Summer Examinations 2015

ENG302015NA

MODULE TITLE
Advanced Electromechanical System Design

LEVEL
Six

TIME ALLOWED
Two hours

Instructions to students:

- Enter your student number **not** your name on all answer books.
- Answer **all** questions.
- All questions are equally weighted. Where a question has more than one part the division of marks is stated.
- Begin each answer on a separate page; label each page clearly with the number of the question you are answering.
- The use of electronic calculators is permitted.
- Graph paper and a formula booklet are provided.
- Students are permitted to remove this examination paper at the end of the examination.

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Question 1

The schematic in Figure Q1.1 (on page 3) is a signal conditioning circuit suitable for interfacing a resistance temperature detector (Pt100) to a MCU such as ATMEGA328. This circuit is used to monitor the temperature in a refrigeration system. The range of oil temperatures considered in this application is between 28 °C and 87 °C. The Pt100 has a temperature coefficient of \( \alpha = 0.00385 \, [\degree C^{-1}] \) and the thermal resistance between the RTD and the oil is \( R_w = 12.5 \, [\degree C/W] \). The sensor resistance varies according to \( R_s = R_0 (1 + \alpha \cdot T) \) where \( R_0 \) is 100Ω at 0°C and \( T \) is the temperature in °C.

a. Find the maximum current that can flow through the Pt100 if the self-heating error is less than 0.1°C.

(8 marks)

b. Derive the formula that relates the output voltage \( V_{out} \) as a function of \( V_{ref}, R_1 \) and \( R_s \) for the circuit shown in Figure Q1.1 (on page 3). Find the values of \( R_1 \) and \( V_{ref} \) required to achieve the desired output shown in Figure Q1.2b (also on page 3).

(15 marks)

c. If the reference voltages of the ADC are \( V_{ref-} = 0V \) and \( V_{ref+} = 5V \), find the temperature resolution after signal conditioning when the total number of bits during the ADC conversion process is 8 bits and 10 bits respectively.

(5 marks)

d. Explain in terms of self-heating errors the advantage of using the RTD signal conditioning circuit shown in Figure Q1.3 (on page 4) over the one in Figure Q1.1 (on page 3).

(5 marks)

An oil temperature controller uses a Pt100 signal conditioning circuit which output matches Figure Q1.2b (on page 3). The controller must regulate the oil temperature according to the following requirements: 50°C (set-point) ±1.5°C (tolerance band). The oil temperature is sensed using an analogue input (A0) and the heating element is controlled by a digital output (Arduino Uno – PIN 5). The heating element is rated to 2kW and it is mains powered using a power relay.

e. Design an NPN relay driver circuit suitable to be interfaced to an Arduino digital output. The driver circuit energises the relay when a voltage greater than 4V is applied to the base resistor. The relay coil resistance is 75Ω and a minimum current of 150mA needs to flow through the coil to energise the relay. The BJT specifications are \( I_c(max) = 750mA \) and \( 100 \leq \beta \leq 1000 \). A 15V DC external power supply can be used to power up the relay.

(7 marks)
f. Explain the PID algorithm as a suitable temperature control strategy using a digital output as a PWM signal of period 5s. Use a flowchart or pseudocode as part of the explanation.

(10 marks)

Figures Q1.1, Q1.2a, Q1.2b (below) and Figure Q1.3 and Q1.4 (on page 4) relate to Question 1.

\[ R_T = R_0 \left(1 + \alpha \cdot T\right) \quad \text{where} \]

\[ T \in [0, 100] \quad [\degree C] \]

\[ V_{CC} = 5 \quad [V] \]

**Figure Q1.1.** Temperature signal conditioning circuit

**Figure Q1.2a** Characteristic curve

**Figure Q1.2b** Output voltage after signal conditioning
**Figure Q1.3.** Pt100 (3 wires) Signal conditioning circuit (Howland current source)

\[
V_{\text{OUT3}} = (V_{\text{IN}} - V_{W1})(1 + R_6/R_5) - V_{\text{IN}}(R_6/R_5)
\]

where:

- \( V_{\text{IN}} = V_{W1} + V_{R\text{TD}} + V_{W3} \)
- \( V_{W3} \) is the voltage drop across the wires to and from the RTD and
- \( V_{\text{OUT3}} \) is the voltage at the output of \( A_3 \)

**Figure Q1.4.** Arduino Uno R3 pinout and industrial Pt100 (3 wires)

**Total: 50 marks**
Question 2

The positional sketch of a feeding device is shown in Figure Q2.1 (on page 6). The end positions of the two cylinder drives 1A and 2A are detected by NPN inductive proximity switches 1B1 and 2B2. The program-controlled sequence is triggered when the operator presses the "START" pushbutton. The sequence comprises the following steps:

**Step 1:** The piston rod of cylinder 1A advances. The workpiece is pushed out of the stack.

**Step 2:** The piston rod of cylinder 2A advances. The workpiece is fed to the machining station.

**Step 3:** The piston rod of cylinder 1A retracts.

**Step 4:** The piston rod of cylinder 2A retracts.

The control system is implemented using double-acting cylinders and 5/2-way double solenoid valves as shown in Figure Q2.2 (on page 6).

Following the system specifications:

a. Provide an I/O table describing the electrical connections to a PLC. (10 marks)

b. Determine the theoretical size of the pneumatic cylinders when it operates at a pressure of 6 bar providing a maximum force of 250N.

A design constraint imposes that the rod diameter must be at least 20% of the piston diameter. In order to regulate cylinder speed, the decaying pressure on the side of the cylinder’s piston open to atmosphere should be approximately 1.5bar and can be considered to work against the cylinder. (10 marks)

c. Determine the air consumption if the stroke is 50cm.

**HINT:** Use Boyles Law \( P_1 \cdot V_1 = P_2 \cdot V_2 \) (10 marks)

d. Implement the control strategy in ladder programming (LD). (20 marks)
Figures Q2.1 and Q2.2 (below) relate to Question 2.

Figure Q2.1

Figure Q2.2

Total: 50 marks

End of Paper