Electrical and Electronic Measurements

For

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Syllabus for Electrical and Electronic Measurements

Bridges and Potentiometers, Measurement of R,L and C. Measurements of Voltage, Current, Power, Power Factor and Energy. A.C & D.C Current Probes. Extension of Instrument Ranges. Q-Meter and Waveform Analyzer. Digital Voltmeter and Multi-Meter. Time, Phase and Frequency Measurements. Cathode Ray Oscilloscope. Serial and Parallel Communication. Shielding and Grounding.

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"Winning isn't everything. It's the only thing."
....Vincent Lombardi

CHAPTER 1

Basics of Measurements and Error Analysis

Learning Objectives

After reading this chapter, you will know:

1. Fundamentals
2. Performance Characteristics, Static Characteristics, Dynamic Characteristics
3. Limiting Errors/Guarantee Errors
4. Types of Errors

Fundamentals

1. **Units:** The magnitude of the fundamental quantities is expressed in units. Units are name or labels for the physical quantities such as meter for length, kilogram for mass, seconds for time, etc. We use the system of units of measurements called the 'International system of units'.

(A) **Fundamental Units:** These include the following along with dimension and unit symbol.

S. No.	Name	Unit	Symbol
1	Length	Metre	M
2	Mass	Kilogram	kg
3	Time	Second	sec
4	Intensity of electric Current	Ampere	A
5	Thermodynamic Temperature	Kelvin	K
6	Luminous Intensity	Candler	Cd

(B) **Supplementary Units**

S. No.	Quantity	Units	Symbol
1	Plane angle	radian	red
2	Solid angle	steradian	sr

(C) **Derived Units**

Name	Unit	Dimension	Quantity	Unit	Dimension
Area	m^2	L^2	Frequency	Hz	T^{-1}
Volume	m^3	L^3	Velocity	m/sec	LT^{-1}
Density	kg/m^3	$L^{-3}M$	Acceleration	m/sec^2	LT^{-2}
Angular velocity	rad/sec	$[L]^0T^{-1}$	Force	Kg m/sec^2	LMT^{-2}
Angular acceleration	rad/sec^2	$[L]^0T^{-2}$			

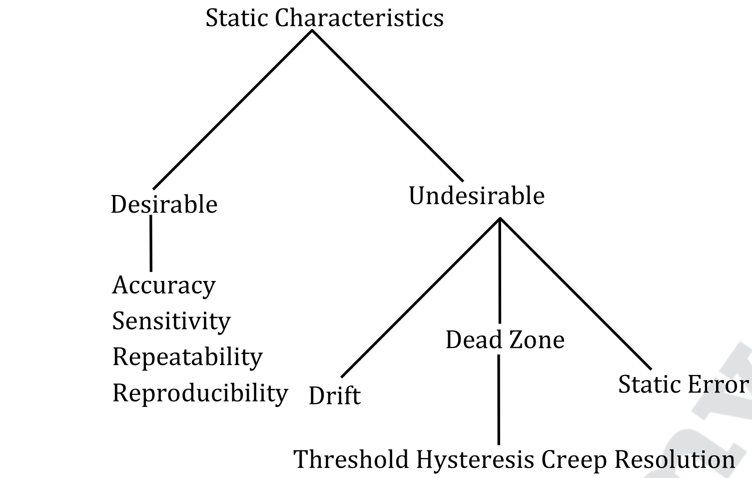
Pressure, Stress	kg/m/sec^2	$L^{-1}MT^{-2}$	Power	Watt (J/sec)	L^2MT^{-3}
Work, Energy	Joule(Nm)	L^2MT^{-2}	EMF	Volt (W/A)	$L^2MT^{-3}I$
Charge	Coulomb	TI			
Electric Field Strength	V/m	$LMT^{-3}I^{-1}$			
Capacitance	(AS/v)	$L^{-2}M^{-1}T^4I^2$			

2. **Conversions**
   Few Standard Conversions
   1 ft = 30.48 cm= 12 inches
   1 m = 3.28 ft
   1 kg = 2.2 pounds
   1 hp = 746 W

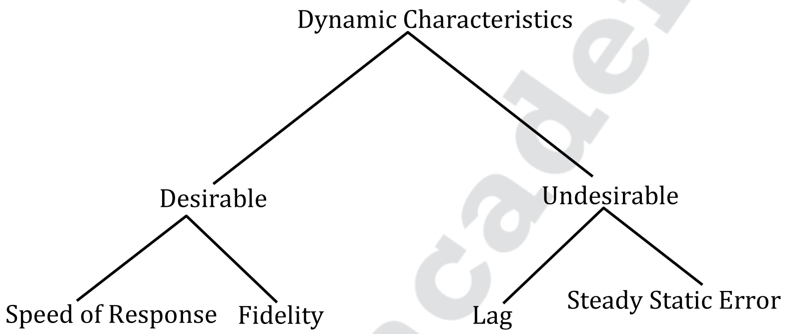
3. **Standards:** A standard is a physical representation of a unit of measurement.
   The equipment/measure used as a 'standard' have a specified value /quantity of the physical item being measured. The classification of standards is based on the function and the application of the standards.
   (A) **International Standards**: The international standards are based on international agreement. They are checked against absolute measurements in terms of the fundamental units.
   (B) **Primary Standards**: Primary standards are absolute standards of very high accuracy that they can be used as the ultimate reference standards. These are maintained by National Standard Laboratories.
   (C) **Secondary Standards**: The secondary standards are the basic reference standards used in international measurement laboratories. These are checked against primary standards available in the region.
   (D) **Working Standards:** Working standards are used to check and calibrate general laboratory instruments for accuracy and performance.

Performance Characteristics

- The performance characteristics of an instrument are mainly divided into two categories:
  1. Static characteristics
  2. Dynamic characteristics



Static Characteristics Tree



Dynamic Characteristics Tree

- Set of criteria defined for the measurements, which are used to measure the quantities, which are slowly varying with time or almost constant, i.e., do not vary with time, are called Static Characteristics.
- While when the quantity under measurement changes rapidly with time, the relation existing between input and output are generally expressed with the help of differential equations and are called "Dynamic Characteristics".

Calibration

- The various performance characteristics are obtained in one form or another by a process called "Calibration".
- It is the process of making an adjustment or marking a scale so that the readings of an instrument agrees with the accepted and the certified standard.

Static Characteristics

Following are the Main Static Characteristics

1. **Accuracy:** It is the degree of closeness with which the instrument reading approaches the true value of the quantity.
   - Accuracy is expressed in the following ways:
     Accuracy as "Percentage of Full Scale Reading.

- In case of instruments having uniform scale, the accuracy can be expressed as percentage of full scale reading.

Example: The accuracy of an instrument having full scale reading of 50 units is expressed as $\pm 0.1\%$ of full scale reading.

Note: This form of notation indicates the accuracy is expressed in terms of limits of error.

- So for the accuracy limits specified above, there will be ± 0.05 units of error in any measurement.
- So for a reading of 50 units, there will be a error of ± 0.05 units i.e., $\pm 0.1\%$ while for a reading of 25 units, there will be a error of ± 0.05 units and i.e., $\pm 0.2\%$.
- Thus as reading decreases, error in measurement is ± 0.05 units but net percentage error is more. Hence specification of accuracy in this manner is highly misleading.
  Accuracy as "Percentage of True Value".
- This is the best method of specifying the accuracy. Here it is specified in terms of true value of quantity being measured.

Example: Accuracy can be specified as $\pm 0.1\%$ of true value. This indicates that as readings gets smaller, error also gets reduced.

Accuracy as "Percentage of Scale Span": For an instrument with a_{max} , a_{min} representing full scale and lowest reading on scale, then $(a_{max} - a_{min})$ is called span of the instrument (or) scale span.

- Accuracy of an instrument can be specified as percent of such scale span.

Example:

- For an instrument having scale span from 25 to 225 units, then accuracy can be specified as $\pm 0.2\%$ of scale span i.e., $\pm\left[(225-25)\times\frac{0.2}{100}\right]$ which is ± 0.4 units of error in every measurement.
  Point Accuracy: Here accuracy is specified at only one particular point of scale.
- It does not give any information about accuracy at any other point on scale.

Example: A wattmeter having a range 1000 W has an error of $\pm$ 1% of full scale deflection. If the true power is 100 W, what would be the range of readings? Suppose the error is specified as percentage of true value, what would be the range of the readings?

Solution: When the error is specified as a percentage of full scale deflection, the magnitude of

limiting error at full scale $= \pm\frac{1}{100}\times 1000 = \pm 10\text{ W}$

Thus the Wattmeter reading when the true reading is 100 W may be 100 $\pm$ 10 W i.e., between 90 to 110 W

Relative error $= \frac{\pm 10}{100}\times 100 = \pm 10\%$

Now suppose the error is specified as percentage of true value.

The magnitude of error $= \pm\frac{1}{100}\times 100 = \pm 1\text{ W}$

Therefore the meter may read 100 $\pm$ 1 W or between 99 to 101 W

- Accuracy can also be defined in terms of static error.

2. **Static Error**: It is the difference between the measured value and true value of the quantity
Mathematically
$\delta_A = A_m - A_t$ ----------- eq (1.1)
δ_A: Absolute error or Static error
Where, A_m: Measured value of the quantity
A_t : True value of the quantity

3. **Static Correction:** It is the difference b/w the true value & measured value of the quantity mathematically
$\delta_C = (-\delta_A) = (A_t - A_m)$
Limiting error or Relative error: $(\varepsilon_r) = \dfrac{\delta A}{A_t}$
$$\varepsilon_r = \frac{A_m - A_t}{A_t}$$
Percentage relative error:
$$\%\,\varepsilon_r = \left(\frac{\delta A}{A_t}\right) \times 100$$
From relative percentage error, accuracy is expressed as
$A = 1 - |\varepsilon_r|$
Where A: relative accuracy
And $a = A \times 100\%$
Where a = Percentage accuracy
   - Error can also be expressed as percentage of Full Scale Deflection (FSD) as,
$$\Rightarrow \frac{A_m - A_t}{F.S.D} \times 100$$

Example: The expected value of voltage to be measured is 150 V. However, the measurement gives a value of 149 V. Calculate (i) Absolute error (ii) Percentage error, (iii) Relative accuracy (iv) Percentage accuracy (v) Error expressed as percentage of full scale reading if scale range is 0 – 200 V.

Solution: Expected value implies true value
$A_t = 150$ V
$A_m = 149$ V
(i) Absolute error $= A_m - A_t = -1$ V
(ii) $\%\,\varepsilon_r = \frac{A_m - A_t}{A_t} \times 100 = \frac{1}{150} \times 100 = -0.66\%$
(iii) $A = 1 - |\varepsilon_r| = 1 - \left|\frac{-1}{150}\right| = 0.9933$
(iv) $\%\,a = A \times 100 = 99.33\%$
(v) $F.S.D = \frac{A_m - A_t}{F.S.D} \times 100$
$$= \frac{-1}{200} \times 100 = -0.5\,\%$$

Example: A Voltage has a true value of 1.50 V. An analog indicating instrument with a scale range of 0 – 2.50 V shows as a voltage of 1.46 V. What are the values of absolute error and correction. Express the error as a fraction of the true value and the full scale deflection (f.s.d.).

Solution: Absolute error $\delta A = A_m - A_t = 1.46 - 1.50 = -0.04$ V

Absolute correction $\delta C = -\delta A = +0.04$ V

Relative error, $\varepsilon_r = \dfrac{\delta A}{A_t} = \dfrac{-0.04}{1.50} \times 100 = -2.67\ \%$

Relative error (expressed as a percentage of F.S.D.) $= \dfrac{-0.04}{2.5} \times 100 = -1.60\ \%$

Where F.S.D. is the Full Scale Deflection.

Example: A meter reads 127.50 V and the true value of the voltage is 127.43 V

Determine (a) The static error, (b) The static correction for this instrument

Solution: From Eqn. 1.1, the error is

$\delta A = A_m - A_t = 127.50 - 127.43 = +0.07$ V

Static Correction $\delta C = -\delta A = -0.07$ V

Example: A thermometer reads 95.45°C and the static correction given in the correction curve is – 0.08°C. Determine the true value of the temperature.

Solution: True value of the temperature $A_t = A_m + \delta C = 95.45 - 0.08 = 95.37$°C

4. **Precision:** It is the measure of degree of agreement within a group of measurements.
   - High degree of precision does not guarantee accuracy.
     Precision is composed of two characteristics
     1. Conformity
     2. Number of significant figures

5. **Conformity**
   - Consider a resistor having value of 2385692 which is being measured by ohmmeter as 2.4M Ω consistently, due to non-availability of proper scale.
   - The error created due to limitation of scale is called precision error.

6. **Significant Figures**
   - Precision of the measurement is obtained from the number of significant figures, in which the reading is expressed.
   - Significant figures convey the actual information about the magnitude and measurement precision of the quantity.

Example: A resistance of 110 Ω, is specified may be closer to 109 Ω, and 111 Ω. Thus, there is 3 significant figures while if it is specified as 110. 0 Ω, then it may be closer to 110.1 Ω or 109.9 Ω. Thus, there are now 4 significant figures.

- Thus, more the significant figures the greater is the precision of measurement.
- Normally, large numbers with zeros are expressed in terms of powers of ten.

Example: Approximate population of a city is reported as 4,90,000 which actually is to be read as the population lies between 4,80,000 to 5,00,000 but due to misconception it can also be implied as population lies between 489,999 to 490,001.

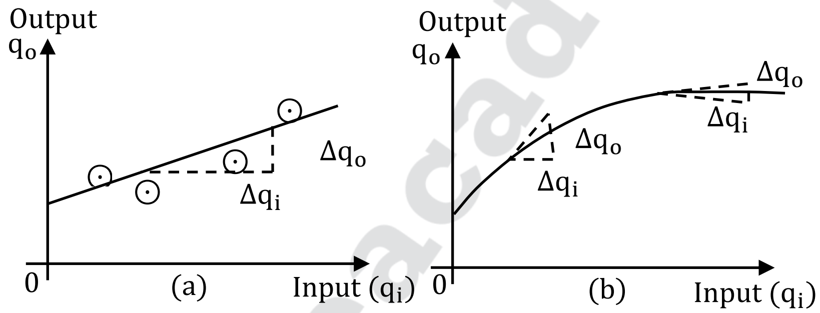
- So it is expressed as 49×10^4 or 4.9×10^5, which is 2 digit significant figure.

7. **Sensitivity:** The sensitivity denotes the smallest change in the measured variable to which the instrument responds.
It is defined as the ratio of the changes in the output of an instrument to a change in the value of the quantity to be measured.
Mathematically it is expressed as,

$$\text{Sensitivity} = \frac{\text{Infinitesimal change in output}}{\text{Infinitesimal change in input}}$$

$$\therefore \text{ Sensitivity } = \frac{\Delta q_o}{\Delta q_i}$$

Thus, if the calibration curve is linear, as shown in the Fig. (a), the sensitivity of the instrument is the slope of the calibration curve.



Sensitivity

If the calibration curve is not linear as shown in the Fig. above (b), then the sensitivity varies with the input.
The sensitivity is always expressed by the manufacturers as the ratio of the magnitude of quantity being measured to the magnitude of the response. Actually, this definition is the reciprocal of the sensitivity is called inverse sensitivity or deflection factor. But manufactures call this inverse sensitivity as a sensitivity.
Inverse Sensitivity = Deflection Factor

$$\therefore \text{ Deflection Factor } = \frac{1}{\text{Sensitivity}} = \frac{\Delta q_i}{\Delta q_o}$$

The units of the sensitivity are millimeter per micro-ampere, millimeter per ohm, counts per volt, etc. While the units of a deflection factor are micro-ampere per millimeter, ohm per millimeter, volts per count, etc.
The sensitivity of the instrument should be as high as possible and to achieve this the range of an instrument should not greatly exceed the value to be measured.

Example: A particular ammeter requires a change of 2 A in its coil to produce a change in deflection of the pointer by 5 mm. Determine its sensitivity and deflection factor.

Solution: The input is current while output is deflection.

$$\text{Sensitivity } = \frac{\text{Change in output}}{\text{Change in input}}$$