Lecture 1 – Topic 1
Basic concepts

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Chapter 1 Introduction

• Learning Outcomes:
  – Process control
  – Instrumentation
  – Basic concepts: system, process, open-loop, closed-loop
  – Basic components of a measuring system and a control system
• Reading: Chapter 1

Chapter 1 Introduction

• Process control
  – Process: relationship between physical variables
  – Example 1.1
  \[ q_{out} = K\sqrt{h} \]
  \[ h = \left( \frac{q_{out}}{K} \right)^2 \]

Figure 1.1 The liquid tank system
Chapter 1 Introduction

• Human aided control vs Automatic control

Figure 1.2 Human-aided process control

Figure 1.3 Automatic process control

Chapter 1 Introduction

• Instrumentation
  – Inventory
  – Quantity management
  – Statistical analysis
  – Test, indication etc.
• Example
  – Tank system
• Overview of history

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• Basic concepts:
  – System

Figure 1.4 Concept of a system

• Signals and Variables

Figure 1.5 Classification of a system's signals
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• Example: Variables of a stirred tank

Input variables?
Output variables?

Figure 1.6: The liquid tank system

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• Block diagram
  (functional block diagram)

Figure 1.7: Block representation of a system

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• Open-loop system:
  – No feedback

Figure 1.9: Open-loop level control system
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• Closed-loop system
  – Feedback signal
  – Comparison of measured OP with Desired Value

• An illustration of closed-loop control principle

An illustration of a heat exchanger when under manual control. The controller and process together form a closed loop of control (represented by the heavy dashed line).
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- Basic components & signals: very complicated control system (e.g. spaceship) can be simplified as the following f.b. diagram

![Diagram showing basic components and signals of a feedback control system]

- Feedback level control system

![Diagram showing a feedback level control system]

- Closed-loop system and energy conversion

![Diagram showing a closed-loop control system and energy conversion]
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• Block diagram showing loop and signal processing

![Block diagram showing loop and signal processing](image1)

Figure 1.17 Block diagram of the feedback level control system

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• Flow diagram using standard symbols

![Flow diagram using standard symbols](image2)

Figure 1.18 Flow diagram (using standard symbols) of a feedback process control system

Chapter 1 Introduction

Control Media
- Electrical
- Hydraulic
- Pneumatic
- Thermal
- Mechanical

Most common: combined
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• Case study: Boiler level control system

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• Case study: Ship and autopilot

Figure 1.13 Ship autopilot control system

Chapter 1 Introduction

• Case study: Ship and autopilot

Figure 1.14 Block diagram of ship autopilot control system
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• Stirred tank with level and temperature controls

Chapter 1 Introduction

• James Watt’s Governor (marine governor)
• Identify input and output variables
• Process variable (to be controlled)?
• Manipulated variable?

Chapter 1

• Industrial control classification
  – Motion control
  – Process control
• Process control
  – Batch process
  – Continuous process
• Batch process cookie machine
Chapter 1 Introduction

• Batch process cookie machine

Chapter 1 Introduction

• A pulp and paper operation is a process control application

Chapter 1 Introduction

• Summary:
  – Basic terms: process control, instrumentation
  – Historical overview
  – Functional block diagram
  – Open-loop, closed-loop systems
  – Basic components and signals
  – Examples of control systems
  – Industrial control systems: motion and process
    • Batch process (discrete-state control)
    • Continuous process
Any Questions?
Lecture 1 – Topic 2
Basic Theory of Measurement

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Lecture 1 Topic 2

• Learning Outcomes
  – PP. A2-3
• 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

Lecture 1 Topic 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 (telemetering)
Lecture 1 Topic 2

• Example 1: Level control system

![Figure 1: Automatic level control system](image1)

Lecture 1 Topic 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**

Lecture 1 Topic 2

• Simple vs complicated

![Figure 2: A simple measuring system](image2)

![Figure 3: A more complicated measuring system including a digital computer](image3)
Lecture 1 Topic 2

• Ideal measuring system: linear, no error
  – Example 2

\[
\frac{\text{True value}}{\text{Measured value}} = \text{Ideal sensor}
\]

Figure 5: An error in the measured value

• Examine:
  • Static performance
  • Dynamic performance

Lecture 1 Topic 2

• Definitions
  – Sensitivity/gain

\[
K = \frac{\Delta y}{\Delta u}
\]

\(\Delta y\) the change in output
\(\Delta u\) the change in input

Unit depends on the instrument or measuring system being considered.

Lecture 1 Topic 2

• Definitions:
  – Sensitivity/gain
  – Example 3

– Example 4: overall sensitivity
Lecture 1 Topic 2

• 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

\[
\text{Linearity} = \frac{\Delta T}{T_{\text{meas}}} \times 100 \, \% \tag{4}
\]

Lecture 1 Topic 2

• Definitions:
  – Linearity
    – Example 5 Linearity

Lecture 1 Topic 2

• Definitions:
  – Range and span
  – Percentage of span
  – Accuracy and precision
    • Accuracy

\[
\text{Percentage error} = \frac{\text{indicated value} - \text{true value}}{\text{true value}} \times 100\% \tag{5}
\]

\[
\text{Percentage error} = \frac{\text{indicated value} - \text{true value}}{\text{true value}} \times 100\% \tag{6}
\]
Lecture 1 Topic 2

• 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 ±0.1 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 1.0 bar was obtained in a test.

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• Definitions:
  – Accuracy and precision
  • Precision

![Diagram of accuracy and precision](image)

(a) High accuracy, high precision
(b) Low accuracy, high precision
(c) Low accuracy, low 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 ±2%, ±3%, and ±4%, 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 square root of the sum of the square of the individual errors, i.e.,

$$ \text{Root-sum-square error of overall system} = \sqrt{(2^2 + 3^2 + 4^2)} \% $$

Example 7: Maximum possible error
For a general measuring system where the errors in the transducer, signal conditioner, and recorder are ±2%, ±3%, and ±4% respectively, calculate the maximum possible system error and the probable or non-sum square error.
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.

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.

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.

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

Step Ramp Sine wave
Lecture 1 Topic 2
• 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:
    \[ \left( \frac{1}{\omega_n^2} \right) \frac{d^2y}{dt^2} + 2 \frac{\xi}{\omega_n} \frac{dy}{dt} + 1 = Ku \]

Summary of basic theory of measurement
• 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

Further readings
• Appendix 2 Basic theory of measurement
• Chapter 1 Introduction to process control (Johnson, 2007)
Any Questions?
Learning Outcomes
- Explain meaning of drawing symbols in the sketch of a measuring or control system
- Apply AD standard drawing symbols in documentation of instrumentation and control systems.

Readings:
Appendix 3 Standard Drawing Symbols
Johnson, CD (2006). Process Control Instrumentation Technology. PE. Chapter 1 Introduction to PC – 1.6.4

Further information:
Australia: Australian Standards (AS) – obsolete
America: ANSI/ISA (American National Standard Institute/Instrument Society of America) ANSI Y32.20 (ISA)
ISO: ISO 5659-1, 2 and 4
Europe: German: DIN 28014, UK: BS 1955 and BS 924
AS Standard Drawing Symbols

- Standards Australia’s Website: http://www.standards.com.au
- Australian Standard Graphical Symbols for General Engineering
  - Part 6 (AS 1101.6 - 1989): Process measurement control functions and instrumentation
  - Part 5 (AS 1101.5 – 1989): Piping, ducting and mechanical services for buildings

Application (Quoted - Part 6)

- The symbols given in this standard are intended for adoption by draft-persons and instrument specialists in the preparation and interpretation of technical drawings and diagrams for the purpose of conveying technical information.
- The symbols are intentionally limited to identification on process flow diagrams, piping and instrument diagrams, etc., and do not provide means of illustrating specific instruments or parts thereof.
  
  *(Source: AS 1101.6 – 1989, Standards Australia)*

Contents of AS 1101.6 - 1989

- Section 1 Scope and General
- Section 2 Codes and Abbreviations
- Section 3 Symbols
- Section 4 Examples of use

AutoCAD/P&ID (Piping & Instrument Diagram, Process & Instrument Diagram) Software
Standard drawing symbols

1.1 General instrument or functional symbols

Standard Drawing Symbols

1.1 GENERAL INSTRUMENT SYMBOLS
1.2 TAG NUMBERS
1.3 INSTRUMENT LINE SYMBOLS
1.4 IDENTIFYING SIGNAL CONNECTING POINTS
1.5 CORRECTING ELEMENTS
1.6 ACTUATING ELEMENTS
1.7 FLOW ELEMENTS
1.8 LEVEL INSTRUMENT CONNECTIONS
1.9 PRESSURE REGULATORS
1.10 SIGNAL MODIFIERS

Examples
- Example 1 (p.2)
- Example 2 (p. 10)
- Example 3 (p. 10)
- Example 4 (p. 10-11)
- Example 5 (p. 11)
More examples

Example 6

Flowrate indicator, locally mounted

Flowrate recorder, locally mounted

Example 7: Heat exchangers

Example 8

- Temperature signal to computer: Temperature signal to computer (input number 211) with temperature recording and high alarm by computer normally accessible to the operator

Level indicator, locally mounted, point of measurement inside vessel
**Example 9**

Level indicator, locally mounted, point of measurement outside vessel

- Flow recording and indication in control room: flow indicator in control room with retransmission to computer for recording and control.

**Example 10**

Illustration of a P and ID for a mixing station.

HCV = hand/manual control valve
Flow control
Temperature control
PSV = pressure safe valve

**Activity 2**

Draw a flow diagram

Tank 1 (A1)

Tank 2 (A2)

Level transmitter

Level controller

Valve 1

Valve 2
Activity 2

- Describe the following control system

![Control System Diagram]

Activity 3

- Describe the following systems (a, b, c)

![Control System Diagram]

Activity 4

- Using the AS symbols draw a flow diagram for the following control system

![Flow Diagram]

Inlet flowrate

Outlet flowrate
Summary of AS Drawing Symbols

- Identifying Code Letters
- Instrument Line Symbols
- Identifying Signal Connecting Points
- Correcting Elements
- Actuating Elements
- Flow Elements
- Level Instrument Connections
- Pressure Regulators
- Signal Modifiers

References

- http://www.roymech.co.uk/Useful_Tables/Drawing/Drawing.html

Any Questions?