Chapter 1

INTRODUCTION TO INSTRUMENTATION

OBJECTIVES

- At the end of this chapter, students should be able to:
  1. Explain the static and dynamic characteristics of an instrument.
  2. Calculate and analyze the measurement error, accuracy, precision and limiting error.
  3. Describe the basic elements of electronic instrument.

INTRODUCTION

- Measurement is the process of determining the amount, degree or capacity by comparison with the accepted standards of the system units being used.
- Instrumentation is a technology of measurement which serves sciences, engineering, medicine and etc.
- Instrument is a device for determining the value or magnitude of a quantity or variable.
- Electronic instrument is based on electrical or electronic principles for its measurement functions.

FUNCTION AND ADVANTAGES

- The 3 basic functions of instrumentation :-
  - Indicating – visualize the process/operation
  - Recording – observe and save the measurement reading
  - Controlling – to control measurement and process
- Advantages of electronic measurement
  - Results high sensitivity rating – the use of amplifier
  - Increase the input impedance – thus lower loading effects
  - Ability to monitor remote signal

PERFORMANCE CHARACTERISTICS

- Performance Characteristics - characteristics that show the performance of an instrument.
  - Eg: accuracy, precision, resolution, sensitivity.
- Allows users to select the most suitable instrument for a specific measuring jobs.
- Two basic characteristics :
  - Static
  - Dynamic

PERFORMANCE CHARACTERISTICS

- Accuracy – the degree of exactness (closeness) of measurement compared to the expected (desired) value.
- Resolution – the smallest change in a measurement variable to which an instrument will respond.
- Precision – a measure of consistency or repeatability of measurement, i.e successive reading do not differ.
- Expected value – the design value or the most probable value that expect to obtain.
- Error – the deviation of the true value from the desired value.
- Sensitivity – ratio of change in the output (response) of instrument to a change of input or measured variable.

ERROR IN MEASUREMENT

- Measurement always introduce error
- Error may be expressed either as absolute or percentage of error

Absolute error, e = $Y_n - X_n$

where Y_n – expected value

X_n – measured value

% error = $\left|\frac{Y_n - X_n}{Y_n}\right| \times 100$

ERROR IN MEASUREMENT

Relative accuracy, $A = 1 - \left|\frac{Y_n - X_n}{Y_n}\right|$

% Accuracy, a = 100% - % error

= $A \times 100$

Precision, P = $1 - \left|\frac{X_n - \overline{X}_n}{\overline{X}_n}\right|$

where X_n - value of the n^{th} measurement

$\overline{X}_n$ - average set of measurement

Example 1.1

Given expected voltage value across a resistor is 80V. The measurement is 79V. Calculate,

i. The absolute error
ii. The % of error
iii. The relative accuracy
iv. The % of accuracy

Solution (Example 1.1)

Given that , expected value = 80V
measurement value = 79V

i. Absolute error, e = $Y_n - X_n$ = 80V – 79V = 1V

ii. % error = $\left|\frac{Y_n - X_n}{Y_n}\right| \times 100 = \frac{80-79}{80} \times 100$ = 1.25%

iii. Relative accuracy, $A = 1 - \left|\frac{Y_n - X_n}{Y_n}\right|$ = 0.9875

iv. % accuracy, a = A x 100% = 0.9875 x 100%=98.75%

Example 1.2

From the value in table 1.1 calculate the precision of 6th measurement?

Table 1.1

No	X_n
1	98
2	101
3	102
4	97
5	101
6	100
7	103
8	98
9	106
10	99

Solution

the average of measurement value

$$\overline{X}_n = \frac{98 + 101 + ... + 99}{10} = \frac{1005}{10} = 100.5$$

the 6th reading

Precision = $1 - \left|\frac{100 - 100.5}{100.5}\right| = 1 - \frac{0.5}{100.5} = 0.995$

Significant Figures

- Significant figures convey actual information regarding the magnitude and precision of quantity
- More significant figure represent greater precision of measurement

Example 1.3

Find the precision value of X_1 and X_2?

$\overline{X}_n = 101$

$X_1 = 98$ ===>> *2 s.f*

$X_2 = 98.5$ ===>> *3 s.f*

Solution (Example 1.3)

$\overline{X_n} = 101$

$X_1 = 98$ ===>> 2 s.f

$X_2 = 98.5$ ===>> 3 s.f

$X_1 =$ Precision $= 1 - \left|\frac{98-101}{101}\right| = 0.97$

$X_2 =$ Precision $= 1 - \left|\frac{98.5-101}{101}\right| = 0.975$ ===>more precise

Significant Figures (cont)

Rules regarding significant figures in calculation

1) For adding and subtraction, all figures in columns to the right of the last column in which all figures are significant should be dropped

Example 1.4

V_1 = 6.31 V

\+ V_2 = 8.736 V

Therefore V_T = 15.046 V

≅ 15.05 V

Significant Figures (cont)

2) For multiplication and division, retain only as many significant figures as the least precise quantity contains

Example 1.5

From the value given below, calculate the value for R_1, R_2 and power for R_1?

I = 0.0148 A ===> 3 s.f

V_1 = 6.31 V ===> 3 s.f

V_2 = 8.736 V ===> 4 s.f

Solution (Example 1.5)

$$R_1 = \frac{V_1}{I} = \frac{6.31V}{0.0148\,A} = 426.35 = 426\Omega$$ ===> 3 s.f

$$R_2 = \frac{V_2}{I} = \frac{8.736V}{0.0148\,A} = 590.27 = 590\Omega$$ ===> 3 s.f

$$P_1 = V_1 \times I = (6.31V)\times(0.0148A)$$

= 0.09339

= 0.0934 ===> 3 s.f

Significant Figures (cont)

3) When dropping non-significant figures

0.0148 ==> 0.015 (2 s.f)
==> 0.01 (1 s.f)

TYPES OF STATIC ERROR

- Types of static error
  1) Gross error/human error
  2) Systematic Error
  3) Random Error

1) Gross Error
- cause by human mistakes in reading/using instruments
- cannot eliminate but can minimize

TYPES OF STATIC ERROR (cont)

2) Systematic Error
- due to shortcomings of the instrument (such as defective or worn parts)
- 3 types of systematic error :-
  (i) Instrumental error
  (ii) Environmental error
  (iii) Observational error

TYPES OF STATIC ERROR (cont)

(i) Instrumental error
- inherent while measuring instrument because of their mechanical structure (bearing friction, irregular spring tension, stretching of spring, etc)
- error can be avoid by:

(a) selecting a suitable instrument for the particular measurement application
(b) apply correction factor by determining instrumental error
(c) calibrate the instrument against standard

TYPES OF STATIC ERROR (cont)

(ii) Environmental error
- due to external condition effecting the measurement including surrounding area condition such as change in temperature, humidity, barometer pressure, etc
- to avoid the error :-
  (a) use air conditioner
  (b) sealing certain component in the instruments
  (c) use magnetic shields

(iii) Observational error
- introduce by the observer
- most common : parallax error and estimation error (while reading the scale)

TYPES OF STATIC ERROR (cont)

3) Random error
- due to unknown causes, occur when all systematic error has accounted
- accumulation of small effect, require at high degree of accuracy
- can be avoid by
  (a) increasing number of reading
  (b) use statistical means to obtain best approximation of true value

- Example 1.6:A voltmeter having a sensitivity of 1kΩ/V is connected across an unknown resistance in series with a milliammater reading 80V on 150V scale. When the milliammeter reads 10mA, calculate the
  i. Apparent resistance of the unknown resistance
  ii. Actual resistance of the unknown resistance
  iii. Error due to the loading effect of the voltmeter

Dynamic Characteristics

- Dynamic – measuring a varying process condition.
- Instruments rarely respond instantaneously to changes in the measured variables due to such things as mass, thermal capacitance, fluid capacitance or electrical capacitance.
- The three most common variations in the measured quantity:
  - Step change
  - Linear change
  - Sinusoidal change

Dynamic Characteristics

- The dynamic characteristics of an instrument are:
  - Speed of response
  - Dynamic error
    - The difference between the true and measured value with no static error.
  - Lag – response delay
  - Fidelity – the degree to which an instrument indicates the changes in the measured variable without dynamic error (faithful reproduction).

LIMITING ERROR

- The accuracy of measuring instrument is guaranteed within a certain percentage (%) of full scale reading
- E.g manufacturer may specify the instrument to be accurate at ±2 % with full scale deflection
- For reading less than full scale, the limiting error increases

LIMITING ERROR (cont)

Example 1.6

Given a 600 V voltmeter with accuracy ±2% full scale.
Calculate limiting error when the instrument is used to measure a voltage of 250V?

Solution

The magnitude of limiting error, 0.02 x 600 = 12V
Therefore, the limiting error for 250V = 12/250 x 100 = 4.8%

LIMITING ERROR (cont)

Example 1.7

A voltmeter reading 70V on its 100V range and an ammeter reading 80mA on its 150mA range are used to determine the power dissipated in a resistor. Both of these instruments are quaranteed to be accurate within ±1.5% at full scale deflection. Determine the limiting error of the power.

Solution

The limiting error for the power = 2.143% + 2.813%
= 4.956%

LIMITING ERROR (cont)

Example 1.8

Given for certain measurement, a limiting error for voltmeter at 70V is 2.143% and a limiting error for ammeter at 80mA is 2.813%. Determine the limiting error of the power.

Solution

The limiting error for the power = 2.143% + 2.813%

= <u>4.956%</u>

Standard

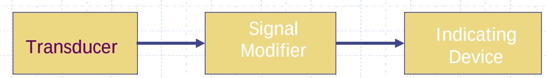
- A standard is a known accurate measure of physical quantity.
- Standards are used to determine the values of other physical quantities by the comparison method.
- All standards are preserved at the International Bureau of Weight and Measures (BIMP), Paris.
  - http://www1.bipm.org/en/home
- Four categories of standard:
  - International Standard
  - Primary Standard
  - Secondary Standard
  - Working Standard

Standard

- International Std
  - Defined by International Agreement
  - Represent the closest possible accuracy attainable by the current science and technology
- Primary Std
  - Maintained at the National Std Lab (different for every country)
  - Function: the calibration and verification of secondary std
- Secondary Std
  - Basic reference std used by measurement & calibration lab in industries.
  - Maintained by the particular industry.
  - Each lab has its own secondary std which are periodically checked and certified by the National Std Lab.
- Working Std
  - Principal tools of a measurement lab.
  - Used to check and calibrate lab instrument for accuracy and performance.
  - Eg: Std resistor for checking of resistance value manufactured.

ELECTRONIC INSTRUMENT

- Basic elements of an electronics instrument



1) Transducer
   - convert a non electrical signal into an electrical signal
2) Signal modifier
   - convert input signal into a suitable signal for the indicating device
3) Indicating device
   - indicates the value of quantity being measure

INSTRUMENT APPLICATION GUIDE

- Selection, care and use of the instrument :-
  - Before using an instrument, students should be thoroughly familiar with its operation ** read the manual carefully
  - Select an instrument to provide the degree of accuracy required (accuracy + resolution + cost)
  - Before used any selected instrument, do the inspection for any physical problem
  - Before connecting the instrument to the circuit, make sure the 'function switch' and the 'range selector switch' has been set-up at the proper function or range

Practice

- A voltmeter has an accuracy of 98% in full-scale measurement readings.
  a) If the voltmeter gives measurement reading of 200V at the range of 500V, calculate the absolute error of the measurement.
  b) Calculate the percent error for the reading in (a)