PRACTICE EXAM 7: PE CONTROL SYSTEMS SIMULATION

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 calibrated for 0–100 in H_2O at a maximum flow of 750 gpm has square root extraction disabled. The DCS displays 50% of the output span. What is the actual flow rate?

A. 375 gpm

B. 530 gpm

C. 635 gpm

D. 265 gpm

2. A Type K thermocouple reference table shows: 75°C = 3.059 mV and 100°C = 4.096 mV (0°C reference). A DCS input reads 3.819 mV. Using linear interpolation, what is the indicated process temperature?

A. 91.2°C

B. 87.4°C

C. 95.6°C

D. 93.3°C

3. A magnetic flowmeter is installed in a 6-inch pipeline carrying a 15% NaCl brine solution with measured conductivity of 45,000 μS/cm. Which statement about this installation is most accurate?

A. The magnetic flowmeter is fully appropriate — the conductivity far exceeds the 5 μS/cm minimum required for reliable operation

B. High conductivity causes electrode polarization, requiring AC excitation above 10 kHz

C. The high conductivity creates eddy currents opposing the magnetic field, producing high readings

D. Magnetic flowmeters are not approved for saline solutions because salt corrodes standard stainless electrodes

4. An open vessel contains a process liquid at SG = 1.35. The lower process tap is at 0% level and the 100% level reference is 4 feet above. What is the transmitter URV in psi?

A. 1.73 psi

B. 3.12 psi

C. 2.34 psi

D. 1.56 psi

5. A flow measurement application requires monitoring gas flow where the composition changes frequently between methane, ethylene, and propane mixtures, with mass flow accuracy of ±0.5% required regardless of gas type. Which technology best meets these requirements?

A. Vortex flowmeter with an online densitometer input for density compensation

B. Coriolis mass flowmeter measuring mass flow directly through the Coriolis force principle

C. Differential pressure orifice plate with temperature and pressure compensation

D. Thermal mass flowmeter calibrated for the most common gas composition

6. In ASME PTC 19.3 TW thermowell analysis, which geometric parameter has the greatest influence on the thermowell natural frequency, and how does natural frequency vary with this parameter?

A. Tip diameter — natural frequency increases linearly with increasing tip diameter

B. Material modulus of elasticity — natural frequency varies with the square root of elastic modulus

C. Wall thickness — natural frequency increases with the cube of increasing wall thickness

D. Insertion length — natural frequency varies approximately inversely with the square of insertion length

7. A process requires measurement of dissolved hydrogen sulfide (H_2S) in a liquid stream at sub-ppm levels for environmental compliance. Which technology is most appropriate?

A. Gas-phase pellistor sensor mounted above the liquid surface in the vessel headspace

B. Infrared absorption sensor measuring H_2S through the pipe wall using attenuated total reflection

C. Membrane-covered amperometric dissolved H_2S sensor designed for direct liquid-phase immersion

D. Flame photometric GC with liquid injection for periodic batch sample analysis

8. A three-wire Pt100 RTD is embedded in a bearing housing. During commissioning, an engineer measures 0.8 Ω resistance imbalance between the two voltage-sensing wires. Using $\alpha = 0.00385$ Ω/Ω/°C, what temperature measurement error does this imbalance introduce?

A. Approximately 2.1°C from the uncompensated resistance difference between the sensing wires

B. Approximately 0.8°C because the error numerically equals the imbalance resistance

C. No error — three-wire compensation completely eliminates all lead resistance including imbalance

D. Approximately 4.2°C because both sensing wires contribute equally to the error

9. An orifice plate is sized for water at SG = 1.00. The process fluid is changed to a glycol solution at SG = 1.12 without recalibration. At full-scale differential pressure, how does actual flow compare to the calibrated maximum?

A. Actual flow is approximately 12% higher than calibrated maximum

B. Actual flow is approximately 6% lower than calibrated maximum

C. Actual flow equals calibrated maximum because differential pressure is unchanged

D. Actual flow is approximately 5.5% lower than the calibrated maximum

10. A guided-wave radar transmitter measures interface level between a lower water phase (SG = 1.00) and an upper hydrocarbon phase (SG = 0.78). What reflections does the GWR detect and what measurements can it simultaneously provide?

A. GWR detects only the upper hydrocarbon surface and infers interface level from total liquid level

B. GWR detects reflections at both the upper hydrocarbon surface and the liquid-liquid interface, providing simultaneous upper level and interface level measurements

C. GWR detects only the water-hydrocarbon interface and requires an independent upper-level device

D. GWR cannot detect interfaces with less than 0.5 dielectric constant difference between layers

11. A nuclear (radiometric) density gauge measures a process slurry by transmitting gamma radiation through the pipe. Slurry density increases from 1.2 to 1.6 kg/L. What happens to the detector count rate?

A. Count rate increases proportionally with increasing slurry density

B. Count rate remains constant — nuclear gauges measure composition, not bulk density

C. Count rate decreases as the denser slurry absorbs more gamma radiation, attenuating the beam

D. Count rate is unaffected because gamma radiation cannot distinguish density from composition changes

12. A plant calibration lab performs a 5-point calibration check on a 0–600 psi transmitter and finds errors of +1.2 psi at every test point. What single adjustment corrects this transmitter?

A. Zero adjustment — the uniform constant error at all five points indicates a pure offset shift

B. Span adjustment — the error is proportional to the measurement range

C. Both zero and span adjustments applied simultaneously

D. Linearity trim using the transmitter's built-in linearization function

13. A noisy flow measurement signal contains legitimate process variation at 0.1–0.5 Hz and high-frequency noise at 15–50 Hz. What digital filter time constant most effectively removes the noise while preserving process dynamics?

A. 5.0 seconds — attenuates all frequencies above 0.03 Hz

B. 0.01 seconds — minimizes phase lag with negligible filtering effect

C. 2.0 seconds — balances noise reduction with acceptable phase lag

D. 0.3 seconds — attenuates 15–50 Hz noise while adding negligible phase lag

14. A positive displacement meter measures crude oil at flow rates varying between 20% and 100% of maximum rated capacity. Compared to a Coriolis meter, which key advantage does the PD meter offer at low flow rates?

A. Higher accuracy because PD meters use a NIST-traceable primary reference calibration

B. Accurate volumetric measurement across the full 5:1 flow range independent of fluid viscosity changes

C. Lower pressure drop at maximum flow compared to Coriolis meters for this pipe size

D. Lower total cost of ownership over a 20-year service life in this service

15. Amperometric dissolved oxygen sensors with membrane technology require periodic membrane and electrolyte replacement. What degradation mechanism most directly limits membrane service life?

A. The diffusion membrane becomes fouled by biological growth, oils, or process contaminants — progressively reducing oxygen permeability and causing the sensor to read low

B. The membrane crystallizes from prolonged exposure to dissolved mineral salts in the process water

C. UV radiation from dissolved organic compounds photolyzes the membrane polymer structure

D. Osmotic pressure drives water into the electrolyte cavity, diluting it below the functional threshold

16. A control valve installation produces 92 dBA at 1 meter during normal operations, exceeding the 85 dBA occupational limit. Which modification most directly addresses the noise at its source?

A. Relocating the valve to an enclosed equipment room lined with acoustic insulation panels

B. Installing a downstream reactive muffler on the valve outlet connection

C. Replacing the standard single-stage trim with a multi-stage anti-noise cage trim distributing pressure drop across multiple restrictions

D. Reducing the operating pressure drop by installing a larger downstream pipe section

17. A Type K thermocouple with its hot junction at 450°C connects to a DCS terminal block at 30°C where cold junction compensation is applied. Approximately what voltage does the DCS measure at its input terminals before applying compensation?

A. The DCS measures 18.5 mV corresponding to 450°C above 0°C reference

B. The DCS measures 1.2 mV corresponding to the 30°C cold junction temperature

C. The DCS measures 19.7 mV from the additive sum of both junction voltages

D. The DCS measures approximately 17.3 mV — the net EMF between the hot and cold junctions

18. An ultrasonic level transmitter on a narrow 18-inch diameter vessel produces erratic measurements that correlate with wind direction at the facility. What is the most likely cause?

A. Wind vibration causes the vessel walls to resonate at the ultrasonic transmitter frequency

B. Wind disturbance creates pressure fluctuations across the vessel top that alter the acoustic propagation path, while the narrow diameter creates standing wave interference patterns

C. Ambient temperature changes from wind cooling shift the speed of sound causing range errors

D. Wind-driven surface waves scatter the transmitted ultrasonic pulse before it can return

19. A DP level transmitter has the following installation parameters: process SG = 0.88, wet leg SG = 1.05, measurement span = 8 feet, wet leg height above lower tap = 12 feet. What is the transmitter LRV in psi?

A. –5.46 psi

B. +3.62 psi

C. –2.41 psi

D. +1.84 psi

20. A flame ionization detector (FID) is used for total hydrocarbon monitoring. Which gas would an FID fail to detect reliably?

A. Methane (CH_4) at 5 ppm in nitrogen carrier gas

B. Benzene (C_6H_6) vapor at low concentrations in air

C. Carbon monoxide (CO) — FIDs cannot ionize inorganic carbon compounds in a hydrogen flame with measurable sensitivity

D. Propane (C_3H_8) at 1 ppm in air

21. A pH electrode shows increasing response sluggishness after 3 months of service, though calibration with fresh buffers appears acceptable. What most likely causes this degraded dynamic response?

A. The reference electrode junction has become clogged, blocking the ionic reference path

B. The measurement preamplifier impedance has increased from moisture ingress into the connector

C. The pH buffer solutions have been contaminated, causing calibration errors that appear as response lag

D. The glass membrane has developed a surface coating that increases membrane resistance and slows hydrogen ion diffusion to the glass surface

22. A transmitter specification states accuracy = ±0.075% URL. The transmitter is installed with a range of 0–200 psi, but its URL is 0–2,000 psi. What is the maximum measurement error at a reading of 50 psi?

A. ±0.038 psi (0.075% of the actual reading value)

B. ±1.50 psi (0.075% of the 2,000 psi URL)

C. ±0.15 psi (0.075% of the 200 psi calibrated range)

D. ±0.75 psi (0.075% of the nominal reading span)

DOMAIN 2: CONTROL SYSTEMS (Questions 23–44)

23. A reactor temperature loop exhibits limit cycling with a consistent 6-minute period and ±3°C amplitude. The engineer suspects valve dead band rather than poor PID tuning. Which observation most strongly supports this diagnosis?

A. The oscillations began shortly after the controller gain was recently increased

B. The oscillation period is much longer than the process time constant

C. The controller output varies continuously but process temperature oscillates in a staircase pattern — the valve moves in discrete jumps each time accumulated integral action overcomes the positioner dead band

D. The oscillations disappear when derivative action is disabled

24. A P&ID shows an instrument tagged "FIAHL-110." According to ANSI/ISA-5.1, what functions does this instrument perform?

A. Flow indication with alarm high and alarm low functions in loop 110

B. Flow integration with analog high-limit and low-limit output in loop 110

C. Flow indicating with alarm high and alarm low-low in loop 110

D. Flow inference with analog high-limit and logic output in loop 110

25. Using the Ziegler-Nichols open-loop method, a bump test on a flow loop yields: process reaction rate $R = 4.0$ %/(%·min), dead time $\theta = 0.5$ min. What are the recommended PID settings?

A. Kc = 1.20, Ti = 2.0 min, Td = 0.50 min

B. Kc = 0.90, Ti = 1.5 min, Td = 0.25 min

C. Kc = 0.45, Ti = 0.5 min, Td = 0.25 min

D. Kc = 0.60, Ti = 1.0 min, Td = 0.25 min

26. A heat exchanger temperature controller shows excellent setpoint tracking but poor disturbance rejection — after an inlet feed temperature change, the PV deviates for 15 minutes before recovering. Which enhancement most directly improves disturbance rejection?

A. Increasing the integral time to accumulate error more slowly during disturbances

B. Adding feedforward compensation from the inlet feed temperature transmitter to the steam valve output

C. Switching from PID to PI control by disabling derivative action during disturbance events

D. Adding a derivative filter time constant equal to the estimated disturbance duration

27. According to ISA-101 High Performance HMI guidelines, which color management approach is correct for process graphics during normal operations?

A. Using primarily gray, muted, and low-saturation colors for normal states — reserving high-contrast colors exclusively for alarms and abnormal conditions

B. Color-coding each process unit with a distinct bright color for rapid area identification

C. Using green for all values within specification and blue for all manually controlled equipment

D. Applying the same color scheme as the original analog panel to maintain operator familiarity

28. In IEC 61131-3 Sequential Function Chart programming, which action qualifier causes an action to execute for exactly one scan cycle at the moment a step becomes active, then immediately deactivate?

A. N — non-stored, active throughout the entire step duration

B. S — set/latch, remains active until explicitly reset by an R instruction

C. P — pulse, executes for one scan cycle when the step activates

D. D — delayed, activates after the step has been active for a specified delay period

29. A pH control loop in a paper mill must maintain pH between 6.5 and 7.5. Process gain changes by a factor of 40 between pH 6 and pH 8. Which control strategy most effectively maintains consistent loop performance across this range?

A. Cascade control with pH as the outer variable and reagent flow as the inner variable

B. Feedforward control measuring influent flow to pre-calculate the reagent dose

C. Lambda tuning with a very large closed-loop time constant ensuring stability across all conditions

D. Gain scheduling — automatically adjusting controller gain as a scheduled function of measured pH

30. The Ziegler-Nichols closed-loop tuning method produces sustained oscillation at Ku = 3.6 with Pu = 180 seconds. What are the recommended PI settings?

A. Kc = 2.16, Ti = 90 s

B. Kc = 1.62, Ti = 150 s

C. Kc = 2.16, Ti = 180 s

D. Kc = 1.08, Ti = 60 s

31. Lambda tuning is applied to a level loop with Kp = 0.6 %/%, $\tau = 180$ s, $\theta = 30$ s, and a selected closed-loop time constant $\lambda = 60$ s. Using $Kc = \tau/(Kp \times (\lambda + \theta))$, what is the calculated proportional gain?

A. 3.33

B. 1.67

C. 5.00

D. 2.00

32. An operator counts 47 alarms activating within a single 10-minute period during a process upset. According to ISA-18.2, which performance category describes this alarm rate?

A. Normal operations — ISA-18.2 permits up to 50 alarms per 10-minute period

B. Acceptable upset — ISA-18.2 defines 30–50 alarms per 10 minutes as manageable

C. Unacceptable — ISA-18.2 identifies more than 10 alarms per 10 minutes as likely unmanageable

D. Marginal — within the ISA-18.2 caution range requiring monitoring

33. A vendor technician with multi-factor authentication connects to the DCS using a corporate laptop also used for email and internet browsing. What residual security concern remains despite MFA being active?

A. MFA tokens may expire before the vendor completes their technical task

B. The corporate laptop may run different antivirus software than the DCS workstations

C. MFA remote access bypasses the DCS audit trail recording for the session

D. The vendor laptop may carry malware from IT network exposure — if compromised, the attacker uses the authenticated session to reach OT systems through the legitimate connection

34. A distillation column uses a pressure-compensated temperature as an inferential composition indicator. Without pressure compensation, column pressure rises 2 psi above design. What effect does this uncompensated pressure increase produce on the temperature reading?

A. The temperature reads artificially high — elevated pressure raises the boiling point, making it appear that a composition change has occurred when none has

B. The elevated pressure causes the temperature transmitter to malfunction intermittently

C. The temperature measurement remains accurate for composition but not for equipment protection

D. The 2 psi pressure variation is too small to meaningfully affect the temperature-composition relationship

35. A reverse-acting PID controller has setpoint = 60%, PV = 57%, Kc = 2.5, and bias output = 50%. What is the current controller output?

A. 42.5%

B. 57.5%

C. 64.0%

D. 50.0%

36. A Model Predictive Controller manages a crude distillation unit with 4 manipulated variables and 8 controlled variables. A feed composition change occurs. What specific advantage does MPC provide over 8 independent PID loops?

A. MPC automatically increases its execution rate when composition changes are detected

B. MPC eliminates the need for feedforward measurement of feed composition

C. MPC explicitly models cross-variable interactions and computes coordinated moves for all 4 manipulated variables simultaneously within a single optimization

D. MPC's integral action accumulates faster than PID during composition transients

37. A batch reactor temperature profile requires: ramp 25°C to 180°C over 90 minutes, hold at 180°C for 60 minutes, cool to 60°C over 45 minutes, hold at 60°C. Which IEC 61131-3 language combination best implements this sequence?

A. Sequential Function Chart defining phase sequence with steps and timer transitions, plus Structured Text calculating ramped setpoint values within each step

B. Function Block Diagram with four connected PID blocks, one per temperature profile phase

C. Ladder Diagram with timer contacts controlling setpoint registers for each sequential phase

D. Instruction List implementing ramp calculations and phase transitions in assembly-level code

38. A control loop analysis shows a gain margin of 2.0 dB and a phase margin of 15 degrees. What is the most appropriate corrective action?

A. Increase controller gain by 20% to bring the gain margin to a safe operating level

B. Disable derivative action — low phase margin is always caused by excessive derivative gain

C. Increase the setpoint to move the operating point away from the stability boundary

D. Retune the controller to achieve gain margin ≥ 6 dB and phase margin ≥ 30° by adjusting gain, integral, and derivative times

39. According to the ISA S88.01 batch control standard, which level of the procedural control hierarchy directly contains Operations?

A. Procedure — the highest procedural level in the hierarchy

B. Unit Procedure — the level grouping Operations for execution within a single process unit

C. Phase — the lowest individually executable procedural level

D. Recipe — the product-specific formulation referencing all lower procedural levels

40. A control loop shows permanent offset from setpoint after a sustained disturbance. Both proportional and integral are configured, but Ti is set to approximately infinity. What is the correct diagnosis?

A. Derivative time is too high, canceling the proportional response and creating apparent offset

B. The controller is in direct-acting mode when reverse-acting is required

C. With Ti effectively infinite, integral action contributes negligibly — the controller behaves as proportional-only, and proportional-only control always produces steady-state offset

D. The process gain has shifted significantly from the design value making proportional insufficient

41. Using the Ziegler-Nichols open-loop method, a bump test yields: Kp = 1.5°C/%, τ = 60 s, θ = 10 s. What are the recommended PID settings?

A. Kc = 2.40, Ti = 40 s, Td = 10 s

B. Kc = 3.60, Ti = 20 s, Td = 10 s

C. Kc = 4.80, Ti = 40 s, Td = 5 s

D. Kc = 4.80, Ti = 20 s, Td = 5 s

42. A three-element boiler feedwater control system experiences drum level instability during rapid load changes despite good steady-state performance. The steam flow feedforward signal reads 10% low due to a calibration error. What specific effect does this calibration error produce?

A. Under-correction during load increases — the feedforward underestimates steam demand, commanding less feedwater than needed, so drum level drops further than it should before the feedback controller recovers

B. Over-correction during load decreases — the low reading commands excess feedwater when demand drops

C. No effect on dynamic performance — feedforward calibration errors only cause steady-state offset

D. Controller output saturation — the 10% error causes the integral to accumulate beyond the output range

43. In a split-range pressure control application, a make-up gas valve operates from 0–50% controller output and a vent valve operates from 50–100%. At 55% controller output, what is the position of each valve?

A. Make-up at 10% open, vent valve fully closed

B. Make-up fully open, vent at 10% open

C. Make-up fully closed, vent at 10% open

D. Both valves at approximately 5% open near the crossover transition

44. Override control uses a high selector to switch between a tank level controller and a pump protection controller for a centrifugal pump outlet valve. When the pump protection controller output exceeds the level controller output, what anti-windup action is required?

A. The level controller takes control — the high selector passes the conservative protective output

B. The pump protection controller takes control via the high selector — the level controller needs external reset feeding the actual valve signal to prevent integral windup during its inactive period

C. Both controllers share control proportionally based on the magnitude difference of their outputs

D. The high selector alternates control based on which controller has been inactive longer

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

45. A control valve in a liquid service has an installed differential pressure of 45 psi and a maximum flow of 220 gpm at SG = 1.05. What Cv is required?

A. 33.6

B. 47.5

C. 22.4

D. 28.9

46. A globe control valve body must be selected for a service containing 15% hydrochloric acid (HCl) at 80°C with moderate flow velocity. Which body material is most appropriate?

A. Carbon steel (A216 WCB) — cost-effective for most chemical process services

B. Type 304 stainless steel — standard grade for mild acid applications

C. Type 316 stainless steel — provides marginal resistance to HCl at elevated temperatures

D. Alloy 20 or Hastelloy C-276 — specifically engineered for concentrated HCl service at elevated temperatures

47. A 200 hp motor drives a large centrifugal blower with high inertia. The electrical distribution cannot tolerate more than 250% of full-load current during starting. Which starting method best satisfies this constraint?

A. Across-the-line starting — NEMA B motors inherently limit starting current to 250% of FLA

B. Star-delta starter — limits starting current to approximately 33% of across-the-line current

C. Electronic soft starter with current limit set at 250% of FLA providing smooth adjustable torque application

D. Autotransformer starter at 80% voltage tap — limits starting current to 64% of across-the-line value

48. A conventional spring-loaded PRV is set at 250 psig with 10% blowdown. The closed relief header superimposed back pressure varies between 0 and 35 psig. What concern does this variable back pressure create?

A. Variable back pressure increases the PRV discharge flow rate by reducing the back pressure effect

B. Variable superimposed back pressure up to 35 psig (14% of set pressure) exceeds the 10% limit for conventional PRVs — this changes the effective set pressure variably and unpredictably

C. Variable back pressure affects only the blowdown — opening pressure remains at 250 psig regardless

D. The 35 psig back pressure reduces relief capacity by 14% but does not affect the opening pressure

49. An equal percentage control valve has a rated Cv of 60 at full open and a rangeability of 50:1. What is the minimum controllable Cv?

A. 1.2

B. 3.0

C. 6.0

D. 0.60

50. A pneumatic spring-return diaphragm actuator must stroke a valve open against unbalanced fluid force of 800 lbf, packing friction of 150 lbf, and spring force of 350 lbf at full open. Instrument air supply is 80 psi. What minimum effective diaphragm area is required?

A. 12.5 in^2

B. 18.0 in^2

C. 10.0 in^2

D. 16.25 in^2

51. A check valve must be selected for a high-elevation discharge system where flow reversal occurs rapidly during pump shutdown. Which design provides the fastest closure to minimize water hammer?

A. Swing check valve with a heavy disc relying on gravity for closure

B. Ball check valve with a spherical ball dropping into seat under gravity

C. Dual-plate wafer check valve — two hinged half-discs travel only 35–45° instead of 90°, providing significantly faster closure than full-disc designs

D. Piston check valve with hydraulic damping orifices controlling closure speed

52. An engineer installs a larger replacement motor in an MCC without changing the existing overload relay setting. What protection concern results?

A. The larger motor draws less current, causing the overload relay to never protect against overload

B. The original relay trip threshold is below the larger motor's full-load current — the relay trips prematurely during normal operation at the new motor's rated load

C. The larger motor's locked-rotor current exceeds the overload relay's rated withstand capability

D. Overload relays are unaffected by motor size changes — only the circuit breaker requires adjustment

53. A PRV sizing calculation for vapor service yields a required orifice area of 0.88 in^2. Available API 526 standard orifices are: G = 0.503 in^2, H = 0.785 in^2, J = 1.287 in^2, K = 1.838 in^2. Which orifice is selected?

A. J orifice (1.287 in^2) — the next standard size above the calculated required area

B. H orifice (0.785 in^2) — the closest standard size to the required area from below

C. Two H orifices in parallel ($2 \times 0.785 = 1.570$ in^2) for adequate combined capacity

D. K orifice (1.838 in^2) — provides maximum margin above the required relief area

54. A gas pipeline ESD valve must close fully within 3 seconds of the SIS output signal. The actuator is a spring-return pneumatic cylinder. What accessory most effectively achieves fast closure?

A. Volume booster on the supply air line to increase actuator charging speed

B. Larger actuator spring with higher spring rate to increase closing force

C. Digital positioner with fast stroke speed mode enabled

D. Quick-exhaust valve installed directly on the actuator exhaust port — rapidly venting actuator air through a large exhaust orifice independent of the positioner exhaust path

55. A rupture disc rated at 200 psig at 70°F is installed on a vessel operating at 180 psig and 250°F. The manufacturer's temperature correction shows derated burst pressure at 250°F is 188 psig. What assessment is correct?

A. Acceptable — operating pressure (180 psig) is below the derated burst pressure (188 psig)

B. Acceptable — the 8 psig margin provides the required minimum safety margin per API 520

C. Unacceptable — the operating-to-burst ratio of 95.7% exceeds recommended limits, leaving insufficient margin for the disc to remain intact reliably throughout its service life

D. Unacceptable — temperature-derated burst pressures cannot be used for discs rated at standard temperature

56. A valve positioner calibration check shows correct travel at 0%, 25%, and 100% input signal values, but at 50% input (12 mA), actual travel reads 45% instead of 50%. What type of calibration error does this pattern indicate?

A. Zero error — the zero calibration point is incorrectly set

B. Linearity error — mid-range output deviates from the straight line between correctly calibrated endpoints

C. Span error — the full travel range is compressed relative to the specified stroke

D. Hysteresis error — the positioner responds differently to increasing versus decreasing signals

57. A self-contained pressure reducing regulator maintains 100 psig downstream from a variable 150–400 psig upstream supply. What factor most justifies retaining the self-contained regulator over a DCS-controlled alternative?

A. Self-contained regulators consistently achieve tighter pressure control than DCS PID loops

B. Self-contained regulators have lower total maintenance cost over a 20-year service life

C. Self-contained regulators respond faster than pneumatically actuated DCS-controlled valves

D. Self-contained regulators operate without external power, instrument air, or control signals — providing inherent pressure control independent of control system availability

58. A valve sizing calculation shows severe cavitation risk with installation sigma $\sigma = 0.25$ and standard trim $\sigma c = 0.80$. Anti-cavitation trim raises σc to 0.18. Is cavitation eliminated with anti-cavitation trim?

A. Yes — $\sigma = 0.25$ exceeds the anti-cavitation trim $\sigma c = 0.18$, confirming cavitation-free operation

B. No — anti-cavitation trim only reduces cavitation intensity without eliminating it at $\sigma = 0.25$

C. Cannot be determined without knowing the downstream pressure recovery factor FL

D. No — installation sigma of 0.25 remains below the 0.8 threshold required for any trim selection

59. A control valve in hot condensate service at 160°C shows distributed erosion damage extending 8–12 inches downstream from the valve outlet into connected piping, with minimal damage concentrated at the trim surfaces. Which phenomenon is most consistent with this damage pattern?

A. Cavitation — bubble collapse produces localized pitting concentrated at the trim surfaces

B. Erosion from entrained solid particles — producing directional wear marks in the flow direction

C. Flashing — stable two-phase flow with high-velocity vapor impingement erodes both the valve outlet and downstream piping over an extended region

D. Acoustic fatigue from choked flow pressure oscillations producing fatigue damage in the piping

60. A valve fails to fully close during an emergency shutdown test. The solenoid de-energized correctly and actuator air vented, but the spring did not complete the stroke. Which cause is most likely?

A. The solenoid valve exhaust port has insufficient flow area for the required depressurization rate

B. Instrument air supply pressure was briefly insufficient during the ESD test

C. The DCS ESD output signal was insufficient to fully de-energize the solenoid coil

D. The spring preload has weakened over time or stem friction has increased — the net spring force no longer overcomes resistance to drive the valve to full closure

61. A normally closed thermal overload contact in series with a motor contactor coil circuit opens when an overload condition occurs. What functional effect does opening this contact produce?

A. It sends a discrete alarm signal to the DCS indicating the overload condition

B. It de-energizes the contactor coil, opening the main power contacts and disconnecting the motor from the supply

C. It activates a cooling delay timer before the motor can be manually restarted

D. It switches the motor from across-the-line to reduced-voltage running mode

62. A modulating control valve is required for a 24-inch cooling water header with a 4:1 flow range and only 5 psi available pressure drop at maximum flow. Which valve type is most appropriate?

A. High-performance butterfly valve — suitable size and weight advantage, achievable rangeability, and compatible with the low pressure drop requirement

B. Globe valve — provides the best flow characteristic for large cooling water service

C. Full-bore ball valve — provides lowest pressure drop and best shutoff for this pipe size

D. Diaphragm valve — appropriate for large-bore services with corrosive water chemistry

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

63. A 4–20 mA loop has: DCS supply = 24 VDC, input resistor = 250 Ω, IS Zener barrier = 150 Ω series resistance, transmitter minimum terminal voltage = 10 VDC. What is the maximum allowable cable loop resistance?

A. 250 Ω

B. 400 Ω

C. 300 Ω

D. 150 Ω

64 In the IEC/ATEX hazardous location classification system, what does Zone 21 designate?

A. A location where a flammable gas atmosphere is present continuously during normal operations

B. A location where a flammable gas atmosphere may be present during normal operations

C. A location where explosive dust is present continuously or for long periods during normal operations

D. A location where an explosive dust cloud may be present during normal operations but not continuously

65. Two instrument cable shields are each grounded at one end. Cable 1 is grounded at the field junction box. Cable 2 is grounded at the control room marshalling cabinet. What correction is needed for Cable 1?

A. Both cables should be grounded at both ends for maximum noise rejection

B. Cable 1 shield ground should be moved to the control room end — all instrument cable shields should be grounded at the control room end to prevent ground potential differences from creating loops

C. Both cables should have shield grounds removed and rely entirely on twisted-pair noise rejection

D. Cable 1 is correct — grounding at the field end reduces radiated interference from long field wiring runs

66. A DCS input card has 12-bit analog-to-digital conversion and is scaled for a 0–100 bar pressure range. What is the minimum resolvable pressure change?

A. 0.0244 bar

B. 0.0488 bar

C. 0.0122 bar

D. 0.100 bar

67. An EtherNet/IP control network uses ring topology with Device Level Ring (DLR) protocol. A single fiber optic cable between two adjacent nodes fails. What is the expected network behavior?

A. The entire network loses communication for 30–50 seconds while Spanning Tree Protocol reconverges

B. All nodes downstream of the fault in the ring direction lose communication until the cable is repaired

C. DLR initiates a managed switchover to a backup copper cable path automatically

D. DLR detects the fault in milliseconds and reconfigures traffic to flow in the opposite ring direction — all nodes maintain uninterrupted communication through the surviving path

68. A HART communicator connected to a live 4–20 mA loop cannot communicate with the transmitter, yet the primary variable reads correctly on the DCS. What condition most likely prevents HART communication?

A. The HART communicator software version is incompatible with the DCS input card firmware

B. The transmitter has failed internally but continues producing a fixed 4–20 mA output

C. Total loop impedance at HART FSK frequencies is below the minimum 230 Ω required — the 250 Ω input resistor may be bypassed or absent in this installation

D. Loop current is below 4 mA, indicating an under-range condition that suppresses HART communication

69. A Foundation Fieldbus H1 field device attempts to publish process data outside its scheduled time slot. How does Foundation Fieldbus H1 handle this situation?

A. The unscheduled transmission overwrites the current scheduled transmission, prioritizing real-time data

B. Foundation Fieldbus H1 supports both scheduled and unscheduled communication — scheduled transfers execute control loops at defined intervals while unscheduled transfers use available bus time for acyclic data and alarm reporting

C. The unscheduled transmission triggers a bus reset resynchronizing all devices to the LAS schedule

D. Only the LAS can initiate communications — field devices cannot transmit without an explicit token

70. A plant must upgrade 20 existing 4–20 mA field instruments scattered across a 400-meter process area with no existing fieldbus infrastructure. Installation cost is the primary constraint. Which protocol offers lower installation cost?

A. WirelessHART — eliminating field wiring removes the dominant cost driver for a distributed upgrade across this area

B. PROFIBUS PA — the lower data rate reduces EMI risk and justifies the cabling investment

C. PROFIBUS PA — the two-wire bus architecture is more cost-effective than individual wireless devices

D. Neither — both technologies have equivalent installation costs in large-area installations

71. A DMZ with dual firewalls separates an OT network and IT network. A process historian in the DMZ receives data from OT and provides reports to IT. Which traffic direction is correct for the OT-facing firewall?

A. Bidirectional — both OT reads and IT writes pass through the OT-facing firewall

B. IT to OT direction only — IT applications push requests to OT field devices

C. OT to IT direction only — the firewall blocks all IT-originated traffic from reaching OT

D. OT to DMZ direction only — the OT-facing firewall permits data from OT to the DMZ historian while blocking all inbound DMZ-to-OT traffic

72. A PROFIBUS DP network experiences intermittent errors at 6 Mbit/s but works reliably at 1.5 Mbit/s. The cable length is within specifications for both baud rates. What is the most likely cause?

A. Too many devices on the segment for the 6 Mbit/s polling cycle time

B. The cable characteristic impedance is too high for 6 Mbit/s operation

C. Termination resistors are missing or incorrectly installed at the cable ends — improper termination causes signal reflections that corrupt data at higher baud rates where reflection timing overlaps with successive bits

D. The PROFIBUS master's clock source is unstable at 6 Mbit/s causing baud rate drift

73. A galvanic isolator has entity parameters V_{oc} = 24 V and I_{sc} = 100 mA. The connected field transmitter has U_i = 26 V and I_i = 120 mA. Is this circuit IS-compliant for voltage and current?

A. No — Voc must be at least 15% below Ui to satisfy IS compliance margin requirements

B. Yes — Voc (24 V) ≤ Ui (26 V) and Isc (100 mA) ≤ Ii (120 mA) both satisfy IS entity parameter compliance

C. No — the current margin of only 20 mA is insufficient for IS certification in Zone 1 areas

D. Yes — but only if circuit inductance and capacitance are also verified against Ca and La limits

74. A process historian collects data from a DCS using OPC-DA and exports to a manufacturing execution system using OPC-UA. What key capability does OPC-UA provide that OPC-DA cannot?

A. OPC-UA provides platform-independent communication with built-in authentication and encryption suitable for cross-network boundaries — OPC-DA relies on Windows DCOM with limited security suitable only for within-domain use

B. OPC-UA supports faster data throughput than OPC-DA for historian data collection rates

C. OPC-UA is designed specifically for process data while OPC-DA is designed for discrete manufacturing

D. OPC-UA automatically discovers all available data items without requiring manual configuration

75. An OT cybersecurity review identifies that DCS engineering workstations use standard Windows password policies with 90-day expiration. What is the recommended best practice for OT workstation privileged account management?

A. Increase password expiration to 180 days to reduce disruption frequency for control operations

B. Remove password expiration — OT systems are physically secured and do not require periodic changes

C. Implement multi-factor authentication and reduce password expiration to 30 days

D. Implement role-based access control with strong unique passwords, manage privileged accounts through a dedicated Privileged Access Management system that controls, monitors, and records all privileged sessions

DOMAIN 5: SAFETY SYSTEMS (Questions 76–85)

76. The IEC 61511 safety lifecycle requires a functional safety assessment at defined phases. At which phase is it most critical to perform an FSA to prevent systematic design errors from embedding into hardware?

A. During the factory acceptance test after SIS hardware and software are fully integrated

B. Before the site acceptance test when field wiring can be verified against engineering documents

C. After the Safety Requirements Specification is completed and before detailed SIS hardware and software design begins — identifying SRS errors before design prevents them from propagating into hardware

D. After one year of operation when field reliability data is available to validate SIL assumptions

77. A SIS uses a 1oo2 pressure sensor configuration with $\beta = 0.08$ and $\lambda\_DU = 1.5\times10^{-6}$/hr each, proof tested annually (TI = 8,760 hr). What is the common cause failure contribution to PFD_avg?

A. 1.02×10^{-4}

B. 5.26×10^{-4}

C. 8.77×10^{-3}

D. 2.63×10^{-4}

78. A HAZOP identifies excess nitrogen pressure in a reactor as a hazard with initiating event frequency = 0.1/year. Two IPLs exist: BPCS controller (PFD = 0.1) and high-pressure operator alarm (PFD = 0.1). Tolerable risk = 10^{-4}/year. Is a SIF required, and if so, what PFD?

A. Yes — a SIF is required with PFD = 0.10 (SIL 1)

B. No — existing IPLs reduce risk below 10^{-4}/year without a SIF

C. Yes — a SIF is required with PFD = 0.01 (SIL 2)

D. Yes — a SIF is required with PFD = 0.001 (SIL 3)

79. A proof test procedure for a 1oo1 high-pressure trip applies a simulated pressure above the trip setpoint, observes the SIS output activating, and the technician marks the test complete. Which critical element of a complete proof test was NOT performed?

A. The technician did not verify the SIS logic solver received the correct input signal

B. The technician did not check the trip setpoint against the SRS specification value

C. The technician did not verify the solenoid valve in the SIS output circuit

D. The technician did not verify the final element achieved its required position within the SRS-specified response time — testing the sensor and logic alone is an incomplete proof test

80. A SIL 2 SIS uses a 1oo1 pressure transmitter ($\lambda\_DU = 2\times10^{-6}$/hr) and a 1oo1 shutdown valve ($\lambda\_DU = 4\times10^{-6}$/hr), both proof tested annually (TI = 8,760 hr). What is the total SIF PFD_avg?

A. 8.76×10^{-3}

B. 2.63×10^{-2}

C. 1.75×10^{-2}

D. 4.38×10^{-3}

81. A HAZOP identifies that blocked cooling water can cause a reactor temperature to exceed safe limits within 45 seconds. The SIS is designed with a 60-second response time from demand to safe state. What IEC 61511 concern does this introduce?

A. The 60-second response time is acceptable because it falls within the SIL 2 response time limits

B. The SIS must be upgraded to 2oo3 voting to reduce response time through parallel activation

C. The SIS response time (60 seconds) exceeds the process safety time (45 seconds) — the SIS cannot achieve the safe state before the hazardous condition occurs, requiring a faster response or design modification

D. Adding a high-high temperature alarm with 30-second response addresses the gap as an additional IPL

82. IEC 61511 Edition 2 added cybersecurity requirements within the functional safety lifecycle. What must be addressed regarding cybersecurity in the Safety Requirements Specification?

A. Cybersecurity threats to the SIS that could prevent it from performing its safety functions must be identified — the SRS must address protective measures against threats that could cause loss of the safety function

B. The SRS must specify firewall rules and VLAN configuration for the SIS network segment

C. All SIS field instruments must use encrypted fieldbus protocols certified under IEC 62443

D. The SRS must include a penetration test schedule performed annually by a third-party assessor

83. A plant increases normal reactor operating temperature from 85% to 97% of the SIF high-temperature trip setpoint. What IEC 61511 management of change concern is most critical?

A. The tighter margin requires recertification of all SIS instruments for the new operating conditions

B. The modification requires a new P&ID to be issued before implementation can proceed

C. The modification requires a complete HAZOP covering all connected process units

D. Operating at 97% of trip setpoint substantially increases the SIF demand rate — minor temperature fluctuations now regularly approach the trip threshold, potentially shifting the SIF from low-demand to high-demand mode and invalidating the existing SIL verification

84. According to IEC 61511, what action is required when a SIS component reaches the end of its specified useful life during continued plant operation?

A. The component must be replaced within 30 days regardless of observed condition

B. The component must be replaced before the end of its useful life, or the SIL verification must be updated using failure rate data appropriate for components operating beyond their useful life period

C. An automatic SIL downgrade of one level is applied until the component is replaced

D. The proof test interval must be halved to compensate for the increasing failure rate beyond useful life

85. A SIF is classified as operating in high-demand mode because process demands exceed one per year on average. Per IEC 61511, which performance metric expresses the SIL requirement for a high-demand SIF?

A. PFD_avg — the probability of failure on demand averaged over the proof test interval

B. Risk reduction factor — same metric as low-demand mode but with a tighter numerical target

C. PFH — the probability of dangerous failure per hour applicable when demand rate exceeds once per year

D. MTTFd — the mean time to dangerous failure expressed as the inverse of the dangerous failure rate

PRACTICE EXAM 7: ANSWER KEY AND EXPLANATIONS

1. B — Without square root extraction, output is proportional to DP, not flow. At 50% output, DP = 50 in H_2O. Flow = 750 × √(50/100) = 750 × 0.707 = 530 gpm. Recognizing whether square root extraction is active is one of the most critical distinctions in DP flow calculation problems.
2. D — Linear interpolation: T = 75 + [(3.819 − 3.059)/(4.096 − 3.059)] × (100 − 75) = 75 + (0.760/1.037) × 25 = 75 + 18.3 = 93.3°C. The interpolation fraction (0.760/1.037 = 0.733) is applied to the 25°C interval between the two table entries.
3. A — Magnetic flowmeters require a minimum fluid conductivity of approximately 5 μS/cm. At 45,000 μS/cm, the brine solution exceeds this minimum by four orders of magnitude, making the magmeter fully appropriate with no conductivity-related concerns.
4. C — URV = SG × h × 62.37/144 = 1.35 × 4 × 62.37/144 = 336.8/144 = 2.34 psi. The SG multiplier accounts for the denser liquid generating more hydrostatic pressure per unit height than the water reference used in the psi/ft conversion factor.
5. B — Coriolis mass flowmeters measure mass flow directly through the Coriolis force effect on a vibrating tube, independent of gas composition, density, or pressure. When gas type changes between methane, ethylene, and propane, the Coriolis meter continues measuring mass flow accurately without recalibration, making it the only technology meeting the ±0.5% mass accuracy requirement.
6. D — Per ASME PTC 19.3 TW, thermowell natural frequency is proportional to $1/L^2$ for a cantilever beam, where L is the unsupported insertion length. Doubling the insertion length reduces natural frequency by a factor of four — making insertion length the most sensitive and dominant design variable for thermowell wake frequency compliance.
7. C — Membrane-covered amperometric dissolved H_2S sensors measure dissolved sulfide directly in the liquid phase through electrochemical oxidation at an electrode, providing continuous sub-ppm level monitoring. This direct liquid-phase immersion measurement eliminates the sampling lag and phase-transfer uncertainties of headspace or extractive approaches.
8. A — In three-wire RTD compensation, the bridge circuit assumes the two voltage-sensing wires have equal resistance. An 0.8 Ω imbalance is not compensated and appears directly as a temperature error: ΔT = 0.8 Ω / (100 × 0.00385 Ω/°C) = 0.8/0.385 = 2.08°C ≈ 2.1°C. Four-wire RTD connections completely eliminate this error by measuring lead resistance independently.

9. D — Flow through a DP device scales as $Q \propto \sqrt{(1/SG)}$ at constant ΔP. Actual flow = $Q_{max} \times \sqrt{(SG_{cal}/SG_{actual})} = Q_{max} \times \sqrt{(1.00/1.12)} = Q_{max} \times 0.945$. The actual flow is approximately 5.5% lower than the calibrated maximum because the denser fluid produces less flow for the same differential pressure.

10. B — GWR transmits microwave pulses along a physical probe. Dielectric discontinuities at the upper hydrocarbon surface and at the hydrocarbon-water interface each generate measurable reflections. Time-of-flight analysis of both echoes provides simultaneous upper level and interface level measurements from a single instrument — one of GWR's key advantages over free-space radar.

11. C — Nuclear density measurement uses gamma ray attenuation — denser materials absorb more radiation. As slurry density increases from 1.2 to 1.6 kg/L, the denser material attenuates the gamma beam more strongly, reducing the photon count rate at the external detector. Detector count rate varies inversely with material density in the beam path.

12. A — A uniform constant error of +1.2 psi at every calibration point indicates the entire output curve has shifted by a fixed offset — a pure zero error. A single zero adjustment shifts all five points simultaneously by −1.2 psi, correcting the transmitter without any span change.

13. D — A filter time constant of 0.3 seconds provides a cutoff frequency of $1/(2\pi \times 0.3) \approx 0.53$ Hz, effectively attenuating signals above approximately 0.5 Hz. This eliminates the 15–50 Hz noise while preserving the 0.1–0.5 Hz process dynamics and adding negligible phase lag relative to the 0.1 Hz lower band of the process signal.

14. B — Positive displacement meters trap and release discrete fixed fluid volumes, providing accurate volumetric measurement independent of viscosity changes across the full 5:1 flow range. At low flow rates where velocity-based meters struggle with bearing friction or minimum Reynolds number requirements, PD meters maintain metrological accuracy — a specific advantage in variable-viscosity crude oil custody transfer.

15. A — The amperometric DO sensor's polymer membrane acts as a selective diffusion barrier for oxygen. Biological fouling, hydrocarbon oils, or surfactants coat or penetrate the membrane, progressively reducing oxygen diffusion rate. The sensor reads artificially low because less oxygen reaches the electrode, even though the calibration points shift minimally until fouling is severe.

16. C — Multi-stage anti-noise cage trim distributes total pressure drop across many sequential restrictions, keeping the per-stage pressure ratio below the threshold where turbulent jet energy generates acoustic noise. Addressing the source of noise generation within the trim is more effective than downstream attenuation or relocation, which treat symptoms rather than the generation mechanism.

17. D — The DCS terminals measure the net EMF between the process junction (450°C) and the reference junction (30°C). EMF at 450°C (0°C reference) ≈ 18.5 mV; EMF at 30°C (0°C reference)

≈ 1.2 mV. Net measured EMF = 18.5 − 1.2 ≈ 17.3 mV. Cold junction compensation then adds the 1.2 mV correction to report the full 450°C temperature.

18. B — The narrow 18-inch diameter creates geometric conditions where ultrasonic pulses can reflect from vessel walls and generate standing wave interference patterns at specific frequencies. Wind pressure fluctuations across the open vessel top alter the acoustic propagation boundary conditions, and these two effects combine to produce the observed wind-direction-correlated erratic measurements.
19. A — LRV calculation at 0% level: HP side = 0 (no liquid above lower tap). LP side (wet leg, 12 ft, SG = 1.05) = 12 × 12 × 1.05 / 27.68 = 5.46 psi. LRV = 0 − 5.46 = −5.46 psi. The negative LRV confirms a suppressed-zero configuration where the wet leg head always exceeds the process head at the low-level condition.
20. C — Flame ionization detectors ionize organic carbon compounds in a hydrogen flame, producing measurable ion current proportional to carbon atom count. Carbon monoxide (CO) is an inorganic carbon compound that does not produce significant ionization in the FID hydrogen flame — FID sensitivity to CO is negligible, making it unsuitable for CO monitoring.
21. D — When a glass pH electrode's dynamic response degrades while static calibration remains acceptable, the glass membrane itself is the likely cause. Surface scaling, protein fouling, or chemical attack increases membrane resistance, slowing the hydrogen ion diffusion process. Increased membrane resistance extends response time dramatically without necessarily shifting the equilibrium potential that calibration measures.
22. B — URL (Upper Range Limit) is the maximum pressure the transmitter can measure at its highest range setting — 2,000 psi. Accuracy specified as ±% URL applies to this URL value: ±0.075% × 2,000 = ±1.50 psi absolute error at any reading, including 50 psi. This represents a ±3% error of reading at 50 psi, illustrating why URL-based specifications can be misleading for instruments operated far below their URL.
23. C — Valve dead band limit cycling produces a characteristic staircase pattern: integral action accumulates continuously until its accumulated output exceeds the positioner dead band threshold, the valve jumps to a new position, the process variable steps, and the cycle repeats. This contrasts with PID tuning instability, which produces smoother sinusoidal oscillations correlated with the loop's natural frequency.
24. A — Per ANSI/ISA-5.1: F = Flow (measured variable), I = Indicating, A = Alarm, H = High, L = Low. Tag letters are read sequentially from left to right after the measured variable. FIAHL-110 identifies a flow indicating instrument with high alarm and low alarm functions in loop 110.
25. D — Z-N open-loop PID with R = 4.0 %/(%·min) and θ = 0.5 min: Kc = 1.2/(R × θ) = 1.2/(4.0 × 0.5) = 0.60. Ti = 2θ = 1.0 min. Td = 0.5θ = 0.25 min. These settings target a quarter-decay ratio

response — the aggressive nature of Z-N tuning at high process reaction rates should be verified against acceptable overshoot for this application.

26. B — Feedforward from the inlet feed temperature directly corrects for the most common disturbance before it propagates through the exchanger's thermal lag to cause a measurable outlet deviation. The feedback controller handles residual model error and unmeasured disturbances, but feedforward specifically eliminates the propagation delay during which the disturbance goes uncorrected in pure feedback systems.

27. A — ISA-101 High Performance HMI specifies predominantly gray and muted low-saturation colors for normal operating states. This reserved baseline ensures that alarm and abnormal conditions displayed in high-contrast colors stand out immediately against the subdued normal background, preserving operator situational awareness during critical events.

28. C — The IEC 61131-3 SFC action qualifier "P" (Pulse or rising-edge) executes its associated action for exactly one program scan cycle when the step becomes active, then immediately deactivates. This one-shot behavior is used for discrete trigger events — resetting a counter, issuing a single setpoint change, or firing a one-time process command at step entry.

29. D — pH process gain varies by a factor of 40 across the operating range due to the highly nonlinear titration curve. Gain scheduling automatically adjusts the controller gain as a function of measured pH, maintaining approximately constant effective loop gain (controller gain × process gain) at every operating point, providing stable control that neither oscillates at pH 7 nor stagnates at the extremes.

30. B — Z-N closed-loop PI settings: $K_c = 0.45 \times K_u = 0.45 \times 3.6 = 1.62$. $T_i = P_u/1.2 = 180/1.2 = 150$ s. The PI-specific multiplier 0.45 (vs. 0.6 for PID) and the 1.2 Ti divisor target a quarter-decay ratio response with more conservative integral action than PID settings to reduce overshoot.

31. A — $K_c = \tau/(K_p \times (\lambda + \theta)) = 180/(0.6 \times (60 + 30)) = 180/(0.6 \times 90) = 180/54 = 3.33$. Lambda tuning's direct specification of the closed-loop time constant ($\lambda = 60$ s) enables the engineer to design for a specific response speed — here, a moderately aggressive setting where λ equals twice the dead time.

32. C — ISA-18.2 defines more than 10 alarms per 10-minute period as "likely unmanageable" — the rate at which operators cannot effectively assess, prioritize, and respond to all activated alarms. Forty-seven alarms in 10 minutes represents a severe alarm flood requiring investigation of alarm rationalization, state-based alarming, or alarm suppression strategy failures.

33. D — Multi-factor authentication verifies user identity but cannot sanitize the endpoint device. Malware on a vendor laptop acquired through email or web browsing exploits the authenticated session to reach OT systems, effectively tunneling malicious traffic through the legitimate MFA-verified connection and bypassing all network perimeter controls that validated the user.

34. A — Elevated column pressure raises component boiling points — a higher temperature is required to maintain the same vapor-liquid equilibrium at higher pressure. Without pressure compensation, the temperature transmitter reads the thermodynamically elevated bubble point as if composition has shifted toward heavier components, sending a false enrichment signal to the composition control strategy.

35. B — For a reverse-acting controller, output increases when PV drops below setpoint. Output = bias + Kc × (SP − PV) = 50 + 2.5 × (60 − 57) = 50 + 7.5 = 57.5%. The reverse-acting response correctly increases controller output to drive the low-reading PV back toward setpoint.

36. C — MPC's process model explicitly captures how each manipulated variable change affects all 8 controlled variables simultaneously. Unlike 8 independent PID loops that cannot anticipate cross-variable effects, MPC computes coordinated moves for all 4 manipulated variables within a single constrained optimization, preventing the interaction-driven instability that plagues independent PID arrangements in highly coupled multivariable systems.

37. A — Sequential Function Chart naturally represents the multi-phase sequential structure — each ramp and hold becomes a distinct step with timer-based transition conditions. Structured Text within each step action calculates linearly ramped setpoint values in real time (e.g., SP = start_temp + rate × elapsed_time), combining the SFC's sequencing capability with ST's mathematical precision.

38. D — Industry minimum stability margins are gain margin ≥ 6 dB and phase margin ≥ 30°. Both margins (GM = 2.0 dB, PM = 15°) are simultaneously below their recommended minimums, indicating the loop operates near the stability boundary. Small changes in process gain, dead time, or valve friction could drive the loop unstable — comprehensive retuning to both margins is required.

39. B — The ISA S88 procedural hierarchy is: Procedure → Unit Procedure → Operation → Phase. Unit Procedures directly contain Operations — the ordered sequences of individual control actions executed within a single process unit to achieve a distinct processing goal. The Procedure level contains multiple Unit Procedures that may span different equipment.

40. C — With Ti set to approximately infinity, the integral contribution (Kc/Ti × ∫e dt) approaches zero, reducing the controller to essentially proportional-only behavior. Proportional-only control always produces steady-state offset because a non-zero error is required to maintain any non-zero output above the bias — the controller can never drive error to exactly zero.

41. D — Z-N open-loop PID with Kp = 1.5, τ = 60 s, θ = 10 s: Kc = 1.2τ/(Kp × θ) = 1.2 × 60/(1.5 × 10) = 72/15 = 4.80. Ti = 2θ = 20 s. Td = 0.5θ = 5 s. The relatively short dead time (θ/τ = 0.167) allows aggressive tuning — Z-N rules produce high gain because the process is relatively easy to control.

42. A — Three-element feedwater control uses steam flow as the feedforward signal. A 10% low calibration error means the feedforward underestimates steam demand during load increases, commanding less feedwater than needed. The drum level drops further and recovers more slowly than it should, producing larger level transients that the feedback controller must then correct.

43. C — Split-range assignment: make-up gas valve receives 0–50% output range (open at 0%, closed at 50%); vent valve receives 50–100% output range (closed at 50%, open at 100%). At 55% output: make-up valve = fully closed (crossed its 50% closing point). Vent valve = (55−50)/(100−50) = 10% open.

44. B — When the pump protection controller's higher output takes control via the high selector, the level controller becomes inactive. Its integral term continues accumulating based on level error during the inactive period (windup). When the level controller eventually takes back control, the wound-up integral produces an excessive output bump. External reset prevents this by feeding the actual valve position signal back to the inactive controller, keeping its output tracking the valve position.

45. A — $Cv = Q \times \sqrt{(SG/\Delta P)} = 220 \times \sqrt{(1.05/45)} = 220 \times \sqrt{(0.02333)} = 220 \times 0.1528 = 33.6$. The SG correction slightly increases the required Cv compared to a pure water calculation at the same conditions.

46. D — Hydrochloric acid at 80°C aggressively attacks carbon steel, 304 SS, and 316 SS at concentrations above approximately 2%. Alloy 20 (N08020) and Hastelloy C-276 are specifically engineered for HCl resistance through their nickel-chromium-molybdenum compositions, which maintain adequate corrosion rates in concentrated HCl service at elevated temperatures.

47. C — An electronic soft starter with a configurable current limit directly enforces the 250% FLA constraint through thyristor-based voltage reduction, regardless of motor inertia or load characteristics. The current limit setting is an electrical constraint applied in real time — unlike star-delta which has fixed reduction ratios and autotransformer starting which has fixed voltage taps.

48. B — Conventional spring-loaded PRVs experience an effective set pressure increase equal to the superimposed back pressure, because back pressure acts on the disc outlet in the same direction as the spring. Variable back pressure of 0–35 psig (up to 14% of 250 psig set pressure) exceeds the conventional PRV's 10% back pressure tolerance, causing variable and unpredictable opening pressures. A balanced bellows or pilot-operated PRV is required.

49. A — Minimum Cv = Rated Cv / Rangeability = 60/50 = 1.2. The rangeability directly defines the ratio of maximum to minimum controllable Cv for a given valve trim. Below this minimum Cv, the flow characteristic becomes unpredictable and stable throttling control is no longer achievable.

50. D — Total force = unbalanced fluid force + packing friction + spring force = 800 + 150 + 350 = 1,300 lbf. Required area = 1,300/80 = 16.25 in^2. The diaphragm must develop sufficient pneumatic force to overcome all mechanical and fluid forces resisting valve movement.

51. C — Dual-plate wafer check valves have two spring-loaded half-discs that pivot only 35–45° from closed to fully open — compared to the 90° travel of swing check discs. The shorter travel allows significantly faster closure during flow reversal, reducing the flow reversal velocity at the time of closure and minimizing the water hammer pressure spike.

52. B — Thermal overload relays are set to the original motor's full-load current. A larger motor has a higher FLA that exceeds the original relay trip setting. The relay interprets the new motor's normal operating current as an overload and trips prematurely, preventing the motor from operating at its rated capacity until the relay is properly set for the new motor.

53. A — PRV sizing always requires the next larger standard orifice than the calculated required area — never a smaller size. The H orifice (0.785 in^2) is below the required 0.88 in^2 and would be undersized. The J orifice (1.287 in^2) is the smallest standard API 526 size that provides adequate relief capacity.

54. D — A quick-exhaust valve installed directly on the actuator exhaust port creates a large direct vent path that bypasses the positioner's restricted internal exhaust. Actuator air escapes through the large-bore quick-exhaust rather than the positioner exhaust orifice, dramatically reducing the depressurization time and achieving the required fast spring-return stroke.

55. C — At 250°F, the temperature-derated burst pressure is 188 psig. Operating at 180 psig produces an operating-to-burst ratio of 180/188 = 95.7%, which exceeds recommended limits for all disc types (70–80% for conventional tension discs, 90% for reverse-buckling discs). Insufficient margin leads to premature fatigue failure from pressure cycling at near-burst operating levels.

56. B — Correct travel at 0%, 25%, and 100% input confirms both zero and span are accurately calibrated. The 5% deviation at 50% input (45% actual vs. 50% expected) with correct endpoints indicates a nonlinear positioner output curve — a linearity error in the mechanical linkage cam profile or electronic characterizer that cannot be corrected by simple zero or span adjustment.

57. D — Self-contained pressure reducing regulators operate through direct mechanical feedback between the downstream pressure-sensing diaphragm and the valve plug, requiring no external power source, instrument air supply, or control signals. This inherent independence from utility systems makes the self-contained regulator available even during total control system failures that would disable any DCS-controlled alternative.

58. A — Cavitation occurs when installation sigma σ falls below the valve's critical sigma σc ($\sigma < \sigma c$). For standard trim: $\sigma = 0.25 < \sigma c = 0.80$ — cavitation occurs. For anti-cavitation trim: $\sigma c = 0.18$. Comparing $\sigma = 0.25$ to $\sigma c = 0.18$: since σ (0.25) > σc (0.18), cavitation does not occur. The anti-

cavitation trim's staged pressure drop prevents local pressure from reaching vapor pressure at any single stage.

59. C — Flashing produces stable two-phase flow that persists downstream when downstream pressure remains below fluid vapor pressure. High-velocity mixed-phase flow erodes both the valve outlet and downstream piping over an extended region. This distributed downstream erosion pattern — extending 8–12 inches — distinguishes flashing from cavitation (concentrated trim pitting) and particle erosion (directional wear marks on flow-impingement surfaces).

60. D — When the solenoid correctly de-energizes and air is confirmed vented but the spring fails to complete the stroke, the spring force is insufficient to overcome mechanical resistance. Spring preload weakens through stress relaxation over time, and stem friction can increase from packing wear, corrosion, or process deposits — eventually exceeding what the weakened spring can overcome during the emergency closure stroke.

61. B — The thermal overload contact in series with the contactor coil circuit interrupts coil energization when it opens. The de-energized magnetic contactor opens its main power contacts, disconnecting all three phases of motor supply voltage and stopping the motor before winding temperatures reach the threshold that degrades insulation.

62. A — A 24-inch globe valve would be extremely heavy, expensive, and require very large actuators for its linear plug design. High-performance butterfly valves at this size provide adequate 4:1 flow rangeability, acceptable modulating control characteristics with appropriate trim selection, and compatibility with the 5 psi available pressure drop — while being a fraction of the globe valve's weight and cost.

63. C — Available voltage for series resistance = 24 − 10 = 14 VDC. Maximum total resistance = 14/0.020 = 700 Ω. Fixed components: 250 Ω (input resistor) + 150 Ω (IS barrier) = 400 Ω. Maximum cable resistance = 700 − 400 = 300 Ω.

64. D — IEC/ATEX Zone 21 designates a location where an explosive dust cloud may be present during normal operations but not continuously — the intermediate hazard zone for combustible dusts, analogous to Zone 1 for flammable gases. Zone 20 is the continuous dust hazard zone; Zone 22 is the abnormal conditions only zone.

65. B — Instrument cable shields must be grounded at one end only — the control room end — to prevent ground loop formation. Grounding at the field end creates risk that potential differences between the field and control room ground connections drive current through the shield conductor, which inductively couples noise into the signal conductors the shield is meant to protect.

66. A — A 12-bit ADC resolves the 100 bar range into 2^{12} = 4,096 counts. Minimum resolvable increment = 100/4,096 = 0.0244 bar. This resolution determines the smallest pressure change the DCS can detect and report — important for process monitoring and control loop performance evaluation.

67. D — Device Level Ring (DLR) protocol continuously monitors the ring for faults. Upon detecting a cable fault, DLR reconfigures traffic to flow in the reverse direction around the ring within milliseconds (typically < 3 ms). All nodes remain reachable through the surviving ring path — this sub-3ms recovery time is essential for process control where communication loss exceeding one control scan is unacceptable.

68. C — HART FSK communication requires a minimum total loop impedance of approximately 230–250 Ω at the 1200/2200 Hz communication frequencies to develop adequate voltage for the HART modem to detect digital signals. The 4–20 mA analog current flows normally on the DC circuit, but without the 250 Ω resistor, the AC HART FSK voltage signal cannot develop sufficient amplitude for reliable digital communication.

69. B — Foundation Fieldbus H1 implements a dual communication architecture: scheduled cyclic transfers executed by the Link Active Scheduler (LAS) at defined intervals carry time-critical control loop data, while unscheduled acyclic transfers use remaining bus time for alarm reporting, operator commands, and configuration data. Both communication types coexist on the same physical segment without conflict.

70. A — WirelessHART eliminates field wiring entirely — the dominant cost driver for a scattered instrument retrofit across a 400-meter area with no existing fieldbus. Each device requires only local power with no cable installation, conduit runs, junction boxes, or cable tray extension. For 20 instruments with no infrastructure in place, the complete elimination of field wiring installation cost is the decisive economic advantage.

71. D — The OT-facing firewall in a dual-firewall DMZ architecture should permit data flow only from OT toward the DMZ historian (OT → DMZ), while blocking all traffic initiated from the DMZ side toward OT. This unidirectional rule ensures that historian data collection proceeds normally while preventing any DMZ-initiated traffic — including traffic from a compromised historian — from reaching OT controllers.

72. C — RS-485 termination resistors absorb transmitted signal energy at cable ends without reflection. At higher baud rates, signal transitions are shorter in duration — reflections from improperly terminated ends arrive during the valid data bit window and corrupt the received signal. At lower baud rates, the longer bit period allows reflections to decay before the next bit is sampled, masking the termination problem.

73. B — IS entity parameter compliance requires $V_{oc} \leq U_i$ AND $I_{sc} \leq I_i$, both satisfied here: 24 V ≤ 26 V and 100 mA ≤ 120 mA. These conditions ensure that even under worst-case fault conditions at the barrier, the maximum voltage and current delivered to the hazardous area cannot exceed the instrument's rated safe limits. Additional verification of Ca and La circuit parameters completes the full IS compliance assessment.

74. A — OPC-DA relies on Windows COM/DCOM — inherently platform-specific, difficult to secure through firewalls, and lacking built-in encryption or certificate-based authentication. OPC-UA's

modern service-oriented architecture includes X.509 certificate authentication, message signing, and AES encryption as standard features, enabling secure cross-network communication independent of Windows infrastructure.

75. D — Role-based access control with a Privileged Access Management system provides layered protection: strong unique passwords prevent credential sharing, role-based permissions enforce least privilege, and PAM records all privileged sessions creating a complete accountability audit trail. This approach simultaneously addresses authentication, authorization, and accountability — the three fundamental pillars of access security for OT systems.

76. C — The FSA before hardware design begins is the most cost-effective and impactful intervention point. SRS errors propagate directly into hardware specifications, procurement, software code, and installation. Finding and correcting an SRS error at this phase costs a fraction of finding the same error during commissioning when field modifications, re-validation activities, and project schedule delays are required.

77. B — CCF term = $\beta \times \lambda\_DU \times TI/2 = 0.08 \times 1.5\times10^{-6} \times 8{,}760/2 = 0.08 \times 0.006570 = 5.256\times10^{-4} \approx 5.26\times10^{-4}$. The CCF contribution typically dominates PFD in 1oo2 configurations at annual proof test intervals — demonstrating why diversity of technology or manufacturer is critical in redundant safety sensor configurations.

78. A — Mitigated frequency = $0.1 \times 0.1 \times 0.1 = 10^{-3}$/year > 10^{-4}/year tolerance, so a SIF is required. Required SIF PFD = $10^{-4}/10^{-3} = 0.10$, which falls within the SIL 1 range. Existing IPLs reduce risk by a factor of 10 but leave residual risk one order of magnitude above the tolerance criterion, requiring one additional decade of risk reduction from the SIF.

79. D — A complete proof test must demonstrate the entire cause-to-effect path: sensor detection → logic solver processing → final element achieving the required safe position within the SRS-specified response time. Testing sensor and logic without confirming final element position and stroke time leaves the most mechanically vulnerable safety component — the shutdown valve — untested against its performance requirements.

80. B — Sensor PFD = $2\times10^{-6} \times 8{,}760/2 = 8.76\times10^{-3}$. Valve PFD = $4\times10^{-6} \times 8{,}760/2 = 1.752\times10^{-2}$. Total PFD = $8.76\times10^{-3} + 1.752\times10^{-2} = 2.628\times10^{-2} \approx 2.63\times10^{-2}$. This falls in the SIL 1 range (0.01–0.1), confirming the SIL 2 requirement is not met — the final element dominates the total PFD and requires redundancy or shorter proof test interval.

81. C — IEC 61511 requires the SIS response time to be less than the process safety time — the time between onset of the hazardous condition and the point where harm becomes irreversible. A 60-second SIS response exceeds the 45-second process safety time, meaning the SIS cannot prevent the hazardous outcome. The design must be modified through faster final elements, changed process design, or reduced process safety time analysis.

82. A — IEC 61511 Edition 2 explicitly requires cybersecurity threats to the SIS to be addressed within the functional safety lifecycle. The SRS must identify specific threats that could cause loss of the safety function — unauthorized logic modification, network attacks disabling SIS communication, or malware corrupting safety logic — and specify proportionate protective measures to ensure the SIS remains available when demanded.

83. D — Operating at 97% of trip setpoint means routine temperature fluctuations of just 3°C above normal can activate the SIF. Normal process dynamics near this margin cause frequent nuisance activations that elevate the annual demand rate. If demand rate exceeds one per year, the SIF classification shifts from low-demand (PFD metric) to high-demand (PFH metric), fundamentally invalidating the existing SIL verification methodology.

84. B — The constant failure rate model applies only during the useful life period — the flat region of the bathtub curve. Beyond the specified useful life, wear-out mechanisms increase the failure rate, making the original failure rate data non-conservative. IEC 61511 requires replacement before the useful life expires, or the SIL verification must be revised with failure rate data appropriate for the aging component's actual condition.

85. C — IEC 61511 defines two SIF operating modes: low-demand (demand rate ≤ once per year), where SIL is expressed as PFD_avg; and high-demand or continuous mode (demand rate > once per year), where SIL is expressed as PFH — probability of dangerous failure per hour. PFH reflects the requirement for continuous availability rather than readiness to respond to infrequent demands.