

Lecture 2 Chapter 2 Basic Theory of Measurement

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Chapter 2

- Learning Outcomes
 - PP. 2-3
- Chapter Contents:
 - General structure of a measuring system
 - Definitions: sensitivity/gain, error, linearity, range and span, percentage of span, accuracy and precision
 - Standards and calibration
 - Dynamic performance

Chapter 2

- Needs for instrumentation:
 - product testing and quality control
 - monitoring in the interest of health, safety or costing
 - part of a control system
 - maintenance and repair
 - research and development
 - analysis and remote sensing (telemetry)

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- Example 1: Level control system



Figure 1 Automatic level control system

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- Basic components of a measuring system

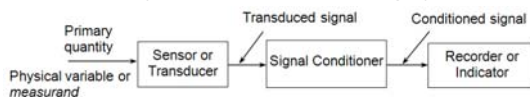


Figure 2 Basic components of a measuring system

- Sensor or transducer
- Signal conditioner
- Recorder/indicator
- Transmitter = sensor/transducer + amplifier + S.C. + recorder: output/s in range of **4mA-20mA** or **0-5V**

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- Simple vs complicated

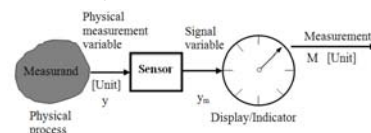


Figure 3 A simple measuring system

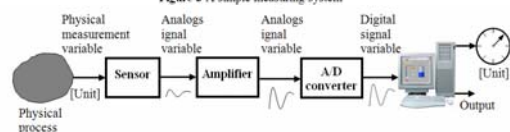


Figure 4 A more complicated measuring system including a digital computer

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- Ideal measuring system: linear, no error
 - Example 2

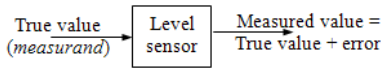


Figure 5 An error in the measured value

- Examine:
 - Static performance
 - Dynamic performance

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- Definitions
 - Sensitivity/gain

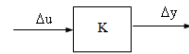


Figure 6 Concept of sensitivity

$$K = \frac{\Delta y}{\Delta u} \quad \begin{array}{l} \Delta y \text{ the change in output} \\ \Delta u \text{ the change in input} \end{array}$$

Unit depends on the instrument or measuring system being considered.

- Definitions:
 - Sensitivity/gain
 - Example 3

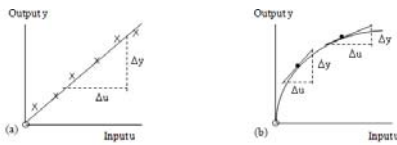


Figure 7 Static sensitivity

- Example 4: overall sensitivity

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- Definitions:
 - Error:
 - Accuracy of a measurement system
 - Difference between a set point and measured variable in a process control system
 - Linearity: associated from a linear input/output relationship

$$\text{Linearity} = \frac{\Delta V}{V_{MAX}} \times 100 (\%) \quad (4)$$

- Definitions:
 - Linearity

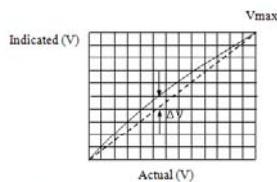


Figure 9 Illustration of determination of normal or end-point linearity

- Example 5 Linearity

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- Definitions:
 - Range and span
 - Percentage of span
 - Accuracy and precision
 - Accuracy

$$\text{Percentage error} = \frac{\text{indicated value} - \text{true value}}{\text{true value}} \times 100\% \quad (5)$$

$$\text{Percentage error} = \frac{\text{indicated value} - \text{true value}}{\text{max scale value}} \times 100\% \quad (6)$$

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- Definitions:
 - Accuracy and Precision
 - Accuracy: Example 6

Example 6 Possible error

A 0 to 10 bar pressure gauge was found to have an error of ± 0.15 bar when calibrated by the manufacturer. Calculate (a) the percentage error of the gauge and (b) the possible error as a percentage of the indicated value when a reading of 2.0 bars was obtained in a test.

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- Definitions:
 - Accuracy and precision
 - Precision

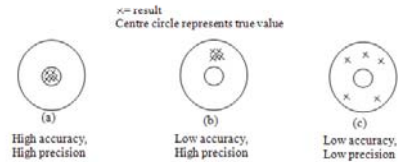


Figure 10 Illustration of difference between accuracy and precision

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- Definitions:
 - Accuracy and Precision
 - Possible and probable errors

Possible and Probable Errors: Consider a measurement involving the use of three devices with maximum possible errors of $\pm a\%$, $\pm b\%$, and $\pm c\%$ respectively. It is unlikely that all three devices will have their maximum errors at the same time; therefore a more practical way of expressing the overall system error is to take the squares root of the sum of the squares of the individual errors, i.e.

$$\text{Root-sum-square error of overall system} = \pm \sqrt{a^2 + b^2 + c^2} \quad (\%) \quad (7)$$

Example 7 Maximum possible error

For a general measuring system where the errors in the transducer, signal conditioner, and recorder are $\pm 2\%$, $\pm 3\%$, and $\pm 4\%$ respectively, calculate the maximum possible system error and the probable or root-sum-square error.

Chapter 2

Standards and Calibration

Standards:

- Requirement for more accurate measurements has evolved as human beings have developed more complex and sophisticated technologies.
- Standards help to make devices manufactured in different places compatible to each other.
- It is important to understand the need for calibration and adjustment of test and production equipment.
- Australian Standards Organization in Sydney, NSW.

Calibration:

- Calibration is the process of adjusting test and production equipment to conform to standards, and verifying (certifying) their compliance to those standards.
- Calibration methods and period are often instructed by manufacturer of the equipment.

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Classification of MSs

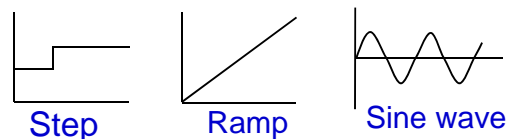
Types of signal: analogue, digital and hybrid (combination of analogue and digital)

Types of physical processes: mechanical, hydraulic, pneumatic, electrical and electronic (microprocessor/computer based)

Trend shows an increase of electronic and computer-based measuring equipment because of rapid speed of response, ease with electrical signals, digital and graphical visualization, and reliability and programmability

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- Dynamic performance/characteristics:
 - To examine how a measuring/control system responds to a changing signal
 - Use test signals: step, ramp, sinewave



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- Dynamic performance/characteristics:

- Zero-order systems: expressed by a linear relationship

$$\frac{y}{u} = K$$

- First-order systems: expressed by a first-order differential equation:

$$\tau \frac{dy}{dt} + y = Ku$$

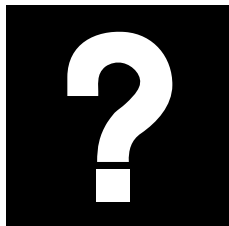
- Second-order systems: expressed by a second-order differential equations:

$$\left(\frac{1}{\omega_n^2} \right) \frac{d^2y}{dt^2} + \frac{2\xi}{\omega_n} \frac{dy}{dt} + 1 = Ku$$

Summary of Chapter 2

- Basic components of a measuring system: sensor/transducer > signal conditioner > Recorder or indicator (amplifier and transmitter)
- Definitions – static performance:
 - Sensitivity/gain
 - Linearity
 - Range and span
 - Percentage of span,
 - Accuracy and precision
- Dynamic performance:
 - Zero-order, first-order, second-order system

Any Questions?



Chapter 2

- **Activity 1** - Data from a dc tachometer test:

	1	2	3	4	5	6	7
Angular velocity (rev/min)	0	500	1000	1500	2000	2500	3000
Output voltage (V)	0	9.1	15.0	23.3	29.9	39.0	47.5

- Plot data on graph of input vs output
- Determine the linearity in the full scale?
 - Least squares to find ideal relationship
 - Calculate the maximum deviation
 - Calculate the linearity.