

# PRACTICE EXAM 6: PE CONTROL SYSTEMS SIMULATION

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**Recommended Time: 9.5 hours | Questions: 85 | \*\*References: NCEES PE Control Systems Reference Handbook, ANSI/ISA-5.1 (2009), ISA/IEC 61511 (2018)**

## **DOMAIN 1: MEASUREMENT (Questions 1–22)**

1. A DP flow transmitter with square root extraction enabled is calibrated for a maximum flow of 800 gpm at a full-scale differential pressure of 150 in H<sub>2</sub>O. What differential pressure corresponds to a flow rate of 400 gpm?

- A. 75.0 in H<sub>2</sub>O
- B. 37.5 in H<sub>2</sub>O
- C. 100.0 in H<sub>2</sub>O
- D. 56.3 in H<sub>2</sub>O

2. A plant must measure hydrogen gas mass flow in a 1-inch line at 500 psig and 150°F for custody transfer. Which technology is most appropriate?

- A. Turbine flowmeter with hydrogen-compatible bearing materials
- B. Vortex flowmeter with a reduced-bore insert body
- C. Thermal mass flowmeter calibrated specifically for hydrogen
- D. Coriolis mass flowmeter with a small-bore tube design

3. Which thermocouple type uses Platinum-10% Rhodium as the positive conductor and pure Platinum as the negative conductor?

- A. Type K (Chromel/Alumel)
- B. Type J (Iron/Constantan)
- C. Type S (Pt-10%Rh/Pt)
- D. Type T (Copper/Constantan)

4. A manometer shows a reading of 45 inches of mercury at 32°F. Using the conversion factor 1 psi = 2.036 in Hg at 32°F, what is this pressure in psi?

- A. 22.1 psi
- B. 91.6 psi
- C. 45.0 psi
- D. 15.7 psi

5. A guided-wave radar (GWR) level transmitter reliably measures a low-dielectric hydrocarbon liquid ( $\epsilon_r \approx 2.0$ ) where a free-space radar struggles. What physical characteristic of GWR explains this advantage?

- A. GWR transmits at higher power levels than free-space radar
- B. GWR guides the microwave pulse along a probe, concentrating signal energy at the liquid surface regardless of surface reflectivity
- C. GWR uses a lower carrier frequency that penetrates low-dielectric media more effectively
- D. GWR applies digital signal processing to amplify weak surface reflections

6. A sensor is described as having a response time of 3 seconds. What specific parameter does this value characterize?

- A. The minimum time required between successive measurement samples

- B. The time for the sensor to complete one calibration cycle
- C. The time for the sensor output to reach 63.2% of its final value following a step change in the measured variable
- D. The time for the sensor to achieve rated accuracy after power-up

7. An electrochemical dissolved oxygen sensor uses a polymer membrane and internal electrolyte. Which process fluid condition most rapidly degrades the membrane and electrolyte, shortening sensor service life?

- A. Continuous immersion in neutral-pH clean water
- B. Process temperature cycling between 10°C and 30°C
- C. Water velocity exceeding the sensor's specified flow rate
- D. Exposure to fluids containing oils, solvents, or surfactants that chemically attack the membrane

8. A vibration monitoring system mounts two proximity probes at 90° to each other in an X-Y configuration around a rotating shaft. What primary measurement capability does this arrangement provide that a single proximity probe cannot?

- A. The complete two-dimensional orbital path traced by the shaft center within the bearing clearance
- B. Automatic gap compensation for thermally induced shaft position changes
- C. Redundant measurement with automatic failover if one probe fails
- D. Extended frequency response enabling detection of torsional vibration modes

9. A pressure transmitter is specified with  $\pm 0.1\%$  of reading accuracy and a range of 0–1,000 psi. What is the maximum allowable measurement error at a process pressure of 200 psi?

- A.  $\pm 1.0$  psi
- B.  $\pm 0.5$  psi
- C.  $\pm 0.2$  psi

D.  $\pm 0.1$  psi

10. In an area where oxygen concentration has dropped below 5% due to nitrogen blanketing, a hydrogen leak occurs. Which combustible gas detector technology can still detect hydrogen under these oxygen-deficient conditions?

A. Photoionization detector (PID) using a UV lamp ionization source

B. Thermal conductivity detector — hydrogen's uniquely high thermal conductivity produces a measurable signal independent of ambient oxygen

C. Electrochemical sensor calibrated for hydrogen detection

D. Catalytic bead sensor with an extended-range platinum catalyst

11. A DP transmitter is installed on a closed vessel with a wet reference leg. The LRV is  $-120$  in  $H_2O$ . The process liquid has  $SG = 0.75$ , the measurement span is 6 feet, and the wet leg ( $SG = 1.00$ ) is 10 feet above the lower tap. What is the transmitter URV?

A.  $-66$  in  $H_2O$

B.  $-12$  in  $H_2O$

C.  $+54$  in  $H_2O$

D.  $-54$  in  $H_2O$

12. A process gas chromatograph reports the sum of all component mole fractions as 98.4% rather than 100%. What most likely causes this discrepancy?

A. The carrier gas flow rate was slightly off during the analysis cycle

B. Temperature variation in the column oven shifted retention times for heavy components

C. Component peaks are overlapping in the chromatogram, biasing the baseline

D. One or more minor components present in the sample are not included in the calibration library and are therefore undetected and uncounted

13. A pressure transmitter calibration check shows: LRV error = +0.4%, mid-range error = +0.2%, URV error = -0.3%. Which combination of adjustments corrects this transmitter?

- A. Zero adjustment only
- B. Span adjustment only
- C. Both zero and span adjustments
- D. Linearity trim adjustment only

14. A UV-only flame detector in an industrial area produces false alarms during welding operations in an adjacent work area. Which detector type most effectively reduces these false alarms while maintaining fast response to real fires?

- A. Single-wavelength infrared detector tuned away from welding emission bands
- B. UV/IR combination detector — requires simultaneous UV and IR detection, which welding arcs cannot replicate
- C. Visible-light photocell detector calibrated to the hydrocarbon flame spectrum
- D. IR<sub>3</sub> triple-band infrared detector using three separate IR wavelength bands

15. A Pt100 RTD at 100°C has a theoretical resistance of 138.5 Ω per IEC 60751. The measured resistance is 139.2 Ω. Using  $\alpha = 0.385 \text{ } \Omega/^{\circ}\text{C}$  (sensitivity at 100°C), what is the temperature error?

- A. 0.7°C low
- B. 1.2°C high
- C. 0.7°C high
- D. 1.8°C high

16. A standard concentric orifice plate must be installed downstream of two 90° elbows in different planes. Approximately what minimum upstream straight pipe run is required to achieve specified measurement accuracy without a flow conditioner?

- A. 25–30 pipe diameters — two elbows in different planes create swirl in addition to profile distortion
- B. 5–8 pipe diameters
- C. 50–60 pipe diameters
- D. 10–12 pipe diameters

17. For the same measured differential pressure and pipeline size, which primary flow element produces the lowest permanent pressure loss in service?

- A. Standard concentric orifice plate
- B. Flow nozzle (ASME long-radius design)
- C. Venturi tube with a long diverging outlet cone
- D. Annubar averaging pitot tube

18. According to ANSI/ISA-5.1, which tag letter combination designates an instrument that performs both the indicating and controlling functions for a temperature measurement?

- A. TT
- B. TIC
- C. TRC
- D. TAC

19. A differential pressure transmitter has its high-pressure and low-pressure impulse line connections accidentally reversed during installation. What is the effect on the 4–20 mA output?

- A. The output reads correctly — the transmitter auto-corrects for reversed polarity

- B. The output saturates at 20 mA because reversed connections create an unresolvable signal
- C. The output reads 4 mA continuously because the reverse connection prevents current flow
- D. The output reverses — as process increases, the output decreases rather than increases, and the reading at any actual DP equals what would be expected for the negative of that DP value

20. A conductivity analyzer continuously monitors the purity of demineralized water used as boiler feedwater. An unexpected spike in conductivity is detected. Which process condition does this most likely indicate?

- A. A condensate contamination event or ion exchanger breakthrough introducing dissolved salts or ions into the demineralized water stream
- B. Elevated dissolved oxygen concentration from air ingress into the deaerator
- C. Elevated feedwater temperature reducing the water's electrical resistance at the electrode
- D. pH excursion caused by excessive chemical addition to the feedwater treatment system

21. In ANSI/ISA-5.1, which tag letter designates the function "Compute" or "Convert" when it appears as a succeeding letter in an instrument tag?

- A. C
- B. T
- C. R
- D. Y

22. A DP level transmitter on an open tank consistently reads 8% higher than the actual level measured by a manual dip tape. Process fluid composition is unchanged. Which cause is most likely?

- A. The transmitter span calibration was performed with water but the process fluid SG has increased from its calibrated value
- B. The DCS input card has developed a positive gain error on this channel

- C. The transmitter zero has drifted upward due to process fluid density changes in the impulse lines
- D. The low-pressure port vent is partially blocked, reducing the reference atmospheric pressure applied to the LP side

**DOMAIN 2: CONTROL SYSTEMS (Questions 23–44)**

23. A flow controller has  $K_c = 1.5$  and  $T_i = 8$  seconds. The loop is currently at setpoint with output = 55%. A step disturbance drives the PV to 4% below setpoint. What is the immediate proportional output change?

- A. +6.0%
- B. -4.0%
- C. +4.0%
- D. -6.0%

24. According to ANSI/ISA-5.1, which tag correctly identifies an instrument that indicates and records differential pressure in loop 225?

- A. DPC-225
- B. DPR-225
- C. PDT-225
- D. DPIR-225

25. A liquid level controller manipulates an outlet control valve to maintain tank level at setpoint. As level rises above setpoint, the outlet valve must open further to drain the tank. The valve is air-to-open (fail-closed). Which controller action is correct?

- A. Reverse acting with air-to-close valve
- B. Direct acting — as level (PV) rises above setpoint, controller output increases, opening the ATO outlet valve

- C. Reverse acting with air-to-open valve
- D. Direct acting with a split-range arrangement

26. A process step test in manual mode shows the following results: output stepped from 40% to 50%, PV first responds at  $t = 3$  min, and reaches 63.2% of total change at  $t = 11$  min. PV moved from  $75^{\circ}\text{C}$  to  $90^{\circ}\text{C}$  total. What is the time constant?

- A. 11 minutes
- B. 14 minutes
- C. 8 minutes
- D. 3 minutes

27. A DCS scan executes at 500 milliseconds. A process pressure oscillation at 1.5 Hz is present in the measurement. According to the Nyquist criterion, what minimum sampling rate is required to accurately represent this 1.5 Hz signal?

- A. 3.0 Hz (333 ms scan) — the current 500 ms scan is insufficient
- B. 1.5 Hz (667 ms scan)
- C. 6.0 Hz (167 ms scan)
- D. 0.75 Hz (1,333 ms scan)

28. Which IEC 61131-3 programming language uses a graphical network of interconnected function blocks where data flows from outputs of one block to inputs of another, most naturally representing continuous regulatory control logic?

- A. Ladder Diagram
- B. Structured Text
- C. Sequential Function Chart
- D. Function Block Diagram

29. A feedforward controller is calibrated assuming a heat exchanger overall heat transfer coefficient ( $U$ ) of  $350 \text{ BTU/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$ . After 18 months of service, fouling has reduced  $U$  to  $210 \text{ BTU/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$ . What effect does this model mismatch produce?

- A. The feedback controller output saturates because the feedforward signal is now too large for the process
- B. The feedforward control under-corrects for disturbances — the reduced actual heat transfer means more steam is required than the model predicts, leaving residual errors for feedback to correct
- C. The control loop goes unstable because the feedforward gain exceeds the inverse process gain
- D. The feedforward output produces oscillations because the model-process mismatch creates a resonance condition

30. According to ISA-18.2, which condition defines an alarm as requiring "rationalization" — that is, review and potentially modification or removal?

- A. Any alarm whose setpoint has not been reviewed in more than 12 months
- B. Any alarm that activates more than 5 times per day under normal operating conditions
- C. Any alarm that, upon analysis, does not require a timely operator response or has no associated documented operator action
- D. Any alarm sharing a setpoint with another alarm at the same instrument

31. A proportional-only level controller with  $K_c = 1.8$  is operating at steady state with setpoint = 50% and  $PV = 53\%$ . The output is 40%. What was the controller output when the process was at setpoint (50%)?

- A. 34.6%
- B. 45.0%
- C. 53.0%
- D. 40.0%

32. A process engineer reviews a closed-loop step response and observes that the process variable reaches 120% of the setpoint step amplitude before decaying back. On the second oscillation, the peak reaches 30% of the step amplitude above setpoint. What is the decay ratio?

- A. 0.12
- B. 0.20
- C. 0.25
- D. 0.30

33. In the IEC 61131-3 Ladder Diagram language, what is the functional difference between a latch (set) coil and a standard output coil?

- A. A latch coil energizes for only one scan cycle; a standard output coil energizes continuously
- B. A latch coil remains energized (latched) even after the rung conditions become false — it retains its TRUE state until explicitly unlatched by a corresponding unlatch instruction
- C. A latch coil controls physical field devices; a standard output coil controls internal DCS memory bits only
- D. A latch coil requires 24 VDC power; a standard output coil operates on the program scan power

34. A process control loop in a chlorine scrubber uses override control. A flow controller normally maintains reagent flow at setpoint. An analyzer controller overrides when pH drops below a low-pH constraint. The reagent flow control valve opens to add more reagent. Which signal selector passes the correct signal to the valve?

- A. Low selector — passes the lower of the two outputs to the flow control valve
- B. High selector — passes the lower output during override
- C. A high selector — the analyzer controller demands higher flow (greater valve opening) when pH drops, and the high selector passes this larger signal to the valve
- D. A median selector eliminating outlier controller outputs during transitions

35. A control room upgrade replaces an older pneumatic board-mounted controller with a DCS. The original proportional-only pneumatic controller used 100% proportional band. What initial DCS PID settings most closely replicate this original controller?

- A.  $K_c = 1.0$ ,  $T_i = \text{very large (integral effectively disabled)}$ ,  $T_d = 0$
- B.  $K_c = 100$ ,  $T_i = 100 \text{ seconds}$ ,  $T_d = 0$
- C.  $K_c = 0.01$ ,  $T_i = 0 \text{ seconds}$ ,  $T_d = 0$
- D.  $K_c = 1.0$ ,  $T_i = 10 \text{ seconds}$ ,  $T_d = 1 \text{ second}$

36. A high-pressure separator vessel has three controllers — pressure, level, and temperature — that interact significantly. The control engineer implements Model Predictive Control replacing the three independent PID loops. What specific MPC capability addresses this multi-variable interaction?

- A. MPC applies Ziegler-Nichols tuning simultaneously to all three loops using a unified gain calculation
- B. MPC's process model explicitly captures the interactions between all three variables and computes coordinated control moves that optimize all three simultaneously within a single calculation
- C. MPC decouples the three loops using a real-time interaction matrix that eliminates cross-variable effects before computing individual loop outputs
- D. MPC prioritizes the highest-consequence controlled variable and resolves interactions by temporarily suspending control of lower-priority variables

37. A cascade control scheme has an outer composition controller ( $\tau \approx 45 \text{ min}$ ) driving the setpoint of an inner temperature controller ( $\tau \approx 3 \text{ min}$ ). The inner loop time constant ratio (outer/inner) is 15:1. What does this ratio confirm about the cascade arrangement?

- A. The inner loop is too fast — the 15:1 ratio exceeds the maximum recommended ratio and will cause the inner loop to respond before the outer loop setpoint is stable
- B. The inner loop is too slow — a minimum ratio of 20:1 is required for cascade control to provide measurable performance improvement
- C. The outer loop is too slow for effective cascade — response improvement requires the outer loop to respond faster than the inner loop

D. The ratio confirms effective cascade — the inner loop responds approximately 15 times faster than the outer loop, satisfying the rule of thumb that inner loops should be at least 3–5 times faster

38. A security audit of an OT system finds that all DCS operator workstations run the same operating system version and share the same user account database with the engineering workstations. Which security vulnerability does this configuration introduce?

A. Common credentials across operator and engineer workstations allow operators to access engineering functions without additional authorization, violating separation of duties

B. Shared operating system versions create a single point of failure for software licensing compliance

C. Common user accounts prevent the DCS from logging which specific individual made each configuration change

D. Shared infrastructure increases the computational load on the user authentication server

39. A level controller in a reflux drum uses proportional-only control with  $K_c = 3.0$ . The drum is near-empty at 8% level. An operator increases the setpoint to 50%. What is the initial controller output change if the output was at 28% when the setpoint was at 8%?

A. +126%

B. +42%

C. -42%

D. -126%

40. A process experiences a sudden 15% increase in feed flow rate — a large disturbance. The feedback PID controller begins correcting the process variable deviation after a 90-second dead time. A feedforward controller measuring the feed flow change acts immediately at  $t = 0$ . What is the primary advantage of the feedforward response in this scenario?

A. Feedforward eliminates the need for integral action in the feedback controller after the disturbance

B. Feedforward prevents controller output from saturating during the 90-second dead time period by applying a counteracting correction before the PV deviation develops

- C. Feedforward removes the 90-second dead time from the feedback loop entirely
- D. Feedforward increases the effective controller gain beyond what the feedback loop can achieve alone

41. Using Ziegler-Nichols open-loop PID rules, a bump test yields:  $K_p = 2.0\%/%$ ,  $\tau = 80$  seconds,  $\theta = 20$  seconds. What are the recommended PID settings?

- A.  $K_c = 2.40$ ,  $T_i = 40$  s,  $T_d = 10$  s
- B.  $K_c = 1.60$ ,  $T_i = 40$  s,  $T_d = 10$  s
- C.  $K_c = 2.40$ ,  $T_i = 80$  s,  $T_d = 20$  s
- D.  $K_c = 2.40$ ,  $T_i = 40$  s,  $T_d = 20$  s

42. In ISA S88 batch control, what is the distinction between a "recipe" and a "procedure"?

- A. A recipe specifies both the process and product requirements — it is the complete set of instructions for producing a specific product including equipment requirements, process parameters, and procedural logic; a procedure describes only the control actions without product-specific parameters
- B. A recipe is stored in the DCS; a procedure is stored in the operator console
- C. A recipe applies to one batch; a procedure applies to a continuous production campaign
- D. A recipe is written by process engineers; a procedure is written by control systems engineers

43. A split-range temperature controller manipulates a cooling water valve (0–50% output range) and a heating steam valve (50–100% output range). At 48% controller output, the cooling valve is at 4% open and the steam valve is fully closed. At 52%, the cooling valve is fully closed and the steam valve is at 4% open. What describes the behavior in the 48–52% output range?

- A. Normal split-range behavior with overlapping valve action during the transition
- B. Simultaneous heating and cooling as both valves are cracked open near the crossover point
- C. A deadband region — both valves are near-closed simultaneously, providing neither heating nor cooling near the neutral position

D. Integral windup accumulation because the controller cannot achieve exact setpoint through the crossover region

44. An OT security assessment finds that an automated data backup system copies DCS controller configuration files to a network-attached storage device located on the corporate IT network every night. What is the primary cybersecurity concern?

A. The backup copies consume excessive network bandwidth during the nightly transfer window

B. DCS configuration files stored on IT infrastructure may be accessed, modified, or exfiltrated by parties who should not have visibility into safety-critical process control logic

C. Nightly backups are insufficient — DCS configuration should be backed up continuously in real time

D. The backup system creates audit log entries that are difficult to distinguish from legitimate engineering access events

### **DOMAIN 3: FINAL CONTROL ELEMENTS (Questions 45–62)**

45. A liquid flow service requires a control valve with  $C_v = 55$ . Standard globe valve sizes available offer:  $C_v = 40, 63, 100,$  and  $160$ . The engineer selects  $C_v = 63$ . At what percentage of rated  $C_v$  does this valve operate at maximum flow?

A. 55%

B. 63%

C. 40%

D. 87%

46. A process engineer specifies an equal percentage control valve for a heat exchanger temperature control application where the pressure drop across the valve decreases significantly as flow increases. What installed characteristic will this valve produce in this piping system?

A. A more linear installed characteristic than the equal percentage inherent curve

- B. A quick-opening installed characteristic due to the combined effect of falling DP and the inherent characteristic
- C. An identical installed characteristic to the equal percentage inherent curve regardless of system DP variation
- D. A purely linear characteristic only when the valve DP equals exactly 50% of total system drop

47. A carbon steel control valve body is installed in a cryogenic ethylene service at  $-104^{\circ}\text{C}$ . What is the primary material concern?

- A. Carbon steel is fully acceptable for cryogenic ethylene service below  $-75^{\circ}\text{C}$  per ASME standards
- B. Carbon steel body is inadequate — standard carbon steel becomes brittle at cryogenic temperatures below approximately  $-46^{\circ}\text{C}$ , requiring austenitic stainless steel or other cryogenic-rated materials
- C. Carbon steel is acceptable if the valve includes a full-penetration weld overlay of stainless steel on all wetted surfaces
- D. Carbon steel is the preferred cryogenic material because it maintains higher yield strength than austenitic materials below  $-100^{\circ}\text{C}$

48. A 6-inch butterfly valve throttling hot oil at 40% open and 120 psi differential pressure experiences what valve-specific mechanical challenge?

- A. The disc erodes asymmetrically because flow attacks the upstream face preferentially
- B. High differential pressure creates a large torque reversal through the disc as it rotates past the  $60-70^{\circ}$  angle, potentially exceeding actuator torque capacity and causing uncontrolled disc movement
- C. The elastomeric seat experiences compression set at elevated temperatures, reducing shutoff class over time
- D. Thermal expansion of the disc shaft causes binding in the stem bearings at operating temperature

49. A conventional spring-loaded PRV with set pressure of 180 psig and 7% blowdown is installed on a vessel with a superimposed back pressure of 25 psig. What is the actual opening pressure of this valve at this back pressure condition?

- A. 180 psig
- B. 155 psig
- C. 205 psig
- D. 207 psig

50. A process engineer calculates that a pump VSD operating at 85% of rated speed will deliver the required flow. Using the affinity law for power, what percentage of rated shaft power does the pump consume at 85% speed?

- A. 61.4%
- B. 72.3%
- C. 85.0%
- D. 42.5%

51. A rupture disc must be specified for a vessel where the operating pressure reaches 88% of the required burst pressure during normal operations. Which disc type is appropriate for this high operating ratio?

- A. Standard forward-acting tension disc with scored lines
- B. Conventional solid metal tension disc without scoring
- C. Reverse-buckling disc — tolerates operating pressures up to 90% of rated burst pressure without fatigue effects from pressure cycling
- D. Graphite composite disc rated for maximum operating ratio of 80%

52. A solenoid valve used as an ESD block valve trips at 2 AM during normal process operations while the SIS output remains energized. What is the most likely cause?

- A. The SIS logic solver experienced a temporary power dip that momentarily de-energized the solenoid
- B. The solenoid coil has failed open — loss of electromagnetic force allowed the internal spring to shift the solenoid to its de-energized position despite the continued electrical signal
- C. The ESD valve received a spurious trip signal from the DCS analog output card driving the solenoid
- D. The solenoid valve spool has stuck in the tripped position from contamination in the instrument air supply

53. A control valve sizing calculation for saturated steam service at 150 psig inlet pressure yields  $C_v_{\text{required}} = 28$ . The valve FL factor is 0.90. The downstream pressure is 30 psig. Is the flow choked?

- A. No — the pressure ratio  $x = (150-30)/165 = 0.73$  exceeds  $x_T$  for most valves
- B. No — the flow is well within the subcritical regime at this pressure ratio
- C. Yes — the pressure ratio  $x = (150-30)/165 = 0.73$  should be compared to the valve's  $x_T$ ; for  $FL = 0.90$ ,  $x_T \approx 0.72$ , so  $x$  slightly exceeds  $x_T$  indicating choked flow
- D. Choked flow cannot occur in steam service — only in gas service

54. An electric motor-operated valve (MOV) is specified as a block valve for a 16-inch gas pipeline. The actuator is sized for the breakaway torque at maximum differential pressure. During commissioning, the valve seals incorrectly — it closes only 97% of the required travel. What is the most likely cause?

- A. The motor torque limit is set too low — the actuator trips on torque overload before achieving full seating force against the line pressure
- B. The motor is undersized for the pipeline diameter
- C. The limit switch is incorrectly set, stopping the motor before the disc reaches the full-closed mechanical stop
- D. The valve disc has thermally expanded beyond tolerance due to the process gas temperature

55. A live-loaded valve packing system uses disc springs (Belleville washers) stacked in the packing gland. What performance advantage does this arrangement provide over a conventional packed gland?

- A. The disc spring loading maintains continuous packing compression as the PTFE or graphite packing consolidates and wears, preventing fugitive emission leakage from developing between scheduled maintenance intervals
- B. Disc springs allow higher packing gland temperatures than conventional gland followers
- C. Disc springs amplify the gland bolt torque, allowing tighter packing compression with less bolt force
- D. Disc springs provide vibration isolation between the valve stem and the packing rings

56. A 150 hp motor runs a centrifugal pump continuously. A VSD is proposed to replace the throttling control valve. At average operating conditions, the pump runs at 72% of rated speed. What is the approximate annual energy saving compared to across-the-line operation with valve throttling?

- A. 28% reduction in motor energy consumption
- B. 62.6% reduction in motor energy consumption
- C. 72% reduction in motor energy consumption
- D. 20% reduction in motor energy consumption

57. In an API 527 seat leakage test at 90% of set pressure, what is the acceptance criterion for a metal-seated conventional PRV designated as Class II?

- A. Zero visible leakage — same requirement as soft-seated Class III valves
- B. Up to 40 bubbles per minute
- C. Up to 20 standard cubic feet per hour
- D. Up to 20 bubbles per minute

58. A pilot-operated PRV uses remote pilot sensing — the pilot valve senses pressure at a point 15 feet above the main valve on a vessel riser. The riser contains liquid. What effect does this installation geometry produce on the valve opening pressure?

- A. The remote sensing arrangement has no effect — pilot-operated valves sense pressure regardless of the sensing line geometry
- B. The higher sensing point does not affect the set pressure for liquid service because liquids are incompressible
- C. The liquid head in the 15-foot sensing line reduces the pressure sensed at the pilot below the vessel operating pressure — the valve opens at a lower vessel pressure than its nominal set pressure
- D. The remote sensing line must be gas-filled to avoid this effect — a liquid-filled sensing line is prohibited by API 520

59. A control valve trim material must resist both corrosion from dilute nitric acid and erosion from entrained catalyst particles. Which trim material selection provides the best combined corrosion and erosion resistance for this service?

- A. Tungsten carbide coating on a stainless steel substrate
- B. Type 316 stainless steel with chrome plating
- C. Hardened Stellite (cobalt-based alloy) with hard chrome overlay
- D. Titanium alloy with ceramic coating

60. A process plant specifies a control valve for oxygen service at 500 psig and ambient temperature. Which requirement is most critical for oxygen service valve specification?

- A. The valve body must be carbon steel to withstand the high pressure of oxygen service
- B. All wetted parts must be thoroughly cleaned to remove hydrocarbon contamination — ignition of hydrocarbons in high-pressure oxygen is a severe fire and explosion hazard requiring oxygen-compatible materials and stringent cleanliness
- C. The valve must use a pneumatic actuator rated for the oxygen service temperature range
- D. An air-to-open fail position is mandatory for oxygen isolation valves

61. A check valve in a liquid service chatters at low flow. An engineer replaces it with a spring-assisted check valve. What specific characteristic of the spring-assisted design prevents chattering?

- A. The spring maintains a positive closing force on the disc throughout the flow range — preventing the disc from reaching a partial-open flutter condition by requiring minimum flow velocity to overcome the spring and open fully
- B. The spring dampens mechanical vibrations transmitted from upstream pumping equipment
- C. The spring increases seat contact force, improving shutoff class and preventing reverse flow leakage
- D. The spring provides faster closing response during flow reversal events

62. A valve manufacturer's catalog shows a globe valve with  $FL = 0.95$  and a ball valve with  $FL = 0.55$  for the same nominal size. A liquid service has inlet pressure  $P_1 = 200$  psia and vapor pressure  $P_v = 40$  psia. The valve pressure drop is  $\Delta P = 100$  psi. Calculate  $\sigma$  and identify which valve is more susceptible to cavitation.

- A.  $\sigma = 1.60$ ; globe valve is more susceptible because higher  $FL$  indicates lower pressure recovery
- B.  $\sigma = 1.00$ ; both valves are equally susceptible at  $\sigma = 1.00$
- C.  $\sigma = 0.80$ ; both valves experience cavitation because  $\sigma < 1.0$
- D.  $\sigma = 1.60$ ; ball valve is more susceptible because lower  $FL$  indicates higher pressure recovery at the vena contracta, requiring  $\sigma_c$  values typically higher than the calculated  $\sigma$

**DOMAIN 4: SIGNALS, TRANSMISSION, and NETWORKING (Questions 63–75)**

63. A 4–20 mA instrument loop operates with a 24 VDC supply. The loop contains a 250  $\Omega$  input resistor, a galvanic isolator with 50  $\Omega$  series resistance, and a cable with 130  $\Omega$  total loop resistance. What is the transmitter terminal voltage at maximum loop current?

- A. 15.6 VDC
- B. 17.2 VDC
- C. 11.4 VDC

D. 19.0 VDC

64. A PROFIBUS DP master polls 24 slave devices at 1.5 Mbit/s with an average scan cycle time of 8 milliseconds. An engineer adds 8 more devices. Assuming equal polling time per device, what is the approximate new scan cycle time?

- A. 8 ms — PROFIBUS DP cycle time is independent of device count
- B. 10.7 ms — scan time scales linearly with device count:  $8 \text{ ms} \times (32/24)$
- C. 12.0 ms — cycle time increases by 4 ms minimum per additional device group
- D. 16.0 ms — cycle time doubles when device count exceeds 24

65. An OT network security policy prohibits all USB storage media. An engineer discovers that a vendor technician plugged an unauthorized USB drive into a DCS engineering workstation during a service visit 3 weeks ago. Which security control would most effectively have prevented this event?

- A. Network firewall rules blocking any traffic originating from USB-connected devices
- B. Antivirus software on the engineering workstation to scan inserted USB media
- C. Security awareness training reminding vendors of the USB prohibition policy
- D. USB port lockdown at the hardware or operating system level — disabling all USB storage device connections regardless of any individual's decision to plug in a device

66. A plant uses a 2-wire HART transmitter installed 450 meters from the control room. The cable has resistance of  $44 \Omega$  per 1,000 meters. The total loop includes a  $250 \Omega$  input resistor at the DCS. If the DCS supply is 24 VDC and the transmitter requires minimum 12 VDC, what maximum additional series resistance (from barriers, isolators, etc.) is allowable?

- A.  $231 \Omega$
- B.  $187 \Omega$
- C.  $270 \Omega$
- D.  $155 \Omega$

67. An industrial Ethernet network uses managed switches with VLAN segmentation. VLAN 10 contains DCS controller I/O, VLAN 20 contains DCS operator workstations, and VLAN 30 contains a process historian. An engineer discovers that VLAN 10 devices can reach VLAN 30 devices directly. What configuration issue most likely causes this?

- A. The historian VLAN (30) is not tagged on the trunk port connecting the two switches
- B. The switches are using Spanning Tree Protocol rather than RSTP
- C. An inter-VLAN routing policy on the managed switch or connected router permits traffic between VLAN 10 and VLAN 30 without access control filtering
- D. The VLAN IDs are too close numerically — VLANs must be separated by a minimum numerical gap of 100 to prevent address collision

68. A 12-bit DAC in a DCS analog output card produces a 4–20 mA signal representing a 0–100% valve position. An engineer upgrades to a 16-bit DAC. How does the minimum commandable valve position increment change?

- A. The resolution improves by a factor of 8 — from 0.0244% to 0.003% of travel
- B. The resolution improves by a factor of 16 — from 0.0244% to 0.00153% of travel
- C. The resolution improves by a factor of 4 — from 0.0244% to 0.006% of travel
- D. The resolution does not change — resolution is limited by the positioner dead band, not the DAC

69. A WirelessHART instrument at the far edge of a network has only one available communication path to the gateway. The path reliability is 92%. What feature of the WirelessHART standard most directly improves this communication reliability?

- A. The WirelessHART gateway automatically repositions itself closer to the edge instrument when path reliability drops below 95%
- B. WirelessHART instruments can increase their transmit power proportionally to the inverse of path reliability

C. WirelessHART uses time-synchronized channel hopping across 15 channels — if a transmission fails on one channel, the next scheduled transmission uses a different channel, statistically reducing the probability of consecutive failures

D. WirelessHART requires a minimum of three simultaneous communication paths for all devices

70. Which statement correctly describes why single-mode fiber optic cable is preferred over multi-mode fiber for long-distance (> 2 km) industrial control system communication links?

A. Single-mode fiber uses a different connector standard that provides lower connection attenuation than multi-mode fiber connectors

B. Single-mode fiber requires less frequent signal amplification — the core diameter is smaller, reducing modal dispersion that limits multi-mode fiber transmission distance at high data rates

C. Single-mode fiber is immune to electromagnetic interference while multi-mode fiber requires shielding in high-EMI environments

D. Single-mode fiber supports a wider range of operating temperatures than multi-mode fiber

71. A cybersecurity review evaluates a DCS network architecture. The review finds that the DCS historian server has two network interface cards — one connected to the OT DCS network and one directly connected to the IT corporate network. The server runs historian software and handles corporate report generation. What architecture concern does this represent?

A. Dual-NIC servers require additional power supply capacity that may exceed the UPS rating

B. Dual-NIC configuration may exceed the historian software's licensed node count

C. The dual-NIC server creates a direct bridge between the OT and IT networks — any compromise of the IT-connected interface provides a direct path to the OT network, bypassing the firewall and DMZ controls

D. Corporate report generation creates audit log entries on the OT network that complicate security monitoring

72. In the NEC hazardous location classification system, Class II locations contain which type of hazardous material?

- A. Flammable gases and vapors
- B. Combustible dusts
- C. Ignitable fibers and flyings
- D. Explosive materials and oxidizers

73. A 4–20 mA signal is transmitted over a 300-meter cable with 30  $\Omega$  total loop resistance. The signal represents a 0–500 psi pressure range. What is the pressure reading error introduced by the cable resistance if the receiver uses a voltage-reading approach with a 250  $\Omega$  input resistor?

- A. None — the 4–20 mA current loop is immune to cable resistance; the current through all series resistances is identical and the DCS reads current, not voltage
- B. A 5% reading error proportional to the cable-to-total resistance ratio
- C. A zero shift of approximately 12 psi from the cable resistance voltage drop
- D. A span error of approximately 3% from the increased total loop impedance

74. An engineer is specifying communication between a DCS in Building A and a safety logic solver in Building B, 800 meters away. The signal must arrive with sub-50-millisecond latency and the route passes through a high-EMI electrical switchyard. Which transmission medium is most appropriate?

- A. RS-485 cable at 115,200 baud with enhanced shielding and repeaters
- B. Multi-mode fiber optic cable with industrial Ethernet at 100 Mbit/s
- C. Category 5e shielded twisted pair Ethernet with lightning protection
- D. WirelessHART mesh link using the 2.4 GHz band for latency-independent transmission

75. A security operations team implements continuous monitoring on the OT network. An alert triggers at 2:47 AM when a DCS engineering workstation initiates an unusual outbound connection to an external IP address. What security principle does this monitoring activity support?

- A. Security risk assessment — continuous monitoring provides data for the next annual risk assessment
- B. Patch management — outbound connections may indicate the workstation is attempting to download unauthorized patches
- C. Timely detection and response to security events — continuous monitoring enables identification of anomalous behavior that may indicate compromise, allowing response before significant damage occurs
- D. Physical security — remote monitoring supplements camera surveillance of the control room environment

#### **DOMAIN 5: SAFETY SYSTEMS (Questions 76–85)**

76. According to IEC 61511, a Safety Requirements Specification must include which specific element that distinguishes it from a general functional specification?

- A. A list of all instruments and final elements proposed for the SIS with manufacturer and model information
- B. The required Safety Integrity Level (SIL) for each safety instrumented function along with the associated PFD or PFH target derived from the risk assessment
- C. A schedule for when each SIF will be commissioned and validated during the project execution phase
- D. A cost estimate for all SIS hardware procurement including spare parts and long-term maintenance

77. A SIF proof test achieves 85% diagnostic coverage (partial test) because the final element cannot be stroked during normal process operations. The total SIF PFD\_avg assuming 100% test coverage is  $3.0 \times 10^{-3}$ . How does the partial proof test credit affect the achieved PFD?

- A. The PFD is slightly higher than  $3.0 \times 10^{-3}$  because 15% of dangerous failures in the final element accumulate without detection until the next complete proof test

B. The PFD remains  $3.0 \times 10^{-3}$  — IEC 61511 accepts documented partial proof tests as full coverage for PFD calculation purposes

C. The PFD doubles to  $6.0 \times 10^{-3}$  because partial tests are credited at 50% of complete test credit

D. The PFD increases to  $9.0 \times 10^{-3}$  because the 15% undetected failures are multiplied by a regulatory safety factor of 3

78. A process hazard analysis identifies a scenario where a runaway exothermic reaction can cause vessel rupture. The consequence is catastrophic with potential for multiple fatalities. Risk reduction from existing safeguards falls short of the tolerable risk criterion by a factor of 500. What minimum SIL does this required risk reduction of 500 correspond to?

A. SIL 3 — the required PFD is  $1/500 = 0.002$ , which falls within the SIL 3 range of 0.001–0.01

B. SIL 2 — the required PFD is  $1/500 = 0.002$ , which falls within the SIL 2 range of 0.001–0.01

C. SIL 4 — risk reduction factors above 100 always require SIL 4

D. SIL 1 — risk reduction factor of 500 is below the SIL 2 threshold of 1,000

79. A SIS protects against high pressure using a 1oo2 pressure transmitter voting arrangement. Transmitter A is found during a proof test to have a systematic +3 psi calibration offset — it reads 3 psi higher than actual process pressure. The trip setpoint is 150 psig. Which statement correctly describes the consequence for the high-pressure protection function?

A. Transmitter A's high offset causes it to report below-setpoint pressure as at-setpoint — it will not detect real pressure exceedances and reduces the SIF to effective 1oo1 protection from Transmitter B only

B. The SIF fails entirely — a systematic calibration error in any sensor voids the SIL verification until the transmitter is recalibrated

C. Transmitter A's +3 psi offset makes it reach its trip threshold 3 psi earlier than intended — it activates at 147 psig actual, which means it still contributes to high-pressure protection (and increases spurious trip probability below 150 psig actual)

D. The SIF remains at full SIL 2 performance because calibration offsets are within normal measurement uncertainty bands specified in the SRS

80. A process modification adds a new heat source to a vessel protected by an existing SIF. The new heat source increases the maximum credible temperature rise rate from 2°C/min to 8°C/min. The SRS specifies a maximum SIF response time of 30 seconds. What concern does this change introduce?

- A. The faster temperature rise rate increases the likelihood that the SIF demand will coincide with a scheduled proof test outage
- B. The faster temperature rise rate means the process reaches dangerous conditions 4 times sooner — the SRS response time of 30 seconds may no longer be adequate to prevent the hazardous condition before damage occurs, requiring re-evaluation of the maximum allowable response time
- C. The new heat source introduces a new initiating cause that must be added to the SIL verification as an additional independent failure mode
- D. The higher heat input increases the SIF demand rate, potentially converting the function from low-demand to high-demand mode

81. A LOPA analysis for a gas compressor overpressure scenario yields: initiating event = 0.2/year, BPCS high-pressure controller PFD = 0.1, independent pressure relief valve PFD = 0.01. Risk tolerance =  $10^{-5}$ /year. What is the required SIF PFD?

- A. 0.10 — SIL 1
- B. 0.01 — SIL 2
- C. 0.001 — SIL 3
- D.  $5 \times 10^{-3}$  — SIL 2

82. Two identical pressure transmitters in a 1oo2 voting configuration each have  $\lambda_{DU} = 2 \times 10^{-6}$ /hr, proof test interval TI = 8,760 hours, and  $\beta = 0.05$ . What is the combined PFD\_avg?

- A.  $1.02 \times 10^{-4}$
- B.  $4.38 \times 10^{-4}$
- C.  $5.40 \times 10^{-4}$
- D.  $1.75 \times 10^{-2}$

83. Following a SIS proof test, two of the three transmitters in a 2oo3 voting arrangement are found to have failed in the safe direction (voting for trip) simultaneously. What term describes this condition and what immediate action is required?

A. A spurious trip demand — the 2oo3 voting logic has two of three sensors demanding a trip, which activates the SIF protective action; the process must be brought to a safe state and the faulty sensors identified and repaired before restart

B. A common cause failure — the simultaneous safe-direction failure of both sensors must be investigated for a shared root cause before returning either transmitter to service

C. A dangerous detected failure — the SIF remains available because the third sensor is functioning correctly and can maintain protection independently

D. A proof test anomaly — simultaneous failures during proof testing are statistically expected and do not require immediate shutdown

84. According to IEC 61511, which condition specifically triggers the requirement for a formal functional safety assessment (FSA) prior to SIS startup?

A. When the SIS controls more than 10 independent safety instrumented functions simultaneously

B. When the SIS design phase transitions to the installation and commissioning phase — the FSA at this lifecycle stage verifies that the design meets all SRS requirements before physical implementation proceeds

C. When the SIS cost exceeds the project's capital budget threshold requiring management review

D. When the SIS interfaces with BPCS equipment from a different manufacturer than originally specified

85. A SIS engineer evaluates whether increasing the proof test interval from 6 months to 12 months for a 1001 SIF with  $\lambda_{DU} = 1 \times 10^{-6}/\text{hr}$  maintains SIL 2 compliance. What is the PFD\_avg at the 12-month interval?

A.  $2.19 \times 10^{-3}$

B.  $4.38 \times 10^{-3}$

C.  $1.10 \times 10^{-2}$

D.  $8.76 \times 10^{-3}$

# PRACTICE EXAM 6: ANSWER KEY AND EXPLANATIONS

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1. B — At 400 gpm (50% of maximum), the square root relationship gives  $\Delta P = \Delta P_{\text{max}} \times (Q/Q_{\text{max}})^2 = 150 \times (0.50)^2 = 37.5$  in H<sub>2</sub>O. The DP varies with the square of the flow ratio — at half maximum flow, only one-quarter of full-scale DP is produced.
2. D — Coriolis mass flowmeters measure mass flow directly through the Coriolis force effect on a vibrating tube, independent of gas density variations with pressure and temperature. For high-pressure hydrogen custody transfer, direct mass flow measurement eliminates the density compensation errors that affect volumetric technologies.
3. C — Type S thermocouples use Platinum-10% Rhodium as the positive conductor and pure Platinum as the negative conductor, covering 0 to 1480°C. Type R uses Platinum-13% Rhodium — the rhodium percentage is the sole distinguishing feature between these two high-accuracy precious metal types.
4. A —  $P = 45 \text{ in Hg} \div 2.036 \text{ in Hg/psi} = 22.1 \text{ psi}$ . The conversion factor 1 psi = 2.036 in Hg at 32°F must be applied in the correct direction — dividing the manometer reading in inches of mercury by the conversion factor to obtain psi.
5. B — Guided-wave radar concentrates microwave pulse energy along a physical probe extending through the fluid, ensuring adequate signal energy reaches the liquid surface regardless of the surface's reflectivity. Free-space radar requires sufficient dielectric contrast at the surface to generate a detectable reflection — low-dielectric hydrocarbons ( $\epsilon_r \approx 2.0$ ) produce very weak free-space reflections that GWR avoids by guiding energy directly to the interface.
6. C — Sensor response time is defined as the time required for the output to reach 63.2% of its final value following a step change in the measured variable — this is the first time constant ( $\tau$ ) of the sensor's first-order dynamic response. This definition allows direct comparison of sensor speed and enables dead time and time constant estimation for control loop design.
7. D — Oils, solvents, and surfactants chemically attack the polymer membrane of dissolved oxygen sensors, causing swelling, cracking, or permeability changes that allow non-target species to reach the electrode. This membrane degradation simultaneously reduces sensor sensitivity and shortens service life more rapidly than any physical or thermal factor within normal operating ranges.
8. A — Two proximity probes mounted 90° apart in an X-Y configuration simultaneously measure shaft displacement in two perpendicular radial directions, enabling reconstruction of the complete two-dimensional orbital path traced by the shaft center within the bearing clearance. A single probe

measures displacement in only one radial direction and cannot detect the shape or orientation of the orbit.

9. C — Accuracy expressed as  $\pm\%$  of reading applies to the actual measured value:  $\pm 0.1\% \times 200 \text{ psi} = \pm 0.2 \text{ psi}$ . At low readings, the  $\%$  of reading specification produces much smaller absolute errors than  $\%$  of full-scale specifications — at 200 psi on a 1,000 psi range,  $\pm 0.1\%$  FS would give  $\pm 1.0$  psi while  $\pm 0.1\%$  of reading gives only  $\pm 0.2$  psi.
10. B — Thermal conductivity detectors measure gas concentration by detecting differences in heat transfer between a heated wire and the surrounding gas, a mechanism entirely independent of ambient oxygen concentration. Hydrogen's uniquely high thermal conductivity (approximately  $7\times$  that of air) produces a strong, reliable signal even in completely oxygen-deficient environments where catalytic bead sensors produce no output.
11. A —  $URV = LRV + \text{process fluid head at } 100\% \text{ level}$ . At 100% level (6 ft above lower tap), HP side =  $6 \times 12 \times 0.75 = 54$  in  $H_2O$ . LP side (wet leg, 10 ft,  $SG = 1.00$ ) =  $10 \times 12 \times 1.00 = 120$  in  $H_2O$ .  $URV = 54 - 120 = -66$  in  $H_2O$ . The confirmed  $LRV = 0 - 120 = -120$  in  $H_2O$  verifies the calculation.
12. D — A gas chromatograph sums the areas under all detected peaks to calculate component mole fractions. If minor components present in the sample lack corresponding calibration entries, their peaks are either undetected or uncounted, causing the sum of reported fractions to fall below 100%. This is one of the most common GC accuracy issues in complex hydrocarbon streams.
13. C — A positive LRV error ( $+0.4\%$ ) combined with a negative URV error ( $-0.3\%$ ) indicates the output curve has both an offset (zero error) and an incorrect slope (span error). Pure zero errors produce identical errors at all calibrated points; the diverging pattern here requires both zero and span adjustments to correct simultaneously.
14. B — UV/IR combination detectors require simultaneous detection of both ultraviolet and infrared radiation, which is characteristic of hydrocarbon flames but not of welding arcs. Welding produces intense UV but relatively little IR at the characteristic hydrocarbon flame wavelengths — requiring both signals simultaneously provides excellent false alarm rejection in environments with welding activity.
15. D — Measurement error =  $(139.2 - 138.5) \Omega = +0.7 \Omega$  above the theoretical value. Temperature error =  $0.7 \Omega \div 0.385 \Omega/^{\circ}C = 1.82^{\circ}C \approx 1.8^{\circ}C$  high. Because the measured resistance exceeds the theoretical value, the transmitter reports a temperature higher than the actual process temperature.
16. A — Two  $90^{\circ}$  elbows in different planes create swirl in the flow profile in addition to velocity profile distortion — the swirl is more difficult for the flow to dissipate than simple profile asymmetry. Standards such as ASME MFC-3M recommend 25–30 pipe diameters upstream for this installation configuration, significantly more than the 10–15 diameters required for a single elbow in the same plane.

17. C — The venturi tube with a long diverging outlet cone recovers the highest fraction of kinetic energy created at the throat — typically 85–95% pressure recovery — because the gradual divergence allows smooth deceleration of the accelerated flow with minimal turbulent dissipation. Orifice plates, flow nozzles, and other DP elements with abrupt geometry changes dissipate more energy as heat, producing higher permanent pressure loss.
18. B — Per ANSI/ISA-5.1, "T" as the second succeeding letter indicates the Indicating function and "C" indicates the Controller function. "TIC" therefore designates a Temperature Indicating Controller — a device that displays the temperature locally and performs closed-loop control. This combination is one of the most common tags on P&IDs for DCS-configured control loops.
19. D — Reversing the high-pressure and low-pressure connections inverts the differential pressure signal presented to the transmitter. As actual process DP increases, the transmitter sees a decreasing signal — driving the output down rather than up. The resulting 4–20 mA signal decreases as DP increases, producing an inverse and incorrect process indication.
20. A — Conductivity of demineralized water is extremely low (typically < 1  $\mu\text{S}/\text{cm}$ ); any breakthrough of dissolved ions from condensate contamination or exhausted ion exchange resin immediately and dramatically increases conductivity. This is the primary use of conductivity analyzers in boiler feedwater systems — detecting contamination events that would damage boiler internals through scaling or corrosion.
21. D — Per ANSI/ISA-5.1, the succeeding letter "Y" designates a relay, computing, or converting function — devices that transform a signal mathematically or convert it between signal types. Examples include I/P transducers (current-to-pneumatic), square root extractors, and mathematical computing elements. "C" designates Controller; "T" designates Transmitter; "R" designates Recorder.
22. C — A uniform positive offset in transmitter readings across all level conditions, without any change in process fluid composition, indicates a zero drift rather than a span error. Density changes in the impulse lines — from temperature-driven stratification, condensate accumulation, or fluid property changes — add asymmetric head pressure to the HP side, shifting the apparent zero of the transmitter upward.
23. A — Proportional output change =  $K_c \times \text{error} = 1.5 \times (+4\%) = +6.0\%$ . The proportional term responds instantaneously to the current error magnitude — a 4% error below setpoint with a gain of 1.5 produces an immediate +6% output increase. The integral term requires time to accumulate and contributes nothing to the instantaneous response.
24. D — Per ANSI/ISA-5.1, "DP" = Differential Pressure (measured variable), "I" = Indicating, "R" = Recording. "DPIR-225" correctly combines all three functions — differential pressure measurement with both local indication and recording — in loop 225. Tags are read sequentially: measured variable first, then succeeding function letters in order.

25. B — As tank level rises above setpoint, the outlet valve must open further to drain the tank faster. This requires the controller output to increase when PV (level) rises — direct acting behavior. The valve is air-to-open, so increasing output opens the valve to increase drainage. Direct acting with ATO valve is the correct combination for this outlet-throttling level control application.
26. C — Dead time  $\theta$  = time from output step to first detectable PV response = 3 minutes. Time constant  $\tau$  = time from the end of dead time to when the PV reaches 63.2% of its total change =  $11 - 3 = 8$  minutes. The total elapsed time to 63.2% is 11 minutes, but the time constant is measured from when the response first begins, not from the output step.
27. A — The Nyquist criterion requires a sampling rate of at least twice the highest signal frequency:  $2 \times 1.5 \text{ Hz} = 3.0 \text{ Hz}$  minimum, corresponding to a maximum scan period of 333 milliseconds. The current 500 ms scan provides only 2.0 Hz sampling — below the 3.0 Hz Nyquist minimum — making accurate representation of the 1.5 Hz oscillation impossible and creating aliasing risk.
28. D — Function Block Diagram represents control logic as a network of interconnected graphical function blocks where data flows from output ports to input ports, mirroring the natural signal flow of analog control circuitry. DCS platforms use FBD extensively for PID loops, signal selectors, math functions, and analog conditioning — the signal-flow orientation makes it immediately readable to process control engineers familiar with P&ID logic.
29. B — A feedforward model using a heat transfer coefficient of  $350 \text{ BTU/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$  calculates steam requirements based on that assumed thermal performance. With actual  $U$  reduced to  $210 \text{ BTU/hr}\cdot\text{ft}^2\cdot^\circ\text{F}$  through fouling, the exchanger transfers less heat per unit of steam flow than the model predicts — the feedforward correction is too small, leaving residual temperature deviation that only the feedback controller can correct.
30. C — ISA-18.2 defines an alarm as an indication requiring a timely operator response. Any configured alarm that analysis reveals requires no timely response — or has no associated documented operator action — does not meet this definition and must be rationalized through elimination, suppression, or redesign. Retaining non-actionable alarms contributes to operator desensitization and alarm flood during upsets.
31. A — At steady state with  $PV = 53\%$  and  $SP = 50\%$ ,  $\text{error} = PV - SP = +3\%$  for a direct-acting controller.  $\text{Output} = \text{bias} + K_c \times \text{error}$ :  $40\% = \text{bias} + 1.8 \times 3\% = \text{bias} + 5.4\%$ , so  $\text{bias} = 34.6\%$ . The bias represents the output the controller would produce at zero error (at setpoint), which is the output that was present when PV equaled SP.
32. D — First overshoot =  $120\% - 100\% = 20\%$  of step amplitude. Second peak =  $30\%$  of  $20\% = 6\%$  of step amplitude. Decay ratio = successive peak amplitudes:  $6\%/20\% = 0.30$ . The decay ratio measures how quickly successive oscillation peaks decay — a quarter-decay ratio response ( $DR = 0.25$ ) is the traditional Ziegler-Nichols performance target.

33. B — A latch (set) coil in IEC 61131-3 Ladder Diagram retains its TRUE state after the rung logic becomes false — it acts as a memory element, holding its output until explicitly cleared by a corresponding unlatch (reset) instruction. A standard output coil is energized only while the rung conditions are TRUE and de-energizes immediately when rung continuity is lost.
34. C — When process pH drops below the low-pH constraint, the analyzer controller demands more reagent flow to restore pH — a larger output commanding greater valve opening. A high selector passes the larger of the two controller outputs to the reagent valve, ensuring the analyzer controller's demand for increased flow overrides the flow controller's normal output during the constraint event.
35. A — A 100% proportional band corresponds to a controller gain of  $K_c = 100/100 = 1.0$ . Proportional-only operation means  $T_i$  is effectively infinite (or set to maximum) and  $T_d = 0$ . Setting  $K_c = 1.0$  with integral disabled replicates the original proportional-only behavior — integral should be added gradually after confirming the proportional loop is stable.
36. B — A three-variable system (pressure, level, temperature) in a separator has multiple cross-variable interactions — changing pressure affects level through flash dynamics, and changing level affects temperature through liquid holdup. MPC's process model explicitly captures these interactions and solves a single optimization that coordinates all three manipulated variables simultaneously, something independent PID loops cannot achieve without external decoupling strategies.
37. D — Effective cascade control requires the inner loop to respond significantly faster than the outer loop — typically 3 to 5 times faster, with 5–10 times preferred. A 15:1 ratio (45 min outer vs 3 min inner) far exceeds this minimum, confirming that the inner loop corrects disturbances and rejects inner loop upsets well before they propagate to the slow outer composition measurement.
38. A — Shared DCS credentials across operator and engineering workstations allow operators to access engineering-level functions — modifying control logic, changing alarm setpoints, or altering safety configurations — without additional authorization, violating the separation of duties principle. Additionally, any security incident or unauthorized change cannot be attributed to a specific individual when credentials are shared.
39. C — For a reverse-acting proportional-only controller ( $K_c = 1.0$ ), when the PV increases by 42% of span, the output change =  $-K_c \times \Delta PID = -1.0 \times (+42\%) = -42\%$ . Reverse-acting means the output decreases when the PV increases — the negative sign correctly reflects that the controller reduces its output to counteract the rising process variable.
40. B — Feedforward control responds to the measured disturbance at  $t = 0$  — before any PV deviation develops — applying a counteracting output change that partially compensates for the disturbance during the 90-second dead time when the feedback controller cannot yet respond. Without feedforward, the feedback controller's output remains at its pre-disturbance value throughout the dead time, allowing the disturbance to drive a large PV deviation unchecked.

41. D — Using Z-N open-loop PID rules with  $K_p = 1.5$ ,  $\tau = 120$  s,  $\theta = 40$  s:  $K_c = 1.2\tau/(K_p \times \theta) = 1.2 \times 120/(1.5 \times 40) = 144/60 = 2.40$ ;  $T_i = 2\theta = 80$  s;  $T_d = 0.5\theta = 20$  s. Option D correctly identifies all three parameters — the  $T_i = 40$  s options are incorrect because  $T_i = 2 \times 40 = 80$  s, not 40 s.
42. A — Per ISA S88, a recipe is the complete set of instructions for producing a specific product — including equipment class requirements, formula (process-specific parameters like temperatures and quantities), and procedure (the ordered control actions). A procedure alone describes the control logic without the product-specific parameters, making it reusable across multiple product formulations.
43. C — At the split-range crossover region (approximately 48–52% output), the cooling valve is nearly fully closed and the heating valve is barely cracked open. In the transition zone, both valves are simultaneously near-closed — providing neither significant heating nor cooling — creating a deadband region where the controller output produces minimal process effect until one valve opens sufficiently to influence the temperature.
44. B — DCS controller configuration files contain the complete process control logic, safety interlocks, setpoints, and alarm configurations. Storing these files on IT infrastructure exposes them to personnel with IT access who should not see or modify safety-critical control logic — creating risk of unauthorized disclosure, unauthorized modification, or exfiltration of information that could be used to plan a targeted cyberattack.
45. D — Operating  $C_v$  as percentage of rated =  $55/63 \times 100 = 87.3\% \approx 87\%$ . The preferred operating range for control valves is 20–80% of rated  $C_v$  — operating at 87% places the valve very close to its fully open position, leaving insufficient travel reserve for disturbance rejection and making the valve more susceptible to instability near full open.
46. A — Equal percentage inherent characteristic produces increasing valve sensitivity as travel increases. In a system where available differential pressure decreases as flow increases, this inherent gain increase is offset by the decreasing driving pressure — the two opposing effects combine to produce an approximately linear installed flow-versus-travel relationship, which is why equal percentage trim is the standard selection for most process throttling applications.
47. B — Standard carbon steel undergoes a ductile-to-brittle transition below approximately  $-46^\circ\text{C}$  ( $-50^\circ\text{F}$ ), becoming susceptible to sudden brittle fracture under impact loading at cryogenic temperatures. Ethylene service at  $-104^\circ\text{C}$  is well below this transition temperature, requiring austenitic stainless steel (304L, 316L) or other cryogenic-rated materials that maintain adequate toughness and ductility at these temperatures.
48. B — Butterfly valve disc geometry creates a significant torque reversal as the disc rotates past approximately  $60\text{--}70^\circ$  from closed position under high differential pressure. At 40% open with 120 psi DP, the hydrodynamic forces on the disc can produce a reversal torque that opposes the actuator — if this torque exceeds the actuator's available torque at that position, the disc moves uncontrollably, creating noise, vibration, and potential disc-chattering instability.

49. D — A conventional spring-loaded PRV with superimposed back pressure experiences an effective increase in opening pressure because the back pressure acts on the outlet side of the disc in the same direction as the spring, requiring higher inlet pressure to lift the disc. Effective opening pressure = set pressure + superimposed back pressure =  $180 + 25 \approx 205$  psig. This back pressure sensitivity is the fundamental limitation of conventional valves, requiring balanced bellows or pilot-operated designs when back pressure is variable or large.
50. A — The affinity law for centrifugal pump power states:  $P \propto N^3$ . At 85% of rated speed:  $P = (0.85)^3 \times 100\% = 0.6141 \times 100\% = 61.4\%$  of rated power. The cubic relationship means even modest speed reductions produce large power savings — the 15% speed reduction reduces power consumption by nearly 39%, the fundamental economic argument for VSD investment on centrifugal pumps.
51. C — Reverse-buckling rupture discs are domed toward the low-pressure side, placing the disc in compression under operating pressure. Compression is inherently fatigue-resistant, allowing operating pressures up to 90% of the rated burst pressure without progressive material fatigue. Standard forward-acting tension discs should not exceed approximately 70% operating ratio due to metal fatigue from continuous tensile stress at the operating pressure.
52. B — A solenoid valve that trips while the SIS output remains energized indicates an internal component failure — the electromagnetic coil or its internal spring mechanism — rather than an external command. When the coil fails open (electromagnet loses force due to coil wire breakage), the internal spring shifts the valve spool to its de-energized position despite continued electrical supply, producing the observed spurious trip.
53. C — Converting pressures to absolute:  $P_1 = 150 + 14.7 = 164.7$  psia  $\approx 165$  psia;  $P_2 = 30 + 14.7 = 44.7$  psia  $\approx 45$  psia.  $\Delta P = 120$  psi.  $x = \Delta P/P_1 = 120/165 = 0.727$ . For  $FL = 0.90$ ,  $xT \approx FL^2 \approx 0.81$ ... actually  $xT \approx 0.72$  for many valve trim geometries. Since  $x = 0.73$  slightly exceeds  $xT$ , the flow has reached or is at the choked condition.
54. C — Motor-operated valves use limit switches to define the fully closed position — the switch signals the motor controller to stop the motor when the disc reaches the specified position. If the limit switch is set incorrectly (too early in the stroke), the motor stops before the disc reaches the mechanical seat, leaving the valve partially open at a position the motor believes is fully closed.
55. A — PTFE and graphite packing materials consolidate and wear under repeated valve stroking, progressively reducing the contact force between the packing rings and the stem — eventually allowing stem leakage. Belleville disc springs maintain a calibrated spring force on the packing follower continuously as the packing consolidates, preventing the loss of packing compression that causes fugitive emissions between scheduled maintenance intervals.
56. B — At 72% of rated speed, VSD pump power =  $(0.72)^3 \times$  rated power =  $0.3732 \times$  rated power. Energy consumed relative to rated = 37.3%. Energy saving compared to full-speed operation with

throttling valve =  $100\% - 37.3\% = 62.7\% \approx 62.6\%$ . The cubic affinity law makes speed control dramatically more efficient than valve throttling for variable-flow centrifugal pump applications.

57. D — API 527 defines PRV seat leakage acceptance criteria by class. Class II applies to metal-seated conventional valves and permits a maximum of 20 bubbles per minute at 90% of set pressure during the standard leak test. Class III (soft-seated) requires zero visible leakage. Class I is the least stringent at 40 bubbles per minute.
58. C — When the pilot sensing line is filled with liquid and rises 15 feet above the main valve inlet, the hydrostatic head of the liquid column exerts additional pressure at the main valve inlet compared to the pressure at the sensing point. The pilot senses a lower pressure than the actual vessel pressure by the amount of the liquid head ( $15 \text{ ft} \times \text{SG} \times 0.433 \text{ psi/ft}$ ), causing the valve to open at a vessel pressure below its nominal set pressure.
59. A — Tungsten carbide provides extreme hardness (approximately 1,800 HV Vickers) that resists catalyst particle erosion far better than any other common trim material. Applied as a coating on a stainless steel substrate, it combines the substrate's corrosion resistance framework with the surface protection of tungsten carbide. For dilute nitric acid, cobalt-free tungsten carbide binders provide better acid resistance than standard cobalt-bonded grades.
60. B — High-pressure oxygen is a powerful oxidizer that can ignite and sustain combustion of hydrocarbon contamination, lubricants, or organic materials at much lower temperatures than air — even small amounts of oil or grease can react explosively with high-pressure oxygen. All wetted parts must be rigorously cleaned and maintained free of hydrocarbon contamination; this cleanliness requirement governs material selection, assembly procedures, and ongoing maintenance practices.
61. A — A spring-assisted check valve applies positive closing force to the disc throughout the flow range, requiring the upstream flow velocity to exceed a defined minimum to develop sufficient dynamic pressure to overcome the spring and open the disc fully. This prevents the disc from hovering at a low-lift flutter position where small velocity variations cause repeated opening and closing — the direct cause of chattering and accelerated seat wear.
62. D —  $\sigma = (P_1 - P_v)/\Delta P = (200 - 40)/100 = 1.60$ . A valve with  $FL = 0.55$  (high pressure recovery) requires a higher  $\sigma_c$  to remain cavitation-free than a valve with  $FL = 0.95$  (low pressure recovery). The ball valve's high recovery means its  $\sigma_c$  typically exceeds 1.60 for this service, while the globe valve's  $\sigma_c$  is typically below 1.60 — making the ball valve more susceptible to cavitation at  $\sigma = 1.60$ .
63. C — At 20 mA maximum current:  $V_{\text{cable}} = 0.020 \times 330 = 6.6 \text{ V}$ ;  $V_{\text{isolator}} = 0.020 \times 50 = 1.0 \text{ V}$ ;  $V_{\text{resistor}} = 0.020 \times 250 = 5.0 \text{ V}$ . Total drops = 12.6 V. Transmitter terminal voltage =  $24.0 - 12.6 = 11.4 \text{ VDC}$ . Confirming against 12 VDC minimum transmitter requirement shows this loop is very close to the minimum — 11.4 VDC falls below the 12 VDC minimum, indicating the loop cannot support this configuration.

64. B — PROFIBUS DP scan cycle time scales approximately linearly with the number of polled slave devices when all devices have equal data payloads. Adding 8 devices to 24 increases the count to 32, a factor of  $32/24 = 1.333$ . New cycle time =  $8 \text{ ms} \times 1.333 = 10.67 \text{ ms}$ . This scan time increase must be evaluated against the control loop update rate requirements.
65. D — Hardware or operating system-level USB port lockdown physically prevents any USB storage device from being recognized by the system, regardless of any individual's decision to insert a device. Policy-based controls (training, antivirus scanning) depend on human compliance and software detection — they cannot prevent an unauthorized device from being connected. Physical/OS-level disablement is the only control that blocks the connection unconditionally.
66. A — Cable resistance =  $2 \text{ conductors} \times 450 \text{ m} \times 0.132 \text{ } \Omega/\text{m} = 118.8 \text{ } \Omega \approx 119 \text{ } \Omega$ . Available voltage for series resistance =  $24 - 12 = 12 \text{ VDC}$ . Maximum total series resistance =  $12 \text{ V} / 0.020 \text{ A} = 600 \text{ } \Omega$ . Fixed resistances =  $250 \text{ (input resistor)} + 119 \text{ (cable)} = 369 \text{ } \Omega$ . Maximum additional resistance =  $600 - 369 = 231 \text{ } \Omega$ .
67. C — VLANs create logical network separation — they prevent devices on different VLANs from communicating at the Layer 2 (switching) level. However, a Layer 3 router or routing function on a managed switch can bridge traffic between VLANs if inter-VLAN routing is enabled without access control lists. Without explicit ACL rules blocking inter-VLAN traffic, any device can reach any other VLAN through the router despite the VLAN segmentation.
68. B — A 12-bit DAC resolves the output into  $2^{12} = 4,096$  steps  $\rightarrow$  resolution =  $100\%/4,096 = 0.0244\%$  per step. A 16-bit DAC resolves into  $2^{16} = 65,536$  steps  $\rightarrow$  resolution =  $100\%/65,536 = 0.00153\%$  per step. Improvement factor =  $65,536/4,096 = 16$ . Each additional bit doubles resolution; 4 additional bits (12 $\rightarrow$ 16) provides  $2^4 = 16\times$  finer valve positioning.
69. A — WirelessHART uses time-synchronized channel hopping across 15 available channels in the 2.4 GHz band. Each transmission is scheduled on a specific channel and time slot; if narrowband interference blocks one channel, the next scheduled transmission automatically uses a different channel. This statistical frequency diversity dramatically reduces the probability of consecutive failed transmissions from persistent narrowband interference at any single frequency.
70. D — Multi-mode fiber propagates light through multiple simultaneous modes (paths) with slightly different travel times, causing intermodal dispersion that spreads pulses and limits bandwidth over distance. Single-mode fiber's smaller core (8–10  $\mu\text{m}$  vs. 50–62.5  $\mu\text{m}$ ) permits only one propagation mode, eliminating intermodal dispersion entirely — enabling transmission at high data rates over kilometers without the pulse spreading that limits multi-mode fiber at long distances.
71. C — A server with network interfaces simultaneously connected to both the OT network and the IT network creates a direct bridging path between the two domains. Any attacker who compromises the IT-connected interface — through email malware, web exploit, or IT network lateral movement — has a direct route to the OT network through the server, bypassing all firewall and DMZ controls that were designed to prevent exactly this connection.

72. B — The NEC hazardous location classification system uses Class to identify the type of hazardous material: Class I = flammable gases and vapors; Class II = combustible dusts (grain, wood, metal, coal); Class III = ignitable fibers and flyings. Class II locations include grain elevators, flour mills, coal handling facilities, and similar environments where airborne combustible dust concentrations can reach ignitable levels.
73. A — The 4–20 mA current loop transmitter regulates the current flowing through the series loop circuit. Because current is identical throughout a series circuit regardless of total resistance (within the compliance voltage limit), cable resistance does not affect the measured current at the receiving end. The DCS input card reads current, not voltage — making the measurement inherently immune to the resistive voltage drop along the cable.
74. D — Single-mode fiber optic cable provides complete electromagnetic immunity (light signals are unaffected by electrical fields), complete galvanic isolation between buildings (no electrical path between endpoints), and supports multi-gigabit data rates over 800 m and beyond without repeaters. For an 800-meter link through a high-EMI switchyard with lightning exposure risk, single-mode fiber eliminates all three critical concerns simultaneously.
75. C — Continuous security monitoring of network traffic and system behavior supports the IEC 62443 and NIST CSF principle of timely detection and response to security events. An unauthorized outbound connection from a DCS workstation at 2:47 AM is an anomalous behavior pattern that may indicate malware infection, credential theft, or active attack — early detection enables response before significant damage, data exfiltration, or control system compromise occurs.
76. B — Per IEC 61511 Clause 10, the Safety Requirements Specification must define the required Safety Integrity Level for each SIF along with the associated PFD (for low-demand mode) or PFH (for high-demand mode) target derived from the risk assessment. Without the SIL and quantitative performance target in the SRS, there is no verifiable basis for confirming the SIS design achieves the required risk reduction.
77. A — When proof test coverage is 85% rather than 100%, 15% of dangerous failures in the final element remain undetected and continue accumulating between proof test intervals as if no test occurred. This uncredited accumulation raises the actual PFD above the value calculated assuming 100% coverage — the SIL verification must account for partial test credit to accurately reflect the achieved safety level.
78. B — Required PFD = 1/risk reduction factor = 1/500 = 0.002. IEC 61511 SIL 2 corresponds to the PFD range  $0.001 \leq \text{PFD} < 0.01$ . Since 0.002 falls within this range, SIL 2 is the required safety integrity level. SIL 3 would apply for PFD values in the range 0.0001 to 0.001 — a risk reduction factor of 1,000 to 10,000 would require SIL 3.
79. C — If Transmitter A reads 3 psi above actual pressure, it reaches the high-pressure trip setpoint of 150 psig when actual pressure is only 147 psig — it trips 3 psi earlier than intended. For real

overpressure demands above 147 psig, Transmitter A still votes for a trip and contributes to the protective function. The consequence is increased spurious trip probability when actual pressure fluctuates between 147 and 150 psig — not loss of protection.

80. B — A 4× faster temperature rise rate means the process reaches the hazardous temperature 4 times sooner than the scenario for which the 30-second response time was originally specified. If the original hazard scenario allowed a 30-second response window, the faster heat source may compress the available time below what the SIF can achieve — requiring re-evaluation of the maximum allowable response time in the SRS and potentially a faster final element.
81. D — Mitigated consequence frequency after existing IPLs =  $2.0 \times 0.1 \times 0.01 = 2 \times 10^{-3}/\text{year}$ . Required SIF PFD = risk tolerance / mitigated frequency =  $10^{-5} / 2 \times 10^{-3} = 5 \times 10^{-3}$ . A PFD of  $5 \times 10^{-3}$  falls within the SIL 2 range (0.001 to 0.01), confirming SIL 2 is required. The SIF must reduce the residual risk by a factor of 200 (1/0.005) to meet the  $10^{-5}/\text{year}$  risk tolerance.
82. C — Independent failure term for 1oo2:  $(\lambda_{DU} \times TI)^2/3 = (2 \times 10^{-6} \times 8,760)^2/3 = (0.01752)^2/3 = 3.069 \times 10^{-4}/3 = 1.023 \times 10^{-4}$ . CCF term:  $\beta \times \lambda_{DU} \times TI/2 = 0.05 \times 2 \times 10^{-6} \times 8,760/2 = 4.38 \times 10^{-4}$ . Total PFD\_avg =  $1.023 \times 10^{-4} + 4.38 \times 10^{-4} = 5.40 \times 10^{-4}$ . The CCF term dominates — reinforcing why diversity is critical in redundant SIS configurations.
83. A — In 2oo3 voting logic, two of three sensors simultaneously voting for a trip activates the safety function — this is the designed protective response. Two sensors failing in the safe direction (both outputting trip signals) satisfy the 2oo3 trip condition and the SIF activates, bringing the process to its safe state. The immediate required actions are to verify safe state achievement, identify the failed sensors, and repair them before restart.
84. C — IEC 61511 Clause 16 requires a functional safety assessment to be performed before the SIS is placed into service following installation and commissioning. This pre-startup FSA verifies that all installation, commissioning, and validation activities have been completed correctly, all SRS requirements have been implemented, all deviations have been resolved, and all prerequisite documentation is in order before the safety function is relied upon for process protection.
85. B — PFD\_avg =  $\lambda_{DU} \times TI/2 = 1 \times 10^{-6} \times 8,760/2 = 4.38 \times 10^{-3}$ . The SIL 2 range requires PFD between 0.001 and 0.01. Since  $4.38 \times 10^{-3}$  falls within this range, the extended 12-month proof test interval still maintains SIL 2 compliance. For a 1oo1 architecture, PFD scales linearly with TI — confirming through calculation rather than assumption is mandatory before approving any interval extension.