Savi LoopIQ

Subscriber Practice Manual

Read the loop. Predict the response. Defend the tune.

26 controlled-variable types / 4 dynamic models / 7 tuning recipe families

15 guided labs / 22 assessment questions / explained answer key

Worked simulation trends / repeat-attempt worksheets / reasoning rubric

For technicians, operators, engineers and instructors developing better diagnostic judgment.

Lab: https://savi-loopiq-training-lab.savage-tech-9538.chatgpt.site

Use the private lab alongside this workbook. You can print the guided labs and worksheets, or keep the complete reference open while you work. No instrument or historian file is needed.

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Original lab-authored exercises use the owned LoopIQ curriculum and numerical rules. Known-model results are learning evidence; they are not field commissioning or professional certification.

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Print the lab pages and blank worksheets for hands-on practice. Keep the type, model and method reference pages nearby. The answer key follows the quiz so you can attempt the questions before checking.

1. Learn by predicting and explaining

A useful learning session produces a defensible explanation, not just a better-looking curve. Write your prediction before changing a control, keep the test conditions fixed, and use both PV and OP to explain what happened.

Who: Technicians inspect instrument and actuator behavior; operators define operating constraints; engineers classify dynamics and select suitable control methods. Instructors review evidence and the reasoning behind each decision.

What: Practice identifying the loop role, process model, controller action, applicable recipe, constraints and quality of test evidence.

When: Start with beginner labs L01-L03 and monitoring L12. Move to practitioner labs L04-L10 once you can explain feedback, offset and limits. Use advanced labs L11 and L13-L15 after that.

Where: In this offline synthetic lab, then in supervised engineering review using real instruments and an approved site process.

Why: Better judgment separates tuning problems from poor measurements, wrong action, insufficient authority, uninformative tests and unsuitable architecture.

A repeatable learning cycle

1. Read the role, model and scope. Refuse unsupported assumptions.

2. Predict a PV/OP change and explain the causal path.

3. Change one thing and run a matched test. Inspect step and load response.

4. Record numbers, accept or reject the candidate, and name a missing field check.

5. Complete the quiz, save a learning attempt and revisit the same test after study.

Suggested practice rhythm

Use one 20-30 minute lab per session. Revisit it after 2-3 days and again after 1-2 weeks. Mix an earlier lab with a new loop type. This is a suggested study pattern, not a required schedule or a promise of competence.

2. Read the trend as engineering evidence

Signal or metric	Meaning	Question to ask
SP / PV / OP	Target / measured response / controller output	What OP move caused this PV correction?
Kp / theta / tau	Gain / transport delay / stable lag	Does the source shape and unit convention support this model?
2% settling / recovery	After the SP or load event, the error stays within 2% of the step through the remaining window	Is the endpoint outside the band? Was the window long enough?
Overshoot	Peak excursion beyond the target in the direction of the step	Would that peak violate process limits?
IAE	Absolute error accumulated over the full test after the SP event	Are model, baseline, target, load, bounds and window identical?
Output travel	Sum of absolute OP changes during the test	Is faster correction bought with more actuator work?
Output limit	Clamps available OP; back-calculation limits windup	Is the target physically reachable with this authority?

What the colors and markers mean

Orange is as-found, teal is as-left, and dashed gray is the setpoint. The shaded band is +/-2% of the step. Event markers identify the step, earliest response after dead time and candidate settling when achieved. The lower plot shows controller OP. Replay or scrub time to connect action to response.

Do not confuse these claims

A known generating model is not a fitted model. A refused source remains refused even after an educational known-truth opt-in. A low IAE is not automatically a better operating decision. A chosen lambda or tau-c is not the measured settling time. A nominal single-loop simulation does not validate an entire control architecture.

3. Process models

Self-regulating / FOPDT

Who: Technicians and control engineers working with a stable local operating point.

What: One stable lag plus a transport delay.

When: A bounded bump settles to a new steady PV and one dominant lag describes the response.

Where: Flow, pressure, temperature and many composition loops.

Why: The plant naturally settles. Feedback corrects error; integral action removes the offset.

```
τ dPV/dt = -PV + Kp × OP(t - θ)
```

Trend: After θ, an open-loop step moves in the sign of Kp and reaches 63.2% of its final change in one τ. Larger response-time targets reduce Kc and usually reduce output movement.

Limits: This is a local linear model. It does not reproduce steep pH chemistry, valve friction or varying gain over a wide operating range.

Two stable lags / SOPDT

Who: Control engineers separating process, mixing and sensor lags.

What: Two cascaded stable lags plus dead time.

When: One lag cannot reproduce the S-shaped or slower-starting bump response.

Where: Thermal systems, mixing processes, analyzer probes and coupled sensor/process dynamics.

Why: The second lag adds phase delay. Model-aware recipes compensate it or deliberately absorb it into a more cautious equivalent model.

```
(τ₁s + 1)(τ₂s + 1) PV(s) = Kp e^(-θs) OP(s)
```

Trend: The initial response is more rounded than FOPDT. SIMC uses Td = τ_2 here; IMC uses a different PID recipe; Lambda reduces the second lag to extra delay and produces PI.

Limits: Two stable lags do not represent oscillatory structural modes, inverse response or full multivariable interaction.

Process models / continued

Integrating / IPDT

Who: Engineers managing inventory, accumulation and flow imbalance.

What: Output changes the PV slope; there is no natural steady-state restoring force.

When: A constant input imbalance produces a continuing ramp instead of a new plateau.

Where: Freely accumulating tanks, interface inventory and mass drawdown.

Why: Kp is a rate gain. PI must stop the imbalance and restore the inventory; stable-process formulas would use the wrong units and dynamics.

```
dPV/dt = Kp × OP(t - θ)
```

Trend: A sustained open-loop bump ramps. In closed loop, OP must return toward zero after moving the inventory; a sustained OP means the PV keeps moving.

Limits: Kp has units PV/(OP / second). The chosen reference time sets the display window and tuning starting point; it is not a physical lag.

Open-loop unstable / runaway

Who: Specialist control engineers studying unstable processes.

What: A positive pole amplifies deviations even after the initiating input stops.

When: PV grows exponentially rather than settling or ramping at a constant rate.

Where: Illustrative exothermic process behavior near an unstable operating point.

Why: Feedback first has to stabilize the unstable pole. The owned SIMC extension searches gains and verifies decay in a long model simulation.

```
τ dPV/dt = +PV + Kp × OP(t - θ)
```

Trend: An underpowered or wrong-sign controller permits growth. A viable candidate must show decaying oscillations and recovery; a short quiet window alone is insufficient.

Limits: The lab models one unstable pole, not reaction chemistry or protective systems. Only the owned verified SIMC extension and manual exploration are offered.

4. Tuning methods and why they work

SIMC / model-based

Who: Skogestad’s Simple/Skogestad IMC family; used by process-control engineers.

What: A model-based PI or PID starting point with a chosen closed-loop response time τc.

When: Known FOPDT, SOPDT or integrating dynamics; an owned verified extension is available for the unstable teaching model.

Where: Regulatory process loops with explicit gain, lag and delay estimates.

Why: Kc is inversely proportional to process gain and to τc + θ. That balances correction strength against the time before the process can respond.

Read the trend: Increase τc: lower Kc, usually gentler OP and slower recovery. For SOPDT, derivative compensates the second lag. For an unstable model, verify decay rather than trusting a nominal time constant.

Limits: A starting point on a known model. Saturation, noise, nonlinear gain and model error can change the outcome.

```
|Kc| = τ/[|Kp|(τc + θ)] = 6/[1.4(6 + 1)] = 0.61224. Ti = min(τ, 4(τc + θ)) = 6 s. Td = 0 s.
```

IMC / model-based

Who: The Rivera-Morari IMC PID family and integrating-process extensions, used by process-control engineers.

What: An internal-model-based PID approximation; λ specifies the desired response/robustness tradeoff.

When: Stable FOPDT or SOPDT models, or an integrating model with its matching recipe.

Where: Process loops where a credible model and moderate robustness target are available.

Why: The controller compensates the modeled plant while a response-time target avoids excessively aggressive inversion. Dead time appears explicitly in the gain and integral/derivative times.

Read the trend: A larger λ reduces Kc. Here FOPDT and SOPDT recipes include derivative; compare overshoot and OP movement as well as IAE.

Limits: The displayed gains are the exact LoopIQ IMC recipes. An internal plant-model block is not separately simulated; its PID approximation is.

```
Ti = τ + θ/2 = 6.5 s. |Kc| = Ti/[|Kp|(λ + θ/2)] = 6.5/[1.4(1.7 + 1/2)] = 2.1104. Td =
τθ/(2τ + θ) = 0.46154 s.
```

Tuning methods / continued

Lambda / response-time design

Who: Process-control practitioners using the Lambda/Dahlin family of response-time design.

What: Choose a desired response time λ, then calculate a model-based PI candidate.

When: A stable or integrating model is credible and a smooth response is more valuable than an aggressive oscillatory response.

Where: Inventory, thermal, flow and delay-limited process loops.

Why: λ deliberately limits feedback speed relative to lag and delay. Larger λ yields less proportional action; the integrating recipe accounts for accumulation rather than a plateau.

Read the trend: Increasing λ usually slows tracking and reduces OP demand. For SOPDT, the second lag is folded into equivalent dead time, so this recipe remains PI.

Limits: λ is a design target, not a promised measured settling time. SIMC and Lambda can coincide for some FOPDT settings but differ for integrating and two-lag models.

```
Equivalent θ = 1 s. |Kc| = τ/[|Kp|(λ + equivalent θ)] = 6/[1.4(12 + 1)] = 0.32967. Ti = 6 s; Td = 0.
```

Cohen-Coon / reaction curve

Who: Cohen and Coon’s empirical reaction-curve method; used for historical comparison and suitable stable-process trials.

What: A PID recipe from a self-regulating FOPDT reaction curve.

When: A usable open-loop bump gives nonzero θ, a stable lag and a reliable gain.

Where: Isolated self-regulating process loops; compare carefully on delay-dominated systems.

Why: The ratio θ/τ modifies Kc, Ti and Td to account for the relative size of transport delay.

Read the trend: Often more aggressive than cautious model-based settings. Watch oscillation, overshoot, saturation and output travel; do not assume a faster first move is a better tune.

Limits: Not offered for integrators, unstable or two-lag models. It uses the known FOPDT truth here, not evidence from an inadequate bump test.

```
α = θ/τ = 0.16667. |Kc| = [4/3 + α/4]/(|Kp|α) = 5.8929. Ti = θ(32 + 6α)/(13 + 8α) = 2.3023 s. Td = 4θ/(11 + 2α) = 0.35294 s.
```

Tuning methods / continued

Ziegler-Nichols / open-loop

Who: Ziegler and Nichols' reaction-curve method, used as a classic benchmark.

What: P, PI or PID gains from the stable open-loop FOPDT step response.

When: The response provides a credible gain, lag and positive dead time.

Where: Historical tuning comparisons on stable process loops.

Why: Kc scales with τ/(|Kp|θ), while integral and derivative time are tied to θ. This yields a strong response as delay becomes small.

Read the trend: The classic intent is an aggressive, approximately quarter-decay response under suitable conditions; this lab does not guarantee that damping. Compare the actual decaying peaks and OP demand.

Limits: Can be aggressive and noise-sensitive. Nonzero θ is required. P alone normally leaves offset; Ti = 0 in the lab means integral is off.

```
PID: |Kc| = 1.2τ/(|Kp|θ) = 5.1429; Ti = 2θ = 2 s; Td = 0.5θ = 0.5 s. τ = 6, |Kp| = 1.4, θ = 1.
```

Ziegler-Nichols / closed-loop / relay

Who: Ziegler and Nichols' ultimate-gain method, using an Åström-Hägglund-style virtual relay experiment for evidence here.

What: P, PI or PID gains calculated from ultimate gain Ku and oscillation period Pu.

When: The virtual relay establishes a repeatable limit cycle on an eligible stable model.

Where: Offline study of classic ultimate-gain tuning; this lab has no live relay operation.

Why: Ku estimates the gain at the oscillation boundary. The recipe deliberately uses a fraction of Ku and times proportional to Pu.

Read the trend: Compare its response against Tyreus-Luyben using the same Ku/Pu. ZN often moves faster and rings more; output bounds can dominate both.

Limits: Relay Ku/Pu are describing-function estimates, not exact manual ultimate-point measurements. The lab does not offer this evidence for non-FOPDT models.

```
Ku = 5.8621, Pu = 3.76 s. PID: |Kc| = 0.6Ku = 3.5172; Ti = Pu/2 = 1.88 s; Td = Pu/8 = 0.47 s.
```

Tuning methods / continued

Tyreus-Luyben / relay PID

Who: Tyreus and Luyben’s detuned ultimate-gain family; the owned LoopIQ relay implementation supplies this PID recipe.

What: A more cautious PID candidate from the same relay Ku and Pu.

When: A clean virtual relay cycle is available and oscillatory ZN tuning is undesirable.

Where: Offline process-loop comparisons using established oscillation evidence.

Why: Kc = Ku/3.2 is smaller and Ti = 2.2Pu is longer than classic ZN PID. Weaker proportional and integral action trades speed for damping.

Read the trend: Compare peak decay and recovery with ZN. Expect less ringing in many cases, but measure IAE, actuator movement and settlement rather than accepting that expectation as proof.

Limits: This lab offers the exact owned PID formula, Td = Pu/6.3. A converged relay does not validate every real process, constraint or operating point.

```
Ku = 5.8621, Pu = 3.76 s. |Kc| = Ku/3.2 = 1.8319; Ti = 2.2Pu = 8.272 s; Td = Pu/6.3 = 0.59683 s.
```

Manual P / PI / PID experiment

Who: Students, technicians and engineers developing feedback intuition.

What: Set Kc, Ti and Td directly; Ti = 0 turns off integral, Td = 0 turns off derivative.

When: Exploring one change at a time or testing a model-derived candidate.

Where: Any tuning-eligible teaching fixture, with its model limits visible.

Why: P responds to current error; I removes sustained error; filtered D responds to PV movement. Action must agree with process gain for negative feedback.

Read the trend: Higher |Kc| often moves faster with more ringing. Smaller Ti strengthens integral and may cause oscillation. D can help lag compensation but increases sensitivity to fast PV changes.

Limits: No automatic optimality or field recommendation is implied. Record the tradeoff and test disturbance recovery.

5. Loop library / characteristics and uses

Flow / Process

Who: Instrument technicians, operators and process/control engineers.

What: Regulate material throughput using a valve or pump.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Water, steam, gas and liquid feed systems.

Why: Fast responses make sampling, valve condition and noise important.

Practice model: {"kind": "FOPDT", "kp": 1.4, "tau": 6, "theta": 1}

Scope: Known synthetic FOPDT ground truth used to compare the production identifier against the generating process.

Case: intro-flow-clean-fast

Pressure / Process

Who: Instrument technicians, operators and process/control engineers.

What: Balance inflow and outflow to maintain vessel or header pressure.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Gas headers, vessels and compressors.

Why: Gas inventory and compressibility determine lag; constraints can dominate.

Practice model: {"kind": "FOPDT", "kp": 0.9, "tau": 14, "theta": 3}

Scope: Known synthetic FOPDT ground truth used to compare the production identifier against the generating process.

Case: intro-pressure-balanced

Loop library / continued

Temperature / Process

Who: Instrument technicians, operators and process/control engineers.

What: Balance heating or cooling against thermal demand.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Heat exchangers, furnaces and jacketed vessels.

Why: Thermal lag and transport delay limit how aggressively feedback can act.

Practice model: {"kind": "FOPDT", "kp": 1.7, "tau": 36, "theta": 6}

Scope: Known synthetic FOPDT ground truth used to compare the production identifier against the generating process.

Case: intro-temperature-basic

Level / Process

Who: Instrument technicians, operators and process/control engineers.

What: Balance inventory by changing an inlet or outlet flow.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Tanks, drums and surge vessels.

Why: A freely accumulating tank integrates; a self-regulating vessel can settle.

Practice model: {"kind": "IPDT", "kp": 0.04, "theta": 3}

Scope: Reproducible local linear teaching model with normalized deviation units; it does not represent a calibrated instrument or every physical effect.

Case: specialty-level

Loop library / continued

Composition / sample analyzer / Process

Who: Instrument technicians, operators and process/control engineers.

What: Regulate composition from a transported or sampled measurement.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Blend systems, chemical processes and sample analyzers.

Why: Sample-system delay can dominate the observed process response.

Practice model: {"kind": "FOPDT", "kp": 1, "tau": 18, "theta": 7}

Scope: Known synthetic FOPDT ground truth used to compare the production identifier against the generating process.

Case: intro-analyzer-basic

Differential pressure / Process

Who: Instrument technicians, operators and process/control engineers.

What: Control a pressure difference across an equipment or airflow path.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Filter banks, HVAC rooms and draft control.

Why: Flow inference and changing resistance affect gain; raw DP and square-root flow are different variables.

Practice model: {"kind": "FOPDT", "kp": 1.2, "tau": 12, "theta": 2}

Scope: Reproducible local linear teaching model with normalized deviation units; it does not represent a calibrated instrument or every physical effect.

Case: specialty-differential-pressure

Loop library / continued

pH / Analytical

Who: Instrument technicians, operators and process/control engineers.

What: Regulate acidity or alkalinity by dosing reagent.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Neutralization tanks and water-treatment systems.

Why: The titration slope changes sharply near equivalence. A tune valid at one point can be poor at another.

Practice model: {"kind": "FOPDT", "kp": 2.5, "tau": 45, "theta": 12}

Scope: Local linear titration slope only. Chemistry and changing reagent gain are not simulated.

Case: specialty-ph

Conductivity / Analytical

Who: Instrument technicians, operators and process/control engineers.

What: Unlike pH, conductivity is usually linear rather than logarithmic and often tunes more like a conventional flow or pressure loop.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Boiler blowdown, Cooling-tower bleed, RO reject monitoring, Water treatment

Why: Generally self-regulating and fairly linear over the normal range; response is fast in-line and slower when sample transport is present.

Practice model: {"kind": "FOPDT", "kp": 1.2, "tau": 20, "theta": 3}

Scope: Reproducible local linear teaching model with normalized deviation units; it does not represent a calibrated instrument or every physical effect.

Case: specialty-analytical-conductivity

Loop library / continued

Dissolved Oxygen / Analytical

Who: Instrument technicians, operators and process/control engineers.

What: Biological coupling and drifting effective gain make DO materially different from conventional chemical composition loops.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Activated sludge, Aerobic fermentation, Bioreactor control

Why: Long probe and mixing lag, possible integrating-like behavior, nonlinear oxygen transfer, and process gain that changes with temperature, biomass, and fouling.

Practice model: {"kind": "SOPDT", "kp": 0.8, "tau1": 100, "tau2": 35, "theta": 18}

Scope: Two-lag local model; biology, fouling and oxygen-transfer nonlinearities are not simulated.

Case: specialty-analytical-dissolved-oxygen

ORP / Analytical

Who: Instrument technicians, operators and process/control engineers.

What: Breakpoint behavior is a different tuning problem from the smoother, though steep, titration behavior of pH.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Disinfection dosing, Cyanide destruction, Dechlorination

Why: Mixing and sample dead time with noisy, fouling-prone measurement and possible breakpoint or threshold nonlinearities.

Practice model: {"kind": "FOPDT", "kp": 1.6, "tau": 60, "theta": 18}

Scope: Local model only; breakpoint chemistry and probe noise are not simulated.

Case: specialty-analytical-orp

Loop library / continued

Turbidity / Analytical

Who: Instrument technicians, operators and process/control engineers.

What: The process response to dosing is often measured in minutes or tens of minutes, requiring conservative tuning and patience during tests.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Clarifier effluent, Filter effluent, Coagulant dosing

Why: Slow self-regulating response with substantial settling and filtration dead time.

Practice model: {"kind": "FOPDT", "kp": -0.8, "tau": 180, "theta": 60}

Scope: Reproducible local linear teaching model with normalized deviation units; it does not represent a calibrated instrument or every physical effect.

Case: specialty-analytical-turbidity

Density / Specific Gravity / Analytical

Who: Instrument technicians, operators and process/control engineers.

What: The measurement is frequently secondary to a blend-ratio controller rather than the only primary loop.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Fuel blending, Concentration inference, Custody-transfer blending

Why: Typically fast and self-regulating, often serving as an inferential composition measurement inside a cascade or ratio strategy.

Practice model: {"kind": "FOPDT", "kp": 0.7, "tau": 25, "theta": 5}

Scope: Reproducible local linear teaching model with normalized deviation units; it does not represent a calibrated instrument or every physical effect.

Case: specialty-analytical-density

Loop library / continued

Viscosity / Analytical

Who: Instrument technicians, operators and process/control engineers.

What: The dominant interaction with temperature makes cascade and multivariable design central to successful control.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Polymer processing, Coatings, Food and beverage

Why: Sample lag and strong temperature coupling; direct viscosity control is often achieved indirectly through temperature or shear rate.

Practice model: {"kind": "SOPDT", "kp": -1.1, "tau1": 60, "tau2": 15, "theta": 8}

Scope: Reproducible local linear teaching model with normalized deviation units; it does not represent a calibrated instrument or every physical effect.

Case: specialty-analytical-viscosity

Gas Analyzer - O2 Trim / Analytical

Who: Instrument technicians, operators and process/control engineers.

What: This is a genuine continuous-control application and must be separated from gas points used only for alarms and trips.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Boiler combustion trim, Furnace efficiency control, Emissions optimization

Why: Self-regulating with analyzer and flue-gas transport delay; commonly cascaded from a boiler or combustion master.

Practice model: {"kind": "FOPDT", "kp": 0.9, "tau": 35, "theta": 15}

Scope: Reproducible local linear teaching model with normalized deviation units; it does not represent a calibrated instrument or every physical effect.

Case: specialty-analytical-o2-trim

Loop library / continued

Gas Analyzer - Safety Monitoring / Analytical

Who: Instrument technicians, reliability or safety specialists responsible for detection and protection.

What: Learners must not treat a toxic or combustible gas trip as a PID tuning exercise.

When: When detecting a condition and reviewing indication, alarms or protection; no PID candidate is offered.

Where: CO monitoring, H2S monitoring, NOx monitoring, %LEL detection

Why: Primarily alarm, interlock, and trip behavior rather than closed-loop setpoint tracking.

Practice model: Monitoring / no regulatory PID

Scope: Owned synthetic indication in normalized 0-100 units. Threshold and dwell settings are educational; this is not an approved alarm or trip basis.

Case: specialty-analytical-gas-safety-monitoring

Weight / Mass / Mechanical

Who: Instrument technicians, operators and process/control engineers.

What: The controlled rate is the derivative of the measured signal, making this different from ordinary level control.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Loss-in-weight feeders, Batching scales, Load-cell inventory

Why: Loss-in-weight systems are integrating because feed rate is derived from the rate of change of measured weight.

Practice model: {"kind": "IPDT", "kp": -0.05, "theta": 2}

Scope: This exercise controls inventory/mass drawdown, not the differentiated loss-in-weight feed-rate estimator.

Case: specialty-mechanical-weight-mass

Loop library / continued

Web / Strip Tension / Mechanical

Who: Instrument technicians, operators and process/control engineers.

What: Interaction and actuator choice dominate the problem more than a single isolated process lag.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Paper machines, Film lines, Textile lines, Wire and cable drawing

Why: Fast, tightly coupled multi-span behavior in which torque or dancer position affects neighboring spans.

Practice model: {"kind": "SOPDT", "kp": 1.3, "tau1": 2, "tau2": 0.5, "theta": 0.15}

Scope: An isolated two-lag span approximation. Neighboring-span interaction and elasticity are not simulated.

Case: specialty-mechanical-web-tension

Torque / Mechanical

Who: Instrument technicians, operators and process/control engineers.

What: Torque frequently belongs in override or selector logic protecting equipment.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Extruders, Mixers, Conveyors

Why: Fast electrical and mechanical response; often used as an overload constraint rather than the primary production setpoint.

Practice model: {"kind": "FOPDT", "kp": 1.4, "tau": 1, "theta": 0.2}

Scope: Local torque response only. Override authority and motor protection are discussed separately.

Case: specialty-mechanical-torque

Loop library / continued

Vibration - Monitoring / Mechanical

Who: Instrument technicians, reliability or safety specialists responsible for detection and protection.

What: Most vibration points should be diagnosed and alarmed, not tuned as process-control loops.

When: When detecting a condition and reviewing indication, alarms or protection; no PID candidate is offered.

Where: Rotating-equipment condition monitoring, Alarm and trip protection

Why: Protective detection and spectral monitoring rather than normal setpoint control.

Practice model: Monitoring / no regulatory PID

Scope: Owned synthetic indication in normalized 0-100 units. Threshold and dwell settings are educational; this is not an approved alarm or trip basis.

Case: specialty-mechanical-vibration-monitoring

Vibration - Active Magnetic Bearing Control / Mechanical

Who: Rotor-dynamics and bearing-control specialists.

What: This is the genuine control-loop exception within the vibration family.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Active magnetic bearings, High-speed rotor stabilization

Why: Very fast continuous feedback with structural modes and tight stability margins.

Practice model: {"kind": "SOPDT", "kp": 1, "tau1": 0.2, "tau2": 0.04, "theta": 0.01}

Scope: A stable two-lag teaching surrogate. Rotor modes, unstable suspension and real bearing controllers are not represented.

Case: specialty-mechanical-active-bearing-control

Loop library / continued

Valve / Actuator Position / Mechanical

Who: Instrument technicians, operators and process/control engineers.

What: Friction and mechanical nonlinearity matter more than ordinary process dead time.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Valve positioners, Actuator position feedback

Why: Fast and self-regulating, with hysteresis, deadband, stiction, and backlash dominating performance.

Practice model: {"kind": "FOPDT", "kp": 1, "tau": 2, "theta": 0.3}

Scope: Nominal local position response only. Friction, stiction and backlash require diagnosis; they are not generated by this model.

Case: specialty-mechanical-valve-position

Interface Level / Mechanical

Who: Instrument technicians, operators and process/control engineers.

What: Measurement uncertainty and two-fluid movement make it meaningfully harder than standard level control.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Oil-water separators, Solvent-aqueous separation

Why: A moving boundary between two fluids, with noisier and less certain density- or capacitance-based measurement than ordinary surface level.

Practice model: {"kind": "IPDT", "kp": -0.03, "theta": 4}

Scope: Reproducible local linear teaching model with normalized deviation units; it does not represent a calibrated instrument or every physical effect.

Case: specialty-mechanical-interface-level

Loop library / continued

Power (kW) / Electrical

Who: Drive and electrical-control engineers, with instrument/control specialists.

What: Operating-point dependence often requires gain scheduling rather than one fixed tuning.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Electric arc furnaces, Resistance heating

Why: Fast electrical response with nonlinear and time-varying gain, especially as arc-furnace conditions evolve.

Practice model: {"kind": "FOPDT", "kp": 1.5, "tau": 2, "theta": 0.2}

Scope: Local stable operating point only; arc variation and gain scheduling are discussed, not simulated.

Case: specialty-electrical-power

Current / Voltage Regulation / Electrical

Who: Drive and electrical-control engineers, with instrument/control specialists.

What: Sampling, execution rate, and cascade bandwidth separation are critical.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: SCR firing control, Motor current limiting

Why: Sub-second inner-loop behavior, commonly nested inside speed or power loops.

Practice model: {"kind": "FOPDT", "kp": 1.2, "tau": 0.4, "theta": 0.06}

Scope: A normalized inner-loop surrogate, not switching electronics or a drive implementation.

Case: specialty-electrical-current-voltage

Loop library / continued

Frequency / Electrical

Who: Drive and electrical-control engineers, with instrument/control specialists.

What: Grid synchronization adds phase and timing requirements absent from ordinary PID loops.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: VFD output frequency, Grid-tie synchronization

Why: Fast and precise; synchronization also requires phase matching rather than simple scalar setpoint tracking.

Practice model: {"kind": "FOPDT", "kp": 1, "tau": 1.5, "theta": 0.15}

Scope: Scalar frequency tracking only; phase synchronization and grid connection are outside the model.

Case: specialty-electrical-frequency

Humidity / Moisture Content / Environmental

Who: Instrument technicians, operators and process/control engineers.

What: Coupled thermal and moisture behavior often requires decoupling or coordinated control.

When: After confirming the measurement role, actuator direction, operating point and a usable dynamic model.

Where: Dryers, HVAC humidity control, Kilns

Why: Significant dead time and strong interaction with temperature; dehumidification frequently changes both variables.

Practice model: {"kind": "SOPDT", "kp": 0.6, "tau1": 90, "tau2": 20, "theta": 12}

Scope: Two local lags. Temperature interaction and cross-coupling are discussed, not simulated.

Case: specialty-environmental-humidity-moisture

L01. Read the loop before touching the tune

Level / goal: Beginner / Identify the signal roles, gain direction, model and evidence.

Select this case: intro-flow-clean-fast

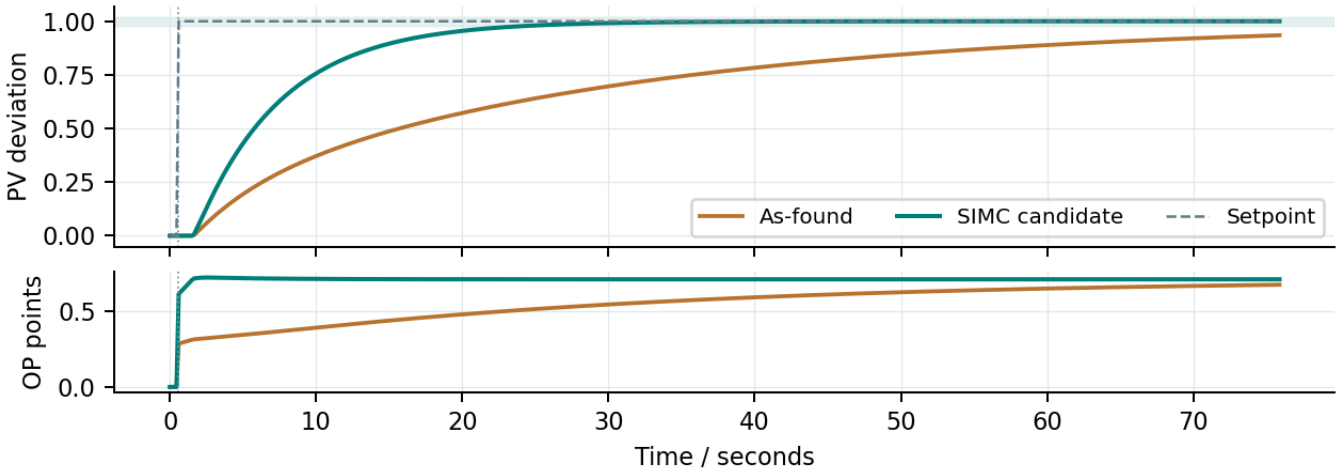
Do the experiment

1. Read Who/What/When/Where/Why and the model scope.

2. Predict the PV direction after a positive OP bump.

3. Replay the source bump and the closed-loop comparison.

4. Explain why source evidence and generating truth are different.



Worked example from the exact owned kernel: Flow 01 - clean fast loop; SIMC; setpoint; SP +1; OP +/-10; 12 reference times.

Settling (s): Not settled -> 24.25; overshoot (%): 0.0 -> 0.0; IAE: 23.53 -> 7.00; OP travel: 0.68 -> 0.74.

Think and explain

1. What is measured and what is manipulated?

2. Why does PV wait before responding?

3. What might a field instrument change that this model does not show?

Evidence to record: Record Kp, delay, lag, evidence verdict and the sign needed for negative feedback.

L02. Diagnose controller action

Level / goal: Beginner / Follow the feedback path on a negative-gain process.

Select this case: advanced-analyzer-reverse

Do the experiment

1. Predict the sign of Kc using error = SP - PV.

2. Record the correct-sign response.

3. Change only the sign of Kc; observe OP and PV.

4. Restore the sign and explain the diagnosis.

Think and explain

1. Does more output always mean more PV?

2. Would adding integral repair wrong action?

3. Which field valve/action convention must be checked?

Evidence to record: Explain Kc times Kp, final error and actuator limit.

L03. Separate P, I and D

Level / goal: Beginner / Explain offset removal without confusing terms with recipes.

Select this case: intro-flow-clean-fast

Do the experiment

1. Keep moderate Kc and set Ti = 0, Td = 0.

2. Observe sustained error after a step.

3. Enable integral with Ti = 6 s; change nothing else.

4. Halve Ti, then restore it; compare ringing and OP.

Think and explain

1. Why can P-only leave offset?

2. Why does smaller Ti mean stronger integral?

3. Why is derivative on PV used?

Evidence to record: Compare matched tests: final error, IAE, overshoot and output travel.

L04. Choose response targets with SIMC and Lambda

Level / goal: Practitioner / Trade speed against correction strength.

Select this case: intro-flow-clean-fast

Do the experiment

1. Apply conservative, balanced and aggressive SIMC targets.

2. Predict OP movement and recovery before each run.

3. Apply Lambda at 6 s and 12 s with the same test.

4. Explain when equal-looking recipes produce equal gains.

Think and explain

1. Is lambda measured settling time?

2. When can a slower target be better?

3. When do SIMC and Lambda coincide on FOPDT?

Evidence to record: Record the target, resulting gains and three response metrics for matched tests.

L05. Tune a real integrator

Level / goal: Practitioner / Distinguish inventory rate gain from a stable lag.

Select this case: specialty-level

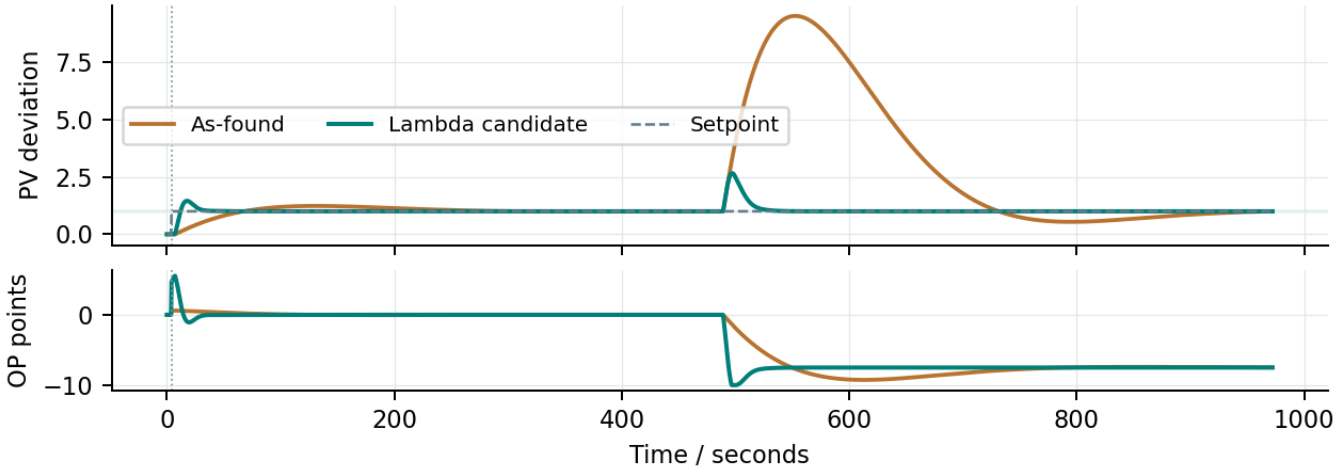
Do the experiment

1. Inspect the source ramp and IPDT rate-gain units.

2. Apply integrating SIMC and Lambda.

3. Add a load and extend to 24 reference times.

4. Observe the OP balancing action after moving inventory.



Worked example from the exact owned kernel: freely accumulating tank; Lambda; disturbance; SP +1; OP +/-10; 24 reference times.

Settling (s): 470.25 -> 51.15; overshoot (%): 851.3 -> 166.1; IAE: 1206.27 -> 38.35; OP travel: 12.49 -> 25.86.

Think and explain

1. Why is reference time not physical tau?

2. What if a small imbalance persists?

3. Why is a stable reaction-curve recipe unavailable?

Evidence to record: Explain PV slope per OP point and compare post-load recovery.

L06. Recognize two lags and derivative

Level / goal: Practitioner / Compare two-lag-aware recipes.

Select this case: specialty-analytical-viscosity

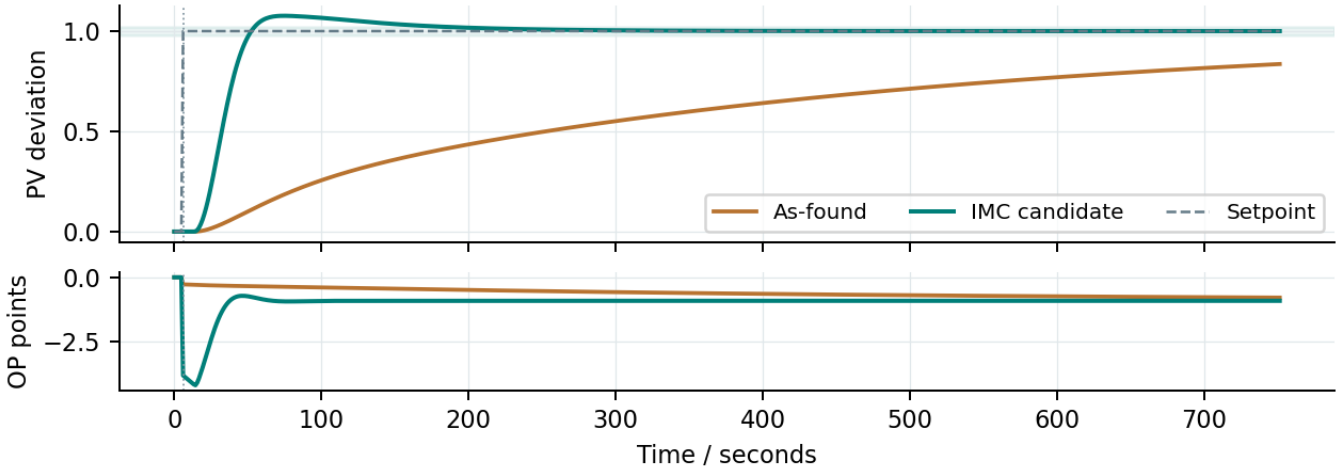
Do the experiment

1. Inspect the rounded SOPDT bump.

2. Apply SIMC and note Td = tau2.

3. Apply IMC and compare different Ti and Td.

4. Apply Lambda using equivalent extra delay and PI.



Worked example from the exact owned kernel: Viscosity - representative local process; IMC; setpoint; SP +1; OP +/-10; 12 reference times.

Settling (s): Not settled -> 182.40; overshoot (%): 0.0 -> 7.6; IAE: 326.37 -> 34.95; OP travel: 0.79 -> 7.89.

Think and explain

1. How does the second lag affect the transient?

2. Why do valid recipes differ?

3. What temperature interaction is absent?

Evidence to record: Document both lags, recipe rationale and actual PV/OP tradeoff.

L07. Compare classic reaction-curve methods

Level / goal: Practitioner / Evaluate ZN open-loop and Cohen-Coon against actual outcomes.

Select this case: intro-flow-clean-fast

Do the experiment

1. Keep baseline, step, bounds and window constant.

2. Apply ZN open-loop P, PI and PID.

3. Apply Cohen-Coon and calculate the method comparison.

4. Compare with SIMC; defend a candidate.

Think and explain

1. Why does small delay drive large gains?

2. Is lowest IAE always best?

3. Does a model trial prove the source is valid?

Evidence to record: Use method table and replay; include overshoot and actuator travel.

L08. Build evidence for relay-based tuning

Level / goal: Practitioner / Explain relay to cycle to Ku/Pu to recipe to verification.

Select this case: intro-flow-clean-fast

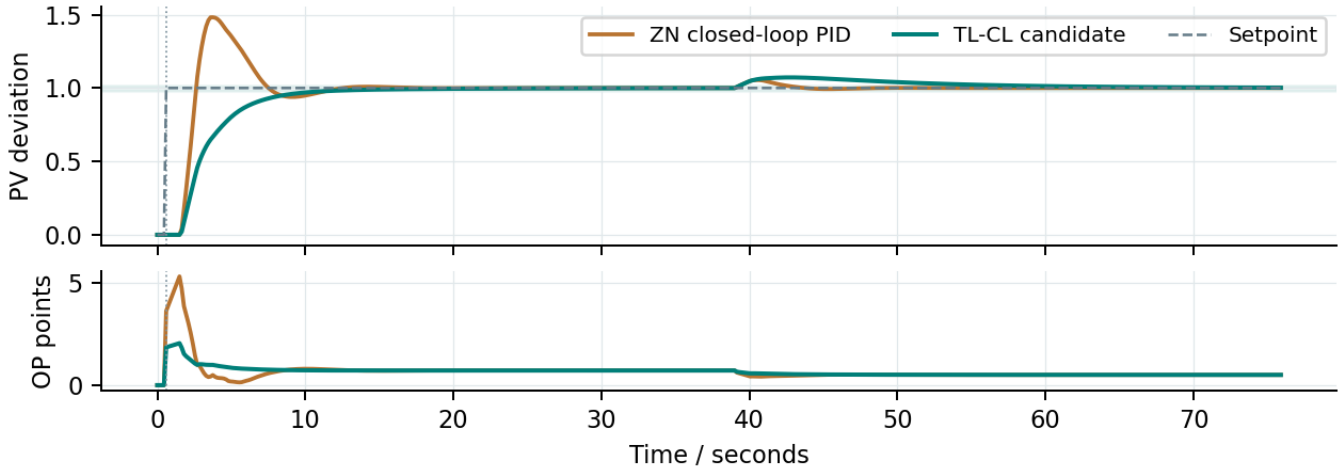
Do the experiment

1. Select ZN closed-loop and run a virtual relay.

2. Inspect half-amplitude, cycle count, Ku and Pu.

3. Apply ZN PID and Tyreus-Luyben using the same evidence.

4. Compare on a load step, then change amplitude and rerun.



Worked example from the exact owned kernel: Flow 01 - clean fast loop; TL-CL; disturbance; SP +1; OP +/-10; 12 reference times.

Settling (s): 4.30 -> 18.00; overshoot (%): 48.3 -> 7.2; IAE: 3.26 -> 4.17; OP travel: 12.22 -> 3.71.

Virtual relay evidence: h = 1 OP; a = 0.2172 PV; Ku = 5.8621; Pu = 3.760 s; cycles = 32.

Think and explain

1. Why is relay not itself a PID recipe?

2. Why is Ku an estimate?

3. Which recipe has lower gain and longer Ti?

Evidence to record: Record h, a, Ku, Pu and recovery/OP differences. Do not invent unsupported Ku/Pu.

L09. Distinguish poor tuning from poor evidence

Level / goal: Practitioner / Refuse an uninformative test even with known truth.

Select this case: intro-pressure-no-excitation

Do the experiment

1. Inspect the source verdict and constant OP.

2. Explain why known truth does not create excitation.

3. Explicitly opt into the known-truth educational trial.

4. Preserve the source refusal in your conclusion.

Think and explain

1. What missing observation blocks identification?

2. What new test is needed?

3. What does simulation establish and what does it not?

Evidence to record: Separate the source verdict from model-only observations.

L10. Recognize actuator authority

Level / goal: Practitioner / Avoid tuning to solve an unreachable target.

Select this case: intro-flow-clean-fast

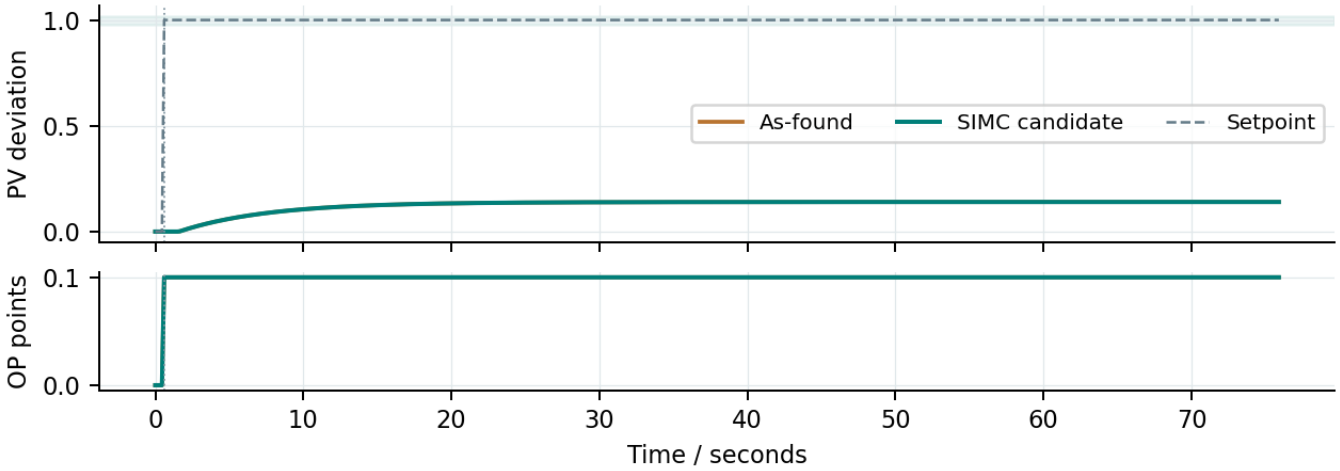
Do the experiment

1. Set step +1 and bound output to +/-0.1.

2. Compute the available steady PV change.

3. Increase Kc and reduce Ti; observe limit and final error.

4. Restore authority and compare recovery.



Worked example from the exact owned kernel: Flow 01 - clean fast loop; SIMC; setpoint; SP +1; OP +/-0.1; 12 reference times.

Settling (s): Not settled -> Not settled; overshoot (%): 0.0 -> 0.0; IAE: 65.87 -> 65.87; OP travel: 0.10 -> 0.10.

Think and explain

1. Why can tuning not reach the target?

2. Does anti-windup create capacity?

3. What field equipment condition could cause this?

Evidence to record: Use 1.4 times 0.1 = 0.14 PV units to explain the constrained trend.

L11. Test operating-point gain changes

Level / goal: Advanced / Explain why one local pH tune may not suit the whole range.

Select this case: specialty-ph

Do the experiment

1. Tune the high-slope pH fixture and record gains.

2. Select the low-slope fixture and reuse those gains manually.

3. Compare with a new model-based low-slope recommendation.

4. Explain gain scheduling and model limits.

Think and explain

1. How much do gains differ?

2. What happens to Kc times Kp with unchanged tuning?

3. Which chemical effects are absent?

Evidence to record: Compare Kp 2.5 and 0.4: ratio 6.25. Separate the local model result from wider chemistry.

L12. Treat monitoring as monitoring

Level / goal: Beginner / Understand detection delay without creating a PID loop.

Select this case: specialty-analytical-gas-safety-monitoring

Do the experiment

1. Inspect the role and normalized indication.

2. Compare threshold 50 at dwell 0 and 10 s.

3. Raise threshold; inspect crossing and detection.

4. Repeat on vibration monitoring and compare the role with active bearing control.

Think and explain

1. What qualifies a breach?

2. What delay does dwell add?

3. Why are these not approved field settings?

Evidence to record: Record first crossing and qualified detection; explain why PID is absent.

L13. Verify an unstable process over enough time

Level / goal: Advanced / Distinguish stabilization from optimal performance.

Select this case: specialty-temperature-runaway

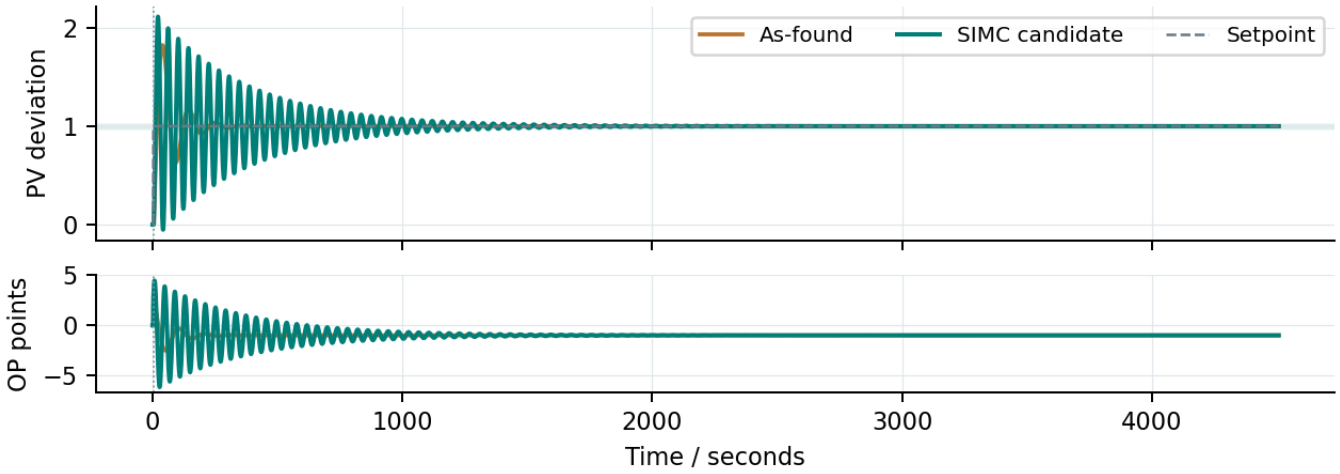
Do the experiment

1. Inspect the growing bump and positive-pole model.

2. Compare baseline and SIMC over 24 reference times.

3. Use the 150-reference-time study; hide as-found if needed.

4. Try weaker manual gain with a load step.



Worked example from the exact owned kernel: unstable process study; SIMC; setpoint; SP +1; OP +/-10; 150 reference times.

Settling (s): 262.90 -> 1463.90; overshoot (%): 82.4 -> 111.4; IAE: 57.93 -> 269.01; OP travel: 11.02 -> 198.91.

Think and explain

1. Why is Kc times Kp > 1 necessary but not sufficient?

2. Why can a verified candidate have worse IAE?

3. Why is a short quiet trend not a stability proof?

Evidence to record: Show peak decay, final error and output bounds. The owned search checks an unconstrained model; verify your bounded trial.

L14. Select architecture before the recipe

Level / goal: Advanced / Recognize what an isolated single-loop trend leaves out.

Select this case: specialty-environmental-humidity-moisture

Do the experiment

1. Read the moisture coupling and advanced lesson.

2. Compare cascade, feedforward and MIMO in the architecture guide.

3. Run the local SOPDT comparison.

4. List extra measurements and models needed for the real architecture.

Think and explain

1. What actuator changes both PVs?

2. What loop is tuned first in cascade?

3. Why does isolated response not validate decoupling?

Evidence to record: List absent interactions and the additional architecture evidence required.

L15. Defend a candidate and repeat the assessment

Level / goal: Advanced / Deliver a defensible model-only tuning review.

Select this case: specialty-analytical-dissolved-oxygen

Do the experiment

1. Write a prediction; inspect model, scope and evidence.

2. Compare two compatible methods on step and load.

3. Accept or reject a candidate using PV, OP and limits.

4. Answer the quiz, record an attempt and repeat the exact test later.

Think and explain

1. What claim is supported?

2. What could fail outside this model?

3. What improved in your reasoning beyond IAE?

Evidence to record: Keep baseline and scenario matched. Use the manual rubric for diagnostic progress.

6. Architecture changes the tuning job

The lab response isolates one regulatory model. These structure lessons explain what else must be modeled and verified; the full architectures below are not simulated by that trend.

Cascade / Two nested feedback loops

Where and when: Temperature master → flow slave; tune and verify the faster inner loop first, then tune the outer loop against the closed inner loop.

Why / tuning workflow: A good inner loop rejects local disturbances before the master sees them. A single-loop trend does not validate both loops.

Feedforward / Act on a measured disturbance

Where and when: Measured feed change → heat or reagent adjustment; identify both the manipulated-input and disturbance paths.

Why / tuning workflow: It anticipates the disturbance; feedback corrects remaining model error. Delay mismatch can make ideal compensation unrealizable.

Ratio / Keep two streams in proportion

Where and when: Blend, fuel/air or dosing applications; first tune the follower flow loop, then set the ratio and scaling.

Why / tuning workflow: The ratio generates the follower setpoint; it is not a replacement PID gain recipe.

Override / selectors / Give an active constraint control authority

Where and when: Torque, pressure or temperature limits; verify the selector, controller action and external-reset tracking.

Why / tuning workflow: The constraint loop temporarily takes control; unselected controllers need tracking to avoid windup.

Split range / One controller drives multiple actuators

Where and when: Heating/cooling or paired valves; verify gain sign, crossover, overlap and each actuator range.

Why / tuning workflow: Two manipulated paths make the effective gain piecewise; a single nominal tune may be inadequate.

MIMO / decoupling / Coordinate interacting variables

Where and when: Humidity/temperature or interacting blend loops; identify the gain matrix and choose pairing before PID tuning.

Why / tuning workflow: A change on one actuator affects multiple PVs. Decoupling reduces cross-effects, but uncertainty limits cancellation.

Architecture / continued

Gain scheduling / Change gains with operating conditions

Where and when: pH, power or nonlinear equipment; identify and validate models at several operating points.

Why / tuning workflow: Keeping similar Kc × process gain maintains more consistent response when plant gain changes.

Smith predictor / Use an internal model to compensate dead time

Where and when: Delay-dominated stable processes with a credible delay estimate.

Why / tuning workflow: An internal undelayed prediction speeds feedback decisions; model mismatch can remove the benefit or reduce robustness.

Batch / ramp-soak / Track a changing recipe

Where and when: Temperature ramp and hold stages; define ramp limits, transition rules and actuator limits.

Why / tuning workflow: The trajectory matters as much as controller tuning. Step-response metrics do not prove ramp tracking.

Valve-position control / Manage actuator headroom with a slow supervisor

Where and when: Trim a master setpoint to keep a downstream valve near a target opening; tune regulatory loops first.

Why / tuning workflow: A slower supervisory loop preserves downstream control authority; interacting time scales must be verified.

MPC / APC / Optimize constrained future trajectories

Where and when: Processes with important interactions and multiple constraints, using a validated prediction model.

Why / tuning workflow: Optimization coordinates future moves; conventional PID recipes alone do not define an MPC controller.

7. Assessment / think before checking

Answer without the key first. Write one sentence explaining each choice. Then review the reasoning in the key and return to the relevant lab if you missed the causal explanation.

1. Negative Kp, error = SP - PV: which Kc sign gives negative feedback?

A. Positive

B. Negative

C. Either

D. Zero is required

2. PV waits after an open-loop step, then approaches a plateau. Which model is a plausible first candidate?

A. Pure integrator

B. Runaway pole

C. Stable lag plus dead time

D. Monitoring only

3. Why can a second stable lag change the recommended recipe?

A. It removes delay

B. Action no longer matters

C. It adds phase delay and changes shape

D. It guarantees zero overshoot

4. A tank rises at constant rate under constant imbalance. What does model Kp describe?

A. Final PV per OP

B. PV rate per OP

C. Settling time

D. Integral time

5. An unstable model remains bounded for a brief test. What is the strongest next step?

A. Certify stability

B. Remove limits

C. Verify peak decay and recovery over a longer window

D. Use a stable reaction curve

Assessment / continued

6. For fixed FOPDT parameters, increasing SIMC tau-c does what to |Kc|?

A. Increases it

B. Reduces it

C. Reverses its sign

D. Removes output bounds

7. Applying IMC here produces what in the response simulation?

A. An online optimizer

B. A model-based PID approximation

C. A field guarantee

D. A live instrument test

8. A selected lambda of 10 s means what?

A. Exactly 10 s measured settling

B. A recipe response/robustness target

C. The measured dead time

D. Alarm dwell

9. Which model supports this lab’s Cohen-Coon recipe?

A. Monitoring

B. IPDT

C. FOPDT with positive delay

D. Any unstable model

10. Why can tiny estimated theta produce very large ZN open-loop gains?

A. Kc scales with tau/(|Kp|theta)

B. Integral removes bounds

C. Kp is ignored

D. Tiny theta requires negative Kc

Assessment / continued

11. What must exist before applying closed-loop ZN in this lab?

A. Only lambda

B. A usable model-specific relay cycle giving Ku/Pu

C. A pressure tag

D. A score from another process

12. With the same Ku/Pu, how does this TL PID compare with ZN PID?

A. More gain and shorter Ti

B. Less gain and longer Ti

C. No I or D

D. Opposite action

13. Halving a positive Ti with Kc fixed changes integral how?

A. Weaker

B. Twice as strong

C. Doubles Kp

D. Disables D

14. Kp = 1.4 and OP bound +/-0.1: can tuning hold a +1 PV-unit target?

A. Yes with small Ti

B. Yes with large Kc

C. No, available steady change is 0.14

D. Only negative Kc

15. Beyond lower IAE, what supports a defensible candidate choice?

A. Nothing else

B. Overshoot, OP travel, limits, evidence and a matched scenario

C. Only method name

D. Only first PV movement

Assessment / continued

16. Truth is known but source OP never changes. What is justified?

A. Accept field tuning

B. Refuse source identification; label model-only study as education

C. Treat truth as excitation

D. Increase D until a fit appears

17. At another pH point |Kp| is much smaller. For comparable Kc times Kp, |Kc| generally does what?

A. Decreases

B. Increases

C. Always reverses sign

D. Becomes irrelevant

18. A gas point is only for indication/protection. What is the correct activity?

A. Apply ZN

B. Tune like O2 trim

C. Study detection and keep PID unavailable

D. Disable indication

19. A breach lasts 4 s with 5 s continuous dwell. What happens?

A. Detect after 1 s

B. Detect immediately

C. The breach does not qualify

D. Kc changes

20. What does the normalized detection exercise establish?

A. Approved trip settings

B. Threshold/dwell effects only

C. SIS validation

D. Sensor calibration

Assessment / continued

21. In conventional cascade, which loop is tuned and verified first?

A. Outer/master

B. Both together

C. Faster inner/slave

D. Neither

22. Why use filtered derivative on PV rather than on error?

A. Remove all noise

B. Avoid derivative kick from SP steps

C. Make positive feedback

D. Disable I

8. Answer key / explain the mechanism

1. action / Answer B: Negative

With PV above SP, error is negative. Negative Kc raises OP; negative Kp then lowers PV. Kc times Kp is positive.

2. fopdt / Answer C: Stable lag plus dead time

Waiting suggests delay; a plateau suggests self-regulation. Check that additional lags or nonlinear effects are small.

3. sopdt / Answer C: It adds phase delay and changes shape

Two lags round the response and add phase delay. Recipes account for that differently; compare actual trends.

4. ipdt / Answer B: PV rate per OP

A sustained imbalance has no final plateau. Kp has units PV/(OP point times second), rather than stable-process gain units.

5. runaway / Answer C: Verify peak decay and recovery over a longer window

A bounded snapshot may hide slow growth or weak damping. Verify stabilizing design and adequate duration under the chosen limits.

6. simc / Answer B: Reduces it

|Kc| = tau/[|Kp|(tau-c + theta)]. A larger denominator weakens correction, usually trading speed for gentleness.

7. imc / Answer B: A model-based PID approximation

Owned IMC formulas return PID gains. This lab simulates that PID, not a separate internal-model runtime block.

8. lambda / Answer B: A recipe response/robustness target

Lambda is a design target. Actual 2% settling depends on model, gains, disturbance and limits.

Follow-up: explain why one incorrect option would lead to a bad diagnosis or an unsupported engineering claim. Correct guessing without explanation is not the target skill.

Answer key / continued

9. cc / Answer C: FOPDT with positive delay

The stable reaction-curve recipe uses theta/tau. Integrators and unstable models require different dynamics.

10. znol / Answer A: Kc scales with tau/(|Kp|theta)

Delay is in the denominator. Tiny or uncertain theta can yield aggressive gains; inspect PV, OP and sampling.

11. zncl / Answer B: A usable model-specific relay cycle giving Ku/Pu

The recipe needs Ku and Pu. This lab estimates them from a converged virtual cycle and refuses unsupported evidence.

12. tl / Answer B: Less gain and longer Ti

TL uses Ku/3.2 and 2.2Pu; ZN uses 0.6Ku and Pu/2. Expect gentler correction, then confirm the actual trend.

13. manual / Answer B: Twice as strong

Integral strength is Kc/Ti. Halving Ti doubles it; offset may disappear faster but ringing can increase.

14. authority / Answer C: No, available steady change is 0.14

1.4 times 0.1 = 0.14. PID and anti-windup cannot create actuator capacity.

15. metrics / Answer B: Overshoot, OP travel, limits, evidence and a matched scenario

Lower error can cost overshoot or actuator work. Use the same model, baseline, target, load, bounds and window.

16. evidence / Answer B: Refuse source identification; label model-only study as education

Knowing truth does not put missing excitation into a trend. Simulation and valid identification are separate claims.

Follow-up: explain why one incorrect option would lead to a bad diagnosis or an unsupported engineering claim. Correct guessing without explanation is not the target skill.

Answer key / continued

17. nonlinear / Answer B: Increases

Model-based gain is inversely related to |Kp|. Validate changed chemistry, delay and constraints rather than just rescaling.

18. monitor / Answer C: Study detection and keep PID unavailable

Protection/monitoring is not regulatory control. O2 trim is a different application with an actuator and process model.

19. dwell / Answer C: The breach does not qualify

The breach must persist through the full dwell. Falling below threshold resets this teaching timer.

20. protect / Answer B: Threshold/dwell effects only

Synthetic normalized data and simple logic cannot establish a field protection basis.

21. cascade / Answer C: Faster inner/slave

The master acts through the closed inner loop. Verify its dynamics and disturbance rejection first.

22. derivative / Answer B: Avoid derivative kick from SP steps

Differentiating a setpoint step creates a kick. D on PV avoids that kick; filtering limits high-frequency amplification but does not eliminate every noise problem.

Follow-up: explain why one incorrect option would lead to a bad diagnosis or an unsupported engineering claim. Correct guessing without explanation is not the target skill.

9. Reasoning rubric and performance over time

Use this rubric after L03, L08 and L15, then revisit the same exercise after further study. Rate the explanation using evidence, preferably with an instructor or peer. This is a practice rubric, not a field certification or an automatic judgment of professional competence.

Dimension	Evidence to review
Role and test quality	Identifies measured/manipulated signals and constraints; distinguishes regulatory control from monitoring; accepts, reviews or refuses source evidence correctly.
Model and method selection	Explains gain sign and units, stable versus integrating/unstable behavior, compatible recipes, response target and scope.
Prediction and interpretation	Predicts a causal PV/OP change, connects at least two numerical observations to it, checks settlement and limits, and explains an unexpected result.
Decision and transfer	Accepts or rejects a candidate with a tradeoff; names absent field checks and architecture effects; defines a matched repeat test.

Score each dimension from 0 to 3

1. 0 / Unsupported: cannot explain the evidence or asserts a claim contradicted by the model or role.

2. 1 / Identifies: names the main signals or facts but gives little causal explanation or ignores a material constraint.

3. 2 / Explains: uses correct model/action and numerical evidence, describes a tradeoff and acknowledges the important model limits.

4. 3 / Defends: anticipates constraints, reconciles prediction with observations, rejects unsupported claims and proposes a specific matched follow-up test.

Four dimensions give a practice total from 0 to 12. A higher later total is meaningful only if the evidence standard is comparable. Quiz score, rubric score and numerical controller performance describe different aspects of learning. A lower IAE alone does not prove growth as a technician or engineer.

Plan your next session

One misconception to repair; one loop type to transfer the lesson to; one unchanged test to repeat:

10. Matched-attempt worksheet / print again

Learner: _____ Reviewer: _____

Case ID and process model: _____

Known Kp / lags / delay and scope: _____

Fixed baseline Kc / Ti / Td: _____

Fixed SP step / load / OP limit / window: _____

Record	Attempt 1	Attempt 2	Attempt 3
Date / method / target			
Candidate Kc / Ti / Td			
Settling / recovery (s)			
Overshoot (%)			
IAE / output travel			
Final error / clamped?			
Quiz score / reasoning 0-12			

Prediction before changing the tune

PV/OP observations, decision and a missing field check

Fair comparison check: same model, baseline, target, load, bounds and window. If one changes, start a new comparison rather than calling it improvement. Export the device learning history to retain your record.

11. Provenance, scope and instructor use

Owned source: Savage-4-Lyfe/loopiq@9acce14292aa94f9d0fe1cd1db522323e04289cc

The original 60 training fixtures, specialty metadata, three-level specialty lessons, process model types, numerical simulator, identifier, rule recipes and virtual relay implementation are retained from the pinned owned source. The lab expands this into 84 exercises and 26 controlled-variable types with new normalized synthetic fixtures and authored learning tasks.

New fixtures, this manual, assessment questions, worksheets, explanation adapters and plotting annotations are lab-authored. Specialty fixtures are disclosed local teaching models, not customer data. The monitoring exercises have normalized synthetic indication and simple non-latching dwell logic.

Numerical method: The owned process simulator uses exact zero-order-hold stable/unstable lag stepping and sampled dead time, ISA dependent PID, derivative-on-PV filtering (N = 10), and back-calculation anti-windup. The owned virtual relay uses its separate discrete first-order update; Ku/Pu are approximate describing-function estimates. The plots here are generated from actual numerical traces, not illustrative artwork.

Metrics: The adapter reports event-relative 2% settling and refuses to label an endpoint outside the band as settled. Load tests measure recovery from the load event while IAE and output travel cover the whole test after the setpoint event.

Method coverage: Seven recipe families: SIMC, IMC, Lambda, Cohen-Coon, ZN open-loop, ZN closed-loop and Tyreus-Luyben PID. Virtual relay is evidence generation; manual P/PI/PID is exploratory tuning. This list matches the owned implemented rule families; it is not a claim to contain every tuning approach in the literature.

Instructor use: Ask the learner to predict first and defend a choice after replay. For each answer, ask what evidence would change the decision. Treat refusal, monitoring classification, saturation recognition and candid reporting of limits as successful engineering outcomes.

Access: The simulator remains privately hosted. This manual does not enroll subscribers, change access rights or connect to live instruments. Distribution to an authorized audience is separate from the lab exercise itself.

Prepared 01 October 2026. The in-app download and this workbook use the same versioned curriculum content.