

PAPER III: SUBJECT SPECIALISATION PAPER FOR INSTRUMENTATION & CONTROL ENGINEERING

- All questions under SECTION A are **COMPULSORY**.

SECTION A

PART I: Multiple Choice Questions [30 marks]

Choose the correct answer and write down the letter of your chosen answer in the Answer Booklet against the question number e.g. 31 (d). Each question carries ONE mark. Any double writing, smudgy answers or writing more than one choice shall not be evaluated.

1. Which of the following is NOT a primary element in a measurement system?
 - a) Sensor
 - b) Transducer
 - c) Signal conditioner
 - d) Controller

2. The range of a 4 – 20 mA signal is chosen because:
 - a) It allows bidirectional transmission
 - b) It avoids zero current for fault detection
 - c) It's cheaper than other ranges
 - d) It works only for digital systems

3. A thermocouple works on which principle?
 - a) Piezoelectric effect
 - b) Seebeck effect
 - c) Hall effect
 - d) Doppler effect

4. In a PID controller, the proportional term:
 - a) Eliminates steady-state error
 - b) Increases speed of response
 - c) Reduces overshoot
 - d) Filters noise

5. What is the output of an LVDT proportional to?
 - a) Velocity
 - b) Acceleration
 - c) Displacement
 - d) Force

6. Which sensor is most suitable for non-contact temperature measurement?
 - a) RTD
 - b) Thermocouple
 - c) Infrared thermometer
 - d) Thermistor

7. Which control strategy is best for processes with large dead time?
 - a) PID control
 - b) Cascade control
 - c) Smith predictor
 - d) Feedforward only
8. In HART communication, the digital signal is superimposed on:
 - a) Voltage
 - b) Pressure
 - c) Current loop
 - d) Optical fiber
9. Which of the following is a secondary transducer?
 - a) Bourdon tube with strain gauge
 - b) Thermistor
 - c) Thermocouple
 - d) LVDT
10. Which is NOT a final control element?
 - a) Pneumatic control valve
 - b) Electric motor
 - c) Solenoid valve
 - d) RTD sensor
11. In PLC programming, which instruction is used for counting events?
 - a) TON
 - b) CTU
 - c) PID
 - d) MOV
12. The main advantage of a 3-wire RTD over a 2-wire RTD is:
 - a) Higher sensitivity
 - b) Better linearity
 - c) Compensation for lead wire resistance
 - d) Higher temperature range
13. The Ziegler–Nichols tuning method is used for:
 - a) Measuring system gain
 - b) Tuning controller parameters
 - c) Designing sensors
 - d) Selecting actuators
14. In a control loop, the actuator's main function is to:
 - a) Measure the process variable
 - b) Convert control signal into physical action
 - c) Calculate error
 - d) Filter noise

15. Which sensor type uses a Wheatstone bridge for measurement?
- a) Strain gauge
 - b) Thermocouple
 - c) Ultrasonic sensor
 - d) Hall effect sensor
16. Dead time in a process can cause:
- a) Faster response
 - b) More stability
 - c) Oscillation and instability
 - d) Lower process gain
17. The term “span” in instrumentation refers to:
- a) Maximum possible output signal
 - b) Difference between upper and lower range limits
 - c) Time delay in response
 - d) Measurement accuracy
18. Which controller action produces the fastest response to sudden disturbances?
- a) Proportional
 - b) Integral
 - c) Derivative
 - d) On/Off
19. In SCADA systems, the RTU stands for:
- a) Remote Transducer Unit
 - b) Remote Terminal Unit
 - c) Real-Time Unit
 - d) Remote Transfer Utility
20. Which valve characteristic provides a linear relationship between flow rate and valve position?
- a) Equal percentage
 - b) Linear
 - c) Quick opening
 - d) Globe
21. The transfer function of a first-order system is:
- a) $K\tau s + 1 \frac{K}{\tau s + 1} \tau s + 1 K$
 - b) $Ks^2 + 1 \frac{K}{s^2 + 1} s^2 + 1 K$
 - c) $1s \frac{1}{s} s 1$
 - d) $K\tau s \frac{K}{\tau s} \tau s K$
22. In a DCS, the control logic is generally executed in:
- a) Operator workstation
 - b) Engineering workstation
 - c) Controller module
 - d) PLC only

23. Which parameter is NOT usually measured in process control?
- a) Temperature
 - b) Flow
 - c) Pressure
 - d) Weightlifting capacity
24. Which sensor type works based on change in inductance?
- a) LVDT
 - b) Capacitive sensor
 - c) Hall effect sensor
 - d) Ultrasonic sensor
25. The main purpose of a signal conditioner is to:
- a) Filter noise and amplify signals
 - b) Convert electrical signals into mechanical signals
 - c) Change AC to DC
 - d) Control the process directly
26. Which of the following is a non-contact displacement sensor?
- a) Strain gauge
 - b) LVDT
 - c) Laser triangulation sensor
 - d) Potentiometer
27. Cascade control is mainly used to:
- a) Reduce dead time
 - b) Reduce effect of load disturbances
 - c) Increase process gain
 - d) Improve sensor accuracy
28. A pneumatic signal standard range is:
- a) 3–15 psi
 - b) 0–100 psi
 - c) 4–20 psi
 - d) 1–10 psi
29. The sampling theorem states that the sampling frequency must be at least:
- a) Twice the Nyquist rate
 - b) Twice the highest frequency component of the signal
 - c) Equal to the signal frequency
 - d) Half the signal frequency
30. Which of the following is an example of a smart transmitter?
- a) Analog-only 4–20 mA transmitter
 - b) HART-enabled pressure transmitter
 - c) Manual pressure gauge
 - d) Bimetallic thermometer

PART II – Short Answer Questions [20 marks]

This part has 4 short Answer Questions. Answer all the questions. Each question carries **5 marks**.

1. Discuss the concept of feedback control and feedforward control in industrial processes. Provide examples of situation where each control strategy is most effective?
2. What is a 4–20 mA current loop and why is it widely used in process control?
3. Explain the working principle of an RTD and mention its advantages over a thermocouple?
4. Explain the concept of gain scheduling in process control and give one example where it is used?

SECTION B: CASE STUDY [50 marks]

Choose either Case I or Case II from this section. Each case study carries 50 marks. The mark for each question is indicated in the brackets

CASE I:

A food plant uses a jacketed mixing tank to heat a product to 70.0 °C. The control system has:

- A **Pt100 RTD (3-wire)** measuring product temperature, wired to a temperature transmitter (4–20 mA).
- A **control valve** actuated by an I/P (4–20 mA → 3–15 psi) controlling steam to the jacket.
- A PLC performing a single-loop PID (temperature control).
- Typical operating point: valve opening about 0.35 (35% fraction), product flow and feed composition are roughly steady.

During commissioning the following observations and test data were recorded:

1. The RTD/transmitter shows **+0.6 °C** higher than a calibrated reference thermometer at 70.0 °C.
2. A step test on valve opening from 0.30 → 0.40 ($\Delta u = 0.10$) produced a delayed rise in product temperature with the following approximate FOPDT behaviour: steady change $\Delta T_{\infty} = +3.0$ °C, apparent first-order time constant $\tau = 120$ s, and dead time $\theta = 8$ s
3. The I/P response test shows outputs slightly nonlinear near low end (3–5 psi) but approximately linear over most of span.
4. Operators report: when set point = 70.0 °C, temperature oscillates between 68.5–71.5 °C; when set point is raised to 71.0 °C the rise is slow and sometimes overshoots by 1.2 °C on cooling when reducing set point.

With the above condition, answer the following questions:

1. List six likely causes (control + instrumentation + process) for the observed oscillations, slow rise, and overshoots. For each cause give a one-line explanation. Give one priority corrective action you would do first and why. **(12 marks)**
2. Sensor calibration & effect **(12 marks)**
 - a) Compute the Pt100 resistance at 70.0 °C. (Use $R_0 = 100 \Omega$, $R_{100} = 100 \Omega$, $\alpha = 0.00385 \Omega/\Omega/^{\circ}\text{C}$, $\alpha = 0.00385 \Omega/\Omega/^{\circ}\text{C}$).
 - b) Compute the resistance error corresponding to the +0.6 °C transmitter bias.
 - c) Explain qualitatively how this +0.6 °C bias affects the control loop behavior.
3. I/P nonlinearity & valve **(12 marks)**
 - a) Explain how moderate I/P nonlinearity near low pressure (3–5 psi) would affect small-signal control around low valve openings.
 - b) Propose two practical fixes (one instrumentation fix, one control/software fix) and explain expected benefit.
4. Validation test & performance check **(14 marks)**

Design a short validation test plan (3 steps) to confirm the loop meets ± 0.5 °C stability around 70.0 °C after you apply your fixes/tuning. For each step state: purpose, action, expected result and what you will measure.

CASE II:

A chemical plant uses a batch reactor to produce a specialty polymer. The process involves the following steps controlled by a PLC/DCS system:

1. **Charging:** Raw materials are charged into the reactor.
2. **Heating:** Reactor temperature is raised from ambient to 150°C.
3. **Reaction:** Maintain temperature at 150°C for 2 hours.
4. **Cooling:** Cool down the reactor to 50°C.
5. **Discharge:** Product is discharged from the reactor.

The PLC/DCS program must manage the following inputs and outputs:

• **Inputs:**

- Start Pushbutton (Start)
- Emergency Stop (E-Stop)
- Temperature sensor (RTD) feedback
- Level sensor for charging and discharge confirmation
- Heater status (On/Off)
- Cooling valve position feedback

• **Outputs:**

- Charging valve control
- Heater On/Off
- Cooling valve actuator
- Discharge valve control
- Alarm indicator

Answer the following question:

1. Draw a block diagram of the batch reactor process control system showing major inputs, outputs, sensors, and actuators. **(10 marks)**
2. Write a high-level logic sequence for the batch process, explaining each step's control action in the PLC/DCS program. **(10 marks)**
3. Explain how you would implement safety interlocks in the PLC program to handle emergency stop and sensor failures. **(10 marks)**
4. Describe how the PLC/DCS can use timers and counters to control the reaction hold time and the batch count. **(10 marks)**
5. Discuss the advantages of using a DCS over a PLC for this batch reactor process and situations where PLC might be preferred. **(10 marks)**