G. PULLAIAH COLLEGE OF ENGINEERING AND TECHNOLOGY
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Department of Electrical and Electronics Engineering

Bridge Course

On

Electrical Measurements

(15A02501)


Introduction to Measurements

What is Measurement?

The process of measuring is essentially that of comparing some unknown value with a value which is assumed to be known.

1)One is standard.

2)Measuring system

Essential Characteristics of Instruments:

- **Calibration**:

All the static characteristics are obtained in one form or another by a process called Calibration. Calibration procedures involve a comparison of the particular instrument with either

a) a primary standard or

b) a secondary standard with a higher accuracy than the instruments be calibrated an instrument of known accuracy.

- **Accuracy**: Accuracy may be defined as the ability of a device or a system to respond to a true value of a measured variable under reference conditions.
- **Precision**: Precision is defined by the degree of exactness for which an instrument is designed or intended to perform.
- **Repeatability**: It is the closeness of agreement among a number of consecutive measurements of the output for the same value of the input, under the same operating conditions.
- **Reproducibility**: It is the closeness of agreement among repeated measurements of the output for the same value of the input, made under the same operating conditions over a period of time.
- **Drift**: It is an undesired change or a gradual variation in output over a period of time that is unrelated to changes in input and operating conditions.
- **Span**: If in a measuring instrument the highest point of calibration is y units and the lowest point x units.

  Then the instrument range y units

  The instrument span is given by

  Span=(x-y) units
- **Sensitivity**: Sensitivity can be defined as the ratio of a change in output to the change in input which causes it.

- **Resolution**: The smallest increment in input (the quantity being measured) which can be detected with certainty by an instrument is its resolution.
- **Dead zone**: Dead zone is the largest range of values of a measured variable to which the instrument does not respond.

What is Error?

The error is defined as the difference between the true value and the measured value of the quantity.

Types of Error:

- **Static Error:** the numerical difference between the true value of a quantity and its value as obtained by measurement.
- **Mistakes:** These are errors due to human mistakes such as careless reading, mistakes in observations, incorrect application of a correction, improper application of instruments and computational errors.

Systematic Error:

- **1) Instrumental Error**: Instrumental errors are the errors inherent in measuring instruments because of their mechanical structure, such as friction in bearings of various moving components, irregular spring tension.
- **2)Environmental Error:** it is due to conditions external to the measuring device including conditions in the area surrounding the instrument such as the effect of change in temp , humidity, barometric pressure , or magnetic or electrostatic fields.
- **Random Error**: the cause of such error is unknown or not determinable in the ordinary process of making measurements. Such errors are normally small and follows the laws of chance.

Sources of error:

1. Insufficient knowledge of process parameters and design conditions.
2. Poor design.
3. Poor maintenance.
4. Error caused by people who operate instrument equipment.
5. Certain design limitations.

Types of Instruments:

Absolute Instruments:

Absolute instruments are those which give the value of the electrical quantity to be measured, in terms of the constant of the instruments and their deflection only, e.g. tangent galvanometer.

Secondary Instruments:

Secondary instruments are those which have been pre calibrated by comparison with an absolute instrument. The value of the electrical quantity to be measured in these instruments can be determined from the deflection of the instrument. Without calibration of such an instrument, the deflection is meaningless.

Different types of secondary

1) Indicating
2) Recording
3) Integrating

1) Indicating:

Indicating instruments are those which indicate the instantaneous value of the electrical quantity being measured, at the time at which it is being measured. Their indications are given by pointers moving over calibrated dials (scale), e.g. ammeters, voltmeters and wattmeter's.

2) Recording:

Recording instruments are those which give a continuous record of variations of the electrical quantity over a selected period of time. The moving system of the instrument carries an inked pen which rests tightly on a graph chart. E.g. recording voltmeters used in supply station.

3) Integrating:

Integrating instruments are those which measure and register the total quantity of electricity (in ampere-hour) or the total amount of electrical energy (in watt-hours or kilowatt-hours) supplied to a circuit over a period of time, e.g. ampere-hour meters, energy meters.

Essentials of Indicating Instruments:

Deflecting Torque (T_d):

It is the torque which deflects the pointer on a calibrated scale according to the electrical quantity passing through the instrument. The deflecting torque causes the moving system and hence the pointer attached to it to move from zero position to indicate on a graduated scale the value of electrical quantity being measured.

Controlling Torque (T_c):

It is the torque which controls the movement of the pointer on a particular scale according to the quantity of electricity passing through it. If deflecting torque were acting alone, the pointer would continue to move indefinitely and would swing over to the maximum deflected position irrespective of the magnitude of current (or voltage or power) to be measured.

Spring Control:

In the spring control method, a hair-spring, usually of phosphor-bronze, attached to the moving system is used. With the deflection of the pointer, the spring is twisted in the opposite direction. This twist in the spring produces a restoring torque which is directly proportional to the angle of deflection of the moving system. The pointer comes to a position of rest (or equilibrium) when the deflecting torque (Td) and controlling torque (Tc) are equal.

$$T_C \propto \theta$$

To give a controlling torque which is directly proportional to the angle of deflection of the moving system, the number of turns of the spring should be fairly large so that the deformation per unit length is small. The stress in the spring must be limited to such a value that there is no permanent set. Springs are made of materials which are

- Non magnetic
- Not subject to much fatigue
- Low in specific resistance
- Have low temperature coefficient of resistance.

Gravity Control:

Gravity control is obtained by attaching a small weight to the moving system in such a way that it produces a restoring or controlling torque when the system is deflected.

$$T_c \propto \sin\theta$$

Thus, controlling torque in a gravity control system is proportional to the sine of the angle of deflection. The degree of control is adjusted by screwing the weight up or down on the carrying system.

Advantages:

The advantages of gravity control system, as compared to spring control, are given below:

1. It is cheap
2. It is unaffected by temperature
3. It is not subjected to fatigue or distortion, with time.

Disadvantages:

The disadvantages of gravity control system, as compared to spring control, are given below:

1. It gives a cramped scale.
2. The instrument has to be kept vertical.

Damping Torque:

If the moving system is acted upon by deflecting and controlling torques alone, then pointer due to inertia will oscillate about its final deflected position for some time before coming to rest. This is often undesirable because it makes difficult to obtain quick and accurate readings. In order to avoid these oscillations of the pointer and to bring it quickly to its final deflected position, a damping torque is provided in the indicating instruments.

There are three types of damping:

Air friction damping:

Air friction damping uses either aluminum piston or vane, which is attached to or mounted on the moving system and moves in an air chamber at one end.

Fluid friction damping:

In fluid friction damping, a light vane (attached to the moving system) is dipped into a pot of damping oil. The fluid produces the necessary opposing (or damping) force to the vane. The vane should be completely submerged in the oil. The disadvantage of this type of damping is that it can only be used in the vertical position.

Eddy Current Damping:

Eddy-current damping uses a conducting material which moves in a magnetic field so as to cut through the lines of force, thus setting up eddy currents. Force always exists between the eddy current and magnetic field which is always opposite to the direction of motion. This is most efficient type of damping and is largely used in permanent magnet moving coil instruments

Fundamentals to Unserstand Measurements

What is Electric Current?

While a potential difference is applied across a conductor, electrical charge flows through it and electrical current is the measure of the quantity of the electrical charge flowing through the conductor per unit time.

$$\text{Current } I = \frac{Q}{t}$$

Types of Current:

Current basically classify as two types. That is

1. Direct current.
2. Alternating current.

Effects of Electric Current:

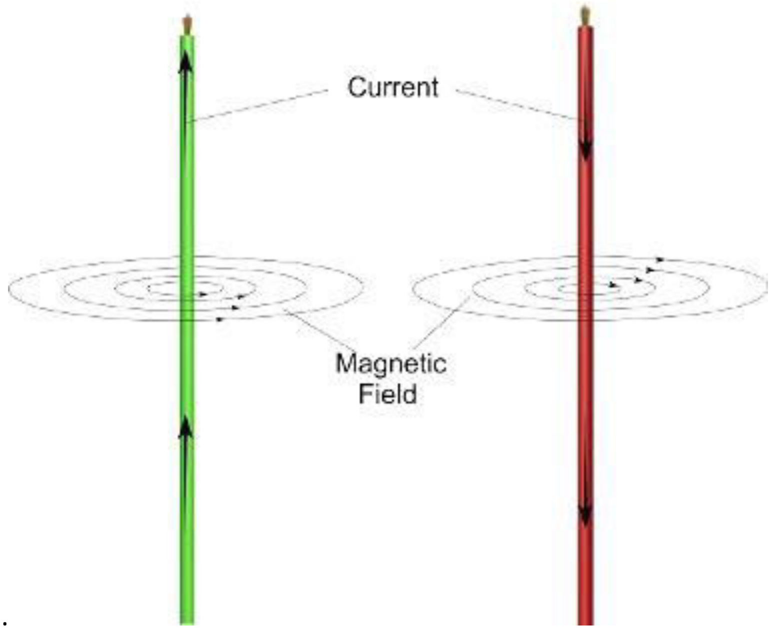
There are mainly two effects of current, such as heating effect and magnetic effect. or examples, the light bulb glows in our house is due to heating effect of current and the fan rotates in our house is due to magnetic effect of current. There are thousands of other examples which can illustrate the effect of current, too.

Heating effect:

Whenever current passes through a conductor there would be a generation of heat due to ohmic loss in the conductor. This is commonly known as heating effect of current. Since, we cannot use electric power directly, we need to convert it into another usable power, like heat, light, or mechanical power etc. When current flows through a conductor some loss occurs and this loss is almost inevitable, and more the resistance of the conductor, more the loss. This loss due to the electrical resistance of conductor is mainly responsible for the heating effect of current.

Magnetic effect:

The magnetic field around the conductor consists of a number of concentric closed lines of force. If we pass an current through a conductor through a card board as shown in the figure and try to plot the field with the help of a magnetic needle on that card board, we shall get the magnetic lines as shown in figure. These are all closed circles and concentric with the conductor. Now if we reverse the current in the conductor and repeat the same experiment as shown in the figure, we shall get the oppositely directed closed circular magnetic lines, concentric with the conductor as shown.



Voltage:

Voltage is the difference in electric potential energy per unit charge between two points. Voltage is the work to be done, upon a unit charge to move between two points, against a static electric field.

Power:

The unit of power is the watt (W) where one watt is one joule per second. Power is defined as the rate of doing work or transferring energy.

Thus, power in watts, P = W t

Where W is the work done or energy transferred in joules and t is the time in seconds.

Thus energy, in joules, W = Pt

Electrical power and energy:

When a direct current of I amperes is flowing in an electric circuit and the voltage across the circuit is V volts,

Then power, in watts P = VI

Electrical energy = Power × time = VIt Joules.

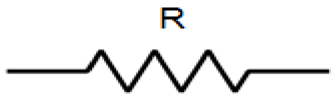
The unit of energy is KWh.

Resistance (R):

The unit of electric resistance is the ohm () where one ohm is one volt per ampere. It is defined as the resistance between two points in a conductor when a constant electric potential of one volt applied at the two points produces a current flow of one ampere in the conductor.

Thus, resistance, in ohms

R = V I



Where V is the potential difference across the two points in volts and I is the current flowing between the two points in amperes.

The reciprocal of resistance is called conductance and is measured in Siemens (S). Thus, conductance, in Siemens G = 1 R where R is the resistance in ohms.

Inductance (L):

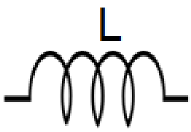
A wire of certain length, when twisted into a coil becomes a basic inductance. If current is made to pass through an inductor, an electromagnetic field is formed. A change in the magnitude of the current changes the electromagnetic field.

The inductance is defined as the inductance is one henry when current through the coil, changing at the rate of one ampere per second, induces one volt across the coil. The unit of inductance is*,* denoted by H.

Voltage across the inductor $V = L\dfrac{di}{dt}$

Current through the inductor $I = \dfrac{1}{L}\int I dt$

Energy stored in inductor= $E = \dfrac{1}{2}CV^2$



Capacitance(C):

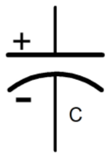
Any two conducting surfaces separated by an insulating medium exhibit the property of a capacitor. A capacitor stores the energy in the form of electric field. The capacitance is given by

$$C = \frac{Q}{V}$$

Current in the capacitor= $I = C\dfrac{dV}{dt}$

Voltage across capacitor $V = \dfrac{1}{C}\int I dt$

Energy stored in capacitor= $E = \dfrac{1}{2}Li^2$



Ohm's law:

The unit of resistance is ohm (Ω). Ohm is defined as the resistance offered by the material when a current of one ampere flows between two terminals with one volt applied across it.

According to ohm's law, the current is directly proportional to the voltage and inversely proportional to the total resistance of the circuit.

$$I = \frac{V}{R} \quad A$$

$$\text{Power} = P = I^2 R \ \text{or}\ P = \frac{V^2}{R}\ W$$

$$\text{Energy} = E = \frac{V^2}{R} t \qquad KWh$$

Kirchhoff's laws:

(a) **Current Law.** At any junction in an electric circuit the total current flowing towards that junction is equal to the total current flowing away from the junction, i.e. I =0

Thus, referring to Figure

I1 + I2 = I3 + I4 + I5 or

I1 + I2 − I3 − I4 − I5 = 0

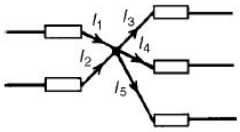


Fig: diagram Kirchhoff's current law

(b) **Voltage Law.** In any closed loop in a network, the algebraic sum of the voltage drops (i.e. products of

Current and resistance) taken around the loop is equal to the resultant e.m.f. acting in that loop.

Thus, referring to Figure:

$E1 - E2 = IR1 + IR2 + IR3$

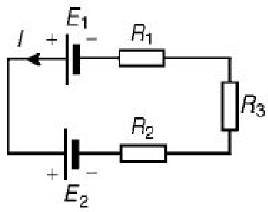
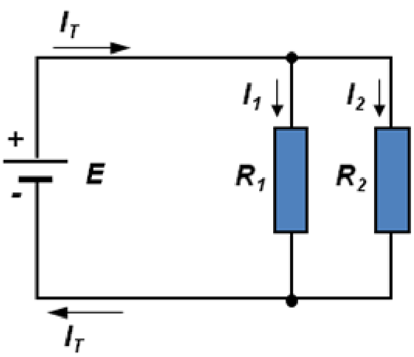


Fig: diagram for Kirchhoff's voltage law.

Current Division Rule:

In parallel circuits the current I_T divides up through the various branches.

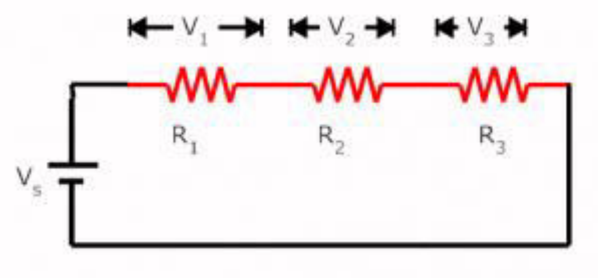


$$I_1 = I_T \frac{R_2}{R_1 + R_2}$$

$$I_2 = I_T \frac{R_1}{R_1 + R_2}$$

When there are only two resistances in parallel we can simplify some of the Ohm's law calculation by use of the current divider principle. The current divider uses the principles of Ohm's law to generate the branch currents I_1 and I_2.

Voltage division rule:



Voltage divider rule is that rule if a series circuit has more than one resistor; the voltage across of each resistor is the ratio of resistor value multiplied with voltage source to total resistance value. Let us consider above circuit there is three resistances. We have to find out each resistance voltage. Using voltage divider rule

$$V_1 = \frac{R_1}{R_1 + R_2 + R_3} V_S$$

$$V_2 = \frac{R_2}{R_1 + R_2 + R_3} V_S$$

$$V_3 = \frac{R_3}{R_1 + R_2 + R_3} V_S$$

Faraday's laws of Electromagnetic induction:

First Law:

It states that flux linked with a circuit changes, an e.m.f is always induced in it. In other words whenever a conductor cuts magnetic flux, an e.m.f is induced in that conductor.

Second Law:

The magnitude of the induced e.m.f is equal to the rate of change of linkages. Suppose a coil has N turns and flux through it changes from an initial value of ϕ_1 webers to final value of ϕ_2 webers in time t seconds. Flux linkages mean the product of number of turns and the flux linked with the coil.

Initial flux linkages $= N\phi_1$

Final flux linkages $= N\phi_2$

Induced e.m.f. $e = \frac{N\phi_2 - N\phi_1}{t}$ wb/s or volts

Putting the above expression in its differential form, we get

$$e = \frac{d}{dt}(N\phi) = N\frac{d}{dt}\phi \text{ volt}$$

Usually, a minus is given to the right-hand side expression to signify the fact that the induced e.m.f sets up current in such a direction that magnetic effect produced by it opposes the very cause producing it.

$$e = -N\frac{d}{dt}\phi \text{ volt}$$

Types of indicating instruments:

PMMC (permanent magnet moving coil)
MI (moving iron)

PMMC Meter:

This type of instrument based on the principle that when a current carrying conductor is placed in a magnetic field, a force acts on the conductor, which tends to move it to one side and out of the field.

- **ADVANTAGE:**

1. Low power consumption.
2. Uniform scale extendable over an arc of 270º or so.
3. High torque weight ratio.
4. No hysteresis loss.
5. Very effective and efficient eddy current damping.
6. Not affected much by stray and magnetic fields due to strong operating field.

- **DISADVANTAGE:**

1. Costlier compared to moving iron instruments, due to delicate construction and accurate machining and assembly of various parts.
2. Some error arises due to the ageing of control springs and the permanent magnet.
3. Use limited to DC only.
4. Scale length of meter can be increased from 120º and 240º or even 270º or 300º.

- **APPLICATION:**

1. PMMC instruments can be used as dc ammeter. And its range can be increased by using a large number of turns in parallel with the instrument.
2. The range of this instrument, when used as a dc voltmeter, can be increased by using a high resistance in series with it.

Moving Iron instruments:

Moving Iron instruments depend for their action upon the magnetic effect of current, and are widely used as indicating instruments. In this type of instrument, the coil is stationery and the deflection is caused by a soft-iron piece moving in the field produced by the coil.

There are two types of moving iron instruments:

i) Attraction type
ii) Repulsion type

Advantages:

1. Cheap, robust and give reliable service.
2. Usable in both AC and DC. Circuits.

Disadvantages:

1. Have non-linear scale.
2. Cannot be calibrating with high degree of precision for d.c. on account of the affect of hysteresis in the iron vanes.
3. Deflection up to 240º only may be obtained with this instrument.
4. This instrument will always have to be put in the vertical position if it uses gravity control.

Errors with MI instruments:

1. Due to hysteresis when used in AC and DC.
2. Due to stray magnetic fields when used both in AC and DC
3. Due to frequency variation when used in AC.
4. Due to waveforms effect when used in AC.

Applications of MI instruments:

As an ammeter:

It may be constructed for full-scale deflection of 0.1 to 30A without the use of shunts or current transformers. To obtain full-scale deflection with currents less than 0.1A, it requires a coil with a large number of fine wire turns, which results in an ammeter with a high impedance.

As an voltmeter:

The MI voltmeter is a fairly low impedance instrument, typically, 50Ω/V for a 100V instrument. The lowest full scale is of the order of 50V.The range of the instrument, when used as a voltmeter, can be extended by using a high non-inductive resistance R connected in series with it. This series resistance is known as ‘multiplier’.