Chapter 7
Introduction to Instrumentation

Control Automático

3º Curso. Ing. Industrial
Escuela Técnica Superior de Ingenieros
Universidad de Sevilla
Summary

- **Introduction**
- Basic concepts
- Properties of measurement devices
- Signals transmission.
- Process and instrumentation diagrams (P & I). Conventional industrial control schemes
Introduction

Close-loop operation

Controller → Process → Output

Reference → Act → Measure
Components

- Measurement devices
- Actuators
- Communication links
- Controllers

Manipulated variable

Controlled variable

Controller → Actuator → Process → Sensor/Transmitter

Measured signals
Summary

- Introduction

- **Basic concepts**
  - Properties of measurement devices
  - Signals transmission.
  - Process and instrumentation diagrams (P & I). Conventional industrial control schemes
**Basic concepts**

- **Measurement of a magnitude**: is the estimation of the magnitude of some attribute of an object, such as its length or weight, relative to a unit of measurement. It can be a direct measurement or indirect measurement.
Measurement of a magnitude

- Primary element (sensor): In contact with process.
- Transducer: converts one type of energy to another for various purposes including measurement or information transfer.
- Transmitter:
  - Converts signal
  - Filter and amplification of measurement signal
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Properties of a measurement instrument

- **Range**: Set of values of the process attribute that can be measured by the sensor. For example 50°C-150°C.
- **Reach**: Difference between the upper and lower limits of the range. For example, 100°C.
- **Margin of error**: Difference between the measurement obtained from the sensor and the real value of the process attribute. It can be static or dynamic.
- **Accuracy**: Maximum margin of error under nominal operating conditions.
  - Absolute value
  - % Reach
  - % Upper range limit
  - % Measured value
  - % Full scale
- **Dead-zone**: Range of variation of the process attribute that does not produce a change on the measured variable. It is related for example to the static friction. (%Reach).

- **Repetitivity**: The sensor is able to obtain the same measurement for the same process attribute (%Reach).

- **Sensitivity**: Relation between the increment of the measured signal and the increment of the process attribute. (slope).
Properties of measurement instrument (III)

- **Resolution:** Minimum increment in the process attribute that generates a change in the measurement signal. It is related to the Dead-zone and Sensitivity (Absolute or %Reach).

- **Hysteresis:** Maximum value of the difference between the measurements obtained in increasing and decreasing sense. (%Reach)

- **Linearity:** Maximum linear approximation error.

![Diagram showing Resolution, Hysteresis, and Linearity](image)
Properties of a measurement instrument (IV)

- **Systematic error**: Constant error that affects the measurement. It can be corrected by calibrating the sensor.
- **Measuring time**: Time needed to obtain a precise measurement.
- **Reliability**: Mean time between measurement faults.
- **Time of operation**: Approximate lifetime of the sensor.
- **Operating conditions**: External conditions (temperature, pressure...) that guarantee a proper functioning of the sensor.
- **Dynamic properties** of the sensor.
How to select a sensor?

- Operating conditions
  - Media: liquid, gas, corrosive, physical properties (viscosity, Reynolds, etc)
  - Temperature, pressure, etc
- Range of measurement
- Measurement errors
  - Tolerance
  - Dynamic error (Time constant * gradient)
  - Systematic error and drift
- Resolution
Example

Assume we want to measure the temperature of a liquid that can vary from 200 to 350 ºC, and we have the following set of sensors:

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Range (ºC)</th>
<th>Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>[100, 400]</td>
<td>2.5 ºC</td>
</tr>
<tr>
<td>B</td>
<td>[100, 500]</td>
<td>1% reach</td>
</tr>
<tr>
<td>C</td>
<td>[150, 450]</td>
<td>0.75% upper limit</td>
</tr>
<tr>
<td>D</td>
<td>[0, 400]</td>
<td>1% measurement</td>
</tr>
<tr>
<td>E</td>
<td>[100, 500]</td>
<td>1.5% full scale</td>
</tr>
</tbody>
</table>

Which one provides the lowest absolute tolerance?
Classification of measurement instruments

- **Energy:**
  - Passive: Use the energy from the process.
  - Active: Use of an external energy source.

- **Measurement value:**
  - Analog: Measurement takes value on an infinite set of values.
  - Digital: Measurement takes value on a finite set of values.

- **Presentation of the information:**
  - Blind: No information is visible.
  - Indicators: The measurement is visible to the operator.
  - Recorders: The measurement is recorded by the instrument.

- **Function:**
  - Primary element: In contact with the process.
  - Transmitter: Signal transmission.
  - Transducer: Converts one type of energy to another for various purposes including measurement or information transfer.
  - Controller: Local or remote
  - Actuators
Summary

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- **Signals transmission.**
- Process and instrumentation diagrams (P & I). Conventional industrial control schemes
Signal transmission

- Transmission medium:
  - Pneumatic
  - Electric
  - Radio
  - Optic fiber

- Codification:
  - Analog/Digital
  - Amplitude or frequency modulation
  - Pulse modulation
Pneumatic medium

- Physical magnitude: Air pressure
- Range: 0.2-1 Kg/cm$^2$ (3-15 psig)
  - Minimum pressure of the link 0.2 Kg/cm$^2$
    - Allows one to detect link failures
    - Improves transmission speed

Advantages:
- Fail-safe link under hard operating conditions
- Not affected by electromagnetic disturbances
- Allows to directly control pneumatic actuators (valves)
Pneumatic medium

- **Disadvantages:**
  - The air is compressible
    - Slow data transmission. Long delays.
    - Can only be applied to short distance links.
  - High sensitivity to air conditions
    - Humidity and dirt
    - Need filters
  - Need a compressor to operate

- **Hydraulic medium**
  - Physical magnitude: Oil pressure
  - Oil is not compressible: Increases speed and power.
  - More expensive and dangerous (oil is inflammable)
Electric medium

- Physical magnitude:
  - Voltage: 1 – 5 V, 0 – 10 V, 0-24 V
    - Voltage drops in wires may introduce errors in data
  - Intensity: 4 – 20 mA
    - Not affected by voltage drops

- Advantages
  - High speed
  - Low cost
  - Controls electronics devices

- Disadvantages
  - High sensitivity to electromagnetic disturbances
    - Interference Protection
Other transmission mediums

- Wireless
  - Long distance radio-links
  - Short distance wireless networks

- Optic fiber
  - Not affected by electromagnetic disturbances
  - High bandwidth
  - Low weight and size
  - High cost

- Usual in Process industry
  - Digital codification
    - Increases signal to noise ratio
  - Electric transmission
    - High amount of electronic components
  - Pneumatic transmission
    - Valve actuation
Modern instrumentation

- Include microcontrollers
- Increased functionality
  - Auto-calibration, auto-diagnosis
  - Network communication

Fieldbus or field bus is an industrial computer network for real-time distributed control.
- Advanced protocols (bandwidth, safety,...)
- Profibus, CAN, etc.

DISTRIBUTED CONTROL
http://en.wikipedia.org/wiki/Fieldbus
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Process and instrumentation diagrams (PI&D diagrams)

Recalentador
Process and instrumentation diagrams (PI&D diagrams)

- Process and instrumentation diagrams are a family of functional one-line diagrams showing hull, mechanical and electrical (HM&E) systems like piping, and cable block diagrams.
- They show the interconnection of process equipment and the instrumentation used to control the process.
- They are the primary schematic drawings used for laying out a process control installation in a factory or plant. In the process industry, a standard set of symbols may be used to prepare drawings of processes, for instance the instrument symbols used may be based on Instrumentation, Systems, and Automation Society (ISA) Standard S5.1.

![Diagram of process and instrumentation](image-url)
### Process and instrumentation diagrams (PI&D diagrams)

(ISA) Standard S5.1

<table>
<thead>
<tr>
<th>1st Letter</th>
<th>2nd Letter</th>
<th>Other letters</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Concentration</td>
<td>Alarm signal</td>
</tr>
<tr>
<td>C</td>
<td>Conductivity</td>
<td>Control signal</td>
</tr>
<tr>
<td>D</td>
<td>Density</td>
<td>Differential</td>
</tr>
<tr>
<td>E</td>
<td>Voltage</td>
<td>Primary element</td>
</tr>
<tr>
<td>F</td>
<td>Flow</td>
<td>Relative</td>
</tr>
<tr>
<td>H</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Intensity</td>
<td>Indicator</td>
</tr>
<tr>
<td>K</td>
<td>Time</td>
<td>Control station</td>
</tr>
<tr>
<td>L</td>
<td>Level</td>
<td>Low</td>
</tr>
<tr>
<td>M</td>
<td>Humidity</td>
<td>Medium</td>
</tr>
<tr>
<td>P</td>
<td>Pressure</td>
<td>Point</td>
</tr>
<tr>
<td>R</td>
<td>Radioactivity</td>
<td>Register</td>
</tr>
<tr>
<td>S</td>
<td>Speed</td>
<td>Security</td>
</tr>
<tr>
<td>T</td>
<td>Temperature</td>
<td>Interrupter</td>
</tr>
<tr>
<td>V</td>
<td>Viscosity</td>
<td>Transmission</td>
</tr>
<tr>
<td>W</td>
<td>Weight</td>
<td>Valve</td>
</tr>
<tr>
<td>Y</td>
<td></td>
<td>Math module</td>
</tr>
<tr>
<td>Z</td>
<td>Position</td>
<td>Servo</td>
</tr>
</tbody>
</table>

### Loop Suffix and Function Identifier

- **First letter**: Function identifier
- **Secondary letters**: Loop identifier
- **Suffix**: Loop identifier

**Example**: P IT 107 A
Examples of instruments

- PDT
- LRC
- PIC
- DT
- FY
- FFC
- ST
- TDT
Process and instrumentation diagrams (PI&D diagrams)

- LRC 128
- PT 014
- Connection to process
- Pneumatic signal
- Instrument in process
- Accessible to the operator
- Not accessible to the operator

- LR C 128
- Digital instrument
- PLC
- Logic controller
- Accessible to the operator

Medium
P&I diagrams examples

Figura 2.14. Destilador simple con tres lazos de control.
P&I diagrams examples

Cascade Control system
P&I diagrams examples

Feed-forward control
P&I diagrams examples

Figura 11.18. Control de nivel en un calderín.
P&I diagrams examples

<table>
<thead>
<tr>
<th>Salida PC</th>
<th>Abertura válvula</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-50% (3-9 psig)</td>
<td>0-100%</td>
</tr>
<tr>
<td>50-100% (9-15 psig)</td>
<td>0-100%</td>
</tr>
</tbody>
</table>

Figura 11.25. Control de gama partida en una columna de destilación.
Esquema de un reactor

- Lazo de Control de Nivel
- Lazo de Control de Caudal
- Lazo de Control de Temperatura
- Lazo de Control de Concentración
- Lazo de Control de Caudal
- Alarma de seguridad de caudal alto y bajo
- Alarma de seguridad por temperatura alta
- Alarma de seguridad por presión alta
- Control secuencial de seguridad