
<u>Lab</u>

Multiple loop tuning: *Question 61*, **completed objectives due by the end of day 5**

<u>Exam</u>

Day 6

Capstone Assessment (see question 62)

Specific objectives for the optional "mastery" exam (worth +5% on the proportional exam score if passed the very first time):

- Electricity Review: Design a simple circuit to achieve a stated objective
- Identify cause of poor loop performance from a trend graph
- Identify problem in control loop based on faceplate display and field data
- Calculate either the numerical derivative or the numerical integral from a graph
- Solve for a specified variable in an algebraic formula (may contain exponents or logarithms)
- Determine the possibility of suggested faults in a 4-20 mA loop circuit given measured values (voltage, current), a schematic diagram, and reported symptoms
- Motor/relay/3phase/PLC Review: Determine status of PLC output given input conditions and RLL program
- INST240 Review: Determine suitability of different level-measuring technologies for a given process fluid type
- INST263 Review: Determine the effect of a component fault or condition change in a selector or override control system

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Recommended daily schedule

<u>Day 1</u>

Theory session topic: Loop problem diagnosis and optimization (continued)

Questions 1 through 20; <u>answer questions 1-10</u> in preparation for discussion (remainder for practice)

Discuss the upcoming Capstone Assessment due by the end of the course (*Question 62*)

<u>Day 2</u>

Theory session topic: Loop problem diagnosis and optimization (continued)

Questions 21 through 40; <u>answer questions 21-29</u> in preparation for discussion (remainder for practice)

<u>Day 3</u>

Theory session topic: Review for exam (site visit)

Questions 41 through 60; <u>answer questions 41-42</u> in preparation for discussion at an industrial site specified by your instructor. (All remaining questions for practice)

Team tool locker inspection: have students inventory their team tool lockers, posting lists to the outside of the locker doors documenting what's missing.

<u>Day 4</u>

Tour

<u>Day 5</u>

Exam

Day 6

Lab Clean-Up Day

Capstone Assessment: *Question 62*, **due by the end of the last day**

The last day of the quarter is a full day, where all students are expected to attend as usual. Together, we will spend this day completing any remaining lab objectives, as well as doing general clean-up, reorganization, equipment repair, and other tasks necessary for the maintenance of our lab facility. See question 63 for a list of necessary tasks to complete.

How To . . .

Access the worksheets and textbook: go to the *Socratic Instrumentation* website located at `http://www.ibiblio.org/kuphaldt/socratic/sinst` to find worksheets for every 2nd-year course section organized by quarter, as well as both the latest "stable" and "development" versions of the *Lessons In Industrial Instrumentation* textbook. Download and save these documents to your computer.

Maximize your learning: complete all homework *before* class starts, ready to be assessed as described in the "Inverted Session Formats" pages. Use every minute of class and lab time productively. Follow all the tips outlined in "Question 0" as well as your instructor's advice. Do not take constructive criticism personally. Make every reasonable effort to solve problems on your own before seeking help.

Identify upcoming assignments and deadlines: read the first page of each course worksheet.

Relate course days to calendar dates: reference the calendar spreadsheet file (`calendar.xlsx`), found on the BTC campus `Y:` network drive. A printed copy is posted in the Instrumentation classroom.

Locate industry documents assigned for reading: use the Instrumentation Reference provided by your instructor (on CD-ROM and on the BTC campus `Y:` network drive). There you will find a file named `00_index_OPEN_THIS_FILE.html` readable with any internet browser. Click on the "Quick-Start Links" to access assigned reading documents, organized per course, in the order they are assigned.

Study for the exams: Mastery exams assess specific skills critically important to your success, listed near the top of the front page of each course worksheet for your review. Familiarize yourself with this list and pay close attention when those topics appear in homework and practice problems. Proportional exams feature problems you haven't seen before that are solvable using general principles learned throughout the current and previous courses, for which the only adequate preparation is independent problem-solving practice every day. Answer the "feedback questions" (practice exams) in each course section to hone your problem-solving skills, as these are similar in scope and complexity to proportional exams. Answer these feedback independently (i.e. no help from classmates) in order to most accurately assess your readiness.

Calculate course grades: download the "Course Grading Spreadsheet" (`grades_template.xlsx`) from the Socratic Instrumentation website, or from the BTC campus `Y:` network drive. Enter your quiz scores, test scores, lab scores, and attendance data into this Excel spreadsheet and it will calculate your course grade. You may compare your calculated grades against your instructors' records at any time.

Identify courses to register for: read the "Sequence" page found in each worksheet.

Receive extra instructor help: ask during lab time, or during class time, or by appointment. Tony may be reached by email at `tony.kuphaldt@btc.edu` or by telephone at 360-752-8477.

Identify job openings: regularly monitor job-search websites. Set up informational interviews at workplaces you are interested in. Participate in jobshadows and internships. Apply to jobs long before graduation, as some employers take *months* to respond! Check your BTC email account daily for alerts.

Impress employers: sign the FERPA release form granting your instructors permission to share academic records, then make sure your performance is worth sharing. Document your project and problem-solving experiences for reference during interviews. Honor all your commitments.

Begin your career: participate in jobshadows and internships while in school to gain experience and references. Take the first Instrumentation job that pays the bills, and give that employer at least two years of good work to pay them back for the investment they have made in you. Employers look at delayed employment, as well as short employment spans, very negatively. Failure to pass a drug test is an immediate disqualifier, as is falsifying any information. Criminal records may also be a problem.

file `howto`

General Values, Expectations, and Standards

Success in this career requires professional integrity, resourcefulness, persistence, close attention to detail, and intellectual curiosity. If you are ever in doubt as to the values you should embody, just ask yourself what kind of a person you would prefer to hire for your own enterprise. Those same values will be upheld within this program.

Learning is the purpose of any educational program, and a worthy priority in life. Every circumstance, every incident, every day here will be treated as a learning opportunity, every mistake as a "teachable moment". Every form of positive growth, not just academic ability, will be regarded as real learning.

Responsibility means *ensuring* the desired outcome, not just *trying* to achieve the outcome. To be a responsible person means you *own* the outcome of your decisions and actions.

Integrity means being honest and forthright in all your words and actions, doing your very best every time and never taking credit for the achievement of another.

Safety means doing every job correctly and ensuring others are not endangered. Lab safety standards include wearing closed-toed shoes and safety glasses in the lab room during lab hours, wearing ear protection around loud sounds, using ladders to reach high places, using proper lock-out/tag-out procedures, no energized electrical work above 30 volts without an instructor present in the lab room, and no power tool use without an instructor present in the lab room.

Diligence in study means exercising self-discipline and persistence, realizing that hard work is a necessary condition for success. This means, among other things, investing the necessary time and effort in studying, reading instructions, paying attention to details, utilizing the skills and tools you already possess, and avoiding shortcuts. Diligence in work means the job is not done until it is done *correctly*: all objectives achieved, all problems solved, all documentation complete, and no errors remaining.

Self-management means allocating your resources (time, equipment, labor) wisely, and not just focusing on the closest deadline.

Communication means clearly conveying your thoughts and paying attention to what others convey, across all forms of communication (e.g. oral, written, nonverbal).

Teamwork means working constructively with your classmates to complete the job at hand. Remember that here the first job is *learning*, and so teamwork means working to maximize everyone's learning (not just your own). The goal of learning is more important than the completion of any project or assignment.

Initiative means recognizing needs and taking action to meet those needs without encouragement or direction from others.

Representation means your actions reflect this program and not just yourself. Doors of opportunity for all BTC graduates may be opened or closed by your own conduct. Unprofessional behavior during tours, jobshadows, internships, and/or jobs reflects poorly on the program and will negatively bias employers.

Trustworthiness is the result of consistently exercising these values: people will recognize you as someone they can rely on to get the job done, and therefore someone they would want to employ.

Respect means acknowledging the intrinsic value, capabilities, and responsibilities of those around you. Respect is gained by consistent demonstration of valued behaviors, and it is lost through betrayal of trust.

<u>Punctuality and Attendance:</u> late arrivals are penalized at a rate of 1% grade deduction per incident. Absence is penalized at a rate of 1% per hour (rounded to the nearest hour) except when employment-related, school-related, weather-related, or required by law (e.g. court summons). Absences may be made up by directing the instructor to apply "sick hours" (12 hours of sick time available per quarter). Classmates may donate their unused sick hours. Sick hours may not be applied to unannounced absences, so be sure to alert your instructor and teammates as soon as you know you will be absent or late. Absence on an exam day will result in a zero score for that exam, unless due to a documented emergency.

<u>Mastery:</u> any assignment or objective labeled as "mastery" must be completed with 100% competence (with multiple opportunities to re-try). Failure to complete by the deadline date caps your grade at a C−. Failure to complete by the end of the *next* school day results in a failing (F) grade for that course.

<u>Time Management:</u> Use all available time wisely and productively. Work on other useful tasks (e.g. homework, feedback questions, job searching) while waiting for other activities or assessments to begin. Trips to the cafeteria for food or coffee, smoke breaks, etc. must not interfere with team participation.

<u>Orderliness:</u> Keep your work area clean and orderly, discarding trash, returning tools at the end of every lab session, and participating in all scheduled lab clean-up sessions. Project wiring, especially in shared areas such as junction boxes, must not be left in disarray at the end of a lab shift. Label any failed equipment with a detailed description of its symptoms.

<u>Independent Study:</u> the "inverted" instructional model used in this program requires independent reading and problem-solving, where every student must demonstrate their learning at the start of the class session. Question 0 of every worksheet lists practical study tips. The "Inverted Session Formats" pages found in every worksheet outline the format and grading standards for inverted class sessions.

<u>Independent Problem-Solving:</u> make an honest effort to solve every problem before seeking help. When working in the lab, help will not be given unless and until you run your own diagnostic tests.

<u>Teamwork:</u> inform your teammates if you need to leave the work area for any reason. Any student regularly compromising team performance through absence, tardiness, disrespect, or other disruptive behavior(s) will be removed from the team and required to complete all labwork individually. The same is true for students found inappropriately relying on teammates.

<u>Communication:</u> check your email daily for important messages. Ask the instructor to clarify any assignment or exam question you find confusing, and express your work clearly.

<u>Academic Progress:</u> your instructor will record your academic achievement, as well as comments on any negative behavior, and will share all these records with employers if you sign the FERPA release form. You may see these records at any time, and you should track your own academic progress using the grade spreadsheet template. Extra-credit projects will be tailored to your learning needs.

<u>Office Hours:</u> your instructor's office hours are by appointment, except in cases of emergency. Email is the preferred method for setting up an appointment with your instructor to discuss something in private.

<u>Grounds for Failure:</u> a failing (F) grade will be earned in any course if any mastery objectives are past deadline by more than one school day, or for any of the following behaviors: false testimony (lying), cheating on any assignment or assessment, plagiarism (presenting another's work as your own), willful violation of a safety policy, theft, harassment, sabotage, destruction of property, or intoxication. These behaviors are grounds for immediate termination in this career, and as such will not be tolerated here.

<u>file `expectations`</u>

Program Outcomes for Instrumentation and Control Technology (BTC)

#1 | Communication

Communicate and express concepts and ideas across a variety of media (verbal, written, graphical) using industry-standard terms.

#2 | Time management

Arrives on time and prepared to work; Budgets time and meets deadlines when performing tasks and projects.

#3 | Safety

Complies with national, state, local, and college safety regulations when designing and performing work on systems.

#4 | Analysis and Diagnosis

Analyze, evaluate, and diagnose systems related to instrumentation and control including electrical and electronic circuits, fluid power and signaling systems, computer networks, and mechanisms; Select and apply correct mathematical techniques to these analytical and diagnostic problems; Select and correctly use appropriate test equipment to collect data.

#5 | Design and Commissioning

Select, design, construct, configure, and install components necessary for the proper function of systems related to instrumentation and control, applying industry standards and verifying correct system operation when complete.

#6 | System optimization

Improve technical system functions by collecting data and evaluating performance; Implement strategies to optimize the function of these systems.

#7 | Calibration

Assess instrument accuracy and correct inaccuracies using appropriate calibration procedures and test equipment; Select and apply correct mathematical techniques to these calibration tasks.

#8 | Documentation

Interpret and create technical documents (e.g. electronic schematics, loop diagrams, functional diagrams, P&IDs, graphs, narratives) according to industry standards.

#9 | Independent learning

Select and research information sources to learn new principles, technologies, and techniques.

#10 | Job searching

Develop a professional resume and research job openings in the field of industrial instrumentation.

file `outcomes_program`

INST 252 Course Outcomes

Each and every outcome in this course is assessed at a mastery level (i.e. 100% competence)

- Tune multiple PID controllers for robust response to setpoint and process load changes. [Ref: Program Learning Outcome #6]

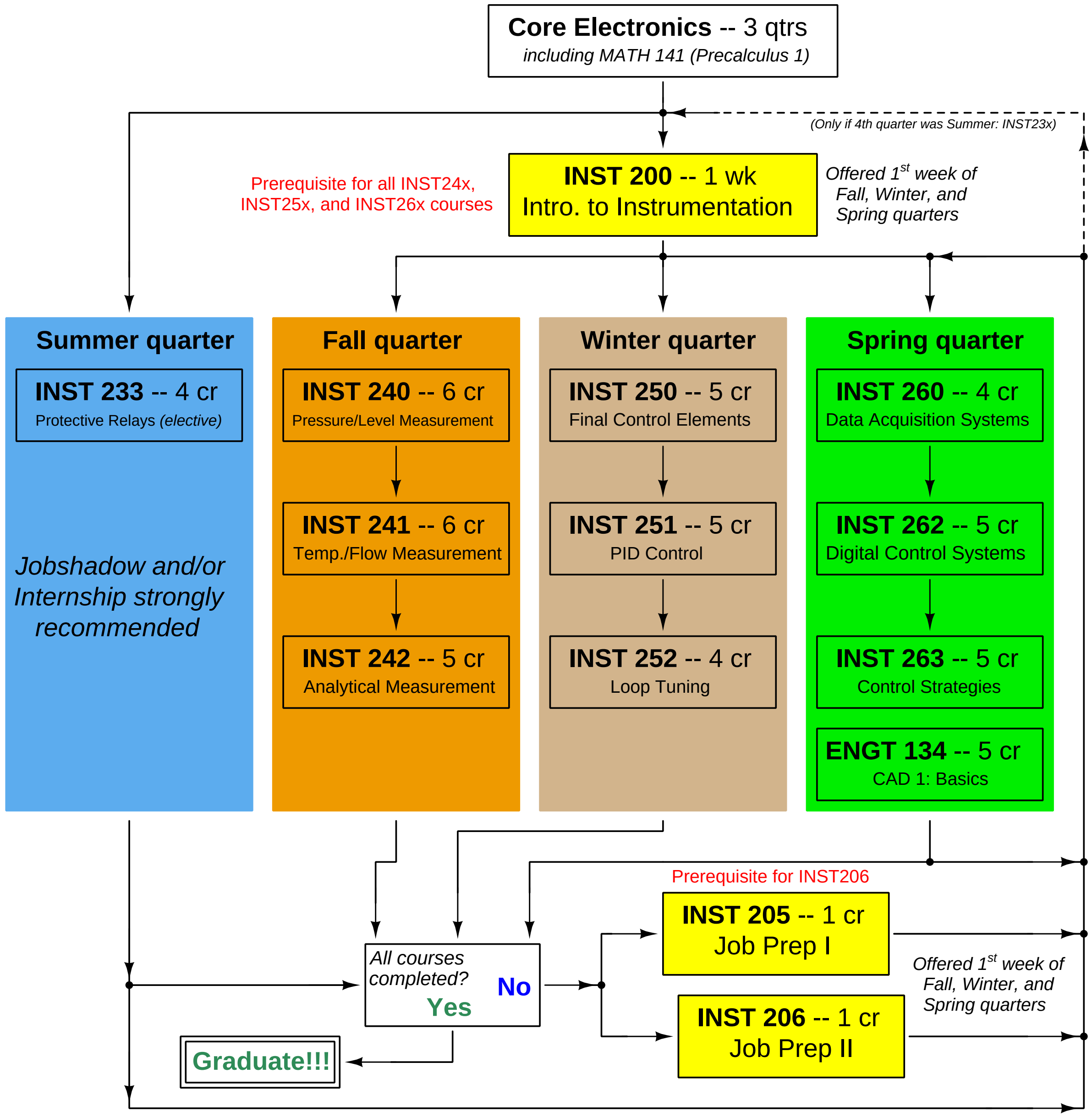
- Design and build a circuit to fulfill a function randomly selected by the instructor (voltage divider, passive filter, capacitive time-delay, or phase shift network) and demonstrate its proper operation using a signal generator and oscilloscope. [Ref: Program Learning Outcome #5]

- Diagnose a random fault placed in another team's PID control system by the instructor within a limited time using no test equipment except a multimeter, logically justifying your steps in the instructor's direct presence. [Ref: Program Learning Outcome #5]

- Construct a working control loop consisting of a pre-made process unit with transmitter and final control element, properly connected to a controller, within a limited time. Both the process and the controller are randomly selected by the instructor, with PID tuning criteria (robust response to either setpoint or load changes) specified by the instructor. [Ref: Program Learning Outcomes #5 and #9]

file `outcomes_INST252`

Sequence of second-year Instrumentation courses



The particular sequence of courses you take during the second year depends on when you complete all first-year courses and enter the second year. Since students enter the second year of Instrumentation at four different times (beginnings of Summer, Fall, Winter, and Spring quarters), the particular course sequence for any student will likely be different from the course sequence of classmates.

Some second-year courses are only offered in particular quarters with those quarters not having to be in sequence, while others are offered three out of the four quarters and must be taken in sequence. The following layout shows four typical course sequences for second-year Instrumentation students, depending on when they first enter the second year of the program:

file sequence

General tool and supply list

Wrenches

- Combination (box- and open-end) wrench set, 1/4" to 3/4" – *the most important wrench sizes are 7/16", 1/2", 9/16", and 5/8"; get these immediately!*
- Adjustable wrench, 6" handle (sometimes called "Crescent" wrench)
- Hex wrench ("Allen" wrench) set, fractional – 1/16" to 3/8"
- *Optional:* Hex wrench ("Allen" wrench) set, metric – 1.5 mm to 10 mm
- *Optional:* Miniature combination wrench set, 3/32" to 1/4" (sometimes called an "ignition wrench" set)

Note: *always maximize surface engagement on a fastener's head to reduce stress on that fastener. (e.g. Using box-end wrenches instead of adjustable wrenches; using the proper size and type of screwdriver; never using any tool that mars the fastener such as pliers or vise-grips unless absolutely necessary.)*

Pliers

- Needle-nose pliers
- Diagonal wire cutters (sometimes called "dikes")

Screwdrivers

- Slotted, 1/8" and 1/4" shaft
- Phillips, #1 and #2
- Jeweler's screwdriver set
- *Optional:* Magnetic multi-bit screwdriver (e.g. Klein Tools model 70035)

Electrical

- Multimeter, Fluke model 87-IV or better
- Assortment of alligator-clip style jumper wires
- Soldering iron (10 to 40 watt) and rosin-core solder
- Resistor, potentiometer, diode assortments (from first-year lab kits)
- Package of insulated compression-style fork terminals (14 to 18 AWG wire size, #10 stud size)
- Wire strippers/terminal crimpers for 10 AWG to 18 AWG wire and insulated terminals
- *Optional:* ratcheting terminal crimp tool (e.g. Paladin 1305, Ferrules Direct FDT10011, or equivalent)

Safety

- Safety glasses or goggles (available at BTC bookstore)
- Earplugs (available at BTC bookstore)

Miscellaneous

- Simple scientific calculator (non-programmable, non-graphing, no conversions), TI-30Xa or TI-30XIIS recommended. Required for some exams!
- Portable personal computer capable of wired Ethernet connectivity, Wi-Fi connectivity, displaying PDF documents, creating text documents, creating and viewing spreadsheets, running PLC programming software (MS Windows only), and executing command-line utilities such as `ping`.
- Masking tape (for making temporary labels)
- Permanent marker pen
- Teflon pipe tape
- Utility knife
- Tape measure, 12 feet minimum
- Flashlight

file `tools`

Methods of instruction

This course develops self-instructional and diagnostic skills by placing students in situations where they are required to research and think independently. In all portions of the curriculum, the goal is to avoid a passive learning environment, favoring instead *active engagement* of the learner through reading, reflection, problem-solving, and experimental activities. The curriculum may be roughly divided into two portions: *theory* and *practical*. All "theory" sessions follow the *inverted* format and contain virtually no lecture.

Inverted theory sessions

The basic concept of an "inverted" learning environment is that the traditional allocations of student time are reversed: instead of students attending an instructor-led session to receive new information and then practicing the application of that information outside of the classroom in the form of homework, students in an inverted class encounter new information outside of the classroom via homework and apply that information in the classroom session under the instructor's tutelage.

A natural question for instructors, then, is what their precise role is in an inverted classroom and how to organize that time well. Here I will list alternate formats suitable for an inverted classroom session, each of them tested and proven to work.

Small sessions

Students meet with instructors in small groups for short time periods. Groups of 4 students meeting for 30 minutes works very well, but groups as large as 8 students apiece may be used if time is limited. Each of these sessions begins with a 5 to 10 minute graded inspection of homework with individual questioning, to keep students accountable for doing the homework. The remainder of the session is a dialogue focusing on the topics of the day, the instructor challenging each student on the subject matter in Socratic fashion, and also answering students' questions. A second grade measures each student's comprehension of the subject matter by the end of the session.

This format also works via teleconferencing, for students unable to attend a face-to-face session on campus.

Large sessions

Students meet with instructors in a standard classroom (normal class size and period length). Each of these sessions begins with a 10 minute graded quiz (closed-book) on the homework topic(s), to keep students accountable for doing the homework. Students may leave the session as soon as they "check off" with the instructor in a Socratic dialogue as described above (instructor challenging each student to assess their comprehension, answering questions, and grading the responses). Students sign up for check-off on the whiteboard when they are ready, typically in groups of no more than 4. Alternatively, the bulk of the class session may be spent answering student questions in small groups, followed by another graded quiz at the end.

Correspondence

This format works for students unable to attend a "face-to-face" session, and who must correspond with the instructor via email or other asynchronous medium. Each student submits a thorough presentation of their completed homework, which the instructor grades for completeness and accuracy. The instructor then replies back to the student with challenge questions, and also answers questions the student may have. As with the previous formats, the student receives another grade assessing their comprehension of the subject matter by the close of the correspondence dialogue.

In all formats, students are held accountable for completion of their homework, "completion" being defined as successfully interpreting the given information from source material (e.g. accurate outlines of reading or video assignments) and constructive effort to solve given problems. It must be understood in an inverted learning environment that students *will* have legitimate questions following a homework assignment, and that it is therefore unreasonable to expect mastery of the assigned subject matter. What is reasonable to expect from each and every student is a basic outline of the source material (reading or video assignments) complete with major terms defined and major concepts identified, plus a good-faith effort to solve every problem. Question 0 (contained in every worksheet) lists multiple strategies for effective study and problem-solving.

Sample rubric for pre-assessments

- **No credit** = Any homework question unattempted (i.e. no effort shown on one or more questions); incomprehensible writing; failure to follow clear instruction(s)
- **Half credit** = Misconception(s) on any major topic explained in the assigned reading; answers shown with no supporting work; verbatim copying of text rather than written in student's own words; outline missing important topic(s); unable to explain the outline or solution methods represented in written work
- **Full credit** = Every homework question answered, with any points of confusion clearly articulated; all important concepts from reading assignments accurately expressed in the outline and clearly articulated when called upon by the instructor to explain

The minimum expectation at the start of every student-instructor session is that all students have made a good-faith effort to complete 100% of their assigned homework. This does not necessarily mean all answers will be correct, or that all concepts are fully understood, because one of the purposes of the meeting between students and instructor is to correct remaining misconceptions and answer students' questions. However, experience has shown that without accountability for the homework, a substantial number of students will not put forth their best effort and that this compromises the whole learning process. Full credit is reserved for good-faith effort, where each student thoughtfully applies the study and problem-solving recommendations given to them (see Question 0).

Sample rubric for post-assessments

- **No credit** = Failure to comprehend one or more key concepts; failure to apply logical reasoning to the solution of problem(s); no contribution to the dialogue
- **Half credit** = Some misconceptions persist by the close of the session; problem-solving is inconsistent; limited contribution to the dialogue
- **Full credit** = Socratic queries answered thoughtfully; effective reasoning applied to problems; ideas communicated clearly and accurately; responds intelligently to questions and statements made by others in the session; adds new ideas and perspectives

The minimum expectation is that each and every student engages with the instructor and with fellow students during the Socratic session: posing intelligent questions of their own, explaining their reasoning when challenged, and otherwise positively contributing to the discussion. Passive observation and listening is not an option here – every student must be an active participant, contributing something original to every dialogue. If a student is confused about any concept or solution, it is their responsibility to ask questions and seek resolution.

If a student happens to be absent for a scheduled class session and is therefore unable to be assessed on that day's study, they may schedule a time with the instructor to demonstrate their comprehension at some later date (before the end of the quarter when grades must be submitted). These same standards of performance apply equally make-up assessments: either inspection of homework or a closed-book quiz for the pre-assessment, and either a Socratic dialogue with the instructor or another closed-book quiz for the post-assessment.

Lab sessions

In the lab portion of each course, students work in teams to install, configure, document, calibrate, and troubleshoot working instrument loop systems. Each lab exercise focuses on a different type of instrument, with a limited time period typically for completion. An ordinary lab session might look like this:

(1) Start of practical (lab) session: announcements and planning
   (a) The instructor makes general announcements to all students
   (b) The instructor works with team to plan that day's goals, making sure each team member has a clear idea of what they should accomplish
(2) Teams work on lab unit completion according to recommended schedule:
   (First day) Select and bench-test instrument(s), complete prototype sketch of project
   (One day) Connect instrument(s) into a complete loop
   (One day) Each team member drafts their own loop documentation, inspection done as a team (with instructor)
   (One or two days) Each team member calibrates/configures the instrument(s)
   (Remaining days, up to last) Each team member troubleshoots the instrument loop
(3) End of practical (lab) session: debriefing where each team reports on their work to the whole class

Troubleshooting assessments must meet the following guidelines:

- Troubleshooting must be performed *on a system the student did not build themselves.* This forces students to rely on another team's documentation rather than their own memory of how the system was built.
- Each student must individually demonstrate proper troubleshooting technique.
- Simply finding the fault is not good enough. Each student must consistently demonstrate sound reasoning while troubleshooting.
- If a student fails to properly diagnose the system fault, they must attempt (as many times as necessary) with different scenarios until they do, reviewing any mistakes with the instructor after each failed attempt.

Distance delivery methods

Sometimes the demands of life prevent students from attending college 6 hours per day. In such cases, there exist alternatives to the normal 8:00 AM to 3:00 PM class/lab schedule, allowing students to complete coursework in non-traditional ways, at a "distance" from the college campus proper.

For such "distance" students, the same worksheets, lab activities, exams, and academic standards still apply. Instead of working in small groups and in teams to complete theory and lab sections, though, students participating in an alternative fashion must do all the work themselves. Participation via teleconferencing, video- or audio-recorded small-group sessions, and such is encouraged and supported.

There is no recording of hours attended or tardiness for students participating in this manner. The pace of the course is likewise determined by the "distance" student. Experience has shown that it is a benefit for "distance" students to maintain the same pace as their on-campus classmates whenever possible.

In lieu of small-group activities and class discussions, comprehension of the theory portion of each course will be ensured by completing and submitting detailed answers for *all* worksheet questions, not just passing daily quizzes as is the standard for conventional students. The instructor will discuss any incomplete and/or incorrect worksheet answers with the student, and ask that those questions be re-answered by the student to correct any misunderstandings before moving on.

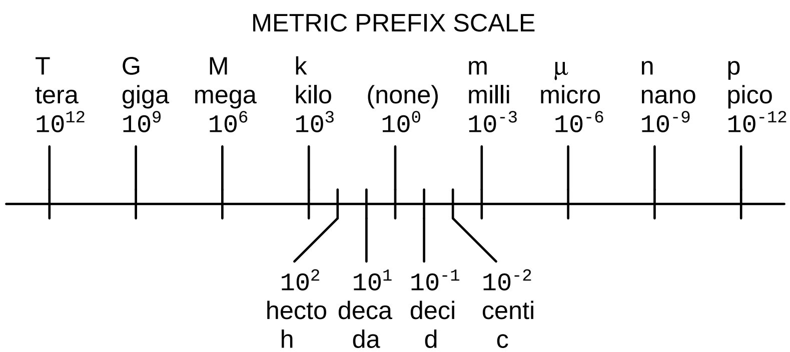
Labwork is perhaps the most difficult portion of the curriculum for a "distance" student to complete, since the equipment used in Instrumentation is typically too large and expensive to leave the school lab facility. "Distance" students must find a way to complete the required lab activities, either by arranging time in the school lab facility and/or completing activities on equivalent equipment outside of school (e.g. at their place of employment, if applicable). Labwork completed outside of school must be validated by a supervisor and/or documented via photograph or videorecording.

Conventional students may opt to switch to "distance" mode at any time. This has proven to be a benefit to students whose lives are disrupted by catastrophic events. Likewise, "distance" students may switch back to conventional mode if and when their schedules permit. Although the existence of alternative modes of student participation is a great benefit for students with challenging schedules, it requires a greater investment of time and a greater level of self-discipline than the traditional mode where the student attends school for 6 hours every day. No student should consider the "distance" mode of learning a way to have more free time to themselves, because they will actually spend more time engaged in the coursework than if they attend school on a regular schedule. It exists merely for the sake of those who cannot attend during regular school hours, as an alternative to course withdrawal.

file `distance`

Metric prefixes and conversion constants

- **Metric prefixes**
- Yotta = 10^{24} Symbol: Y
- Zeta = 10^{21} Symbol: Z
- Exa = 10^{18} Symbol: E
- Peta = 10^{15} Symbol: P
- Tera = 10^{12} Symbol: T
- Giga = 10^{9} Symbol: G
- Mega = 10^{6} Symbol: M
- Kilo = 10^{3} Symbol: k
- Hecto = 10^{2} Symbol: h
- Deca = 10^{1} Symbol: da
- Deci = 10^{-1} Symbol: d
- Centi = 10^{-2} Symbol: c
- Milli = 10^{-3} Symbol: m
- Micro = 10^{-6} Symbol: μ
- Nano = 10^{-9} Symbol: n
- Pico = 10^{-12} Symbol: p
- Femto = 10^{-15} Symbol: f
- Atto = 10^{-18} Symbol: a
- Zepto = 10^{-21} Symbol: z
- Yocto = 10^{-24} Symbol: y



- **Conversion formulae for temperature**
- ^{o}F = (^{o}C)(9/5) + 32
- ^{o}C = (^{o}F - 32)(5/9)
- ^{o}R = ^{o}F + 459.67
- K = ^{o}C + 273.15

Conversion equivalencies for distance

1 inch (in) = 2.540000 centimeter (cm)

1 foot (ft) = 12 inches (in)

1 yard (yd) = 3 feet (ft)

1 mile (mi) = 5280 feet (ft)

Conversion equivalencies for volume

1 gallon (gal) = 231.0 cubic inches (in^3) = 4 quarts (qt) = 8 pints (pt) = 128 fluid ounces (fl. oz.) = 3.7854 liters (l)

1 milliliter (ml) = 1 cubic centimeter (cm^3)

Conversion equivalencies for velocity

1 mile per hour (mi/h) = 88 feet per minute (ft/m) = 1.46667 feet per second (ft/s) = 1.60934 kilometer per hour (km/h) = 0.44704 meter per second (m/s) = 0.868976 knot (knot – international)

Conversion equivalencies for mass

1 pound (lbm) = 0.45359 kilogram (kg) = 0.031081 slugs

Conversion equivalencies for force

1 pound-force (lbf) = 4.44822 newton (N)

Conversion equivalencies for area

1 acre = 43560 square feet (ft^2) = 4840 square yards (yd^2) = 4046.86 square meters (m^2)

Conversion equivalencies for common pressure units (either all gauge or all absolute)

1 pound per square inch (PSI) = 2.03602 inches of mercury (in. Hg) = 27.6799 inches of water (in. W.C.) = 6.894757 kilo-pascals (kPa) = 0.06894757 bar

1 bar = 100 kilo-pascals (kPa) = 14.504 pounds per square inch (PSI)

Conversion equivalencies for absolute pressure units (only)

1 atmosphere (Atm) = 14.7 pounds per square inch absolute (PSIA) = 101.325 kilo-pascals absolute (kPaA) = 1.01325 bar (bar) = 760 millimeters of mercury absolute (mmHgA) = 760 torr (torr)

Conversion equivalencies for energy or work

1 british thermal unit (Btu – "International Table") = 251.996 calories (cal – "International Table") = 1055.06 joules (J) = 1055.06 watt-seconds (W-s) = 0.293071 watt-hour (W-hr) = 1.05506 x 10^{10} ergs (erg) = 778.169 foot-pound-force (ft-lbf)

Conversion equivalencies for power

1 horsepower (hp – 550 ft-lbf/s) = 745.7 watts (W) = 2544.43 british thermal units per hour (Btu/hr) = 0.0760181 boiler horsepower (hp – boiler)

Acceleration of gravity (free fall), Earth standard

9.806650 meters per second per second (m/s^2) = 32.1740 feet per second per second (ft/s^2)

Physical constants

Speed of light in a vacuum (c) = 2.9979×10^8 meters per second (m/s) = 186,281 miles per second (mi/s)

Avogadro's number (N_A) = 6.022×10^{23} per mole (mol^{-1})

Electronic charge (e) = 1.602×10^{-19} Coulomb (C)

Boltzmann's constant (k) = 1.38×10^{-23} Joules per Kelvin (J/K)

Stefan-Boltzmann constant (σ) = 5.67×10^{-8} Watts per square meter-Kelvin^4 (W/m^2·K^4)

Molar gas constant (R) = 8.314 Joules per mole-Kelvin (J/mol-K)

Properties of Water

Freezing point at sea level = 32^{o}F = 0^{o}C

Boiling point at sea level = 212^{o}F = 100^{o}C

Density of water at 4^{o}C = 1000 kg/m^3 = 1 g/cm^3 = 1 kg/liter = 62.428 lb/ft^3 = 1.94 slugs/ft^3

Specific heat of water at 14^{o}C = 1.00002 calories/g·^{o}C = 1 BTU/lb·^{o}F = 4.1869 Joules/g·^{o}C

Specific heat of ice ≈ 0.5 calories/g·^{o}C

Specific heat of steam ≈ 0.48 calories/g·^{o}C

Absolute viscosity of water at 20^{o}C = 1.0019 centipoise (cp) = 0.0010019 Pascal-seconds (Pa·s)

Surface tension of water (in contact with air) at 18^{o}C = 73.05 dynes/cm

pH of pure water at 25^o C = 7.0 (*pH scale = 0 to 14*)

Properties of Dry Air at sea level

Density of dry air at 20^{o}C and 760 torr = 1.204 mg/cm^3 = 1.204 kg/m^3 = 0.075 lb/ft^3 = 0.00235 slugs/ft^3

Absolute viscosity of dry air at 20^{o}C and 760 torr = 0.018 centipoise (cp) = 1.8×10^{-5} Pascal-seconds (Pa·s)

How to get the most out of academic reading:

- Outline, don't highlight! Identify every major idea presented in the text, and express these ideas in your own words. A suggested ratio is one sentence of your own thoughts per paragraph of text read.
- Articulate your thoughts as you read (i.e. "have a conversation" with the author). This will develop *metacognition*: active supervision of your own thoughts. Note points of agreement, disagreement, confusion, epiphanies, and connections between different concepts or applications.
- Work through all mathematical exercises shown within the text, to ensure you understand all the steps.
- Imagine explaining concepts you've just learned to someone else. Teaching forces you to distill concepts to their essence, thereby clarifying those concepts, revealing assumptions, and exposing misconceptions. Your goal is to create the simplest explanation that is still technically accurate.
- Create your own questions based on what you read, as a teacher would to challenge students.

How to effectively problem-solve and troubleshoot:

- Rely on principles, not procedures. Don't be satisfied with memorizing steps – learn *why* those steps work. Each step should make logical sense and have real-world meaning to you.
- Sketch a diagram to help visualize the problem. Sketch a graph showing how variables relate. When building a real system, always prototype it on paper and analyze its function *before* constructing it.
- Identify what it is you need to solve, identify all relevant data, identify all units of measurement, identify any general principles or formulae linking the given information to the solution, and then identify any "missing pieces" to a solution. Annotate all diagrams with this data.
- Perform "thought experiments" to explore the effects of different conditions for theoretical problems. When troubleshooting, perform *diagnostic tests* rather than just visually inspect for faults.
- Simplify the problem and solve that simplified problem to identify strategies applicable to the original problem (e.g. change quantitative to qualitative, or visa-versa; substitute easier numerical values; eliminate confusing details; add details to eliminate unknowns; consider simple limiting cases; apply an analogy). Remove components from a malfunctioning system to simplify it and better identify the nature and location of the problem.
- Check for exceptions – does your solution work for *all* conditions and criteria?
- Work "backward" from a hypothetical solution to a new set of given conditions.

How to manage your time:

- Avoid procrastination. Work now and play later, every single day.
- Consider the place you're in when deciding what to do. If there is project work to do and you have access to the lab, do that work and not something that could be done elsewhere (e.g. homework).
- Eliminate distractions. Kill your television and video games. Turn off your mobile phone, or just leave it at home. Study in places where you can concentrate, like the Library.
- Use your "in between" time productively. Don't leave campus for lunch. Arrive to school early. If you finish your assigned work early, begin working on the next assignment.

Above all, cultivate persistence, as this is necessary to master anything non-trivial. The keys to persistence are (1) having the desire to achieve that mastery, and (2) realizing challenges are normal and not an indication of something gone wrong. A common error is to equate *easy* with *effective*: students often believe learning should be easy if everything is done right. The truth is that mastery never comes easy!

file `question0`

Checklist when reading an instructional text

"Reading maketh a full man; conference a ready man; and writing an exact man" – Francis Bacon

Francis Bacon's advice is a blueprint for effective education: reading provides the learner with knowledge, writing focuses the learner's thoughts, and critical dialogue equips the learner to confidently communicate and apply their learning. Independent acquisition and application of knowledge is a powerful skill, well worth the effort to cultivate. To this end, students should read these educational resources closely, write their own outline and reflections on the reading, and discuss in detail their findings with classmates and instructor(s). You should be able to do all of the following after reading any instructional text:

$\boxed{\surd}$ Briefly OUTLINE THE TEXT, as though you were writing a detailed Table of Contents. Feel free to rearrange the order if it makes more sense that way. Prepare to articulate these points in detail and to answer questions from your classmates and instructor. Outlining is a good self-test of thorough reading because you cannot outline what you have not read or do not comprehend.

$\boxed{\surd}$ Demonstrate ACTIVE READING STRATEGIES, including verbalizing your impressions as you read, simplifying long passages to convey the same ideas using fewer words, annotating text and illustrations with your own interpretations, working through mathematical examples shown in the text, cross-referencing passages with relevant illustrations and/or other passages, identifying problem-solving strategies applied by the author, etc. Technical reading is a special case of problem-solving, and so these strategies work precisely because they help solve any problem: paying attention to your own thoughts (metacognition), eliminating unnecessary complexities, identifying what makes sense, paying close attention to details, drawing connections between separated facts, and noting the successful strategies of others.

$\boxed{\surd}$ Identify IMPORTANT THEMES, especially GENERAL LAWS and PRINCIPLES, expounded in the text and express them in the simplest of terms as though you were teaching an intelligent child. This emphasizes connections between related topics and develops your ability to communicate complex ideas to anyone.

$\boxed{\surd}$ Form YOUR OWN QUESTIONS based on the reading, and then pose them to your instructor and classmates for their consideration. Anticipate both correct and incorrect answers, the incorrect answer(s) assuming one or more plausible misconceptions. This helps you view the subject from different perspectives to grasp it more fully.

$\boxed{\surd}$ Devise EXPERIMENTS to test claims presented in the reading, or to disprove misconceptions. Predict possible outcomes of these experiments, and evaluate their meanings: what result(s) would confirm, and what would constitute disproof? Running mental simulations and evaluating results is essential to scientific and diagnostic reasoning.

$\boxed{\surd}$ Specifically identify any points you found CONFUSING. The reason for doing this is to help diagnose misconceptions and overcome barriers to learning.

General challenges following a tutorial reading assignment

- Summarize as much of the text as you can in one paragraph of your own words. A helpful strategy is to explain ideas as you would for an intelligent child: as simple as you can without compromising too much accuracy.
- Simplify a particular section of the text, for example a paragraph or even a single sentence, so as to capture the same fundamental idea in fewer words.
- Where did the text make the most sense to you? What was it about the text's presentation that made it clear?
- Identify where it might be easy for someone to misunderstand the text, and explain why you think it could be confusing.
- Identify any new concept(s) presented in the text, and explain in your own words.
- Identify any familiar concept(s) such as physical laws or principles applied or referenced in the text.
- Devise a proof of concept experiment demonstrating an important principle, physical law, or technical innovation represented in the text.
- Devise an experiment to disprove a plausible misconception.
- Did the text reveal any misconceptions you might have harbored? If so, describe the misconception(s) and the reason(s) why you now know them to be incorrect.
- Describe any useful problem-solving strategies applied in the text.
- Devise a question of your own to challenge a reader's comprehension of the text.

General follow-up challenges for assigned problems

- Identify where any fundamental laws or principles apply to the solution of this problem.
- Describe in detail your own strategy for solving this problem. How did you identify and organized the given information? Did you sketch any diagrams to help frame the problem?
- Is there more than one way to solve this problem? Which method seems best to you?
- Show the work you did in solving this problem, even if the solution is incomplete or incorrect.
- What would you say was the most challenging part of this problem, and why was it so?
- Was any important information missing from the problem which you had to research or recall?
- Was there any extraneous information presented within this problem? If so, what was it and why did it not matter?
- Examine someone else's solution to identify where they applied fundamental laws or principles.
- Simplify the problem from its given form and show how to solve this simpler version of it. Examples include eliminating certain variables or conditions, altering values to simpler (usually whole) numbers, applying a limiting case (i.e. altering a variable to some extreme or ultimate value).
- For quantitative problems, identify the real-world meaning of all intermediate calculations: their units of measurement, where they fit into the scenario at hand.
- For quantitative problems, try approaching it qualitatively instead, thinking in terms of "increase" and "decrease" rather than definite values.
- For qualitative problems, try approaching it quantitatively instead, proposing simple numerical values for the variables.
- Were there any assumptions you made while solving this problem? Would your solution change if one of those assumptions were altered?
- Identify where it would be easy for someone to go astray in attempting to solve this problem.
- Formulate your own problem based on what you learned solving this one.

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file `license`

Question 1

Read and outline Case History #67 ("Problems Encountered In Level Controls") from Michael Brown's collection of control loop optimization tutorials.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Any points of confusion, and precisely why you found the text confusing.
(5) Questions of your own you would pose to another reader, to challenge their understanding.
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

Be sure to answer the following questions:

- Explain what Mr. Brown means when he says, "Integrating processes are always 'balancing' processes . . ."

- Examine the trend of a tank level control in Figure 1 and determine if the controller is *direct* or *reverse* acting.

- Examine the "As-Found" response of a tank level control shown in Figure 1 and determine the dominant control action (P, I, or D) as revealed by the PV and Output waveforms. Is this action reasonable for an integrating process such as level control? Why or why not?

- Examine the "As-Left" response of a tank level control shown in Figure 2 and determine how this tuning differs from the "As-Found" tuning shown in Figure 1.

- Explain how we can definitely determine the control system graphed in Figure 4 has a bad valve.

- Explain the rationale behind the instrument technician's creative "fix" for that bad control valve, shown in Figure 5.

Suggestions for Socratic discussion

- Discuss how we may use PV/Output phase shift to identify a controller's dominant action, based on the information contained in the "Recognizing an Over-Tuned Controller by phase shift" subsection of the "Heuristic PID Tuning Procedures" section of the "Process Dynamics and PID Controller Tuning" chapter in your *Lessons In Industrial Instrumentation* textbook and discuss this with your classmates.
- Explain why a process with "positive lead integrator" behavior (e.g. Figure 6) will be very challenging to control using PID.

file i01572

Question 2

Read and outline Case History #87 ("Problems Beyond Belief!") from Michael Brown's collection of control loop optimization tutorials.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Any points of confusion, and precisely why you found the text confusing.
(5) Questions of your own you would pose to another reader, to challenge their understanding.
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

Be sure to answer the following questions:

- In Mr. Brown's experience, how many fast-responding control loops can you reasonably expect to optimize in a working day? How does this compare with the amount of time you have found yourself spending to characterize (open-loop test) and tune a PID loop?

- Describe what Mr. Brown discovered while trying to optimize the flow-control loop whose trend is shown in Figure 1. The details here are actually quite funny.

- The next loop described in this case history was another flow-control loop, and it was discovered that the operators had purposely left a bypass valve open around the control valve. Explain what their purpose was in doing this, and why it compromised the quality of control in this system. Also explain what sort of problem can be seen in the open-loop trend of Figure 2, and why this loop's control stability was doomed because of it.

- Examine the trend shown in Figure 4. Even though this is a closed-loop (automatic mode) test, we can still discern what type of problem the control valve has when we look at the PV, SP, and Output plots. Explain how the shapes of these graphs reveal the poor health of the control valve.

Suggestions for Socratic discussion

- In this case history, Mr. Brown briefly discusses "advanced control strategies" and their interface with "base-layer" PID controls. Explain how these advanced control strategies work in a regular control system, especially how they are dependent upon good tuning of the PID control loops.
- The trend shown in Figure 4 also reveals quite a bit about the controller's PID tuning. Examine the PV, SP, and Output trends and then explain what we may discern about the controller's tuning from this. Is the tuning P, I, or D-dominant? Can we calculate the controller's gain, reset time, or rate time?

file i01717

Question 3

Read and outline Case History #52 ("Dynamics Can Suddenly Change In A Control Loop") from Michael Brown's collection of control loop optimization tutorials.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Any points of confusion, and precisely why you found the text confusing.
(5) Questions of your own you would pose to another reader, to challenge their understanding.
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

Be sure to answer the following questions:

- Examining the trend in Figure 1, how may we determine just by inspection of the PV graph that this controller has *too little integral* action and *too much proportional* action? Note there is no setpoint graph and no output graph displayed on this trend screen. Can we even tell for sure what mode the controller is in, without having Michael Brown tell us?

- Figure 2 shows the control valve responding very well to manual-mode (open-loop) step-changes in the controller's output. Comment on the features of this graph, identifying exactly how it reveals good valve performance and trim characteristics.

- Explain what happened in this control loop when they placed it in auto-cascade mode (with the flow controller now "slaved" to the level controller's output), and how Mr. Brown was able to properly identify the problem.

- Figure 6 shows another interesting problem discovered in the loop when operating in cascade mode. This trend shows the PV signal reaching 100% with the control valve at (only) about 81% open. Do you think this is a control valve problem or a transmitter problem? Explain your answer.

Suggestions for Socratic discussion

- Explain what "gain scheduling" is, and identify a synonym for it.
- Mr. Brown mentions "it is a good thing to put an output limit on a controller when there is an oversized valve in the loop". Explain what he means by an *output limit* on a controller, and why this would be a good idea to implement for an oversized control valve.
- Identify where "porpoising" behavior is revealed in one of this article's trend graphs. Explain why porpoising is always a bad thing for a control loop, and what causes it to happen.

file i02329

Question 4

Read and outline Case History #46 ("Analysis Uncovers Control Problems In A Process Plant") from Michael Brown's collection of control loop optimization tutorials.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Any points of confusion, and precisely why you found the text confusing.
(5) Questions of your own you would pose to another reader, to challenge their understanding.
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

Be sure to answer the following questions:

- Explain why, according to Mr. Brown, that most people working at highly automated facilities do not realize so many of their PID-controlled systems are performing poorly.

- The fact that poor PID tuning is so commonplace in industry, yet these industries continue to operate, reveals which kind of process type is most common: *self-regulating*, *integrating*, or *runaway*?

- When Mr. Brown works to optimize a control loop, he does so mainly using three specific tests. Identify what these tests are, and why they are performed in that order. Comment also on his technique, and how it contrasts with some conventional PID tuning approaches.

- One of the reasons the flow-control loop F0102 was never noticed as problematic is because the controller had excessive *filtering* programmed into it. Explain why this was a problem for control, and how the operations staff reacted when Mr. Brown removed the filtering. Is there any other place in this system filtering could have been active besides the DCS controller?

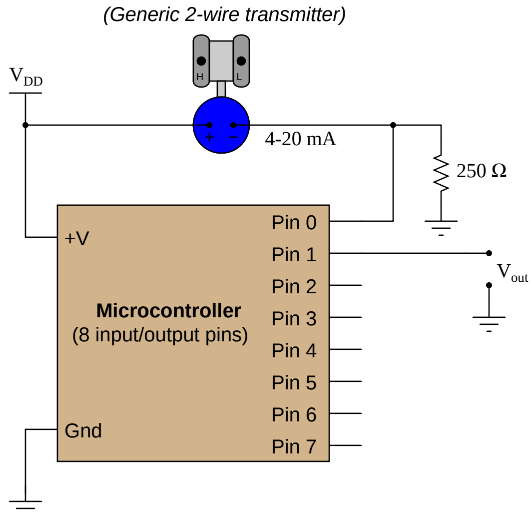
Suggestions for Socratic discussion

- Examining the trend graph shown in Figure 1, explain how we are able to tell that the controller was switched from automatic to manual mode (other than the text box Mr. Brown has added to the trend).
- Explain how we can tell that the control valve of loop F0102 is grossly oversized, both from an examination of the open-loop trend as well as from the closed-loop trend.

file i01549

Question 5

An instrumentation student programs a microcontroller to act as a proportional controller, but makes a mistake in writing his program:



Pseudocode listing

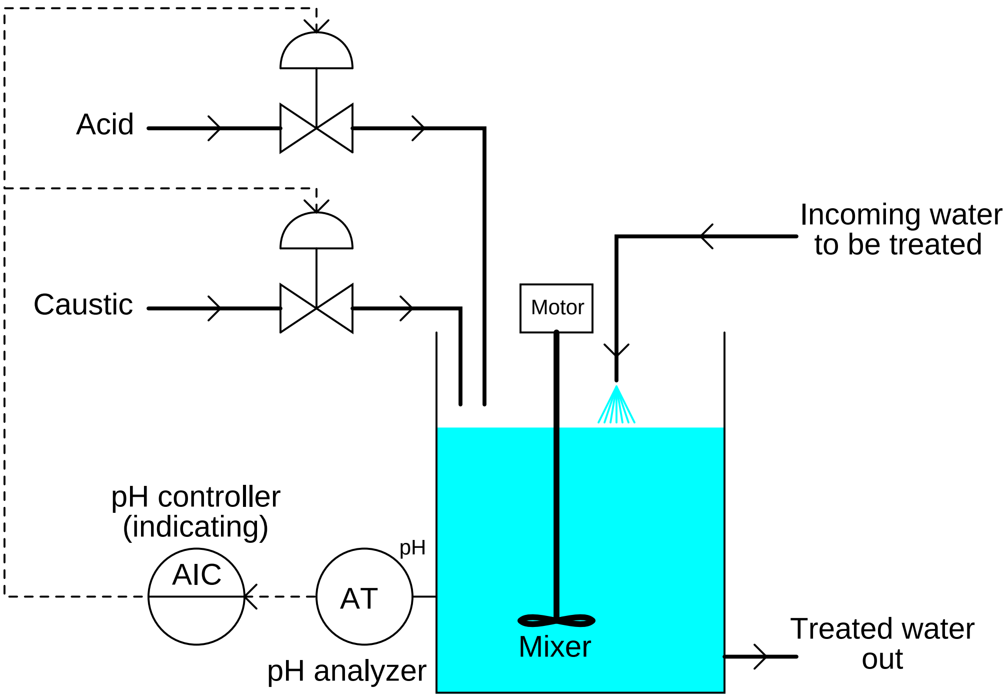
```
Declare Pin0 as an analog input (scale 0 to 5 volts = 0 to 1023)
Declare Pin1 as an analog output (scale 0 to 5 volts = 0 to 1023)
Declare SP as a variable, initially set to a value of 614
Declare ERROR as a variable
Declare GAIN as a variable, initially set to a value of 1.0
Declare BIAS as a constant = 614
Set ERROR = Pin0 - SP

LOOP
  Set Pin1 = (GAIN * ERROR) + BIAS
ENDLOOP
```

When executed, this program sets the output to a specific voltage value that never changes as the process variable changes (except when the microcontroller is re-started). Explain what is wrong with this program, and what is required to fix it. Also, identify whether this is programmed to be a *direct-acting* controller or a *reverse-acting* controller.

file i01497

Question 6

This pH control system adds either acid or caustic to the mixing tank (but never both at the same time!) to maintain a constant pH of the water. Recall that the addition of acid decreases the pH value of the water while the addition of caustic increases it. The pH analytical transmitter outputs 4 mA at a pH value of 4 pH and 20 mA at a pH value of 10 pH.



Assuming direct action in the controller, determine the proper split ranges of the two control valves:

Acid valve position	Controller output signal
Fully shut (0%)	??? mA
Wide open (100%)	??? mA

Caustic valve position	Controller output signal
Fully shut (0%)	??? mA
Wide open (100%)	??? mA

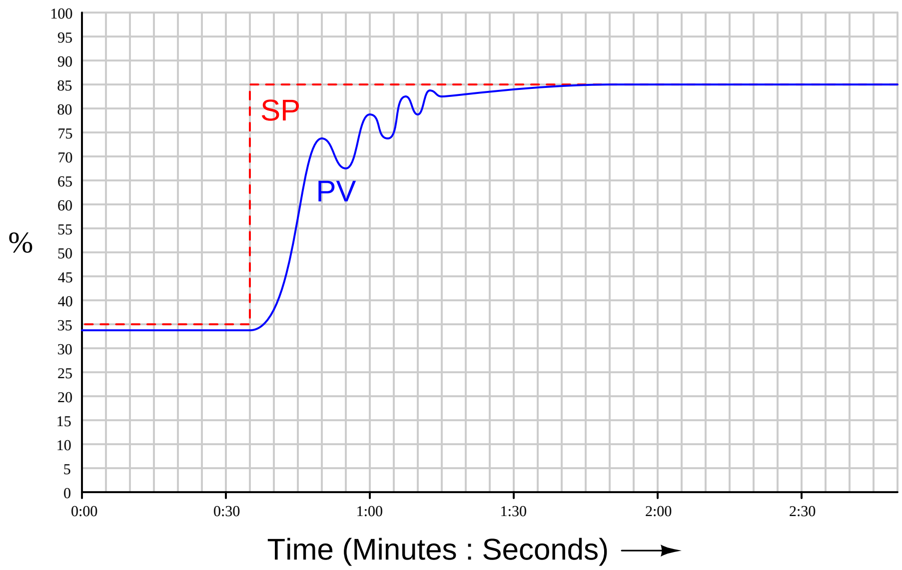
Suggestions for Socratic discussion

- Do you suspect this process will be self-regulating, integrating, or runaway? Explain your answer.
- Do you suspect this process will have substantial lag time? Explain your answer.
- Do you suspect this process will have multiple lags? Explain your answer.
- Do you suspect this process will have substantial dead time? Explain your answer.
- What exactly is *pH*, and why do we care about controlling this variable in wastewater?
- How is pH most commonly measured?
- Identify the consequence of losing instrument air to the control valves – what will happen to the effluent pH?

file i03782

Question 7

Examine this process trend, showing the response of the process variable to a 50% step change in the controller setpoint (placed in automatic mode). This is a P+I controller (no derivative), and the output trend is not shown:



Note how the process variable oscillates on its way up to the new setpoint value. This oscillatory motion *prior* to achieving setpoint (sometimes referred to by the charming term of "porpoising") is definitely the result of excessive proportional action and cannot be the result of integral action.

Explain how we can know this with confidence. How is it possible to tell, just from viewing the "porpoising" action of the process variable, that the controller has too much gain rather than too much reset? Expressed another way, how can we know with certainty that integral action is not responsible for the porpoising?

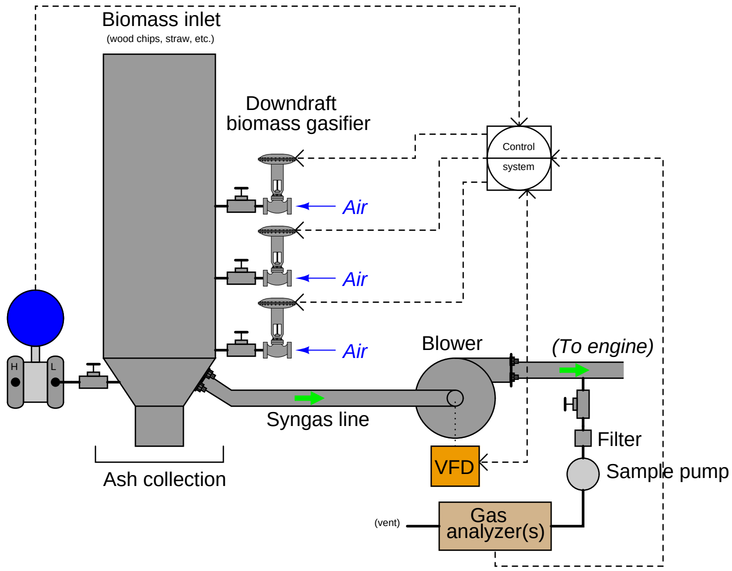
Suggestions for Socratic discussion

- What's wrong with porpoising anyway, so long as the PV never overshoots SP?
- How *would* a process variable oscillate if it were the integral action of the controller tuned too aggressively?
- Is there any way to tell from an examination of the closed-loop trend whether the cause of the porpoising is proportional action or derivative action?

file i03401

Question 8

Biomass gasification is a process where organic matter liberates flammable gases such as hydrogen (H_2) and carbon monoxide (CO) when heated to high temperatures. A *gasifier* is a machine designed to heat the organic matter to the necessary temperature (usually by partial combustion) in order for this to occur:



Besides hydrogen and carbon monoxide, there are other gases mixed in the "syngas" outlet from the gasifier, which we desire to measure in order to properly control the chemical reactions happening inside the gasifier. These include nitrogen oxide (NO) and carbon dioxide (CO_2). Upon investigation, you discover two different gas analyzer technologies capable of accurately measuring all these gases: one is an *NDIR* (Non-dispersive infra-red) analyzer with multiple detectors, and the other is a *chromatograph*. For this application, you happen to find analyzers of both types at comparable cost, which eliminates cost as a deciding factor when choosing the analyzer type.

NDIR analyzers typically have measurement dead times in the range of seconds, whereas chromatographs typically exhibit measurement dead times in the order of minutes. Based on this criterion, which is the preferred analyzer technology for closed-loop control, and most importantly *why?*

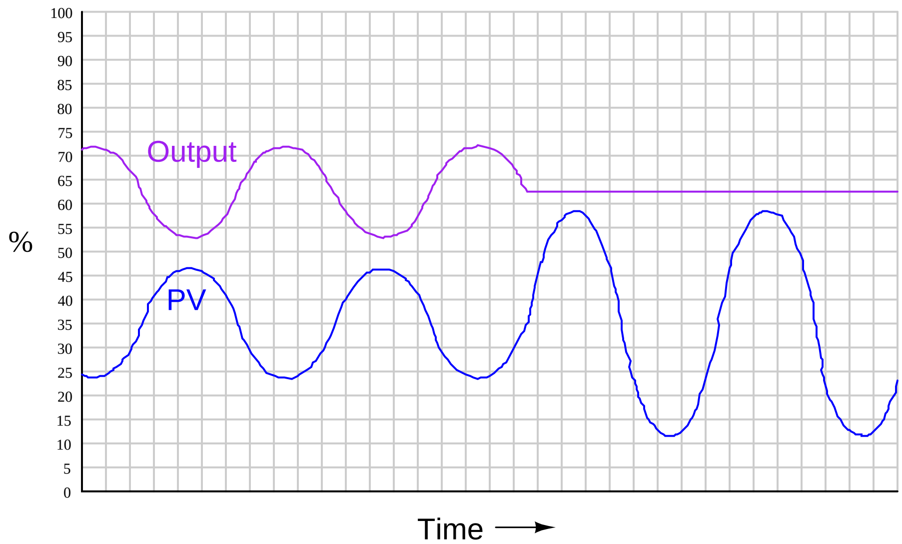
Suggestions for Socratic discussion

- Explain why the differential pressure transmitter has its *low-pressure* port connected to the gasifier (with the high-pressure port vented), rather than the other way around.
- Explain why a *VFD* is a good choice for a final control element on the syngas line, as opposed to a constant-speed blower and a control valve.
- Identify the most significant safety hazard(s) inherent to this process, as well as any PPE (Personal Protective Equipment) operators and technicians could use while working near it.

file i01535

Question 9

An operator calls you over to a DCS display to show you the trend of a "cycling" loop. Your first diagnostic test is to place the loop controller in manual mode. The results before and after the auto-to-manual mode change are captured on this trend:



The result of placing the controller in manual mode surprises you – if anything, you expected the PV to "calm down" rather than become *more* cyclic! Determine what this trend tells us about the nature of the cycling problem and its potential cause(s). Also, explain why placing the controller in manual mode was a good idea for diagnostic purposes.

If you were the instrument technician who discovered this, what would be your next diagnostic step?

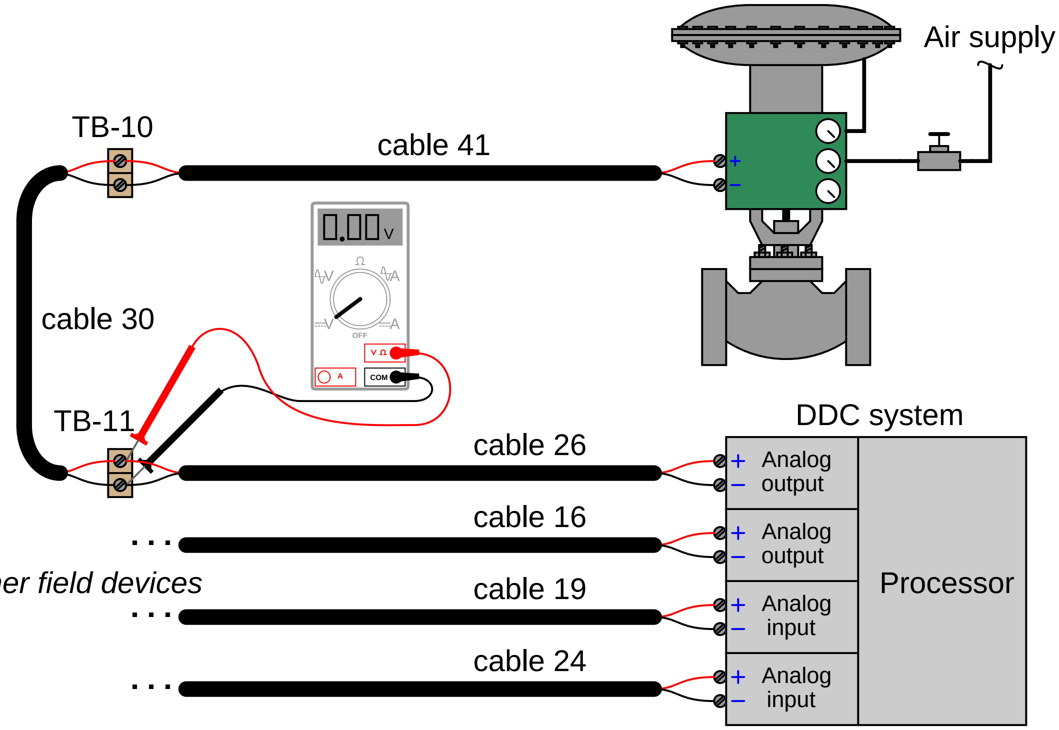
Suggestions for Socratic discussion

- Generally, the appearance of a nice, *sinusoidal* oscillation tells us something specific about the cause of the oscillation. What does the sinusoidal shape of the oscillation suggest to us?
- Based on this trend graph, can we tell whether this is a direct-acting or a reverse-acting controller? If so, which action is it?
- Based on this trend graph, can we identify the dominant control action (P, I, or D) of the controller? If so, identify which action is doing most of the work here.
- Based on this trend graph, can we identify the amount of gain (P action) is programmed in the controller? If so, estimate the controller's gain value.
- Based on this trend graph, can we identify the amount of gain in the process? If so, estimate the process gain value.

file i01648

Question 10

A DDC (Direct Digital Control) system used for building automation sends a 4-20 mA control signal to a steam valve with an electronic positioner. This particular loop has a problem, for the valve remains in the full-closed (0%) position regardless of what the DDC tries to tell it to do. A technician begins diagnosing the problem by taking a DC voltage measurement at terminal block TB-11 in this loop circuit:



The technician knows a reading of 0 volts could indicate either an "open" fault or a "shorted" fault in the wiring. Based on the location of the measured voltage (0.00 VDC), determine where in the wiring a single "open" fault would be located (if that is the culprit), and also where in the wiring a "short" fault would be located (if that is the culprit).

For the next diagnostic test, the technician disconnects the black wire of cable 30 where it attaches to the screw terminal on TB-10, and re-measures voltage at TB-11. After disconnecting the wire, the new voltage measurement at TB-11 still reads 0.00 volts. Determine what this result tells us about the nature and location of the fault.

What would be your recommended "next test" after this?

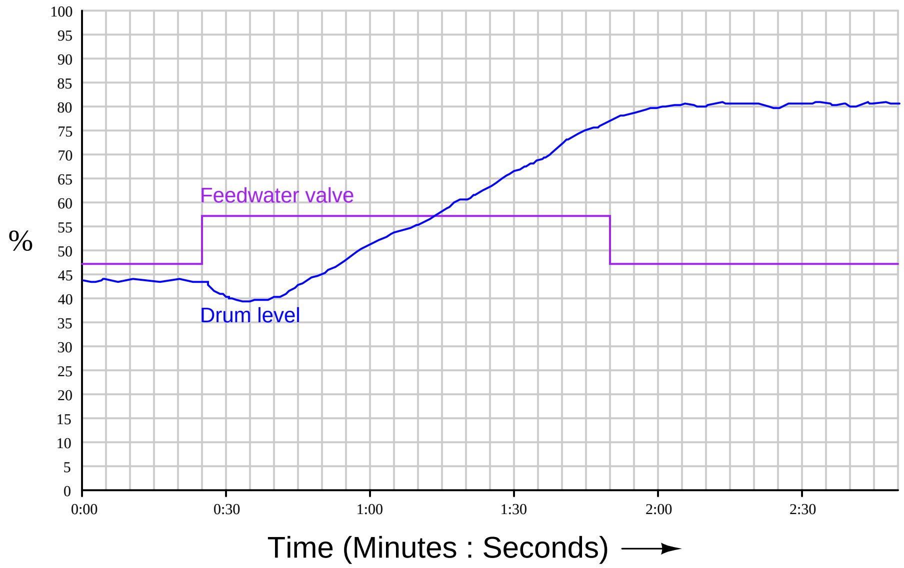
Suggestions for Socratic discussion

- Explain why it is critically important to determine the identities of the valve and DDC card as being either electrical *sources* or electrical *loads* when interpreting the diagnostic voltage measurements.
- Identify some of the pros and cons of this style of testing (measuring voltage at a set of points before and after a purposeful wiring break) compared to other forms of multimeter testing when looking for either an "open" or a "shorted" wiring fault.
- Identify a fault other than open or shorted cables which could account for all the symptoms and measurements we see in this troubleshooting scenario.

file i01527

Question 11

If the feedwater control valve for a boiler is placed in manual and then given a "step-change" in position, the effect on steam drum water level will look something like this:



It seems quite normal that water level would ramp up at a constant rate, liquid level control being a characteristically *integrating* process. However, that initial "shrink" in water level is quite unexpected to anyone unfamiliar with boiler controls.

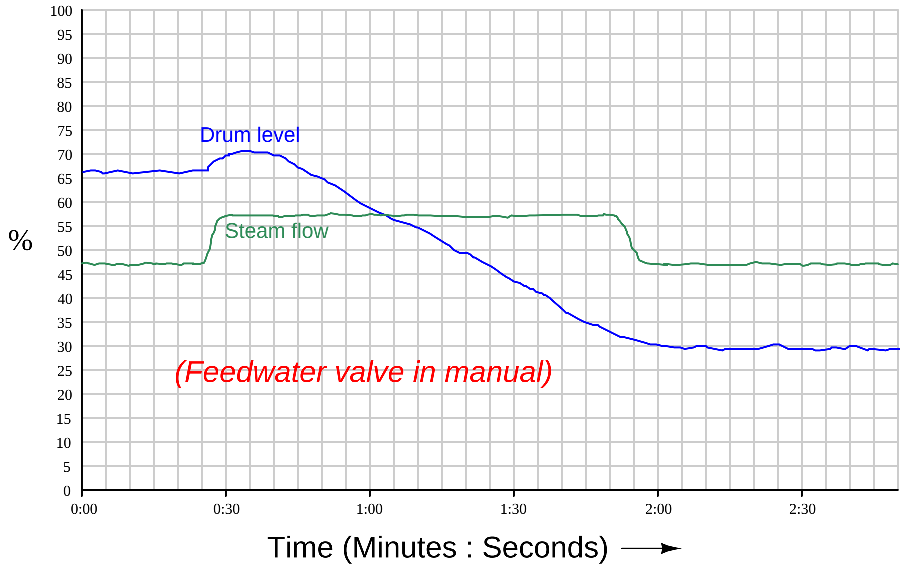
The shrink results from the addition of more (cool) feedwater to the boiler, which immediately reduces boiler temperature, causing some of the steam bubbles rising in the tubes and drum to re-condense into water. This artificially drops the steam drum level a bit before it begins to rise from the added water.

Boiler shrink is a problem for drum level control, because it makes the controller "think" the water level is moving *the wrong direction*. Explain how this physical effect negatively impacts feedback control, and determine whether the impact is more pronounced in a *single-element* or a *two-element* feedwater control system.

file i01798

Question 12

If the feedwater control valve for a boiler is placed in manual and then a "step-change" increase occurs in steam demand, the effect on steam drum water level will look something like this:



It seems quite normal that water level would ramp down at a constant rate with a greater steam flow (water being boiled away at a greater rate), liquid level control being a characteristically *integrating* process. However, that initial "swell" in water level is quite unexpected to anyone unfamiliar with boiler controls.

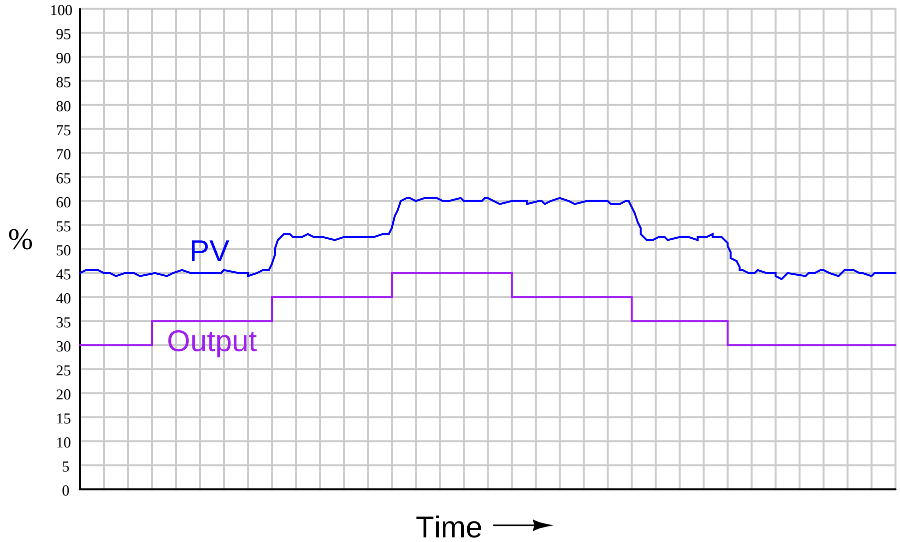
The swell results from an immediate reduction in boiler pressure following the increase in steam demand, causing more steam bubbles to form in the tubes and drum. This artificially swells the volume of fluid in the steam drum before it begins to decrease from the mismatch between higher steam demand and unchanged feedwater flow.

Boiler swell is a problem for drum level control, because it makes the controller "think" the water level is moving *the wrong direction*. Explain how this physical effect negatively impacts feedback control, and determine whether the impact is more pronounced in a *single-element* or a *two-element* feedwater control system.

file i01799

Question 13

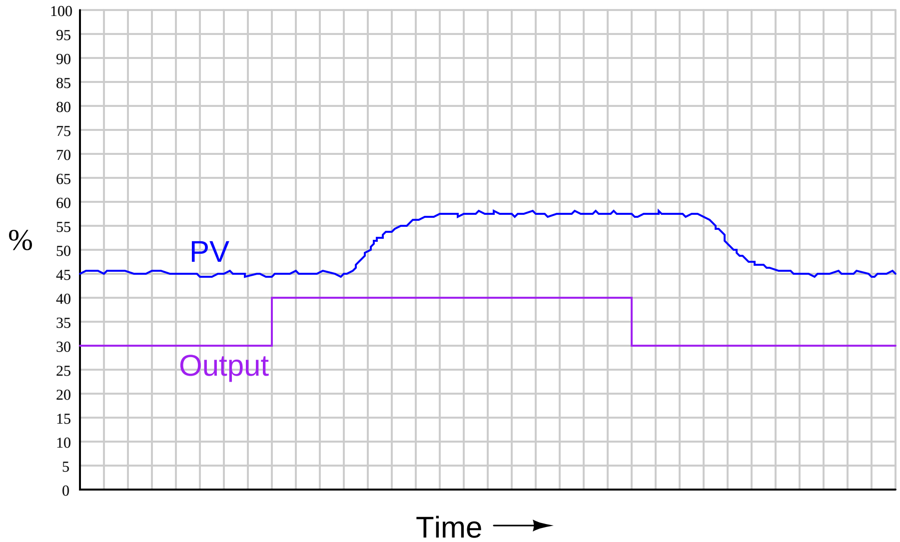
Shown here is the response of a process to a series of step-changes on the controller output (all made with the controller in "manual" mode). Based on your observations, what can you ascertain about the process and its related instrumentation?



file i01649

Question 14

Shown here is the response of a process to a series of step-changes on the controller output (all made with the controller in "manual" mode). Based on your observations, what can you ascertain about the process and its related instrumentation?

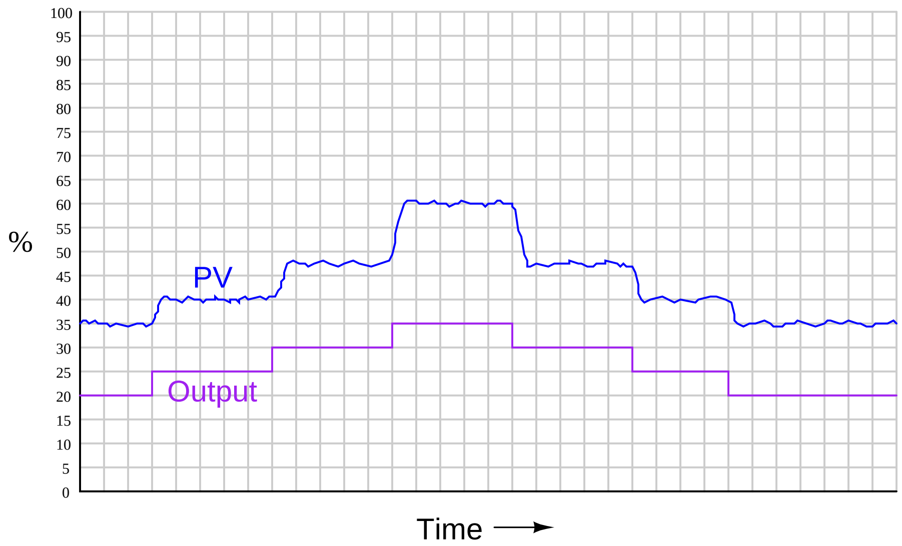


Also, calculate the *steady-state gain* (K) of this process, based on the trend shown above.

file i01650

Question 15

Shown here is the response of a process to a series of step-changes on the controller output (all made with the controller in "manual" mode). Based on your observations, what can you ascertain about the process and its related instrumentation?

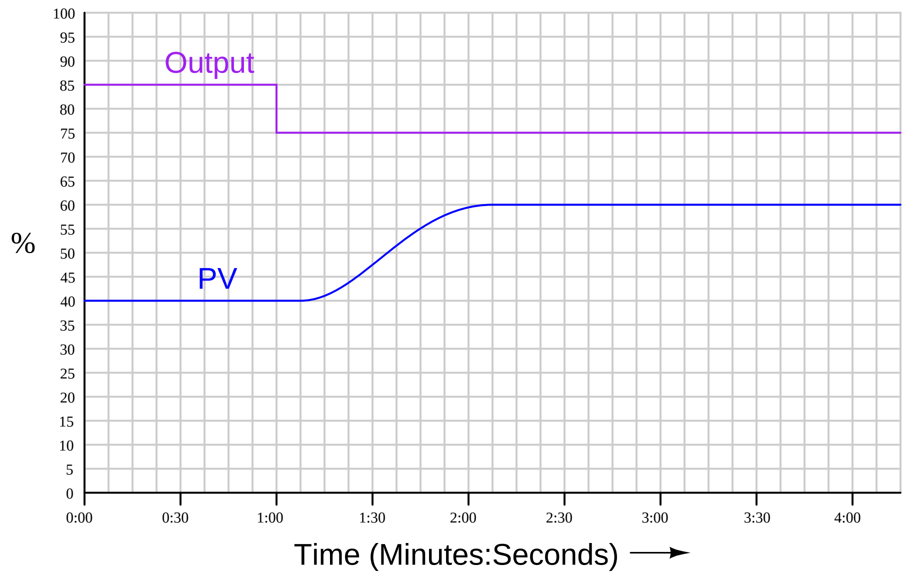


Is this process response a potential problem? If so, what type of problem is it?

file i01651

Question 16

Shown here is the response of a process to a single step-change on the controller output (made with the controller in "manual" mode). Based on your observations, determine the steady-state gain (K), dead time (L_R), and reaction rate (R_R):



$K =$ __________ $L_R =$ __________ $R_R =$ __________

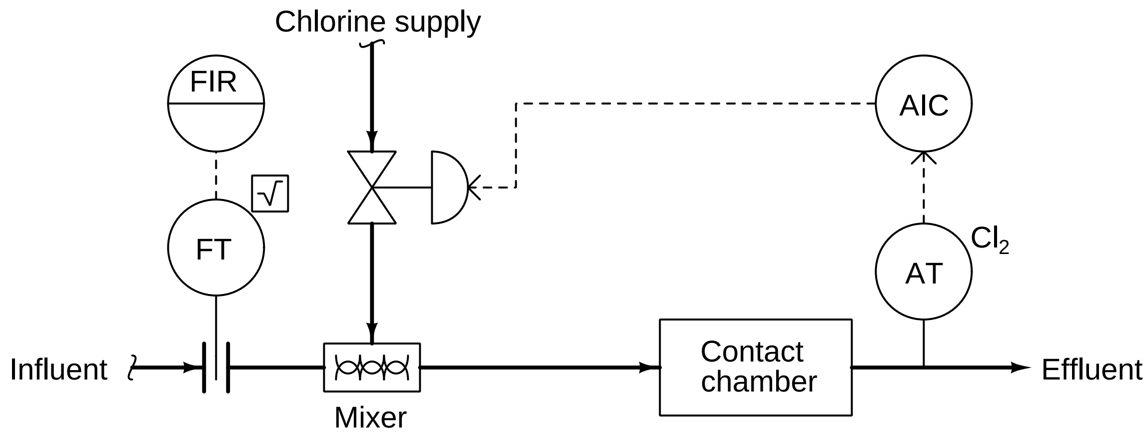
Also, determine whether the controller will need to be configured for *direct* or *reverse* action to successfully control this process.

file i01657

Question 17

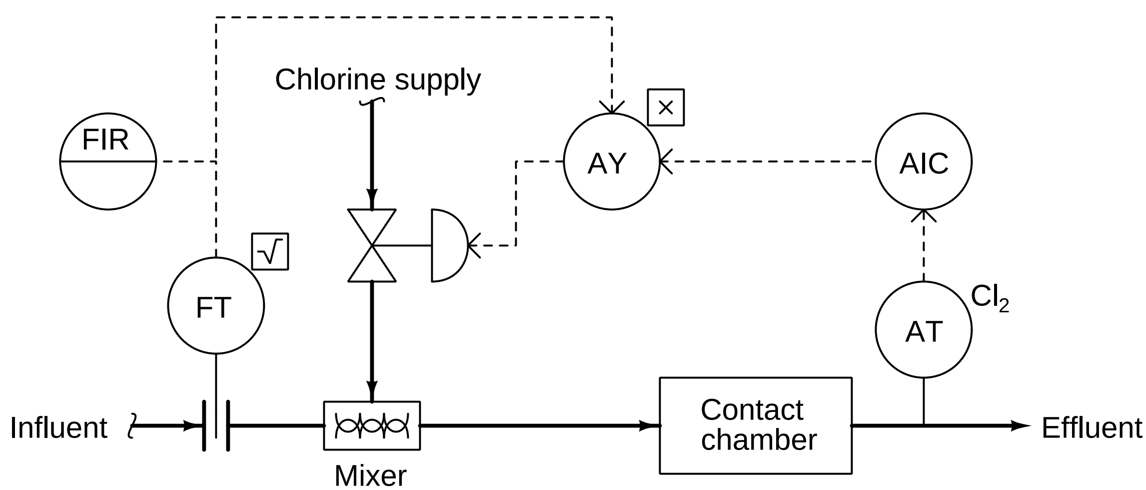
The following chlorine disinfection system (common to wastewater treatment systems) has a subtle problem the loop's stability changes with the weather. Influent in this case comes from the discharge of an open aeration lagoon, which collects rainwater during stormy weather but of course does not during dry weather.

When the influent water flow rate is low, the control system will oscillate. When the influent water flow rate is high, the system will respond sluggishly:

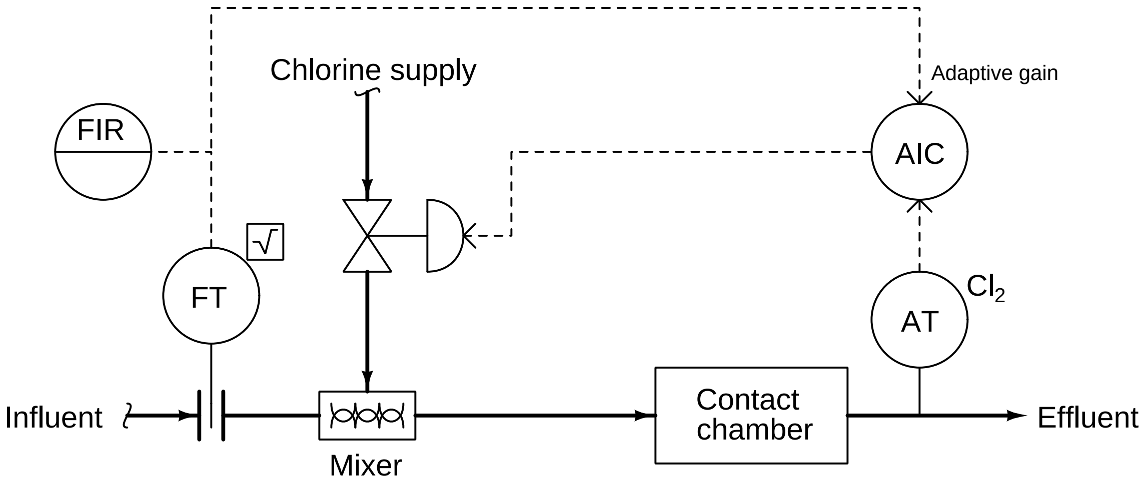


So far, instrument technicians' approach to solving this problem has been to re-adjust the PID tuning parameters seasonally. Identify how you think the controller's PID tuning parameters would need to be adjusted between the seasons and wet seasons, being as specific as you can. Explain *why* the process itself seems to control so differently based on influent flow rate.

Explain why the following modification will go a long way toward correcting this problem:



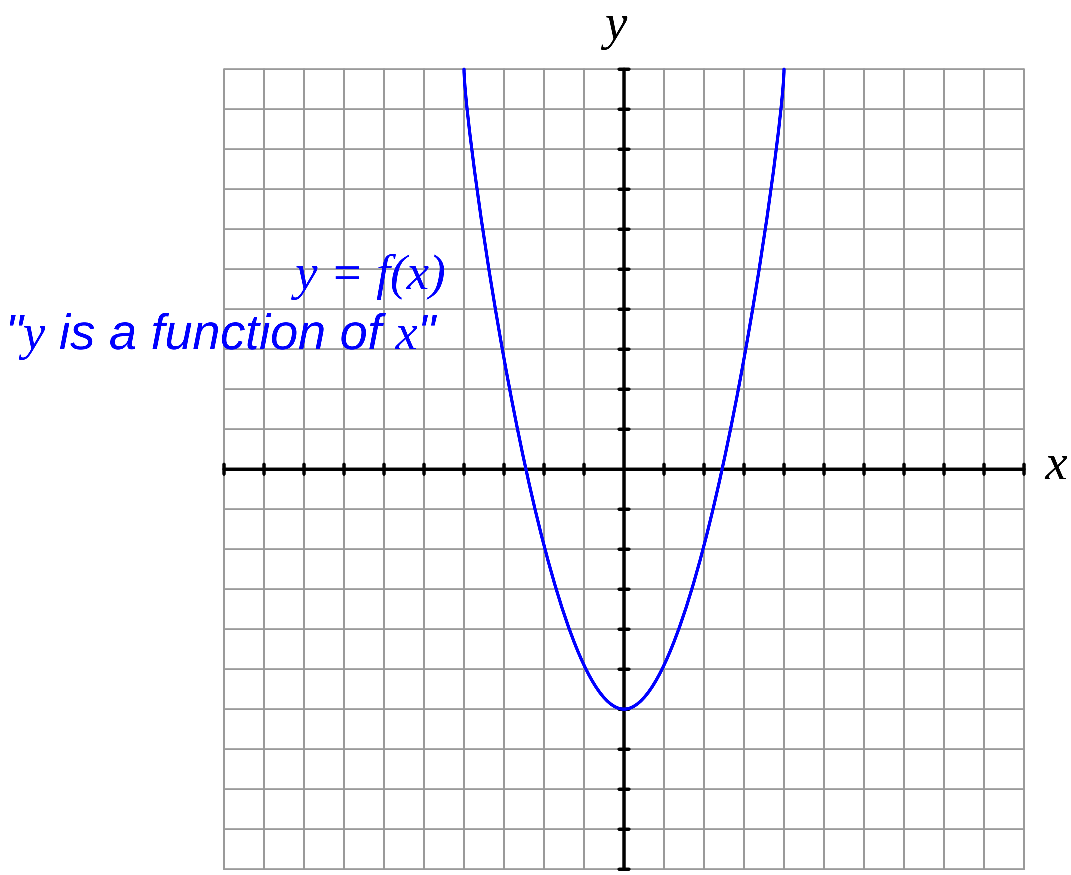
Explain why this next modification works as it does, being an alternative to the former solution:



file i01815

Question 18

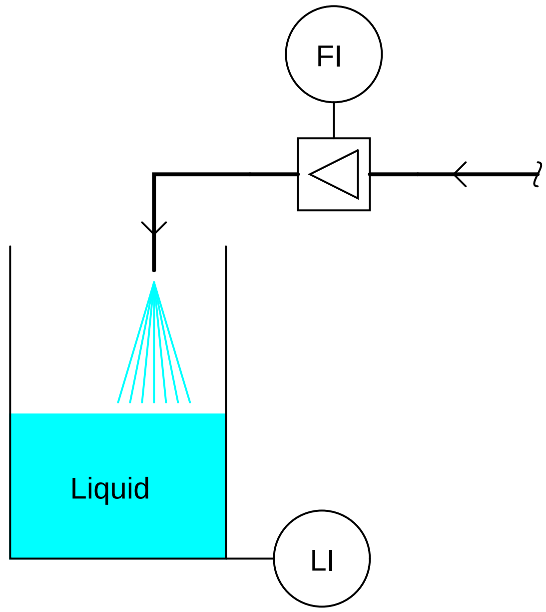
Qualitatively sketch the *derivative* of the function shown here. In other words, draw another function that describes how *quickly* the given curve changes:

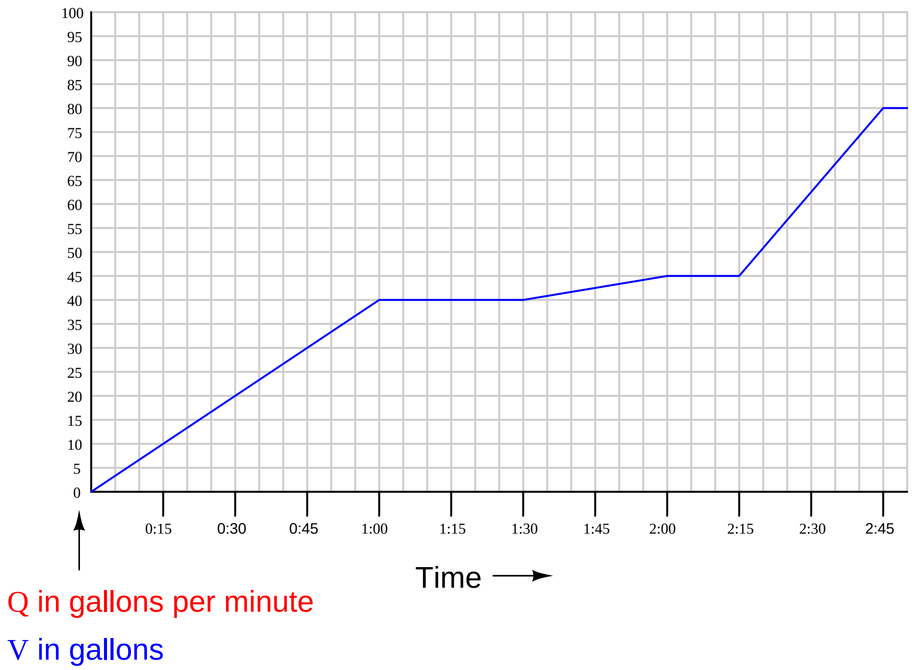


file i01532

Question 19

Plot the flow rate (Q) of liquid into this vessel, given the graph of liquid volume (V) accumulation over time. The function you graph (describing liquid flow) will be the *time-derivative* of the function shown (describing liquid volume):

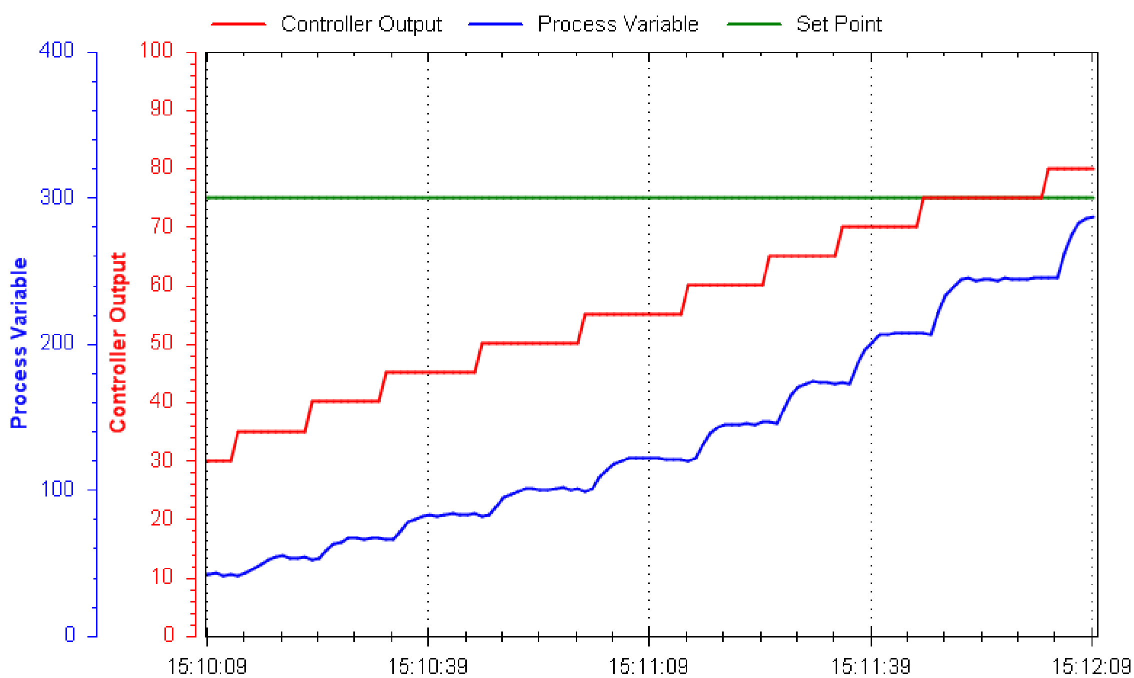




file i01531

Question 20

Examine this process trend showing the PV, SP, and Output of a loop controller:



Based on what you see here, determine the following:

- Whether this is an open-loop or a closed-loop response
- Whether the controller is (or needs to be) *direct-acting* or *reverse-acting*
- If possible, identify any problems with the field instrumentation
- If possible, identify any problems with the controller PID tuning
- Qualitatively identify the kind of PID tuning we will need for robust control

file i01925

Question 21

Read and outline Loop Problem Signatures #16 ("The Full PID Controller and Response to Setpoint or Load Changes") from Michael Brown's collection of control loop optimization tutorials.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Any points of confusion, and precisely why you found the text confusing.
(5) Questions of your own you would pose to another reader, to challenge their understanding.
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

Be sure to answer the following questions:

- According to Mr. Brown, most industrial control loops require different speeds of controller response to setpoint changes versus load changes. Which of these should a loop controller typically respond faster to, and what is the rationale for having the controller respond differently to the two types of changes?

- Identify a process type that definitely needs its controller to respond quickly to setpoint changes as well as load changes (i.e. an exception to the above rule).

- Some different PID algorithms have been designed to provide a difference in response between setpoint changes and load changes. Explain how they achieve this goal, and also what some of the disadvantages of these "different" PID algorithms are.

- Mr. Brown cites a specific case where the wrong selection of PID control algorithm led to annual losses for a manufacturing company estimated to be *14 million pounds!* (British). Explain why the "other" PID algorithm would have responded better, and why this particular company did not make the change throughout its facility.

file i01825

Question 22

Read and outline Case History #71 ("The Amazing Problem Free Plant") from Michael Brown's collection of control loop optimization tutorials.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Any points of confusion, and precisely why you found the text confusing.
(5) Questions of your own you would pose to another reader, to challenge their understanding.
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

Be sure to answer the following questions:

- At the beginning of this report, Mr. Brown cites an estimate where a plant with 30% of its automatic controls running inefficiently would incur an *opportunity cost* of $350,000 annually. Explain what this phrase "opportunity cost" means.

- Identify features in the graphs of Figure 1 showing *integral* controller action as well as *proportional* controller action. Also, explain how we may determine from this graph the fact that the control valve has problems, and explain how we may determine the direction of controller action (direct or reverse) from the trends.

- Examine the trend shown in Figure 3, and identify the problem revealed in it. Explain how we can tell this is a control valve "saturation" problem and not a transmitter "saturation" problem.

- On loop #7 at this plant – a level control loop – Mr. Brown recommended the application of filtering on the PV signal to deal with the large amount of noise. Why not just reduce the amount of proportional action in the controller and substitute with aggressive integral action instead?

Suggestions for Socratic discussion

- "Opportunity cost" is a very useful economic concept, with many practical applications in industrial as well as everyday (personal) life. Identify some opportunity costs in your own experience. Hint: what is/are the opportunity cost(s) of going to school full-time?
- The trend shown in Figure 1 reveals quite a bit about the controller's PID tuning. Examine the PV, SP, and Output trends and then explain what we may discern about the controller's tuning from this. Is the tuning P, I, or D-dominant? Can we calculate the controller's gain, reset time, or rate time?
- In Mr. Brown's analysis of loop #5, he concludes "Either the valve was passing, or it was stroked incorrectly." Explain what this statement means.

file i01550

Question 23

Read and outline Case History #61 ("The Case Of The Mysterious Cycle On A Paper Machine") from Michael Brown's collection of control loop optimization tutorials.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Any points of confusion, and precisely why you found the text confusing.
(5) Questions of your own you would pose to another reader, to challenge their understanding.
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

Be sure to answer the following questions:

- Describe the "blend chest" control loops illustrated in this case history, identifying all process variables and final control elements. Also, explain what a *refiner* does to wood pulp.

- One of the process variables common to wood pulp processing is *consistency*. What, exactly, is "consistency" of wood pulp, and what is done to the wood pulp in order to influence its consistency?

- In this report, Mr. Brown claims the actual liquid level control in the blend chest was not a critical parameter, and could vary significantly with no ill effect to the process. Explain why this is useful knowledge when optimizing control loops, especially in this particular case with wood pulp blending.

- Describe the diagnostic test(s) used in an attempt to locate the source of the mysterious (2-minute period) cycle.

- Identify what the source of the 2-minute cycle was determined to be, and why it was so difficult to find.

- In Figure 5 we see an open-loop test of a control valve, with non-linear installed characteristics. Assuming this valve had a "linear" trim from the factory, which trim characteristic might we replace it with, *quick-opening* or *equal-percentage*? Explain why, from the graph.

Suggestions for Socratic discussion

- Explain the purpose and operation of the *bypass flow* controller shown in the diagram of Figure 2. What effect does this flow controller have on the level of pulp in the blend chest?
- One of the pulp flows into this blend chest is called *broke*, which is pulp made from rejected paper product recovered from later steps in the paper-making process. The pulp and paper industry is unusually abundant with a range of bizarre terms and labels for parts of the process. Why do you suppose this particular term is used to refer to re-pulped paper?
- The inconsistent process gains observed in the open-loop test of Figure 5 might very well be caused by the wrong characteristic of valve, but there is another possible cause as well. Assuming a valve with truly linear (installed) behavior, explain why this same gain problem could have been caused by (wrongly) having square-root extraction programmed into the DP flow transmitter *and* the flow controller's input.
- Why would long filter time constants programmed into some of the magnetic flowmeters at this pulp mill pose a problem for good control?

- Explain why there is no refiner on the "broke" pulp line, as there are on both of the other pulp lines. Bear in mind that the purpose of a refiner is to break long wood fibers into shorter wood fibers.

  file i01565

Question 24

Read and outline Case History #29 ("Scan Rate Problem In a DCS On a Fast Loop") from Michael Brown's collection of control loop optimization tutorials.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Any points of confusion, and precisely why you found the text confusing.
(5) Questions of your own you would pose to another reader, to challenge their understanding.
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

Be sure to answer the following questions:

- The control strategy in this example is similar to a *split-ranged* valve loop. Explain both the similarities and the differences, and also *why* this control system is designed like this.

- Explain how the poor performance of this gas pressure-control loop actually created monetary loss on the oil rig.

- Examine the closed-loop trend of Figure 2, and determine the dominant mode of control (P, I, or D). Does this mode make sense for the type of process this is (pressure control with large volumes)?

- Explain what is meant by the phrase, "Scan Rate" in a digital computer system, and why this is significant when using a computer to control a process.

- Examine Figures 2 and 3, then explain how we can tell from these trends that the scan rate of the DCS is slow. Also explain why one of the ratio block outputs had a much slower scan rate than the other.

- Explain why Mr. Brown was unable to properly fix the problem during his visit to the oil rig.

- Examine the closed-loop trend of Figure 4, and determine the dominant mode of control (P, I, or D) with Mr. Brown's new tuning. How does it differ from the "As-Found" tuning of Figure 2?

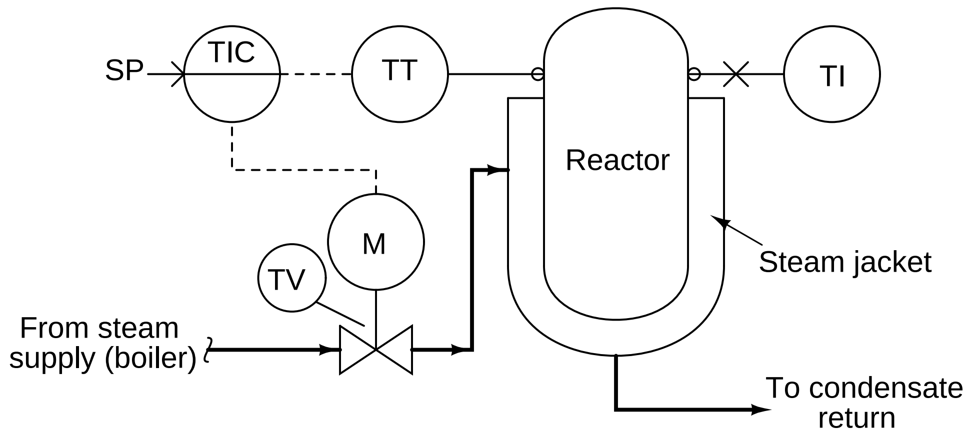
Suggestions for Socratic discussion

- Why do you think computer control systems like this have adjustable scan rates for different function blocks? What possible benefit might there be to operating a function with a very slow scan rate?
- At first one might be inclined to say that the trend shown in Figure 2 is open-loop (manual mode) rather than closed-loop (automatic mode), but it is in fact closed-loop. Explain why the trend is misleading, and what is causing its unusual appearance.
- How fast is the scan rate on your team's controlled process? If this parameter is not advertised by the manufacturer, how could you measure the scan rate?
- Examine the C language source code of caSCADA "pid" and determine how its scan rate is specified (hint: look for the `nanosleep()` function), then try altering this scan rate to see the effect it has on the control of a real process.

file i01573

Question 25

Consider this control system, set up to maintain the temperature of a chemical reactor vessel at a constant ("setpoint") value. The reactor's source of heat is a steam "jacket" where hot steam is admitted through a motor-operated (M) control valve (TV) according to the temperature inside the reactor sensed by the temperature transmitter (TT):



You arrive at work one day to find the operator very upset. The last batch of product emptied from the reactor was out of spec, as though the temperature were too cold, yet the controller (TIC) displays the temperature to be right at setpoint where it should be: 175 ^{o}F.

Your first step is to go to the reactor and look at the temperature indicating gauge (TI) mounted near the same point as the temperature transmitter. It registers a temperature of only 137 ^{o}F.

From this information, determine what is the most likely source of the problem, and explain how you made that determination.

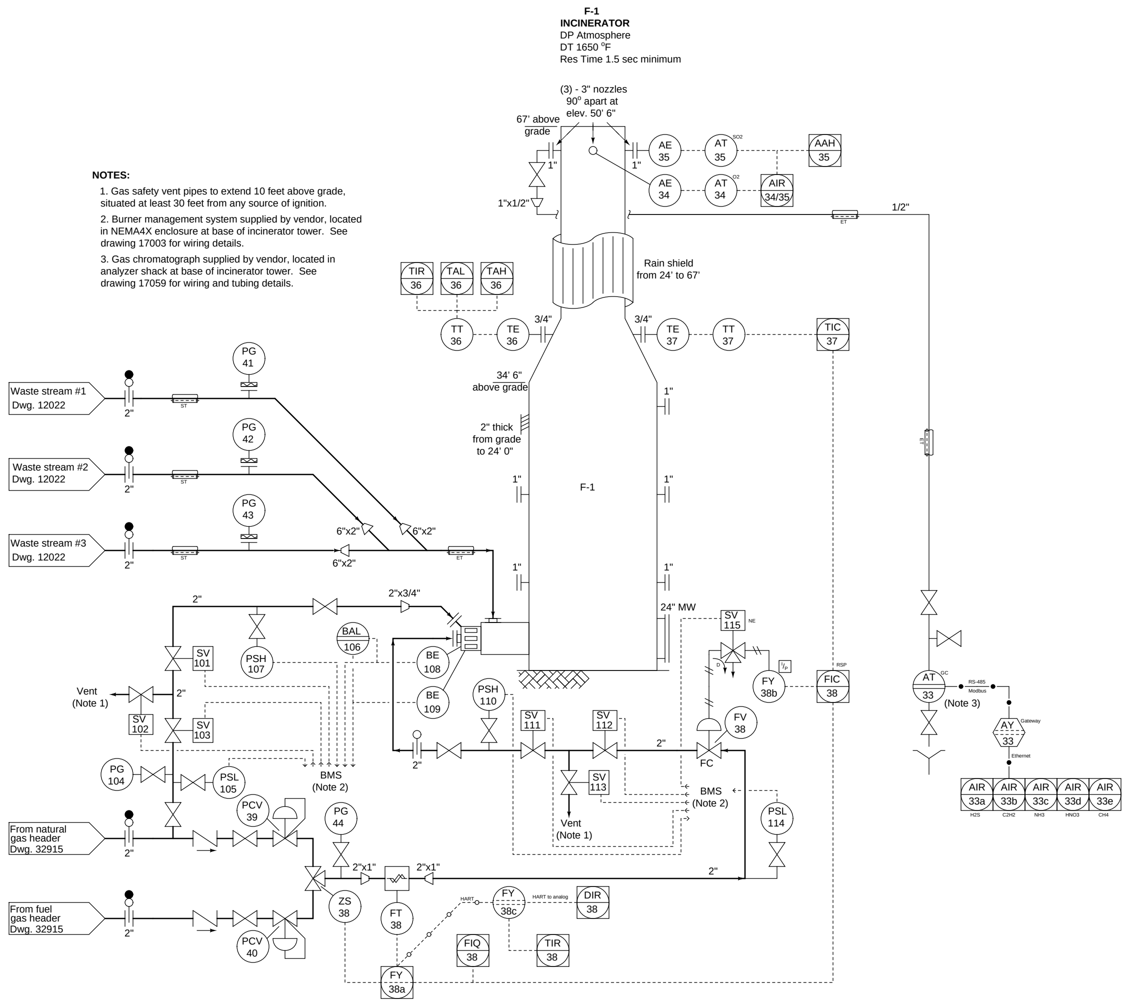
Suggestions for Socratic discussion

- Why was it a good decision to consult the temperature gauge (TI) on the reactor as a first diagnostic step?
- Suppose a fellow instrument technician were to suggest to you that the problem in this system could be a controller configured for the wrong action (e.g. direct action instead of reverse action). Do you think this is a plausible explanation for the symptoms reported here? Why or why not?
- Could the problem be that someone left the controller in *manual* mode rather than automatic mode as it should be? Explain why or why not.
- Based on the P&ID shown, are the instruments pneumatic or electronic?
- Given the fact that we know this reactor is steam-heated, is it possible to conclude that the chemical reaction taking place inside it is either endothermic (heat-absorbing) or exothermic (heat-releasing)?
- Safety shutdown systems often use a "two-out-of-three" (2oo3) voting algorithm to select the best measurement from three redundant transmitters. Explain how this same concept may be applied by the instrument technician in the course of troubleshooting the problem.

file i00137

Question 26

A *burner management system* (BMS) monitors the status of the flame at the base of this incinerator, to ensure fuel gas does not keep entering the combustion chamber unless there is an established fire to burn it:



Explain the purpose of solenoid valve SV-115, identifying whether it is normally energized (NE) or normally de-energized (NDE).

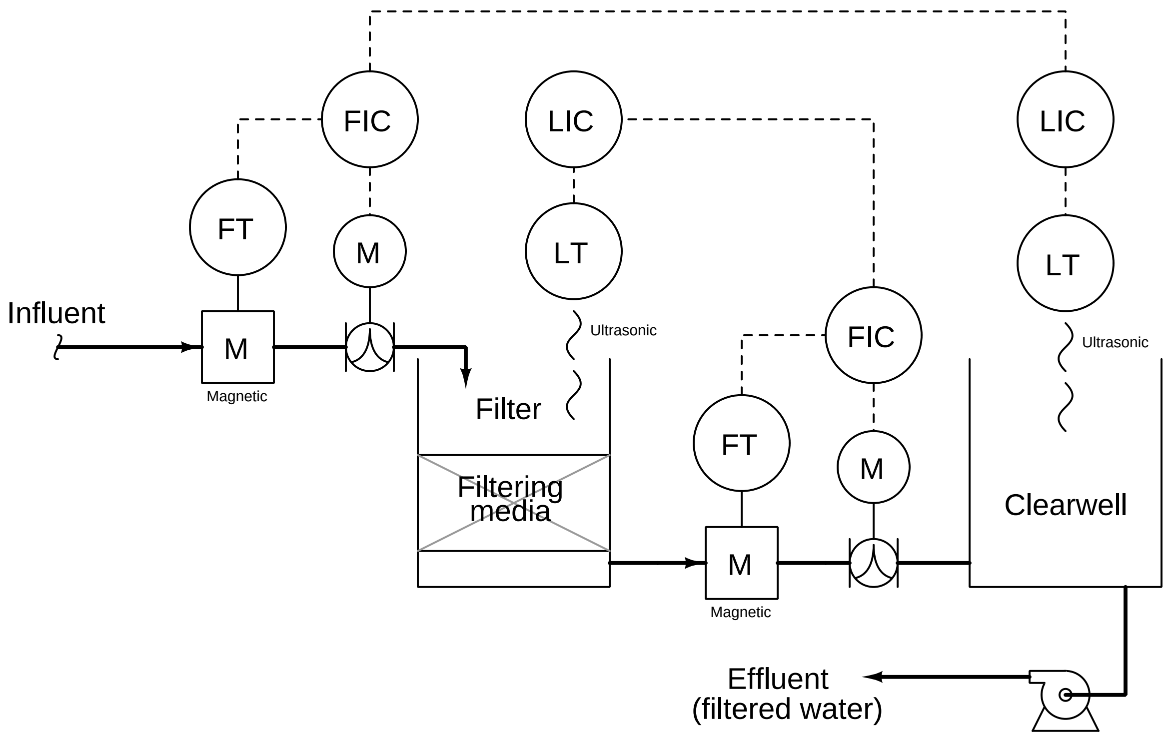
Suggestions for Socratic discussion

- Is it possible to determine the "normal" energization statuses of solenoid valves SV-111, SV-112, and/or SV-113 from the information given in the diagram? Explain why or why not.
- Explain what may happen in this system if solenoid SV-111 were to fail.
- Explain what may happen in this system if solenoid SV-103 were to fail.
- Explain what may happen in this system if solenoid SV-113 were to fail.
- Explain what may happen in this system if solenoid SV-102 were to fail.

file i00866

Question 27

Examine this water filter control system, then answer the following questions:



- Identify all primary and secondary (cascaded) loops.
- The necessary control actions (direct/reverse) for each controller, assuming direct-acting transmitters and signal-to-open control valves.
- What will happen to the filter water level if the influent supply suddenly shuts off?
- What will happen to the clearwell reservoir water level if the influent supply suddenly shuts off?

Suggestions for Socratic discussion

- A useful analytical technique for any complex control system is to annotate the diagram with "+" and "−" symbols at the instrument bubble inputs, designating "noninverting" and "inverting" characteristics, respectively. Show how this helps you track of all directions of action, making it easier to figure out how the control system responds to changes.
- For those students who have studied level measurement, what kind of transmitters are being used here and how do they function?
- For those students who have studied flow measurement, what kind of transmitters are being used here and how do they function?
- For those who have studied PID tuning, what PID tuning parameters (qualitative) would you recommend for each controller in this system?
- Explain what will happen in this system if the influent water pressure increases?
- Explain what will happen in this system if the influent water pressure decreases?
- Explain what will happen in this system if the effluent water demand (flow) increases?
- Explain what will happen in this system if the effluent water demand (flow) decreases?
- Explain what will happen in this system if the influent flow transmitter fails with a low signal.

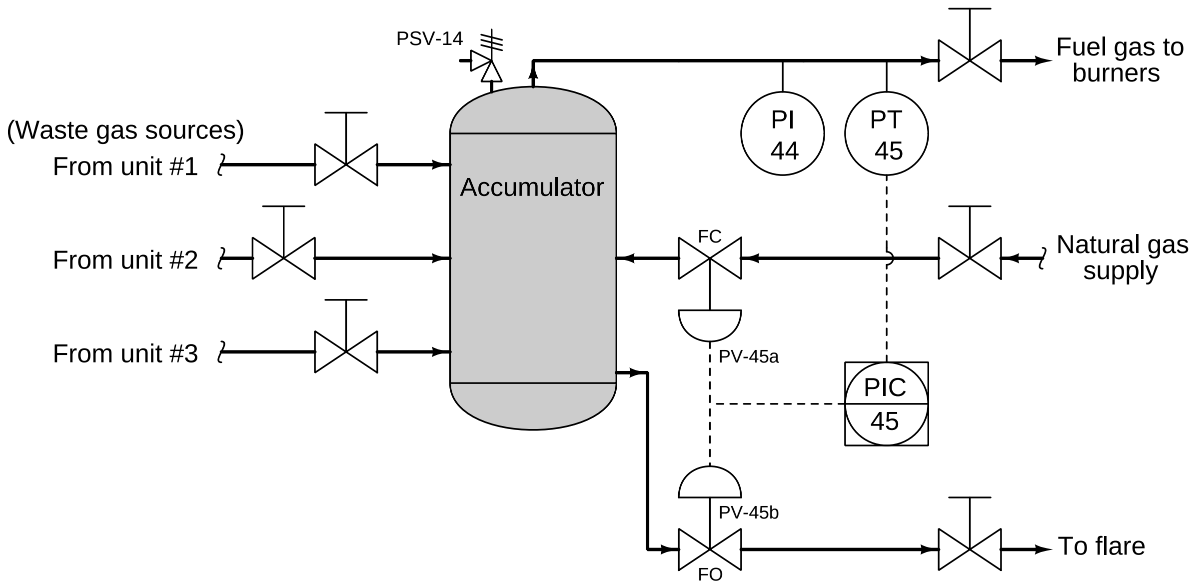
- Explain what will happen in this system if the influent flow transmitter fails with a high signal.
- Explain what will happen in this system if the filter level transmitter fails with a low signal.
- Explain what will happen in this system if the filter level transmitter fails with a high signal.
- Explain what will happen in this system if the clearwell level transmitter fails with a low signal.
- Explain what will happen in this system if the clearwell level transmitter fails with a high signal.

file i01812

Question 28

Many flammable gases are produced in chemical processing and oil refineries as "waste" products. These "waste" gases may be used as fuel for steam boilers and combustion heaters in other parts of the refinery. The problem is, "waste" fuel gas production is often unsteady, and the demand for fuel gas in boilers and heaters is unsteady as well. There are times when there will be a surplus of waste gas (more than can be used), and times when there will not be enough.

The following pressure control system works to maintain constant fuel gas pressure in the accumulator vessel despite changes in waste gas flows and fuel gas demands:



Identify the proper split-ranges for control valves PV-45a and PV-45b, given the purpose of the control system and the necessary fail-safe modes for each valve as shown in the P&ID, assuming they are driven off the exact same 4-20 mA signal from PIC-45. Also, determine the necessary action (direct or reverse) for PIC-45:

Valve	Fully closed at (mA)	Fully open at (mA)
PV-45a		
PV-45b		

Suppose an operator shut the flare line block valve during the last "turnaround" (complete system shut-down for maintenance), locking it in place and labeling the valve with a safety tag (lock-out, tag-out), then forgetting to unlock and open the valve prior to system start-up. What effect would this locked valve have on the operation of the system? What process symptoms, if any, would indicate that the flare block valve was still shut? What would be the proper way to remove the operator's lock and tag so that the block valve could be opened?

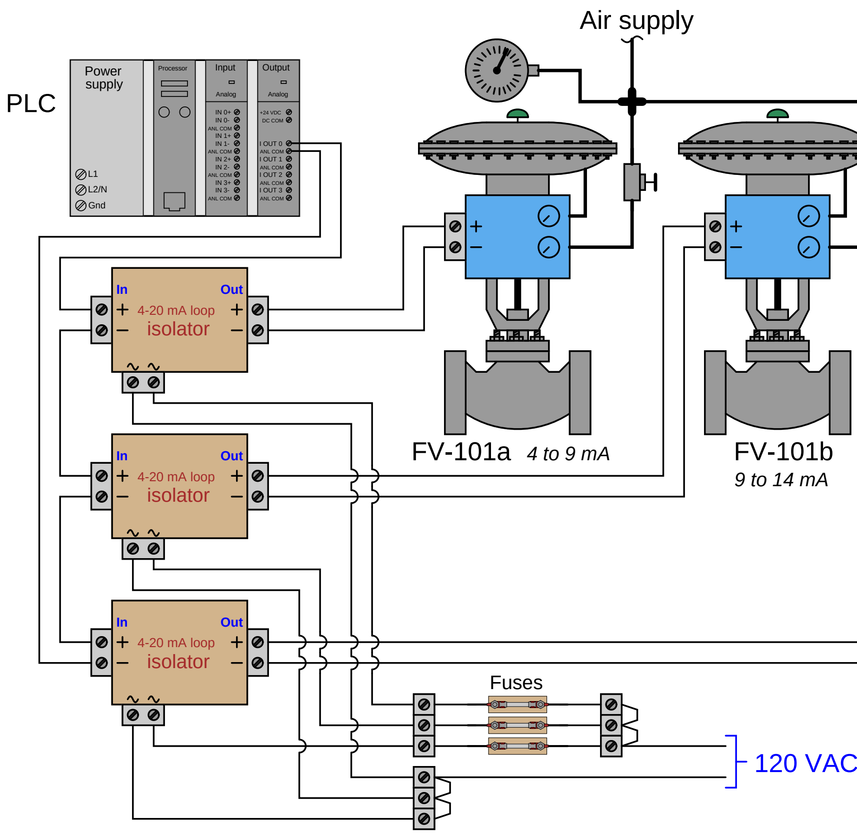
Suggestions for Socratic discussion

- Explain the possible rationale for closing and locking the flare block valve during the turnaround.
- Describe how this pressure control system will respond if PT-45 fails with a high signal.
- Describe how this pressure control system will respond if the instrument air to FV-45a fails.
- Describe how this pressure control system will respond if the instrument air to FV-45b fails.

file i01526

Question 29

This split-ranged valve system uses *4-20 mA isolators* to drive identical current signals to each of three progressively split-ranged control valves, because the PLC's analog output card does not produce enough voltage to successfully power all three valve positioners if connected in series:



Unfortunately, this system has a problem. When the PLC attempts to drive an output signal of 70%, FV-101a is wide open, FV-101b is 86% open, and FV-101c is 20% open.

Determine the diagnostic value of each of the following tests. Assume only one fault in the system, including any single component or any single wire/cable/tube connecting components together. If a proposed test could provide new information to help you identify the location and/or nature of the one fault, mark "yes." Otherwise, if a proposed test would not reveal anything relevant to identifying the fault (already discernible from the measurements and symptoms given so far), mark "no."

Diagnostic test	**Yes**	**No**
Check main air supply pressure gauge indication		
Check FV-101a positioner supply pressure gauge indication		
Check FV-101b positioner supply pressure gauge indication		
Check FV-101c positioner supply pressure gauge indication		
Measure DC current at PLC output card terminals		
Measure DC current at FV-101a positioner terminals		
Measure DC current at FV-101b positioner terminals		
Measure DC current at FV-101c positioner terminals		

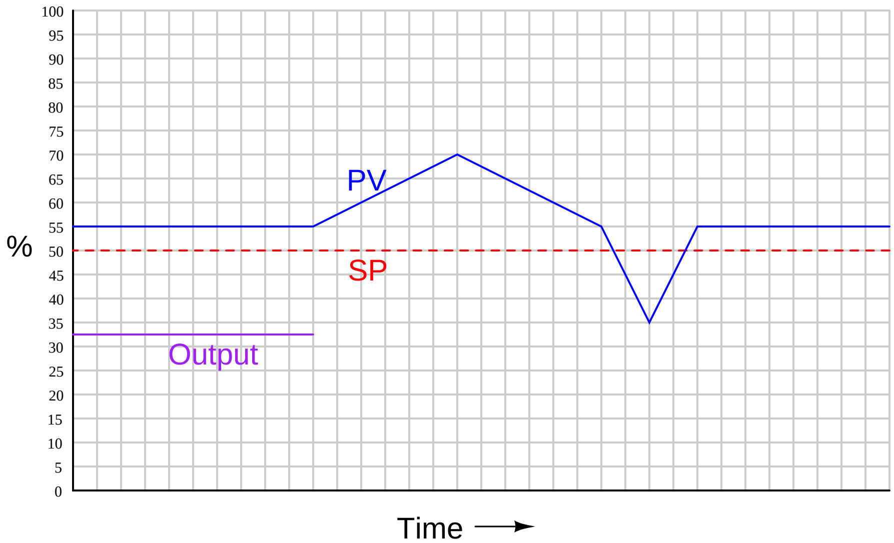
Suggestions for Socratic discussion

- A problem-solving technique useful for making proper connections in pictorial circuit diagrams is to first identify the directions of all DC currents entering and exiting component terminals, as well as the respective voltage polarity marks (+,−) for those terminals, based on your knowledge of each component acting either as an electrical *source* or an electrical *load*. Discuss and compare how these arrows and polarity marks simplify the task of properly connecting wires between components.

file i01455

Question 30

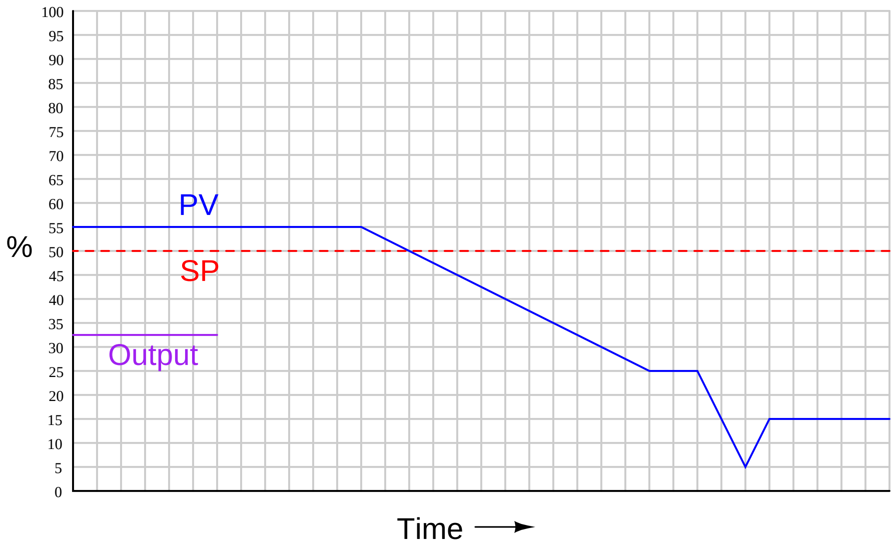
Qualitatively graph the response of an hypothetical derivative-only controller over time to the following changes in process variable:



Assume *reverse* control action.
file i01537

Question 31

Qualitatively graph the response of an hypothetical derivative-only controller over time to the following changes in process variable:

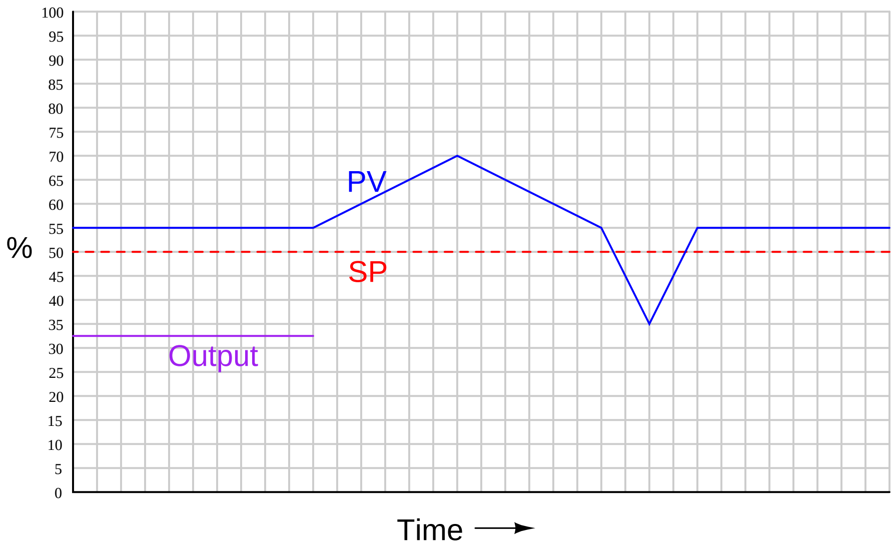


Assume *reverse* control action.

file i01538

Question 32

Qualitatively graph the response of a proportional-only controller over time to the following changes in process variable:

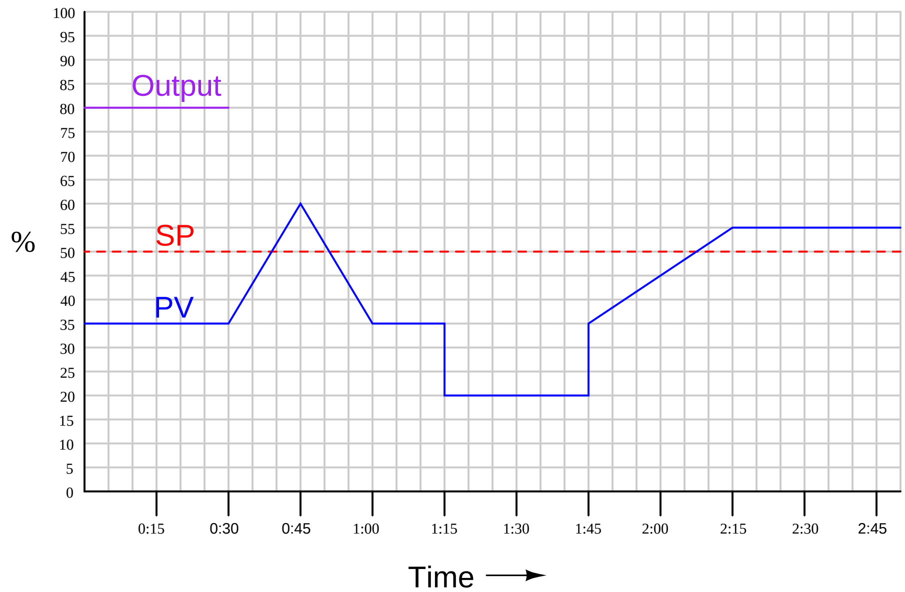


Assume *reverse* control action.

file i01536

Question 33

Graph the response of a proportional+derivative controller to the following input conditions, assuming a proportional band of 200% and a derivative constant of 15 seconds. The controller's action is *reverse*, and the algorithm it follows is shown below the graph:



The time scale on the chart is minutes:seconds, and the P+D algorithm is as follows:

$$m = K_p \left(e + \tau_d \frac{de}{dt} \right) + b$$

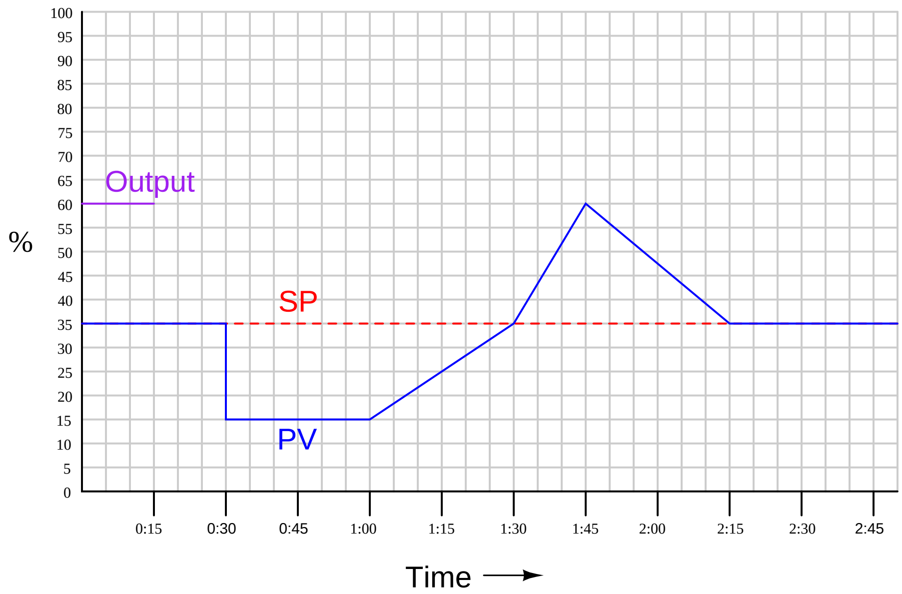
Where,

m = Controller output (manipulated variable)
K_p = Gain
e = Error signal (SP−PV)
τ_d = Derivative time constant
b = Bias

file i01546

Question 34

Graph *just the derivative response* a proportional+derivative controller to the following input conditions, assuming a proportional band of 500% and a derivative constant of 1.5 minutes. The controller's action is *direct*, and the algorithm it follows is shown below the graph:



The time scale on the chart is minutes:seconds, and the P+D algorithm is as follows:

$$m = K_p \left(e + \tau_d \frac{de}{dt} \right) + b$$

Where,

m = Controller output (manipulated variable)

K_p = Gain

e = Error signal (PV−SP)

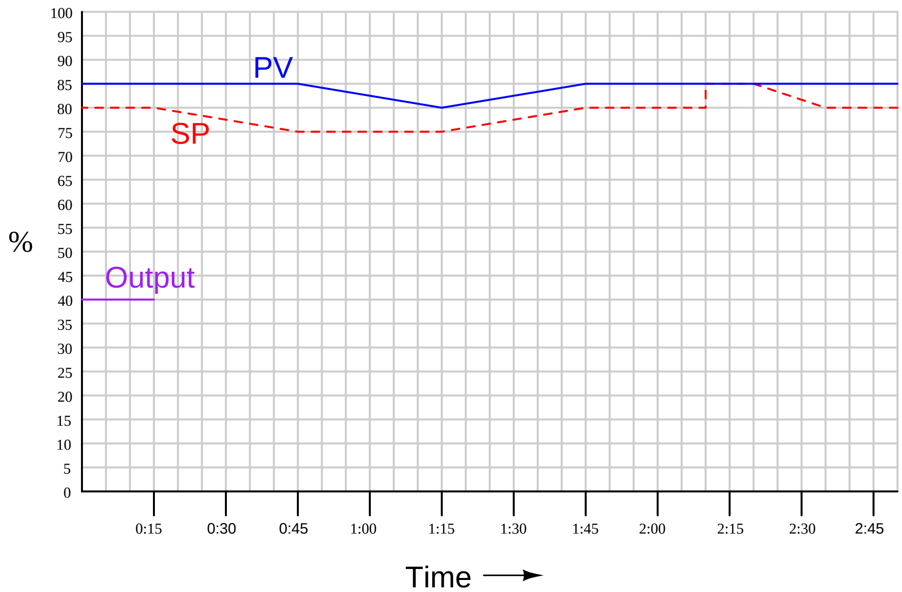
τ_d = Derivative time constant

b = Bias

file i01547

Question 35

Graph *just the derivative response* a proportional+derivative controller to the following input conditions, assuming a proportional band of 250% and a derivative constant of 4 minutes. The controller's action is *reverse*, and the algorithm it follows is shown below the graph:



The time scale on the chart is minutes:seconds, and the P+D algorithm is as follows:

$$m = K_p \left(e + \tau_d \frac{de}{dt} \right) + b$$

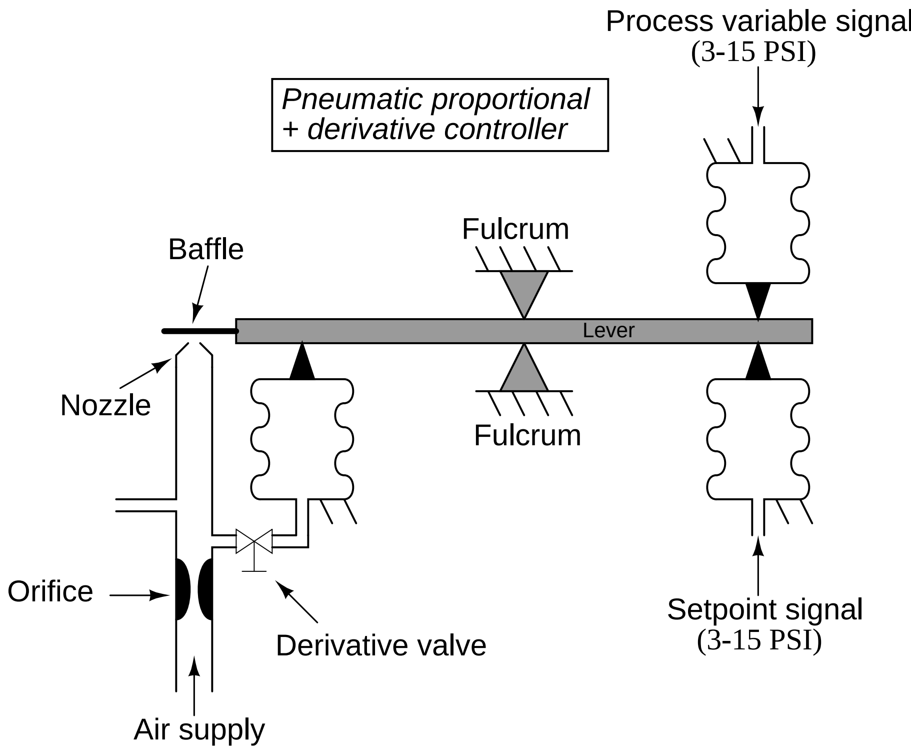
Where,

m = Controller output (manipulated variable)
K_p = Gain
e = Error signal (SP−PV)
τ_d = Derivative time constant
b = Bias

file i01548

Question 36

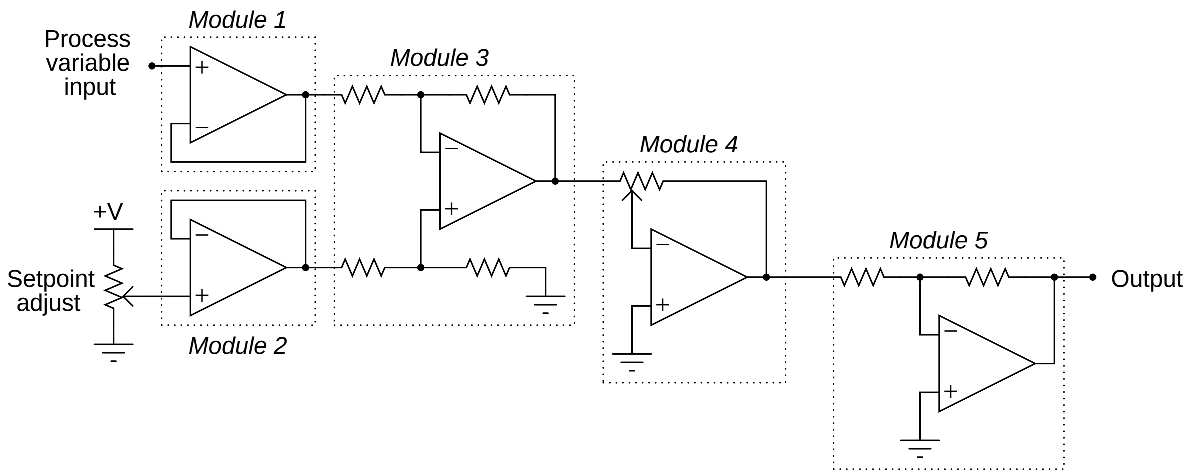
Explain what you would have to do to this pneumatic controller mechanism to *increase* the derivative time constant (τ_d) and also explain why it works:



file i01551

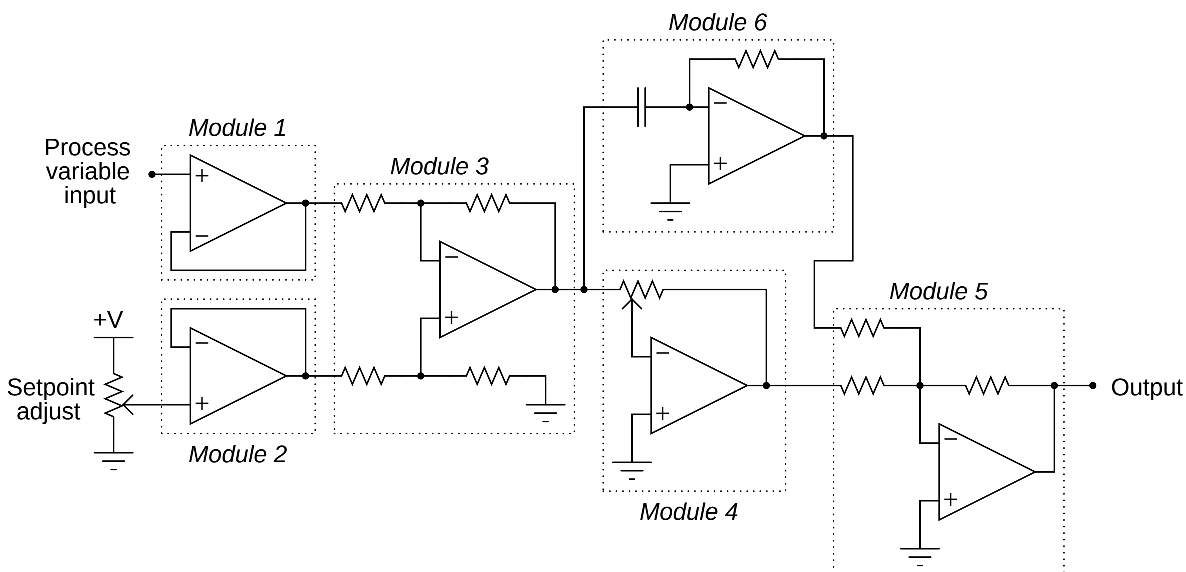
Question 37

Shown here is a schematic diagram for a simple, analog electronic, proportional-only controller:



Explain what you would have to do to increase the proportional band of this controller circuit, and also determine whether it is *direct-acting* or *reverse-acting*.

Now, consider this modification to the controller circuit, giving it *proportional* and *derivative* control capability, sometimes referred to as P+D or PD control:

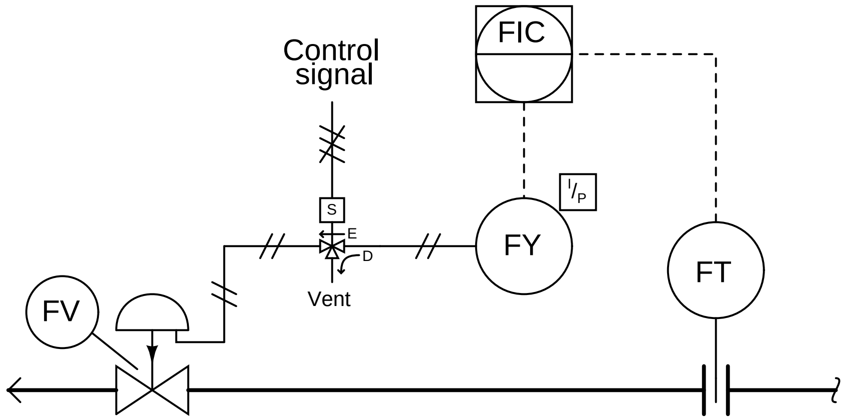


Explain how the additional module (Module 6) implements derivative control action, and what would have to be changed in the circuit to increase τ_d (i.e. make the derivative action more aggressive).

file i01534

Question 38

Explain what this electric solenoid valve will cause the pneumatically-actuated control valve to do when de-energized. What sort of fail-safe mode does this solenoid provide for the control valve that the valve would not otherwise exhibit on its own?



Also, based on how you know liquid flow controllers are typically tuned, how will the controller (FIC) react in automatic mode if the solenoid "trips"?

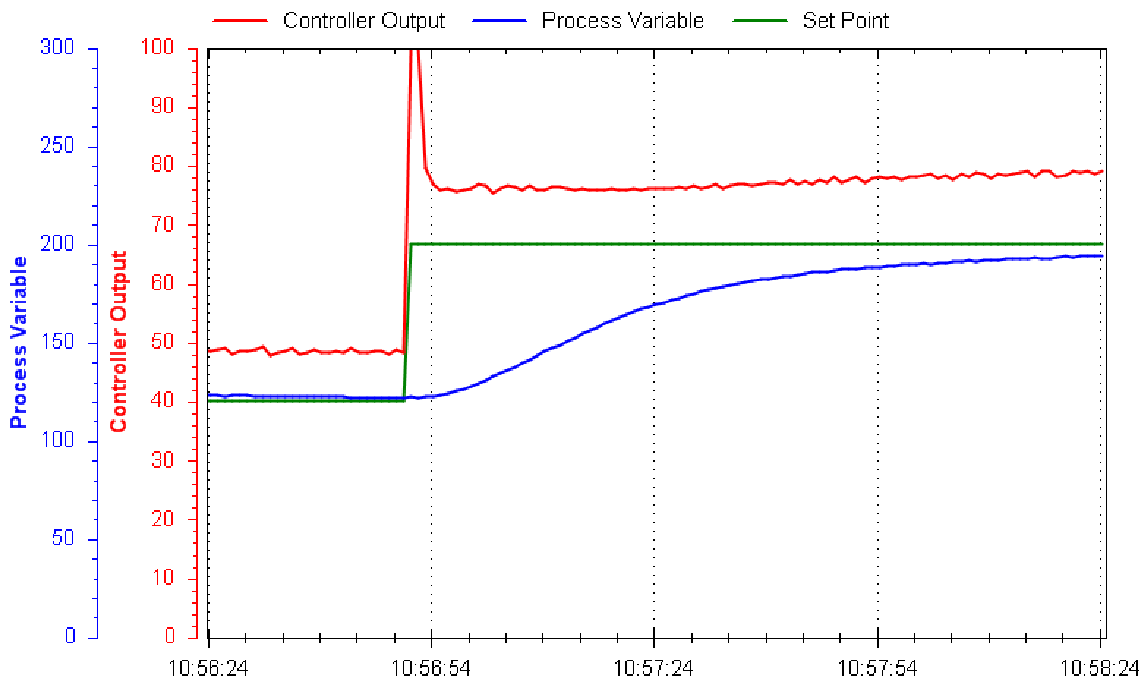
Suggestions for Socratic discussion

- What type of process is liquid flow: *self-regulating*, *integrating*, or *runaway*?
- Ideally, how should a liquid flow controller be tuned?

file i00917

Question 39

Examine this process trend showing the PV, SP, and Output of a loop controller:



Based on what you see here, determine the following:

- Whether this is an open-loop or a closed-loop response
- Whether the controller is (or needs to be) *direct-acting* or *reverse-acting*
- If possible, identify any problems with the field instrumentation
- If possible, identify any problems with the controller PID tuning
- Qualitatively identify the kind of PID tuning we will need for robust control

file i01926

Question 40

Suppose you are asked to troubleshoot a pH control system in a water treatment facility, where *caustic soda* (a white powdery substance with a high pH value) is added to drinking water to raise its pH value. According to the operator, the quality of control has been steadily growing worse as time wears on. He first shows you a trend display captured months ago with the pH value holding steady at setpoint, then another trend taken a couple of weeks ago showing some oscillation of the PV around setpoint, then today's trend showing a large oscillation of the PV around setpoint. Every day he looks at this trend display, he says, the oscillation gets worse.

Examining and comparing the last two trends closely, you notice two things about the more recent oscillation: it is *higher amplitude*, and also *lower frequency* than the trend captured a couple of weeks ago. Consulting a more experienced technician about this interesting development, she tells you the pH probe is probably just dirty and needs to be cleaned.

Although this advice seems odd to you, you decide to take it because it certainly cannot hurt to clean the pH probe. Removing the probe from service, you find it is heavily coated with sludge. After cleaning it off and recalibrating the pH transmitter, you go check the PV trend and find that indeed this fixed the problem.

Explain *why* the other instrument technician's advice was correct. How, exactly, would a *dirty* sensor cause the pH to oscillate? You can understand how a contaminated sensor might suffer a zero or span error, but neither of those would cause the loop to oscillate!

Suggestions for Socratic discussion

- Before removing the pH probe from the process and cleaning it, what should you do to ensure the pH control system does not react to your work on the probe? Remember, this is a *running* process you are working on!
- Is there a need to lock-out and/or tag-out any piece of equipment when performing the work described in this scenario? If so, what?
- For those who have studied pH measurement, how exactly does one re-calibrate a pH transmitter?

file i01533

Question 41

Describe your recent learning experiences succinctly enough to be included as a line-item in your résumé. Identify how this learning has made you more marketable in this career field. Be as specific as you can, and feel free to include non-technical as well as technical learning in your description (e.g. project management, organization, independent research, troubleshooting, design, software applications, electric circuit analysis, control theory, etc.)!

Identify any knowledge and/or skill areas in which you would like to become stronger, and describe practical steps you can take to achieve that goal. Don't limit yourself to just technical knowledge and skills, but consider behavioral habits (e.g. patience, attention to detail, time management) and general academic abilities (e.g. reading, writing, mathematics) as well. If you find yourself struggling to achieve a goal, don't just say "I'll work harder" as your plan of action – identify something *different* you can do to achieve that goal.

Note: your responses to these questions will not be shared in Socratic discussion with classmates without your consent. Feel free to maintain these as private notes between yourself and your instructor.

A helpful guide to traits and skills valued by employers are the "General Values, Expectations, and Standards" pages near the beginning of this worksheet. Another is the "So You Want To Be An Instrument Technician?" career guide.

file i00999

Question 42

Site visit!

As part of today's inverted theory session, you will meet your instructor at a site containing real processes controlled by feedback control systems, where you will evaluate those systems for quality of control and also the potential benefit of control strategies such as cascade or feedforward. Prepare yourself to do the following while on site:

- Perform simple tests on a functioning control system to check robustness
- Suggest PID tuning optimizations to improve loop performance
- Identify proper controller action based on inspection of process equipment
- Identify loads in the process based on an inspection of the piping and vessels
- Suggest alternative control strategies for a given process
- Estimate necessary C_v rating for a control valve in a given process
- Wear safety glasses and sturdy (closed-toed) shoes

file i01741

Question 43

Read and outline Case History #82 ("Problems In A Canadian Plant") from Michael Brown's collection of control loop optimization tutorials.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Any points of confusion, and precisely why you found the text confusing.
(5) Questions of your own you would pose to another reader, to challenge their understanding.
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

Be sure to answer the following questions:

- Comment on Mr. Brown's observations regarding the competence of Canadian instrument technicians in general, and also about specific deficiencies in control curricula worldwide.

- Explain what "anti-reset windup" (ARW) is in a digital PID controller, and what purpose it serves.

- The control loop behavior shown in Figures 1 and 2 is very strange. What looked at first like a control valve problem was in fact a weird problem in the DCS. Explain how this control system's anti-reset winding (ARW) feature worked, and why it accounted for the strange closed-loop behavior seen in the trend of Figure 1.

- Examine the open-loop test shown in Figure 4, and identify what feature(s) of this trend clearly indicate a control valve problem.

- Examine the closed-loop trend shown in Figure 5, and determine from the graphs what the dominant control mode (P, I, or D) is in the loop controller. Also, determine if this controller is direct-acting or reverse-acting.

- Examine the closed-loop trend shown in Figure 6, and identify those features of the output (PD) graph clearly showing *proportional* action, and those features clearly showing *integral* action.

Suggestions for Socratic discussion

- Variable-speed pumps are often considered nearly ideal from the perspective of control characteristics. Explain why a variable-speed pump might be preferable to a throttling valve in a control loop.
- Examine the trend graph shown in Figure 1 and calculate the controller's *proportional band*.

file i00351

Question 44

Read and outline Case History #92 ("The Controller Has Gone Out Of Tune!") from Michael Brown's collection of control loop optimization tutorials.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Any points of confusion, and precisely why you found the text confusing.
(5) Questions of your own you would pose to another reader, to challenge their understanding.
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

Be sure to answer the following questions:

- As Mr. Brown points out, the title of this case history is rather ridiculous given the use of digital PID controllers. Yet, this attitude persists in industry. Why do you suppose this is?

- According to Mr. Brown, what single type of instrument problem accounts for the vast majority of loop control problems?

- Identify the dominant controller mode (P, I, or D) in the trend of Figure 4, as well as the controller's direction of action (i.e. direct vs. reverse).

- A fair portion of this case history is devoted to an explanation of *aliasing* and how this phenomenon may cause instability in a control system. Explain the concept of "aliasing" in your own words.

- Is aliasing a problem when the control system has a *fast* scan rate or a *slow* scan rate? Explain your answer.

- Explain what parameter(s) in this particular DCS affected its scan rate, and why that was significant to the problem experienced in the level control loop whose performance is documented in Figures 4 and 5.

- Figure 5 shows an example of how a high-frequency oscillation in the PV results in a low frequency on the controller output signal due to aliasing. Suppose a technician suggested this oscillation could be caused by machinery vibration near the transmitter. Would you agree with this possibility, or not? Why?

Suggestions for Socratic discussion

- Examine and then explain Mr. Brown's recommended test for valve hysteresis, shown in Figure 1.
- The controller cycling shown in Figure 5 did not create a level-control problem, according to Mr. Brown, however it did cause problems for another section of the process. Identify what this other section was.
- The problem of *signal aliasing* is common to the field of electronics engineering, and is especially relevant to analog-to-digital converter (ADC) circuitry. Explain in your own words what "aliasing" is, and why an ADC might be susceptible to it.
- Mr. Brown says he corrected the aliasing problem seen in Figure 5 by using *filtering*. If you were the one applying this "fix" to the problem, would you place the filtering in the smart transmitter or in the controller?

- A stroboscope is a tool used to "freeze" the motion of a rotating machine, by flashing a bright strobe light in the direction of the machine once per revolution to make it look as though the spinning component is standing still. If the stroboscope is not precisely set to the right frequency, the component looks as though it is spinning, but much slower than it actually is. Explain how this is an example of *aliasing*.

  file i01541

Question 45

Read and outline Case History #68 ("Control Mayhem On A Mine") from Michael Brown's collection of control loop optimization tutorials.

After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(1) Your written summary of all major points of the text, expressed as simply as possible in your own words. A "Table of Contents" format works well for this.
(2) Active helpful reading strategies (e.g. verbalizing your thoughts as you read, simplifying long sentences, working through mathematical examples, cross-referencing text with illustrations or other text, identifying the author's problem-solving strategies, etc.).
(3) General principles, especially physical laws, referenced in the text.
(4) Any points of confusion, and precisely why you found the text confusing.
(5) Questions of your own you would pose to another reader, to challenge their understanding.
(6) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.

Be sure to answer the following questions:

- Examine the PV and Output (PD) trends shown in Figure 1, and explain where you think the "steps" originate from in both waveforms.

- Examine the ore crusher control strategy shown in Figure 2, and explain the metallurgists' rationale for the "selector" strategy between the level and power controllers.

- Describe the strange "interlock" control strategy for level programmed into this PLC that resulted in the feed belt being automatically shut off, and what effect(s) this had on the PID controller block while it was being overridden by the interlock logic.

- Another problem discovered while investigating the crusher level control loop was that the feeder belt speed did not precisely follow the controller's output. Explain how this may be discerned from the trend of Figure 5, and also how this is analogous to an incorrectly-sized control valve.

- In the "Addendum" section of this case history, Mr. Brown relates another PLC programming problem where a certain necessary feature in the PID function blocks could not be accessed. Identify this blocked feature, its significance, and why any PLC programmer in their right mind could think it would be okay to do this sort of thing.

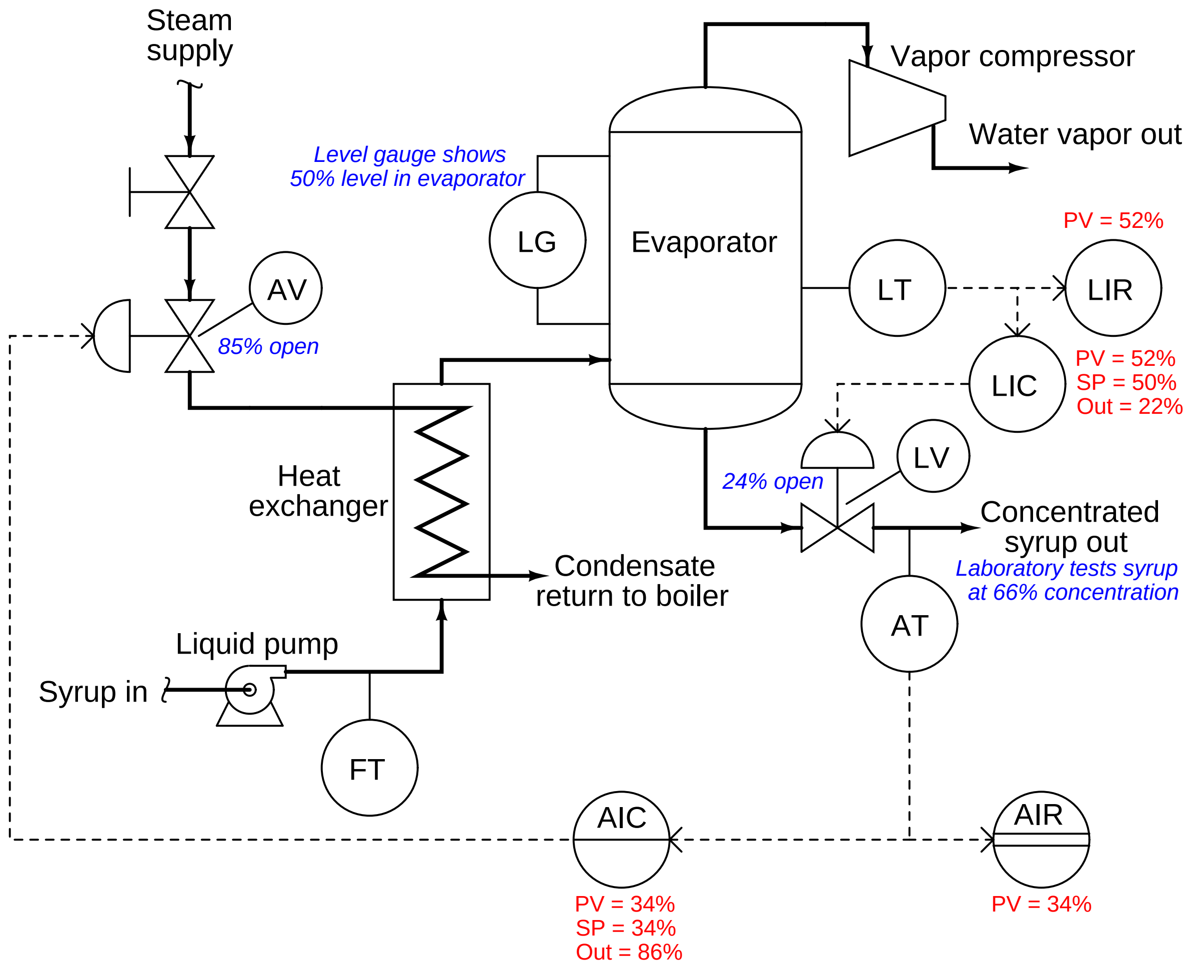
Suggestions for Socratic discussion

- How may we tell that the control valve in the slurry flow loop (Figure 1 closed-loop test) is oversized?
- Identify which points in time on the trend of Figure 3 the control system is operating in "level" mode and which points in time it is operating in "power" mode.
- Where do you suppose the 15 seconds' worth of dead time originates in the ore-crushing process shown in Figure 2?
- Devise a different control strategy for the ore-crushing process shown in Figure 2 that might work better (i.e. avoid) than the one shown.
- Comment on the *installed characteristic* of the final control element (e.g. quick-opening, linear, or equal-percentage) in the control loop whose trend is shown in Figure 5. Is there any "stiction" in this FCE?

file i01597

Question 46

In this process, maple syrup is heated as it passes through a steam heat exchanger, then enters an evaporator where the water boils off. The purpose of this is to raise the sugar concentration of the syrup, making it suitable for use as a food topping. A level control system (LT, LIR, LIC, and LV) maintains constant syrup level inside the evaporator, while an analytical control system (AT, AIR, AIC, and AV) monitors the sugar concentration of the syrup and adjusts steam flow to the heat exchanger accordingly.



Examine the live variable values shown in the above diagram, and then determine where any problems may exist in this syrup concentrating system.

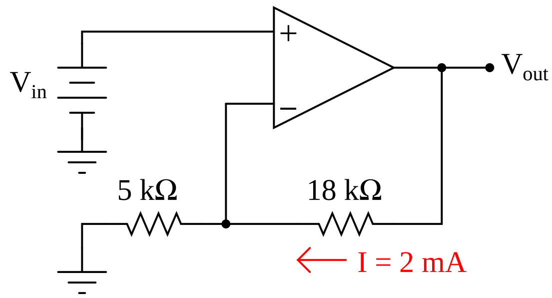
Suggestions for Socratic discussion

- A valuable principle to apply in a diagnostic scenario such as this is *correspondence*: identifying which variables correspond at different points within the system, and which do not. Apply this comparative test to the variables scenario shown in the diagram, and use the results to defend your answer of where the problem is located and what type of problem it is.

file i02934

Question 47

Determine both the input and output voltage in this circuit:



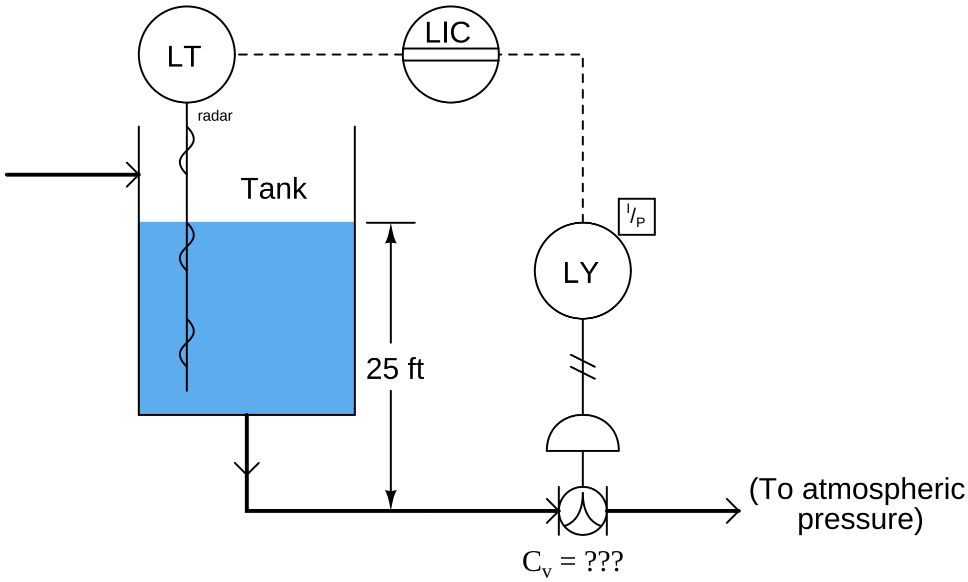
Suggestions for Socratic discussion

- When analyzing opamp circuits, it is helpful to bear in mind the "simplifying assumptions" of negative-feedback opamp circuits. Identify some of these assumptions, especially the one regarding input voltages to the opamp when negative feedback is in effect.
- Identify which fundamental principles of electric circuits apply to each step of your analysis of this circuit. In other words, be prepared to explain the reason(s) "why" for every step of your analysis, rather than merely describing those steps.
- Identify all the effects of the 18 kΩ resistor failing open.
- Identify all the effects of the 5 kΩ resistor failing open.
- Identify all the effects of the 18 kΩ resistor failing shorted.
- Identify all the effects of the 5 kΩ resistor failing shorted.

file i03262

Question 48

Calculate the proper C_v value for a control valve used to control liquid level in a tank. A guided-wave radar level transmitter measures the level of the liquid in the tank, and a controller throttles the valve to maintain that liquid level at approximately 25 feet above the centerline of the valve piping. Assume a maximum valve flow rate of 350 GPM, and water as the process liquid:



Also, calculate the approximate pipe size of control valve necessary to achieve this flow capacity, assuming the use of a characterized ball valve (C_d = 25).

Now, re-calculate both the C_v and valve pipe size, assuming the process liquid is kerosene (density = 51.2 lb/ft^3) instead of water. Does this change require a larger valve, a smaller valve, or will the same valve size work for kerosene as it did for water? Explain your answer.

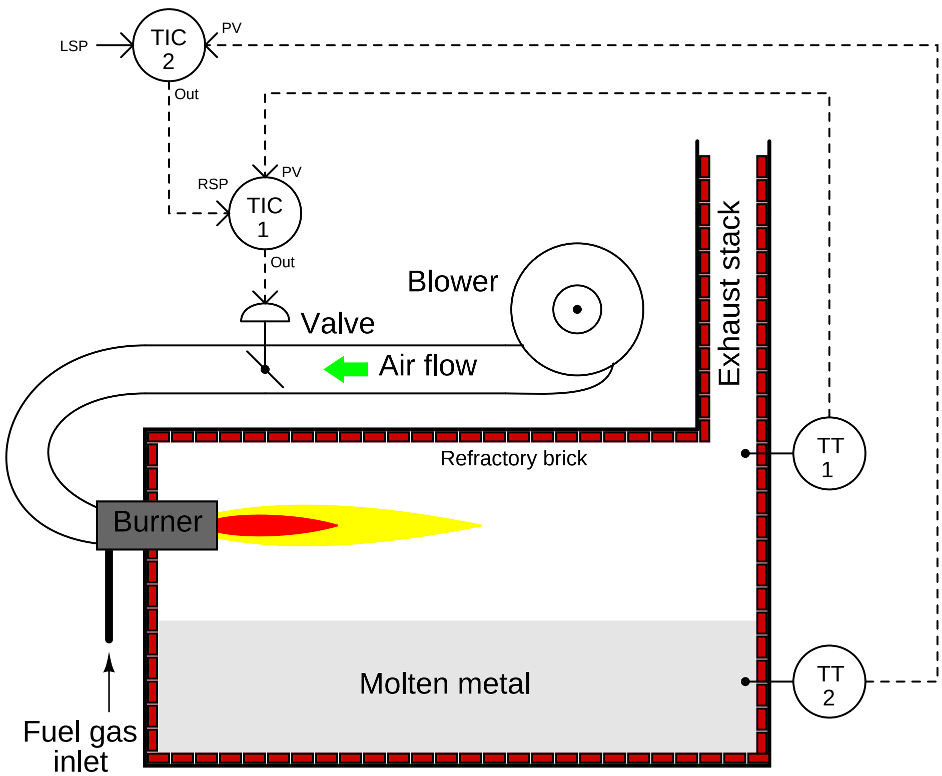
Suggestions for Socratic discussion

- Suppose the control valve discharged liquid to a line with a constant pressure of 4 PSI instead of discharging to atmospheric pressure. How would this change affect the necessary sizing of the control valve?
- Based on what you see here, will this process exhibit a *self-regulating*, *integrating*, or *runaway* characteristic?
- Identify in qualitative terms how you would expect to have to tune the level controller in this system. Would you expect to use aggressive proportional action, integral action, and/or derivative action? Are there certain control actions such as derivative you would *not* with to use in this loop? Explain your reasoning.
- For those who have studied liquid level measurement, explain how a *radar* level transmitter senses liquid level in the process vessel.
- Suppose this loop-powered radar level transmitter were replaced by one that was wireless, powered by a battery instead of by 24 VDC loop power. Such transmitters conserve battery power by reporting the process variable infrequently. Explain how this change may affect the quality of control for this process.

file i03220

Question 49

This metal-melting furnace has a cascade control system, whereby a "bath" controller (sensing the temperature of the molten metal) acts as the primary, and a "crown" controller (sensing the temperature of the refractory wall and roof) acts as the secondary:



One day the crown thermocouple (the sensor for TT-1) goes bad, causing TT-1 to "fail high" with a 20.6 mA signal. Determine the effect(s) this will have on the control system as a whole, and on the furnace temperature in particular.

Suppose an instrument technician replaces the bad thermocouple, but the trend of crown temperature over time begins to cycle (oscillate) more than it ever did before, refusing to settle down to setpoint. You are called to troubleshoot this problem, and you find that the replacement thermocouple was not fully inserted into the *thermowell* (the protective sheath protruding into the furnace, acting as a sort of "sock" into which the thermocouple sensor is inserted to measure temperature without direct exposure to the environment inside the furnace).

Explain how something as simple as improper thermocouple insertion could cause the crown temperature control loop to cycle.

Suggestions for Socratic discussion

- Determine the necessary control actions (direct vs. reverse) for each controller in this system, assuming a signal-to-open valve.
- Why do you think a cascade control strategy is used to control the burner?
- For those who have studied thermocouples, what *type* (letter code) of thermocouple would you recommend for this application, assuming a crown temperature upwards of 1800 ^{o}F?

file i01530

Question 50

Suppose a Limitorque model L120-10 electric valve actuator has a problem: the valve remains in the fully closed position and refuses to open when the local "open" switch (pushbutton PB1) is pressed. Note: you will need to locate the schematic diagram for this MOV in order to diagnose this problem.

Your first diagnostic test is to measure AC voltage between terminals 21 and 20: there your meter shows you 117 volts AC. After that, you measure 117 volts AC between terminals 1 and 20 with the "open" pushbutton PB1 depressed (pushed) by a fellow technician helping you diagnose the problem.

Identify the likelihood of each specified fault for this circuit. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this circuit.

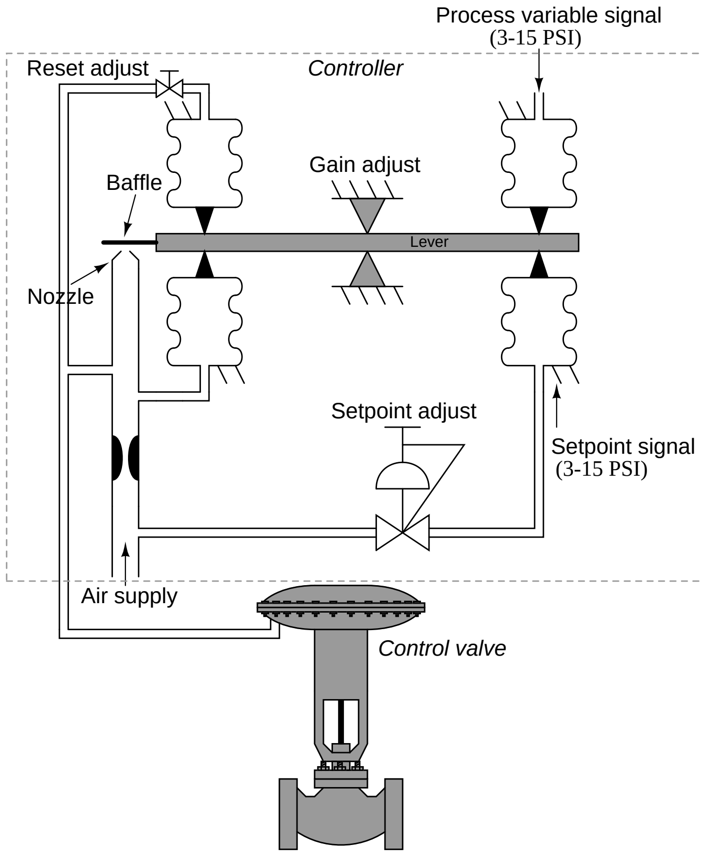
Fault	**Possible**	**Impossible**
"Bypass" switch (#1) failed open		
"Bypass" switch (#5) failed open		
"Opening" torque switch (#18) failed open		
"Closing" torque switch (#17) failed open		
"Open" limit switch (#4) failed open		
"O" relay coil failed open		
"C" relay coil failed open		
Thermal overload switch(es) tripped		
480V fuse(s) blown to input of transformer		

Finally, identify the *next* diagnostic test or measurement you would make on this system. Explain how the result(s) of this next test or measurement help further identify the location and/or nature of the fault.

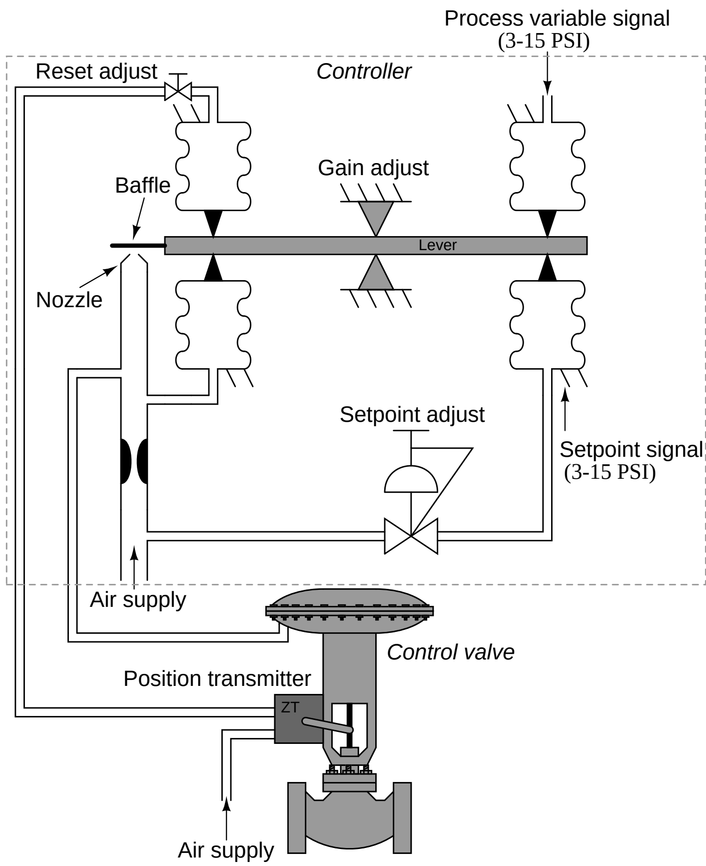
file i01464

Question 51

Here is a pneumatic P+I controller mechanism, with reset (integral) action implemented in the standard way:



This is called "internal reset" action. There is, however, an alternative method for implementing reset action in a pneumatic controller, and it involves the addition of a pneumatic position transmitter on the valve to signal valve stem position to the controller. This alternative method is called "external reset:"



The benefit of a controller with external reset is that the reset action has less of a tendency to "wind up." Explain why this is.

Hint: imagine the valve is equipped with a minimum-travel "stop" so that its furthest-closed position is 15%. Stops are sometimes used on flow-control valves where a certain minimum flow rate must be maintained for process safety reasons (e.g. flow control for process fluid in a combustion heater where zero flow might result in overheated and ruptured tubes). How would external reset help prevent the controller from winding down under certain low-setpoint conditions?

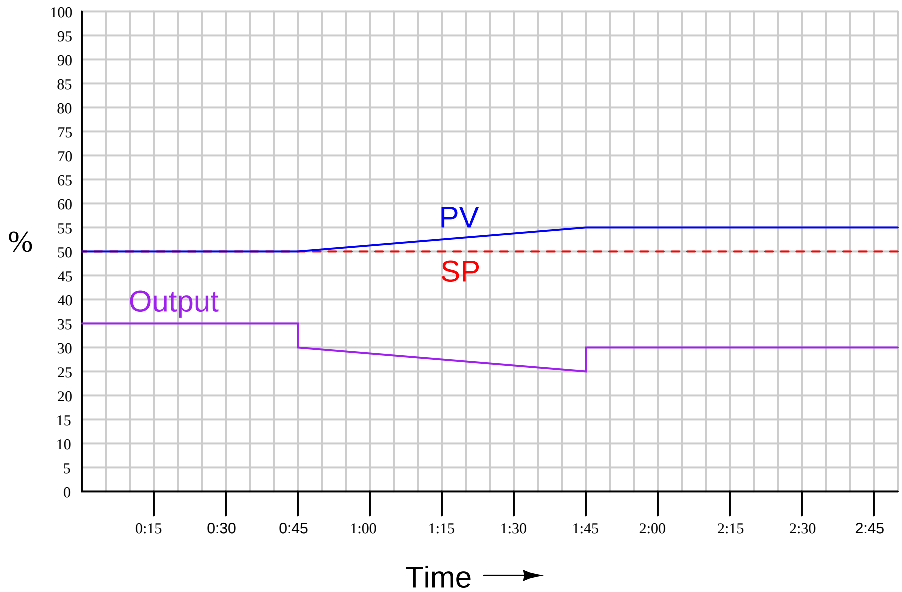
Suggestions for Socratic discussion

- A powerful problem-solving technique is performing a *thought experiment* where you mentally simulate the response of a system to some imagined set of conditions. Describe a useful "thought experiment" for this system, and how the results of that thought experiment are helpful to answering the question. If you find this system too complex, apply another problem-solving technique: *simplify* the system, then analyze the simpler system.
- How would this external reset scheme work on a control valve with really bad hysteresis (stiction)? Would the loop "cycle" as a normal internal-reset controller driving a sticky valve would exhibit a stick-slip cycle, or not?
- Identify how you could increase the gain of this controller without moving the fulcrum.

file i01610

Question 52

Shown here is the response of a proportional+derivative controller to a ramping process variable (with a constant setpoint). Calculate the controller's proportional and derivative constant settings, based on what you see in the graph. Also, determine whether this controller is direct or reverse acting, and mark the features of the output plot corresponding to proportional action and to derivative action.

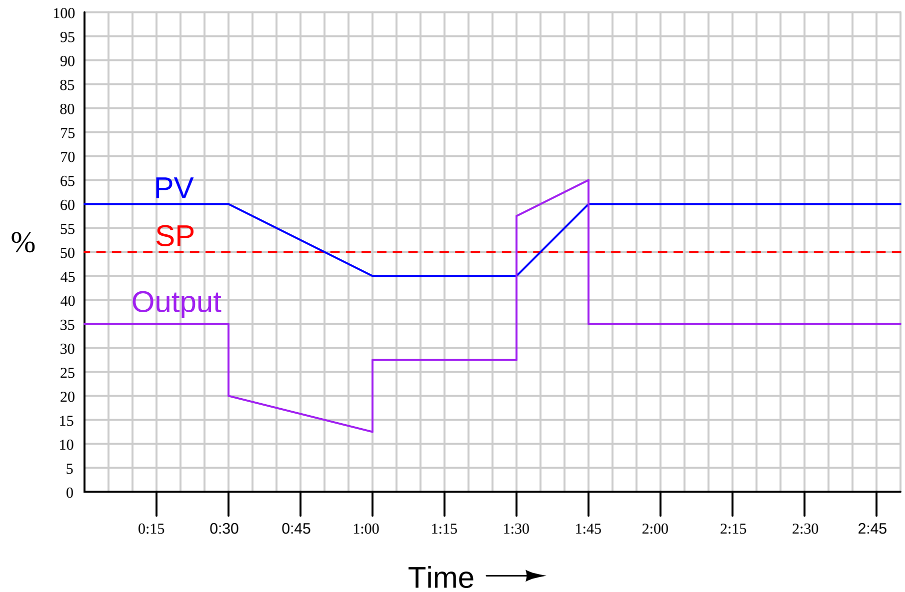


The time scale on the chart is minutes:seconds.

file i01543

Question 53

Shown here is the response of a proportional+derivative controller to a ramping process variable (with a constant setpoint). Calculate the controller's proportional and derivative constant settings, based on what you see in the graph. Also, determine whether this controller is direct or reverse acting, and mark the features of the output plot corresponding to proportional action and to derivative action.



The time scale on the chart is minutes:seconds, and the P+D algorithm is as follows:

$$m = K_p \left(e + \tau_d \frac{de}{dt} \right) + b$$

Where,

m = Controller output (manipulated variable)
K_p = Gain
e = Error signal (SP−PV or PV−SP)
τ_d = Derivative time constant
b = Bias

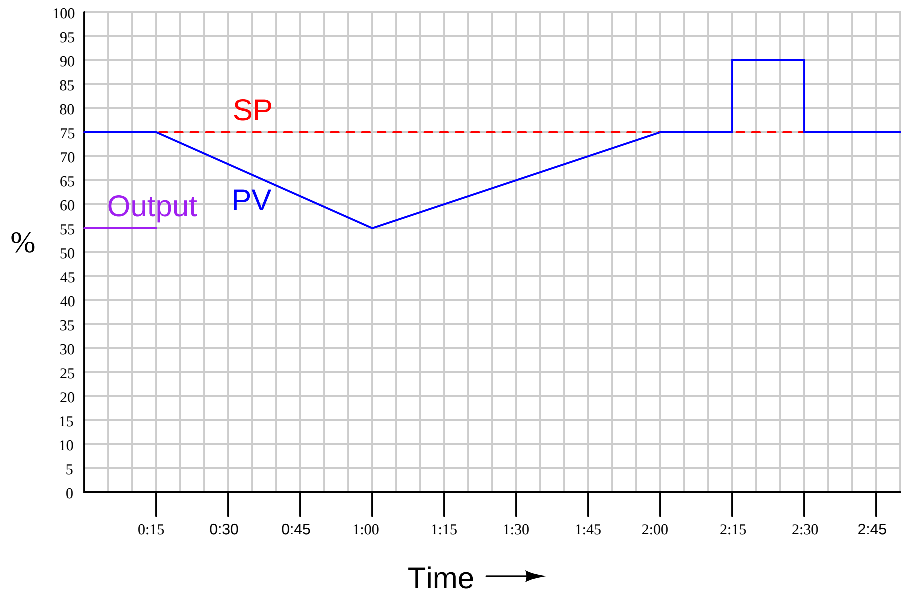
Also, determine the gain and derivative constant values if you were told the PD algorithm were this instead:

$$m = K_p e + \tau_d \frac{de}{dt} + b$$

file i01544

Question 54

Graph the response of an hypothetical *derivative-only* controller for the following input conditions. Assume a control action that is *direct-acting*, and a derivative constant (τ_d) of 2 minutes:



The time scale on the chart is minutes:seconds, and the algorithm for this controller is as follows:

$$m = \tau_d \frac{de}{dt} + b$$

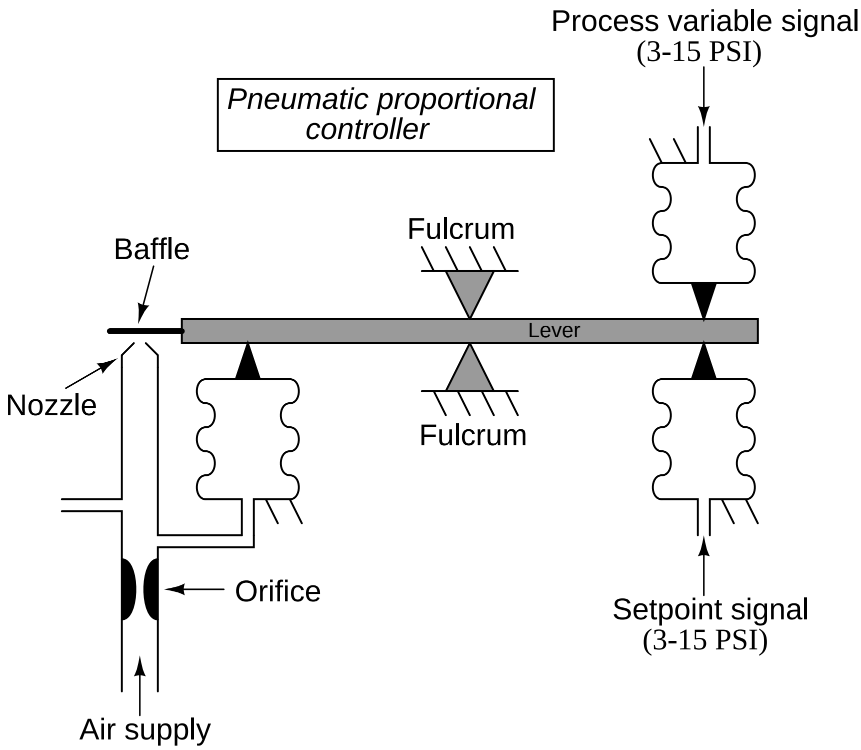
Where,

m = Controller output (manipulated variable)
e = Error signal (PV−SP)
τ_d = Derivative time constant
b = Bias

file i01545

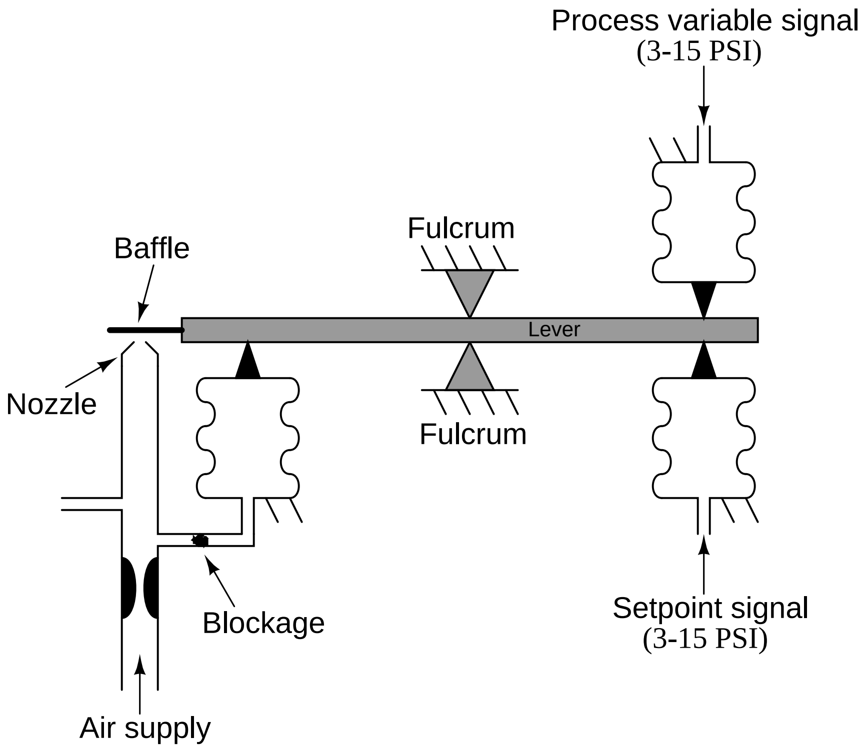
Question 55

Shown here is the mechanism for a simplified (no amplifying relay, no bias spring) proportional-only pneumatic controller:



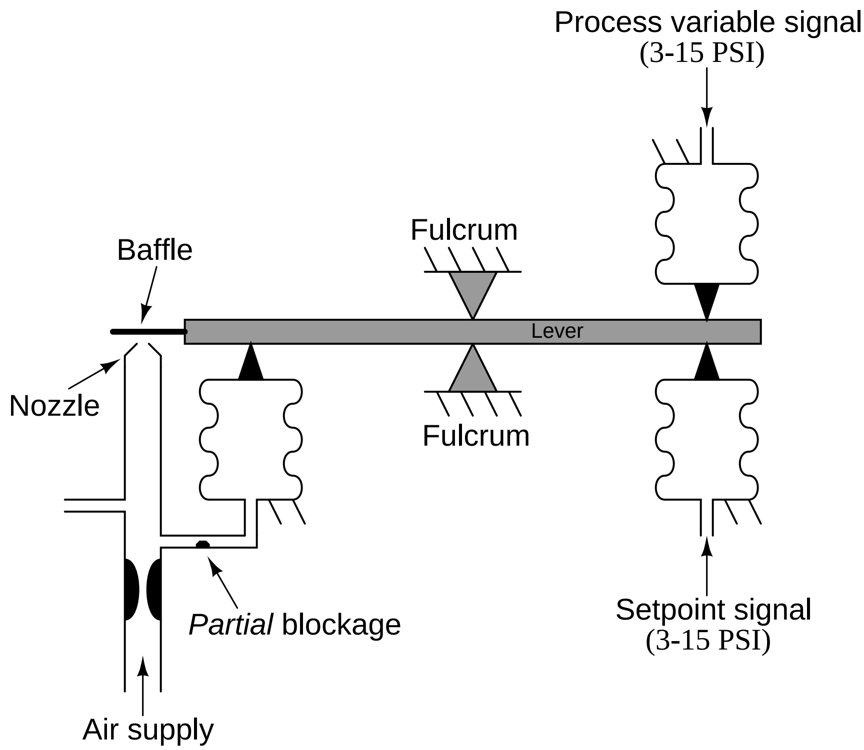
Explain how this controller mechanism functions, being sure to include the concept of *negative feedback* in your explanation.

Suppose this pneumatic controller developed a problem: the short tube connecting to the feedback bellows becomes completely plugged. This does not allow the feedback bellows to sense air pressure at the nozzle:



Describe and explain the effect this tube blockage will have on controller behavior.

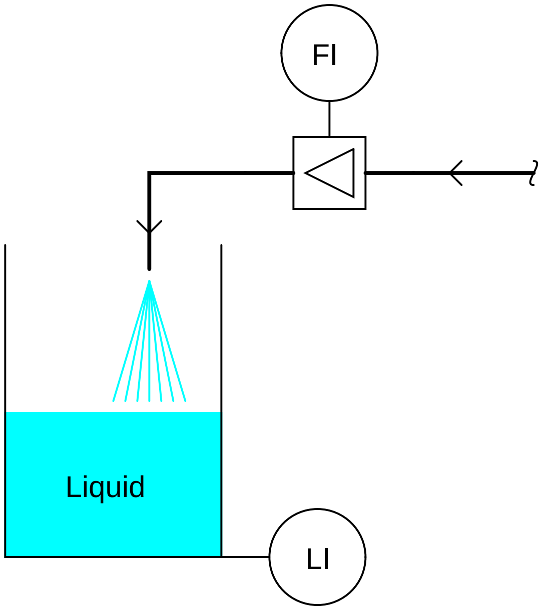
Now suppose the same tube were only *partially* plugged, with the effect of slowing down air passage through it, so that the bellows pressure lags behind the nozzle pressure in time:

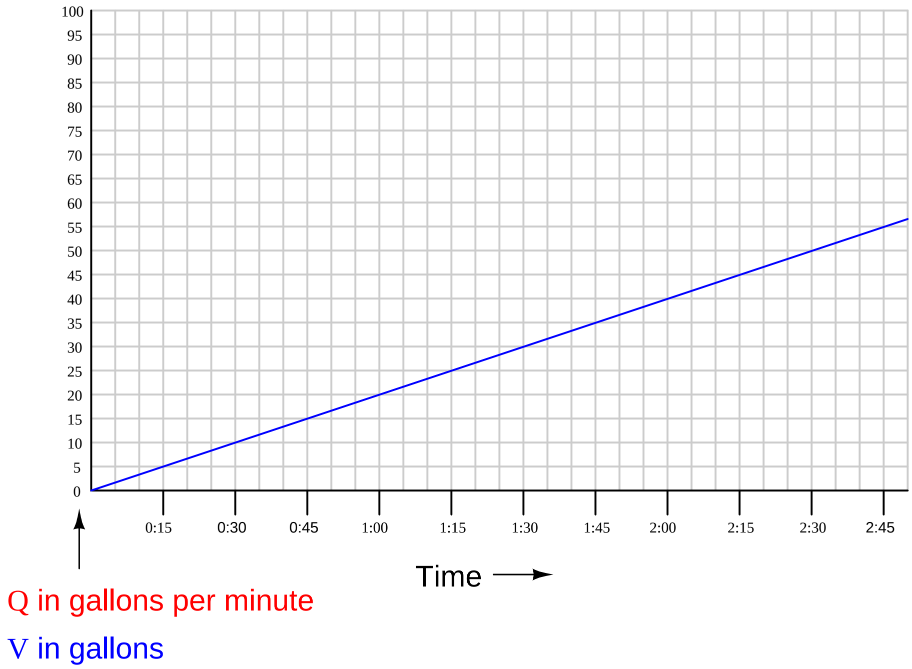


file i01542

Question 56

Suppose the liquid volume in this vessel steadily accumulates due to a constant flow rate of liquid entering the vessel through the pipe. Graph this constant value of flow over time, given the graph of accumulating volume over time. The function you graph (describing liquid flow) will be the *time-derivative* of the function shown (describing liquid volume):

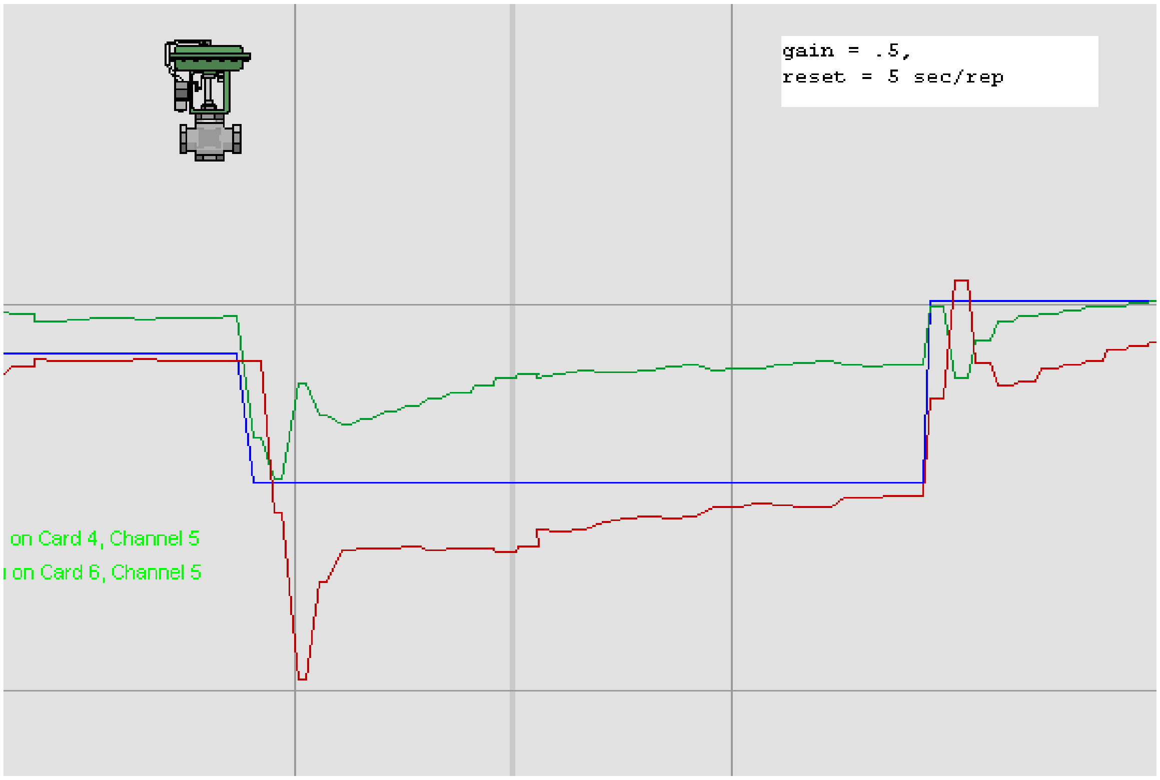




The unit of time for the graph's horizontal axis is minutes:seconds, not hours:minutes.
file i01529

Question 57

Examine this process trend showing the PV (red), SP (blue), and Output (green) of a loop controller:



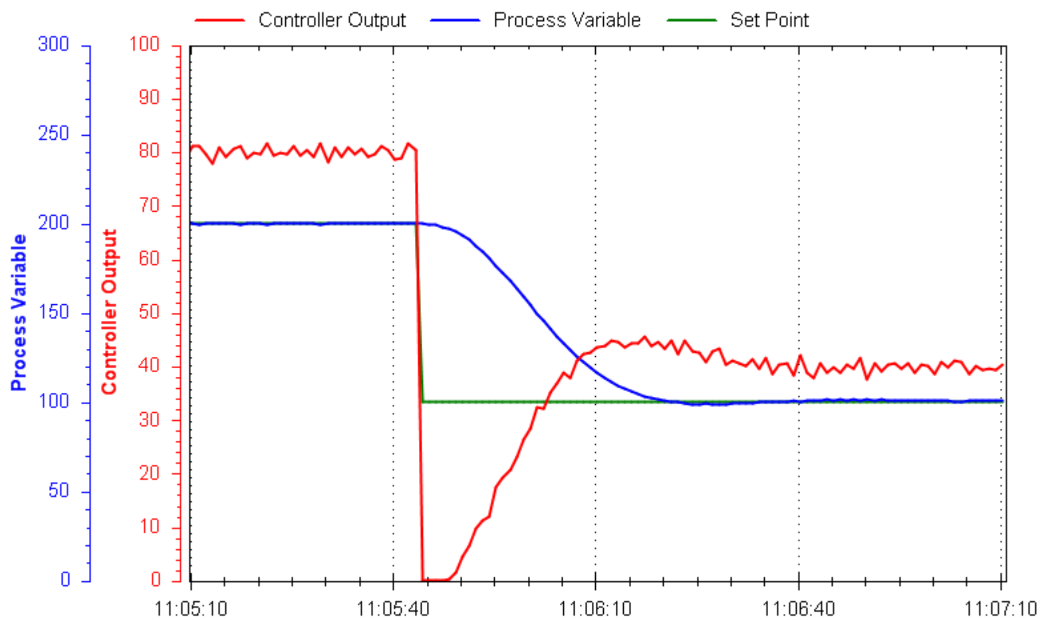
Based on what you see here, determine the following:

- Whether this is an open-loop or a closed-loop response
- Whether the controller is (or needs to be) *direct-acting* or *reverse-acting*
- If possible, identify any problems with the field instrumentation
- If possible, identify any problems with the controller PID tuning
- Qualitatively identify the kind of PID tuning we will need for robust control

file i02643

Question 58

Examine this process trend showing the PV, SP, and Output of a loop controller:



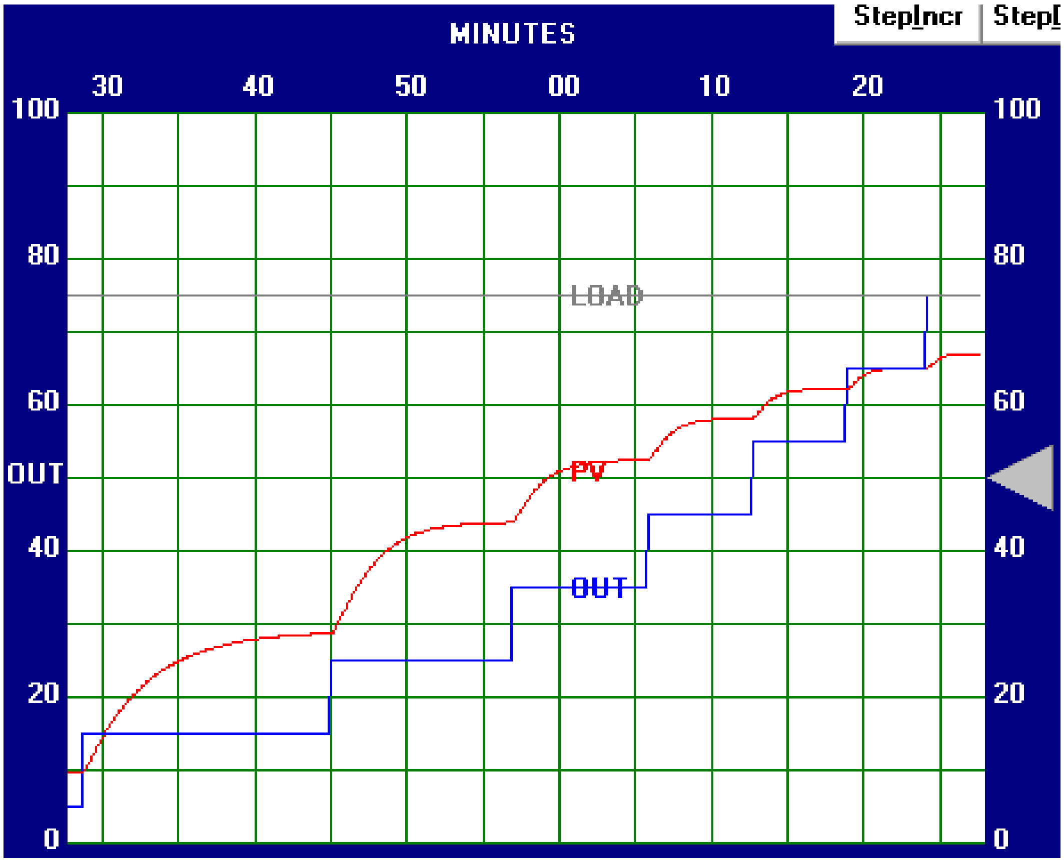
Based on what you see here, determine the following:

- Whether this is an open-loop or a closed-loop response
- Whether the controller is (or needs to be) *direct-acting* or *reverse-acting*
- If possible, identify any problems with the field instrumentation
- If possible, identify any problems with the controller PID tuning
- Qualitatively identify the kind of PID tuning we will need for robust control

file i02644

Question 59

Examine this process trend showing the PV, SP, and Output of a loop controller:



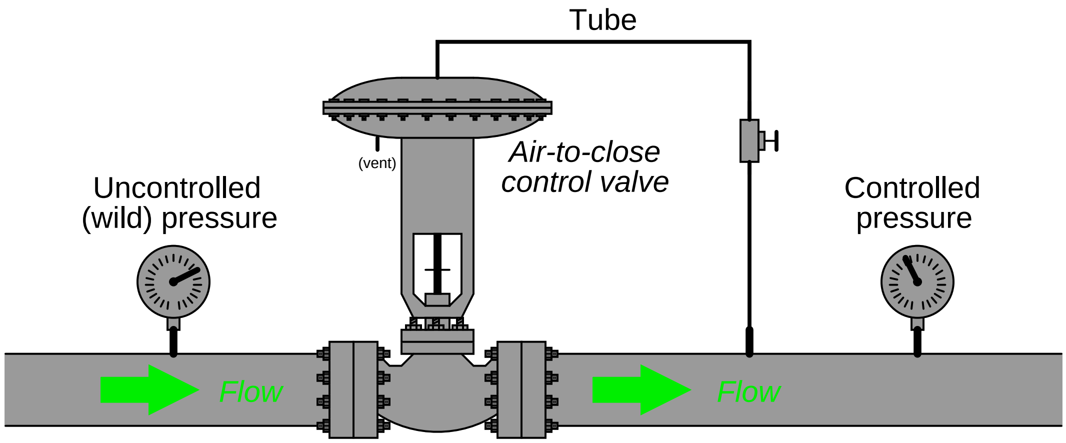
Based on what you see here, determine the following:

- Whether this is an open-loop or a closed-loop response
- Whether the controller is (or needs to be) *direct-acting* or *reverse-acting*
- If possible, identify any problems with the field instrumentation
- If possible, identify any problems with the controller PID tuning
- Qualitatively identify the kind of PID tuning we will need for robust control

file i02645

Question 60

A control valve (all by itself!) may act as a crude proportional controller for controlling pressure of a gas or vapor in a pipe:



Unfortunately, this simple pressure-regulating system has a problem. The downstream pressure is much less than it should be, despite this system working just fine several days ago. Assume the control valve is a stem-guided, single-ported globe valve with an actuator ranged from 6 to 30 PSI. The setpoint for this system is 12 PSI, and that the temperature of the gas inside the pipe is 94 ^{o}F.

Identify the likelihood of each specified fault for this pressure-regulating system. Consider each fault one at a time (i.e. no coincidental faults), determining whether or not each fault could independently account for *all* measurements and symptoms in this system.

Fault	**Possible**	**Impossible**
Control valve stem jammed by metal debris between plug and seat		
Control valve stem jammed by metal debris between plug and bonnet		
Block valve downstream of control valve closed		
Block valve upstream of control valve closed		
Tear (leak) in actuating diaphragm		
Hand valve shut off		
Upstream pressure lower than normal		

Finally, identify the *next* diagnostic test or measurement you would make on this system. Explain how the result(s) of this next test or measurement help further identify the location and/or nature of the fault.

Suggestions for Socratic discussion

- Identify any advantages this pressure-control system enjoys over a control system based on a remote PID controller.
- Could this control strategy work just as well for a liquid application rather than a gas application? Explain why or why not.

file i01614

Question 61

Lab Exercise

Your primary task is to independently (i.e. no assistance from team members or other classmates) tune multiple control loops, documenting the process open-loop response as well as the process closed-loop responses to both setpoint and load changes. This documentation must be in the form of computer screen captures, showing the graphic trends of the process as it responds to open-loop and closed-loop tests. You must do your own loop testing and tuning, the consequence of plagiarism being a failing grade for the course.

Two of the processes you will tune must be *real*, working processes of differing type (e.g. pressure versus temperature). The last process may be simulated, or it may be another real process with different characteristics than the first two. All tuning objectives are "mastery" – they must be demonstrated to instructor satisfaction for completion, with no penalty for multiple attempts.

Performance objective	**Real #1**	**Real #2**	**Real #3 or Simulated**
Description of process			
PV alarm points (*set by instructor*)			
Self-reg. *vs.* Integ. *vs.* Runaway?			
Measurement of dead time (sec)			
Measurement of time constant (sec)			
Measurement of valve stiction (%)			
P value after tuning (K_p)			
I value after tuning (K_i or τ_i)			
D value after tuning (K_d or τ_d)			
Robust response to SP change?			
Robust response to load change?			
Instructor initials			

In addition to process tuning, you must also complete a circuit design challenge and troubleshoot a control system the same as in regular team-based lab exercises. A crucial different is that none of the objectives in this entire lab exercise are team-based; rather, all are individual.

Performance objective	**Grading**	**Individual**
Circuit design challenge	mastery	
Troubleshooting	mastery	
Safety and professionalism	deduction	
Lab percentage score	proportional	
Decommission and lab clean-up	(ungraded)	

The "proportional" score for this activity is based on the number of attempts require to master each objective. Every failed attempt is marked by a 0, and every pass by a 1. The total number of 1 marks divided by the total number of marks (both 1's and 0's) yields a percentage value. Team objectives count as part of every team member's individual score. The *Safety and professionalism* deduction is a flat −10% per instance, levied on occasions of unprofessional or unsafe conduct.

When all students are finished with their circuit design challenges, as well as tuning and troubleshooting their control loops, the last step is to decommission all the working systems as per usual procedure. On the last day of the quarter (dedicated to lab clean-up) each team will show their team tool locker for inspection.

Note: this lab worksheet is your only record of the instructor's validation (signed initials). Do not lose it, and do not lose your screen-captures of the process responses either!

Lab Exercise – objectives and expectations

Each objective is assessed at the *mastery* level, which means it is not complete until it meets *all* expectations. Re-tries are allowed, but failed attempts will be recorded and factored into your score for this lab exercise.

Loop tuning

Gather data and tune three different processes (one of which may be a computer simulation of a process). Capture screenshots of trend graphs as evidence of your work, both for characterizing the process (e.g. measuring dead time) and for demonstrating robust control response. The instructor will assign high and low process alarm values prior to your working on that system, and all trend graphs must show the PV between these prescribed limits in order to receive credit.

Circuit design challenge

Design, build, and demonstrate the operation of a simple circuit based on random selections by the instructor, using a digital oscilloscope as the test instrument.

Troubleshooting

Logically diagnose the nature and location of a fault placed in a working system that your team did not build. This will be limited in time, with each student passing or failing individually.

Lab percentage score

Successful completion of the lab exercise requires demonstrated mastery of all objectives. A percentage value is based on the number of attempts required to achieve mastery on these objectives: the number of objectives divided by the number of total attempts equals the percentage. Thus, a perfect lab percentage score is possible only by completing all objectives on the first attempt. Marks given for team objectives factor into each individual's score. If one or more members of a team repeatedly compromise team performance, they may be removed from the team and required to complete remaining lab exercises alone.

Deductions from this percentage value will be levied for instances of unsafe or unprofessional conduct (see below), the final result being the lab percentage score.

Safety and professionalism (deduction)

In addition to completing the specified learning objectives in each lab exercise, each student is responsible for abiding by all lab safety standards and generally conducting themselves as working professionals (see the *General Values, Expectations, and Standards* page near the beginning of every worksheet for more detail). Expectations include maintaining an orderly work environment and returning all tools and test equipment by the end of every school day (team), as well as following clear instructions (e.g. instructions given in equipment manuals, lab documentation, verbally by the instructor), communicating with teammates, formulating a plan to complete the lab project in the allotted time, and productively managing time. As with the other objectives, chronic patterns of poor performance in this domain may result in the offending student being removed from the team. Deductions to the lab percentage score will *not* be made for performance already graded such as tardiness and attendance.

General format and philosophy

This lab exercise is *project-based:* the instructor serves as the project engineer, while each student's role is to implement the standards set for the project while budgeting time and resources to complete it by the deadline date. Students perform real work as part of the lab exercise, managing their work day and functioning much the same as they will on the job. The tools and equipment and materials used are all industry-standard, and the problems encountered are realistic. This instructional design is intentional, as it is proven effective in teaching project management skills and independent working habits.

When you require the instructor's assistance to answer a question or to check off an objective, write your name (or your team's name) on the lab room whiteboard. Questions take priority over checkoffs, so please distinguish questions from other requests (e.g. writing a question-mark symbol "?" after your name makes this clear). **There will be times when you must wait for extended periods** while the instructor is busy elsewhere – instant service is an impossibility. Adequate time *does* exist to complete the lab exercise if you follow all instructions, communicate well, and work productively. Use all "down time" wisely: filling it with tasks not requiring the instructor's assistance such as other lab objectives, homework, feedback questions, and job searches.

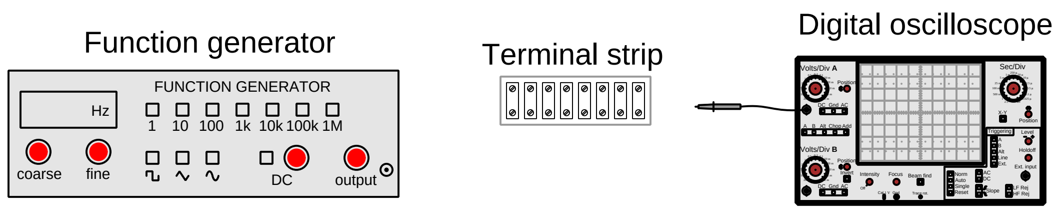
Remember that the lab facility is available to you at all hours of the school day. Students may perform non-hazardous work (e.g. circuit work at less than 30 volts, documentation, low air pressures, general construction not requiring power tools) at *any time during the school day* without the instructor's presence so long as that work does not disturb the learning environment for other students.

DO NOT TAKE SHORTCUTS when completing tasks! Learning requires focused attention and time on task, which means that most 'shortcuts" actually circumvent the learning process. Read the lab exercise instructions, follow all instructions documented in equipment manuals, and follow all advice given to you by your instructor. Make a good-faith effort to solve all problems on your own *before* seeking the help of others. Always remember that this lab exercise is just a means to an end: no one *needs* you to build this project; it is an activity designed to develop marketable knowledge, skills, and self-discipline. In the end it is your *professional development* that matters most, not the finished project!

Lab Exercise – circuit design challenge

Design, build, and test a circuit to fulfill one of the functions listed below (randomly selected by your instructor). All electrical connections must be made using a terminal strip (no solderless breadboards, twisted wires, crimp splices, wire nuts, spring clips, or "alligator" clips permitted). The only electrical source allowed in this circuit will be the function generator.

This exercise tests your ability to apply basic electrical principles to the design, construction, and proving (testing) of a simple passive circuit intended to fulfill a specific function, as well as your ability to use a digital oscilloscope and function generator.



The following components and materials will be available to you: **terminal strips** ; lengths of **hook-up wire** ; digital **oscilloscope** ; and **function generator**. You must provide all electronic components, tools, and digital multimeter (DMM) as well as a copy of this page for your instructor to mark objectives.

SEQUENCE: (1) Instructor chooses criteria; (2) You build and test circuit without any power sources at all; (3) Instructor observes you energizing the circuit for the first time; (4) You demonstrate to the instructor that the circuit fulfills its intended function.

Circuit function (randomly selected by the instructor):

- Voltage divider with total resistance between __________ and __________ ohms, with a division ratio of _____ : _____
- Low-pass filter with total impedance between __________ and __________ ohms, with a cutoff frequency of __________ Hz
- High-pass filter with total impedance between __________ and __________ ohms, with a cutoff frequency of __________ Hz
- Time-delay *charging* where the voltage rises to a value of __________ percent of the final (maximum) in __________ seconds
- Time-delay *discharging* where the voltage falls to a value of __________ percent of the initial (maximum) in __________ seconds
- Phase-shifter with total impedance between __________ and __________ ohms, where the output voltage lags the input voltage by __________ degrees
- Phase-shifter with total impedance between __________ and __________ ohms, where the output voltage leads the input voltage by __________ degrees

Study references: all your textbooks and lessons from the first year of the program. Also, specific modules contained in the *Modular Electronics Learning Project* which is found online at `http://www.ibiblio.org/kuphaldt/socratic/model/index.html`.

Lab Exercise – PV alarm points

Most loop controllers have built-in *alarm* capability to signal whenever the process variable (PV) goes outside of prescribed bounds. In this lab exercise you will configure your controller's "high" and "low" PV alarm points according to values set by the instructor. The purpose in doing this is to set limits beyond which you should never take the process variable for two different reasons: (1) to mimic real-life constraints whereby process quality may be affected if the PV wanders too far away from normal values, and (2) to force you to tune the controller differently to match the process characteristics in a different range.

This second reason for PV alarm limits bears further explanation. It is quite common for processes to exhibit different operating characteristics at different PV ranges. Parameters such as dead time, lag time, and/or self-regulation may vary depending on the exact value of the process variable. This is why PID controller tuning parameters which may work very well to control a process within a certain PV range fail to achieve the same level of robust control within a different PV range. When the instructor sets PV alarm points at different values for each student, the process essentially poses a new tuning challenge for each student so that the PID tuning work of another student cannot simply be copied.

The procedure for setting alarm point values is documented in the manufacturer's manual for the control system, and is typically a setting available to operations personnel (i.e. not requiring engineering-level privileges on the control system to change). You will need to research how to do this.

When showing your screen-shots of open-loop testing and closed-loop PID response to the instructor, these high and low PV limits should be denoted on the trend graph for easy reference, as proof that the system's PV never strayed beyond these prescribed limits.

Note that if you are using the `looptune` application on a caSCADA system to simulate a process, all PV alarm values (low-low, low, high, and high-high) are randomly assigned by the computer upon invocation. Your documented work needs to show the PV remaining between the low and high alarm limits at all times, but know that the simulation will automatically abort if the process variable goes beyond either the low-low or high-high limits, resulting in a complete loss of data (your PID tuning parameter values, the simulation process parameters, etc.)!

Lab Exercise – how to capture "screen-shots" on a PC

An essential part of this lab exercise is capturing graphical trend data from the screen of a personal computer, either running control software (e.g. Emerson DeltaV Operate) or data acquisition software used to monitor process data (e.g. WinDAQ, LabVIEW). Fortunately, this is really easy to do on any personal computer.

When you have the screen of the computer displaying what you wish to capture, simply press the "Print Screen" key on your keyboard. This key is usually located to the right of the "Function" key row at the top (on a standard desktop keyboard layout – laptop keyboards are famous for locating seldom-used keys like this in random places). Pressing the "Print Screen" key tells the computer's operating system to copy the entire screen image into a buffer for pasting into any graphics-manipulation or word-processing program you desire.

A utility standard on every Windows operating system is *Paint*: a bitmap image creation and manipulation program. Paint is simple to the point of being crude, but it works just fine for this purpose. After starting Paint, simply "Paste" the captured screen-shot image and save it under any filename you wish. I strongly recommend using a filename that is unique to you (e.g. `John_Doe_process1_trend2.bmp`). Remember that you will be capturing multiple screen-shots in this lab exercise, and will need to save every one for presentation to the instructor.

You may also use Paint (or even a more sophisticated image-manipulation program such as *Photoshop* or *Gimp*) to add text annotations to your screen-shot images. For example, some students like to add arrows and lines showing where they measured process gain, or arrows pointing to problems in the trend such as where the control valve sticks.

Common mistakes:

- Forgetting to move screenshot files to personal drive, leaving them on the hard drive of the school computer where they may be deleted by other students
- Not collecting enough screenshots to adequately document work done on the process
- Failing to label and organize the screenshot files so as to be able to remember what exactly was being done in each one of the trends

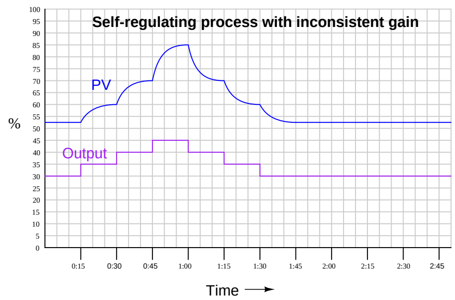
Lab Exercise – open-loop testing

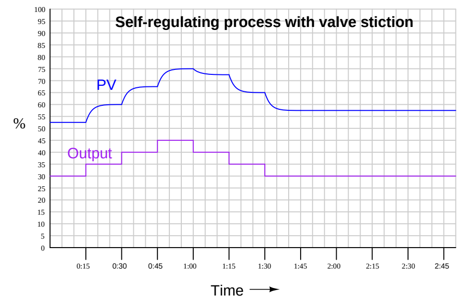
Before you can begin to successfully tune a PID-controlled process, you must first understand the characteristics of that process. A very good way to do this is by performing an *open-loop* test: placing the PID controller in manual mode and changing the output value (5% or so is usually a good amount for the first test) to see what effect this has on the process variable over time. The PV's response to this "step-change" in output can not only reveal the basic characteristics of the process (i.e. self-regulating, integrating, runaway, lag time magnitude, lag order(s), dead time magnitude) but also certain instrument problems (valve stiction, transmitter filtering, etc.).

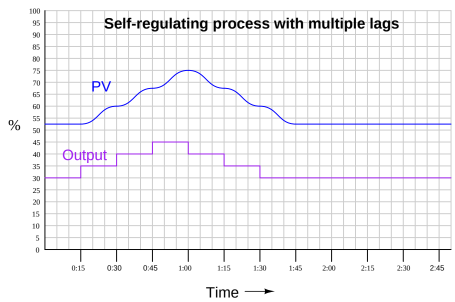
During all your testing, be sure to maintain the process variable within the alarm limits prescribed by the instructor! All of your documentation for the process characteristics (and the final tuning results) must show the PV remaining within these limits.

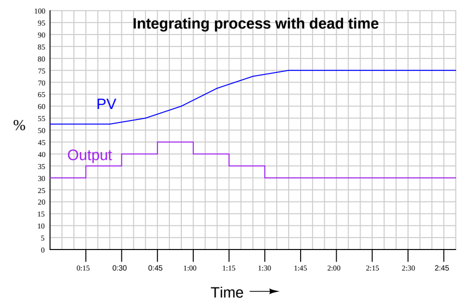
You should perform several open-loop step-changes to probe the process characteristics: a few in the same direction, then the rest in the other direction. An analysis of the PV responses following multiple output step-changes will reveal two important characteristics of the process:

- How consistent the process gain is
- Whether the valve has significant hysteresis or stiction (compare opening versus closing)



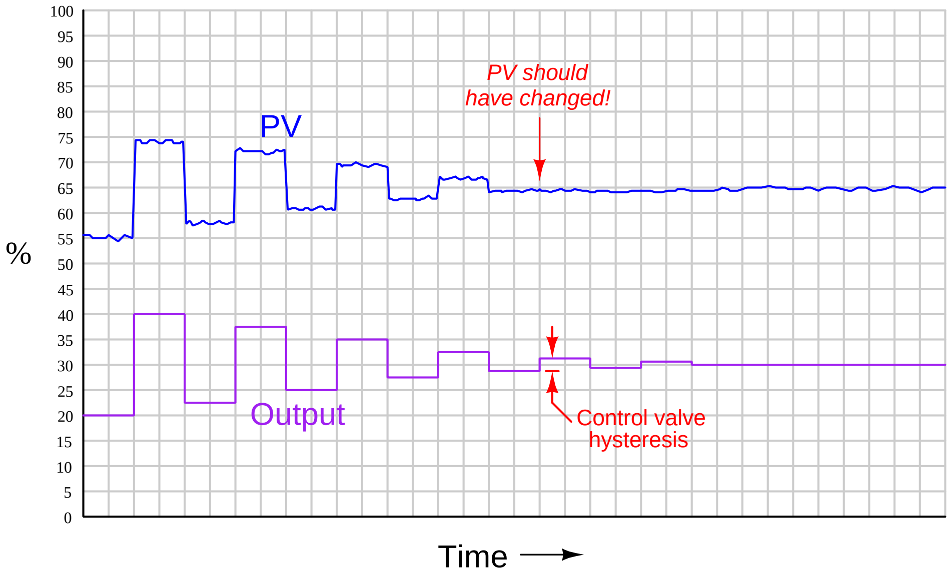






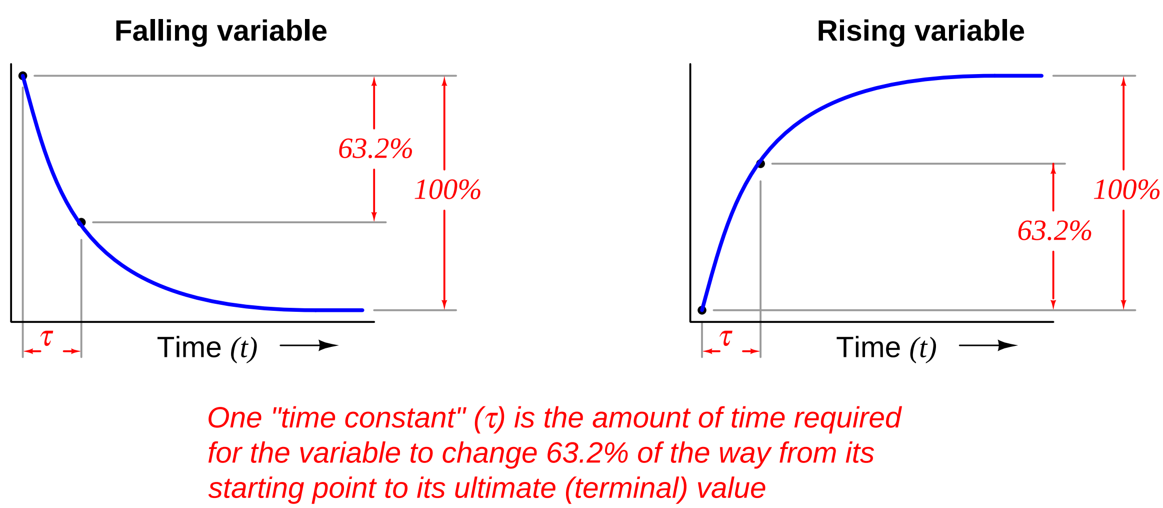
A common mistake among students is to try to determine process characteristics with the controller in *automatic* mode (i.e. closed-loop testing). This generally gives poor results because the process response seen on the trend graph while in automatic mode is not just the natural response of the process, but also the automatic (regulating) response of the controller. A controller that isn't tuned aggressively enough, for example, may make a fast process appear to have long lag times. By placing the controller in manual mode and performing open-loop tests, you get to see the natural response of the process itself without any controller interference.

Valve stiction is best determined by making alternating (up and down) step-changes in manual mode in progressively smaller intervals, noting the largest of those step-changes resulting in no measurable PV change. This is a superior test to multiple step-changes in the same direction because step-changes in the same direction tend to be additive while reversing steps are not. The following illustration shows this test applied to a fast, self-regulating process:



Another important test of process characteristics is the process *lag time*, also known as the process *time constant* symbolized by the Greek letter τ. This is precisely the same concept you have explored in previous courses with charging and discharging circuits (i.e. resistor-capacitor and inductor-capacitor circuits), and is empirically measured in precisely the same way.

With the controller in manual mode, you are to introduce a step-change in the output signal and then record the process variable's response. For self-regulating processes, the process variable will initially begin to ramp at a high rate of change, and then level off until it settles at its new self-regulated value. The amount of time it takes for the process variable to go 63.2% of the way from its initial to final values is the lag time (τ).



One of the common misconceptions regarding time constant is that you can first measure the amount of time it takes for the variable in question to reach its final value, and then divide that time by 5, because it is commonly taught that it takes 5 time constants' worth of time (5τ) for the changing variable to settle to its final value. *The truth is that five is the closest whole-number multiple of τ that gets you within just 1 percent of the variable's final (settled) value.* One percent is an entirely arbitrary figure, and so "five time constants' worth of time" is a poor standard to use in this manner.

Instead, what you must do to measure the lag time of a process is to follow the model presented to you in the previous graphs, where you base the time strictly by the horizontal distance on the trend that it takes for the process variable to traverse a 63.2% vertical interval. If the trend graph of your loop's controller does not provide fine-line divisions to help mark the variable's value (vertical) as well as the time (horizontal), you may have to resort to printing the trend on paper and sketching your own division lines to mark where these important points are.

One final note on the subject of lag time is that integrating processes do not strictly possess a lag time. Since in an integrating process the process variable never "levels out" on its own, there is no basis upon which to determine when it has traversed 63.2% of the way to its final value (because it *has no* final value).

Common mistakes:

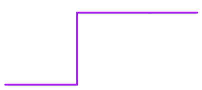
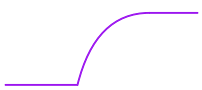
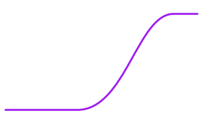
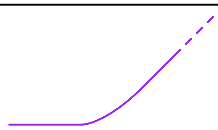
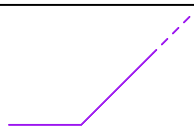
- Trying to probe the process characteristics with the controller in *automatic* mode rather than *manual* mode
- Making output step-changes that are too large (resulting in PV excursions beyond the alarm limit values)
- Not making enough step-changes to fully test process gain consistency or valve stiction
- Incorrectly measuring process lag time (time constant τ)

Notes on process characteristics and PID tuning strategies

After you have determined the characteristics of the process and corrected any instrument problems such as transmitter filtering or valve stiction, your next step is to determine how you will tune the PID controller. Several algorithmic procedures exist, including two methods proposed by Ziegler and Nichols in their 1942 paper, and several more modern methods. You are free to use whatever tuning method you would like to try, so long as you document the data supporting your tuning decisions (i.e. process characteristics) and also document the trend data showing improvement in process stability as you use your understanding of PID control to fine-tune each process.

Truth be told, many working professionals use algorithmic methods such as Ziegler-Nichols because they really don't understand how PID works, or is supposed to be applied to a real process. The goal of this lab exercise is to give you plenty of opportunity to try your hand at PID tuning, and to improve upon simple step-by-step methods such as Ziegler-Nichols. With practice, you will find it possible to make dramatic improvements over "canned" PID tuning methods simply by understanding the characteristics of the process and choosing control actions appropriate for those characteristics.

The following table shows several PV responses following a single controller output step-change in manual mode, with suggesting heuristic tuning strategies for each:

	Pure self-regulating	*May be controlled with aggressive integral action, and perhaps with a bit of proportional action. Use absolutely no derivative action!*
	Self-reg w/ pure 1st order lag	*Responds well to aggressive proportional action, with integral action needed only for recovery from load changes.*
	Self-reg w/ multiple lags	*Proportional action needed for quick response to setpoint changes, integral action needed for recovery from load changes, and derivative needed to prevent overshoot. Proportional and integral actions are limited by tendency to oscillate.*
	Integrating w/ lag(s)	*Proportional action should be aggressive as possible without generating oscillations. Integral action needed only for recovery from load changes.*
	Pure integrating	*Responds well to aggressive proportional action, with integral action needed only for recovery from load changes.*

Remember that the presence of certain other characteristics in significant amounts (e.g. PV noise, dead time, etc.) also impacts how one should tune a controller.

Common mistakes:

- Making tuning parameter changes that are too large without considering the ill effects those changes might have (e.g. increasing gain by a factor of 10)
- Attempting to "de-tune" process or instrument problems that should be repaired (transmitter filtering, valve stiction, etc.)

Lab Exercise – robust PID response

In this exercise you will be asked to demonstrate "robust" loop response to both setpoint changes and load changes, which naturally demands a definition for "robust" response. In this context, robust PID response meets all of the following criteria:

- The process variable is brought to setpoint as fast as possible following both setpoint changes and load changes
- The process variable exhibits as little over/undershoot as possible following both setpoint changes and load changes
- The process variable *never* strays outside of the prescribed alarm limits
- The process variable *never* porpoises (i.e. oscillates prior to reaching setpoint)

A controller that is tuned too "fast" will take little time reaching setpoint, but it will do so at the expense of overshooting or undershooting the setpoint value before settling in to the setpoint value. A controller that is tuned too "slow" will not over- or under-shoot setpoint, but will exhibit extended periods of time where the PV is approaching setpoint yet the output value is nowhere near saturation (i.e. the controller is not "trying" as hard as it can).

When testing for robust response to load changes, you should introduce load changes in a manner similar to how you introduce setpoint changes: change the load *and leave the load in that new state long enough to watch the controller compensate for it.* A very common error students make when introducing load changes is to do so very briefly, so briefly in fact that the controller never gets a chance to correct for the new load condition. What you see in such a case is the PV changing due to the load change, and then returning back to setpoint *only because the load returned to its previous value, not because the controller actually did anything to make PV return to setpoint!* So remember, when you introduce load changes, do so the same way you introduce setpoint changes: change the load condition and leave it in that new state, then watch the controller's response to see how quickly the PV returns to the setpoint value, whether there is under- or over-shooting of the setpoint, and/or whether any porpoising occurs.

You will notice that ideal tuning for response to setpoint changes is often different from ideal tuning for response to load changes. One reason for this is that setpoint changes typically occur more suddenly than load changes. Another reason is that load changes tend to alter the processes' equilibrium point (i.e. the FCE value necessary to maintain the setpoint) more than setpoint changes. If you notice a great different between these two responses, you may wish to set the PID algorithm to one where more of the PID equation responds only to changes in PV and not to changes in *error*. If you cannot achieve robust control for both setpoint *and* load changes, you may consult your instructor as you would operations personnel on the job to see which of these two scenarios is more realistic to the process, and then optimize your controller's response accordingly.

If your controller "porpoises" at all, it is detrimental to process control. "Porpoising" occurs when either the controller's proportional action or derivative action is too aggressive, causing the controller to over-correct during the PV's approach to setpoint. Integral is incapable of causing porpoising, because integral action cannot reverse direction unless and until the error changes sign (i.e. until PV crosses setpoint), and porpoising is defined as oscillations occurring *prior* to setpoint. Perhaps the best tool for determining whether excessive gain or excessive derivative action is causing porpoising is to examine the *phase shift* between PV and Output during the porpoising period: little or no phase shift reveals excessive P action, while nearly 90^o phase shift reveals excessive D action.

Common mistakes:

- Not properly diagnosing field instrument problems (e.g. sticky valves, over-damped transmitters) prior to tuning. *Pay close attention to your open-loop tests prior to any PID tuning parameter adjustments!!!*
- Relying too much on proportional action (gain) to control fast-acting, self-regulating processes.
- Introducing transient load changes that don't persist long enough to test the controller's ability to correct (i.e. to bring the PV back to SP with different load conditions).

Lab Exercise – troubleshooting

The most important aspect of this lab exercise is *troubleshooting*, where you demonstrate your ability to logically isolate a problem in the system. All troubleshooting must be done on a system you did not help build, so that you must rely on others' documentation to find your way around the system instead of from your own memory of building it. Each student is given a limited amount of time to identify both the location and nature of the fault. All troubleshooting activities must be proctored by the instructor to assess proper diagnostic reasoning and technique.

The standard procedure involves a group of no more than four students troubleshooting the same faulted system, with the builders of that system playing the role of operators. All troubleshooters are given a two-minute period to individually identify a plausible fault based on observable symptoms and submit it in writing to the instructor for assessment. Those students whose faults are indeed plausible advance to the next round, where each one takes turns making diagostic tests on the system. One minute is given to each student for devising this test, but no time limit is placed on the execution of that test. Whenever someone decides enough data has been collected to pinpoint the location and nature of the fault, they declare to have reached a conclusion and submit to the instructor in writing for assessment.

Individual troubleshooting with a five-minute time limit is also an acceptable format, but this generally only works with small class sizes.

Failure to correctly identify both the general location and nature of the fault within the allotted time, and/or failing to demonstrate rational diagnostic procedure to the supervising instructor will disqualify the effort, in which case the student must re-try with a different fault.

A standard multimeter is the only test equipment allowed during the time limit. No diagnostic circuit breaks are allowed except by instructor permission, and then only after correctly explaining what trouble this could cause in a real system.

The instructor will review each troubleshooting effort after completion, highlighting good and bad points for the purpose of learning. Troubleshooting is a skill born of practice and failure, so do not be disappointed in yourself if you must make multiple attempts to pass! One of the important life-lessons embedded in this activity is how to deal with failure, because it *will* eventually happen to you on the job! There is no dishonor in failing to properly diagnose a fault after doing your level best. The only dishonor is in taking shortcuts or in giving up.

Common mistakes:

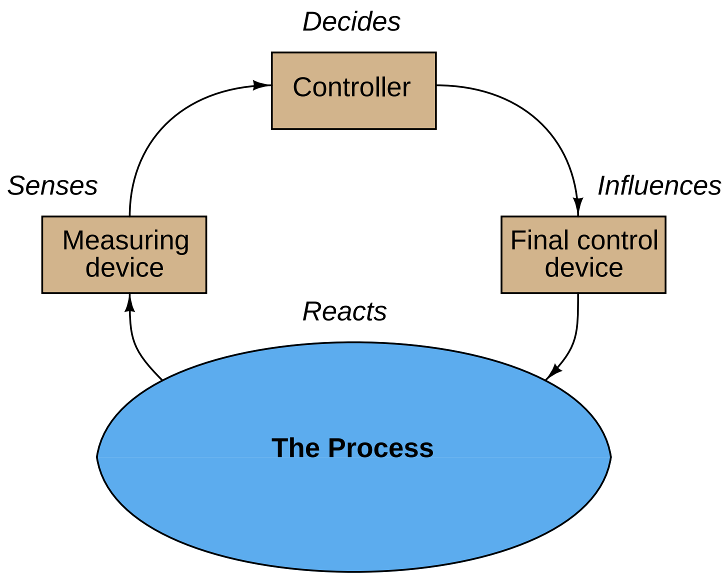
- Attempting to *visually* locate the fault.
- Neglecting to take measurements with your multimeter.
- Neglecting to check other measurements in the system (e.g. pressure gauge readings).
- Incorrectly interpreting the loop diagram (e.g. thinking you're at the wrong place in the system when taking measurements).
- Incorrect multimeter usage (e.g. AC rather than DC, wrong range, wrong test lead placement). This is especially true when a student comes to lab unprepared and must borrow someone else's meter that is different from theirs!

The purpose of every troubleshooting exercise is to foster and assess your ability to intelligently diagnose a complex system. Finding the fault by luck, or by trial-and-error inspection, is no demonstration of skill. Competence is only revealed by your demonstrated ability to logically analyze and isolate the problem, correctly explaining all your steps!

Troubleshooting takes a lot of lab time, usually at least two 3-hour lab sessions for everyone in a full class to successfully pass. Budget for this amount of time as you plan your work, and also be sure to take advantage of your freedom to observe others as they troubleshoot.

Notes on troubleshooting feedback control loops

Recall that every feedback control loop consists of four basic elements: an element that *senses* the process variable (e.g. primary sensing element, transmitter), an element that *decides* what how to regulate this process variable (e.g. a PID controller), an element that *influences* the process variable (e.g. a control valve, motor drive, or some other final control device), and finally the process itself which *reacts* to the final control device's actions:



You can check each element of your feedback control loop by comparing its input with its output to see if each element is doing what it should:

(1) **Decision-making:** Carefully examine the controller faceplate, looking at the values of PV, SP, and Output. Is the controller taking appropriate action to force PV equal to SP? In other words, is the Output signal at a value you would expect if the controller were functioning properly to regulate the process variable at setpoint? If so, then the controller's action and tuning are most likely not at fault. If not, then the problem definitely lies with the controller.

(2) **Sensing:** Compare the controller's displayed value for PV with the actual process variable value as indicated by local gauges, by feel, or by any other means of detection. If there is good correspondence between the controller's PV display and the real process variable, then there probably isn't anything wrong with the measurement portion of the control loop (e.g. transmitter, impulse lines, PV signal wiring, analog input of controller, etc.). If the displayed PV disagrees with the actual process variable value, then something is definitely wrong here.

(3) **Influencing:** Compare the controller's displayed value for Output with the actual status of the final control element. If there is good correspondence between the controller's Output display and the FCE's status, then there probably isn't anything wrong with the output portion of the control loop (e.g. FCE, output signal wiring, analog output of controller, etc.). If the controller Output value differs from the FCE's state, then something is definitely wrong here.

(3) **Reacting:** Compare the process variable value with the final control element's state. Is the process doing what you would expect it to? If so, the problem is most likely not within the process (e.g. manual valves, relief valves, pumps, compressors, motors, and other process equipment). If, however, the process is not reacting the way you would expect it to given the final control element's state, then something is definitely awry with the process itself.

Lab Exercise – decommissioning and clean-up

The final step of this lab exercise is to decommission your team's entire system and re-stock certain components back to their proper storage locations, the purpose of which being to prepare the lab for the next lab exercise. Remove your system documentation (e.g. loop diagram) from the common holding area, either discarding it or keeping it for your own records. Also, remove instrument tag labels (e.g. FT-101) from instruments and from cables. Perform general clean-up of your lab space, disposing of all trash, placing all tools back in their proper storage locations, sweeping up bits of wire off the floor and out of junction boxes, etc.

Leave the following components in place, mounted on the racks:

- Large control valves and positioners
- I/P transducers
- Large electric motors
- Large variable-frequency drive (VFD) units
- Cables inside conduit interconnecting junction boxes together
- Pipe and tube fittings (do not unscrew pipe threads)
- Supply air pressure regulators

Return the following components to their proper storage locations:

- Sensing elements (e.g. thermocouples, pH probes, etc.)
- Process transmitters
- "Jumper" cables used to connect terminal blocks within a single junction box
- Plastic tubing and tube fittings (disconnect compression-style tube fittings)
- Power cables and extension cords
- Adjustment (loading station) air pressure regulators

Finally, you shall return any control system components to their original (factory default) configurations. This includes controller PID settings, function block programs, input signal ranges, etc.

Lab Exercise – team tool locker inspection

The instructor will work with each team to inspect their tool locker for all required items, and also to ensure nothing else is being stored there.

First, the locker will be entirely emptied. Next, the instructor will inspect each tool before placing it in the locker, following the order of the inventory list taped to the inside of the locker door. The team is responsible for finding or replacing any missing items. Any items not on the inventory list will be left out of the locker.

Any damaged or worn components will be replaced. Inexpensive items such as drill bits and taps will be replaced at student expense. More expensive items will be replaced at the school's expense, with students doing research to identify the replacement cost of the item(s) in question.

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Question 62

Capstone Assessment (end of quarter)

This performance assessment tests your mastery of many important instrumentation concepts. You are to automate a pre-built process based on prototype diagrams you sketch of all instrument connections, and demonstrate the automatic control of this process. All this must be done individually with no assistance from anyone else, within one continuous time block not to exceed three hours. You may refer to manufacturer documentation and/or textbooks, but not to personal notes, while building your loop.

You are entirely responsible for figuring out how the process works and what you must do to control it, based on your inspection of it after it has been selected for you. This includes identifying the process variable, the final control element, any loads, instrument model numbers, and locating manufacturer's documentation for the instrumentation.

You may perform the assessment activity at any time in the quarter. Successful completion counts as the "mastery" portion of the course exam(s). There will be no grade penalty for repeated attempts, however successful completion of this activity is required to pass the course.

In addition to exhibiting a steady-state control in automatic mode (i.e. the process variable follows changes made to the setpoint and settles at or near the setpoint value without oscillation after some time), the process must also meet the following criteria based on courses you have completed:

- If you have passed or are currently taking the *INST241* course, your transmitter and controller must be properly configured to register the process variable (in engineering units, not percent) over a range specified by the instructor. Note: if the transmitter is analog rather than "smart," the instructor will have you determine its "As-Found" range and direct you to range the loop controller to match the transmitter rather than calibrate the analog transmitter to a specified range.
- If you have passed or are currently taking the *INST252* course, the controller must be tuned for robust response to perturbations (changes) in either setpoint or load as selected by the instructor at or near a setpoint value also specified by the instructor. "Robust" control is defined here as the controller compensating for perturbations as quickly as possible without creating any process variable oscillations (i.e. a *critically damped* response). It will be your decision to use P, I, D, or any combination thereof in the controller's tuning.
- If you have passed or are currently taking the *INST260* course, you must connect a data acquisition unit (DAQ) to record a variable in the process selected by the instructor and display a trend graph and/or a scaled representation of the measured variable on a personal computer networked to the DAQ. For example, if you are instructed to display the controller's output value using the DAQ, the display should register on a scale of 0% to 100% just like the controller's output is ranged from 0% to 100%. If the DAQ needs to show the process variable, it must register that variable in the same range as the transmitter. If your DAQ provides a trend graph, the vertical scale markings of that trend graph must be similarly ranged.

Given the time constraint of this assessment, you will not be required to cut and fit flexible conduit to the field instruments. All other wiring must be neatly installed so as to avoid creating safety hazards (tripping, etc.) and confusion for other students assembling their loops.

Limited availability of components and physical space in the lab means that only a few students will be able to work on this assessment at once, so plan on attempting this *well before* the final due date!

Capstone assessment check-list (listed in sequential order) Name: _______________

Bring a printed copy of this check-list with you when beginning the capstone assessment! Remember that you must work independently once the instructor assigns you a vest to wear. Any consultation with classmates, use of personal notes, or deviation from your approved diagram(s) will result in immediate disqualification, which means you must take everything apart and re-try the capstone assessment on a different process. Any damage done to the process or instrumentation will similarly result in disqualification, and you must repair the damage prior to re-trying the capstone assessment. You are allowed to use manufacturer documentation, as well as any documentation provided by the instructor (e.g. textbooks).

No teamwork is allowed while wearing the vest!

Selection	**(Instructor writes/checks)**
Instructor assigns a vest for you to wear	
Instructor selects a process for you to automate	
Instructor selects process variable range (*INST241 only*)	
Instructor selects setpoint/load & SP value (*INST252 only*)	@ SP =
Instructor selects DAQ variable to measure (*INST260 only*)	
Instructor selects controller – **label with your name!**	
Instructor verifies no wiring connected to the process	

The time clock starts now! **Start time:** _______________

Criterion	**(Instructor verifies)**
You sketch basic loop diagram – instructor verifies correctness	
You sketch DAQ connection diagram – instructor verifies correctness	

Now you may begin wiring and configuring the components

Criterion	**(Instructor verifies)**
Steady-state control in automatic mode	
Controller correctly registers the process variable (*INST241 only*)	
Controller responds robustly to perturbations (*INST252 only*)	
DAQ measurement correctly scaled and/or graphed (*INST260 only*)	

The time clock stops now! **Stop time:** _______________

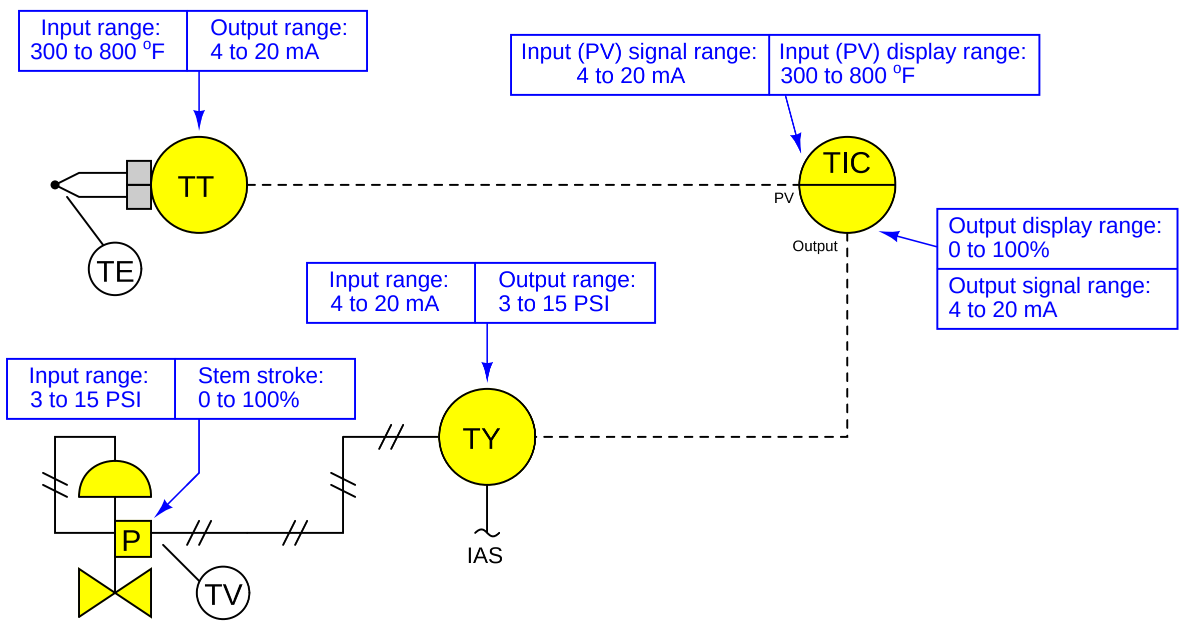
Criterion	**(Instructor verifies)**
Instructor verifies all signal wires/tubes disconnected	
Instructor verifies controller reset to original configuration	
Instructor verifies DAQ is returned to team tool locker	
Instructor collects your diagrams	

Your mastery score will not be recorded until all steps are complete!

Notes on instrument ranging

An important configuration parameter for any practical measurement or control system is *process variable ranging*. This entails setting both the transmitter and indicator/controller to a specified measurement range, with the controller indicating the process variable in real "engineering units" (e.g. PSI or degrees F rather than just percent). The following tutorial describes how this works and which configuration parameters to modify in a variety of different control systems found in the Instrumentation lab room.

The reason this is an issue at all is because loop controllers operating on 4-20 mA analog signals don't "know" what those signals are supposed to represent unless someone configures the controller with the proper range reflecting real-world conditions. For example, if a student is assigned a temperature transmitter with a range of 300 to 800 degrees Fahrenheit, not only does the transmitter have to output 4 mA when sensing 300 ^{o}F and output 20 mA when sensing 800 ^{o}F, but the controller must display an indication of 300 ^{o}F when it receives a 4 mA signal from the transmitter, and display an indication of 800 ^{o}F when it receives a 20 mA signal from the transmitter. None of this happens on its own – the student must range the transmitter for 300-800 ^{o}F input (and 4-20 mA output) as well as range the controller to display 300-800 ^{o}F over its 4-20 mA input scale. A typical loop is shown here with all instrument ranges displayed:



Analog (non-"smart") transmitters, I/P transducers, and valve positioners are ranged using "zero" and "span" adjustments, typically screws or nuts. The ranging of analog instruments is discussed in the "Instrument Calibration" chapter of the *Lessons In Industrial Instrumentation* textbook.

Digital ("smart") transmitters and valve positioners are ranged by setting LRV and URV parameters using a "communicator" device or a personal computer equipped with the appropriate interface and software. This too is discussed in the "Instrument Calibration" chapter of the *Lessons In Industrial Instrumentation* textbook.

Digital electronic loop controllers contain parameters specifying the process variable (PV) ranges. The following page lists examples of PV range configuration parameters for several different makes and models of loop controllers.

- Siemens/Moore 352 controller: process variable range parameters are located in the "Operator's Display" function block (FB15):
  → LRV = *Process Lo*
  → URV = *Process Hi*

- Siemens/Moore 352P and 353 controller: process variable range parameters are located in the "Analog Input" function block (AIN):
  → LRV = *Minscale*
  → URV = *Maxscale*

- Emerson DeltaV DCS: process variable range parameters are located in the "Analog Input" function block (AI) and "PID" function block (PID):
  → (AI block) = the *OUT_SCALE* parameter contains both high and low range limits, engineering units (e.g. deg F), and decimal point position. The *L_Type* parameter needs to be set to "indirect" to allow scaling to occur ("direct" mode prohibits scaling), and the *XD_Scale* parameter needs to be ranged 0 to 100%. Note that the "direct" and "indirect" options for *L_Type* have absolutely nothing to do with "direct" and "reverse" PID controller action, which is configured elsewhere.
  → (PID block) = the *PV_SCALE* parameter contains both high and low range limits, engineering units (e.g. deg F), and decimal point position. Note: the PID block's *PV_SCALE* range must exactly match the *OUT_SCALE* range of the AI block!

- Honeywell UDC 2500 controller: process variable input #1 range parameters are located in the "Input 1" set-up group of parameters:
  → LRV = *IN1 LO*
  → URV = *IN1 HI*

- Automation Direct "SOLO" controller: process variable range parameters are located in the following registers:
  → LRV = *P3-4 Input Range Low*
  → URV = *P3-3 Input Range High*

- Allen-Bradley PLC5, SLC500, and MicroLogix controllers: process variable scaling parameters are typically located either in a "Scale" instruction (SCL) or a "Scale with Parameters" instruction (SCP). In either case, the instruction takes the raw count value from the input channel's analog-to-digital converter and scales it into the desired process variable display range. A YouTube video on our BTCInstrumentation channel shows how to do this for the networked MicroLogix PLCs in the lab using the SCP instruction. *Note: SCP instruction parameters may be edited online. For this reason, downloading edits is not necessary for the MicroLogix PLCs in our lab. In fact, it is very important that you not save or download the PLC program, because doing so may alter the PLC's network address and lead to communication problems. Just make the changes while the PLC is in "Run" mode and then exit the program*:
  → (SCL instruction) = *Rate* and *Offset* values scale the signal according to the slope-intercept formula $y = mx + b$, where *Rate* is $10000m$ and *Offset* is b
  → (SCP instruction LRV) = *Scaled Min.*
  → (SCP instruction URV) = *Scaled Max.*

- Allen-Bradley Logix5000 controller: process variable scaling parameters are located in the "PID" instruction (PID):
  → LRV = *.MINS*
  → URV = *.MAXS*

- caSCADA "`pid`" control program: process variable scaling parameters are located in one of the source code files which must be modified using a text editor program, then recompiling the `pid` program so the new parameters may take effect. This control program may be initiated from the Linux command line by typing `./pid` and pressing the Enter key, after which a set of instructions will appear on the screen showing the default LRV and URV range values, and which file to find these parameters within. After editing and saving this file, you will need to type `make` at the Linux command line and press Enter to recompile the program. Finally, type `./pid` and press Enter to initiate the recompiled program.
  → LRV = *pid[0].LRV*
  → URV = *pid[0].URV*

file `ranging`

Notes on controller action

An important set of configuration parameters for any control system are *controller action* and *PID tuning*. Proper controller action means that the control system reacts to setpoint changes and process variable disturbances in the correct direction (e.g. a temperature control system that acts to reduce heat input when the process variable is above setpoint). Proper PID tuning means that the control system reacts to setpoint changes and process variable disturbances to an appropriate degree over time (e.g. a temperature control system that applies the right amount of additional heat input when the process variable goes below setpoint). A controller with the wrong action will cause a process to "run away" to one extreme value or the other. A controller with poor PID tuning will fail to achieve setpoint, and/or oscillate needlessly. The following is a list of configuration parameters to modify in a variety of different control systems found in the Instrumentation lab room.

If the controller happens to be programmed using function blocks, these important parameters will be found in the "PID" function block. For other controller models, there will be a menu option with action (direct/reverse) and tuning (P/I/D) parameters. Note that some controllers provide a quick-access feature to edit the PID tuning parameters, but generally not for changing the direction of action. Here are some examples:

- Siemens/Moore 352 controller: control action parameters are located in the "PID" function block (FB13). Note that the P, I, and D tuning parameters may be quickly accessed by pressing the "Tune" button rather than by entering the PID function block edit menu:
  → Direction (Direct/Reverse)= *SA1*
  → Proportional (P) = *SPG1* as a unitless gain value
  → Integral (I) = *STI1* in units of minutes per repeat
  → Derivative (D) = *STD1* in units of minutes

- Siemens/Moore 352P and 353 controller: control action parameters are located in the "PID" function block (PID). Note that the P, I, and D tuning parameters may be quickly accessed by pressing the "Tune" button rather than by entering the PID function block edit menu:
  → Direction (Direct/Reverse)= *DIR ACT*
  → Proportional (P) = *PG* as a unitless gain value
  → Integral (I) = *TI* in units of minutes per repeat
  → Derivative (D) = *TD* in units of minutes

- Emerson DeltaV DCS: control action parameters are located in the "PID" function block (PID) conforming to the FOUNDATION Fieldbus standard:
  → Direction (Direct/Reverse)= Found in the *CONTROL_OPTS* set of parameters as a "check-box" where a checked box sets direct action and an unchecked box sets reverse action.
  → Proportional (P) = *GAIN* as a unitless gain value
  → Integral (I) = *RESET* in units of seconds per repeat
  → Derivative (D) = *RATE* in units of seconds

- Honeywell UDC 2500 controller: control direction is located in the "CONTRL" set-up group of parameters, while the PID tuning coefficients are located in the "TUNING" set-up group of parameters:
  → Direction (Direct/Reverse)= *Action*
  → Proportional (P) = *PB* or *Gain* as a proportional band percentage or as a unitless gain value, respectively
  → Integral (I) = *I Min* or *I RPM* in units of minutes or repeats per minute, respectively
  → Derivative (D) = *Rate T* in units of minutes

- Automation Direct "SOLO" controller: process variable range parameters are located in the following registers:
  → Direction (Direct/Reverse)= *P3-7 Heating/Cooling*
  → Proportional (P) = *P1-4 Proportional band* as a proportional band percentage
  → Integral (I) = *P1-5 Integral time* in units of seconds
  → Derivative (D) = *P1-6 Derivative time* in units of seconds

- Allen-Bradley PLC5, SLC500, and MicroLogix controllers: control action parameters are located in the "PID" instruction. A YouTube video on our BTCInstrumentation channel shows how to do this for the networked MicroLogix PLCs in the lab (reading the PV on the first analog input and sending the output to the first analog output of the I/O card):
  → Direction (Direct/Reverse)= Found in the *Control Mode* field where E=PV−SP represents direct action and E=SP−PV represents reverse action.
  → Proportional (P) = *Controller Gain* K_c as a unitless gain value
  → Integral (I) = *Reset* T_i in units of minutes per repeat
  → Derivative (D) = *Rate* T_d in units of minutes

- Allen-Bradley Logix5000 controller: control action parameters are located in the "PID" instruction (PID):
  → Direction (Direct/Reverse)= E where PV−SP represents direct action and SP−PV represents reverse action.
  → Proportional (P) = K_p or K_c as a unitless gain value
  → Integral (I) = K_i in units of seconds per repeat
  → Derivative (D) = K_d in units of minutes

- caSCADA "`pid`" control program: control action parameters are located on the operator interface screen, above the trend graph. This control program may be initiated from the Linux command line by typing `./pid` and pressing the Enter key. Once the `pid` control program is running (reading the PV on analog input AIN0 and sending the output to analog output DAC0 of the LabJack DAQ), each parameter may be selected by pressing the `S` key as often as needed, and the parameter values changed by pressing the arrow and page up/down keys. Note that the control direction may only be switched while the controller is in manual mode. Tuning parameters may be altered in either manual or automatic modes.
  → Direction (Direct/Reverse)= will either show "`Direct-acting`" or "`Reverse-acting`"
  → Proportional (P) = `K_P` as a unitless gain value
  → Integral (I) = `K_I` in units of repeats per minute
  → Derivative (D) = `K_D` in units of seconds

Notes on controller tuning

For those who have never tuned a controller before but need to set the PID parameters for basic loop stability in automatic mode, here are some tips for setting the P, I, and D parameter values. Every PID controller provides means to alter the tuning coefficients named *proportional* (also called *gain*), *integral* (also called *reset*), and *derivative* (also called *rate or pre-act*). Settings which are virtually assured to yield stable control are as follows:

- **P** – a "gain" value of less than one (i.e. a "proportional band" value of at least 100%).
- **I** – a "reset" value of zero repeats per minute, or the largest value possible for minutes per repeat.
- **D** – a "rate" value of zero.

Mind you, these parameters will not yield *good* control, but merely *stable* control. In other words, these tuning parameter values will make the controller fairly unresponsive, but at least it won't oscillate out of control. Also bear in mind that having an integral (reset) value set for minimum action (i.e. zero repeats per minute, or very high minutes per repeat) will result in a controller that never quite makes the process variable value reach setpoint – instead, there will be a persistent "offset" between PV and SP with integral action essentially turned off.

file `control`

<u>file i00998</u>

Question 63

The maintenance of a working lab facility is extensive, especially for a program such as Instrumentation, where most of the equipment comes in the form of donations which must be pieced together, and where many of the systems are custom-built for the purpose. Every student bears a responsibility for helping maintain the lab facility, because every student benefits from its provisions.

On the last day of every quarter, time is allocated to the clean-up and re-organization of the lab facility. This is a full work day, with attendance enforced as per usual. In order to help students focus on the tasks that need to be done, the following list documents some of the work necessary to make the lab ready for next quarter. Tasks preceded by a blank line will be assigned to lab teams for completion.

Lab tasks

- Check to see that all small items bearing BTC inventory tags are painted a bright color to make them easy to spot for each year's inventory check.
- __________ Sweep all lab floor areas, recycling or discarding any waste material.
- __________ Sweep all storage room floor areas, recycling or discarding any waste material. Place items found on floor back on shelves where they belong.
- __________ Collect all copper tube segments and place them in the copper/brass recycling receptacle.
- __________ Collect all aluminum, stainless steel, brass, and copper wire scrap (pieces shorter than 1 foot) in the scrap metal buckets near the north-west exit door.
- __________ Haul recyclable metals to a local scrap dealer, and return with cash to buy pizza for today's lunch.
- __________ Organize storage bins for danger tags and masking tape. Collect any unused danger tags from around the lab room and place them in that bin.
- __________ Help search for any missing Team Tool Locker items.
- __________ Clean all workbench and table surfaces.
- __________ Remove items from the compressor room, sweep the floor, and make sure there is no junk being stored there.
- __________ Collect lengths of cable longer than 1 foot and place in the storage bins inside the DCS cabinets for future use.
- __________ Re-organize wire spool storage area: remove any empty spools from the rack, ensure all boxes and unmounted spools are neatly stacked on the floor.
- __________ Collect all plastic tubes and return them to the appropriate storage bin.
- __________ Re-organize tube fitting drawers (north-west corner of lab room), ensuring no pipe fittings are mixed in, that all fittings are found in the proper drawers, and that all drawers are properly labeled (these drawers should have sample fittings attached to the fronts).
- __________ Re-organize pipe fitting drawers (north-west corner of lab room), ensuring no tube fittings are mixed in.
- __________ Re-organize hose fitting drawers (north-west corner of lab room).
- __________ Re-organize terminal block and ice-cube relay drawers (north end of lab room).
- __________ Drain condensed water out of air compressor tank (in the compressor room).
- __________ Return all books and manuals to bookshelves.
- __________ Inspect each and every control panel in the lab, removing all wiring except for those which should be permanently installed (120 VAC power, signal cables between junction boxes). Ensure that each junction box's power cords are securely fastened and grounded.
- __________ Inspect each and every signal wiring junction box in the lab, removing all wiring except for those which should be permanently installed (e.g. 120 VAC power, signal cables between junction boxes.). Ensure that each junction box's power cords are securely fastened and grounded.
- __________ Check condition of labels on all junction boxes and control panels, making new labels if the old labels are missing, damaged, or otherwise hard to read.
- __________ Check condition of labels on all permanently-installed cables (e.g. between junction boxes), making new labels if the old labels are missing, damaged, or otherwise hard to read.

- __________ Check condition of labels on all terminal blocks inside control panels and junction boxes, making new labels if the old labels are missing or otherwise hard to read.
- __________ Remove all debris left in control panels and junction boxes throughout the lab room, using a vacuum cleaner if necessary.
- __________ Clean up deadweight testers (they tend to leak oil). *Hint: WD-40 works nicely as a solvent to help clean up any leaked oil.*
- __________ Maintenance on turbocompressor system: (safety tag-out, check oil level, repair any oil leaks, repair any poor wire connections, clean debris out of control cabinet, re-tighten all power terminal connections).
- __________ Return all shared tools (e.g. power drills, saws) to the proper storage locations (hand tools to the tool drawer in the north-east corner of the lab room, and power tools to the tool shelf in the upstairs storage area).
- __________ Remove items from all storage cabinets on the north end of the lab room, cleaning all shelves of junk (e.g. pH probes that have been left dry) and returning all items to their proper places. Install covers on all transmitters missing them, especially on pneumatic transmitters which are vulnerable to damage without their covers attached.
- __________ Visually inspect all general-purpose pressure regulators stored in the north storage shelves for missing adjustment bolts, missing tube connectors, damaged port threads, etc. Make repairs as necessary.
- __________ Test all pressure transmitters not labeled "good" to see if they are indeed defective. Repair if possible, salvage parts and discard if not. Check for stripped screw heads and replace screws if necessary. *Do not discard any instrument with a BTC inventory tag!*
- __________ Test all temperature transmitters not labeled "good" to see if they are indeed defective. Repair if possible, salvage parts and discard if not. Check for stripped screw heads and replace screws if necessary. *Do not discard any instrument with a BTC inventory tag!*
- __________ Test all I/P converters not labeled "good" to see if they are indeed defective. Repair if possible, salvage parts and discard if not. Check for stripped screw heads and replace screws if necessary. *Do not discard any instrument with a BTC inventory tag!*
- __________ Test all precision pressure gauges not labeled "good" to see if they are indeed defective. Repair if possible, salvage parts and discard if not. *Do not discard any instrument with a BTC inventory tag!*
- __________ Test all precision pressure regulators not labeled "good" to see if they are indeed defective. Repair if possible, salvage parts and discard if not. *Do not discard any instrument with a BTC inventory tag!*
- __________ Test all hand air pumps used for pressure calibration work. If a pump leaks, disassemble the pump to clean and inspect its internal parts. Repair if possible, salvage parts and discard if not. *Do not discard any instrument with a BTC inventory tag!*
- __________ Return all field instruments (e.g. transmitters) and miscellaneous devices (e.g. pressure gauges and regulators) to their proper storage locations. *Note that I/P transducers and valve positioners should remain near their respective control valves rather than be put away in storage!*
- __________ Store all 2×2 foot plywood process boards in secure locations, ensuring each one is ready to use next quarter.
- __________ Ensure that each and every control valve mounted on the racks in the lab room has an I/P transducer mounted nearby, complete with Swagelok tube connectors in good condition for connecting compressed air supply and signal to the valve.
- __________ Check to make sure that each valve is securely mounted to the rack, and if there is a positioner attached that the feedback arm is properly connected to the valve stem (e.g. no missing tension springs, bent linkages, obvious misalignments).
- __________ Remove all items from the flammables cabinet, wipe all shelves of liquid and reside, then re-stock in a neat and safe manner.
- __________ Clean all bar-be-que grills of residue left over from lunches and fundraisers. *Note: you may need to take the grill racks and grease drip trays to a car wash station and use the engine degreaser solution to clean them thoroughly enough!*

- __________ Re-set all function block parameters in the DCS "Generic Loops" to their default settings. See the documentation on the main BTC_PPlus workstation for instructions on parameter values.
- __________ Check manometers on the calibration bench, ensuring those filled with red fluid are at their fluid levels and that all the others (normally filled with distilled water) are completely drained.
- __________ Turn on compressed air to the calibration bench, checking for leaks and ensuring every pressure regulator is functioning as it should.
- __________ Clean refrigerators, throwing away any food items remaining within.
- __________ Thoroughly clean all food ovens and any other cooking tools.
- __________ Return all shelf boards to their appropriate places on the racks.
- __________ Clean and re-organize all shelves in classroom DMC 130 storing components for the hands-on mastery assessments. Throw away any damaged jumper wires, battery clips, etc. Discard any batteries whose terminal voltages are less than 80% of their rating (e.g. less than 7.2 volts for a 9-volt battery).
- __________ Shut off power to all control systems except for the DCS.
- __________ Store any donated components in the proper locations.
- __________ Clean all whiteboards using Windex, so they actually look white again!

- *Instructors may add items to this list as necessary:*

- __________

- __________

- __________

- __________

- __________

- __________

- __________

Personal tasks

- Apply "sick hours" to missed time this quarter (remember, this is *not* automatically done for you!).
- Donate unused "sick hours" to classmates in need.
- Take any quizzes missed due to classroom absence this quarter (remember, a quiz not taken will be counted as a failed quiz!).

file i01229

Answers

Answer 1

Answer 2

Answer 3

Answer 4

Answer 5

This will be a *direct-acting* controller, once the programming problem is fixed.

Answer 6

Hint: I suggest a "thought experiment" whereby you imagine a process condition far from setpoint, and then you imagine what valve positions would be necessary to bring the process variable back to setpoint.

Answer 7

Oscillation in the process variable is the result of the controller's output (valve position) reversing direction. Integral action *cannot* reverse valve direction so long as the error remains the same sign (either positive or negative). Therefore, the only actions capable of reversing valve direction prior to achieving setpoint are proportional and derivative. Since we know this particular controller has no derivative action, the excess must be proportional (i.e. too much gain).

Answer 8

The NDIR analyzer is clearly the better choice from the perspective of dead time. More dead time in a feedback loop results in slower (possible) automatic control response, because a controller response appropriate for a minimal-deadtime loop will oscillate given the presence of additional dead time.

For a more complete explanation of this, refer to *Lessons In Industrial Instrumentation* in the section describing "dead time" as a process characteristic, and how its presence affects feedback control.

Answer 9

Whatever the problem is, it is *not* in this loop controller!

Answer 10

Answer 11

By initially moving the "wrong direction" in response to a change in feedwater flow, the drum level feedback signal to the controller actually constitutes *positive* feedback rather than negative. The 180^o phase shift of proportional action combined with the 180^o phase shift of boiler "shrink" makes 360_o.

Follow-up question: integrating processes such as liquid level typically respond well to aggressive proportional control action (proportional bands of 10% or less!), but not in this case. How would you recommend tuning the level controller in a boiler feedwater control system, given the effect of "shrink?"

Answer 12

By initially moving the "wrong direction" in response to a change in steam flow, the drum level feedback signal acts as an *inverted* feedforward signal for steam flow, exacerbating the load change's effect instead of preempting it.

Follow-up question: integrating processes such as liquid level typically respond well to aggressive proportional control action (proportional bands of 10% or less!), but not in this case. How would you recommend tuning the level controller in a single-element boiler feedwater control system, given the effect of "swell?"

Challenge question: explain how both two-element and three-element feedwater control helps to mitigate the effect of boiler swell.

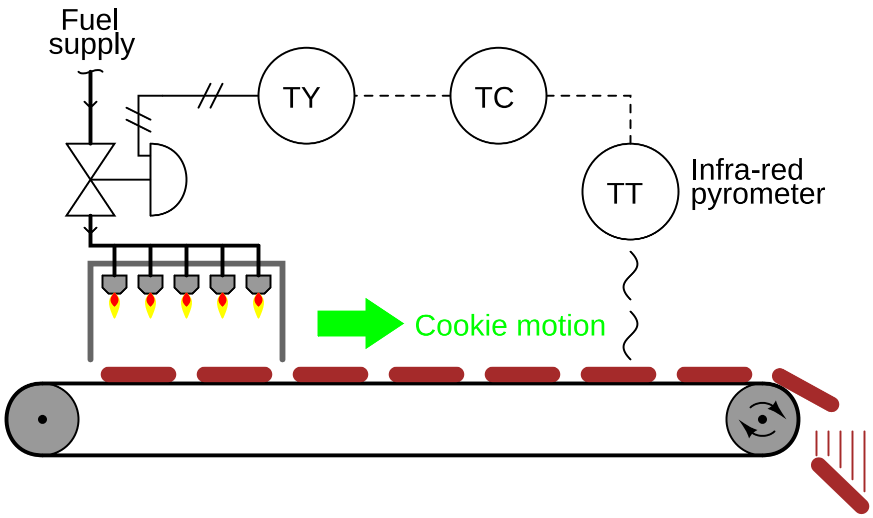
Answer 13

This plot of PV response for several step-changes in output shows the process to possess a significant amount of *hysteresis*. If this is a process controlled by a valve, I would suspect that the valve had significant "stiction" and/or looseness in a mechanical coupling.

Note how the first upward output step-change has no measurable effect on the process variable. But on the second and third upward step-changes, the process variable responds immediately with upward jumps. Likewise, on the first downward output step-change, there is no measurable effect on the process variable. However, the process responds swiftly to the second and third downward output step-changes. In summary, we see no effect on the first output reversal-of-direction. This is characteristic of *hysteresis*, wherever it may reside in the system. The most likely source of this hysteresis is in the control valve (stiction).

Answer 14

This plot of PV response for several step-changes in output shows the process to possess a significant amount of *dead time*, technically known as *transport delay*. There are many potential causes of dead time, but the most common is poor location of the primary sensing element (PSE), so that a significant amount of time must elapse before the process flow carries the result of the final control element's change to the sensor. An example of this is temperature control on items carried by a conveyor belt, with the temperature sensor and heating element located far apart from each other on the belt:



Other possibilities exist, however. For instance, this phenomenon may also be produced by a combination of stiction and limited air flow in a pneumatic valve actuator.

The *steady-state gain* of a self-regulating process is defined as the change in process variable (ΔPV) resulting from a change in manipulated variable (ΔOutput). In this case, a 10% step-change in output produced approximately 12.5% of change in the process variable (from about 45% to about 57.5%): a ratio of 1.25.

$K = 1.25$ (approximately)

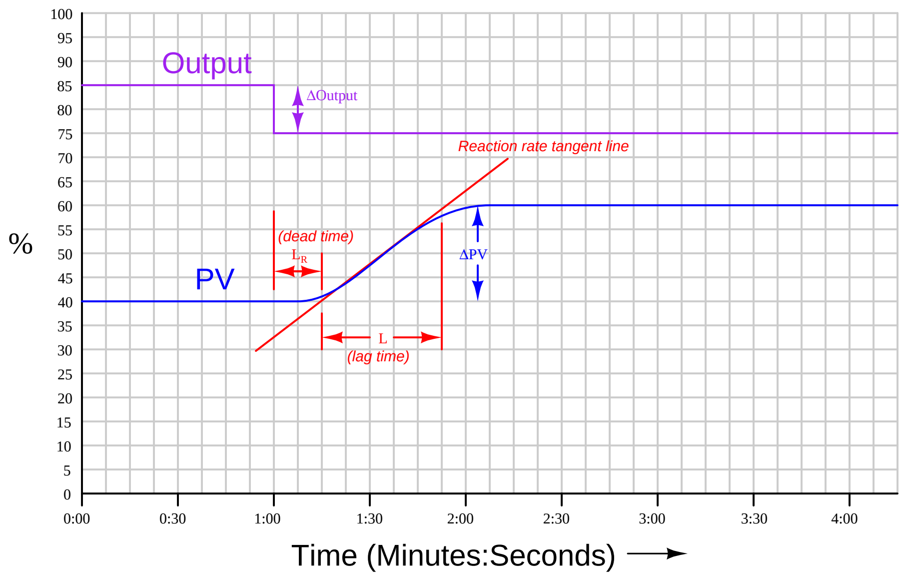
Answer 15

The process (as a whole) has a variable gain. If the process has a variable gain, it means the entire loop gain will increase and decrease depending on the PV's value. This means the loop will be less stable at some PV values than at others.

This may be due to a severe nonlinearity in the transmitter or in a signal transducer, a control valve with a nonlinear installed characteristic (in this case, an equal-percent *installed* characteristic – very unlikely), or something inherent to the process itself (most likely).

To counter this gain instability, the controller (or some other element in the control loop) must be configured to have an inverse gain response, so that the loop gain always remains constant. An *adaptive gain* controller may be used for this purpose, or perhaps a different valve characteristic may be installed.

Answer 16



- Steady-state gain $(K) = 2$
- Dead time $(L_R) = 0.25$ minutes
- Reaction rate $(R_R) = 3.2\%$ / unit-minute

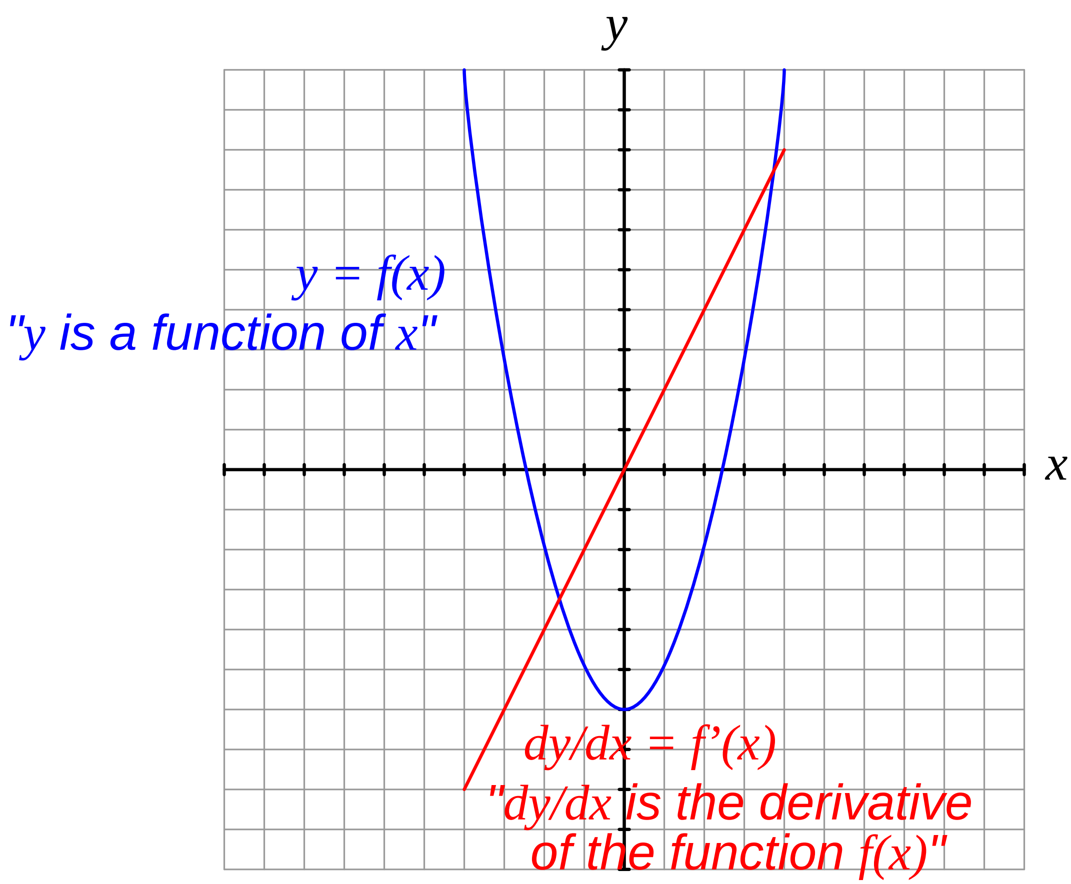
Note: the unit of "unit-minute" for reaction rate refers to reaction rate corrected for percentage of output step. In other words, this is not the raw reaction rate figure, but rather the reaction rate per percent of output step.

This controller must be configured for **direct** action in order to control this process.

Answer 17

The fundamental problem here is that the *process gain* varies inversely to flow rate. During the rainy seasons when the lagoon captures rainwater and the influent flow rate is high, it takes a big change in valve position to make a significant difference in chlorine concentration. When the weather is dry and the influent flow rate is low, even small moves in valve stem position generate large changes in chlorine concentration.

The multiplication relay (or adaptive gain controller) attempts to keep the overall *loop gain* constant despite changes in process gain.

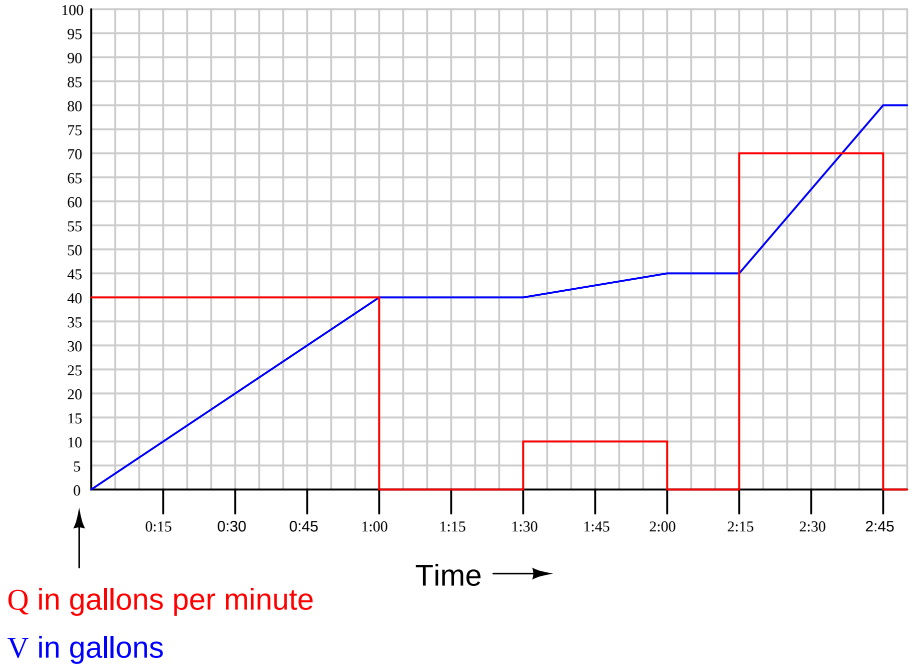


In this particular example:

$$y = f(x) = x^2$$

$$\frac{dy}{dx} = f'(x) = 2x$$

Answer 19



Periods where volume increases linearly (straight-line slope) indicate a constant flow rate into the vessel. To calculate that flow rate, measure change in volume (ΔV) and divided by change in time (Δt), for a rise/run slope.

Between 0:00 and 1:00, the volume increased steadily from 0 gallons to 40 gallons over a period of 1 minute. Therefore, the rate of flow for that time period was 40 gallons per minute.

Between 1:00 and 1:30, the volume remained constant. This indicates a period of no liquid flow into the vessel, so the flow rate here is 0 gallons per minute.

Between 1:30 and 2:00, the volume increased steadily from 40 gallons to 45 gallons over a period of 0.5 minutes (1/2 minute). Therefore, the rate of flow for that time period was 10 gallons per minute.

Between 2:00 and 2:15, the volume remained constant. Again, this indicates a period of no liquid flow into the vessel, so the flow rate here is 0 gallons per minute.

Between 2:15 and 2:45, the volume increased steadily from 45 gallons to 80 gallons over a period of 0.5 minutes (1/2 minute). Therefore, the rate of flow for that time period was 70 gallons per minute.

Between 2:45 and the end of the graph, the volume remained constant. No flow into the vessel here (0 gallons per minute).

Answer 20

This is an *open-loop test*, based on the fact the output signal is square-wave stepping as it would when a human operator enters new values in manual mode.

Since this is a manual-mode test, we know we are looking at the response of the *process*, not the *PID controller*. Based on this test, we see the process has a direct response, which means the controller must be *reverse-acting* in order to have the negative feedback we need for stable control.

The process exhibits a varying gain, increasing as the valve is opened further. We cannot pinpoint the cause of this problem; it could be an incorrect control valve characteristic, a nonlinear transmitter, or perhaps some nonlinearity inherent to the process itself.

We cannot tell if there are any tuning problems with the controller, because this trend does not show us the results in automatic mode (closed-loop).

We can tell from the process response that this is a self-regulating process with a few seconds of first-order lag combined with a very short dead time. Consequently, we would expect to need integral action to avoid offset between PV and SP, plus some proportional action. The presence of some noise on the PV signal makes the application of derivative unlikely.

Answer 21

Answer 22

Answer 23

Answer 24

Answer 25

Answer 26

Answer 27

Partial answer:

Both flow controllers must be *reverse-acting*. The filter level controller must be *direct-acting*, while the clearwell reservoir level controller must be *reverse-acting*. In the event of a water supply failure, the clearwell will fail low (become empty).

Answer 28

Partial answer:

Valve	**Fully closed at** (mA)	**Fully open at** (mA)
PV-45a	12 mA	
PV-45b	12 mA	

PIC-45 must be configured for *reverse* control action.

A strong indication of the block valve being left shut is accumulator pressure significantly greater than setpoint with FV-45b wide open.

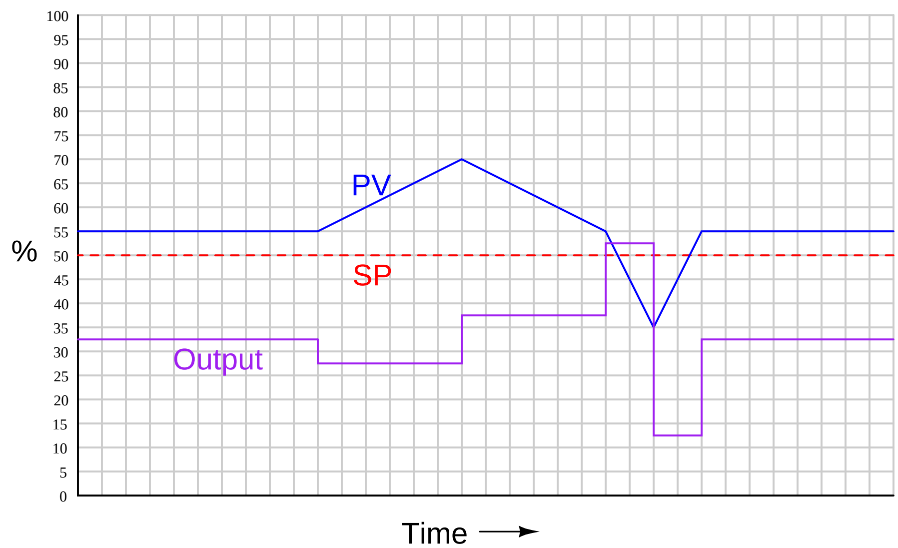
Answer 29

Partial answer:

Diagnostic test	**Yes**	**No**
Check main air supply pressure gauge indication		
Check FY-101a positioner supply pressure gauge indication		√
Check FY-101b positioner supply pressure gauge indication		
Check FY-101c positioner supply pressure gauge indication		
Measure DC current at PLC output card terminals		√
Measure DC current at FV-101a positioner terminals		
Measure DC current at FV-101b positioner terminals		
Measure DC current at FV-101c positioner terminals		

Answer 30

The controller output graph shown here is *qualitative* only. Although drawn to scale (i.e. all changes in the output are properly scaled relative to each other), the scale itself is arbitrary and therefore may not match the scale of your sketch:

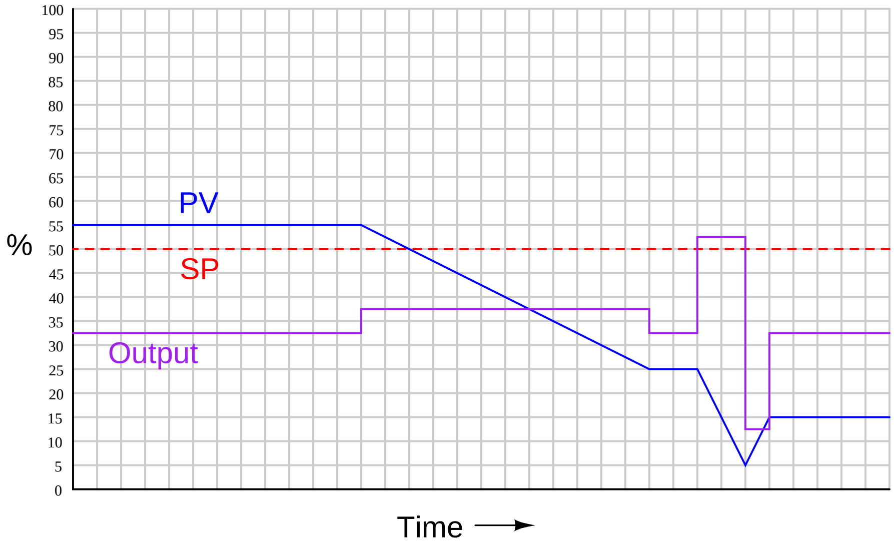


Derivative action looks only at the *rate-of-change* of the error signal. In this case, since the SP is constant, derivative acts only on the PV's *slope*. During the time period where the PV rises 15% over a run (time span) of 6 units, I plot the output as a constant 5% below the original output signal value (from 32.5% to 27.5%). When the PV falls the same amount (15%) over the same time span, the output goes to a value 5% above the original value (from 32.5% to 37.5%).

When the PV begins to fall at a faster rate (20% in 2 units), the rise/run slope ratio is 4 times as much as before. Thus, the output goes to a value 4 times as great as before (20% instead of 5%), from 32.5% to 52.5%. When the PV returns to SP at the same (steep) rate, the output drops 20% below the original starting value (from 32.5% to 12.5%).

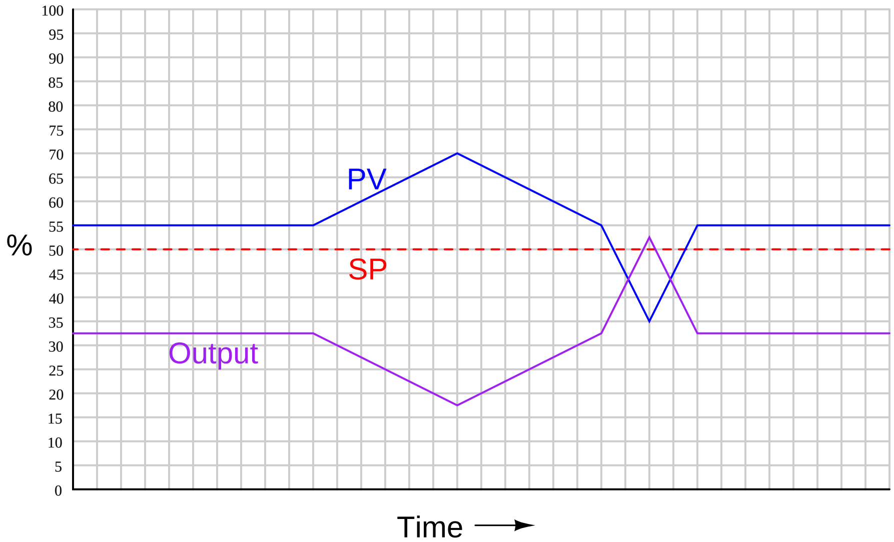
Answer 31

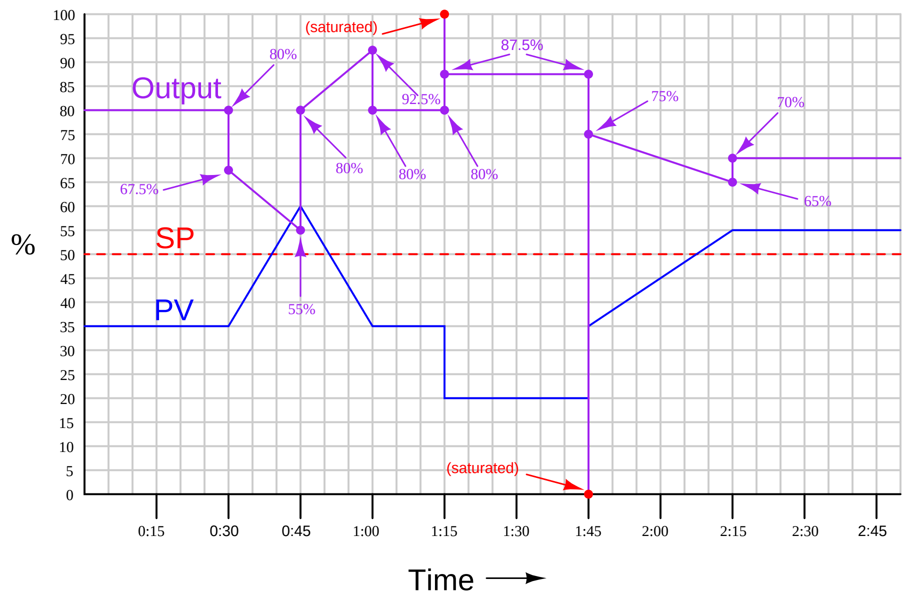
The controller output graph shown here is *qualitative* only. Although drawn to scale (i.e. all changes in the output are properly scaled relative to each other), the scale itself is arbitrary and therefore may not match the scale of your sketch:



Answer 32

The controller output graph shown here is *qualitative* only. Although drawn to scale (i.e. all changes in the output are properly scaled relative to each other), the scale itself is arbitrary and therefore may not match the scale of your sketch:

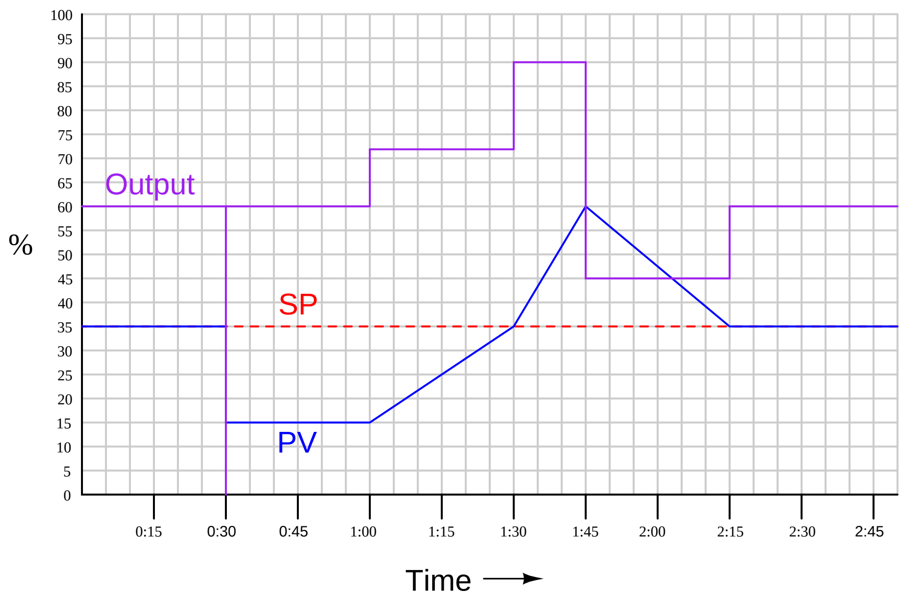




When the PV begins its initial upward ramp from 35% to 60%, it does so at a slope of 100% per minute (25% over a 15 second period of time). Since derivative action is the slope multiplied by the derivative constant (15 seconds, or 1/4 minute), multiplied by the gain (PB of 200% = gain of 0.5), the derivative term's action here is to step down 12.5%. Then, we see proportional action (with a gain of 0.5) ramp the output down at a slope 1/2 that of the PV's slope, to a point of 55%.

Then, when the PV ramp reverses direction and descends at the same rate it ascended previously, the derivative action stops *subtracting* 12.5% from the output and begins to *add* 12.5% to the output, for a total step-change in the output of 25% (from 55% to 80%). Proportional action, of course, ramps the output up 12.5% from time 0:45 to time 1:00 (from 80% to 92.5%) as the PV changes 25% in 15 seconds. When the PV levels off at 1:00, at the same value it stated at, the derivative action ceases, and the output returns to its original value of 80%.

At time 1:15, the 15% downward step-change taken by the PV causes derivative action to go "wild" and saturate the output at 100%. Proportional action steps up the output by 7.5%, so that after the transient rise of the PV the output settles at 87.5%. At time 1:45, the 15% upward step-change of the PV causes derivative action to saturate the output once more, this time in the downward direction at 0%. After this transient, the output settles at 75%: a combined effect of proportional action (driving the output down to 80%) and derivative action (driving the output down 5%, because the PV's upward slope is 40% per minute – 40%/min times 0.25 minutes times a K_p of 0.5). Proportional action ramps the output down 10% (from 75% to 65%) until time 2:15, when the ramping stops and derivative action ceases, allowing the output to step up by 5% (from 65% to 70%) to its final value.



First, let us understand that a proportional band of 500% is equivalent to a gain of 1/5, or 0.2.

The downward step-change of the PV at time 0:30 causes the derivative to saturate the output to 0%. When the PV levels off, the derivative response goes to 0, leaving the output at the value where it started (60%).

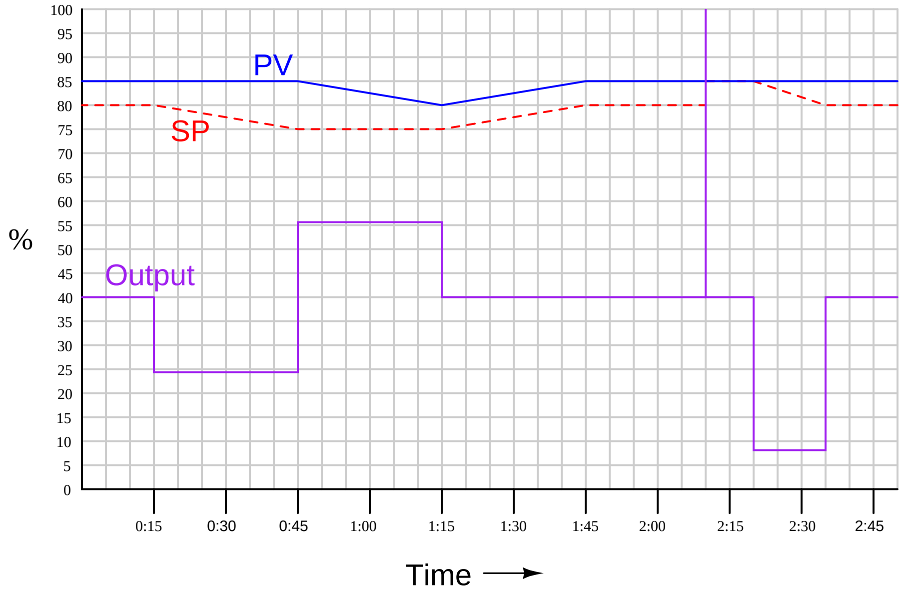
From 1:00 to 1:30, the PV ramps from 15% to 35%, for a de/dt slope of +40% per minute. Multiplied by a τ_d constant of 1.5 and a gain (K_p) of 0.2, the derivative term's contribution is +12%. Thus, the output steps from 60% to 72%.

At 1:30, the PV ramp increases to a rate of 100% per minute (from 35% to 60% over 15 seconds), resulting in a derivative term output of +30%. Thus, the output steps to new level of 90% (original 60% value + 30% = 90%).

Between 1:45 and 2:15 the PV slopes negatively. This results in a negative derivative response (60% to 35% over 30 seconds = -50% per minute, times 1.5 times 0.2 = -15%). Thus, the output goes from 60% to 45%.

At 2:15, the PV levels off and the derivative response ceases, leaving the output at its original value of 60%

Answer 35



First, let us understand that a proportional band of 250% is equivalent to a gain (K_p) of 0.4. Also, we must realize that as a reverse-acting controller, the output will go in the same direction as the SP, but opposite that of the PV.

As the SP descends 5% between 0:15 and 0:45, it creates a de/dt slope of -10% per minute. This figure, times $\tau_d = 4$ and times $K_p = 0.4$ gives us a derivative term contribution of -16%. Thus, the output steps down from 40% to 24% during this time.

When the PV descends at the same rate between 0:45 and 1:15, derivative action drives the output up by the same amount (16%), from 40% to 56%.

Between 1:15 and 2:10, there is no change of error between PV and SP, even though ramping takes place between 1:15 and 1:45. At 2:15, the positive SP step-change causes the output to saturate at 100% momentarily, then return to 40%.

From 2:20 to 2:35, the SP slopes downward 5%, for a de/dt rate of -20% per minute. This gives a derivative response of -32%, stepping the output down from 40% to 8%. At time 2:35 when the SP stops ramping, the derivative action ceases and the output returns to 40%.

Answer 36

To increase τ_d, turn the "derivative valve" a bit further shut.

Answer 37

To increase proportional band (reduce the gain), move the potentiometer wiper to the right (Module 4). This is a *reverse-acting* controller.

To increase the aggressiveness of derivative action, increase the capacitor value (Module 6) and/or decrease the summing input resistor value in Module 5 that accepts Module 6's output signal.

Answer 38

Answer 39

This is a *closed-loop test*, based on the fact the output signal responds dynamically to the changing process variable, as well as to the step-change in setpoint.

This is a *reverse-acting* controller: the output steps up when the setpoint steps up (implying the output would step down if the process variable stepped up).

We really cannot discern any problems with field instrumentation from this trend. A manual-mode (open-loop) test would be more informative in that regard.

The response to the setpoint change seems sluggish, as the process variable takes a slow and gentle approach to the new setpoint value. Derivative action is definitely present, as revealed by the "spike" immediately following the setpoint change. Proportional action is also in effect (with a gain of about 1), based on the output step-change we see that is approximately the same magnitude as the setpoint step-change. What is really lacking, though, is more aggressive integral action. Here, we see the controller hardly moving the valve at all from 10:56:54 to 10:58:24, as the process variable makes its very slow approach to setpoint.

Faster integral action would help the process reach setpoint quicker. This controller could possibly use more aggressive proportional action as well, since the action shown here is nowhere near being too aggressive (no sign of oscillation at all). Given the total lack of noise, derivative action might be helpful as well, to cancel some of the lag time as well as permit more aggressive proportional and integral actions.

Answer 40

A build-up of sludge on a pH probe will tend to add *lag time* and possibly even *dead time* to its measurement. Either of these will slow down the loop's natural cycle time (its *ultimate period*).

Answer 41

Answer 42

Answer 43

Answer 44

Answer 45

Answer 46

The one glaring discrepancy we see here is between the laboratory's measurement of syrup concentration and what the AIC and AIR indicate. Given that both the AIC and AIR agree with each other on PV value, we may conclude that the signal to both of these instruments corresponds to a 34% measurement. The problem is either the transmitter (AT) mis-measuring the syrup concentration, or else it is sensing the concentration okay but outputting the wrong 4-20 mA signal nonetheless, or else the laboratory made a measurement error of their own and incorrectly reported a syrup concentration that is too high.

We also see some minor discrepancies between controller output indications and actual valve stem positions, but these are small enough to ignore. Likewise, the discrepancy between the level gauge (LG) indication and the level controller/recorder indications is small enough that it does not pose a serious problem.

Answer 47

$V_{in} = 10$ V $\qquad V_{out} = 46$ V

Answer 48

First, calculating the pressure drop across the valve, based on the downstream side being atmospheric (0 PSIG) and the upstream side having 25 feet of water column:

$$\Delta P = \left(\frac{25 \text{ ft WC}}{1}\right)\left(\frac{12 \text{ "}}{1 \text{ ft}}\right)\left(\frac{1 \text{ PSI}}{27.68 \text{ "WC}}\right) = 10.838 \text{ PSI}$$

Calculating valve C_v based on the available pressure (10.838 PSID) at a flow rate of 350 GPM:

$$C_v = \frac{Q}{\sqrt{\frac{\Delta P}{G_f}}} = \frac{350}{\sqrt{\frac{10.838}{1}}} = 106.3$$

Next, calculating the line size based on the valve's necessary C_v rating of 106.3 and also the relative flow capacity of a characterized ("segmented") ball valve ($C_d = 25$):

$$C_d = \frac{C_v}{d^2}$$

$$d^2 = \frac{C_v}{C_d}$$

$$d = \sqrt{\frac{C_v}{C_d}} = \sqrt{\frac{106.3}{25}} = 2.062 \text{ inches diameter}$$

$d = 2.062$ inches, rounded up to 2.5 inches nominal.

Kerosene, being less dense than water, will generate less hydrostatic head. However, less hydrostatic head will be necessary to force the same flow rate through the valve, since G_f is part of the valve sizing equation. So, specific gravity ends up being irrelevant in this problem.

Answer 49

A "high burnout" TT-1 would cause the furnace to cool down, as the temperature control system would "think" the furnace was too hot and take the necessary action of stopping heat input.

Specifically, lag time in a feedback control system leads to greater phase shift, which may result in oscillation (cycling) given enough controller gain. This is quite common in temperature control applications such as this, where the process itself may have only one dominant lag, allowing aggressive proportional action from the controller to achieve tight, fast control. The addition of more lag times in a loop like that will often lead to oscillation, as the high gain of the controller now has enough phase shift to complement it and meet (or exceed) the Barkhausen criterion.

Answer 50

A reading of 120 VAC between terminals 21 and 20 proves that we have 120 VAC control power available. A reading of 120 VAC between terminals 1 and 20 proves we have power all the way to and through the "Open" pushbutton when pressed. The fault must lie between the blue wire (to the right of the Open pushbutton) and wire P2 at the overload contacts.

Fault	**Possible**	**Impossible**
"Bypass" switch (#1) failed open		√
"Bypass" switch (#5) failed open	√	
"Opening" torque switch (#18) failed open	√	
"Closing" torque switch (#17) failed open		√
"Open" limit switch (#4) failed open	√	
"O" relay coil failed open	√	
"C" relay coil failed open		√
Thermal overload switch(es) tripped	√	
480V fuse(s) blown to input of transformer		√

If the "bypass" switch (#5) were failed open, it might prevent the valve from opening if the opening torque switch tripped due to the valve being stuck in the seat. If the "opening" torque switch (#18) were failed open, the bypass switch (#5) would allow the motor to move in the "open" direction just a bit, but as soon as the bypass switch returned to its normal (open) state the valve would refuse to open any further.

The thermal overload could be tripped if and only if it happened to trip during the last "close" cycle, for instance if the "close" torque switch failed and allowed the motor to become overloaded.

A good "next test" would be to try taking voltage measurements at switch terminals in the "open" rung of the circuit with the button pressed as before. For example, measuring between terminal 18C on the open torque switch and terminal 20 would tell you (by a 0 volt reading) if either switch #4 was open or both switch #5 and #18 were open.

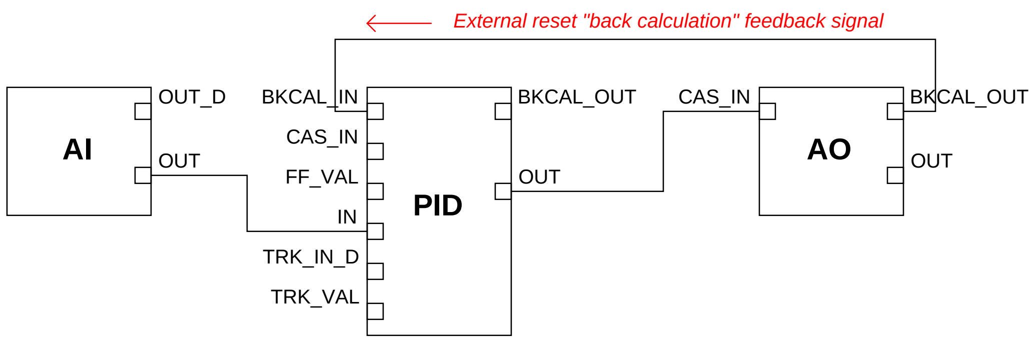
Answer 51

External anti-reset windup is a feature available on some controllers for preventing "windup" of the integral (reset) term, by monitoring valve position or some other real-world indication of output saturation. It works by stopping integration whenever the actual final control element is saturated, rather than stopping integration based on a maximum or minimum set value programmed into the controller.

With integral action based on valve position rather than the controller's output signal magnitude, windup will be prevented over a wider range of conditions. For instance, if the valve were to become jammed or limited in travel by a "stop," integration would cease at that limit, rather than blindly progress until the actual controller output pressure reached saturation as would be the case with internal anti-reset windup.

This will not prevent all cases of reset windup, but it will help the controller recover from incidents of windup resulting from valve position saturation.

Interestingly, this very same technique is used in FOUNDATION Fieldbus PID loops, where the analog output function block provides a "back calculation" signal (BKCAL_OUT) for the input of the PID block. If the final control element cannot attain a certain state, for whatever reason, the PID block will know this and cease integrating, thus preventing needless windup:

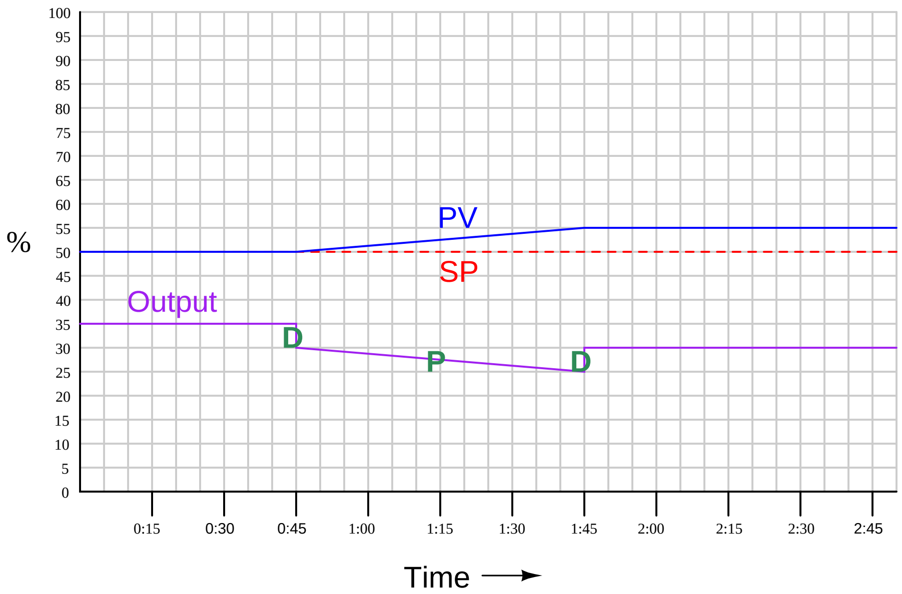


Answer 52

Controller action = *reverse*

$K_p = 1$

τ_d = 1 minute = 60 seconds

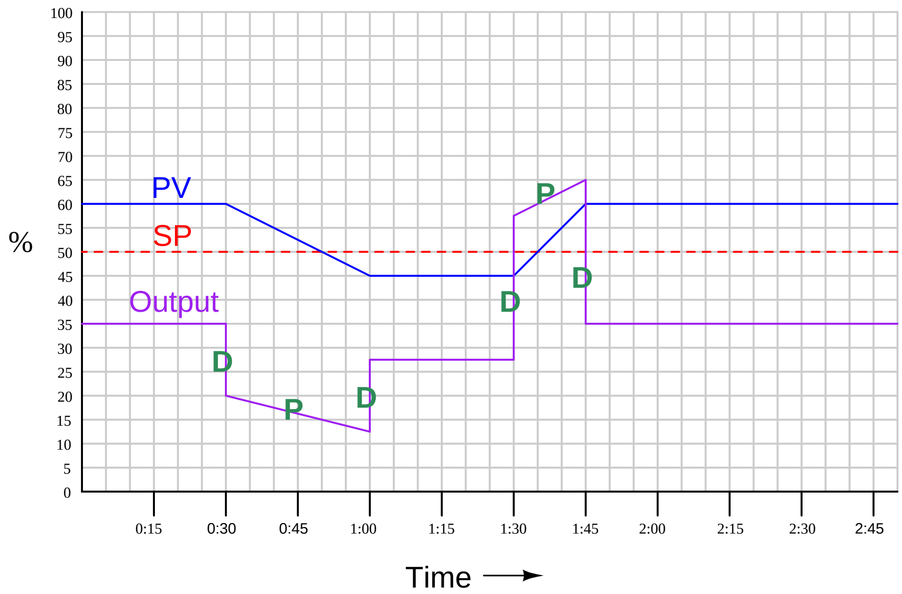


Answer 53

Controller action = *direct*

$K_p = 0.5$ (proportional band = 200%)

$\tau_d = 1$ minute = 60 seconds

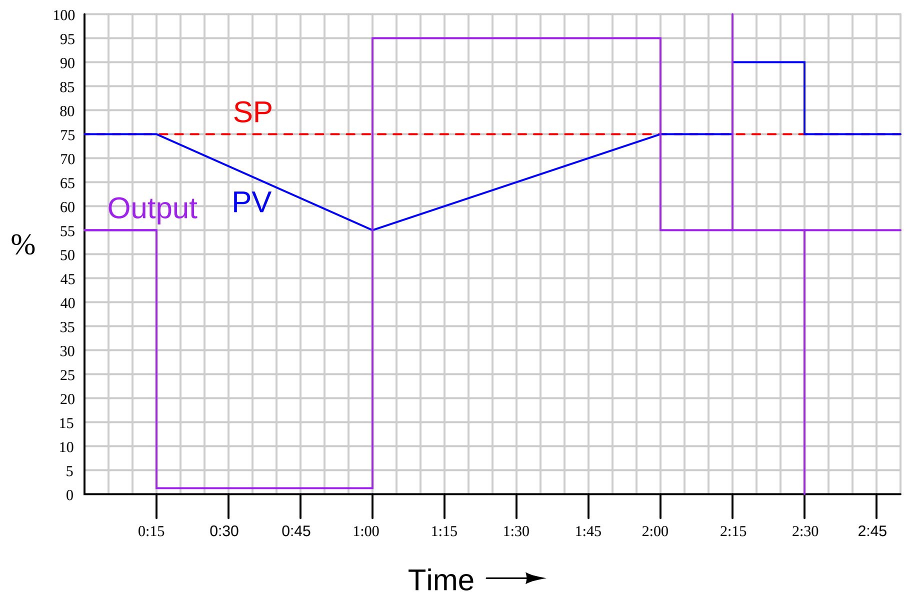


If the other algorithm were used, the gain and derivative constants would be:

$K_p = 0.5$ (proportional band = 200%)

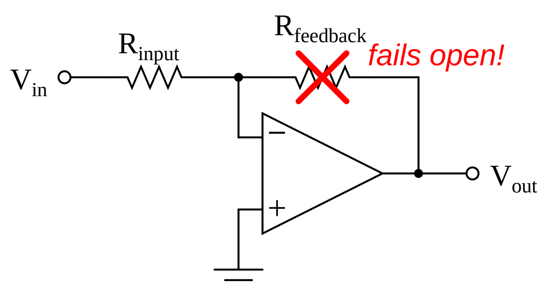
$\tau_d = 0.5$ minute = 30 seconds

Answer 54

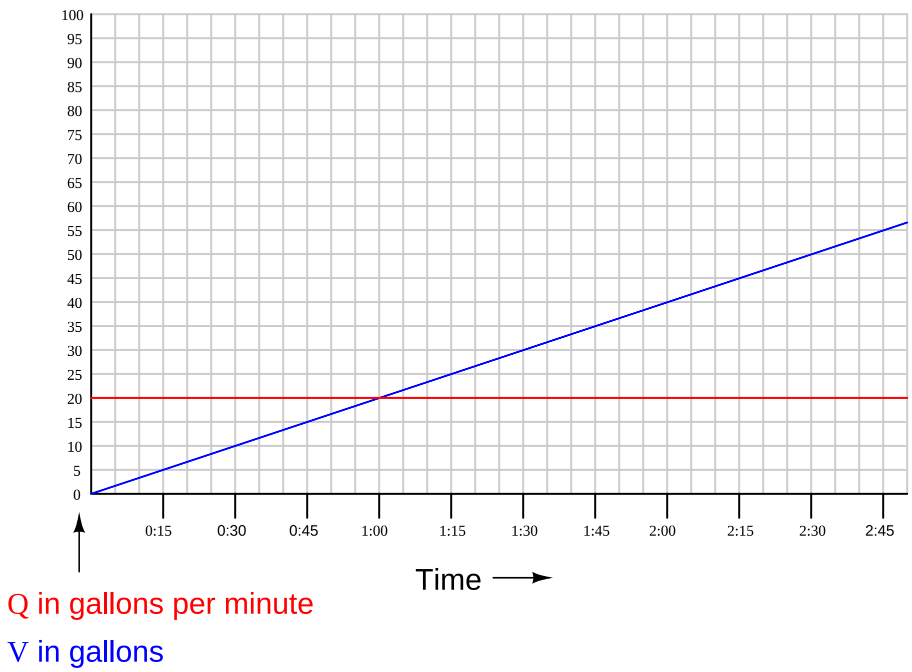


Answer 55

I will answer the question of total tube blockage with another question: what will happen in the following operational amplifier circuit if the feedback resistor fails open?



Given a partial blockage, the controller will "over-react" to sudden changes in either PV or SP, then settle out at the normal output signal value expected as a proportional controller.



100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
0:15
0:30
0:45
1:00
1:15
1:30
1:45
2:00
2:15
2:30
2:45
Time
Q in gallons per minute
V in gallons

Answer 57

This is a *closed-loop test*, based on the fact the output signal responds dynamically to the changing process variable, as well as to the step-change in setpoint.

This is a *reverse-acting* controller: the output steps up when the setpoint steps up (implying the output would step down if the process variable stepped up).

One feature evident in this trend is some final control element hysteresis (e.g. a "sticky" control valve). The evidence of valve stiction is the different process gains ($\frac{\Delta \mathrm{PV}}{\Delta \mathrm{Output}}$) when the valve changes direction! We know this is probably not due to process gain variability because this marked process gain change happens at similar PV values.

The controller tuning is clearly too aggressive for this process. Note the "porpoising" action of the PV as it approaches SP following the SP step-change. Only two types of controller action can cause this to occur: *proportional*, or *derivative*. Porpoising is when an oscillation occurs in the PV prior to it crossing setpoint, which explains why integral action cannot ever be to blame for porpoising: the only way a loop oscillation can occur is when the final control element oscillates as well (i.e. changes direction), and since integral action will never change direction until PV crosses SP, oscillations that occur on one side of SP cannot be caused by integral action. It would appear that the culprit is proportional action (gain), given the 180^o phase shift between PV and output following SP step-changes. It is also clear that more integral action could be used – it appears as though the person who tuned this was trying to control the process mostly with proportional, even though the tuning parameters (gain = 0.5 and reset = 5 seconds/repeat) actually appears heavily weighted toward reset action.

This is definitely a self-regulating process, as revealed by the fact a new output value is required to achieve a new setpoint value. This means integral control action will definitely be necessary. More integral action (reset less than 5 seconds per repeat) and less proportional action (gain lower than 0.5) is what we need here.

Answer 58

This is a *closed-loop test*, based on the fact the output signal responds dynamically to the changing process variable, as well as to the step-change in setpoint.

This is a *reverse-acting* controller: the output steps down when the setpoint steps down (implying the output would step down if the process variable stepped up).

There do not appear to be any field instrumentation problems revealed in this trend. We can see some multiple-order lag time, but this is not necessarily an instrument problem.

The controller tuning is actually quite good. The only possible criticism here is that the output trend is a bit noisy, which if controlling a valve may cause the valve to move excessively (using more compressed air than is necessary, and wearing out the packing).

This is clearly a self-regulating process with multiple orders of lag. Ordinarily, some derivative action will help permit more aggressive proportional and integral actions that would otherwise be possible with a P+I controller, but here with the noise problem we may have to be careful how much derivative action we put into this loop controller. As was mentioned earlier, the tuning in this loop is actually quite good.

Answer 59

This is an *open-loop test*, based on the fact the output signal remains steady (flat) during those periods of time when the PV is settling to some new value. The stair-step shape of the output trend is another clue that the controller is in manual mode: someone keeps "bumping" the output value to check the response of the PV.

This will need to be a *reverse-acting* controller, since the PV steps in the same direction as the output. That is to say, the process is "direct-acting" from controller output to PV, so therefore the controller needs to be reverse acting (from PV to output) in order to deliver the negative feedback necessary to stabilize the loop.

One significant problem is clearly apparent in this open-loop test, and that is a variable process gain. Note how small the PV steps are at the end compared to what they were at the beginning, all with equal-sized steps of the output. This may be due to process dynamics, or perhaps something such as the wrong type of control valve trim characterization (e.g. linear trim when it should be equal-percentage trim). Otherwise, there do not appear to be any field instrumentation problems revealed in this trend. The process does exhibit a single-order lag, but that may very well be the dynamics of the process itself and not the fault of any field instrumentation.

This is an open-loop test, so one cannot comment on the controller's tuning as it stands!

This is clearly a self-regulating process with minimal noise and a single-order lag characteristic. This means it ought to respond well on just aggressive proportional action, with perhaps a bit of integral to help out with load changes. Remember that purely first-order lag processes cannot generate any more than 90^o of phase shift, and therefore cannot oscillate with negative feedback. This allows us to "go crazy" with controller gain (at least in theory). In real life, other inescapable lags in the system create enough phase shift at high gains to oscillate, and so there is always a practical limit to how high we can go with controller gain.

Answer 60

Partial answer:

Fault	**Possible**	**Impossible**
Control valve stem jammed by metal debris between plug and seat		
Control valve stem jammed by metal debris between plug and bonnet		
Block valve downstream of control valve closed		$\surd$
Block valve upstream of control valve closed		
Tear (leak) in actuating diaphragm		
Hand valve shut off	$\surd$	
Upstream pressure lower than normal		

Answer 61

Answer 62

The only "answer" to this question is a properly documented and functioning instrument loop!

Answer 63