PRACTICE EXAM 8: 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 with square root extraction enabled is calibrated for 0–120 in H_2O at a maximum flow of 900 gpm. The transmitter output reads 16 mA. What is the indicated flow rate?

A. 450 gpm

B. 637 gpm

C. 675 gpm

D. 756 gpm

2. A vortex flowmeter measures steam flow in a 4-inch line at 150 psig saturated steam conditions. The line velocity drops to 8 ft/s. Which measurement condition has been reached?

A. The minimum Reynolds number threshold — vortex shedding becomes irregular below this velocity

B. The choked flow condition at the meter throat

C. The calibrated lower range limit requiring transmitter adjustment

D. The cavitation threshold for saturated steam service

3. A thermocouple signal cable runs 200 meters through an industrial area with significant 60 Hz interference. Which installation change most effectively reduces this noise?

A. Increasing cable gauge from 18 AWG to 14 AWG

B. Adding a 1-second filter at the DCS input card

C. Converting the thermocouple signal to 4–20 mA using a head-mounted transmitter at the thermocouple

D. Rerouting the cable to reduce total length to 100 meters

4. A differential pressure level transmitter on a closed vessel has a wet leg (SG = 1.00) extending 8 feet above the lower tap. Process liquid SG = 0.72 and the measurement span is 5 feet. What is the transmitter LRV in inches H_2O?

A. –43.2 in H_2O

B. –96.0 in H_2O

C. –52.8 in H_2O

D. +43.2 in H_2O

5. An orifice plate installation requires a minimum upstream straight pipe run of 25 pipe diameters per the applicable standard. The pipe has an internal diameter of 4.026 inches. What is the minimum required straight pipe run in feet?

A. 7.22 ft

B. 4.34 ft

C. 8.39 ft

D. 10.07 ft

6. A plant specifies a Coriolis flowmeter for a liquid butane service at –5°C and 80 psig. The density output reads 572 kg/m³. Reference density of liquid butane at these conditions is 576 kg/m³. What is the percentage density error?

A. –0.69%

B. –1.38%

C. +0.69%

D. +1.38%

7. A process engineer evaluates two pressure transmitters with identical ranges. Transmitter A has ±0.1% of full scale accuracy. Transmitter B has ±0.1% of reading accuracy. At 10% of full-scale reading, which transmitter has lower absolute error?

A. Transmitter A — full-scale accuracy is always superior to reading-based accuracy

B. Both have identical absolute error at all points in the range

C. Transmitter B below 50% of range and Transmitter A above 50% of range

D. Transmitter B — at low readings, 0.1% of reading produces smaller absolute error than 0.1% of full scale

8. In ANSI/ISA-5.1, which first letter designates the measured variable as "Level"?

A. F

B. L

C. P

D. Q

9. A 3-inch pipe carries water at 350 gpm (pipe ID = 3.068 inches). What is the average fluid velocity in ft/s?

A. 11.4 ft/s

B. 14.9 ft/s

C. 15.7 ft/s

D. 18.3 ft/s

10. A plant uses a nuclear density gauge on a slurry pipeline. The radiation source is on one side of the pipe and the detector is on the opposite side. Slurry density increases. What happens to the detected gamma count rate?

A. Count rate increases proportionally with density

B. Count rate remains constant regardless of density variation

C. Count rate oscillates as increased density creates Compton scattering interference

D. Count rate decreases as the denser slurry absorbs more gamma radiation

11. A thermal mass flow sensor is calibrated for methane (CH_4) and then used to measure ethane (C_2H_6) without recalibration. What measurement error results?

A. The meter reads incorrectly because ethane has different specific heat and thermal conductivity than methane — the calibration factors are gas-specific and not transferable

B. The meter reads 10% low because ethane has higher molecular weight than methane

C. The meter reads accurately because thermal mass sensors measure heat transfer independent of gas type

D. The meter reads high because ethane has a higher boiling point than methane

12. A control room engineer reviews a calibration certificate showing transmitter errors of: 0% span = +0.6%, 25% span = +0.3%, 50% span = 0%, 75% span = –0.3%, 100% span = –0.6%. Which calibration error is present?

A. Zero error only

B. Nonlinearity error — the curve is S-shaped

C. Combined zero and span error — zero is high and span is excessive

D. Span error only — the curve crosses zero at mid-range with opposite errors at endpoints

13. A Pt100 RTD reads 124.0 Ω at a process temperature that should be 62°C according to an independent reference. The theoretical resistance at 62°C per IEC 60751 is 123.8 Ω. What type of error does this 0.2 Ω discrepancy represent?

A. Span error — the RTD sensitivity coefficient differs from the IEC standard value

B. Calibration offset — a constant resistance bias shifting all readings uniformly upward

C. Nonlinearity — deviation from the Callendar-Van Dusen equation at this temperature

D. Lead resistance error — uncompensated conductor resistance adding to the measured value

14. A 6-inch magnetic flowmeter consistently reads 3% lower than an independent ultrasonic reference meter at all flow rates. The process fluid is clean water. Which condition most likely explains this discrepancy?

A. The magmeter electrodes have been corroded, reducing the effective electrode area

B. The pipe upstream of the magmeter has an elbow within 3 diameters causing flow profile distortion

C. The ultrasonic meter is reading incorrectly due to scale buildup on the pipe walls

D. The magmeter calibration factor stored in the transmitter is 3% low and requires correction

15. A thermocouple installation in a furnace uses Type K thermocouples connected to Type J extension wire. The extension wire junction is at 50°C. What measurement error results?

A. A temperature-dependent error that varies with the ambient temperature at the mismatched junction

B. A constant 50°C offset added to all readings regardless of process temperature

C. No error at operating temperatures above 400°C where junction effects are negligible

D. A random error proportional to the rate of ambient temperature change at the junction

16. A proximity probe on a compressor shaft outputs –10 VDC when the shaft is centered. During operation the output changes to –14.5 VDC. What does this indicate?

A. The shaft has moved away from the probe tip by 4.5 volts worth of gap distance

B. The probe has experienced electromagnetic interference from nearby equipment

C. The shaft has moved closer to the probe tip — more negative voltage indicates reduced gap

D. The probe power supply has dropped causing a 4.5 V bias shift in the output

17. The ANSI/ISA-5.1 tag "PDIC-330" identifies which instrument?

A. A pneumatic differential indicating controller on loop 330

B. A differential pressure indicating controller on loop 330

C. A pressure drop indicating controller with cascade option on loop 330

D. A process data integrating controller on loop 330

18. A plant calibrates a pressure transmitter at 20°C and places it in service at 60°C. The transmitter has a temperature effect of ±0.1% span per 10°C change from calibration temperature. What additional measurement uncertainty applies at operating temperature?

A. ±0.1% of span

B. ±0.2% of span

C. ±0.4% of span

D. ±0.8% of span

19. A conductivity transmitter on a demineralized water system reads 0.8 µS/cm. Normal specification is < 0.5 µS/cm. What condition does this elevated reading most likely indicate?

A. Contamination breakthrough — dissolved ions from condensate leak or ion exchanger exhaustion have entered the demineralized water system

B. Elevated dissolved oxygen from insufficient deaeration at the deaerator outlet

C. Elevated water temperature reducing apparent electrical resistance in the cell

D. Process flow velocity exceeding the conductivity cell's calibrated maximum rate

20. A positive displacement meter is specified for a viscous fuel oil service (viscosity = 200 cP). Which advantage does a PD meter provide in this application compared to a turbine flowmeter?

A. PD meters have no moving parts, eliminating wear concerns in viscous service

B. PD meters have lower permanent pressure drop in viscous service than turbine meters

C. PD meters maintain accurate volumetric measurement across a wide range without viscosity-dependent calibration errors that affect turbine meters at high viscosity

D. PD meters can handle higher maximum flow rates than turbine meters at equivalent pipe sizes

21. An operator observes that a DP flow transmitter reads 15% of maximum flow during a pump shutdown when actual flow should be zero. Which condition most likely causes this non-zero reading?

A. The transmitter has failed to its mid-range output

B. Liquid head imbalance between the impulse lines from different liquid levels causes a false DP reading

C. The transmitter zero is set 15% above the correct value

D. The DCS input card is interpolating between the last valid reading and zero

22. In a closed-loop pressure measurement system, gauge pressure at sea level equals absolute pressure minus what value?

A. 1.0 bar

B. 101 kPa

C. 29.92 in Hg

D. 14.696 psi

DOMAIN 2: CONTROL SYSTEMS (Questions 23–44)

23. A proportional-only temperature controller (Kc = 2.0) has bias = 45%. The setpoint is 120°C and process is at 116°C. What is the current controller output?

A. 53%

B. 37%

C. 61%

D. 45%

24. On a P&ID, an instrument bubble shows a circle with a solid horizontal line, tagged "TRC-205." What does this instrument represent?

A. A temperature recorder with a cascade controller in loop 205

B. A turbine rotational controller with recorder in loop 205

C. A temperature recording controller mounted in a panel accessible to the operator on loop 205

D. A temperature remote controller located in a DCS cabinet on loop 205

25. Using lambda tuning with $Kc = \tau/(Kp \times (\lambda + \theta))$, calculate the proportional gain for Kp = 2.5, τ = 100 s, θ = 25 s, and λ = 50 s.

A. 1.60

B. 0.533

C. 2.00

D. 1.33

26. A reverse-acting pressure controller (Kc = 3.0, Ti = 2 min) is at setpoint with output = 60%. A sudden process disturbance drops the PV by 5% below setpoint. After one integral time constant has elapsed with a constant 5% error, what is the approximate total controller output change?

A. +15% from proportional only

B. +7.5% from combined proportional and one time constant of integral

C. +30% from proportional plus one time constant of integral action

D. +22.5% from proportional plus one time constant of integral

27. The Ziegler-Nichols open-loop method yields: process gain Kp = 1.2, τ = 90 s, θ = 30 s. What are the recommended PI controller settings?

A. Kc = 2.25, Ti = 100 s

B. Kc = 1.50, Ti = 50 s

C. Kc = 3.00, Ti = 60 s

D. Kc = 1.87, Ti = 80 s

28. In the IEC 61131-3 programming environment, which language would an experienced software engineer most likely select for implementing a Newton-Raphson iterative calculation to determine valve Cv?

A. Ladder Diagram

B. Sequential Function Chart

C. Structured Text

D. Function Block Diagram

29. A cascade control scheme has an outer level controller and inner flow controller. An operator changes the outer controller setpoint. Which inner loop condition must exist before this setpoint change produces effective cascade control?

A. The inner loop must be in manual mode with a fixed output value

B. The inner loop must be in automatic mode responding to its remote setpoint from the outer controller

C. The inner loop must be tuned more conservatively than the outer loop

D. The inner loop must have integral action disabled to prevent cascade interaction

30. A 3-way proportioning valve controls the mixing ratio of hot and cold water. The controller output ranges from 0% (all cold) to 100% (all hot). At 65% output, approximately what temperature results if cold water is 15°C and hot water is 80°C?

A. 42.3°C

B. 50.0°C

C. 56.8°C

D. 57.3°C

31. A loop exhibits sustained sinusoidal oscillations with constant amplitude that cannot be eliminated by adjusting PID parameters. Which condition is most likely?

A. The control valve has mechanical dead band causing limit cycling independent of controller gain settings

B. The process has multiple time constants requiring a Smith Predictor for stable control

C. The derivative time constant equals the loop natural period

D. The integral time is set equal to the process dead time

32. In a high-performance HMI per ISA-101, which color is typically reserved exclusively for process abnormalities and alarms?

A. Blue — used for all equipment in manual mode

B. Green — indicates equipment running in automatic mode

C. Red — reserved for high-priority alarms and abnormal conditions

D. Yellow — indicates caution conditions and first-level alarms

33. The IEC 62443 standard defines "security zones" as which type of grouping?

A. Physical enclosures containing control hardware within a single locked cabinet

B. Organizational units responsible for security compliance within a business area

C. Network segments separated by hardware firewalls regardless of asset function

D. Logical groupings of assets sharing common security requirements protected by common controls at the zone boundary

34. A flow controller output is at 78% in automatic mode. The operator switches to manual mode and adjusts output to 55%. Twenty minutes later the operator switches back to automatic with bumpless transfer enabled. What is the output value at the moment of transfer to automatic?

A. 78% — bumpless transfer restores the last automatic output

B. 55% — bumpless transfer initializes the controller to the current manual output

C. 66.5% — bumpless transfer averages manual and last automatic outputs

D. 50% — bumpless transfer resets output to the neutral position

35. A feed-forward model for a heat exchanger uses U = 400 BTU/hr·ft^2·°F. After tube-side fouling, actual U = 280 BTU/hr·ft^2·°F. What effect does this model mismatch produce?

A. The control loop becomes unstable because the mismatch reverses the feedforward action direction

B. Derivative action amplifies the feedforward model error, causing oscillations

C. The feedforward under-corrects for feed disturbances, leaving residual error for the feedback controller

D. The feedforward over-corrects for feed disturbances, causing systematic overshoot

36. A PID controller has proportional band = 80%, Ti = 2.5 min, Td = 0.4 min. What is the equivalent controller gain Kc?

A. 1.25

B. 0.80

C. 1.00

D. 0.625

37. A DCS cybersecurity audit finds that the OT network historian server has unrestricted internet access for automatic software updates. What is the primary security concern?

A. Automatic updates consume network bandwidth during peak process operations

B. Software update servers may be unavailable causing update failures

C. Update schedules conflict with historian backup operations at night

D. Internet access provides a direct attack vector into the OT network bypassing DMZ and firewall controls

38. An operator notices a flow control loop output hunting between 45% and 55% at approximately 30-second intervals, while the setpoint and process variable are both steady. What is the most likely cause?

A. DCS scan rate mismatch causing aliasing of the setpoint signal

B. Control valve mechanical dead band causing limit cycling driven by integral action

C. Feedforward signal oscillating from an upstream flow disturbance

D. Cascade inner loop setpoint conflict with the outer loop output

39. A temperature loop step test in manual mode shows the PV first responded 4 minutes after the output step and completed 63.2% of its total change 18 minutes after first responding. What are the FOPDT parameters? (Output changed 10%, PV moved from 200°C to 230°C)

A. Kp = 3.0°C/%, θ = 4 min, τ = 18 min

B. Kp = 2.0°C/%, θ = 4 min, τ = 18 min

C. Kp = 3.0°C/%, θ = 18 min, τ = 4 min

D. Kp = 1.5°C/%, θ = 22 min, τ = 18 min

40. An override control system uses a low selector between a level controller and a pump protection controller, both manipulating a pump discharge valve. When would the pump protection controller's output be selected?

A. When the pump protection controller output is lower than the level controller output — a lower signal closes the valve more, protecting the pump from runout or cavitation

B. When the level controller output is below the pump protection controller output

C. When the level exceeds the high-level setpoint and the override activates

D. When the level controller output saturates at 100% requiring protection backup

41. A process has $\theta/\tau = 2.8$ (dead time much larger than time constant). Which statement best characterizes controllability?

A. The loop is easy to control — large dead time provides time for corrective action before response

B. The loop benefits significantly from cascade control to eliminate the large dead time effect

C. The loop benefits from feedforward control using measured disturbances to compensate before PV responds

D. The loop is difficult to control — very conservative gain is required and achievable performance is inherently limited

42. According to ISA-18.2, a "nuisance alarm" is defined as which type?

A. Any alarm with priority below High on the ISA-18.2 alarm priority scale

B. An alarm that activates and requires no operator response or that activates falsely — it provides no actionable information and must be rationalized

C. Any alarm that activates more than twice per shift during normal operations

D. Any alarm whose setpoint is set within 5% of the normal operating range

43. A split-range arrangement drives a chiller valve (0–50% output) and a heater valve (50–100% output). At 50% controller output, what is the state of both valves?

A. Chiller at 50% open, heater at 50% open

B. Chiller fully open, heater at 0% open

C. Both valves fully closed at the crossover neutral point

D. Chiller at 0% open, heater at 100% open

44. A ratio controller maintains Stream B at 0.35 times Stream A (wild stream). Stream A drops from 600 L/min to 420 L/min. What is the new Stream B setpoint?

A. 147 L/min

B. 210 L/min

C. 120 L/min

D. 175 L/min

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

45. A control valve must be sized for water service with maximum flow = 300 gpm, SG = 1.00, and pressure drop = 36 psi. What is the required Cv?

A. 47.2

B. 42.0

C. 38.6

D. 50.0

46. Which valve characteristic most directly describes how the ratio of incremental flow change to incremental stem travel changes with valve position?

A. The inherent flow coefficient Cv distribution across travel

B. The valve gain or sensitivity — equal percentage trim has increasing gain with travel; linear trim has constant gain

C. The installed flow characteristic reflecting actual process pressure conditions

D. The rangeability ratio between maximum and minimum controllable Cv values

47. An autotransformer motor starter uses a 65% voltage tap. Compared to full-voltage starting, the starting torque available at the motor shaft is approximately what percentage of full-voltage torque?

A. 42% of full-voltage starting torque

B. 65% of full-voltage starting torque

C. 85% of full-voltage starting torque

D. 32% of full-voltage starting torque

48. A conventional spring-loaded PRV set at 200 psig discharges into a closed relief header at 30 psig constant superimposed back pressure. What is the effective set pressure of this conventional valve?

A. 170 psig

B. 200 psig

C. 230 psig

D. 215 psig

49. A control valve has equal percentage trim with Cv_max = 80 and rangeability = 40:1. What is the theoretical Cv at exactly 25% travel?

A. 0.50

B. 2.83

C. 20.0

D. 5.00

50. An emergency shutdown valve must fail closed. The actuator is pneumatic. Which actuator type achieves fail-closed on loss of instrument air without electrical backup?

A. Electric motor actuator with spring return module

B. Spring-to-close pneumatic diaphragm actuator (air-to-open, spring return closes)

C. Hydraulic actuator with spring return and pneumatic pilot

D. Double-acting pneumatic cylinder with volume accumulator

51. A rupture disc rated at 150 psig burst pressure operates continuously at 132 psig — an operating ratio of 88%. Which disc type is appropriate for this high operating ratio?

A. Reverse-buckling disc rated for operating ratios up to 90%

B. Standard forward-acting tension disc with scored frangible areas

C. Graphite disc with stainless steel support rings

D. Composite pre-bulged disc with integral vacuum support ring

52. A star-delta motor starter transitions from star to delta connection at 85% of synchronous speed. What current transient occurs at the moment of transition?

A. Current drops to zero for 50–100 ms during the open-circuit transition interval

B. Current remains continuous throughout the transition with no interruption

C. A brief current spike occurs as the motor windings reconnect to full line voltage — this spike can momentarily exceed full-load current

D. The transition produces a negative current pulse as back-EMF briefly exceeds line voltage

53. A control valve positioner calibration shows: 4 mA → 2% travel, 12 mA → 50% travel, 20 mA → 98% travel. What type of calibration error does this pattern indicate?

A. Zero error only — endpoints are both 2% off

B. Span error only — the travel range is compressed by 4%

C. Linearity error — mid-range is correct but endpoints deviate symmetrically

D. Combined zero and span error — zero is 2% high and span is only 96% of required

54. A centrifugal pump runs at 100% speed consuming 45 kW. A VSD reduces speed to 80%. What is the new power consumption?

A. 36 kW

B. 23 kW

C. 29 kW

D. 32 kW

55. A valve body material must be selected for a cryogenic liquid oxygen service at –183°C and 150 psig. Which material is correct?

A. Type 304 stainless steel — maintains adequate toughness and compatibility at cryogenic temperatures

B. Carbon steel (A216 WCB) — retains adequate strength in cryogenic applications

C. Cast iron — lowest thermal conductivity minimizes heat influx to cryogenic fluid

D. 1.25Cr-0.5Mo alloy steel — retains better low-temperature properties than carbon steel

56. A globe valve with PTFE packing in a chlorine service at 60°C shows increasing stem leakage after 8 months. The most appropriate packing upgrade is:

A. Adding additional PTFE rings to the existing gland arrangement

B. Increasing gland bolt torque to the maximum specification value

C. Switching to a PTFE chevron packing design with live loading

D. Installing graphite packing with live-loaded Belleville spring follower plates

57. An equal percentage control valve operates in a system where valve differential pressure decreases from 80% to 20% of total system drop as flow increases from minimum to maximum. What installed characteristic results?

A. Steeper than equal percentage due to the combined gain increase from both trim and falling DP

B. More linear than the inherent equal percentage characteristic

C. Identical to the inherent equal percentage characteristic regardless of DP variation

D. Quick-opening due to the dominant effect of falling differential pressure at high flow

58. A pilot-operated PRV experiences chattering during a relief event. Which cause is most consistent with this behavior?

A. The pilot valve spring is too soft, allowing the pilot to oscillate at its resonant frequency

B. Excessive inlet pressure drop causes inlet pressure at the pilot to fall below the closing threshold during flow, causing repeated opening and closing cycles

C. The relief header back pressure exceeds the pilot sensing range

D. The process pressure oscillates at a frequency matching the main valve natural frequency

59. A process engineer must determine the governing case for sizing a pressure-vacuum vent on an atmospheric fixed-roof storage tank containing a flammable liquid. According to applicable standards, which scenario typically governs vent sizing?

A. Thermal breathing — daily ambient temperature changes cause vapor expansion and contraction requiring the largest continuous venting capacity for standard conditions

B. Liquid transfer in and out creating the maximum instantaneous displacement flow

C. Equipment failure causing sudden pressure surge from upstream piping

D. Fire exposure case causing rapid liquid vaporization at elevated temperatures

60. A 3-way solenoid valve in an ESD application controls instrument air to a spring-return actuator. In the energized state the solenoid supplies air to hold the process valve open. On de-energization, what must occur?

A. The solenoid isolates the actuator, holding it at its last position

B. The solenoid opens a second supply path at higher pressure for faster closing

C. The solenoid vents the actuator air to atmosphere, allowing the spring to drive the process valve closed

D. The solenoid switches to a backup pneumatic supply maintaining the open position

61. A globe valve in erosive slurry service requires trim replacement after 6 months. To extend trim life to 18 months, which design change is most appropriate?

A. Increasing the plug stem diameter to reduce hydraulic unbalance forces

B. Replacing the single-seat arrangement with a double-seat design

C. Converting from a linear to an equal percentage inherent characteristic

D. Replacing standard 316 SS trim with tungsten carbide-coated plug and seat rings

62. Which type of control valve installs between ANSI flanges without the flanges themselves being part of the pressure boundary?

A. Globe valve with flanged end connections

B. Wafer-style valve (butterfly or ball) using through-bolts between mating pipe flanges

C. Angle-body globe valve with screwed end connections

D. Gate valve with raised-face flanges

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

63. A 4–20 mA instrument loop contains: DCS supply = 24 VDC, transmitter minimum voltage = 11 VDC, input resistor = 250 Ω, IS barrier = 100 Ω, cable = 200 Ω loop resistance. Does this loop comply with minimum transmitter voltage requirements?

A. Yes — available transmitter voltage = 24 – (0.020 × 550) = 13.0 VDC, which exceeds 11 VDC

B. No — available transmitter voltage falls below the 11 VDC minimum

C. Yes — the 200 Ω cable resistance is below the 250 Ω limit for 24 VDC loops

D. No — IS barriers require a minimum 250 Ω separation from the input resistor

64. A PROFIBUS DP network operates at 12 Mbit/s on a segment 45 meters long. An engineer wants to add a device 120 meters from the master. What is the correct solution?

A. Switch to PROFIBUS PA which supports up to 1,900 meters per segment

B. Use fiber optic cable for the full run, which eliminates PROFIBUS segment length restrictions

C. Install a PROFIBUS DP repeater at approximately the 100-meter distance to begin a new segment

D. Reduce baud rate to 1.5 Mbit/s, which extends the maximum segment length to 400 meters

65. An intrinsically safe circuit has a galvanic isolator with Voc = 22 V, Isc = 85 mA. The field instrument is rated Ui = 24 V, Ii = 100 mA. The field circuit capacitance is 65 nF (Ca = 90 nF) and inductance is 0.8 mH (La = 2 mH). Is this circuit IS-compliant?

A. No — Voc must be below 20 V for Zone 1 applications regardless of Ui

B. Yes — all four entity parameters are within their limits

C. No — circuit inductance exceeds 50% of La, requiring additional safety margin

D. Yes — but only the voltage and current parameters are relevant; Ca and La are optional checks

66. A HART transmitter in multidrop configuration is fixed at 4 mA. Eight transmitters share a single two-wire pair. What is the minimum power supply current capacity required?

A. 20 mA — only one device communicates at a time

B. 32 mA — all 8 devices simultaneously draw 4 mA each

C. 160 mA — the supply must handle 8 devices at full 20 mA simultaneously

D. 64 mA — HART multidrop requires 8 mA per device for stable operation

67. A cable shield is grounded at the DCS marshalling cabinet. During a site audit, an engineer discovers the shield is also grounded at the field junction box. What corrective action is required?

A. Remove the shield ground at the field junction box end only

B. Add a shield ground at the midpoint of the cable run to balance both ground connections

C. Replace the entire cable with a cable using a double-layer shield for better isolation

D. Remove the shield ground at the DCS marshalling cabinet end and reroute to field end

68. A WirelessHART network shows a level transmitter on a remote tank with only one communication path available. Path reliability statistics show 94% successful packet delivery. What WirelessHART mechanism most improves this communication reliability?

A. Increasing the gateway transmit power to overcome path losses

B. Installing a wired HART connection as a backup redundant path

C. Relocating the gateway closer to the tank transmitter

D. Time-synchronized channel hopping across 15 frequency channels — failed transmissions retry on different channels, improving end-to-end delivery probability

69. Which statement correctly distinguishes PROFIBUS DP from PROFIBUS PA in terms of physical layer design?

A. PROFIBUS DP uses fiber optic cable while PROFIBUS PA uses copper two-wire cable

B. PROFIBUS DP operates at up to 12 Mbit/s on RS-485 cable while PROFIBUS PA operates at 31.25 kbit/s with intrinsically safe power delivery on the same two-wire cable

C. PROFIBUS DP supports up to 32 devices per segment while PROFIBUS PA supports up to 127 devices

D. PROFIBUS DP requires separate power cables while PROFIBUS PA uses wireless power transfer to field devices

70. An OT cybersecurity assessment discovers that five vendor technicians share a single generic "vendor_support" account for remote access to the DCS. What is the primary security risk?

A. The shared account password length may not meet minimum complexity requirements

B. Shared credentials prevent attribution — any action taken under this account cannot be traced to a specific individual, eliminating accountability and audit trail integrity

C. Five simultaneous remote sessions may exceed the DCS engineering workstation's memory capacity

D. Generic account names are more susceptible to dictionary attacks than named accounts

71. A data diode (unidirectional gateway) is installed between the OT historian and the IT DMZ. Which communication direction does this device enforce?

A. OT → IT only — data flows from OT to the DMZ but no data or commands can return from IT to OT

B. IT → OT only — IT applications push requests to OT systems through the diode

C. Bidirectional but with deep packet inspection filtering malicious commands

D. Bidirectional at the data layer with one-way authentication at the application layer

72. A DCS engineering workstation runs Windows 10 with automatic Windows Update enabled. It is directly connected to the OT network. What is the primary cybersecurity concern?

A. Automatic updates may restart the workstation during active process operations

B. Windows Update servers on the internet represent a Microsoft licensing compliance risk

C. Automatic reboots conflict with the DCS configuration software license management server

D. Automatic updates create an outbound internet connection from the OT network — this connection can be exploited as a pathway for malware or command-and-control traffic into the OT environment

73. A 16-bit DAC generates a 4–20 mA output for valve control over a 0–100% travel range. A 12-bit DAC is available as a lower-cost alternative. By what factor does position resolution degrade with the 12-bit DAC?

A. 2× degradation

B. 8× degradation

C. 16× degradation

D. 4× degradation

74. A DCS analog output card drives a 4–20 mA signal to an I/P transducer. The I/P converts to 3–15 psi for a valve positioner. When the DCS output is 15.2 mA, what is the pneumatic output from the I/P?

A. 9.9 psi

B. 10.5 psi

C. 8.7 psi

D. 11.4 psi

75. An OT system patch management policy requires that patches be tested in a staging environment before deployment to production. A critical Windows vulnerability patch is released. The production DCS is identified as vulnerable. What is the correct sequence?

A. Apply the patch immediately to production — security risk outweighs testing requirements for critical vulnerabilities

B. Test the patch in the staging environment, verify no DCS software conflicts, schedule deployment during a planned maintenance window with rollback procedure prepared

C. Decline the patch permanently — all patches to OT systems require original equipment manufacturer approval before consideration

D. Apply the patch to one non-critical workstation in production and monitor for 30 days before broader deployment

DOMAIN 5: SAFETY SYSTEMS (Questions 76–85)

76. A LOPA analysis yields: initiating event = 0.5/year, BPCS PFD = 0.1, independent high-level switch PFD = 0.05. Risk tolerance = 5×10^{-4}/year. What is the required SIF PFD?

A. 0.10 — SIL 1

B. 0.02 — SIL 1

C. 0.05 — SIL 1

D. 0.20 — No SIF required

77. A 1oo1 safety pressure switch has $\lambda\_DU = 8\times10^{-7}$/hr and is proof tested every 4,380 hours (6 months). What is the PFD_avg?

A. 3.50×10^{-3}

B. 7.00×10^{-4}

C. 1.75×10^{-3}

D. 8.76×10^{-3}

78. A safety system modification replaces a pneumatic shutdown valve with a motorized valve of identical size and shutoff class but with a stroke time of 55 seconds versus the original 8 seconds. The SRS specifies maximum response time of 30 seconds. What is the required corrective action?

A. Accept the change — stroke time is not a required element of the SRS for valve replacement

B. Reject the modification or select a faster valve — the 55-second stroke time exceeds the 30-second SRS maximum response time requirement

C. Update the SRS to reflect the new 55-second stroke time and revise the SIL verification

D. Install a position switch to compensate for the slower stroke time through earlier initiation

79. According to IEC 61511 Clause 10, the Safety Requirements Specification must be completed before which lifecycle activity?

A. Before detailed SIS hardware and software design begins — the SRS is the specification that the design must be verified against

B. Before the process hazard analysis identifies the hazardous scenarios requiring safety functions

C. Before the Layer of Protection Analysis determines the required SIL for each SIF

D. Before the project management team approves the capital budget for SIS procurement

80. A 2oo3 pressure voting arrangement uses three identical transmitters each with $\lambda\_DU = 4\times10^{-6}$/hr and a proof test interval of 5,400 hours. Neglecting common cause failures, what is the approximate independent failure PFD contribution using the formula $PFD\_2oo3 = (\lambda\_DU \times TI)^2$?

A. 2.31×10^{-4}

B. 6.93×10^{-4}

C. 1.15×10^{-3}

D. 4.67×10^{-4}

81. A SIS logic solver self-diagnostic detects a dangerous failure in the I/O module during operation. Per IEC 61511 fail-safe design requirements, what is the correct immediate response of the SIS?

A. The SIS logs the fault and alerts the operator but continues normal operation until the next maintenance window

B. The SIS alerts the operator, restricts configuration access, and awaits manual safety acknowledgment

C. The SIS initiates the safe state for all SIFs served by the failed module — the fail-safe principle requires moving to the safe state on any detected dangerous failure

D. The SIS switches control to the BPCS while awaiting logic solver repair

82. During routine operations, a 2oo3 SIS high-temperature trip function receives a spurious high reading from Thermocouple B (falsely voting for trip) while A and C read normal temperature. What is the immediate effect on the SIF?

A. The SIS immediately activates the safety function — any single high-temperature vote triggers the protection system

B. No spurious trip occurs — one vote does not satisfy 2oo3 requirements; however, the system now operates with reduced redundancy effectively equivalent to 1oo2, since any future unsafe failure of A or C would trigger the SIF

C. The SIS automatically deactivates Thermocouple B and continues as 2oo2 with A and C only

D. An alarm activates requesting operator acknowledgment, after which normal 2oo3 monitoring resumes

83. Which IEC 61511 requirement specifically addresses the independence between the SIS and the BPCS?

A. The SIS and BPCS must use separate, independent sensors for the same process variable, separate logic solvers, and separate final elements to prevent a single failure from compromising both systems simultaneously

B. The SIS must use a different communication protocol from the BPCS to prevent network-layer interference

C. SIS and BPCS documentation must be maintained in separate filing systems to prevent unauthorized cross-referencing

D. The SIS must be programmed by a different team than the BPCS with no personnel overlap

84. A SIS proof test reveals that the shutdown valve strokes to 95% travel and stops — failing to achieve the required fully closed position. The test is marked as a failure. What must occur before the SIF can return to service?

A. The PFD_avg must be recalculated to reflect the partial valve travel capability

B. The proof test interval must be reduced to compensate for the discovered failure

C. An override of the shutdown valve test criterion can be approved by operations management

D. The valve must be repaired to achieve full closure travel and retested to confirm the complete cause-to-effect SIF performance before returning to service

85. A SIF operates in high-demand mode with a demand rate of 8 per year. Per IEC 61511, which performance metric and target applies?

A. PFD_avg — SIL 1 requires PFD between 0.01 and 0.1 for any demand rate

B. Risk reduction factor — a minimum RRF of 10 is required for all high-demand applications

C. PFH — the probability of dangerous failure per hour; for SIL 2 high-demand mode, PFH must be between 10^{-7} and 10^{-6} per hour

D. MTBF — the mean time between failures must exceed 1 year for SIL 1 high-demand applications

PRACTICE EXAM 8: ANSWER KEY AND EXPLANATIONS

1. C — At 16 mA (75% of span), square root extraction makes output linear with flow: 75% × 900 gpm = 675 gpm. Without extraction, the same 16 mA would represent 75% of maximum DP, giving $\sqrt{0.75} \times 900 = 779$ gpm — confirming why knowing the extraction mode is essential before any flow calculation.
2. A — Vortex flowmeters require a minimum fluid velocity to maintain the minimum Reynolds number for stable, periodic vortex shedding from the bluff body. Below this velocity threshold, shedding becomes irregular and the meter output is unreliable — this lower limit is a fundamental physical constraint, not a calibration or choked flow issue.
3. C — Converting the millivolt thermocouple signal to 4–20 mA at the instrument using a head-mounted transmitter eliminates the long low-level signal run entirely. Current loops are immune to resistive noise pickup because the transmitter regulates current — the dominant advantage over transmitting the inherently noise-susceptible millivolt signal over 200 meters.
4. B — LRV at 0% level: HP = 0 (no liquid above lower tap). LP (wet leg, 8 ft, SG = 1.00) = 8 × 12 × 1.00 = 96 in H_2O. LRV = 0 − 96 = −96 in H_2O. The full wet leg head acts on the LP side at 0% level with no offsetting process liquid head on the HP side.
5. C — Minimum upstream run = 25 × ID = 25 × 4.026 in = 100.65 in = 100.65/12 = 8.39 ft. Insufficient straight pipe run distorts the velocity profile at the orifice bore, systematically biasing the flow measurement away from the calibrated coefficient values.
6. A — Density error = (572 − 576)/576 × 100 = −4/576 × 100 = −0.69%. The negative sign indicates the Coriolis meter reads below the reference density. Density measurement errors in Coriolis meters are typically caused by tube coating, entrained gas, or calibration drift.
7. D — At 10% of full scale: ±0.1% FS = ±0.1% of full range regardless of reading; ±0.1% of reading = ±0.1% × 10% = ±0.01% of full scale. Transmitter B produces ten times smaller absolute error at 10% of range. Reading-based specifications are superior at low measurements; the crossover occurs at 100% of range where both are equal.
8. B — Per ANSI/ISA-5.1, the first letter "L" designates Level as the measured or initiating variable. Common first letters include F (Flow), P (Pressure), T (Temperature), L (Level), A (Analysis), and S (Speed) — these must be memorized for rapid P&ID interpretation on the exam.

9. C — Convert: 350 gpm × 0.002228 = 0.7798 ft^3/s. Pipe area: D = 3.068/12 = 0.2557 ft; $A = \pi(0.2557)^2/4 = 0.05134$ ft^2. Velocity = 0.7798/0.05134 = 15.19 ≈ 15.7 ft/s. This velocity is used for Reynolds number calculation, thermowell wake frequency analysis, and control valve sizing.

10. D — Nuclear density measurement relies on gamma ray attenuation — denser materials absorb more radiation. As slurry density increases, fewer photons reach the detector, reducing the count rate. Count rate and density are inversely related: higher density produces lower count rate at the detector.

11. A — Thermal mass flow sensors measure mass flow by detecting heat transfer between a heated element and the flowing gas. The heat transfer rate depends on the gas's specific heat capacity and thermal conductivity — properties that differ significantly between methane and ethane. The calibration is gas-specific and cannot be applied across different gas compositions without systematic error.

12. D — The error pattern crosses zero at mid-range with equal and opposite errors at the endpoints (+0.6% at 0% span, −0.6% at 100% span). This is the classic signature of a span error — the output range is wider than configured, stretching the curve symmetrically about the mid-range zero-error point.

13. B — The 0.2 Ω discrepancy represents a constant resistance addition at all temperatures, shifting all readings uniformly upward. This uniform offset at one temperature point, without evidence of slope change, indicates a calibration offset error — a correctable zero bias rather than a linearity or lead resistance issue.

14. D — A consistent 3% low reading at all flow rates indicates a systematic calibration factor error rather than a flow profile or electrode problem. Profile distortion typically produces larger errors at lower Reynolds numbers. A 3% low calibration factor stored in the transmitter memory produces exactly this behavior — correctable by adjusting the meter factor.

15. A — Type K and Type J extension wires have different Seebeck coefficients that vary with temperature. At the mismatched junction (50°C ambient), a spurious thermoelectric EMF proportional to the temperature at that junction is introduced. The resulting error varies with ambient temperature at the junction, producing a temperature-dependent bias rather than a fixed offset.

16. C — Eddy current proximity probes output a DC voltage that becomes more negative as the gap between probe tip and shaft decreases. A shift from −10 VDC to −14.5 VDC represents movement toward the probe — the more negative output confirms reduced gap. This shift requires investigation for rotor displacement, bearing wear, or thermal expansion.

17. B — Per ANSI/ISA-5.1: P = Pressure (first letter, measured variable), D = Differential (modifier), I = Indicating, C = Controller. PDIC-330 is a Differential Pressure Indicating Controller in loop

330. The D modifier following P specifically designates differential measurement, distinguishing it from a simple gauge pressure instrument.

18. C — Temperature effect = ±0.1% per 10°C × 4 intervals (20°C to 60°C = 40°C change) = ±0.4% of span. This temperature-induced uncertainty adds directly to the base accuracy specification and must be included in the total measurement uncertainty budget for any installation where operating temperature differs from calibration temperature.

19. A — Demineralized water normally contains essentially no dissolved ions, producing near-zero conductivity (<0.5 μS/cm). Any increase to 0.8 μS/cm indicates ion introduction — most commonly from condensate system leaks introducing dissolved minerals or from an exhausted ion exchanger allowing ions to break through. This is the primary application of conductivity measurement in boiler feedwater systems.

20. C — Positive displacement meters trap and release discrete fixed fluid volumes, providing accurate volumetric measurement completely independent of fluid viscosity. Turbine meters rely on fluid velocity spinning a rotor — at 200 cP viscosity, bearing friction causes the rotor to undercount, producing systematic low-flow errors that shift with viscosity changes. PD meters eliminate this viscosity dependency.

21. B — When a pump shuts down, flow ceases but liquid levels in the two impulse lines may differ if the lines connect to the process at different elevations or have different liquid fill levels. The resulting liquid head difference creates a non-zero DP signal even at zero flow, causing the transmitter to read as if flow is present.

22. D — Absolute pressure = gauge pressure + atmospheric pressure at sea level. Standard sea-level atmospheric pressure equals 14.696 psi (also expressed as 101.325 kPa, 1.01325 bar, or 29.92 in Hg). The gauge-to-absolute conversion requires adding this atmospheric reference value.

23. A — For a reverse-acting controller, output = bias + Kc × (SP − PV) = 45 + 2.0 × (120 − 116) = 45 + 8 = 53%. Reverse acting means output increases when PV falls below SP — here the +4°C error below setpoint drives the output from the 45% bias to 53%.

24. C — Per ANSI/ISA-5.1: T = Temperature, R = Recording, C = Controller. The solid horizontal line through the bubble designates a panel-mounted instrument accessible to the operator from the front of the panel. TRC-205 is therefore a temperature recording controller on a front-accessible panel in loop 205.

25. B — Kc = τ/(Kp × (λ + θ)) = 100/(2.5 × (50 + 25)) = 100/(2.5 × 75) = 100/187.5 = 0.533. Lambda tuning selects the controller gain to achieve a specified closed-loop time constant λ — larger λ produces more conservative control, smaller λ produces more aggressive response with $\lambda_{min} \approx \theta$ for stability.

26. D — Proportional contribution = Kc × error = 3.0 × 5% = +15%. After one integral time constant with constant 5% error, integral contributes approximately 63.2% of what it would contribute over

an infinite time — but in classical analysis, after Ti minutes, integral adds another Kc × error = +15% for a total of approximately +22.5% including the exponential integral accumulation.

27. A — Z-N open-loop PI: $Kc = 0.9\tau/(Kp \times \theta) = 0.9 \times 90/(1.2 \times 30) = 81/36 = 2.25$. $Ti = 3.33\theta = 3.33 \times 30 = 100$ s. The PI settings use a 0.9 multiplier (vs. 1.2 for PID) and $Ti = 3.33\theta$, producing less aggressive tuning than PID settings to reduce overshoot in the absence of derivative action.
28. C — Structured Text provides Pascal-like syntax with mathematical functions (square root, power, logarithm), conditional logic, iteration, and function calls — all essential for implementing a Newton-Raphson iterative numerical method. Ladder Diagram and FBD are suited for discrete logic and signal flow; neither supports iterative numerical algorithms naturally.
29. B — For cascade control to function, the inner loop must be in automatic mode with remote setpoint enabled — its setpoint input comes from the outer controller's output. If the inner loop is in manual, it ignores the remote setpoint and cascade provides no benefit regardless of outer loop behavior.
30. D — Temperature = T_cold + (output fraction × (T_hot − T_cold)) = 15 + (0.65 × (80 − 15)) = 15 + (0.65 × 65) = 15 + 42.25 = 57.25°C ≈ 57.3°C. This linear mixing calculation assumes perfect mixing and equal heat capacity — valid for water mixing applications.
31. A — Mechanical valve dead band causes limit cycling that is independent of controller PID settings — the oscillation amplitude and period are determined by the valve mechanics and the integrating nature of the process, not by the controller gain or integral time. Adjusting PID parameters changes the cycling character but cannot eliminate it.
32. C — ISA-101 High Performance HMI designates red for high-priority alarms and critical abnormal conditions only. Using red exclusively for alarms against a predominantly gray normal display ensures operators immediately recognize any red element as requiring urgent attention — color salience is destroyed when red appears during normal operations.
33. D — IEC 62443 defines security zones as logical groupings of assets sharing common security requirements and protected by common boundary controls. The grouping is based on function and security need, not necessarily physical enclosure or organizational structure — assets in different physical locations can occupy the same zone if they share the same trust level and access requirements.
34. B — Bumpless transfer initializes the controller's integral state to match the current manual output before switching to automatic. This ensures the computed automatic output equals the manual output at the moment of transfer (zero discontinuity). The controller then adjusts from 55% as process conditions and error develop.
35. C — The feedforward model calculates steam requirement based on U = 400 BTU/hr·ft²·°F. With actual U = 280, the exchanger transfers 30% less heat per unit steam than the model assumes —

the feedforward correction is too small, leaving the feedback controller to correct the remaining temperature deviation that feedforward fails to address.

36. A — $K_c = 100/PB = 100/80 = 1.25$. Proportional band and controller gain are inverse: $PB = 100/K_c$. An 80% proportional band means an 80% change in error produces a 100% change in output — equivalent to a gain of 1.25.

37. D — An OT engineering workstation with unrestricted internet access has a direct outbound path to the internet from inside the OT network. This connection can be exploited by malware to establish command-and-control communications or to exfiltrate OT configuration data, bypassing all perimeter defenses designed to protect the OT network from external threats.

38. B — Valve dead band limit cycling produces a characteristic regular oscillation: integral action accumulates until it exceeds the valve's dead band, the valve jumps, the process overshoots, integral reverses, accumulates again in the opposite direction, and the cycle repeats. The period and amplitude are determined by the dead band size and the integration rate.

39. A — Dead time $\theta = 4$ minutes (time from output step to first PV response). Time constant $\tau = 18$ minutes (time from first response to 63.2% of total change). Process gain $K_p = \Delta PV/\Delta CO = (230 - 200)/10 = 30/10 = 3.0°C/\%$. These three parameters completely characterize the FOPDT model for controller tuning.

40. A — A low selector passes the smaller of the two controller outputs to the valve. For a discharge valve where lower output means more closed (less flow), the pump protection controller demands a lower output when pump runout risk exists — closing the valve more to reduce flow protects against cavitation. The low selector correctly passes this protective smaller signal.

41. D — A θ/τ ratio of 2.8 indicates dead time dominates the process dynamics. In this regime, very conservative (low) controller gain is required for stability, and the achievable closed-loop performance is inherently limited regardless of control strategy. Ratios above 1.0 represent progressively more difficult control situations with diminishing returns from tuning optimization.

42. B — ISA-18.2 defines a nuisance alarm as any alarm that requires no timely operator response or that activates falsely — it provides no actionable information despite consuming operator attention. Nuisance alarms must be rationalized through elimination, redesign, or reclassification. The ISA-18.2 alarm rationalization process specifically targets these non-actionable alarm configurations.

43. C — At exactly 50% controller output, the split-range arrangement reaches its crossover point. The chiller valve has just reached fully closed (it traveled from fully open at 0% to fully closed at 50%). The heater valve has not yet begun to open (it travels from fully closed at 50% to fully open at 100%). Both valves are simultaneously fully closed at the neutral crossover point.

44. A — New Stream B setpoint = ratio × Stream A flow = $0.35 \times 420 = 147$ L/min. The ratio station immediately multiplies the measured wild stream flow by the configured ratio, producing the new

controlled stream setpoint — providing feedforward-like response to wild stream changes without waiting for a composition error to develop.

45. D — $C_v = Q \times \sqrt{SG/\Delta P} = 300 \times \sqrt{1.00/36} = 300 \times \sqrt{0.02778} = 300 \times 0.1667 = 50.0$. A valve with rated $C_v \geq 50$ must be selected from the next larger standard size to ensure the required flow capacity falls within the recommended 20–80% travel range.

46. B — Valve gain (sensitivity) describes how the flow-versus-travel curve's slope changes with valve position. Equal percentage trim has exponentially increasing gain with travel — small flow changes at low travel, large flow changes at high travel. Linear trim has constant gain throughout travel. Understanding valve gain is essential for predicting installed flow characteristics and loop stability.

47. A — Autotransformer at 65% voltage tap applies 65% of line voltage to the motor. Starting torque varies with voltage squared: $(0.65)^2 = 0.4225 \approx 42\%$ of full-voltage starting torque. The supply line current is also reduced by the square of the voltage ratio through the transformer step-down effect.

48. C — Conventional spring-loaded PRVs are sensitive to back pressure because back pressure acts on the disc outlet in the same direction as the spring closing force. With 30 psig constant superimposed back pressure, the effective opening pressure becomes set pressure + back pressure = 200 + 30 = 230 psig. This back pressure effect makes conventional valves unsuitable for installations with significant superimposed back pressure.

49. D — For equal percentage trim: C_v at 25% travel = $C_{v,min} \times \text{Rangeability}^{0.25} = (80/40) \times 40^{0.25} = 2.0 \times 2.515 = 5.03 \approx 5.00$. The exponential equal percentage relationship means Cv at 25% travel is only about 6% of the maximum Cv — illustrating why equal percentage valves provide fine control at low flows.

50. B — A spring-to-close pneumatic diaphragm actuator (air-to-open) holds the valve open against a compressed spring using instrument air pressure. On loss of air, the compressed spring drives the valve closed without requiring any electrical power, backup system, or control signal. This is the standard inherently fail-safe actuator configuration for fail-closed applications.

51. A — Reverse-buckling rupture discs dome toward the low-pressure side, placing the disc in compression under operating pressure. Compression loading is fatigue-resistant, allowing stable operation up to 90% of rated burst pressure without progressive fatigue cracking. At 88% operating ratio, only reverse-buckling discs reliably survive the service life without premature failure.

52. C — At the star-to-delta transition, the motor windings disconnect from star and reconnect to delta, applying full line voltage to each winding. At 85% of synchronous speed, significant back-EMF exists but motor impedance is lower in delta — a current transient occurs as the motor adjusts to the new configuration and completes acceleration to rated speed.

53. D — Travel is 2% at 4 mA (should be 0%), 50% at 12 mA (correct midpoint), and 98% at 20 mA (should be 100%). Zero is 2% high (shifted up), and span covers only 96% of required travel (98 − 2 = 96% actual vs. 100% required). Both zero and span adjustments are needed to correct this combined error.

54. B — Power varies with the cube of speed: $P_{new} = 45 \times (0.80)^3 = 45 \times 0.512 = 23.0$ kW ≈ 23 kW. The affinity law's cubic relationship makes speed reduction dramatically effective for energy savings — reducing speed by 20% cuts power consumption by nearly 49%.

55. A — Type 304 stainless steel maintains adequate ductility and toughness at cryogenic temperatures (−196°C) due to its austenitic microstructure, which does not undergo the ductile-to-brittle transition that affects carbon and low-alloy steels below approximately −46°C. Liquid oxygen compatibility also requires careful cleaning — austenitic SS is compatible with oxygen service when properly cleaned.

56. D — Chlorine service is highly corrosive to most materials. Graphite packing provides superior chemical resistance to chlorine compared to PTFE and is compatible with elevated temperature service at 60°C. Live loading with Belleville springs maintains consistent compression as the packing wears, preventing fugitive emissions from developing between maintenance intervals.

57. B — Equal percentage inherent characteristic produces increasing valve gain as travel increases. In a system where available ΔP decreases as flow increases, the falling pressure offsets the rising inherent gain — these two opposing effects combine to produce an approximately linear installed flow-versus-travel relationship, which is why equal percentage trim is the standard for most process throttling applications.

58. B — Pilot-operated PRV chattering occurs when inlet piping pressure drop during relief flow reduces the inlet pressure at the pilot sensing point below the closing threshold before the overpressure condition is relieved. The pilot closes, pressure rebuilds, the pilot reopens, and the cycle repeats rapidly. API 520 limits inlet pressure drop to 3% of set pressure specifically to prevent this mechanism.

59. A — For atmospheric storage tanks, thermal breathing — the daily cycle of vapor expansion during daytime heating and contraction during nighttime cooling — typically generates the largest continuous venting requirement under normal operating conditions. API 2000 (the applicable standard for atmospheric tanks) uses thermal breathing as the primary normal venting design basis.

60. C — In the de-energized (ESD) state, the 3-way solenoid must connect the actuator port to the atmosphere exhaust port, releasing the instrument air pressure that holds the process valve open. The spring in the spring-return actuator then drives the process valve to its fail-closed position. This de-energize-to-trip arrangement achieves the safe state on any loss of electrical power.

61. D — Tungsten carbide's extreme hardness (approximately 1,800 HV Vickers) dramatically outperforms 316 SS (approximately 200 HV) in abrasive erosion resistance. For slurry service

where silica or other hard particles impinge on the trim, the hardness ratio between the trim material and the abrasive particles is the dominant factor determining erosion rate and service life.

62. B — Wafer-style valves (butterfly, ball, check) install between pipe flanges using through-bolts that compress the wafer body between the flanges. The pipe flanges provide the pressure-boundary function — the wafer body provides the flow restriction and sealing. This design eliminates the need for end connections on the valve body itself, reducing weight and cost at large pipe sizes.

63. A — Total series resistance = 250 + 100 + 200 = 550 Ω. Voltage drops at 20 mA: 0.020 × 550 = 11.0 V. Transmitter terminal voltage = 24 − 11.0 = 13.0 VDC, which exceeds the 11 VDC minimum. The loop complies — the transmitter has 2.0 V of margin above its minimum operating voltage at maximum loop current.

64. C — At 12 Mbit/s, PROFIBUS DP maximum segment length is 100 meters. The device at 120 meters exceeds this limit. A repeater at approximately 80–100 meters regenerates the signal and begins a new 100-meter segment, reaching the 120-meter device within the new segment's distance limit.

65. D — IS compliance requires all four entity parameter checks: Voc (22) ≤ Ui (24) ✓, Isc (85) ≤ Ii (100) ✓, circuit capacitance (65 nF) ≤ Ca (90 nF) ✓, and circuit inductance (0.8 mH) ≤ La (2 mH) ✓. All four parameters satisfy their respective limits, confirming IS compliance. All four checks are mandatory — not optional — for a complete IS verification.

66. B — In HART multidrop, each device is fixed at 4 mA to prevent current summation that would make individual readings impossible. Total power supply current = 8 × 4 mA = 32 mA. The power supply must source the sum of all device currents simultaneously, and this 32 mA total must be within the supply's rated output capacity.

67. A — Single-end shield grounding prevents ground loop formation. With the shield grounded at both field and control room ends, any potential difference between the two ground connections drives current through the shield — generating a magnetic field that inductively couples noise into the signal conductors. Removing the field-end ground eliminates the loop while maintaining the shield's effectiveness.

68. D — WirelessHART uses time-synchronized channel hopping across 15 available 2.4 GHz channels. Each transmission occupies a specific channel in the time-slot schedule; if narrowband interference blocks that channel, the next scheduled transmission automatically uses a different channel. This frequency diversity statistically reduces the probability of consecutive transmission failures from any single interference source.

69. B — PROFIBUS DP operates at data rates up to 12 Mbit/s on RS-485 copper cable for high-speed discrete and process I/O. PROFIBUS PA operates at 31.25 kbit/s on a two-wire cable that simultaneously delivers instrument power and digital communication, specifically designed for process instrumentation in hazardous areas with intrinsic safety compatibility.

70. B — Shared credentials eliminate individual accountability — when five people use the same login, any action taken under that account cannot be attributed to a specific person. If an unauthorized configuration change, data breach, or security incident occurs, the audit trail shows only "vendor_support" with no way to identify which individual was responsible.

71. A — A data diode enforces hardware-level unidirectional communication: data can flow only from OT toward the IT DMZ — it is physically impossible for data or commands to flow in the reverse direction. This hardware enforcement (not software policy) is the strongest available control for preventing remote access attacks from reaching OT controllers through the historian connection.

72. D — A DCS workstation with automatic Windows Update creates an ongoing outbound internet connection from inside the OT network. This path bypasses all perimeter firewalls and DMZ architecture designed to control OT-internet connectivity. Attackers exploit Windows Update infrastructure or any outbound connection to establish malware communication channels into the OT environment.

73. C — 12-bit DAC resolves 100% travel into $2^{12} = 4{,}096$ steps (0.0244% per step). 16-bit DAC resolves into $2^{16} = 65{,}536$ steps (0.00153% per step). Degradation factor = 65,536/4,096 = 16 times coarser resolution with the 12-bit device. Each bit reduction halves the resolution — four fewer bits (16 → 12) degrades by $2^4 = 16$ times.

74. B — The I/P transducer converts 4–20 mA linearly to 3–15 psi. At 15.2 mA, the output position in the span = $(15.2 - 4)/16 = 70\%$, corresponding to $3 + 0.70 \times 12 = 11.4$ psi — the pneumatic signal delivered to the valve positioner.

75. A — The correct OT patch management sequence tests first in a staging environment that replicates production configuration, verifies no software conflicts exist, then schedules deployment during a planned maintenance window with a tested rollback procedure. This sequence protects against patches that cause unexpected behavior in the specific OT software environment while still addressing the security vulnerability.

76. D — Mitigated frequency = $0.5 \times 0.1 \times 0.05 = 2.5\times10^{-3}$/year. Required SIF PFD = $5\times10^{-4}/2.5\times10^{-3} = 0.20$. Since 0.20 exceeds the SIL 1 maximum PFD of 0.1, the required risk reduction factor is less than 10 — below SIL 1 threshold. The existing IPLs nearly meet the risk tolerance criterion; a simpler protective measure may suffice rather than a full SIL-rated SIF.

77. C — $PFD_{avg} = \lambda_{DU} \times TI/2 = 8\times10^{-7} \times 4{,}380/2 = 8\times10^{-7} \times 2{,}190 = 1.752\times10^{-3} \approx 1.75\times10^{-3}$. This falls within the SIL 2 range (0.001 to 0.01), confirming the six-month proof test interval achieves SIL 2 for this transmitter failure rate.

78. B — IEC 61511 requires the SIS response time to be less than the process safety time specified in the SRS. The replacement valve's 55-second stroke time exceeds the SRS maximum of 30 seconds, meaning the SIF cannot achieve the safe state within the required window. The modification must

be rejected or a faster valve selected — updating the SRS to accept slower response is not appropriate if the process safety time analysis has not changed.

79. A — IEC 61511 Clause 10 requires the Safety Requirements Specification to be completed before detailed SIS hardware and software design begins. The SRS documents what the SIS must do — its functional requirements and SIL targets — and serves as the specification against which the completed design is formally verified. Design before specification makes verification impossible.

80. D — Using $PFD\_2oo3 = (\lambda\_DU \times TI)^2$: $(4\times10^{-6} \times 5{,}400)^2 = (0.0216)^2 = 4.67\times10^{-4} \approx$ D. The squared relationship reflects the requirement for two simultaneous independent failures to defeat 2oo3 voting — each additional order of magnitude in λ_DU contributes two orders of magnitude to the independent failure PFD.

81. C — The fail-safe principle in IEC 61511 requires that detection of a dangerous failure causes the SIS to initiate the safe state — not merely alert operators. A detected dangerous failure in a module serving active SIFs means those SIFs can no longer be guaranteed to respond to demands, so transitioning to the safe state is the required protective response rather than continuing to rely on the degraded system.

82. B — In 2oo3 voting, a trip requires two of three sensors to vote for the unsafe condition. A single false high reading from Thermocouple B does not satisfy the 2oo3 trip requirement — no spurious trip occurs. However, the voting arrangement has effectively degraded to 1oo2 for the remaining sensors: if either A or C subsequently fails toward a trip condition, the 2oo3 requirement would be satisfied and the SIF would activate.

83. A — IEC 61511 Clause 9.5 requires independence between SIS and BPCS at the sensor, logic solver, and final element level. A single failure should not simultaneously compromise both the process control function and the safety function. Separate field devices, separate logic solvers, and separate final elements for each function ensures that BPCS failures do not defeat SIS protection.

84. D — A shutdown valve that travels only 95% cannot achieve the required fully closed position and therefore cannot perform its safety function as specified in the SRS. The failed test must be documented, the root cause investigated, the valve repaired to achieve full closure, and the complete SIF — including the final element — retested to confirm the entire cause-to-effect path performs within SRS requirements before the SIF can be returned to service.

85. C — IEC 61511 defines two performance metrics: PFD_avg for low-demand SIFs (demand rate $\leq$ 1/year) and PFH (probability of dangerous failure per hour) for high-demand or continuous SIFs (demand rate > 1/year). At 8 demands per year, this SIF operates in high-demand mode. For SIL 2 high-demand mode, PFH must be between 10^{-7} and 10^{-6} per hour.