ELEC207 - Instrumentation & Control

Part-A: Instrumentation

Problem Class 2

Dr Saqib Khursheed

S.Khursheed@Liverpool.ac.uk

Lecture schedule:

Monday 1700-1800 (CHAD-CHAD)

Thursday 1400-1500 (CTH-LTA)

Office Location: Room 513, Electrical Engineering

Lecture covers

- Exam questions on:
  - Temperature measurement devices
    - Thermocouples
    - Resistance Temperature Device (RTD)
    - Thermistor
  - Error Analysis
- Feedback on:
  - HW-2
  - Online Survey

Feedback on HW-2
Resistance Temperature Device (RTD)

a) A platinum resistive temperature detector (RTD) is used to measure the temperature of a jet engine wall. Assuming that the temperature is never below 0° C. Write the (quadratic) Callender-van Dusen equation which relates the RTD resistance to its temperature. **(7 Marks)**

Solution:

$$R(T) = R_0(1 + a_1 T + a_2 T^2 + \cdots + a_n T^n)$$

$$R(T) = R_0(1 + a_1 T + a_2 T^2)$$

Quadratic form (Callender-van Dusen equation)

Where, R_0 is resistance at 0°C, a_1 and a_2 are metal specific coefficients.

Feedback on HW-2
Resistance Temperature Device (RTD)

b) Given the Callender-van Dusen coefficients for platinum $A=3.9x10^{-3}\ ^oC^{-1}$, $B=-5.8x10^{-7}\ ^oC^{-2}$, the RTD resistance Ro=100 Ω at 0^oC, and the range of measurements (full scale deflection - FSD) from 0^oC to 850^oC calculate:

i) The RTD resistance RT at 800^oC. **(5 Marks)**

Solution:

$$R(T) = R_0(1 + a_1 T + a_2 T^2)$$

a_1 → A; a_2 → B

$$R(800) = 100.[1 + (3.9x10^{-3}).(800) + (-5.8x10-7).(800)^2]$$

$$R(800) = 100.[1 + 3.12 \ - 0.3712]$$

$$R(800) = 374.88\ \Omega$$

Feedback on HW-2
Error Analysis

b) Given the Callender-van Dusen coefficients for platinum $A=3.9\text{x}10^{-3}\ {}^{o}C^{-1}$, $B=-5.8\text{x}10^{-7}\ {}^{o}C^{-2}$, the RTD resistance Ro=100 Ω at $0^{o}C$, and the range of measurements (full scale deflection - FSD) from $0^{o}C$ to $850^{o}C$ calculate:

ii) Assuming endpoint linearity calculate the RTD sensitivity for the given FSD. **(5 Marks)**

Solution:

$$Sensitivity = \frac{R(850) - R(0)}{\Delta T}$$

$$R(850) = 100.[1 + (3.9\text{x}10^{-3}).(850) + (-5.8\text{x}10{-}7).(850)^2]$$

$$R(850) = 100.[1 + 3.315\ - 0.41905]$$

$$R(850) = 389.595\ \Omega$$

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Feedback on HW-2
Error Analysis

b) Given the Callender-van Dusen coefficients for platinum $A=3.9\text{x}10^{-3}\ {}^{o}C^{-1}$, $B=-5.8\text{x}10^{-7}\ {}^{o}C^{-2}$, the RTD resistance Ro=100 Ω at $0^{o}C$, and the range of measurements (full scale deflection - FSD) from $0^{o}C$ to $850^{o}C$ calculate:

ii) Assuming endpoint linearity calculate the RTD sensitivity for the given FSD. **(5 Marks)**

Solution:

$$Sensitivity = \frac{R(850) - R(0)}{\Delta T}$$

$$R(850) = 389.595\ \Omega$$

$$Sensitivity = \frac{389.595 - 100}{850} = \frac{289.585}{850} = 0.3407\ \Omega\ {}^{o}C^{-1}$$

Error Analysis

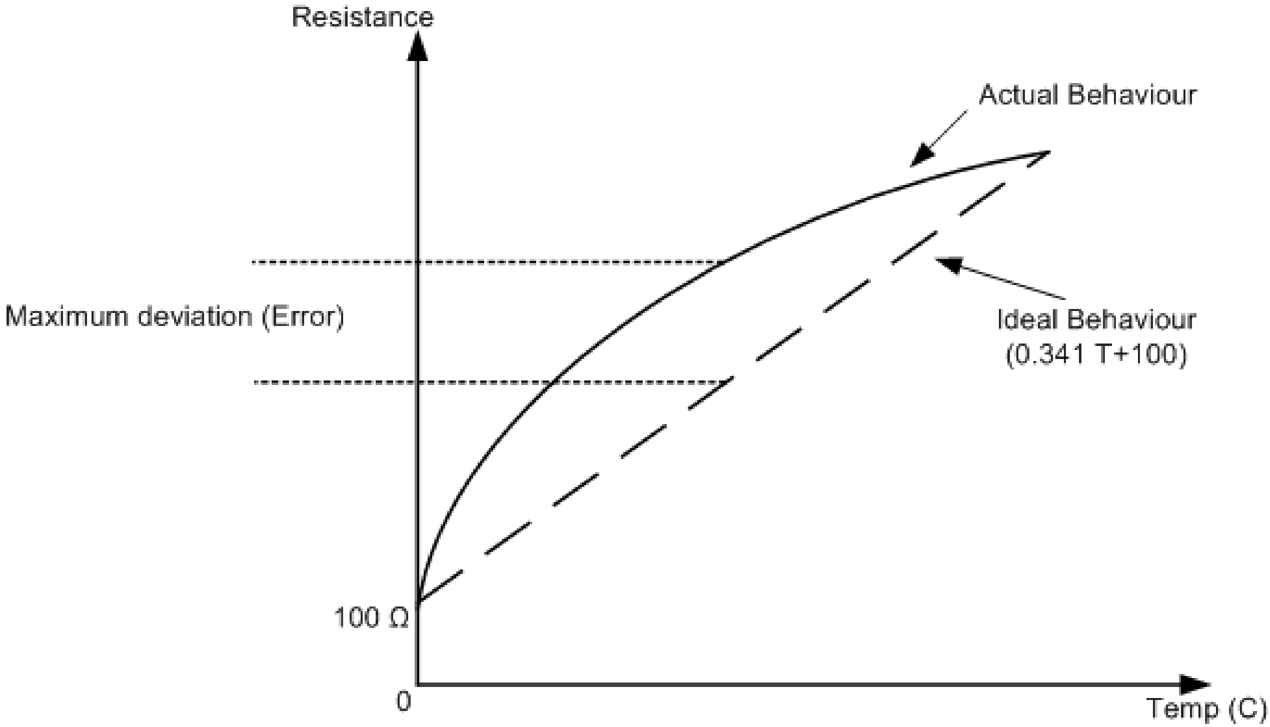
b) Given the Callender-van Dusen coefficients for platinum $A=3.9\times10^{-3}\ ^{o}C^{-1}$, $B=-5.8\times10^{-7}\ ^{o}C^{-2}$, the RTD resistance Ro=100 Ω at $0^{o}C$, and the range of measurements (full scale deflection - FSD) from $0^{o}C$ to $850^{o}C$ calculate:

iii) The maximum endpoint linearity error in % FSD.

(8 Marks)

See Bentley, Chapter 2, pages 9-11 for more details.

Error Analysis



$$\varepsilon(T) = R(T) - R(Ideal)$$

$$\varepsilon(T) = [R_0(1 + a_1T + a_2T^2)] - (0.341T + 100)$$

Error Analysis

$$\varepsilon(T) = [R_0(1 + a_1T + a_2T^2)] - (0.341T + 100)$$

$$\varepsilon(T) = [100.[\cancel{1} + (3.9\text{x}10^{-3})T + (-5.8\text{x}10^{-7})T^2] \\ - (0.341T + 1\cancel{0}0)]$$

$$\varepsilon(T) = [100.[(3.9\text{x}10^{-3})T - (5.8\text{x}10^{-7})T^2] \\ - (0.341T)]$$

$$\varepsilon(T) = (3.9\text{x}10^{-1})T - (5.8\text{x}10^{-5})T^2 - (0.341T)]$$

$$\boxed{\varepsilon(T) = 0.049\,T - 5.8\text{x}10^{-5}T^2 \qquad \cdots (1)}$$

Error Analysis

$$\boxed{\varepsilon(T) = 0.049\,T - 5.8\text{x}10^{-5}T^2 \qquad \cdots (1)}$$

Differentiate w.r.t "T" and equate to 0, for maximum deviation

$$\frac{d\,\varepsilon(T)}{dT} = 0.049\ - (2).(5.8\text{x}10^{-5})T = 0$$

$$\frac{d\,\varepsilon(T)}{dT} = 0.049\ - 1.16\text{x}10^{-4}T = 0$$

$$T = \frac{0.049}{1.16\text{x}10^{-4}}$$

$$\boxed{T = 422.41\ ^\circ\text{C}}$$

Error Analysis

$$\boxed{T = 422.41\ °\mathrm{C}}$$

Substituting the value in Eq. 1

$$\varepsilon(T) = 0.049\,T - 5.8\text{x}10^{-5}T^2 \qquad \cdots (1)$$

$$\varepsilon(T_{Max}) = 0.049\,(422.41) - 5.8\text{x}10^{-5}(422.41)^2$$

$$\varepsilon(T_{Max}) = 20.6981 - 10.3489$$

$$\boxed{\varepsilon(T_{Max}) = 10.35\ \Omega}$$

Error Analysis

$$\boxed{\varepsilon(T_{Max}) = 10.35\ \Omega}$$

In terms of % of FSD

$$\varepsilon\ (\%FSD)\ = \frac{10.35}{389.595 - 100} * 100$$

$$\boxed{\varepsilon\ (\%FSD)\ = 3.57\%}$$

Thermocouples

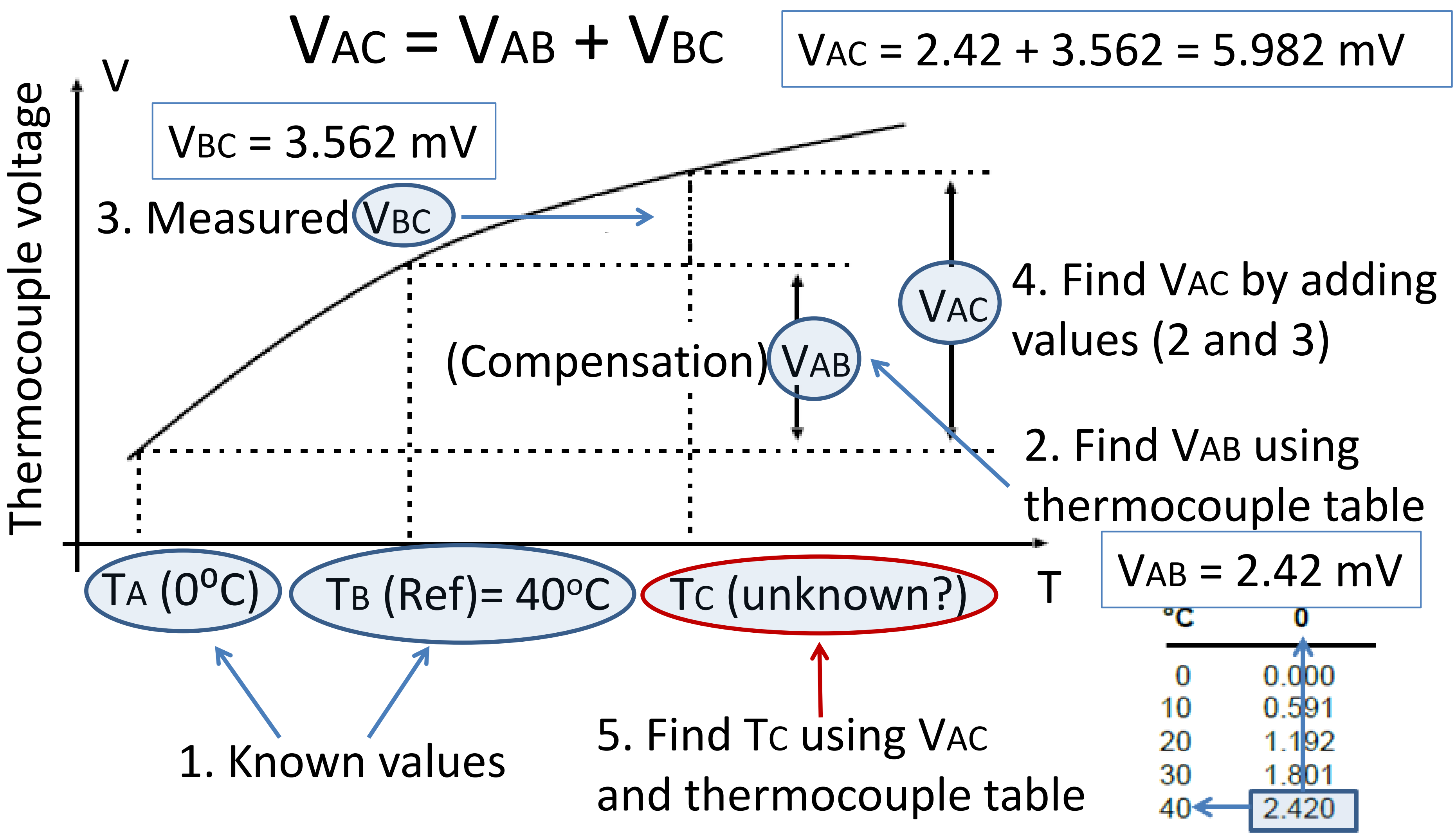
The output voltage of a thermocouple with its reference junction at 40◦C is 3.562 mV. Using Table Q1 determine the temperature measured by the thermocouple. **(8 Marks)**

Similar Questions in 2012-2015 exams

°C	0	1	2	3	4	5	6	7	8	9	10
0	0.000	0.059	0.118	0.176	0.235	0.294	0.354	0.413	0.472	0.532	0.591
10	0.591	0.651	0.711	0.770	0.830	0.890	0.950	1.010	1.071	1.131	1.192
20	1.192	1.252	1.313	1.373	1.434	1.495	1.556	1.617	1.678	1.740	1.801
30	1.801	1.862	1.924	1.986	2.047	2.109	2.171	2.233	2.295	2.357	2.420
40	2.420	2.482	2.545	2.607	2.670	2.733	2.795	2.858	2.921	2.984	3.048
50	3.048	3.111	3.174	3.238	3.301	3.365	3.429	3.492	3.556	3.620	3.685
60	3.685	3.749	3.813	3.877	3.942	4.006	4.071	4.136	4.200	4.265	4.330
70	4.330	4.395	4.460	4.526	4.591	4.656	4.722	4.788	4.853	4.919	4.985
80	4.985	5.051	5.117	5.183	5.249	5.315	5.382	5.448	5.514	5.581	5.648
90	5.648	5.714	5.781	5.848	5.915	5.982	6.049	6.117	6.184	6.251	6.319

mV

Thermocouples



Thermocouples

°C	0	1	2	3	4	5	6	7	8	9	10
0	0.000	0.059	0.118	0.176	0.235	0.294	0.354	0.413	0.472	0.532	0.591
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70	4.330	4.395	4.460	4.526	4.591	4.656	4.722	4.788	4.853	4.919	4.985
80	4.985	5.051	5.117	5.183	5.249	5.315	5.382	5.448	5.514	5.581	5.648
90	5.648	5.714	5.781	5.848	5.915	5.982	6.049	6.117	6.184	6.251	6.319

mV

Oil temperature is 95^{o} C

Thermistor

d) Determine the temperature measured by a thermistor if it has a resistance of 50 kΩ at 25°C, the characteristic temperature of 2000 K, and the measured resistance 150 kΩ. **(8 Marks)**

Lecture 5.pdf

$$R = R_0 e^{\left[\beta\left(\frac{1}{T}-\frac{1}{T_0}\right)\right]}$$

R is the resistance at temperature T,
R_0 is the resistance at temperature T_0,
β is a material constant
β, T and T_0 are expressed in ‘K’

Thermistor

$$R = R_0 e^{[\beta\left(\frac{1}{T}-\frac{1}{T_0}\right)]}$$

$\beta = 2000\ K$

$R_0 = 50\ K\Omega$ $\qquad T_0 = 25\ ℃ = 25 + 273 = 298\ K$

$R = 150\ K\Omega$ $\qquad T = ?$

$$150\ K = 50\ K e^{[2000\left(\frac{1}{T}-\frac{1}{298}\right)]}$$

Thermistor

$$3 \quad 1\cancel{5}0\,\cancel{K} = \cancel{5}0\,\cancel{K}\, e^{\left[2000\left(\frac{1}{T}-\frac{1}{298}\right)\right]}$$

$$3 = e^{\left[2000\left(\frac{1}{T}-\frac{1}{298}\right)\right]}$$

$$3 = e^{\left[2000\left(\frac{298-T}{298.T}\right)\right]}$$

$$\ln(3) = 2000\left(\frac{298-T}{298.T}\right)$$

Thermistor

$$\ln(3) = 2000\left(\frac{298 - T}{298.T}\right)$$

$$1.0986 = 2000\left(\frac{298 - T}{298.T}\right)$$

$$0.0005493 = \frac{298 - T}{298.T}$$

$$0.1637T = 298 - T$$

$$1.1637T = 298$$

Thermistor

$$1.1637T = 298$$

$$T = \frac{298}{1.1637}$$

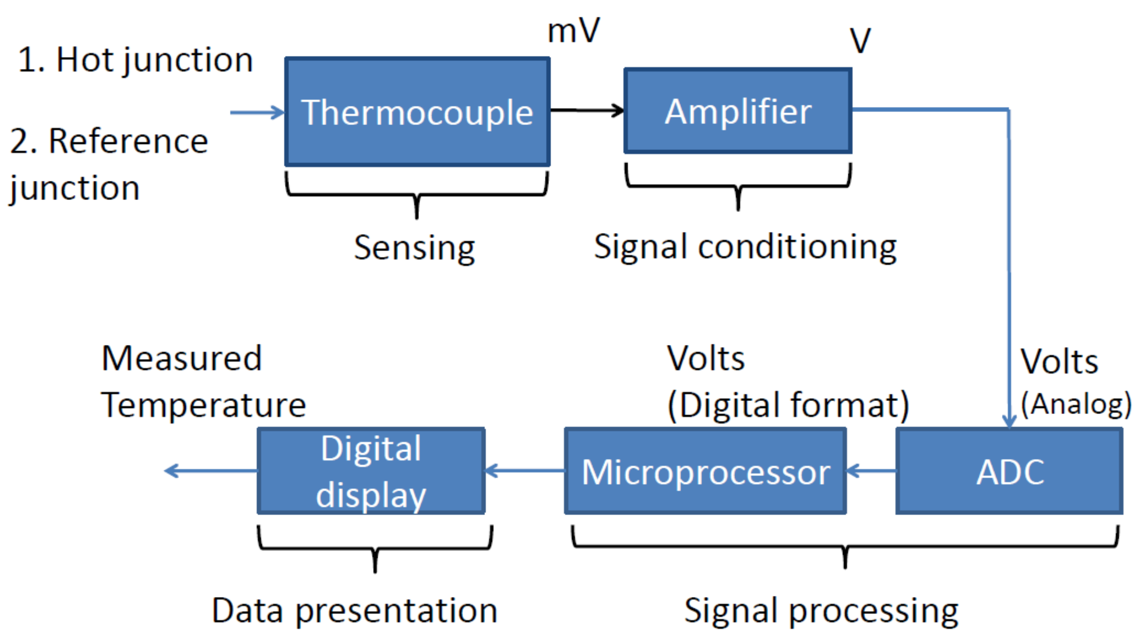
$$T = 256.1\ K$$

$$T = 256.1 - 273 = -16.9\ ℃$$

$$\boxed{T = -16.9\ ℃}$$

Measurement System (2014-15)

Q. With the aid of a block diagram, show how a thermocouple is used in a temperature measurement system. The block diagram should clearly show the sensing element, the required signal conditioning and signal processing elements. (5 Marks)



Slide 4, Lecture 5.pdf

Summary

Topics covered:

- ✓ Exam questions on:
  - ✓ Temperature measurement devices.
    - ✓ Thermocouples
    - ✓ RTDs
    - ✓ Thermistors
  - ✓ Error Analysis
- ✓ Feedback on:
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Next Lecture:

- Monday, 9th Nov 2015 (CHAD-CHAD) 1700-1800