EE309 ELECTRONICS INSTRUMENTATION

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Chapter 1

INTRODUCTION

TO

INSTRUMENTATION

OBJECTIVES



At the end of this chapter, students should be able to:

- Explain the static and dynamic 1. characteristics of an instrument.
- 2. Calculate and analyze the measurement error, accuracy, precision and limiting error.
- Describe the basic elements of electronic 3. instrument.

INTRODUCTION

 Instrumentation is a technology of measurement which serves sciences, engineering, medicine and etc.

Measurement is the process of determining the amount, degree or capacity by comparison with the accepted standards of the system units being used.

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 <u>instrument</u>.
 - Eg: accuracy, precision, resolution, sensitivity.
- Allows users to select the most suitable instrument for a specific measuring jobs.
- Two basic characteristics :
 - Static measuring a constant process condition.
 - Dynamic measuring a varying process condition.

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.
- Sensitivity ratio of change in the output (response) of instrument to a change of input or measured variable.
- 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.

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 =
$$1 - \left| \frac{X_n - X_n}{\overline{X_n}} \right|$$

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where $\frac{X_n}{X_n}$ - value of the nth measurement $\overline{X_n}$ - average set of measurement

The precision of a measurement is a quantitative or numerical indication of the closeness with which a repeated set of measurement of the same variable agree with the average set of measurements.

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



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 $\pm 2\%$ full scale. Calculate limiting error when the instrument is used to measure a voltage of 250V?

Solution

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

LIMITING ERROR (cont)

Example 1.7

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>

Exercise

A voltmeter is accurate 98% of its full scale reading.
 i. If the voltmeter reads 200V on 500V range, what is the absolute error?
 ii. What is the percentage error of the reading in (i).

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 ? $\overline{X_n} = 101$ $X_1 = 98 ===>> 2 \text{ s.f}$ $X_2 = 98.5 ===>> 3 \text{ s.f}$



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 $V_T = 15.046 V$ $\cong 15.05 V$

Significant Figures (cont)

 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)

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

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

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



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

TYPES OF STATIC ERROR

1) Gross Error

- cause by human mistakes in reading/using instruments
 may also occur due to incorrect adjustment of the instrument and the computational mistakes
- cannot be treated mathematically
- cannot eliminate but can minimize
- Eg: Improper use of an instrument.
 - This error can be minimized by taking proper care in reading and recording measurement parameter.
- In general, indicating instruments change ambient conditions to some extent when connected into a complete circuit.
- Therefore, several readings (at three readings) must be taken to minimize the effect of ambient condition changes.

2) Systematic Error

- due to shortcomings of the instrument (such as defective or worn parts, ageing or effects of the environment on the instrument)
- In general, systematic errors can be subdivided into static and dynamic errors.
 - Static caused by limitations of the measuring device or the physical laws governing its behavior.
 - Dynamic caused by the instrument not responding very fast enough to follow the changes in a measured variable.

- 3 types of systematic error :(i) Instrumental error
(ii) Environmental error
(iii) Observational error

(i) Instrumental error

- inherent while measuring instrument because of their mechanical structure (eg: in a D'Arsonval meter, friction in the bearings of various moving component, 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

Environmental error

(ii)

- 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)

- Eg: an observer who tend to hold his head too far to the left while reading the position of the needle on the scale.

- 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

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. Pure delay in time is often encountered where the instrument waits for some reaction to take place. Such industrial instruments are nearly always used for measuring quantities that fluctuate with time. Therefore, the dynamic and transient behavior of the instrument is important.

- The dynamic behavior of an instrument is determined by subjecting its primary element (sensing element) to some unknown and predetermined variations in the measured quantity.
- The three most common variations in the measured quantity:
 - Step change
 - Linear change
 - Sinusoidal change

- Step change-in which the primary element is subjected to an instantaneous and finite change in measured variable.
- Linear change-in which the primary element is following the measured variable, changing linearly with time.
- Sinusoidal change-in which the primary element follows a measured variable, the magnitude of which changes in accordance with a sinusoidal function of constant amplitude.

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

Standard



- 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.
- 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
- Each lab has its own secondary std which are periodically checked and certified by the National Std Lab.
- For example, in Malaysia, this function is carried out by SIRIM.

Standard

Secondary Standard

- Secondary standards are basic reference standards used by measurement and calibration laboratories in industries.
- Each industry has its own secondary standard.
- Each laboratory periodically sends its secondary standard to the National standards laboratory for calibration and comparison against the primary standard.
- After comparison and calibration, the National Standards Laboratory returns the secondary standards to particular industrial laboratory with a certification of measuring accuracy in terms of a primary standard.

Working Std

- Used to check and calibrate lab instrument for accuracy and performance.
- For example, manufacturers of electronic components such as capacitors, resistors and many more use a standard called a working standard for checking the component values being manufactured.

ELECTRONIC INSTRUMENT

• Basic elements of an electronics instrument



1) Transducer

- convert a non electrical signal into an electrical signal
- e.g: a pressure sensor detect pressure and convert it to electricity for display at a remote gauge.

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

INSTRUMENT APPLICATION GUIDE



Analog Multimeter

INSTRUMENT APPLICATION GUIDE



Digital Multimeter

CHAPTER REVIEW

- Define the terms accuracy, error, precision, resolution, expected value and sensitivity.
- State three major categories of error.
- A person using an ohmmeter reads the measured value as 470 ohm when the actual value is 47 ohm. What kind of error does this represent?
- State the classifications of standards.
- What are primary standards? Where are they used?
- What is the difference between secondary standards and working standards?
- State three basic elements of electronic instrument.

THE END

