Lesson 10: Sensor and Transducer Electrical Characteristics

ET 438b Sequential Control and Data Acquisition
Department of Technology

Learning Objectives

After this presentation you will be able to:

- Explain the key characteristics of analog sensors and transducers.
- Compute the sensitivity, resolution, span and linearity of sensors and transducers
- Determine the dynamic parameters of a transducer or sensor
- Develop and utilize calibration curves for sensors and transducers

Measuring Instrument Characteristics

Static Characteristics

Error = (measured value) – (ideal value)

Ways of expressing instrument error

1.) In terms of measured variable
Example (+ 1 C, -2 C)
2.) Percent of span
Example (0.5% of span)
3.) Percent of actual output
Example (+- 1% of 100 C)

Measuring Instrument Characteristics

The difference between the upper and lower measurement limits of an instrument define the device's span

Span = (upper range limit) – (lower range limit)

Resolution is the smallest discernible increment of output. Average resolution is given by:

$$\text{Average Resolution (\%)} = \frac{100}{\text{N}}$$

Where: N = total number of steps in span
100 = normalized span (%)

Instrument Characteristics

Example: A tachogenerator (device used to measure speed) gives an output that is proportional to speed. Its ideal rating is 5 V/ 1000 rpm over a range of 0-5000 rpm with an accuracy of 0.5% of full scale (span) Find the ideal value of speed when the output is 21 V. Also find the speed range that the measurement can be expected to be in due to the measurement error.

Example Solution

Determine the maximum output voltage

$$V_{max} = n_{max} \cdot G$$

Where: V_{max} = maximum output voltage
n_{max} = maximum speed
G = tachogenerator sensitivity (V/rpm)

Find V_{max}

$$n_{max} = 5000\text{ rpm}$$
$$G = 5\text{ V/1000 rpm}$$
$$V_{max} = (5000\text{ rpm})\cdot(5\text{ V/1000 rpm}) = 25\text{ V}$$

Find ideal value of speed

$$V_{out} = 21\text{ V}$$
$$n_{ideal} = \frac{V_{out}}{G} = \frac{21\text{ V}}{(5\text{ V/1000 rpm})} = \frac{21\text{ V}}{0.005\text{ V/rpm}} = 4200\text{ rpm}$$

Ideal speed

Accuracy +-0.5% of full scale
+-0.005(5000) = +-25 rpm

Speed range
4200+25 = 4225 rpm
4200-25 = 4175 rpm

Span, Resolution, and Sensitivity

A 1200 turn wire-wound potentiometer measures shaft position over a range from -120 to +120 degrees. The output range is 0-20 volts. Find the span, the sensitivity in volts/degree, the average resolution in volts and percent of span.

$$\text{span} = (120^\circ - (-120^\circ)) = 240^\circ$$

$$\text{sensitivity} = \frac{V_{max} - V_{min}}{\text{span}} = \frac{20-0}{240^\circ} = 0.0833\ \text{V/degree}$$

$$\text{resolution}(\%) = \frac{100\%}{1200} = 0.0833\,\%\ \text{of span}$$

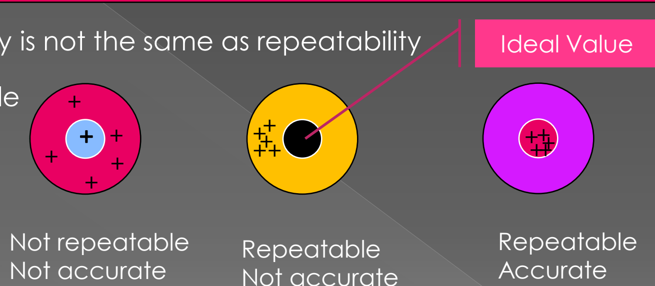
$$\text{resolution(V)} = \frac{20\ \text{V}}{1200} = 0.01667\ \text{V}$$

Repeatability and Accuracy

Repeatability - measurement of dispersion of a number of measurements (standard deviation)

Accuracy is not the same as repeatability

Example



Reproducibility - maximum difference between a number of measurements taken with the same input over a time interval

Includes hysteresis, dead band, drift and repeatability

Calibration Curves

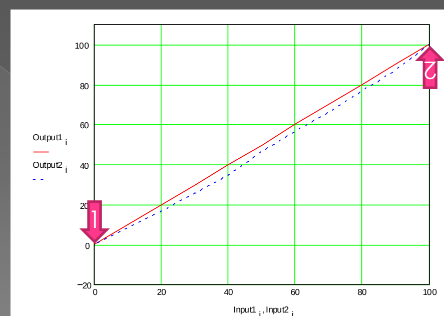
Determining the accuracy of a measuring instrument is called calibration. Measure output for full range of input variable. Input could be increased then decreased to find hysteresis. Repeat input to determine instrument repeatability.

$Input1_i :=$	$Output1_i :=$
0	-0.06
10	9.80
20	19.69
30	29.65
40	39.70
50	49.85
60	60.2
70	70.16
80	80.21
90	90.19
100	100.08

Increasing Input Measurements

$Input2_i :=$	$Output2_i :=$
100	100.08
90	87.24
80	77.26
70	66.22
60	57.12
50	46.80
40	34.70
30	25.73
20	16.75
10	8.83
0	-0.01

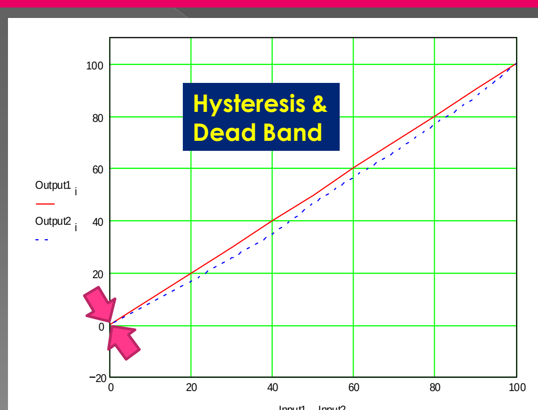
Decreasing Input Measurements



Plot the data

Calibration Curve Characteristics

Hysteresis and Dead Band
Difference between upscale and downscale tests called hysteresis and dead band



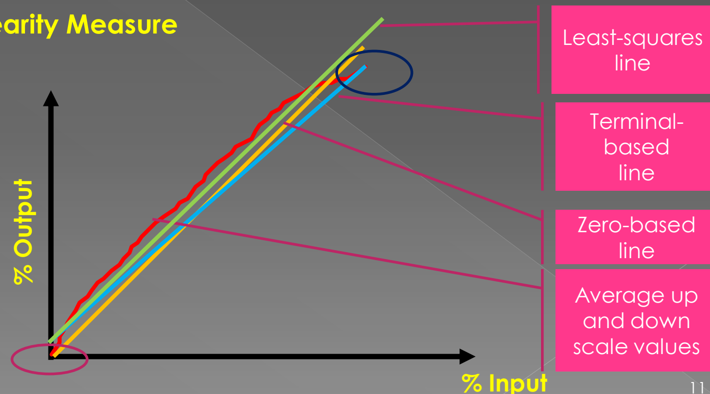
Calibration Curve Characteristics

Linearity

Ideal instruments produce perfectly straight calibration curves. Linearity is closeness of the actual calibration curve to the ideal line.

Types of Linearity Measure

Least-squares minimizes the distance between all data points



Dynamic Characteristics

First order instrument response

First order model transfer function

$$\frac{C_m(s)}{C(s)} = \frac{G}{1+\tau s}$$

Where : $C_m(s)$ = instrument output
$C(s)$ = instrument input
G = steady-state gain of instrument
τ = instrument time constant

For step input

$$C(s) = \frac{K}{s}$$

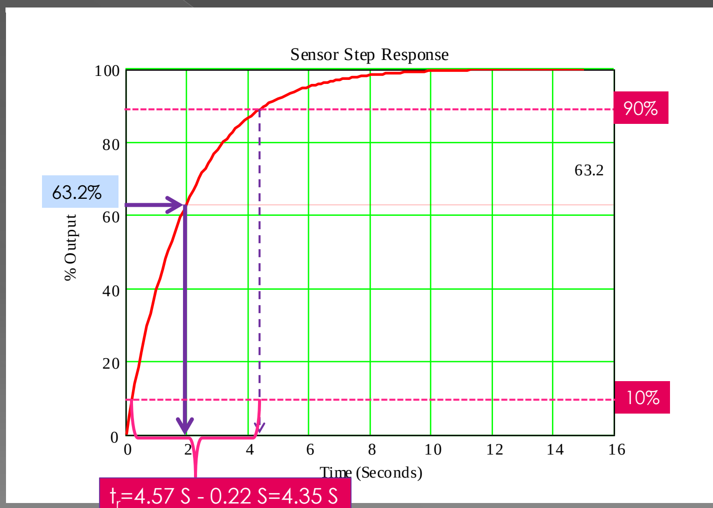
with K = step input size (1 for unit step)

Step response

$$C_m(s) = \frac{KG}{s(1+\tau s)}$$

Exponentially increasing function time constant

Dynamic Characteristics



Time required to reach 63.2% of final value is time constant, τ
τ=2

Time required to go from 10% to 90% of final value is the rise time, t_r

$t_{90} - t_{10} = t_r$

t_{90} = 4.57 S

t_{10} = 0.22 S

Dynamic Characteristics

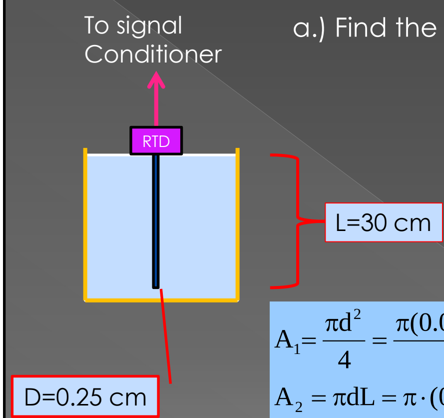
Typical Instrument time constants

Bare thermocouple in air (35 Sec)
Bare thermocouple in liquid (10 Sec)

Thermal time constant determined by thermal resistance R_T and thermal capacitance C_T. $\tau = R_T \cdot C_T$

Example: A Resistance Temperature Detector (RTD) is made of pure Platinum. It is 30.5 cm long and has a diameter of 0.25 cm. The RTD will operate without a protective well. Its outside film coefficient is estimated to be 25 W/m^2-K. Compute: a.) the total thermal resistance of the RTD, b.) the total thermal capacitance of the RTD, c.) The RTD thermal time constant.

Example Solution



a.) Find the surface area of the probe to find R_T

$$d = (0.25\ \text{cm})\cdot\left(\frac{1\ \text{m}}{100\ \text{cm}}\right) = 0.0025\ \text{m}$$

$$L = (30.5\ \text{cm})\cdot\left(\frac{1\ \text{m}}{100\ \text{cm}}\right) = 0.305\ \text{m}$$

$$A_1 = \frac{\pi d^2}{4} = \frac{\pi(0.0025\ \text{m})^2}{4} = 4.91\times10^{-6}\ \text{m}^2$$

$$A_2 = \pi dL = \pi\cdot(0.0025\ \text{m})\cdot(0.305\ \text{m}) = 2.395\times10^{-3}\ \text{m}^2$$

$$A_T = A_1 + A_2 = 4.91\times10^{-6}\ \text{m}^2 + 2.395\times10^{-3}\ \text{m}^2 = 2.4\times10^{-3}\ \text{m}^2$$

$h_o = 25\ \text{W/m}^2\text{-K}$

$$R_T = \left(\frac{1}{h_o\cdot A_T}\right) = \left(\frac{1}{(25\ \text{W/m}^2-\text{K})\cdot(2.4\times10^{-3}\ \text{m}^2)}\right)$$

$$R_T = 16.67\ \text{K/W}$$

Example Solution

b.) Find the volume of the probe to find C_T

$$C_T = \rho\cdot V\cdot S_m$$

Where: ρ = density of Platinum = 21,450 Kg/m³
V = volume of probe
S_m = specific heat of Platinum = 0.13 kJ/Kg-K

Find volume of cylinder

$$V = \left(\frac{\pi d^2}{4}\right)\cdot L = \frac{\pi(0.0025\ \text{m})^2}{4}(0.305\ \text{m}) = 1.497\times10^{-6}\ \text{m}^3$$

Now find the thermal capacitance

$$C_T = \rho\cdot V\cdot S_m$$

$$C_T = (21{,}450\ \text{Kg/m}^3)\cdot(1.497\times10^{-6}\ \text{m}^3)\cdot(0.13\ \text{kJ/Kg-K})\cdot\left(\frac{1000\ \text{J}}{1\ \text{kJ}}\right)$$

$$C_T = 4.174\ \text{J/K}$$

Example Solution

c.) Find the RTD time constant

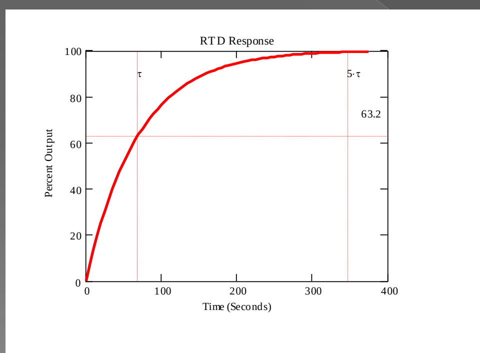
$R_T = 16.67\ \mathrm{K/W}$

$C_T = 4.174\ \mathrm{J/K}$

$\tau = R_T \cdot C_T$

$\tau = (16.67\ \mathrm{K/W}) \cdot (4.174\ \mathrm{J/K})$

$\tau = 69.6\ \mathrm{S}$



RTD Response curve

Lesson 10_et438b.pptx 17

End Lesson 10: Sensor and Transducer Electrical Characteristics

ET 438b Sequential Control and Data Acquisition

Department of Technology

18

Lesson 10_et438b.pptx