12.6 Sensors and actuators

Name: _____ Class: _____ Date: _____ **Total: 16 marks**

KEY WORDS measurand • platinum resistance thermometer • signal chain • error budget • bandwidth

Objective

Scale a sensor's signal chain to the ADC, find its resolution, combine independent errors into a budget by root sum of squares, and state an actuator's speed and torque limits.

1 Key knowledge and worked examples

■ **Scale every stage, then budget**

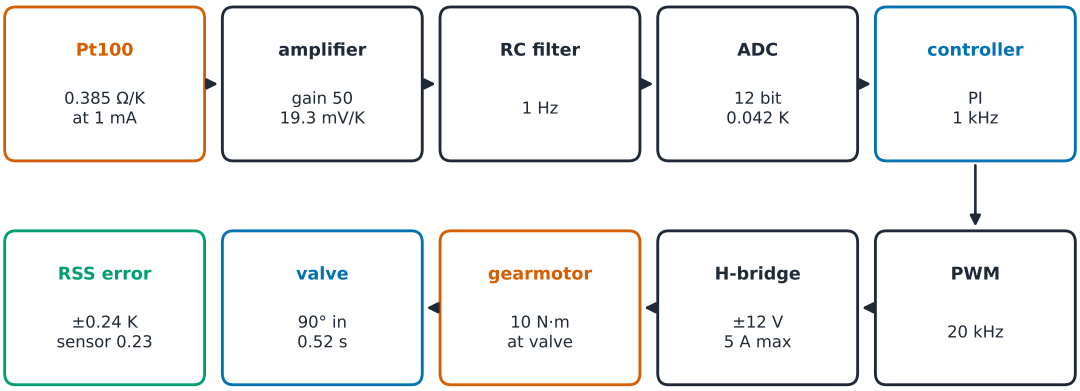
- Choose the principle for the **measurand** : a **platinum resistance thermometer** (Pt100) changes by 0.385 Ω/K.
- **Signal chain** : excitation current × 0.385 Ω/K × gain = mV/K; ADC step $V_{ref}/2^n$; rounding $\sigma = \text{step}/\sqrt{12}$.
- **Error budget** : independent errors combine as $\sqrt{\sum e_i^2}$; the largest decides.
- Self-heating I^2R divided by the dissipation constant (mW/K); RC filter gain $1/\sqrt{1+(f/f_c)^2}$.
- Actuator limits: volts → speed, amps → torque, and **bandwidth** .

■ **Worked example. The error budget at 40 °C**

Pt100 at 1 mA, gain 50 (19.25 mV/K), 12-bit ADC over 3.3 V.

- Step $3.3/4096 = 0.806$ mV $= 0.042$ K; $\sigma = 0.012$ K.
- Class A sensor $\pm(0.15 + 0.002T) = 0.23$ K; gain 0.04 K; self-heating 0.05 K.
- RSS: $\sqrt{0.23^2 + 0.012^2 + 0.04^2 + 0.05^2} = \pm\mathbf{0.24}$ K; the sensor dominates.

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2 Practice

A Pt100 is driven at 1 mA into an amplifier of gain 40 and a 12-bit ADC over 3.3 V.

2.1 Find the sensitivity at the ADC (mV/K), the temperature per ADC step (four decimals, K) and the rounding σ (four decimals, K). [3]

2.2 What voltage does a 0 to 100 °C range use, and why leave the rest of the 3.3 V unused? [2]

2.3 A 1 Hz RC filter sits before the ADC. Find its gain at 5 Hz (three decimals). [2]

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3 Exam-style questions

3.1 The chain of 2.1 measures water at 60 °C. Errors: a class B sensor, $\pm(0.3 + 0.005T)$; amplifier gain error 0.2% of the reading; self-heating at 2 mW/K with $R = 123.1\ \Omega$ at 60 °C; ADC rounding from 2.1. (a) Find each term (three decimals, K) and the RSS budget (two decimals, K). (b) Would a 16-bit ADC help? What would? (c) The valve actuator of sheet 12.2 delivers 0.314 N · m at the motor at 200.7 rad/s under load: find its shaft power, and give the limit set by voltage and the one set by current. [9]

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Solutions

2.1

- 1 mA $\times$ 0.385 Ω/K $\times$ 40 = **15.4** mV/K.
- Step = 3.3/4096 = 0.806 mV; 0.806/15.4 = **0.0523** K.
- σ = step/$\sqrt{12}$ = **0.0151** K.

2.2

- 100 $\times$ 15.4 = **1.54** V.
- Headroom for offset, drift and over-range (a fault reading above 100 °C should still be readable, not clipped).

2.3

- $1/\sqrt{1+(5/1)^2}$ = **0.196**: 5 Hz noise is cut to about 20%.

3.1

- (a) Sensor: $0.3 + 0.005 \times 60$ = **0.600** K.
- Gain: 0.002×60 = **0.120** K.
- Self-heating: $I^2R = (10^{-3})^2 \times 123.1 = 0.123$ mW, and 0.123/2 = **0.062** K; ADC **0.015** K.
- RSS: $\sqrt{0.600^2 + 0.120^2 + 0.062^2 + 0.015^2}$ = $\pm$**0.62** K.
- (b) No: the ADC term is already negligible. A class A (or 1/3 DIN) sensor, or calibrating it, attacks the dominant term.
- (c) $P = T\omega = 0.314 \times 200.7$ = **63** W.
- Voltage caps speed (24 V $\rightarrow$ 6.69 rad/s at the valve under load); current caps torque (6 A $\rightarrow$ 12.2 N $\cdot$ m at the valve).

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