Electronic Measurements: EC207

Lecture Notes, MO-23

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Contents

Syllabus

Module-1: Introduction of measurements and measurement systems: Significance of measurements, different methods of measurements, Instruments used in measurements, Electronic Instruments and its classification, Elements of a Generalized Measurement System. Characteristics of instruments, Static characteristics, Errors in measurements, scale, range, and scale span, calibration, Reproducibility and drift, Noise, Accuracy and precision, Significant figures, Linearity, Hysteresis, Threshold, Dead time, Dead zone, Resolution and Loading Effects.

Module-2: Analogue Instruments: Classification and Principles of Operation, Working Details Moving Coil (PMMC) and Moving Iron Instruments Construction, DC Ammeter, DC Voltmeter, Series and Shunt type Ohmmeter. Analogue Electronic voltmeter, DC Voltmeter with chopper type DC amplifier.

Module-3: Introduction of DC and AC Bridges: Wheatstone Bridge, Kelvin Double Bridge, Maxwell's Bridge, and Hay's Bridge, Anderson's Bridge, Schering's Bridge, Wien's Bridge, Sources of errors in Bridges and their elimination by shielding and grounding, Q meter.

Oscilloscopes: CRT, Construction, Basic CRO circuits, Block diagram of a modern oscilloscope, Y-amplifiers, X-amplifiers, Triggering, Oscilloscopic measurement. Special CRO's: Dual trace, Dual beam.

Module-4: Digital Instruments and D/A and A/D converters: Sample-and-hold circuit, D/A converters: Weighted-resistor D/A Converter, R-2R Ladder type D/A converter, Specifications for D/A Converters, A/D Converters: Parallel-comparator type A/D converter, Successive approximation type A/D converter, Counter type A/D converter, Dual slope converter, Comparison of converter types, Digital Voltmeters, Digital Multimeters, Digital frequency Meter, Sampling oscilloscope, Storage CROs.

Module-5: Transducers: Definition, Classification, Principle of Analogue transducer: Resistive (Strain Gauge, POT, Thermistor and RTD), Capacitive, Piezoelectric, Thermocouple and Inductive (LVDT) and RVDT) transducer, Working principle of Digital Transducer and Optical transducer. Application of above transducers to be discussed on the basis of Pressure, Displacement, Level, Flow and Temperature measurements.

** **Disclaimer: These notes are just a summary of the topics in the syllabus and do not provide a complete coverage of the course.**

Chapter 1

Chapter-1: Introduction of measurements and measurement systems

1.1 Measurement

Measurement is a process of gathering information from a physical world and comparing this information with agreed standards. The measurement of a given quantity is an act or the result of comparison between the quantity and predefined standard. It is the process of conversion of physical parameters to meaningful numbers. The results of measurement are meaningful if two basic requirements are met:

- The standard used for comparison purposes must be accurately defined and generally accepted.
- The apparatus used and the method adopted must be provable and generally accepted.

The importance of measurement in engineering applications can be understood by considering two major functions of all the branches of engineering:

- Design of new equipments and processors,
- Proper operation and maintenance of equipments and processes.

Both these functions require measurements. This is because proper design, operation, and maintenance requires a feedback of information. This information is supplied by suitable measurement.

Consider, for example, the working of an air conditioner. The air conditioner has a temperature sensor that measures the room temperature then, by comparing the room temperature to the temperature set by the user, the processing unit in the air conditioner is able to determine whether the room temperature is lower or higher than what the user wants and accordingly, adjusts the room temperature to either increase the temperature or decrease the room temperature.

1.1.1 Methods of Measurement

The methods of measurement are basically classified into two categories, namely, direct and indirect methods:

- **Direct methods:** In these methods, the unknown quantity (also called the measurand) is directly compared against a standard.

  Direct methods are quite common for measurement of physical quantities like length, mass, and time. Consider for example measuring length by comparing against measuring tape.

- **Indirect methods:** Measurement by direct methods is not always possible, or is quite inaccurate, in such cases, indirect methods are used. For indirect measurement, measurement systems are used.

  A measurement system consists of a transducing element which converts the quantity to be measured into some analogous signal, which is then processed by the system components to give the reading. All the measuring instruments that we used in the lab or in our daily lives like electronic weighing scale, voltmeter, etc, are examples of indirect instruments.

1.2 Measuring Instruments

An instrument is defined as a device for determining the value or magnitude of a quantity or variable. Most instruments have three basic components:

1. A detector,
2. An intermediate processing/transfer device,
3. An end device, which can be an indicator, a display, or a storage device.

Instruments can be classified in different ways:

- **On the basis of operation:** (i) Mechanical, (ii) Electrical, and (iii) Electronic instruments.
- **On the basis of measurement:** (i) Absolute instruments (ii) Secondary instruments
  1. **Absolute instruments:** These instruments give the magnitude of the quantity under measurement in terms of the physical constants of the instruments and their deflections. E.g., Tangent Galvanometer. There is no need to calibrate these instruments.
  2. **Secondary instruments:** These instruments are constructed in a way that the quantity under measurement can only be measured by absorbing the output indicated by the instrument. These instruments are calibrated by comparison against an absolute instrument, or another secondary instrument that has already been calibrated against an absolute instrument. Examples of secondary instruments include a voltmeter, a glass thermometer, etc.

     Note that, working with absolute instruments for routine work is time consuming, because every time a measurement is made, it takes a lot of time to compute the magnitude of the quantity under measurement.
- **On the basis of mode of operation:** Secondary instruments work in two modes: (i) Analog mode (ii) Digital mode

1. Analog mode: Signals that vary in continuous fashion and take on an infinite number of values in any given range are called analog signals. The devices that produce/work with these signals are called analog devices
2. Signals that are discrete in time and magnitude are called digital signals. Devices that work with/produce such signals are called digital devices.

   Note that, most of the data that arises in a physical system is analog in nature. However, most of the computing/processing devices work with digital data. So, we use an analog to digital (A/D) converter at the input of the computing unit. Sometimes a digital to analog converter (D/A) is used at the output of the computing unit.

1.3 Measurement System

A measurement system is a combination of different components that together achieve the task of measuring an unknown quantity. There are three basic applications of measurement systems:

1. Monitoring of processes and operations
2. Control of processes and operations
3. Experimental engineering analysis

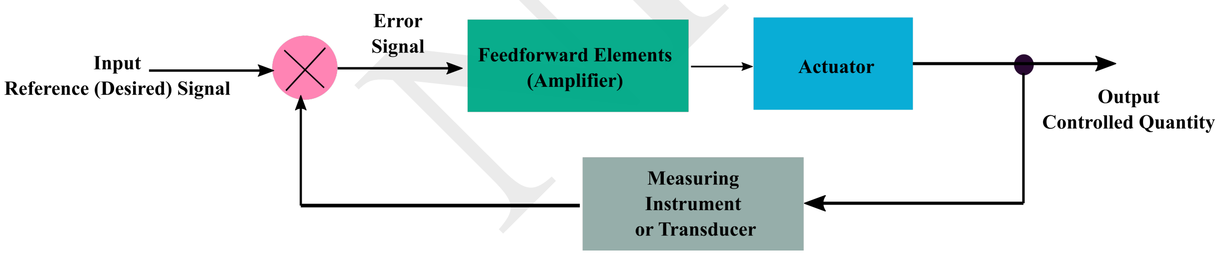

Figure 1.1: Block diagram of a simple control system.

Figure 1.1 shows a simple control system as an example, where a measurement system is used to control a process.

1.3.1 Elements of a generalized measuring system

Most of the measurement systems contain five main functional elements. Figure 1.2 shows the Elements of Generalized Measurement System.

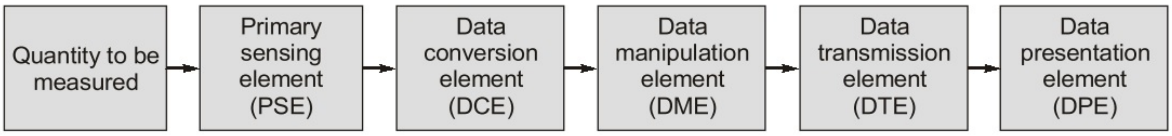

Figure 1.2: Elements of Generalized Measurement System

1. **Primary sensing element:** These elements are in direct contact with quantity under measurement. It is used to sense the quantity to be measured.
   Example: transducer and other sensing element.

2. **Variable conversion element:** This element converts one form of the data to another form, but the basic information carried over by the data is preserved.
   Example: voltage to frequency converter, voltage to current converter, ADC, DAC.

3. **Data Manipulation Element:** This element changes the level of signal preserving its basic nature.
   EXample: amplification, modulation, attenuation etc.

4. **Data Transmission Element:** This element provides transmission channel.
   Example: optical fibres, coaxial cables, transmission lines etc.

5. **Data presentation element:** This element is used either to store or to display the signal receiver.
   Example: CRO, recorder, digital display, plotters etc.

1.4 Characteristics of Instruments and Measurement Systems

Characteristics: The relationship between the input a system and it's output of that can qualify the quality of the measurement.
Instrument and measurement system characteristics can be divided into two distinct categories:
(i) Static characteristics, and (ii) Dynamic characteristics.

- **Static characteristics:** Static characteristics of a measurement system are considered when the system is used to measure a condition not varying with time.

- **Dynamic characteristics:** Many measurements are concerned with rapidly varying quantities and, therefore, for such cases we must examine the dynamic relations which exist between the output and the input. This is normally done with the help of differential equations. Performance criteria based upon dynamic relations are called the Dynamic Characteristics.

1.4.1 Static Characteristics

1. **Accuracy:** Closeness with which an instrument reading approaches the true value of the variable being measured. Accuracy can be specified in terms of limits of error. The accuracy of a measurement means conformity to truth. Higher accuracy means lower error.

2. **Precision:** It is the measure of consistency of the result and is a probabilistic term. For a fixed value of the measured variable, precision is a measure of the degree to which successive measurements differ from one another. Precision also depends upon number of significant figures. The more is significant figures the more is the precision.
   NOTE: Precision does not guarantee accuracy. The high precision does not means high accuracy always, it only means that successive measurements are close to one another, these measurements might not be accurate. So we can say that precision is an essential but not sufficient condition for

an accurate system.

3. **Static Sensitivity:** It is the ratio of the magnitude of the output signal or response to the magnitude of the input signal or the quantity being measured (Fig. 1.3).

$$\text{Sensitivity} = \frac{\text{Small change in output}}{\text{Small change in input}} = \frac{\Delta \mathrm{V_o}}{\Delta \mathrm{V_i}} \tag{1.1}$$

The sensitivity of an instrument should be high.

$$\text{Deflection factor} = \frac{1}{\text{Static Sensitivity}} \tag{1.2}$$

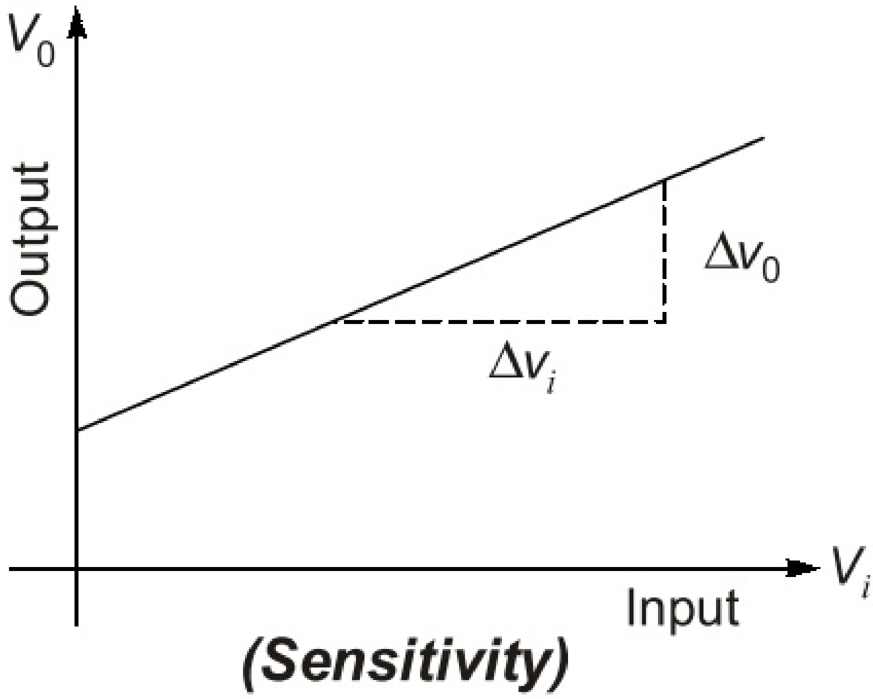

Figure 1.3: Sensitivity

Example: A Wheatstone bridge required a change of $9.2\,\Omega$ in the unknown arm of the bridge to produce a change in deflection of 5 mm of the galvanometer. Find the value of the deflection factor.

Solution:

$$Sensitivity = \frac{\text{Small change in output}}{\text{Small change in input}} = \frac{5\,mm}{9.2\,\Omega} = 0.54\,mm/\Omega$$

$$\text{Deflection factor} = \frac{1}{\text{Sensitivity}} = 1.84\,\Omega/mm$$

4. **Resolution:** The smallest change in the input to which the instrument will respond. If the input is slowly increased from some arbitrary (non-zero) input value, it will be found that output does not change at all until a certain increment is executed. This increment is called resolution.

   We can say that resolution defines the smallest measurable input change while the threshold defines the smallest measurable input.

5. **Repeatability and Reproducibility:**

   - **Repeatability:** It is a measure of the variability/change in the output of the measurement system over a period of time.
   - **Reproducibility:** It is a measure of the variability/change in the output of the measurement system caused by the differences between users and the physical conditions in which the instrument is used.

6. **Linearity:** One of the best characteristics of an instrument; or a measurement system is considered to be linearity, that is, the output is linearly proportional to the input. Most of the systems require a linear behaviour as it is desirable.

   Note that, even though a linear behaviour is desirable, a non-linear behavior of an instrument does not essentially lead to inaccuracy, see for example, Fig. 1.4.

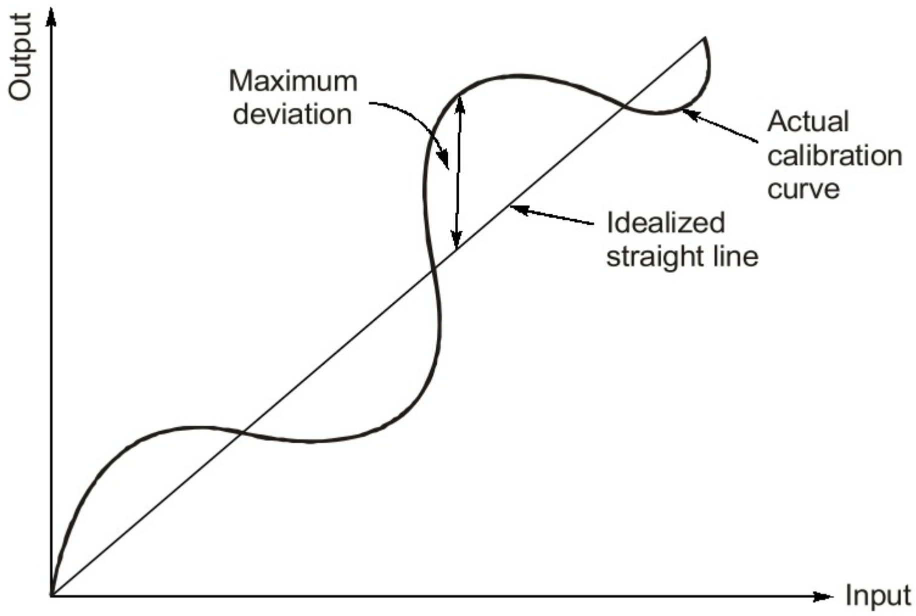

Figure 1.4: Linearity with respect to actual calibration curve and idealized straight line

7. **Dead Time and Dead Zone:**

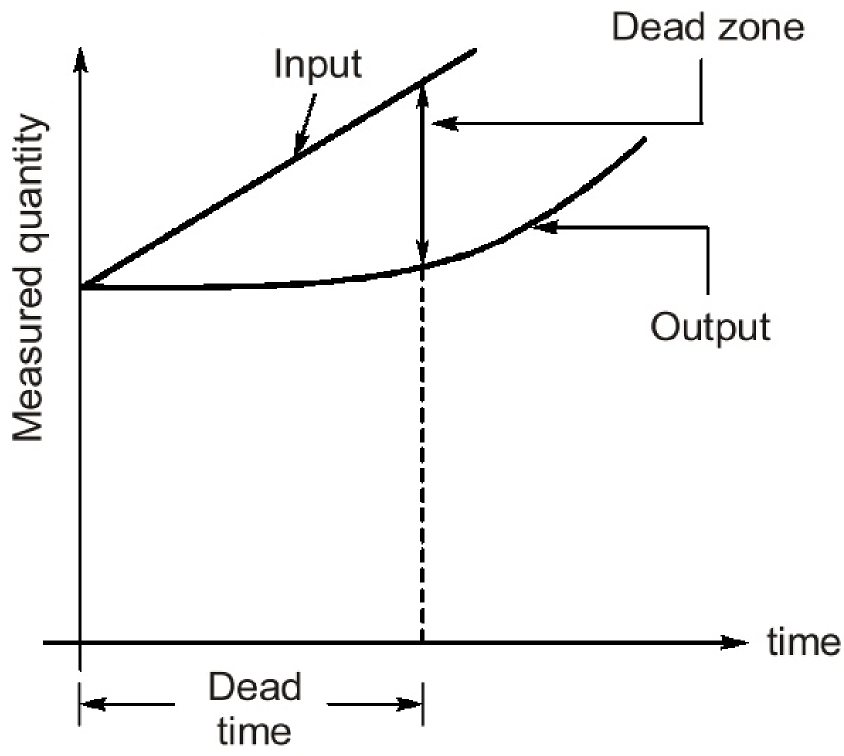

Figure 1.5: Dead Zone and Dead Time

- **Dead Time:** The time required for the measurement to begin to respond to the changes in the measured is known as dead time. It is the time after which the instrument begin to respond after the measured quantity has been changed.
- **Dead Zone:** Dead zone is the largest change of input quantity for which there is no output of the instrument.

8. **Drift:** Drift is an error in measurement (or, deviation from the true value) of the measured quantity caused by a gradual shift in the output of the instrument over time. For example, slowing of a wall clock over time.
9. **Noise:** Noise may be defined as any unwanted signal that does not convey any useful information. There are many sources of noise. Noise may originate at the primary sensing device, in a communication channel, or other intermediate links. The noise may also be produced by indicating elements of the system.

   The common sources of noise are:

   - **Stray electrical and magnetic fields** present in the neighbourhood of the instruments produce extraneous signals which tend to distort the original signal. The effects of these stray fields can be minimized by adequate shielding or relocation of the components of the instruments.
   - **Mechanical shocks and vibrations** are another source of trouble. Their effect can be eliminated by proper mounting devices.

- **Thermal Noise:** Resistors generate thermal agitation noise due to thermal motion of the electrons in their interior. The effect increases with increased temperature of the resistor. This is called Johnson or Thermal noise. The magnitude of this noise voltage is:

$$\begin{aligned}
&V = 2\sqrt{kTR\Delta f} \quad volt \\
&where, \quad k = \text{Boltzmann constant} = 1.38 \times 10^{-28}\ J/K, \\
&\qquad\quad T = \text{Absolute temperature of the resistor in Kelvins,} \\
&\qquad\quad R = \text{Resistance, } \Omega \\
&\qquad\quad \Delta f = \text{Frequency range over which measurement is being made}
\end{aligned} \tag{1.3}$$

10. **Signal to Noise Ratio (SNR):** Signal-to-noise ratio (SNR) is a measure used in science and engineering that compares the level of a desired signal to the level of background noise. The signal-to-noise ratio is typically measured in decibels and can be calculated by using a base 10 logarithm. The exact formula depends on how the signal and noise levels are measured.

    For example, if they're measured in volts, the following formula can be used:

    $$\text{SNR}_{db} = 20\log_{10}\left(\frac{Signal\ Voltage\ (V_s)}{Noise\ Voltage\ (V_n)}\right) \tag{1.4}$$

    Else, if they're measured in watts, the following formula can be used:

    $$\text{SNR}_{db} = 10\log_{10}\left(\frac{Signal\ Power\ (P_s)}{Noise\ Power\ (P_n)}\right) \tag{1.5}$$

    In any measurement system, it is desired to have a large signal-to-noise ratio.

11. **Scale Range and Scale Span:** The Scale Range of an instrument is defined as the difference between the largest and the smallest reading of the instrument. Supposing the highest point of calibration is X_{max} units while the lowest is X_{min} units and that the calibration is continuous between the two points. Then welcan say that the instrument range is between X_{min} and X_{max} (or many a times we say that the instrument range is X_{max}).

    The instrument span is given by : $Span = X_{max}{}^{-}X_{min}$

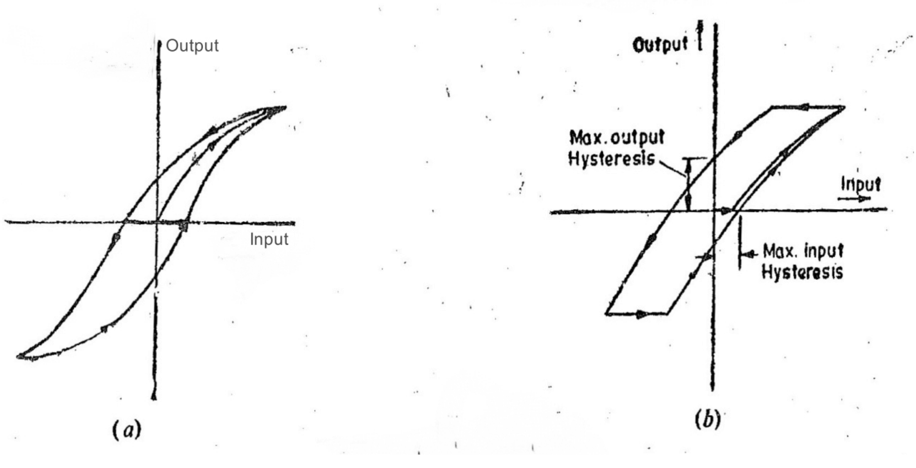

Figure 1.6: Hysteresis effects

12. **Hysteresis:** Hysteresis effects show up in any physical, chemical or electrical phenomenon. Hysteresis is a phenomenon which depicts different output effects when loading and unloading whether it is a mechanical system or an electrical system and for that matter any system. Hysteresis is non-incidence of loading and unloading curves. Hysteresis, in a system, arises due to the fact that all the energy put into the stressed parts when loading is not recoverable upon unloading. This is because the second law of thermodynamics rules out any perfectly reversible process in the world. Hysteresis effect curves are shown in Fig. 1.6

13. **Loading Effects:** The ideal situation in a measurement system is that when an element used for any purpose may be for signal sensing, conditioning, transmission or detection is introduced into the system, the original signal should remain unchanged. This means that the original signal should not be distorted in any form by introduction of any element in the measurement system. However, under practical conditions it has been found that introduction of any element in a system results, invariably, in extraction of energy from the system thereby distorting the original signal. This effect is called the loading effect.

    Consider, for example, a voltmeter has a very high input resistance, so as not to draw any current when connected in parallel.