SAMPLE STUDY MATERIAL

Electronics Engineering

EC / E & T

Postal Correspondence Course

GATE, IES & PSUs

Electrical & Electronic Instrumentation

CONTENT

CHAPTER-1

INTRODUCTION

Basics of Measurement

Measurement generally involves using an instrument as a physical means of determining a quantity or variable.

Some Terms Used in Measurement

Accuracy: It is the closeness with which on instrument reading approaches the true value of the variable being measured.

Precision: It is a measure of the reproducibility of the measurements; *i.e.*, given a fixed value of a variable, precision is a measure of the degree to which successive measurements differ from one another.

Sensitivity: The ratio of output signal or response of the instrument to a change of input or measurement variable.

Resolution: The smallest change in measured value to which the instrument will respond.

Error: Deviation from the true value of the measured variable.

- It should be noted that precision of a measurement does not guarantee accuracy.

Significant Figures

- An indication of the precision of the measurement is obtained from the number of significant figures in which the result is expressed.
- The more significant figures, the greater the precision of measurement.

For Example: If a resistor is specified as having a resistance of $68\,\Omega$, its resistance should be closer to $68\,\Omega$ than to $67\,\Omega$ or $69\,\Omega$. If the value of the resistor is described as $68.0\,\Omega$, it means that it's resistance is closer to $68.0\,\Omega$ than it is to $67.9\,\Omega$ or $68.1\,\Omega$.

In $68\,\Omega$ there are two significant figures; in $68.0\,\Omega$ there are three.

The later, with more significant figures expresses a measurement of greater precision than the former.

Types of Error:

A study of errors is a first step in finding ways to reduce them.

Errors may come from different sources and are usually classified under three main headings.

1. Gross Errors:

This class of errors mainly covers human mistakes in reading or using instruments and in recording and calculating measurement results.

As long as human beings are involved, some gross errors will inevitably be committed. Although complete elimination of gross errors is probably impossible, one should try to anticipate and correct them.

One common gross error, frequently committed by beginners in measurement work, involves the improper use of an instrument.

For example, a well calibrated voltmeter may give a misleading reading when connected across a high resistance circuit. This example illustrate that the voltmeter has a "loading effect" on the circuit, altering the original situation by the measurement process.

Errors caused by the loading effect of the voltmeter can be avoided by using it intelligently.

A large number of gross errors can be attributed to carelessness or bad habits, such as improper reading of an instrument, recording the result differently from the actual reading taken, or adjusting the instrument incorrectly. Errors like these cannot be treated mathematically; they can be avoided only by taking care in reading and recording the measurement data.

2. Systematic Errors

This type of error is usually divided into two different categories:

(*i*) Instrumental errors, defined as shortcoming of the instrument.

(*ii*) Environmental errors, due to external conditions affecting the measurement.

Instrumental errors are errors inherent in measuring instruments because of their mechanical structure. For example, in the d'Arsonval movement friction in bearings of various moving components may cause incorrect readings.

Instrumental errors may be avoided by :

(*i*) Selecting a suitable instrument for the particular measurement application.

(*ii*) Applying correction factors after determining the amount of instrumental error.

Environmental errors are due to conditions external to the measuring device, including conditions in the area surrounding the instrument, such as the effects of change in temperature, humidity, pressure.

- Systematic errors can also be subdivided into static or dynamic errors.

Static errors are caused by limitations of the measuring device or the physical laws governing it's behavior. Dynamic errors are caused by the instrument not responding fast enough to follow the changes in a measured variable.

3. Random Errors

These errors are due to unknown causes and occur even when all systematic errors have been accounted for.

Limiting Errors or Guarantee Errors:

In most indicating instruments the accuracy is guaranteed to a certain percentage of full scale reading. Circuit components (such as capacitors, resistors etc.) are guaranteed within a certain percentage of their rated value.

The limits of these deviations from the specified values are known as limiting errors or guarantee errors. For example, if the resistance of a resistor is given as $500\,\Omega \pm 10$ percent, the manufacturer guarantees that the resistance falls between the limits $450\,\Omega$ and $550\,\Omega$.

The magnitude of a quantity having a nominal value A_s and a maximum error or limiting error of $\pm\delta A$ must have a magnitude A_s between the limits

$$A_s - \delta A \text{ and } A_s + \delta A$$

⇒ The relative or fractional error is defined as the ratio of the error to the specified magnitude of a quantity.

Relative limiting error $\varepsilon_r = \dfrac{\delta A}{A_s} = \dfrac{\varepsilon_o}{A_s}$

$$\varepsilon_o = \delta A = \varepsilon_r A_s$$

Percentage limiting error

$$\boxed{\% \varepsilon_r = \varepsilon_r \times 100}$$

Let a meter is guaranteed to have an error of less than 2 percent of full scale with 200 V as full scale reading. Now when we measure 100 V with this the limiting error will be

$$\frac{4}{100} \times 100 = 4\%$$

(Twice that at full scale deflection)

If further smaller voltages are measured with this meter, the limiting errors will further increase because the magnitude of the limiting error δA is based upon the full scale reading of the meter and is a fixed quantity, while the actual voltage readings can be of any magnitude between 0 – 200 V. Thus the measurement with a meter should be taken near it's full scale value.

Combination of Quantities with Limiting Errors

1. Sum and difference two quantities

Let X be the result which is the sum of measured quantities

$$X = X_1 + X_2 + X_3 \,........\, X_n$$

If the limiting errors in the quantities, $x_1, x_2, x_3, ... x_n$ is $\pm\delta x_1, \pm\delta x_2, \pm\delta x_3, ... \pm\delta x_n$

Then the corresponding relative limiting error in X is given by

$$\frac{\delta X}{X} = \pm\left[\frac{x_1}{X}\frac{\delta x_1}{x_1} + \frac{x_2}{X}\frac{\delta x_2}{x_2} + \dots\dots \frac{x_n}{X}\frac{\delta x_n}{x_n}\right]$$

Note: Same formula is applicable if X is difference of the two quantities.

If we have

$$X = \pm X_1 \pm X_2 \pm X_3$$

$$\frac{\delta X}{X} = \pm\left(\frac{x_1}{X}\frac{\delta x_1}{x_1} + \frac{x_2}{X}\frac{\delta x_2}{x_2} + \frac{x_3}{X}\frac{\delta x_3}{x_3}\right)$$

2. Product and Quotient of Two Quantities:

Let $X = x_1\, x_2\, x_3$ or $X = \frac{x_1}{x_2\, x_3}$ or $X = \frac{x_1}{x_1\, x_2\, x_3}$

Relative limiting error in X

$$\frac{\delta X}{X} = \pm\left(\frac{\delta x_1}{x_1} + \frac{\delta x_2}{x_2} + \frac{\delta x_3}{x_3}\right)$$

Composite Factors

Let $X = x_1^n\, x_2^m$

Then relative limiting error in X

$$\frac{\delta X}{X} = \pm\left(n\frac{\delta x_1}{x_1} + m\frac{\delta x_2}{x_2}\right)$$

Statistical Analysis

A statistical analysis of measurement data is common practice because it allows an analytical determination of the uncertainty of the final test result.

Arithmetic Mean:

The most probable value of a measured variable is the arithmetic mean of the number of readings taken.

The best approximation will be made when the number of readings of the same quantity is very large.

The arithmetic mean in given by the following expression

$$\bar{x} = \frac{x_1 + x_2 + x_3 + \dots\dots x_n}{n} = \frac{\Sigma x_i}{n}$$

$\bar{x}$ = arithmetic mean

$x_1, x_2, \dots\dots x_n$ = reading taken

n = number of readings

Deviation from the Mean

Deviation is the departure of a given reading from the arithmetic mean of the group of readings.

Deviation from the mean can be expressed as

$$d_1 = x_1 - \bar{x}\ ,\ d_2 = x_2 - \bar{x}\ , \dots\dots\dots\dots\dots\dots\ d_n = x_n - \bar{x}$$

Note that algebraic sum of all the deviations must be zero.

Average Deviation

The average deviation is an indication of the precision of the instruments used in making the measurement.

Highly precise instrument will yield a low average deviation between readings.

By definition, average deviation is the sum of the absolute values of the deviations divided by the number of readings.

$$\mathrm{D} = \frac{|d_1| + |d_2| + |d_3| + \dots\dots\dots\dots |d_n|}{n} = \frac{\Sigma |d|}{n}$$

Standard Deviation

The standard deviation σ of an infinite number of data is the square root of the sum of all the individual deviations squared, divided by the number of readings.

$$\sigma = \sqrt{\frac{d_1^2 + d_2^2 + d_3^2 + \dots\dots\ d_n^2}{n}}$$

$$= \sqrt{\frac{\Sigma d^2}{n}}$$

In practice, of course, the possible number of observations is finite. The standard deviation of a finite number of data is given by

$$\sigma = \sqrt{\frac{d_1^2 + d_2^2 + d_3^2 + \ldots\ldots. d_n^2}{n}} = \sqrt{\frac{\Sigma d^2}{n-1}}$$

Variance (V) = Means square deviation = σ^2

Probable Error

Probable error is defined as

Probable error $r = \pm 0.6745\,\sigma$

This value is probable in the sense that there is an even chance that any one observation will have a random error not greater than ± r.

Variance and Standard Deviations of Combination of Components

Suppose X is a function of several component variables, each of which is subject to random effects, thus we have

$$X = f(x_1, x_2, \ldots\ldots., x_n)$$

Where, $x_1, x_2, \ldots\ldots., x_n$ are independent variables.

The variance of X is denoted by V_x and is given by

$$V_x = \left(\frac{\partial X}{\partial x_1}\right)^2 V_{x_1} + \left(\frac{\partial X}{\partial x_2}\right)^2 V_{x_2} + \ldots\ldots\ldots \left(\frac{\partial X}{\partial x_n}\right)^2 V_{x_n}$$

where V_{x_1} is mean value of variance of x_1

The standard deviation of X is σ_X and is equal to

$$\sigma_X = \sqrt{V_X} = \sqrt{\left(\frac{\partial X}{\partial x_1}\right)^2 \sigma\, x_1^2 + \left(\frac{\partial X}{\partial x_2}\right)^2 \sigma\, x_2^2 + \ldots\ldots\ldots \left(\frac{\partial X}{\partial x_n}\right)^2 \sigma\, x_n^2}$$

Standard of Measurement

A standard of measurement is a physical representation of a unit of measurement.

A unit is realized by reference to an arbitrary material standard or to natural phenomena including physical and atomic constants.

For example, the fundamental unit of mass in the international system (SI) is the kilogram, defined as the mass of a cubic decimeter of water at its temperature of maximum density of 4ºC.

This unit of mass is represented by a material standard : The mass of the international prototype kilogram, consisting of a platinum iridium alloy cylinder. This cylinder is preserved at the international Bureau of weights and measures at serves, near Paris, and is the material representation of the kilogram.

Standards of measurement are classified by their function and application in the following categories.

(*a*) International standards

(*b*) Primary standards

(*c*) Secondary standards

(*d*) Working standards

The international standards are defined by international agreement. They represent certain units of measurement to the closest possibly accuracy that production and measurement technology allow.

International standards are periodically evaluated and checked by absolute measurement in terms of the fundamental units. These standards are maintained at the international Bureau of weights and measures and are not available to the ordinary user of measuring instruments for purposes of comparison or calibration.

The primary standards are maintained by national standards laboratories in different part of the world. The primary standards, again representing the fundamental units and some of the derived mechanical and electrical units, are independently calibrated by absolute measurements at each of the national laboratories.

Primary standards are not available for use outside the national laboratories. One of the main functions of primary standards is the verification and calibration of secondary standard.

Secondary standards are the basic reference standards used in industrial measurement laboratories. The responsibility for maintenance and calibration of secondary standards rests entirely with the industrial laboratory itself.

Secondary standards are generally sent to the National Standards laboratories on a periodic basis for calibration and comparison against the primary standard.

Working standard are the principle tools of a measurement laboratory.

They are used to check and calibrate general laboratory instruments for accuracy and performance or to perform comparison measurements in industrial applications.

Standard for mass, length and volume, time frequency

The metric unit of mass was originally defined as the mass of a cubic decimeter of water at it's temperature of maximum density.

The material representation of this unit is the international prototype kilogram, preserved at the international Bureau of weights and measures near Paris.

- The latest standard of length meter is simply the distance light propagates in a vacuum in $\frac{1}{299792, 458}$ seconds.
- The unit of volume is a derived quantity and is not represented by an international standard.
- The international committee of weights and measures has defined the second in terms of the frequency of the cesium transition, assigning a value of 9192631770 Hz to the hyper fine transition of the cesium atom unperturbed by external fields.

Electrical Standards

1. The Absolute Ampere

By international agreement, the value of the international ampere was based on the electrolytic deposition of silver form a silver nitrate solution.

International ampere was then defined as that current which deposits silver at the rate of 1.118 mg/s from a standard silver nitrate solution.

In 1948 the international ampere was superseded by the Absolute ampere. The determination of the absolute ampere is made by means of a current balance, which weights the force exerted between two current carrying coils. The absolute ampere is now the fundamental unit of electric current in the SI and is universally accepted by international agreement.

2. Resistance Standards

The absolute value of the ohm in the SI system is defined in terms of the fundamental units of length, mass and time.

The standard resistor is a coil of wire of some alloy like Manganin which has a high electrical resistivity and a low temperature coefficient of resistance. The resistance coil is mounted in a double walled sealed container to prevent change in resistance due to moisture.

CHAPTER-2

ANALOG INSTRUMENTS

Analog Instruments

- The output of an analog instrument is a continuous function of time and is proportional to the quantity being measured as an input.
- There are three types of analog instruments:

(*i*) Indicating (*ii*) Recording (*iii*) Integrating.

- Indicating instruments have indicators (Dial and Pointer) to indicate the magnitude of a quantity being measured.

Analog Indicating are of Two Types

(*i*) Electromechanical instruments

(*ii*) Electronic Instrument

Electromechanical principles are used in electronic instrument and some electronic circuits are added to increase the sensitivity or input impedance.

- When a recording mechanism such as pen or stylus is provided to the moving system of an instrument, then instrument continuously record the quantity being measured. This type of instruments are called as recording instruments.

The record may be used for future reference or computation work.

- Integrating instrument gives an output which is the total effect of an event over a specified period of time. Ampere hour and watt hour meters are examples of these instruments.
- Analog instruments may also be classified on the basis of method used for comparing the unknown quantity with the unit of measurement.

1. Direct Measuring Instruments:

This instrument uses the energy of the quantity being measured to produce a deflection which is proportional to the quantity being measured.

The examples of this class of instruments are ammeters, voltmeters, watt meters.

2. Comparison Instruments

These instruments compare the unknown quantity with a standard.

In most of the engineering works direct measuring instruments are used for the purpose of measurement as they are simple, cheaper, and gives the result in shortest time.

Whereas comparison instruments have higher accuracy because they work on null detection principle.

General Discussion of Electro Mechanical Indicating Instruments

Operating Forces

There are three type of forces operating on an indicating instrument

1. Deflecting Force

Deflecting force is produced using the energy of to the quantity being measured and this force deflects the moving system from the zero position.

2. Controlling Force

Controlling force produced by the controlling system is equal to the deflecting force at the final position of the pointer.

Controlling force is required in an indicating instrument to produce a finite deflection.

In absence of the controlling force the pointer will swing beyond the final steady position for any magnitude of the deflecting force.

Controlling force also brings back the pointer when the deflecting force is zero.

3. Damping Force

Damping force is used to quickly bring the pointer at rest at final steady state position.

If damping force is not used the pointer will oscillates about its final steady position.

Constructional Details

Moving System

Moving system should be light and the frictional forces should be minimum.

If moving system is heavy and/or frictional forces are significant, the instrument will require more power for its operation.

The moving system can be made light by using aluminium as for as possible. The frictional forces are reduced by using a spindle mounted between jewel bearings and by carefully balancing the system.

Support of the Moving System

Operating forces in indicating instruments are small, hence the frictional forces must be kept to a minimum in order that the instrument reads correctly.

There are three main type of supports

(*i*) Suspension (*ii*) Taut suspension

(*iii*) Pivot and jewel bearing

- **Torque by Weight Ratio**

If the weight of the moving system is large, the frictional force will be high.

The torque by weight ratio of on indicating instrument should be high.

Control System

The moving system of most of the indicating instrument is mounted on a pivoted spindle.

There are two type of control methods used for such a mounted system.

1. Gravity Control

The controlling torque is produced by a small weight placed on an arm attached to the moving system

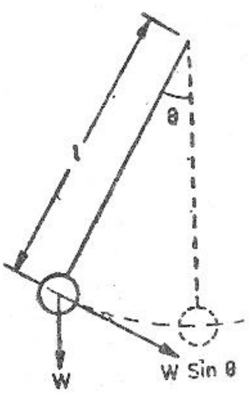

Figure: Gravity Control

The instruments employing gravity control must be used in vertical position.

Controlling Torque

$$T_c = W\sin\theta \times l = Wl\sin\theta = K\sin\theta \qquad K = \omega l = \text{constant}$$

The instruments also be mounted in level position to avoid the zero error.

2. Spring Control

A hair spring attached to the moving system exerts a controlling torque.

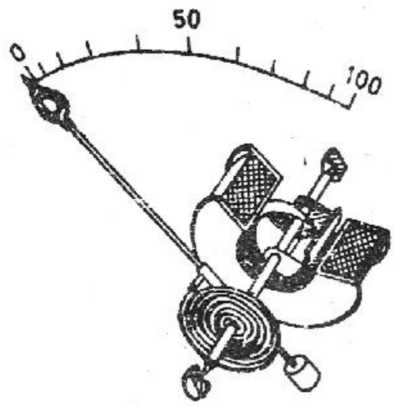

Figure: Spring control.

Flat spiral springs are used in almost all indicating instruments. Phosphor bronze is used as a spring material.

- Gravity control method is cheap, control is independent of temperature but gives a cramped scale at the lower end, even if the deflecting torque is proportional to the quantity being measured.
- Spring control is costlier, temperature dependent, but gives uniform scale when the deflecting force is proportional to the quantity being measured.

Damping System

- The damping torque should bring the pointer quickly without over shooting.
- The moving system will achieve the final steady state position when the instrument is critically damped.

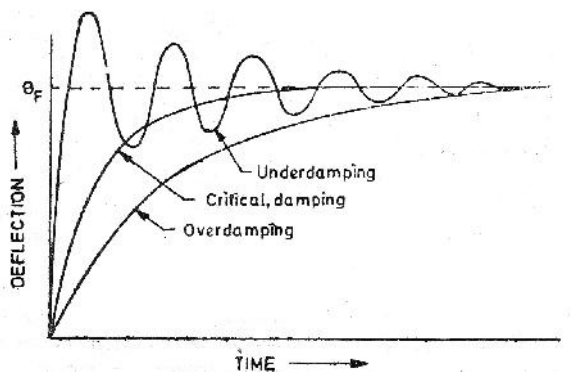

Figure: Setting curves for different type of damping.

- The moving system will move rapidly but smoothly to its final steady state position when the instrument is critically damped.

- When the system is over damped the moving system will move to its final position in a lethargic manner.
- The damping system produces damping torque only when the moving system is in motion

There are four methods for producing damping torque.

(*i*) Air friction damping

(*ii*) Fluid friction damping

(*iii*) Eddy current damping

(*iv*) Electromagnetic damping.