engineering works and still be cheap as compared with any other type of a.c. instrument of same accuracy and ruggedness. The general principle is as follows;

- A plate or vane of soft iron or of high permeability steel forms the moving element of the system.
- This iron vane is so situated that it can move in a magnetic field produced by a stationary coil.
- The coil is excited by the current or voltage under measurement.
- When the coil is excited, it becomes an electromagnet and the iron vane moves in such a way so as to increase the flux of the electromagnet.
- This is because the vane tries to occupy a position of minimum reluctance.
- Thus, the force produced is always in such direction so as to increase the inductance of coil (this is because inductance is inversely proportional to reluctance of magnetic circuit of the coil).

4.12.1 General Torque Equation of Moving Iron Instruments:

The deflecting torque in Moving iron Instruments is given as

$$T_d = \frac{1}{2} I^2 \frac{dL}{d\theta}$$

dθ = Change in deflection

dL = Change in Inductance

θ = deflection

In moving iron instruments, the controlling torque is provided by spring. Controlling torque due to spring is given as

$$T_c = K\theta$$

Where K = Spring constant
Ɵ = Deflection in the needle
In equilibrium state, deflecting and controlling torque shall be equal as below.
Deflecting Torque = Controlling Torque
Td = Tc

$$K\theta = \frac{1}{2} I^2 \frac{dL}{d\theta}$$

From the above torque equation, we observe that the angular deflection of needle of moving iron instruments is square of rms current flowing through the coil.

4.12.2 Classification of Moving Iron Instruments:

Moving iron instruments are of two types:

(i) Attraction type.
(ii) Repulsion type

4.12.2.1 Construction of Attraction Type Moving Iron Instruments:

- Figure 4.12.1 shows the constructional details of an attraction type moving iron instrument.
- 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.

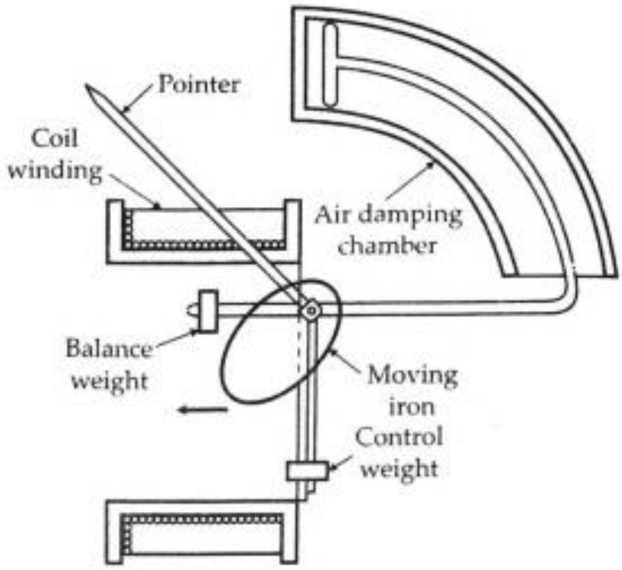

Fig 4.12.1 Attraction type moving iron instrument.

- Damping is provided by air friction with the help of a light aluminium piston (attached to the moving system) which moves in a fixed chamber closed at one end as shown in Fig. 4.12.1.

4.12.2.2 Construction of Repulsion Type Moving Iron Instruments:

- In the repulsion type, there are two vanes inside the coil one fixed and other movable.
- These are similarly magnetised when the current flows through the coil and there is a force of repulsion between the two vanes resulting in the movement of the moving vane.
- Two different designs are in common use:
  (i) **Radial Vane Type**. In this type, the vanes are radial strips of iron. The strips are placed within the coil as shown in Fig. 9.25(a). The fixed vane is attached to the coil and the movable one to the spindle of the instrument.

(ii) **Co-axial Vane Type**. In this type of instrument, the fixed and moving vanes are sections of co-axial cylinders as shown in Fig. 9.25(F). The controlling torque is provided by springs. Gravity control can also be used in vertically mounted instruments. The damping torque is produced by air friction as in attraction type instruments.

- The operating magnetic field in moving iron instruments is very weak and therefore eddy current damping is not used in them as introduction of a permanent magnet required for eddy current damping would distort the operating magnetic field.

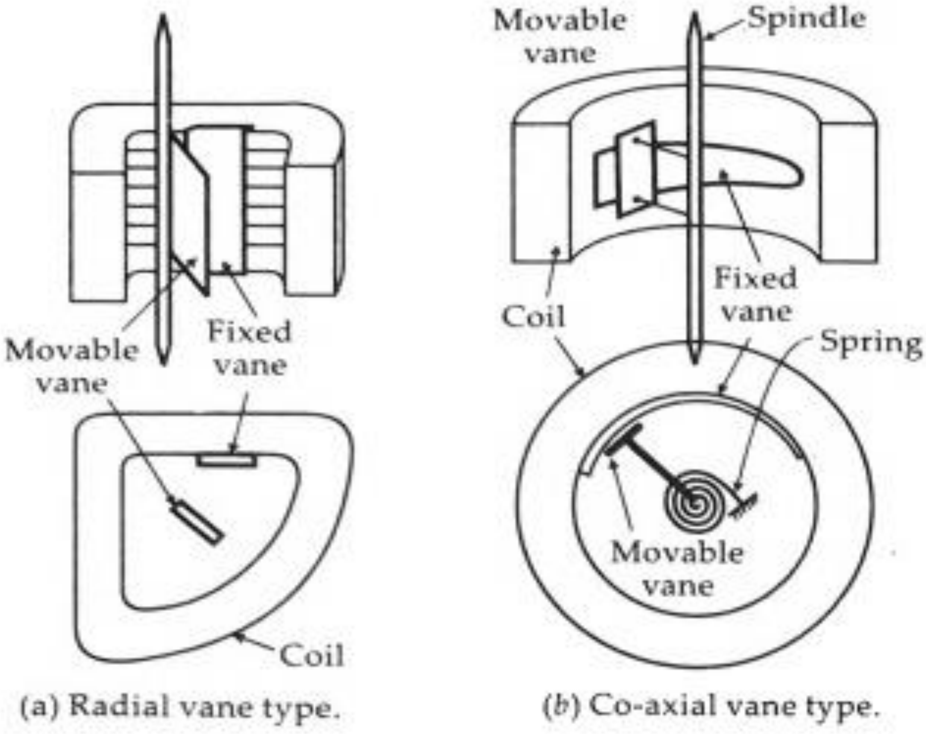

Fig.4.12.2(a) and **(b)** Repulsion type moving iron Instruments

- It is clear that whatever may be the direction of the current in the coil of the instrument, the iron vanes are so magnetised that there is always a force of attraction in the attraction type and repulsion in the repulsion type of instruments.
- Thus, moving iron instruments are unpolarised instruments i.e., they are independent of the direction in which the current passes. Therefore, these instruments can be used on both a.c. and d.c.

4.12.3 Errors in Moving Iron Instruments:

1. Hysteresis error
2. Temperature error
3. Frequency errors

4.12.4 Advantages and Disadvantages of Moving Iron Instruments:

1. Universal use: These instruments can be used for both a.c. and d.c.
2. Less friction errors
3. Cheapness
4. Robustness
5. Accuracy: The initial accuracy of high-grade instruments is stated to be 0.75 percent. They may be expected to be accurate within 0.2% to 0.3% at 50 Hz if carefully designed.
6. The scale of moving iron instruments is not uniform and is cramped at the lower end
7. These instruments are subjected to serious errors due to hysteresis, frequency changes and stray magnetic fields.

4.12.5 Applications of Moving Iron Instruments:

1. Moving iron instruments are used as Voltmeter and Ammeter only.
2. Both can work on AC as well as on DC.

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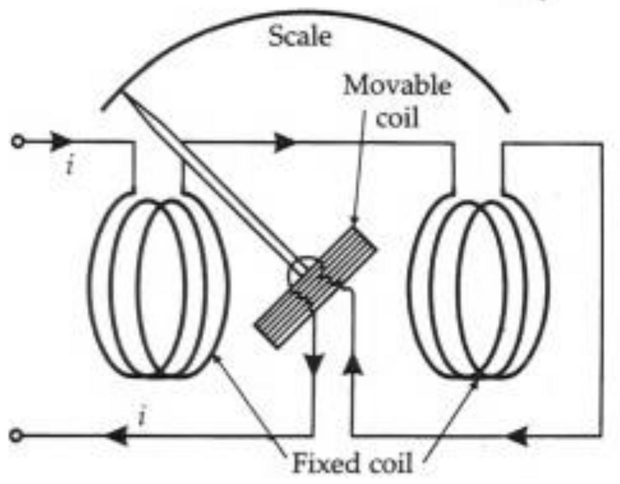
4.13 Dynamometer type Instruments

These instruments are the modified form of permanent magnet moving coils type. Here operating field is produced by a permanent but by another fixed coil. The moving system and the control system are similar to those of permanent magnet type. Such instruments can be used for both a.c and d.c circuits. They can be used as ammeters and voltmeters but are generally used as wattmeters.

4.13.1 Construction of Dynamometer type Instruments:



Fixed coils:

- The field is produced by a fixed coil.
- This coil is divided into two sections to give a more uniform field near the centre and to allow passage of the instrument shaft.

- The instrument as shown in Fig. 4.13.1 may be a milliammeter, or may become a voltmeter by the addition of a series resistance.
- The fixed coils are wound with fine wire for such applications. Fixed coils are usually wound with heavy wire carrying the main current in ammeters and wattmeters. The wire is stranded where necessary to reduce eddy current losses in conductors.
- The coils are usually varnished and baked to form a solid assembly.
- The mounting supports are preferably made out of ceramic, as metal parts would weaken the field of the fixed coil on account of eddy currents.

Moving coil:

- A single element instrument has one moving coil.
- The moving coil is wound either as a self-sustaining coil or else on a non-metallic former.
- A metallic former cannot be used as eddy currents would be induced in it by the alternating field.
- Light but rigid construction is used for the moving coil.
- It should be noted that both fixed and moving coils are air cored.

Control:

The controlling torque is provided by two control springs. These springs act as leads to then moving coil.

Moving system:

The moving coil is mounted on an aluminium spindle. The moving system also carries the counter weights and truss type pointer. Sometimes a suspension may be used in case a high sensitivity is desired.

Damping.

Air friction damping is employed for these instruments and is provided by a pair of aluminium vanes, attached to the spindle at the bottom. These vanes move in sector shaped chambers. Eddy current damping cannot be used in these instruments as the operating field is very weak (on account of the fact that the coils are air cored) and any introduction of a permanent magnet required for eddy current damping would distort the operating magnetic field of the instrument.

Shielding:

- The field produced by the fixed coils is somewhat weaker than in other types of instruments. It is nearly 0.005 to 0.006 Wb/m.
- In d.c. measurements even the earth's magnetic field may affect the readings. Thus, it is necessary to shield an electrodynamometer type instrument from the effect of stray magnetic fields, by enclosing them in a casing of high permeability alloy.
- This shunts external magnetic fields around the instrument mechanism and minimizes their effects on the indication.

Cases and scales:

- Laboratory standard instruments are usually contained in highly polished wooden cases.
- These cases are so constructed as to remain dimensionally stable over long periods of time.
- The glass is coated with some conducting material to completely remove the electrostatic effects.

4.13.2 Deflecting torque of Dynamometer type instruments:

Let

I_f = current through fixed coil

I_m = current through moving coil

Since $I_f = I_m$ because the fixed and coils are in series,

Td = I^2

Since the control is by springs, therefore,

controlling torque is proportional to the angle of deflection

Tc proportional deflection

The pointer will come to rest at a position when Td = Tc

we get deflection proportional I^2

$$\theta = I^2$$

It is clear that deflection of the pointer is directly proportional to the square of the operating current. Hence, the scales of these instruments is non - uniform being crowded in their lower parts and spread out at the top.

4.13.3 Advantages of Dynamometer type instruments:

1. These instruments can be used for both a.c and d.c measurements.
2. Such instruments are free from hysteresis and eddy current errors.

4.13.4 Disadvantages of Dynamometer type instruments:

1. Since torque / weight ratio is small, therefore, such instruments have frictional errors which reduce sensitivity.
2. Scale is not uniform.
3. These instruments are sensitive to overloads and mechanical impacts
4. These instruments are costlier than types and, therefore, they are rarely used as ammeters and voltmeters.

4.13.5 Errors in Electrodynamometer Instruments:

The various errors in electrodynamometer instruments are,

1. Torque to weight ratio
2. Frequency errors
3. Eddy current errors
4. Stray magnetic field error
5. Temperature error

4.13.6 Applications of Dynamometer type Instruments:

1. Power measurement in electrical circuit
2. Calibration of other instruments
3. Power factor correction
4. Energy management
5. As ammeter, voltmeter and wattmeter

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4.14 DC Potentiometer

A potentiometer is an instrument designed to measure an unknown voltage by comparing it with a known voltage. The known voltage may be supplied by a standard cell or any other known voltage reference source.

4.14.1 Basic Potentiometer Circuit:

The principle of operation of all potentiometers is based on the circuit of Fig. 4.14.1, which shows the schematic diagram of the basic slide wire potentiometer.

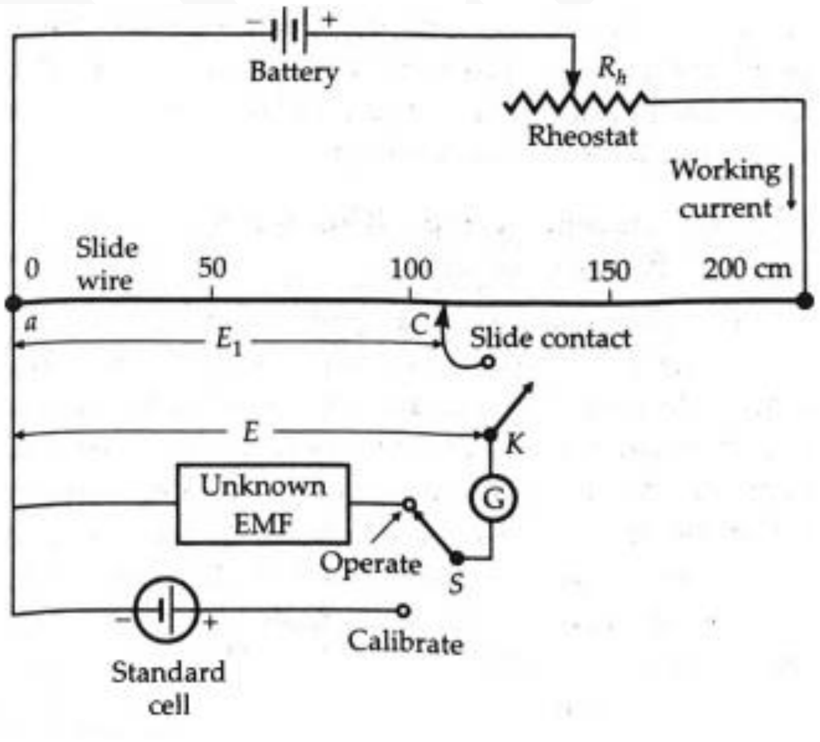

Fig 4.14.1 schematic diagram of the basic slide wire potentiometer

4.14.2 Construction of DC Potentiometer:

1. All the ***resistors*** in a potentiometer, with the exception of slide wires are made of ***manganin***. This is because manganin has a high stability, a low temperature co-efficient and has freedom from thermo-electric effects against copper.
2. The ***slide wire*** is usually made of ***platinum-silver alloy*** and the sliding ***contact*** are of a ***copper gold-silver*** alloy. This combination of materials for slide wire and sliding contacts results in a good contact, freedom from thermo-electric emfs and minimum wear of slide wire.
3. It is very important that internal thermo-electric emfs in a potentiometer are minimum.
4. It is desirable that all the parts work at the same temperature. Therefore, all the parts are covered in a single case.
5. In order to prevent leakage, all the parts must be enclosed, so as to protect them from moisture. The working parts are normally ***mounted*** on ***ebonite*** or ***keramot*** panels.

4.14.3 Working of DC Potentiometer:

1. With switch 'S' in the "operate" position and the galvanometer key K open, the battery supplies the "working current" through the rheostat R and the slide wire.
2. The working current through the slide wire may be varied by changing the rheostat setting.
3. The method of measuring the unknown voltage, E, depends upon finding a position for the sliding contact such the galvanometer shows zero deflection, i.e., indicates null condition, when the galvanometer key, K, is closed.
4. Zero galvanometer deflection or a null means that the unknown voltage, E, is equal to the voltage drop Ey across portion ac of the slide wire.
5. Thus determination of the value of unknown voltage now becomes a matter of evaluating the voltage drop Ej along the portion ac of the slide wire.
6. The slide wire has a uniform cross-section and hence uniform resistance along its entire length. A calibrated scale in cm and fractions of cm, is placed along the slide wire so that the sliding contact can be placed accurately at any desired position along the slide wire.

7. Since the resistance of slide wire is known accurately, the voltage drop along the slide wire can be controlled by adjusting the value of working current. The process of adjusting the working current so as to match the voltage drop across a portion of sliding wire against a standard reference source is known as "**Standardisation**".

4.14.4 Applications of D.C. Potentiometers:

i. Calibration of voltmeter
ii. Calibration of ammeter
iii. Measurement of resistance
iv. Measurement of power
v. Calibration of wattmeter

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4.15 Digital Voltmeter

- A digital voltmeter (DVM) displays the value of a.c. or d.c. voltage being measured directly as discrete numerals in the decimal number system.
- Numerical readout of DVMs is advantageous since it eliminates observational errors committed by operators.
- The errors on account of parallax and approximations are entirely eliminated. The use of digital voltmeters increases the speed with which readings can be taken.
- Also, the output of digital voltmeters can be fed to memory devices for storage and future computations.
- A digital voltmeter is a versatile and accurate voltmeter which has many laboratory applications. On account of developments in the integrated circuit (IC) technology, it has been possible to reduce the size, power requirements and cost of digital voltmeters. In fact, for the same accuracy, a digital voltmeter now is less costly than its analog counterpart.
- The decrease in size of DVMs on account of use of ICs, the portability of the instruments has increased

4.15.1 Types of DVMs

The increasing popularity of DVMs has brought forth a wide number of types employing different circuits. The various types of DVMs in general use are:

i. Ramp type DVM,
ii. Integrating type DVM,

iii. Potentiometric type DVM,
iv. Successive approximation type DVM, and
v. Continuous balance type DVM

4.15.2 Potentiometric Type Digital Voltmeter:

- A potentiometric type of DVM, employs voltage comparison technique.
- In this DVM the unknown voltage is compared with a reference voltage whose value is fixed by the setting of the calibrated potentiometer.
- The potentiometer setting is changed to obtain balance (i.e., null conditions). When null conditions are obtained the value of the unknown voltage, is indicated by the dial setting of the potentiometer.
- In potentiometric type DVMs, the balance is not obtained manually but is arrived at automatically.
- Thus, this DVM is in fact a self-balancing potentiometer. The potentiometric DVM is provided with a readout which displays the voltage being measured.
- The block diagram of basic circuit of a potentiometric DVM is shown in Fig. 4.15.1

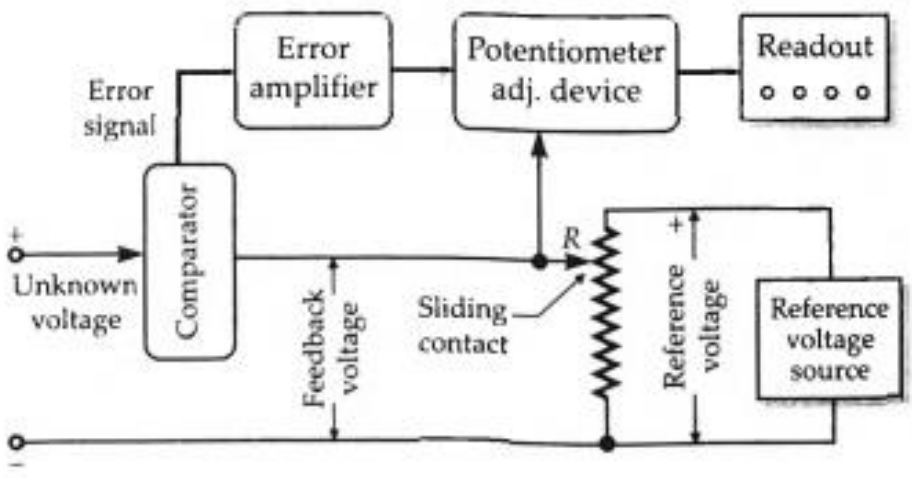

Fig. 4.15.1 Basic block diagram of a potentiometric DVM.

- The unknown voltage is filtered and attenuated to suitable level.
- This input voltage is applied to a comparator (also known as error detector).
- This error detector may be chopper.
- The reference voltage is obtained from a fixed voltage source.
- This voltage is applied to a potentiometer R.
- The value of the feedback voltage depends upon the position of the sliding contact.

- The feedback voltage is also applied to the comparator.
- The unknown voltage and the feedback voltages are compared in the comparator. The output voltage of the comparator is the difference of the above two voltages. The difference of voltage is called the error signal.
- The error signal is amplified and is fed to a potentiometer adjustment device which moves the sliding contact of the potentiometer. This magnitude by which the sliding contact moves depends upon the magnitude of the error signal.
- The direction of movement of slider depends upon whether the feedback voltage is larger or the input voltage is larger.
- The sliding contact moves to such a place where the feedback voltage equals the unknown voltage. In that case, there will not be any error voltage and hence there will be no input to the device adjusting the position of the sliding, contact and therefore it (sliding contact) will come to rest.
- The position of the potentiometer adjustment device at this point is indicated in numerical form on the digital readout device associated with it.
- Since the position at which no voltage appears at potentiometer adjustment device is the one where the unknown voltage equals the feedback voltage, the reading of readout device indicates the value of unknown voltage.
- The potentiometer adjustment device i.e., the device which moves the sliding contact is a 2- phase servomotor.
- The reference voltage source must be extremely stable and generally consists of a standard cell or a Zener diode sources.

Applications of DVM:

1. Electronic Circuit Testing and Troubleshooting
2. Power Supply Monitoring:
3. Automotive Electrical Systems
4. Battery Testing
5. Quality Control in Manufacturing
6. Educational Labs:
7. Home Electronics Repair:
8. Biopotential Measurements
9. Testing and Calibration of Medical Equipment

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4.16 Multimeter

Multimeter or Volt-Ohm-Milli-Ammeter (V.O.M.):

The ammeter, the voltmeter and the ohmmeter all use a basic d'Arsonval movement. The difference between these instruments is the circuit in which the basic movement is used. It is therefore obvious that an instrument can be designed to perform these three measurement functions. This instrument which contains a function switch to connect the appropriate circuits to the d'Arsonval movement, is called a "Multimeter" or "Volt-ohm-milli-ammeter" (V.O.M.).

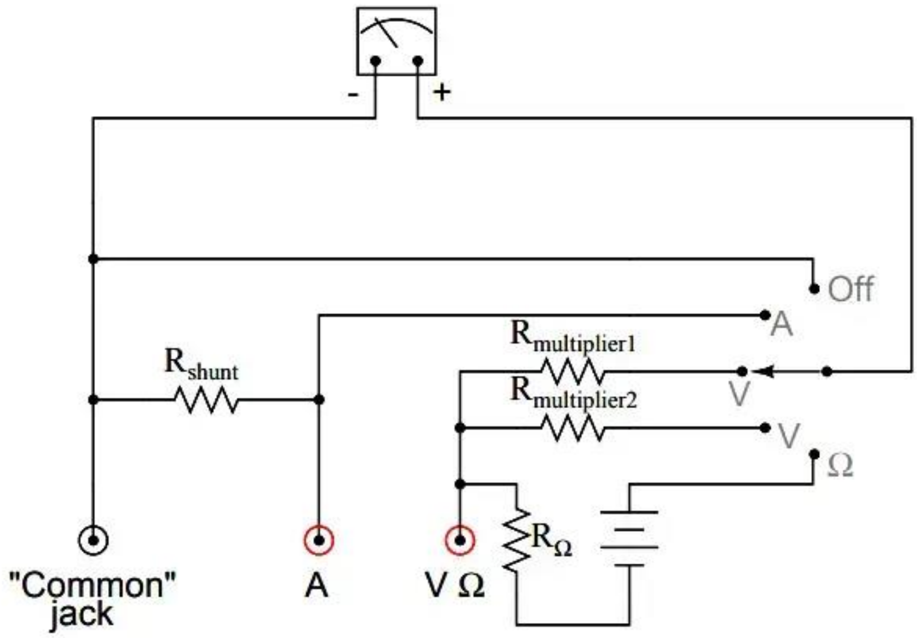

Figure 4.16.1 Multimeter Schematic circuits

One position of the selector switch directly connects the meter movement between the black common binding post and the red V/mA binding post. In this position, the meter is a sensitive ammeter with a range equal to the full-scale current rating of the meter movement.

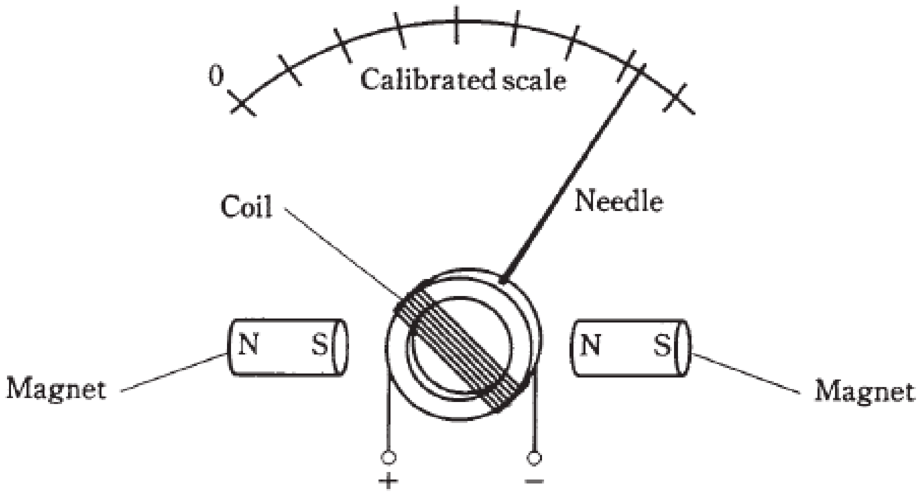

Fig. 4.16.2 D' Arsonval movement

Construction and working of multimeter :

1. An analog multimeter employs an electromechanical component known as a D'Arsonval movement to move the pointer along the scales in order to display measured values that are linked to a circuit, device, or circuit component.
2. It operates using the d'Arsonval galvanometer principle. It is made up of a needle that indicates the measured value on the scale.
3. A coil moves in a magnetic field when current passes through it. The coil is attached to the indicating needle.
4. It consists of a coil sandwiched between two permanent magnets. On top of the coil is a needle.
5. As current flows through the coil, a magnetic field is created in the coil, which reacts with the magnetic field of the permanent magnets, causing the pointer attached to the drum to deflect on the scale, indicating the current reading.
6. It also has springs attached to it that provide an opposing force to the motion of the drum in order to control the deflection of the pointer.
7. As a result, the coil rotates, causing the needle to move across the scale. The amount of current flowing through the coil determines the angle of rotation. This

arrangement is also known as a galvanometer. It has a low resistance and thus is more sensitive.

Analog Multimeter Measuring Quantities:

- The typical analog multimeter range varies depending on the application: Standard DC voltage range settings include 0.5 V, 2.5V, 10V, 50V, 250V, and 1000V.
- Standard AC voltage settings are 10V, 50V, 250V, and 1000V. Amperes are used to measure current, with standard DC settings of 2.5, 25, and 250 amperes. AC current is seldom measured.
- Standard resistance settings in ohms are around 20, 200, 2000, 20,000, and 200,000 ohms.

Functions of Multimeter:

Here are some of the common functions and features of a multimeter:

1. **Voltage Measurement** (Volts): Multimeters can measure both direct current (DC) and alternating current (AC) voltage. They are used to check the voltage levels in a circuit.
2. **Current Measurement** (Amperes): Multimeters can measure the flow of electric current in a circuit. They are capable of measuring both DC and AC current.
3. **Resistance Measurement** (Ohms): Multimeters can measure the resistance of a component or a circuit. This is useful for troubleshooting and determining if a component is faulty.
4. **Continuity Test**: This function is used to check if there is a continuous path for current flow between two points in a circuit. It is often employed to identify open circuits or faulty connections.
5. **Diode Test**: Multimeters can test diodes and other semiconductor devices for proper functioning. This feature is useful for electronics troubleshooting.
6. **Capacitance Measurement**: Some multimeters come with the capability to measure capacitance, which is the ability of a component to store electrical charge.
7. **Temperature Measurement**: Certain models of multimeters may include a temperature measurement function, allowing users to measure the temperature of components or environments.

8. **Frequency Measurement**: Some multimeters can measure the frequency of an AC signal, which is particularly useful in electronics and electrical engineering applications.

Applications of Multimeter:

1. Biomedical engineers and technicians may use multimeters to troubleshoot and maintain medical equipment.
2. In laboratory settings, researchers studying electrophysiology may use multimeters to measure electrical properties of tissues or cells.
3. It is used to measure AC and DC voltage and current.
4. It is also used to measure resistance.
5. It is also used to check the diodes.
6. It is also used to measure the frequency as well as the capacitance of an electronic device.
7. It is also used to test batteries, switches, light bulbs, and outlets.

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