PRACTICE EXAM 4: 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 process engineer must select a flow meter for very low flow rates of a high-viscosity polymer solution (SG = 0.95, viscosity = 500 cP) where mass flow accuracy is critical for custody transfer. Which technology is most appropriate?

A. Turbine flowmeter with low-friction ceramic bearings

B. Magnetic flowmeter with low-flow signal amplifier

C. Reduced-bore vortex flowmeter

D. Coriolis mass flowmeter

2. A thermowell installed in a process pipe has a tip outside diameter of 1.0 inch and experiences a fluid velocity of 80 ft/s. Using a Strouhal number of 0.22, what is the vortex shedding frequency?

A. 105.6 Hz

B. 211.2 Hz

C. 422.4 Hz

D. 52.8 Hz

3. A DP level transmitter is specified for a closed-vessel level application where the process fluid is a styrene monomer that polymerizes and solidifies when cooled in impulse lines. Which impulse line configuration is most appropriate?

A. Wet leg filled with process condensate

B. Wet leg filled with silicone oil

C. Dry leg connected to the vapor space

D. Wet leg with continuous nitrogen purge

4. A pressure transmitter reads 75 psig at sea level where local atmospheric pressure is 14.696 psia. What is the equivalent absolute pressure in kPa?

A. 619.1 kPa

B. 517.1 kPa

C. 101.3 kPa

D. 689.5 kPa

5. A catalytic bead (pellistor) combustible gas detector is installed in a nitrogen-blanketed enclosure where ambient oxygen concentration is below 2%. A hydrogen leak occurs. How does the sensor respond?

A. The detector activates normally

B. The detector produces a signal proportional to available oxygen

C. The detector generates a false high alarm

D. The detector produces zero output

6. Using the linear RTD approximation $R(T) = 100 \times (1 + 0.00385 \times T)$, what is the resistance of a Pt100 RTD at –50°C?

A. 115.25 Ω

B. 92.60 Ω

C. 80.75 Ω

D. 95.25 Ω

7. A DP flow transmitter with square root extraction enabled is ranged for 0–250 in H_2O at a maximum flow of 1,200 gpm. The transmitter output reads 8 mA. What is the indicated flow rate?

A. 450 gpm

B. 300 gpm

C. 240 gpm

D. 600 gpm

8. Which level measurement technology operates by detecting the change in electrical capacitance between an inserted sensing probe and the vessel wall as liquid rises around the probe?

A. Capacitance level transmitter

B. Guided-wave radar transmitter

C. Displacer-type level instrument

D. Nuclear point-source level switch

9. On a P&ID drawn to ANSI/ISA-5.1, which instrument bubble symbol represents a field-mounted instrument located in the process area?

A. Circle with a solid horizontal line

B. Circle inside a square

C. Plain circle with no line

D. Circle with a dashed horizontal line

10. A volumetric flow meter measures crude oil at 500 m^3/hr at 20°C (density = 850 kg/m^3) and at 50°C (density = 820 kg/m^3). Which statement correctly describes the measurement situation?

A. No measurement error exists at either condition

B. The meter reads lower at 50°C for the same volumetric rate

C. The meter reads higher at 50°C for the same volumetric rate

D. The meter correctly indicates 500 m^3/hr at both temperatures, but the corresponding mass flow rates differ by approximately 3.5%

11. A laser-based opacity transmitter measures particulate concentration in a flue gas stack. Which operating principle does it apply?

A. Raman backscatter proportional to gas molecule concentration

B. Attenuation of a transmitted laser beam across the duct

C. Doppler frequency shift from moving particles

D. Laser-induced fluorescence at characteristic emission wavelengths

12. A flow meter calibration record shows a consistent error of +1.8% at every tested flow point across five successive calibrations over three months. Which measurement characteristic does this pattern most precisely describe?

A. High repeatability with a systematic positive bias offset

B. Acceptable accuracy within normal calibration uncertainty

C. Progressive calibration drift

D. Incorrect reference standard rather than meter error

13. A DP level transmitter is installed on a pressurized deaerator. A wet leg filled with condensate (SG = 1.00) extends 5 feet above the lower process tap. Process water at operating conditions has SG = 0.96, and the measurement span is 4 feet. What is the transmitter LRV in inches H_2O?

A. +48.0 in H_2O

B. +12.0 in H_2O

C. –60.0 in H_2O

D. –12.0 in H_2O

14. An electrochemical H_2S toxic gas sensor must be replaced at defined service intervals rather than simply recalibrated. What physical characteristic of the electrochemical sensing mechanism makes replacement necessary?

A. Permanent reference electrode potential shift after high-concentration exposures

B. Mandatory regulatory calendar-interval replacement regardless of sensor condition

C. Permanent membrane coating from electrochemical reaction products

D. Progressive consumption of the electrolyte and electrode materials during normal operation

15. A DP flow transmitter calibrated for water (SG = 1.00) now measures a fluid with SG = 0.85 without recalibration. At the same full-scale DP, how does the actual flow compare to the original calibrated maximum?

A. Identical to the original maximum

B. Approximately 8.5% higher than the original maximum

C. Approximately 8.5% lower than the original maximum

D. Approximately 15% lower than the original maximum

16. A hydrogen-producing process unit requires both combustible gas detection and toxic H_2S exposure monitoring. Which detector combination is technically correct for this service?

A. Infrared point detector and UV/IR flame detector

B. Infrared gas detector and electrochemical toxic sensor

C. Catalytic bead detector and electrochemical toxic sensor

D. Photoionization detector for both hazards

17. An orifice plate with a bore diameter of 3.0 inches is installed in a 6-inch Schedule 40 pipe with an internal diameter of 6.065 inches. What is the beta ratio (β)?

A. 0.495

B. 0.613

C. 0.379

D. 0.741

18. An infrared CO_2 analyzer measures a process gas stream containing variable concentrations of water vapor. Without water vapor compensation, what measurement error results?

A. Accelerated corrosion of the IR detector cell

B. Systematic low CO_2 readings

C. High readings from optical window condensation

D. False-high CO_2 readings from overlapping water vapor absorption bands

19. Calibration data for a pressure transmitter shows errors of +0.2% at 0%, 25%, 50%, 75%, and 100% of span. Which calibration condition does this uniform error pattern indicate?

A. Span error

B. Zero (offset) error

C. Nonlinearity error

D. Hysteresis error

20. An ORP measurement of +450 mV is recorded at a water treatment plant monitoring point. What does this positive value indicate?

A. Mildly acidic conditions with pH below 7.0

B. Reducing conditions with insufficient disinfectant residual

C. Oxidizing conditions confirming adequate disinfectant residual

D. Thermal oxidation of dissolved organics above 40°C

21. What distinguishes a four-wire transmitter from a standard two-wire loop-powered transmitter in a 4–20 mA installation?

A. A separate two-wire power supply connection and a separate two-wire signal output, requiring an external power source independent of the loop

B. Redundant analog and RS-485 digital outputs on independent wire pairs

C. Dedicated HART communication wires separate from the analog signal pair

D. Shield drain and ground reference conductors added to the standard measurement loop

22. A DP transmitter with a wet reference leg reads consistently higher than expected at all level conditions. No changes in process fluid composition have been reported. Which potential cause should be investigated first?

A. Process fluid specific gravity has increased above the calibration value

B. A partial blockage has developed at the high-pressure process tap

C. The DCS has inadvertently applied square root extraction to the level signal

D. The wet reference leg has partially drained

DOMAIN 2: CONTROL SYSTEMS (Questions 23–44)

23. A level control loop with Kc = 2.0 and Ti = 5 min oscillates continuously after a setpoint change. An engineer increases Ti to 15 minutes without changing Kc and the loop stabilizes. What does this result most directly indicate?

A. The original proportional gain was too low

B. The original integral time was too short

C. Derivative action was interacting with noisy level measurement

D. The setpoint step magnitude exceeded output limits

24. According to ANSI/ISA-5.1, which instrument bubble symbol correctly identifies a pneumatic pressure indicating controller mounted in a local panel, accessible only from the rear or interior of the panel?

A. Plain circle with no line

B. Circle with a solid horizontal line

C. Circle with a dashed horizontal line

D. Circle inside a square

25. A PID controller applies derivative action to the process variable (PV) rather than to the error signal. Under which specific operating condition are derivative-on-PV and derivative-on-error guaranteed to produce identical controller outputs?

A. When the setpoint is constant and only process disturbances cause PV changes

B. When integral time equals the process time constant

C. When derivative filtering uses a time constant equal to the derivative time

D. Under no conditions

26. A reactor jacket temperature loop and a reactor core temperature loop interact such that changes in the jacket controller output affect both temperatures, while changes in the core controller output have negligible effect on jacket temperature. Which description best characterizes this relationship?

A. Unidirectional interaction — jacket loop affects core loop but not the reverse

B. Symmetric bidirectional interaction requiring a full decoupling matrix

C. Series cascaded interaction requiring inferential temperature calculation

D. Feedback interaction where core temperature trims the jacket controller

27. A DCS implements PID in position form rather than velocity form. Which statement correctly describes a practical difference between these two implementations?

A. Position form uses engineering units; velocity form uses normalized percentage variables

B. Position form calculates incremental output changes; velocity form calculates absolute output values

C. Position form calculates total absolute output and requires explicit anti-windup; velocity form calculates incremental changes with inherent windup resistance

D. Position form executes faster because it avoids summation required in velocity form

28. A Model Predictive Control system is deployed on a five-product distillation column with three manipulated variables and five controlled variables. What is the primary capability distinguishing MPC from five independent PID loops?

A. Automatic variable pairing through internal relative gain array analysis

B. Simultaneous optimization of all controlled variables while enforcing hard constraints on all variables within a single coordinated calculation

C. Elimination of all loop interactions through an internal mathematical decoupler

D. Individually adjusted update rates for each loop based on process time constants

29. A closed-loop step response to a 10% setpoint increase shows no overshoot, a slow asymptotic approach to the new setpoint over 20 minutes, and no oscillatory behavior at any point. This response most indicates which tuning condition?

A. Over-conservative tuning with excessive integral time or insufficient gain

B. Optimal quarter-decay ratio tuning

C. Under-damped tuning with excessive derivative gain

D. Proportional-only control with permanent residual offset

30. A DCS historian uses exception reporting with a 0.5% deadband. An engineer notices that historical pressure trends appear smoother than actual process behavior observed at a local gauge. What most likely explains this discrepancy?

A. A 1-second moving average filter is applied to all analog inputs before historian storage

B. The pressure transmitter's internal damping is configured to a 10-second time constant

C. The 1-second historian polling rate is too slow for high-frequency pressure variations

D. Small rapid variations within the 0.5% deadband are not stored

31. In an IEC 61131-3 Function Block Diagram implementing split-range heating-cooling control, a single PID output feeds two separate valve control blocks. Which additional function blocks are essential to correctly distribute the PID output?

A. A gain scheduler adjusting PID tuning parameters at the 50% split point

B. A high/low signal selector routing the output based on PV relative to setpoint

C. Signal scaling blocks mapping the 0–50% and 50–100% output sub-ranges to the full 0–100% command range for each valve

D. Separate anti-windup feedback blocks for each valve during its limit condition

32. A cybersecurity assessment identifies a direct Ethernet connection between the DCS process historian and a corporate IT file server. What is the correct security architecture improvement?

A. Add TLS encryption to the connection and configure the firewall to log transfers

B. Replace the direct connection with a DMZ architecture using an intermediate data exchange server

C. Install host-based firewall software on the historian workstation

D. Schedule automatic file transfers to off-hours only

33. A process bump test steps the controller output from 45% to 55% in manual mode. The process temperature first responds 2 minutes after the step and reaches 63.2% of its total change (from 180°C to 195°C) exactly 8 minutes after first responding. What are the correct FOPDT parameters?

A. Kp = 1.5°C/%, θ = 2 min, τ = 8 min

B. Kp = 0.67°C/%, θ = 2 min, τ = 10 min

C. Kp = 1.5°C/%, θ = 10 min, τ = 8 min

D. Kp = 1.5°C/%, θ = 8 min, τ = 2 min

34. A well-tuned DCS temperature controller is placed in manual mode. An operator makes a large manual output adjustment then switches back to automatic without bumpless transfer. What occurs at the moment of transfer?

A. The controller immediately resets its output to 0% to reinitialize the integral accumulator

B. The controller holds the last manual output pending operator confirmation

C. The controller displays a tuning configuration error requiring parameter re-entry

D. The controller generates a large output bump driven by its accumulated integral state

35. A ratio control station maintains a steam-to-feed mass flow ratio of 2.5:1 in a steam methane reformer. The feed flow transmitter fails high at its 20 mA maximum output. What effect does this failure produce on the steam flow setpoint?

A. The steam setpoint drops to zero

B. The steam setpoint holds at its last valid value

C. The steam setpoint rises to its maximum configured value

D. The ratio station switches to fixed-setpoint mode at the design operating point

36. According to IEC 62443, which description most accurately defines the purpose of an OT security risk assessment?

A. Functional testing of installed security controls against acceptance criteria

B. Systematic identification of threats and vulnerabilities and prioritization of controls to reduce risk to an acceptable level

C. Documentation of security requirements before detailed OT system design

D. Auditing personnel compliance with access control and password policies

37. A surge tank level control loop uses gap control with a setpoint of 50% and a ±15% deadband — control activates only outside the 35–65% level range. The level rises to 72%. How does the controller respond?

A. Switches to full on-off mode, commanding the outlet valve fully open

B. Integral action alone drives the output while proportional action is suppressed

C. Output ramps at a constant rate until level re-enters the gap

D. Activates its configured PID action and generates output based on the deviation beyond the upper gap boundary

38. Using the lambda tuning formula $Kc = \tau / (Kp \times (\lambda + \theta))$, calculate the proportional gain for a process with $Kp = 0.8$, $\tau = 60$ s, $\theta = 20$ s, and $\lambda = 40$ s.

A. 1.25

B. 0.94

C. 0.75

D. 1.50

39. A flow control loop develops sustained continuous oscillations with an approximately 4-minute period after a 5% setpoint increase. The oscillations persist without damping and appear correlated with the integral action rate. What is the most probable cause?

A. Valve dead band causing limit cycling through the unresponsive zone

B. Controller gain at the ultimate gain value

C. Integral time too short relative to the process dynamics

D. Increased process dead time from a partially closed downstream valve

40. In an IEC 61131-3 Ladder Diagram, a normally open contact from the output coil is placed in parallel with a momentary start pushbutton contact. What functional behavior does this parallel arrangement provide?

A. The output coil requires simultaneous closure of both contacts to energize

B. Once the output coil energizes and closes the seal-in contact, the circuit latches and remains energized after the pushbutton is released

C. A one-scan delay prevents false triggering from momentary input noise

D. The seal-in contact electronically converts the pushbutton from momentary to maintained operation

41. A new process unit HMI display is being designed following high-performance HMI principles per ISA-101. Which color management approach is most consistent with these guidelines?

A. Bright red backgrounds for all active running equipment

B. Dynamic color coding — green within tolerance, yellow approaching limits, red in alarm

C. A unique color per process unit from a 16-color palette

D. Predominantly gray and muted tones for normal states with high-contrast colors reserved for alarms and abnormal conditions

42. A cascade control scheme has an outer composition controller ($\tau \approx 30$ min) and an inner temperature controller ($\tau \approx 5$ min). Before placing the outer loop in cascade mode, which inner loop condition must be confirmed?

A. The inner loop must be in automatic mode

B. The inner loop must be in manual mode during the transfer procedure

C. Inner loop mode does not affect cascade operation

D. Both loops must transfer to cascade mode simultaneously

43. A steam pressure control loop previously controlled by a pneumatic proportional-only controller with a proportional band of 50% is migrated to a DCS PID controller. What are the correct initial DCS settings?

A. Kc = 0.5 with integral enabled at Ti = 5 minutes

B. Kc = 50 with derivative enabled and integral disabled

C. Kc = 2.0 with integral time set to a very large value or disabled initially

D. Kc = 0.02 with integral enabled at Ti = 30 seconds

44. A newly commissioned pressure control loop shows 10% overshoot and 3-minute settling time on setpoint steps but slowly drifts away from setpoint between changes, requiring periodic manual setpoint trimming. Which tuning element is most likely deficient?

A. Proportional gain

B. Integral action

C. Derivative action

D. Controller action direction

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

45. A new cooling water system requires a 20-inch diameter control valve. A project engineer is comparing a butterfly valve against a globe valve. Which factor most favors the butterfly valve for this service?

A. Tighter shutoff ratings at large pipe sizes

B. Inherently equal percentage installed flow characteristic

C. Less frequent maintenance due to the self-contained rotary mechanism

D. Substantially lower weight, cost, and actuator thrust requirements at 20-inch pipe size

46. A control valve must be sized for a liquid service with: maximum flow = 180 gpm, SG = 0.92, and pressure drop across the valve = 30 psi. What is the required flow coefficient (Cv)?

A. 31.4

B. 24.7

C. 44.7

D. 19.1

47. An equal percentage control valve has a rated Cv of 50 at full open and a rangeability of 50:1. What is the approximate Cv at exactly 50% travel?

A. 25.0

B. 7.1

C. 1.0

D. 35.4

48. API 527 specifies PRV seat leakage testing at 90% of set pressure. Which leakage class requires a soft-seated pressure relief valve to show zero visible leakage at this test pressure?

A. Class I

B. Class II

C. Class III

D. Class IV

49. A control valve is required for an application where flow must be accurately throttled in both the forward and reverse directions through the same piping. Which selection is most appropriate?

A. Standard single-ported globe valve

B. Standard butterfly valve

C. Check valve in the forward direction with a bypass control valve for reverse flow

D. A bidirectional-rated ball or double-ported globe valve specifically designed and tested for bidirectional service

50. A motor star-delta starter transitions from star to delta at approximately 80% of synchronous speed. What occurs in the supply line current at the exact moment of transition?

A. A brief current transient that can momentarily exceed full-load current

B. Current drops instantly to zero during the open-circuit interval

C. Current remains constant because back-EMF compensates for the configuration change

D. Current permanently doubles after transition to delta connection

51. A check valve downstream of a centrifugal pump shows accelerated seat wear and chattering after several months operating at 25% of the pump's design flow. What is the most likely cause?

A. The disc material is too heavy for the line size

B. The check valve is oversized for the actual operating flow

C. Intermittent backflow from downstream equipment forces the disc open in reverse

D. Cavitation damage from high-velocity flow through the partially opened disc

52. A self-contained pressure reducing regulator set at 80 psig is observed passing full upstream pressure of 150 psig to the downstream system. What is the most likely cause?

A. Upstream supply pressure dropped below the regulator setpoint

B. The downstream isolation valve failed closed, trapping high pressure

C. The regulator trim has failed open

D. The setpoint spring has permanently elongated

53. A variable-speed drive controls a cooling water pump to maintain constant pressure at a remote header. A pressure transmitter measures header pressure, compares it to setpoint, and commands VFD speed adjustment. Which control strategy does this arrangement implement?

A. Feedforward control

B. Split-range control

C. Cascade control

D. Closed-loop feedback pressure control using the VFD as the final control element

54. Post-inspection of a failed control valve trim reveals localized pitting damage concentrated on the downstream face of the seat ring and plug contact surface, with no significant erosion extending into the downstream body or piping. Which fluid dynamic phenomenon is most consistent with this damage pattern?

A. Cavitation

B. Flashing

C. Solid particle erosion

D. Acoustic fatigue

55. A conventional spring-loaded PRV has a set pressure of 200 psig and a specified blowdown of 7%. At what inlet pressure does the valve reseat after a relief event?

A. 214 psig

B. 186 psig

C. 193 psig

D. 174 psig

56. An emergency shutdown valve must fully close in under 2 seconds on a 16-inch pipeline for a high-consequence safety application. Which actuator selection best meets this requirement?

A. High-speed electric motor actuator with planetary gearbox

B. Hydraulic vane actuator with proportional valve speed control

C. Standard pneumatic diaphragm actuator with digital positioner

D. Large-bore pneumatic piston actuator with quick-exhaust valve and ESD solenoid

57. A V-ball (characterized ball) valve is compared to an equivalent globe valve for a throttling application with moderately viscous liquid. Which advantage does the V-ball valve provide?

A. Tighter shutoff due to increasing seating force near the closed position

B. Smaller actuator requirements due to lower rotary torque demands

C. Higher Cv, lower pressure drop at full open, and an approximately equal percentage inherent characteristic

D. Self-cleaning capability from the V-notch edge scraping the seat on each stroke

58. A control valve in liquid service has P_1 = 150 psia, vapor pressure Pv = 30 psia, and maximum ΔP = 80 psi. What is the cavitation parameter sigma (σ)?

A. 1.50

B. 2.50

C. 0.88

D. 1.25

59. A fail-closed ESD valve uses an air-to-open spring-return actuator. A 3-way solenoid valve supplies control air during normal operations. In the energized state, which connection must the solenoid establish?

A. Exhaust port to actuator

B. Supply port to actuator

C. Supply port to exhaust port

D. Actuator port to supply line

60. A control valve with PTFE stem packing in a styrene service at 120°C shows progressively increasing fugitive emissions over an 18-month service interval. Which corrective measure most effectively addresses the root cause?

A. Increasing gland tightening torque beyond the manufacturer's specification

B. Replacing PTFE packing with graphite packing

C. Removing the valve and installing fresh PTFE packing rings

D. Installing a live-loaded disc spring packing system

61. A positioner calibration check confirms 0% and 100% travel at 4 mA and 20 mA respectively. At 12 mA, actual stem position is 55% rather than the expected 50%. What type of calibration error does this pattern represent?

A. Zero error

B. Span error

C. Linearity error

D. Hysteresis error

62. A process safety review finds a pilot-operated PRV set at 300 psig protecting a vessel with an MAWP of 285 psig. Which assessment is correct?

A. This installation is non-compliant — per ASME Section VIII, PRV set pressure must not exceed the vessel MAWP

B. ASME Section VIII permits PRV set pressure up to 10% above MAWP for pilot-operated designs

C. Pilot-operated PRVs are exempt from the MAWP set pressure limitation

D. The set pressure includes the 10% accumulation allowance — actual opening occurs at the vessel MAWP

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

63. A 16-bit DAC generates a 4–20 mA output for controlling a valve positioned 0–100% travel. What is the minimum valve position increment the DCS can command?

A. 0.0061% of travel

B. 0.00153% of travel

C. 0.0244% of travel

D. 0.049% of travel

64. A PROFIBUS PA segment connects 12 process instruments in a Zone 1 classified hazardous gas area. Which physical layer characteristic makes PROFIBUS PA compatible with intrinsic safety requirements?

A. Exclusive use of fiber optic cable

B. Integrated Zener barriers within each instrument housing

C. 2.4 GHz frequency-hopping spread spectrum with no physical field wiring energy

D. Power delivery over the two-wire bus at current levels compatible with IS requirements when used with an appropriate power conditioner

65. A new instrument installation in a plant with large variable-speed drives requires maximum EMI protection. Which combination of cable selection and installation practice is most effective?

A. Unshielded twisted pair in continuous metallic conduit

B. Overall-shielded multipair cable with shields bonded to ground at both cable ends

C. Individually shielded twisted pair with overall shield, all shields grounded at the control room end only, routed in dedicated trays separated from VSD output cables

D. Standard instrument cable with aluminum foil wrapping applied around bundles at 10-foot intervals

66. A HART-configured transmitter outputs process temperature as its 4–20 mA primary variable. A commissioning engineer needs the raw RTD resistance value for diagnostics without interrupting the primary measurement. How is this secondary variable most appropriately accessed?

A. By connecting a HART communicator to the loop

B. By briefly switching the transmitter to HART multidrop mode

C. By installing a dedicated second analog output module in the transmitter

D. By reading the transmitter's local display module

67. A twisted-pair RS-485 cable with 120 Ω characteristic impedance is terminated with 100 Ω resistors at both ends instead of 120 Ω. What problem results?

A. The termination resistors overheat and eventually fail open

B. Excessive current draw from connected transceivers overloads the bus power supply

C. Negligible practical effect because termination resistors are effective within ±25% of cable impedance

D. Incomplete signal reflection termination produces residual reflections that can corrupt data at higher baud rates

68. A WirelessHART level transmitter is 200 meters from the network gateway, with two other WirelessHART instruments positioned between them. What WirelessHART feature most ensures reliable communication over this distance?

A. Automatic gateway transmit power boost when signal strength drops below threshold

B. Superior long-distance propagation of the 2.4 GHz frequency band

C. Self-organizing mesh routing through intermediate instruments as relay nodes

D. MIMO antenna technology at the gateway for spatial diversity combining

69. A DCS analog input card displays 105% of span for a pressure transmitter calibrated 0–1,000 psi. An independent gauge at the same point reads 810 psi, well within the calibrated range. What has most likely occurred?

A. Actual pressure is 1,050 psi and the transmitter is reading correctly

B. The transmitter's 4–20 mA output has risen above 20 mA

C. The DCS analog input card has experienced gain drift

D. Thermal expansion of the transmitter housing has strained the sensing diaphragm

70. Which statement correctly identifies a key technical difference between OPC-DA and OPC-UA in OT-IT integration?

A. OPC-UA is platform-independent with built-in authentication, encryption, and audit logging; OPC-DA is Windows-specific, relies on DCOM, and provides limited built-in security

B. OPC-DA provides higher real-time throughput than OPC-UA for historian data collection

C. OPC-UA requires proprietary OPC Foundation network hardware; OPC-DA operates on standard Ethernet

D. OPC-DA supports write operations to OT systems; OPC-UA is restricted to read-only data publication

71. A control building must communicate with a remote pump station 2 kilometers away through a cable route passing through a high-EMI electrical substation. Which transmission medium is most appropriate?

A. Category 6 shielded twisted pair Ethernet with signal boosters

B. Enhanced double-shielded RS-485 at 9,600 baud with repeaters

C. WirelessHART mesh radio routing around the interference zone

D. Single-mode fiber optic cable

72. Which combination of protection technique and zone classification represents the most protective implementation for instrumentation in a Zone 0 area?

A. Type Y purging (Ex p)

B. Increased safety (Ex e) terminal enclosures

C. Intrinsic safety (Ex ia)

D. Explosion-proof (Ex d) enclosures

73. A digital oscilloscope connected across a 4–20 mA instrument loop displays a stable DC current of approximately 12 mA with a small alternating component containing 1200 Hz and 2200 Hz frequencies. What does this measurement indicate?

A. Inductive coupling from a nearby variable-speed drive

B. Active HART digital communication superimposed on the loop

C. A failed filter capacitor in the loop power supply

D. An internal transmitter oscillation fault

74. A managed industrial Ethernet switch is configured with separate VLANs for DCS controller I/O traffic and process historian workstation traffic. What security benefit does this VLAN segmentation provide?

A. Traffic isolation limiting lateral movement between the controller and historian network segments

B. Doubled effective bandwidth through two parallel communication paths

C. Automatic AES-256 encryption of all inter-VLAN traffic

D. Physical port security preventing unauthorized device connections

75. An OT cybersecurity policy requires all remote vendor support sessions to be limited to 4 hours, fully logged, and restricted to specific IP addresses and port numbers. Which network component is specifically responsible for enforcing these requirements?

A. The process historian server

B. The DCS engineering workstation antivirus software

C. The corporate IT security operations center

D. A dedicated remote access gateway in the OT DMZ

DOMAIN 5: SAFETY SYSTEMS (Questions 76–85)

76. A SIS engineer compares a standard 1oo2 sensor configuration with a 1oo2D configuration having a diagnostic coverage factor of DC = 0.90. What effect does the continuous diagnostic monitoring have on PFD_avg?

A. No effect — diagnostics only detect safe failures

B. Diagnostics increase PFD by adding failure modes from the diagnostic circuitry

C. Diagnostics reduce PFD by converting 90% of dangerous undetected failures to detected failures allowing prompt repair

D. Continuous diagnostics eliminate the need for periodic proof testing

77. In a 2oo3 SIS pressure sensor voting configuration, which specific failure mode combination most directly causes an undesired spurious trip?

A. Two sensors simultaneously fail in the dangerous direction

B. Two sensors simultaneously fail in the safe direction

C. All three sensors fail in the dangerous direction within the same interval

D. One sensor fails safe while the other two detect a genuine process demand

78. A functional safety assessment requires SIL 2 for a proposed SIF using a 1oo1 sensor ($\lambda\_DU = 1\times10^{-6}$/hr), a SIL 2-certified logic solver, and a 1oo1 final element ($\lambda\_DU = 3\times10^{-6}$/hr), all proof tested annually (TI = 8,760 hr). What is the total SIF PFD_avg and is SIL 2 achieved?

A. PFD ≈ 4.38×10^{-3} — SIL 2 is achieved

B. PFD ≈ 4.38×10^{-3} — SIL 2 is not achieved due to individual subsystem certification requirements

C. PFD ≈ 1.75×10^{-2} — SIL 2 is achieved due to logic solver certification

D. PFD ≈ 1.75×10^{-2} — SIL 2 is not achieved

79. A HAZOP identifies a reactor explosion scenario where simultaneous failure of cooling water supply and loss of agitation creates the hazardous demand condition. The consequence is catastrophic. Which SIL selection method is most appropriate?

A. LOPA — quantifies each initiating cause separately and credits each independent protection layer

B. Risk graph — catastrophic consequence automatically specifies SIL 4

C. Safety layer matrix — addresses simultaneous failures through an additive risk pathway

D. Neither LOPA nor risk graph — simultaneous failures require hardware redundancy solutions only

80. During a SIF proof test, the shutdown valve does not respond to the remote SIS command. A technician uses the manual handwheel to close the valve and seat leakage testing subsequently passes. What is the correct disposition?

A. Accept as passed — the valve achieved closure and passed leakage testing

B. Accept with documented exception and schedule actuator inspection at the next turnaround

C. Record as failed — inability to remotely actuate the valve through the SIS automated path constitutes a safety function failure

D. Record as partially passed and reschedule the automated actuation test for the following month

81. According to IEC 61511, how are independent protection layers credited in a LOPA calculation?

A. Only the IPL with the lowest PFD provides meaningful credit

B. Each verified independent IPL is credited by multiplying its PFD by the current mitigated event frequency — the product of all IPL PFDs and the initiating event frequency gives the mitigated consequence frequency

C. IPLs are credited as binary — meeting a 0.1 PFD threshold or receiving no credit

D. IPL PFDs are summed rather than multiplied

82. A process modification increases normal operating pressure from 60% to 95% of the SIS high-pressure trip setpoint. Which functional safety concern most urgently requires assessment?

A. Increased mechanical fatigue risk on the SIS final element valve body

B. Requirement for revised P&IDs submitted to engineering and regulatory authorities

C. Invalidated PRV calculations requiring complete API 520 re-analysis

D. Elevated SIF demand rate from normal pressure variations near the trip setpoint, potentially shifting the SIF from low-demand to high-demand mode

83. At which point in the safety lifecycle does a functional safety assessment most effectively prevent systematic design errors from propagating into the physical installation?

A. After the SRS is completed and before detailed SIS design begins

B. During the SIS factory acceptance test

C. After field installation and before the site acceptance test

D. After one year of operation using field reliability data

84. A scheduled proof test on a 2oo3 high-pressure trip SIS reveals one pressure transmitter consistently reads 15 psi below actual process pressure. No self-diagnostic alarm has been generated. What type of failure is this, and what is the required action?

A. Safe detected failure — schedule correction at the next planned maintenance window

B. Safe undetected failure — low-reading bias toward tripping improves response to demands so repair is not urgent

C. Dangerous undetected failure — the transmitter will not vote for a trip when actual pressure reaches setpoint, requiring immediate recalibration and SIL verification review

D. Dangerous detected failure — proof test detection classifies it as detected regardless of self-diagnostic status

85. A SIL 2 SIS achieves PFD_avg = 3.5×10^{-3} using three identical pressure transmitters from the same manufacturer. The plant manager proposes adding a fourth identical transmitter to further improve SIL achievement. Which concern must be raised?

A. Adding a fourth transmitter requires changing to 3oo4 voting, which IEC 61511 Annex F does not address

B. Four identical transmitters from the same manufacturer increase exposure to common cause failures — additional identical redundancy may provide limited PFD improvement when CCF dominates

C. The SIL 2 target is already achieved and additional redundancy adds cost without meaningful benefit

D. A fourth transmitter requires a new regulatory safety case requiring approximately 24 months to complete

PRACTICE EXAM 4: ANSWER KEY AND EXPLANATIONS

1. D — Coriolis mass flowmeters measure mass flow directly through the Coriolis force principle and maintain high accuracy independent of fluid viscosity, density, or temperature. At 500 cP viscosity, turbine and vortex meters suffer significant bearing friction and shedding instability, and magnetic flowmeters cannot measure non-conductive polymers. Coriolis is the definitive technology for viscous, low-flow custody transfer applications.
2. B — Wake frequency = St × V / d. Convert tip diameter: 1.0 in ÷ 12 = 0.0833 ft. $f_w = 0.22 \times 80 / 0.0833 = 17.6 / 0.0833 = 211.2$ Hz. This frequency must be compared against the thermowell's natural frequency using the ASME PTC 19.3 TW criterion — the frequency ratio must remain below 0.8.
3. C — A dry leg connected to the vapor space contains no liquid reference fluid, eliminating the source of polymer plugging entirely. Wet legs filled with any liquid — process condensate, silicone oil — would contact the process vapor, condense styrene monomer, and eventually solidify. The dry leg removes all liquid from the low-pressure impulse path.
4. A — Convert 75 psig to psia: 75 + 14.696 = 89.696 psia. Convert to kPa: 89.696 × 6.8948 = 618.5 kPa ≈ 619.1 kPa absolute. The conversion factor is 1 psi = 6.8948 kPa — always convert to absolute pressure before converting unit systems in thermodynamic calculations.
5. D — Catalytic bead sensors require oxygen to oxidize combustible gas on the catalyst surface — the oxidation reaction is the source of the heat that changes bead resistance and produces the measurement signal. Without oxygen, no catalytic combustion occurs and the sensor produces zero output regardless of combustible gas concentration. This is a critical limitation of pellistor technology in oxygen-deficient environments.
6. C — $R(T) = 100 \times (1 + 0.00385 \times (-50)) = 100 \times (1 - 0.1925) = 100 \times 0.8075 = 80.75\ \Omega$. The negative temperature coefficient term reduces resistance below the 0°C reference value of 100 Ω at sub-zero temperatures. This linear approximation introduces minor error compared to the full Callendar-Van Dusen equation but is acceptable for most exam calculations.
7. B — At 8 mA, the output is 25% of the 4–20 mA span. With square root extraction, output percentage equals flow percentage directly: 25% × 1,200 gpm = 300 gpm. Without extraction, the same 8 mA would represent 25% of maximum DP, corresponding to $\sqrt{0.25} \times 1{,}200 = 600$ gpm — the distinction between these two configurations is critical.

8. A — Capacitance level transmitters insert a probe into the vessel and measure the change in electrical capacitance between the probe and the vessel wall as the dielectric medium surrounding the probe changes from vapor to liquid. GWR uses microwave pulse travel time, displacers use buoyant force, and nuclear devices use gamma attenuation — none operate on the capacitance principle.

9. C — Per ANSI/ISA-5.1, a plain circle with no line through it represents a field-mounted instrument located in the process area. A circle with a solid horizontal line indicates a panel-mounted instrument accessible to the operator. A dashed line indicates panel-mounted but inaccessible. A circle inside a square indicates a computer or DCS software function.

10. D — A volumetric meter correctly measures 500 m^3/hr at both temperatures — its reading is volume per unit time regardless of fluid density. However, the mass flow rates differ: at 20°C, mass flow = 500 × 850 = 425,000 kg/hr; at 50°C, mass flow = 500 × 820 = 410,000 kg/hr — a 3.5% difference. Volumetric measurement requires density compensation to determine mass flow.

11. B — Laser opacity transmitters measure the attenuation of a transmitted laser beam crossing the duct from source to detector on the opposite side. Higher particulate loading absorbs and scatters more laser energy, reducing transmitted intensity at the detector. The degree of attenuation is directly proportional to particulate concentration in the measurement path.

12. A — A consistent +1.8% error at every flow point across five successive calibrations indicates excellent repeatability — the meter consistently produces the same reading regardless of when it is tested. The systematic positive bias indicates a calibration offset error rather than random scatter. Repeatability and accuracy are distinct properties — this meter is highly repeatable but inaccurate.

13. C — LRV at 0% level: HP side = 0 in H_2O (no liquid above lower tap). LP side (wet leg) = 5 ft × 12 in/ft × 1.00 = 60 in H_2O. ΔP = HP − LP = 0 − 60 = –60 in H_2O. The negative LRV indicates the LP side always exceeds the HP side at 0% level due to the wet reference leg — a suppressed zero configuration requiring a transmitter capable of negative LRV input.

14. D — Electrochemical sensors consume electrolyte and electrode material as part of the electrochemical detection reaction — these reagents are not replenished during operation. When the electrolyte is depleted or the electrodes are sufficiently degraded, the sensor can no longer generate an adequate electrochemical signal and must be replaced. This consumptive mechanism distinguishes electrochemical sensors from pellistors and IR sensors that can often be recalibrated without replacement.

15. B — Flow = K × √(ΔP/SG). At the same DP, actual flow = original calibrated flow × √(SG_original/SG_actual) = Q_max × √(1.00/0.85) = Q_max × 1.085. The lower-density fluid flows approximately 8.5% faster through the same restriction at the same differential pressure. The uncorrected transmitter under-reads flow when the actual fluid is less dense than the calibration fluid.

16. C — Infrared gas detectors cannot detect hydrogen because H_2 is a diatomic homoatomic molecule with no IR-active absorption bands. Catalytic bead sensors detect hydrogen through catalytic oxidation and are the correct combustible technology for hydrogen service. Electrochemical sensors provide the toxic H_2S monitoring. This pairing correctly addresses both hazards with appropriate technologies.

17. A — $\beta = d/D = 3.0$ in / 6.065 in = 0.495. The beta ratio is the ratio of the orifice bore diameter to the pipe internal diameter and governs the differential pressure generated at a given flow rate. Beta ratios for orifice plates are typically specified between 0.20 and 0.75 — this installation at 0.495 falls well within the acceptable range.

18. D — Water vapor has significant IR absorption bands that overlap with CO_2 absorption wavelengths. The analyzer attributes water vapor IR absorption to CO_2, reporting a false-high CO_2 concentration. Compensation algorithms using a separate water vapor measurement or a reference wavelength outside the CO_2 band correct this interference. Uncompensated water vapor interference is one of the most common analytical accuracy problems in IR gas analyzers.

19. B — A uniform +0.2% error at all calibration points (0%, 25%, 50%, 75%, 100%) indicates the entire output curve has shifted upward by a constant offset. This is a zero (offset) error — the slope of the output curve is correct but the intercept has shifted. Zero errors are corrected by adjusting the transmitter's zero trim without changing the span adjustment.

20. C — Positive ORP values indicate oxidizing conditions — the presence of an oxidizing agent such as free chlorine, chloramine, or ozone. In water treatment, +450 mV confirms adequate disinfectant residual maintaining treatment effectiveness at the measurement point. Negative ORP values would indicate reducing conditions and insufficient disinfectant.

21. A — A four-wire transmitter has two separate wire pairs: one pair for external DC power supply and one pair for the 4–20 mA signal output. It does not draw operating power from the signal loop, unlike a two-wire transmitter that modulates the loop current for both power and signal. Four-wire configurations are used for analyzers, flowmeters with active displays, and other instruments requiring more power than the 4 mA minimum loop current can provide.

22. D — If the wet reference leg has partially drained, the hydrostatic head on the LP side of the transmitter decreases. With less pressure on the LP side, the differential pressure (HP − LP) increases at all level conditions, causing the transmitter to read consistently higher than expected across the full range. This is a common maintenance issue in wet leg installations where condensate can drain from the reference line over time.

23. B — Sustained oscillations that stabilize when integral time is lengthened indicate that the original Ti was too short — integral action was driving the output to correct the error faster than the process dynamics could respond, creating a resonance condition. Increasing Ti slows the integral contribution, allowing the process to respond to each correction before the next correction is applied, breaking the oscillation cycle.

24. C — Per ANSI/ISA-5.1, a circle with a dashed horizontal line through the center represents a panel-mounted instrument that is inaccessible to the operator from the front of the panel — accessible only from the rear or interior. The solid horizontal line indicates front-panel-accessible mounting. The distinction matters for operations because inaccessible instruments cannot be adjusted or read by the operator during normal duties.

25. A — When the setpoint is constant, $d(SP)/dt = 0$, so $d(error)/dt = d(SP - PV)/dt = -d(PV)/dt$. The derivative of the error equals the negative of the derivative of the PV, making both implementations mathematically identical for disturbance-only changes. Only when the setpoint changes does the difference emerge — derivative-on-error produces a spike proportional to the setpoint step rate; derivative-on-PV does not.

26. A — The jacket-to-core interaction is unidirectional: jacket changes affect core temperature, but core controller changes do not materially affect jacket temperature. This asymmetric coupling is important for tuning strategy — the jacket loop can be tuned first in automatic, and the core loop tuned second with the jacket already in automatic, avoiding the destabilizing interactions that would occur with symmetric bidirectional coupling.

27. C — Position form calculates the total (absolute) output at each scan by summing the proportional, integral, and derivative terms — the integral accumulates over time and can wind up beyond limits if not explicitly managed. Velocity form calculates incremental output changes (ΔCO) at each scan, which are then added to the previous output — this incremental calculation inherently cannot produce outputs beyond the limits since each increment is a small change.

28. B — MPC's defining advantage over independent PID loops is simultaneous optimization of all controlled variables while explicitly enforcing hard constraints on all manipulated and controlled variables within a single coordinated optimization calculation. PID loops cannot enforce constraints directly and handle interactions through separate decoupling strategies. This integrated constraint handling enables MPC to operate processes safely at equipment limits that PID loops cannot approach reliably.

29. A — A slow asymptotic approach with no overshoot and no oscillation is the signature of an overdamped, over-conservative controller. Either the proportional gain is too low (insufficient corrective force) or the integral time is too long (integral action contributes negligibly). The result is slow, sluggish but stable response — acceptable for non-critical applications but wasteful of available process capacity and response speed.

30. D — Exception reporting stores a new historian value only when the measurement changes by more than the configured deadband. Small rapid variations that stay within ±0.5% of the last stored value are invisible to the historian — they appear in the trend as a flat line at the last stored value. The local gauge shows the true continuous process behavior, which appears far noisier than the smoothed historian trend for the same signal.

31. C — Split-range control requires signal scaling blocks that divide the 0–100% PID output into two sub-ranges and map each sub-range to the full 0–100% operating range of each valve. Without scaling, both valves would respond to the full 0–100% output simultaneously rather than sequentially in their respective portions of the output range. The scaling blocks are the essential implementation element that creates the split-range sequential valve behavior.

32. B — A direct connection between the OT historian and the IT file server creates a direct OT-IT path that bypasses the security boundary. The correct remediation places a data exchange server in the DMZ — the historian delivers data to the DMZ server from the OT side, and the IT file server collects data from the DMZ server from the IT side. No direct OT-IT connection exists in the corrected architecture.

33. A — Dead time θ = time from output step to first PV response = 2 minutes. Time constant τ = time from first response to 63.2% of total change = 8 minutes. Process gain $K_p = \Delta PV / \Delta CO = (195 - 180)°C / (55 - 45)\% = 15/10 = 1.5°C/\%$. These three FOPDT parameters completely characterize the process dynamics for controller tuning calculations.

34. D — Without bumpless transfer, when switching from manual to automatic the controller initializes with its integral state reflecting the prior automatic period output, not the manually adjusted output. The difference between the prior automatic output and the current manual output drives an immediate integral-based output bump at the moment of transfer. Bumpless transfer initializes the integral state to the current manual output before enabling automatic mode, eliminating the bump.

35. C — The ratio station calculates the steam setpoint by multiplying the measured feed flow by the ratio factor (2.5). A failed-high feed transmitter at 20 mA outputs the maximum feed flow signal, causing the ratio station to demand maximum steam flow (20 mA feed × 2.5 = maximum steam setpoint). This maximum steam flow demand can damage the catalyst bed through thermal excursion and overload the reformer tubes.

36. B — An OT security risk assessment systematically identifies threats (who might attack and how), evaluates vulnerabilities (weaknesses that could be exploited), assesses the likelihood and consequence of successful attacks, and prioritizes security controls to reduce risk to an acceptable level. This is a proactive analytical activity distinct from auditing (verifying compliance), documentation (recording requirements), or functional testing (verifying controls work).

37. D — When level exceeds the upper gap boundary (65%), the gap control activates its configured control action and generates output based on the error between the current level (72%) and the upper gap boundary (65%) — a 7% deviation. The controller works to return level toward the setpoint. Between 35% and 65%, the controller takes no action — only outside the gap does active correction occur.

38. A — $K_c = \tau / (K_p \times (\lambda + \theta)) = 60 / (0.8 \times (40 + 20)) = 60 / (0.8 \times 60) = 60 / 48 = 1.25$. Lambda tuning sets the controller gain to produce a closed-loop time constant equal to λ. With λ = 40 s and

$\theta = 20$ s, the denominator reflects the total desired closed-loop response time — the larger $\lambda + \theta$ is, the more conservative the calculated gain.

39. C — When integral time is too short relative to the process time constant, each integral correction arrives before the process has finished responding to the previous correction. The controller over-corrects repeatedly, creating a sustained resonance where each correction drives the process past setpoint in the opposite direction and back again. Lengthening the integral time reduces the correction rate, allowing the process to settle between corrections.

40. B — The normally open seal-in contact, wired in parallel with the start pushbutton, closes when the output coil energizes. This provides a parallel conduction path that maintains the rung continuity after the momentary start pushbutton is released and its contact opens. The sealed circuit holds the coil energized until the rung is broken by a normally closed stop contact opening — this is the standard motor start-stop latch circuit.

41. D — High-performance HMI guidelines (ISA-101 and the ABNORMAL SITUATION MANAGEMENT principles) specify that normal operating displays should use subdued, low-contrast gray and muted tones. This baseline ensures that alarm conditions displayed in high-contrast red, yellow, or amber immediately stand out visually. Bright colors for normal operations desensitize operators to color-coded warnings, reducing situational awareness during abnormal conditions.

42. A — The outer cascade controller's output becomes the remote setpoint for the inner loop. If the inner loop is in manual mode, it ignores all remote setpoint commands and maintains whatever output the operator has set manually. The cascade control strategy provides no benefit with a manually operated inner loop. The inner loop must be in automatic mode and performing well before the outer loop is placed in cascade.

43. C — The equivalent DCS gain is $Kc = 100/PB = 100/50 = 2.0$, matching the pneumatic controller's proportional action. Since the pneumatic controller was proportional-only (no integral or derivative), the DCS should initially be configured with the equivalent gain and integral effectively disabled (very large Ti). Once stable proportional operation is confirmed, integral can be gradually reduced from a large Ti to eliminate the offset that proportional-only control produces.

44. B — The 10% overshoot and 3-minute settling time indicate acceptable proportional response — the gain is appropriate. The slow drift during steady-state periods indicates that the integral action is insufficient to continuously correct small accumulated errors as process conditions shift. Adequate integral action would continuously sum the error and drive the output to eliminate any steady-state deviation without requiring manual setpoint adjustment.

45. D — At 20-inch pipe size, a butterfly valve weighs a fraction of an equivalent globe valve and costs significantly less to procure and support. The quarter-turn rotary design requires substantially lower actuator thrust per unit pipe cross-section than a globe valve's linear plug fighting against full differential pressure across a large seat area. For large-diameter cooling water services where

tight shutoff and precise flow characterization are secondary to cost and weight, butterfly valves are the standard selection.

46. A — $Cv = Q \times \sqrt{(SG / \Delta P)} = 180 \times \sqrt{(0.92 / 30)} = 180 \times \sqrt{(0.03067)} = 180 \times 0.1751 = 31.52 \approx 31.4$. The SG correction accounts for the fact that the lighter fluid (SG = 0.92) flows faster than water at the same differential pressure — slightly increasing the required Cv compared to a pure water calculation at the same flow and ΔP.

47. B — For an equal percentage valve, Cv at mid-travel = $Cv_{max} / \sqrt{Rangeability} = 50 / \sqrt{50} = 50 / 7.071 = 7.07 \approx 7.1$. The equal percentage characteristic follows an exponential relationship — Cv grows multiplicatively with travel rather than linearly. At 50% travel the valve is near the lower-sensitivity portion of its exponential curve, producing only about 14% of its maximum Cv.

48. C — API 527 Class III defines the bubble-tight leakage requirement for soft-seated PRVs at 90% of set pressure — zero visible bubble leakage is the acceptance criterion. Metal-seated valves (Class I and II) have defined allowable leakage rates reflecting the mechanical difficulty of achieving zero leakage with metal-to-metal seats. Soft seats can achieve bubble-tight closure that metal seats cannot, justifying the Class III zero-leakage requirement.

49. D — Standard control valves are designed and characterized for unidirectional flow. In reverse flow, the plug may unseat from an unintended side, flow characteristics become unpredictable, and trim erosion accelerates from flow attacking surfaces not designed for that direction. Bidirectional-rated valves use symmetrical trim designs, tested and certified for both flow directions. Standard globe and butterfly valves are not adequate for bidirectional throttling without specific manufacturer qualification.

50. A — At the moment of transition, the motor windings are momentarily open-circuited (star opens before delta closes), then reconnected in the higher-voltage delta configuration. The reduced back-EMF at 80% speed means the motor is not fully generating — when full line voltage is applied in delta, a brief inrush current spike occurs as the motor accelerates the remaining 20% to rated speed. This transition spike is a well-known limitation of star-delta starting.

51. B — A check valve sized for full design flow requires minimum flow velocity across the disc to maintain it in the stable fully-open position. At 25% design flow, velocity is insufficient — the disc floats at a low-lift position where small velocity variations cause it to repeatedly open and close against the seat. This chattering causes rapid mechanical impact wear on the disc and seat faces. Correct solution is replacing with a properly sized check valve matched to actual operating flow conditions.

52. C — The only failure mode that allows full upstream pressure to reach the downstream system despite the regulator being correctly set is a trim failure that creates an unobstructed flow path — diaphragm rupture destroying the sensing and control mechanism, spring failure eliminating closing force, or trim seizure preventing the plug from closing. All other options (supply drop,

downstream isolation failure, spring elongation) produce different failure signatures inconsistent with the described condition.

53. D — This is a standard closed-loop feedback control system where the pressure transmitter provides the process variable, the PID controller compares it to the setpoint and calculates a corrective output, and the VFD acts as the final control element by adjusting pump speed. The VFD replaces a throttling valve as the flow manipulation element but the overall architecture is conventional single-loop feedback pressure control.

54. A — Cavitation produces localized pitting damage from vapor bubble collapse (implosion) concentrated at the downstream faces of the plug and seat ring near the vena contracta — exactly the described damage pattern. Flashing produces distributed downstream erosion. Particle erosion produces directional cutting wear with a distinct morphology. Acoustic fatigue produces fatigue cracking at stress concentrations rather than contact surface pitting.

55. B — Blowdown is the pressure reduction below set pressure required for the valve to reseat. Reseat pressure = set pressure × (1 − blowdown%) = 200 × (1 − 0.07) = 200 × 0.93 = 186 psig. The blowdown margin prevents rapid opening and closing cycling (chattering) that would occur if the valve reseated at exactly set pressure — a 7% blowdown provides sufficient hysteresis for stable operation.

56. D — A large-bore pneumatic piston actuator with a quick-exhaust valve provides the fastest achievable spring-return stroke for a large ESD valve. The quick-exhaust valve opens a large direct exhaust port that bypasses the restrictive positioner exhaust path — the actuator depressurizes through the large-bore exhaust port rather than the narrow positioner path, enabling very fast spring-return closure. Electric actuators are inherently slower than pneumatic for large valves; diaphragm actuators cannot develop sufficient force for 16-inch ESD service.

57. C — V-ball valves provide a significantly higher flow coefficient (Cv) in a given body size than equivalent globe valves, and the low-obstruction ball design produces minimal pressure drop at full open. The V-notch geometry creates a predictable approximately equal percentage inherent flow characteristic that makes the valve suitable for modulating throttling control. These combined advantages — high capacity, low pressure drop, and predictable characteristic — are the defining benefits of V-ball valves over globe valves.

58. A — $\sigma = (P_1 - P_v) / \Delta P = (150 - 30) / 80 = 120 / 80 = 1.50$. If σ exceeds the valve's critical sigma (σ_c), the installation is free of cavitation. If σ falls below σ_c, cavitation occurs. The calculated $\sigma = 1.50$ must be compared to the manufacturer's published σ_c for the specific valve trim to determine whether corrective action is needed.

59. B — A fail-closed ESD valve uses an air-to-open actuator — air pressure holds the valve open against the return spring. During normal operations, the solenoid must supply air to the actuator to maintain the valve open. When the ESD system de-energizes the solenoid, it must shift to connect

the actuator to the exhaust port, venting air and allowing the spring to close the valve. The energized (normal) state therefore requires supply-to-actuator connection.

60. D — PTFE packing consolidates and wears over time, progressively reducing the compression force on the packing rings and allowing increasing stem leakage. A live-loaded packing system uses Belleville disc springs that continuously maintain compression on the packing stack as the PTFE wears, preventing the leakage gap from developing. This addresses the root cause — loss of packing compression — rather than masking it by overtightening the gland nut, which increases friction and valve dead band.

61. C — With correct calibration at both endpoints (0% at 4 mA and 100% at 20 mA) but a 5% mid-range deviation, the positioner's output curve does not follow a straight line between the two calibrated endpoints. This is a linearity error — the mechanical linkage or electronic characterizer introduces a nonlinear deviation at intermediate positions while correctly hitting both end points. Zero and span errors would shift all points including the endpoints; hysteresis would show different values for increasing vs. decreasing signals.

62. A — ASME Section VIII, Division 1, paragraph UG-134 specifies that the set pressure of a pressure relief device shall not exceed the MAWP of the protected vessel. A PRV set at 300 psig on a vessel with 285 psig MAWP directly violates this requirement. The 10% accumulation allowance applies to the maximum pressure during a relief event, not to the set pressure itself. This installation requires immediate correction — either lowering the set pressure or re-rating the vessel.

63. B — A 16-bit DAC resolves the output into 2^{16} = 65,536 counts. Minimum position increment = 100% / 65,536 = 0.001526% ≈ 0.00153% of travel. This extremely fine resolution is the key advantage of 16-bit over 12-bit (4,096 counts, 0.0244% resolution) output cards — critical in precision flow and composition control where very small valve position changes must be commanded reliably.

64. D — PROFIBUS PA delivers instrument operating power and digital communication data over the same two-wire bus cable using voltage-mode physical layer signaling. The segment current levels (total current draw of all connected devices plus the conditioned bus voltage) are specifically designed to fall within intrinsic safety energy limits when used with an IS-rated PA power conditioner, enabling installation in Zone 1 and Zone 2 hazardous areas without separate power supplies for each instrument.

65. C — Individually shielded twisted pair cable with an overall shield provides maximum protection against both inter-pair crosstalk (individual shields) and external EMI coupling (overall shield). Grounding all shields at the control room end only prevents ground loop currents. Physical separation in dedicated instrument cable trays kept away from VSD output cables addresses the dominant EMI source at the root. This combination attacks interference through both cable selection and installation discipline.

66. A — HART communication superimposes FSK digital data on the 4–20 mA loop without disturbing the analog signal. A HART communicator connected to the loop reads all secondary variables — including raw RTD resistance — through the digital communication channel while the 4–20 mA temperature signal continues uninterrupted. This is one of HART's primary operational advantages: rich diagnostic and secondary variable data available without interrupting the primary measurement.

67. D — RS-485 cable has a characteristic impedance of 120 Ω — termination resistors must match this impedance to absorb signal energy at the cable end without reflection. With 100 Ω termination (17% mismatch), some signal energy is reflected back toward the source rather than being absorbed. These residual reflections arrive at transceivers as spurious voltage transitions following each signal edge, potentially causing bit errors at higher baud rates where the reflection arrival time overlaps with the next data bit period.

68. C — WirelessHART's self-organizing mesh network automatically discovers all available communication paths, including multi-hop routes through intermediate instruments. When the direct 200-meter path to the gateway has marginal signal strength, the network routes messages from the tank transmitter through the intermediate instruments to the gateway. Each intermediate device retransmits received messages, effectively extending the network range without any manual configuration or infrastructure changes.

69. B — An analog input card calibrated for 4–20 mA cannot display above 100% of span from a valid measurement — reading 105% indicates the loop current has exceeded 20 mA. Electronic transmitter failure causing output lock-up above 20 mA, incorrect transmitter configuration, or external DC voltage injection into the loop can all drive the current above 20 mA. The independent gauge reading of 810 psi (within range) confirms the process pressure is not at fault.

70. A — OPC-DA relies on Microsoft's Component Object Model (COM) and Distributed COM (DCOM) middleware — inherently Windows-specific, complex to configure across firewalls, and lacking built-in encryption or authentication. OPC-UA uses a platform-independent service-oriented architecture with built-in security including X.509 certificate authentication, message signing, and encryption, making it suitable for cross-network OT-IT integration through firewall-controlled boundaries.

71. D — Single-mode fiber optic cable is the definitive solution for this application. Light signals are completely immune to electromagnetic interference — the substation generates no effect on the optical signal. The fiber provides complete galvanic isolation between the two buildings, eliminating ground loop issues. Single-mode fiber supports multi-gigabit transmission over 2+ kilometers without repeaters. No copper-based or wireless technology combines all three advantages of EMI immunity, galvanic isolation, and 2 km distance capability.

72. C — Intrinsic safety (Ex ia) is the only IEC protection technique specifically rated for Zone 0 (continuously hazardous) environments. Ex ia limits electrical energy in the field circuit below the

minimum ignition energy under both normal operation and any single component failure — a standard that is inherently suited to areas where a hazardous atmosphere is always present. Ex d and Ex p contain or exclude ignition sources but do not limit energy in the field circuit to safe levels under all fault conditions.

73. B — HART protocol uses frequency-shift keying modulation: binary 1 is represented by a 1200 Hz sine wave and binary 0 by a 2200 Hz sine wave, superimposed as an AC component on the DC 4–20 mA loop current. The oscilloscope display of 12 mA DC (50% of span = 50% of measured range) with 1200 Hz and 2200 Hz AC components is the definitive signature of a HART-communicating field device actively transmitting digital data on a live measurement loop.

74. A — VLANs create logical network segments within a physical switch — devices on different VLANs cannot communicate directly without routing through an inter-VLAN routing device that can enforce access control. If a historian workstation is compromised, the attacker is confined to the historian VLAN and cannot directly reach controller I/O devices on the separate controller VLAN. This traffic isolation limits the blast radius of a workstation compromise, a fundamental defense-in-depth measure.

75. D — A dedicated remote access gateway (also called a jump server or secure remote access platform) positioned in the OT DMZ is the correct enforcement point for all OT remote access policy requirements. It authenticates users before allowing any OT access, enforces configurable session time limits with automatic disconnection, logs all keystrokes and session activity, and applies firewall rules restricting source IP addresses and destination ports. No other single component has both the visibility and the enforcement capability for all stated requirements simultaneously.

76. C — Diagnostics with DC = 0.90 detect 90% of dangerous failures automatically, triggering alarms that enable prompt repair — converting dangerous undetected failures to dangerous detected failures. The average time these 90% of failures go undetected is the mean time to repair (MTTR), typically hours to days, rather than the full proof test interval (months to a year). This dramatically reduces their PFD contribution, improving overall SIF availability and achieved SIL.

77. B — In 2oo3 voting, two of three sensors must agree to initiate the safety action. If two sensors simultaneously fail in the safe direction — outputting a trip signal regardless of actual process pressure — the voting logic sees two inputs demanding a trip and activates the SIF even though no actual process demand exists. This is the mechanism for spurious trips in redundant safety systems and is why safe failure rate matters in availability analysis.

78. D — Sensor PFD = $\lambda_{DU} \times TI/2 = 1\times10^{-6} \times 8{,}760/2 = 4.38\times10^{-3}$. Final element PFD = $3\times10^{-6} \times 8{,}760/2 = 1.31\times10^{-2}$. Total SIF PFD = $4.38\times10^{-3} + 1.31\times10^{-2} = 1.75\times10^{-2}$. A PFD of 1.75×10^{-2} falls in the SIL 1 range (0.01 to 0.1), not SIL 2. The final element with its higher failure rate dominates — a redundant final element configuration or shorter proof test interval is required to achieve SIL 2.

79. A — LOPA is the correct method because it quantifies each initiating cause (simultaneous cooling water failure and agitation loss) separately, treats each as an individual hazardous scenario with its own initiating event frequency, and credits each truly independent protection layer by multiplying their PFD values. LOPA's quantitative framework handles multi-cause scenarios rigorously, while the risk graph's categorical approach cannot adequately resolve the combined scenario frequency needed to determine the required SIF PFD.

80. C — The safety function requires automatic valve closure through the SIS electrical output path — solenoid valve de-energization, actuator depressurization, and spring-driven closure — without any manual intervention. The automated path failed to perform; manual override is not equivalent because a real process demand requiring SIS activation occurs in milliseconds without operator presence or response time. The proof test must record a failure, root cause analysis must be performed, and the automated path must be repaired and successfully retested before the SIS returns to service.

81. B — LOPA credits each IPL by multiplying its probability of failure on demand by the current mitigated event frequency — each multiplication step reduces the frequency by one order of magnitude for a well-designed IPL with PFD = 0.1. The critical requirements are genuine independence: each IPL must function independently of the initiating cause and of all other credited IPLs. The product of the initiating event frequency and all IPL PFD values gives the final mitigated consequence frequency compared to the risk tolerance criterion.

82. D — Operating at 95% of the trip setpoint means normal pressure variations of ±5% can inadvertently cross the trip threshold, generating SIF demands from routine process noise rather than genuine hazardous conditions. This elevated demand rate may shift the SIF from low-demand mode (< 1 demand/year, PFD metric) to high-demand mode (≥ 1 demand/year, PFH metric), fundamentally changing the SIL verification methodology and the required hardware performance specification.

83. A — A functional safety assessment of the SRS before design begins is the most cost-effective intervention point in the lifecycle. Errors in the SRS — wrong trip setpoints, incorrect safe state definitions, omitted SIFs — propagate directly into the hardware design, procurement, installation, and validation. Finding and correcting SRS errors before design begins costs orders of magnitude less than discovering the same errors during commissioning or operations when field modifications and revalidation are required.

84. C — A transmitter reading 15 psi below actual process pressure will not reach the trip setpoint while the true process pressure is at or near the setpoint — it reports a pressure 15 psi lower than reality. In a 2oo3 configuration, this transmitter consistently votes against tripping when the other two transmitters correctly detect an over-pressure condition, effectively converting the voting to 1oo2 for any real demand. This directly increases the PFD and requires immediate recalibration — the failure was not detected by self-diagnostics, confirming it is dangerous and undetected.

85. B — Common cause failures affect all channels sharing the same design, manufacture, installation environment, or maintenance procedures — adding more identical channels from the same manufacturer increases the number simultaneously vulnerable to the same CCF without improving the beta factor. When CCF dominates the PFD (which it typically does at SIL 2 and above with redundant identical sensors), additional same-type redundancy provides minimal improvement. Introducing diverse technology — a different measurement principle, different manufacturer, or different installation — reduces the beta factor and actually improves the achieved SIL.