Sensor/Transmitter and Filtering

Dr. Ir. Yeffry Handoko Putra, M.T

Session Outlines & Objectives

Outlines

- Common sensor type used to measure physical quantities in process control
- Static and dynamics properties of sensor/transmitter

Objectives

- Know the properties of sensor/transmitter affecting process control performances
- Know the sensor/transmitter used in process control

Measurement System & Devices

- A measurement system is any set of interconnected parts that include one or more measurement devices
- Measurement devices perform a complete measuring function, from initial detection to final indication
- Measurement devices such as sensors, or primary elements, measure the variable

Sensor, Transmitter & Transducer

- Sensor
  - Primary sensing element
  - Converts the physical quantity to signal that can be recognized by other component such as display, transmitter
- Transmitter
  - Generates an industrial standard signal from the sensor output
  - Standard instrumentation signal levels
    - Voltage: 1 – 5 VDC, 0 – 5 VDC, -10 – +10 VDC, etc.
    - Current: 4 – 20 mA
    - Pneumatic: 3 – 15 psig
- Transducer
  - Changes one instrument signal value to another instrument signal value
  - Signal conversion
  - I/P or P/I transducer: current-to-pressure or vice versa
  - P/E or E/P: pressure-to-voltage or vice versa

Sensor Types

- Flow rate
  - Orifice, venturi, magnetic, ultrasonic, Coriolis effect
- Pressure
  - Bellows, bourdon tube, diaphragm
- Liquid level
  - Displacement, float, differential pressure
- Temperature
  - Thermocouple, RTD, thermistor
- pH
  - pH electrode
- Viscosity
  - Pressure drop across venturi or vane deflection
- Composition
  - Density, conductivity, IR, UV

Primary Measuring Element Selection & Characteristics

- Transmitter Gain
- Range
  - Span & Zero
- Response time
- Accuracy
- Precision
- Sensitivity
- Dead band
- Costs
- Installation problems

Transmitter Gain, Range, Span & Zero

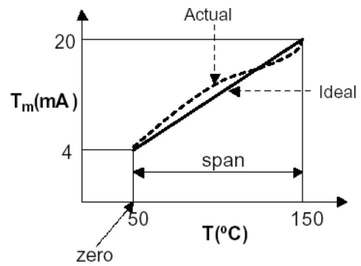
- Transmitter Gain (K_T): adjustable
  - Amplification ratio: (output span) / (input span)
- Span and Zero: adjustable
  - Span: magnitude of range of transmitter signal
  - Zero: lower limit of transmitter signal

Ex.: Temperature transmitter

$$K_T = \frac{(20\ \text{mA} - 4\ \text{mA})}{(150\ ^oC - 50\ ^oC)} = 0.16\ [\text{mA}/^oC]$$

Span = 100 ^{o}C

Zero = 50 ^{o}C

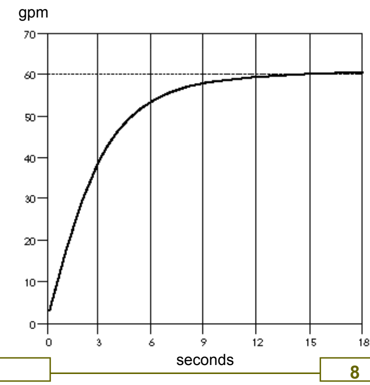


Response Time

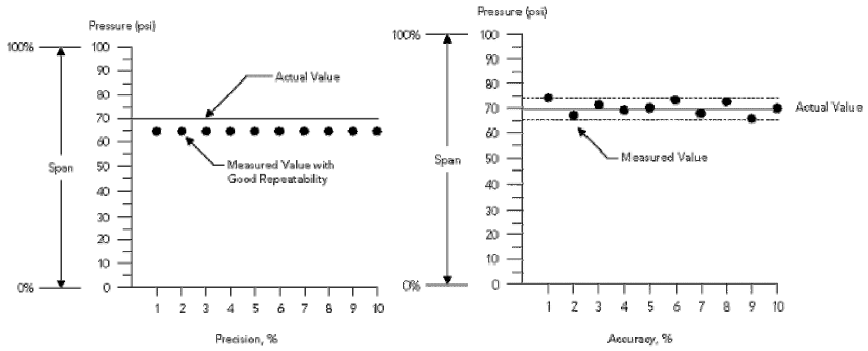
- Response time is the amount of time required for a sensor to respond completely to a change in input
- The response time of the control loop is the combination of the responses of all the parts, including the sensor

Example:

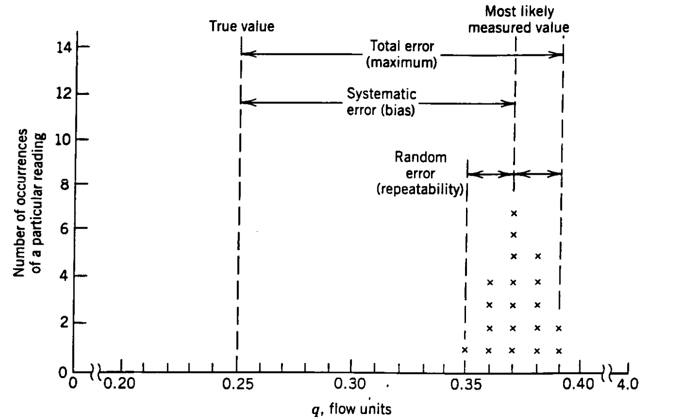
	Calculation	Sensor Measurement
After one time constant, the sensor registers 63.2% of the change	0.632 x 60 =	37.92 gpm
After two time constant, the sensor register 63.2% of the remaining difference	60 – 37.92 = 22.08 0.632 x 22.08 = 13.95 13.95 + 37.92 =	51.87
After three time constant, the sensor register 63.2% of the remaining difference	22.08 – 13.95 = 8.13 0.632 x 8.13 = 5.14 5.14 + 51.87 =	57.01



Precision vs. Accuracy



Error Types



Analysis of types of error for a flow instrument whose range is 0 to 4 flow units.

Sensitivity, Dead band & Dead time

- The sensitivity of the sensor is a measurement of how small a change in the process variable it can actually measure
  - The greater the sensitivity, the greater the sensor's reaction to an input stimulus
- Dead band is the "unresponsiveness" of the sensor
  - It describes how much change to the process is required before the sensor actually responds to it or even detects it
  - The term sensitivity has frequently been used to denote dead band, but the terms are not truly interchangeable
  - Sensitivity refers to the reaction of the sensor
- Dead time applies to the time it takes for the sensor to react

Costs & Installation Problems

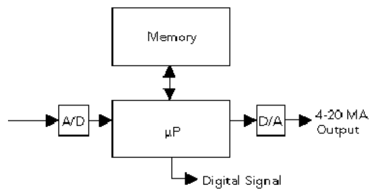
- Cost:
  - The initial purchase
  - Maintaining the instrument
- Installation problems:
  - Can include special problems in the environment such as humidity, vibration, temperature, or dust
  - Can also be anything that causes a problem to the devices installed, such as, installing the device in a difficult to reach location

Signal Transmission Types

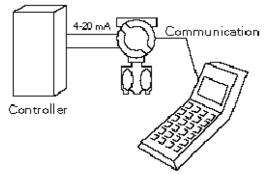
- Electronic
- Pneumatic
- Optical
- Radio
- Hydraulic

Smart Transmitters

- They can convert analog signals to digital signals (A/D), making communication swift and easy and can even send both analog and digital signals at the same time as denoted by D/A



- Features:
  - Configuration
  - Re-ranging
  - Signal conditioning
  - Self-diagnosis



Flow Measurement Types

- Differential pressure
  - Includes orifices, venturi, flow nozzles, pitot tubes
- Mechanical (positive) displacement
  - Includes turbine, nutating-disk, and rotating vane
- Velocity
  - Includes vortex shedding, electromagnetic, and ultrasonic
- Mass meters
  - Coriolis and thermal

Differential Pressure Meters

- The use of differential pressure as an inferred measurement of a liquid's rate of flow

$$\Delta P \propto F^2 \rightarrow F \propto \sqrt{\Delta P}$$

- Have a primary and secondary element
  - The primary element creates the differential pressure in the pipe
  - The secondary element measures the differential pressure and provides the signal or read-out that is converted to the actual flow value
- Over 50 percent of all liquid flow measurement applications use this type of unit

Differential Pressure Primary Elements

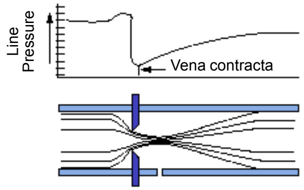


Fig. Orifice

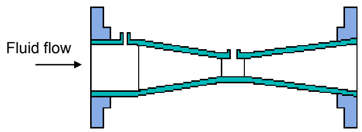


Fig. Venturi

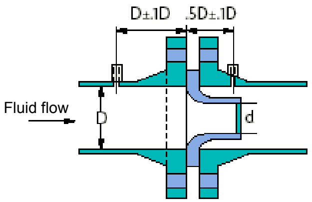


Fig. Flow nozzle

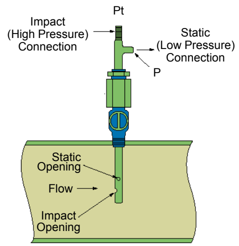


Fig. Pitot tube

Mechanical Displacement Meters

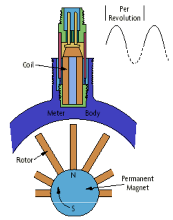


Fig. Turbine meter

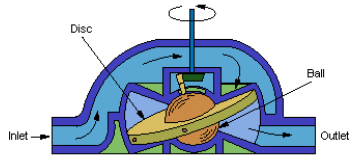


Fig. Nutating disc

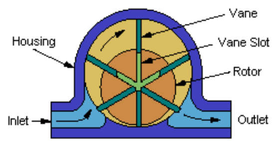


Fig. Rotating vane

Velocity Meters

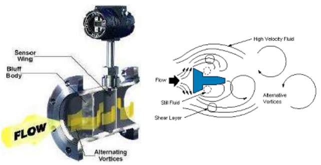


Fig. Vortex flow meter & shedding

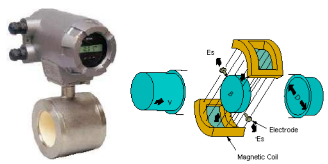


Fig. Magnetic flowmeter

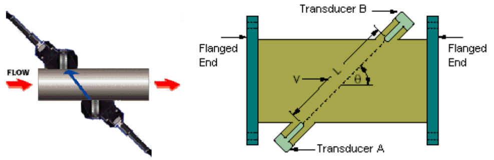


Fig. Ultrasonic flowmeter

Mass Meters (1)

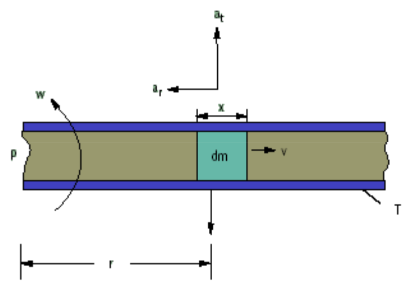


Fig. Coriolis meter principles

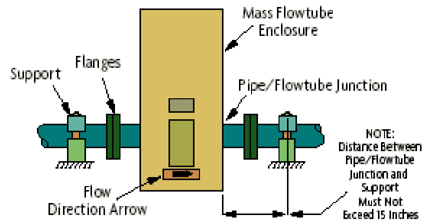


Fig. Installation of coriolis meter

Mass Meters (2)

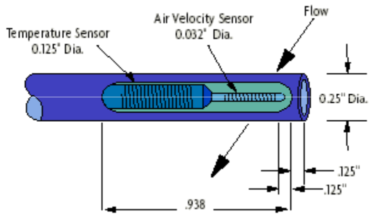


Fig. Probe configuration of thermal meter

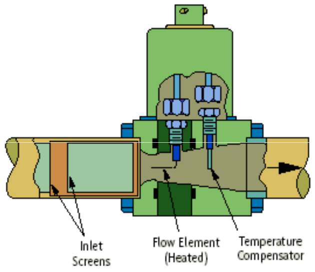
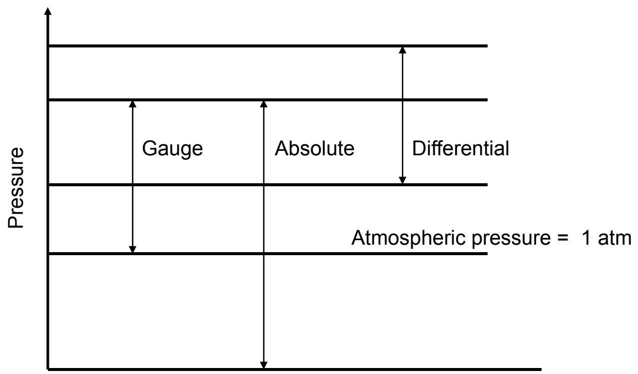


Fig. Venturi insertion of thermal meter

Pressure Measurements

- Depending on the reference pressure used, they could indicate:
  1. Absolute
  2. Gauge, and
  3. Differential pressure
- Based on mechanical principles, i.e. deformation based on force:
  1. Bourdon
  2. Bellow
  3. Diaphragm
- Based on electrical principles; some convert a deformation to a change in electrical property, others a force to an electrical property
  1. Capacitive
  2. Strain gauge
  3. Piezoelectric

Absolute, Gauge & Differential Pressure



Bourdon, Bellow, & Diaphragm

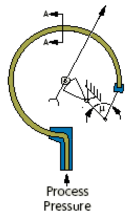


Fig. Bourdon

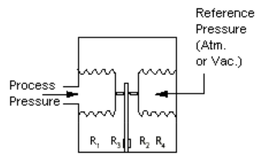


Fig. Bellow

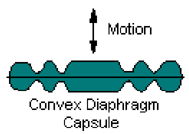


Fig. Diaphragm

Capacitive, Strain Gauge & Piezoelectric

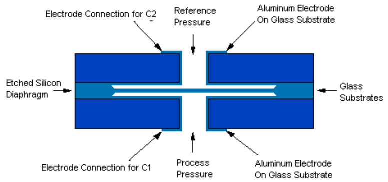


Fig. Capacitance-based pressure cell

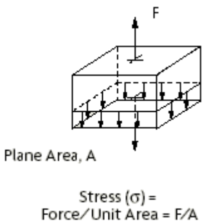


Fig. Strain gauge

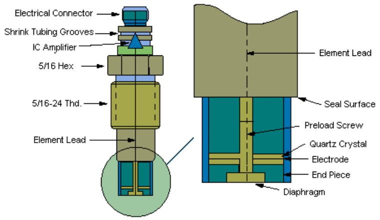


Fig. Piezoelectric

Temperature Measurement

1. **Contact Temperature Sensors**
   - Thermocouple, Resistance Temperature Dependent (RTD), Thermistor
2. **Non-contact Temperature Sensors and Thermography**
   - Infrared Thermometer, Thermal Imagers

Contact Temperature Sensors

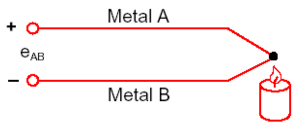


Fig. Thermocouple

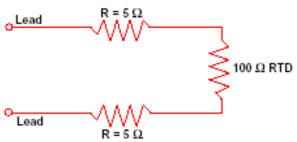


Fig. RTD

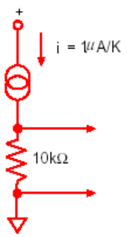


Fig. Thermistor

Temperature Sensor Attributes			
Criteria	**Thermocouple**	**RTD**	**Thermistor**
Cost-OEM Quality	Low	High	Low
Temperature Range	Very wide -450°F +4200°F	Wide -400°F +1200°F	Shot to medium -100°F +500°F
Interchangeability	Good	Excellent	Poor to fair
Long-term Stability	Poor to fair	Good	Poor
Accuracy	Medium	High	Medium
Repeatability	Poor to fair	Excellent	Fair to good
Sensitivity (output)	Low	Medium	Very high
Response	Medium to fast	Medium	Medium to fast
Linearity	Fair	Good	Poor
Self Heating	No	Very low to low	High
Point (end) Sensitive	Excellent	Fair	Good
Lead Effect	High	Medium	Low
Size/Packaging	Small to large	Medium to small	Small to medium

Non-contact Temperature Sensors

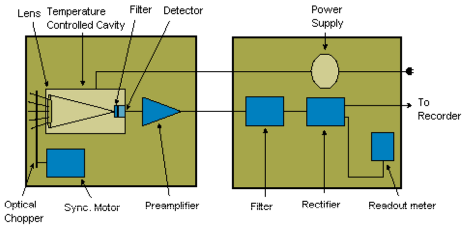


Fig. Pyrometer

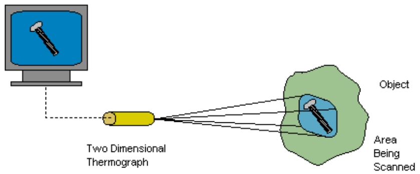


Fig. Thermal Imaging

Temperature Sensor Advantages/Disadvantages		
Sensor	**Advantages**	**Disadvantages**
Thermocouple	•Self-powered •Simple •Rugged •Inexpensive •Wide variety •Wide range	•Non-linear •Low voltage •Reference required •Least stable •Least sensitive
RTD	•Most stable •Most accurate •More linear than thermocouple	•Expensive •Current source required •Small •Low absolute resistance •Self heating
Thermistor	•High output •Fast •Two-wire ohms measurement	•Non-linear •Limited range •Fragile •Current source required •Self heating
Infrared	•No contact required •Very fast response time •Good stability over time •High repeatability •No oxidation/corrosion to affect sensor	•High initial cost •More complex/support electronics •Spot size restricts application •Emissivity variations affect readings •Accuracy affected by dust, smoke and background radiation

Level Measurement

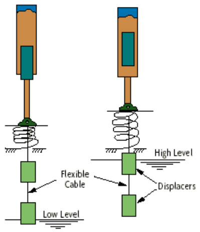


Fig. Displacement

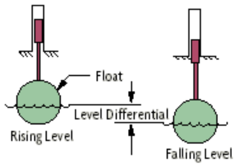


Fig. Float

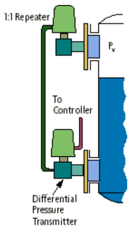


Fig. Differential Pressure

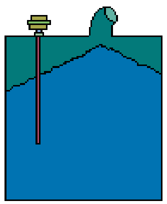
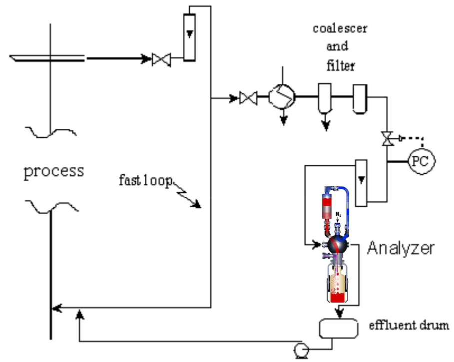


Fig. Capacitance

Analyzer

- Any sensor that measures a physical property of the process material, such as purity (e.g., mole % of various components), a basic physical property (e.g., density or viscosity), or an indication of product quality demanded by the customers in the final use of the material (e.g., gasoline octane or fuel heating value)



The Control Relevant Aspects of Sensors

- Accuracy
- Good reproducibility
- Fast dynamic response
- Reliable

Filtering (1)

- Noise source
  - Process nature (turbulence, vibration, oscillation)
  - Various noise source from environment
  - Power line, electromagnetic force
- Removing noise
  - Analog filter
    - First order filter

$$\tau_f \frac{dy_f}{dt} + y_f = y$$

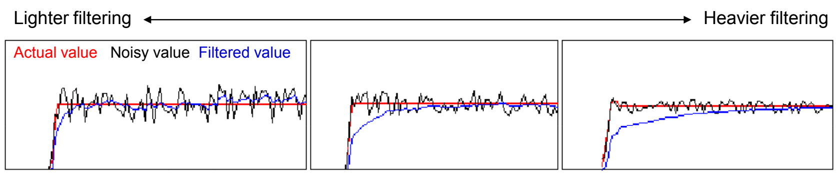
y ← Measured output

τ_f ← Filter time constant

y_f ← Filtered output

Filtering (2)

- As τ_f increases, heavier filter is applied



Session Summary

- Sensor/transmitter is used to obtain the information from process
- Each sensor/transmitter has static and dynamic properties to be evaluated in order to obtain the good informations for control purpose