EE-336: Electrical Measurement & Instrumentation (3-3-4)

- Dr. Amjad Ullah, Professor,
- Engr. Numan Khurshid, Lecturer,
- Grading:
  - 50 % Final
  - 25 % Mid Term
  - 25 % Sessionals
- Recommended Books:
  - Modern Electronic Instrumentation and Measurements Techniques by A.D.Helfrick, W.D. Cooper
  - Electrical Instrumentation and Measurement techniques ,By A.K.Sawhney

Course Out lines

- Please note them now
- You will not be provided with any soft copy of syllabus or lectures; you have to read the book thoroughly
- Definitions and classification of errors,
  - instrument errors,
  - environmental errors, temperature effect,
- Method of avoiding and correction errors.
- Engineering units and Standards,

Course Out lines…….

- Principle, Operation, working and Construction of Different Analog and Digital Meters,
  - Oscilloscope and its Measurements,
  - Recording Instruments and signal generators.
  - Transducers,
- Different types of Bridges for Measurements of
  - Resistance,
  - Inductance,
  - Capacitance. High Voltage Measurements,

Course Out lines…….

- Precision Measurements Terminologies Including
  - Resolution,
  - Sensitivity,
  - Accuracy,
  - Uncertainty.
- Mechanical Measurements:
  - Length,
  - Force,
  - Displacement,
  - Stress and Strain.

Course Out lines…….

- Thermodynamic Measurements
  - temp and
  - pressure,
- Measurements in fluid Flows:
  - velocity,
  - Flow rate,
- Data Manipulation and presentation
- Basic data Manipulation skills using personal Computers.
  - Spread sheets and graphs,
- Static and Dynamic Measurements:
  - Time Series and Sampling Requirements.
- Data Acquisition System. Software Simulation.

- Electronics
  - deals with motion of electrons

- Measurement :

man uses his imaginative skills

- to identify a physical phenomena
  - Developed & utilized a means to understand this.

- To measure = to determine the magnitude or extent or degree of the condition of system in terms of some standard.
- All measuring systems- based on laws of nature.
  - E.g. Venturimeter- flow measurement – Bernoulli's theorem

- Meter :
  - instrument used to indicate or record measured value
- Measurand :
  - variable under measurement
- Metrology :
  - science dealing with precise and accurate measurements

Instrument : A *device for determining the value or magnitude of or variable*.

- The instrument serves as an extension of human faculties
- and in many cases enables a person to determine the value of an unknown quantity which his unaided human faculties could not measure
- The electronic instrument, as its name implies, is based on electrical or electronic principles for its measurement function
- A device of simple construction such as a basic dc current meter

- **Instrument** :

tool or equipment for

  - Sensing
  - Detecting
  - Measuring
  - Recording
  - Controlling
  - Communicating
    - Measurand Can be manual or automatic

Definitions & Terms

- ***Instrument:*** a device for determining the value or magnitude of a quantity or variable.
- ***Accuracy:*** closeness with which an instrument reading approaches the true value of the variable being measured.
- ***Precision:*** 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 another.
- ***Sensitivity:*** the ratio of output signal or response of the instrument to a change of input or measured variable.
- ***Resolution:*** the smallest change in measured value to which the instrument will respond.
- ***Error:*** deviation from the true value of the measured variable.

- Error Minimization Techniques
- Several techniques may be used to minimize the effects of errors
- For example, in making precision measurements, it is advisable to record a series of observations rather than rely on one observation.
- Alternate methods of measurement, as well as the use of different instruments to perform the same experiment, provide a good technique for increasing accuracy.
- These techniques tend to increase the *precision* of measurement by reducing error, they cannot account for instrumental error

Accuracy And Precision

- Accuracy refers to the degree of closeness or conformity to the true value of the quantity under measurement.
- Precision refers to the degree of agreement within a group of measurements or instruments.
- But what is the difference?
- Lets have two voltmeters of the same make and model may be compared.
- Both meters have knife-edged pointers and mirror-backed scales to avoid parallax and they have carefully calibrated scales.
- They may therefore be read to the same *precision*.
- But If the value of the series resistance in one meter changes considerably,
  - its readings may be in error by a fairly large amount.
- Therefore the *accuracy* of the two meters may be quite different.

- **Precision**
- Precision is composed of two characteristics:
  - *Conformity* and
  - the number of *significant figures* to which a measurement maybe made
- Example
- A resistor, whose true resistance is 1,384,572 Ω, is measured by an ohmmeter which consistently and repeatedly indicates 1.4 MΩ.
- estimates from the scale reading consistently yield a value of 1.4 MΩ i.e. close to the true value
- But the "***error***" created by the limitation of the scale reading is a ***precision error***
- Precision is a necessary, but not sufficient, condition for accuracy.
- the accuracy of a reading is not necessarily guaranteed by its precision.

Significant Figures

- An indication of the precision of the measurement is obtained from the number of significant figures in which the result is expressed
- Significant figures convey actual information regarding the magnitude and the measurement precision of a quantity the more significant figures,
  - the greater the precision of measurement.
- For example,
- if a resistor is specified as having a resistance of 68Ω, its resistance should be closer to 68Ω than to 67Ω or 69Ω.
- If the value of the resistor is described as 68.0Ω,
  - it means that its resistance is closer to 68.0Ω than it is to 67.9Ω or 68.1Ω.
  - more significant figures, expresses a measurement of greater precision

- **Significant Figures……**
- **Another example**,
- the population of a city is reported in six figures as 380,000.
- This may imply that the true value of the population lies between 379,999 and 380,001
- Means the population is closer to 380,000 than to 370,000 or 390,000.
- A more technically correct notation uses powers of ten, 38×10^4 or $3.8 \times l0^5$.
  - **Means no confusion for a technical person**
- Another way of expressing result indicates the range of possible error.
- The voltage may e.g. be expressed 117.1 ± 0.05 V, indicating that the value of the voltage lies between 117.15 V and 117.15 V.

- **EXAMPLE: 1-1**

  A set of independent voltage measurements taken by four observers was recorded as 117.02 V, 117.11 V, 117.08 V, and 117.03 V. Calculate (a) the average voltage; (b) the range of error

- **Solution:** a. $E_{av} = \frac{E_1 + E_2 + E_3 + E_4}{N}$

$$= \frac{117.02 + 117.11 + 117.08 + 117.03}{4} = 117.06V$$

b. Rang = $E_{max} - E_{av}$ = 117.11 – 117.06 = 0.05V

But also

$E_{av} - E_{min}$ = 117.06 – 117.02 = 0.04 V

The average range of error therefore equals $\frac{0.05 + 0.04}{2} = \pm 0.045 = \pm 0.05V$

  - When two or more measurements with different degrees of accuracy are added, the result is only as accurate as the least accurate measurement

- **Example: 1-2** **(See Examples 1-3,1-4 & 1-5)**
- Two resistors, R_1 and R_2, are connected in series. Individual resistance measurements, using a digital multimeter, give R_1 = 18.7Ω and R_2 3.624Ω. Calculate the total resistance to the appropriate number of significant figures.
- **Solution**

R_1 = 18.7Ω (three significant figures)

R_2 = 3.624Ω (four significant figures)

$R_T = R_1 + R_2$ = 22.*324* Ω (five significant figures) = 22.3Ω

- The doubtful figures are written in italics to indicate that in the addition of R_1 and R_2 the last three digits of the sum are doubtful figures.
- There is no value whatsoever in retaining the last two digits (the 2 and the 4) because one of the resistance is accurate only to three significant figures or tenths of an ohm.
- The result should therefore also be reduced to three significant figures or the nearest tenth, i.e., 22.3 Ω.

- **Types Of Errors**
- No measurement can be made with perfect accuracy,
- but it is important to find out
  - what the accuracy actually is ? and
  - how different errors have entered into the measurement ?
- A study of errors is a first step in finding ways to reduce them
- Such a study also allows us to determine the accuracy of the final test result.

Sources of Errors

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

1. ***Gross errors:*** largely human errors, among them misreading of instruments incorrect adjustment and improper application of instruments, and computational mistakes.
2. ***Systematic errors:*** shortcomings of the instruments, such as defective or worn parts, and effects of the environment on the equipment or the user.
3. ***Random errors:*** those due to causes that cannot be directly established because of random variations in the parameter or the system of measurement.

Gross Errors

- This class mainly covers human mistakes in reading or using instruments and in recording and calculating measurement results.
- Inevitable if human factor is involved
- Although complete elimination of gross errors is probably impossible,
  - Try to anticipate and
  - Correct them
- One common gross error, involves the improper use of an instrument
- In general, indicating instruments change conditions when connected into a complete circuit
  - the measured quantity is altered by the method employed
  - For example, a well-calibrated voltmeter may give a misleading reading when connected across two points in a high-resistance circuit

- **Example: 1-7** **(see example 1-8)**
- A voltmeter, having a sensitivity of 1,000 Ω/V, reads 100 V on its 150-V scale when connected across an unknown resistor in series with a milliammeter. When the milliammeter reads 5 mA, calculate (a) the apparent resistance of the unknown resistor; (b) the actual resistance of the unknown resistor; (c) the error due to the loading effect of the voltmeter.
- **Solution:**

a. The total circuit resistance equals $R_T = \frac{V_T}{I_T} = \frac{100V}{5mA} = 20k\Omega$

Neglecting the resistance of the milliammeter, the value of the unknown resistor is R_x 20 kΩ,

b. The voltmeter equals $RV = 1{,}000\frac{\Omega}{V} \times 150V = 150k\Omega$

Since the voltmeter is in parallel with the unknown resistance, we can write

$$RX = \frac{R_T R_V}{R_V - R_T} = \frac{20 \times 150}{130} = 23.05k\Omega$$

c. % Error = $\frac{\text{actual} - \text{apparent}}{\text{actual}} \times 100\% = \frac{23.05}{23.05} \times 100\%$ = 13.23%

- **Gross Errors**
- Errors caused by the loading effect of the voltmeter can be avoided by using it intelligently.
  - For example, a low-resistance voltmeter should not be used to measure voltages in a vacuum tube amplifier. In this particular measurement, a high-input impedance voltmeter (such as a VTVM or TVM) is required.
- A large number of gross errors can be attributed to carelessness or bad habits
  - improper reading of an instrument,
  - recording the result differently from actual reading taken,
  - or adjusting the instrument incorrectly
  - e.g. multirange voltmeter errors in range selection scale
- Errors like these cannot be treated mathematically.
- They can be avoided only by taking care in reading and recording the measurement data.

Systematic Errors

- This type of error, is usually divided into two different categories:
  - 1. instrumental error, defined as shortcomings of the instruments;
  - 2. environmental errors, due to extern conditions affecting the measurement.
- *Instrumental errors* are errors inherent in measuring instruments because of their mechanical structure.
- For example the d'Arsonval movement friction in bearings of various moving components may cause incorrect readings
- Irregular spring tension, stretching of the spring, or reduction in tension due to improper handling or overloading of the instrument will result in errors.
- calibration errors, causing the instrument to read high or low along its entire scale

Systematic Errors……

- There are many kinds of instrumental errors, depending on the type of instrument used.
- The experimenter should always take precautions to insure that the instrument he is using is operating properly and does not contribute excessive errors for the purpose at hand.
- Faults in instruments may be detected by checking for erratic behavior, and stability and reproducibility of results.
- A quick and easy way to check an instrument is to compare it to another with the same characteristics or to one that is known to be more accurate.

Systematic Errors……Avoid?

- Instrumental errors may be avoided by:
  - selecting a suitable instrument for the particular measurement application;
  - applying correction factors after determining the amount of instrumental error;
  - calibrating the instrument against a standard.
- Environmental errors are due to conditions external to the measuring device, including
- conditions in the area surrounding the instrument, such as
  - the effects of changes in temperature,
  - humidity,
  - barometric pressure,
  - or of magnetic or electrostatic fields.
- Change in ambient temperature at which the instrument causes a change in the elastic properties of the spring in a moving-coil mechanism and so affects the reading of the instrument.

Systematic Errors……

- Corrective measures to reduce these effects include
  - air conditioning,
  - hermetically sealing certain components in the instrument,
  - use of magnetic shields, and the like.
- Systematic errors can also be subdivide into
- ***Static Errors***
  - Static errors caused by limitations of the measuring device or the physical laws governing its behavior.
  - A static error is introduced in a micrometer when excessive pressure is applied in turning the shaft.
- ***Dynamic errors***
  - Dynamic errors are caused by fast enough to follow the changes in a measured variable.

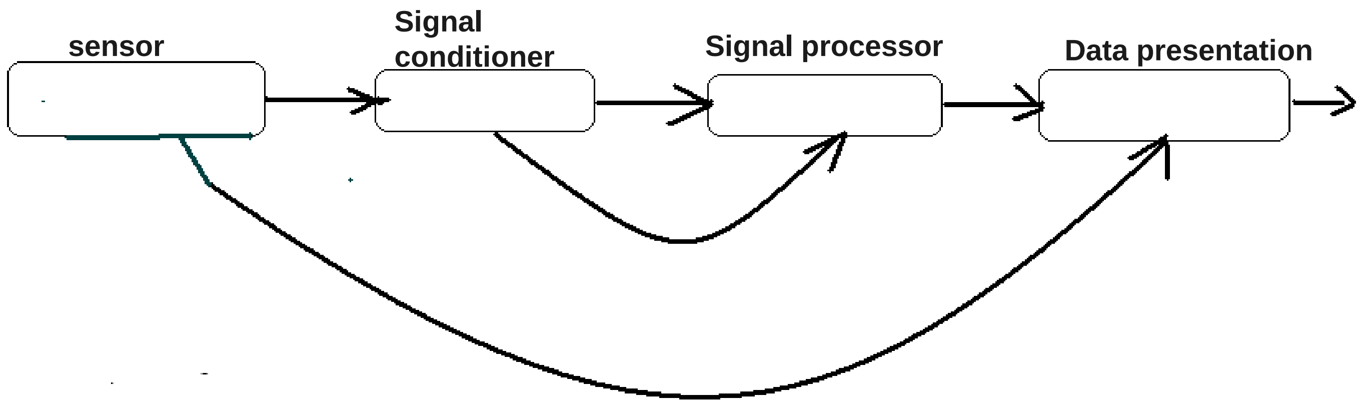
Random Errors

- These errors are due to unknown causes and occur even when a1l systematic errors have been accounted for.
- In well-design experiments, few random errors usually occur, but they become important in high-accuracy work.
  - Suppose a voltage is being monitored by a voltmeter which is read at half-hour intervals.
  - Though the instrument is operated under ideal environmental conditions and has been accurately calibrated
  - But the readings vary slightly over the observation.
- This variation cannot be corrected by any method ‘or other known method of control and
- it cannot be explained till investigation.
- The only way to offset these errors is by increasing the number of readings and using statistical means to obtain the best approximation

Instrumentation

- Deals with Science and technology of measurement of large no. of variables
- Uses principles in physics , chemistry & Appld. Science(Engg),Electrical. Electronics, Mech,computer, commn. etc.
  - i.e., parameters measured need to be txd, stored, may be processed (for control applns.)

General Measurement Systems

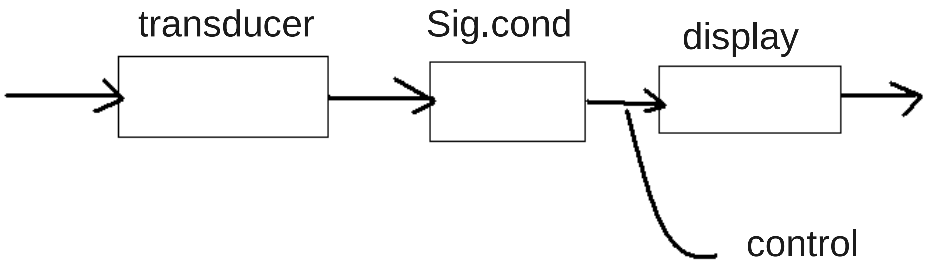


Sensor :

- detecting element
- Use to locate the presence of matter or energy
    - (energy in the form of heat, light, sound, electrical, pressure, velocity)
- Contacts with the process
- Sensitive to either light or temp. or impedance or capacitance etc.

- Signal conditioner:
  - o/p of sensor is converted to required form by conditioner
- Signal processor :
  - filtering, shaping, adding, subtracting , multiplying, linearization etc.
- Data o/p :
  - display, recording etc.

Measuring System



Instrumentation Engg. is:

- Multi disciplinary branch of Engg.
- Deals with design , manufacture, & utilization of instruments

"When you can measure, what you are speaking and express it in numbers, you know something about it."

Lord Kelvin

Units

- Standard measure of each kind of a Physical quantity
- Two types:
  - Fundamental - LMT
  - Derived – area, volume etc

Without units , the number obtained by measuring has no physical meaning.

Systems of Units

- French system - Universal system of standard
- FPS – Foot Pound Second – The British
- CGS – Centimeter Gram Second-designed for practical engg. applications
- MTS-Meter Ton Second in France designed for engg. purpose
- SI –Meter Kilogram Second Ampere

- Standard Organizations to maintain
  - International System of Units (SI)

1. International Bureau of Weights & Measures
2. General Conference on Weights & Measures
3. International Committee for Weight & Measures

- European systems
  - Institute for Reference Materials & measurements-Geel, Belgium + 7 other
  - American systems (National Institute for stds.& tech +2 others NIST)

Standards

- Physical representation of unit of measurement
- Unit is realized by reference to a standard e.g. 1.kg = mass of one cubic deci meter of as its temp of max density of 4c

Categories

1. International Standards
2. Primary standard
3. Secondary Standard
4. Working standards

International Standards

- Defined by international agreement maintained at International Bureau of Weights and Measures (one organization for SI unit)
- Not available to ordinary uses

Primary or Basic Standards

- Maintained by National standard labs of each country
- India –National Physical Lab in New Delhi
- Not available outside National Labs

Secondary standards

- Basic reference standards for industrial measurement labs
- Maintained by particular industry
- Checked locally
- Occasionally sent to primary lab for calibration, then primary labs will give certificate

Working standard

- Primary tool of measuring labs

General Instrumentation systems

Static Characteristics

- Features which does not vary or vary very slowly with respect to time.
- Or they are features which considered when a system or instrument ,when a condition does not vary with time.
  - Some are :***Accuracy, Sensitivity, Reproducibility,*** Drift, Static error, Dead zone etc.

True value :

- Ideal case (impossible to measure)
- Measured by "*Examplar*" method (method agreed by experts as being sufficiently accurate).
- Defined as average of infinite no. of measured values when the average deviation due to various factors tend to zero.
  - take it as best measured quality

- Accuracy
- nearness to the true value

Or

- closeness with which an instrument approaches the true value of quantity being measured
- Accuracy is measured in terms of error.

Static error

- defined as the difference b/w the measured value and true value of quantity.

i.e.,

$$\delta A = A_m - A_t$$

Where ,

δA = *error*

A_m = *measured value*

A_t = *true value*

δA – *static error of quantity A under measurement*

- Quantity of measurement is provided by ***relative static error***

Relative static error ε_r

$$\varepsilon_r = \delta A / A_t$$

$$= \varepsilon_o / A_t$$

$$\% \varepsilon_r = \varepsilon_r \text{ X } 100$$

$$A_t = A_m - \delta A$$
$$= A_m - \varepsilon_o$$
$$= A_m - \varepsilon_r . A_t$$
$$A_m = A_t / (1 + \varepsilon_r)$$
$$\text{So, } A_t = A_m / (1 - \varepsilon_r)$$

Static correction (δC)

$$\delta C = A_t - A_m$$

A_t = true value

A_m = measured value

Problems :

A meter reads 127.50 V and the true value of the voltage is 127.43 V . Determine the static error and static correction .

(Ans : error : 0.07, correction = -0.07)

Problem 2

A thermometer reads 95.45 C & static correction in correction curve is - 0.08 C. Find the true value

Ans : 95.37 C.

Quiz No 1

A voltage has a true value of 1.5 V on an analogindicating meter with a range 0 to 2.5 V shows a voltage of 1.46 V. Determine the value of absolute error and correction.Express the error as a fraction of true value & full scale defection