UNIVERSITY MECHANICAL ENGINEERING • EXERCISE SHEET

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

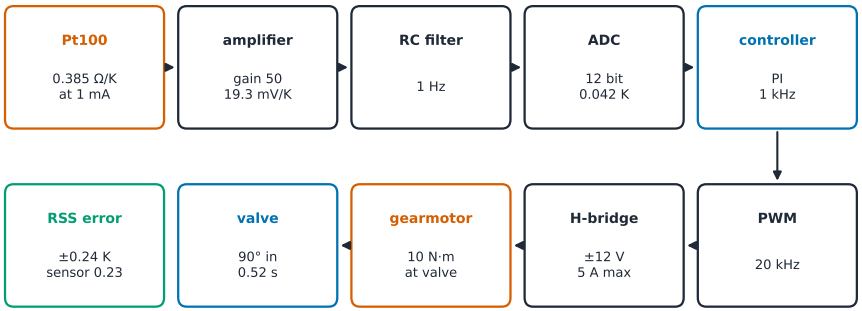
■ **Scale every stage, then budget**

- 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.



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]

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]