INST 251 (PID control), section 1

Lab

Split-ranged valves with pneumatic positioners: *Questions 91 and 92*, **completed objectives due by the end of day 5, section 2**

Exam

Day 5 of next section – **Complete mastery of these objectives due by the next exam date**

Specific objectives for the "mastery" exam:

- Electricity Review: Calculate voltages and currents in an ideal AC transformer circuit
- Predict the response of a single-loop control system to a component fault or process change
- Determine the effect of a component change on the gain of a pneumatic controller mechanism
- Calculate instrument input and output values given calibrated ranges
- Solve for a specified variable in an algebraic formula
- Determine the possibility of suggested faults in a simple relay circuit given measured values (voltage, current), a schematic diagram, and reported symptoms
- Motor/relay/3phase/PLC Review: Determine status of PLC discrete output given input switch conditions and a simple RLL program listing
- INST241 Review: Calculate flow rate / pressure drop for a nonlinear flow element
- INST262 Review: Determine proper AI block parameters to range a Fieldbus transmitter for a given application

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Recommended daily schedule

Day 1

Theory session topic: Instrument tube fitting (guest speaker)

Questions 1 through 20 (all for practice)

Day 2

Theory session topic: Feedback control

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

Day 3

Theory session topic: Pneumatic process controllers

Questions 41 through 60; answer questions 41-49 in preparation for discussion (remainder for practice)

Day 4

Theory session topic: Analog electronic process controllers

Questions 61 through 80; answer questions 61-69 in preparation for discussion (remainder for practice)

Feedback questions *(81 through 90)* are optional and may be submitted for review at the end of the day

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. <u>Download</u> and <u>save</u> 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: <u>Mastery exams</u> 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. <u>Proportional exams</u> 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 <u>all</u> 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.

<u>file `howto`</u>

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.

Punctuality and Attendance: 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.

Mastery: 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.

Time Management: 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.

Orderliness: 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.

Independent Study: 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.

Independent Problem-Solving: 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.

Teamwork: 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.

Communication: 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.

Academic Progress: 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.

Office Hours: 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.

Grounds for Failure: 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.

file `expectations`

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 251 Course Outcomes

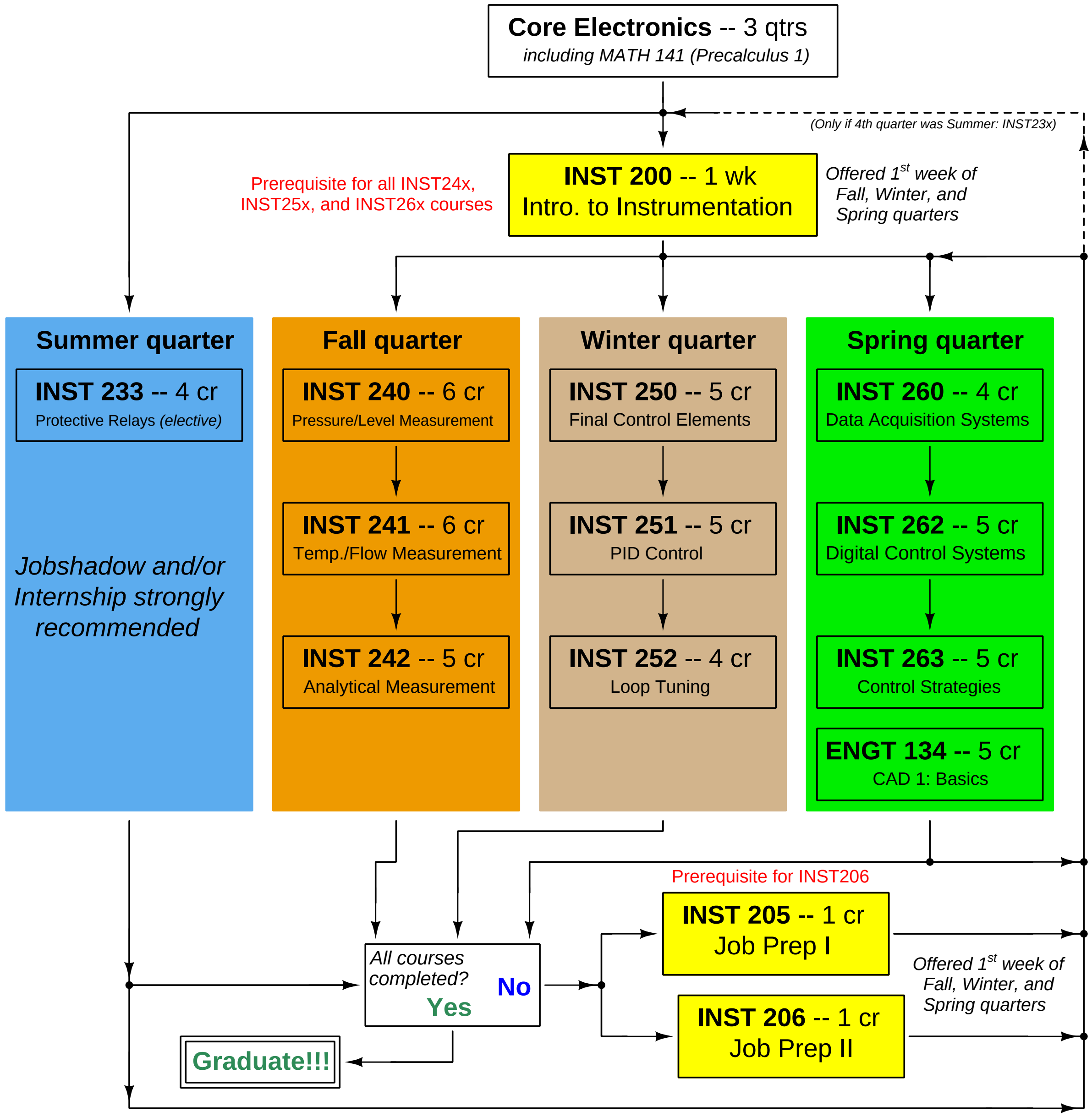
Each and every outcome in this course is assessed at a mastery level (i.e. 100% competence)

- Calculate voltages and currents in an ideal AC transformer circuit. [Ref: Program Learning Outcome #4]
- Calculate voltages, currents, and phase shifts in an AC reactive circuit. [Ref: Program Learning Outcome #4]
- Predict the response of an automatic control system to a component faults or process change, given pictorial and/or schematic illustrations. [Ref: Program Learning Outcome #4]
- Determine the effect of a component change on the gain of a pneumatic controller mechanism. [Ref: Program Learning Outcome #4]
- Compute the value of the numerical derivative at a single specified point on a graph. [Ref: Program Learning Outcome #4]
- Compute the value of the numerical integral over a specified interval on a graph. [Ref: Program Learning Outcome #4]
- Identify the response of a loop controller as being either P, I, or D based on a comparison of process variable, setpoint, and output trend graph recordings. [Ref: Program Learning Outcome #6]
- Solve for specified variables in algebraic formulae. [Ref: Program Learning Outcome #4]
- Determine the possibility of suggested faults in simple circuits given measured values (voltage, current), schematic diagrams, and reported symptoms. [Ref: Program Learning Outcome #4]
- Demonstrate proper use of safety equipment and application of safe procedures while using power tools, and working on live systems. [Ref: Program Learning Outcome #3]
- Communicate effectively with teammates to plan work, arrange for absences, and share responsibilities in completing all lab work. [Ref: Program Learning Outcomes #1 and #2]
- Construct and commission a hand control loop using a pneumatic controller and pair of split-ranged pneumatic control valves. [Ref: Program Learning Outcome #5]
- Connect a loop controller to the electronic transmitter and final control element of a pre-constructed process, then commission all components to form a working feedback control loop. [Ref: Program Learning Outcome #5]
- Generate accurate loop diagrams compliant with ISA standards documenting your team's control systems. [Ref: Program Learning Outcome #8]
- Adjust the PID settings of your team's control loop for stable operating behavior. [Ref: Program Learning Outcome #6]
- Wire and program a VFD (Variable Frequency motor Drive) for remote starting and stopping of an AC induction motor using pushbutton switches, measuring motor line current with a clamp-on ammeter. [Ref: Program Learning Outcome #5]
- Research equipment manuals to sketch a complete circuit connecting a loop controller to either a 4-20 mA transmitter or a 4-20 mA final control element, with all DC voltages and currents correctly

annotated, all electrical sources and loads properly identified, given components randomly selected by the instructor. [Ref: Program Learning Outcomes #5 and #9]

- Diagnose a random fault simulated by computer in a 4-20 transmitter circuit, logically justifying your steps before an instructor. [Ref: Program Learning Outcome #4]

file `outcomes_INST251`


Core Electronics -- 3 qtrs
including MATH 141 (Precalculus 1)
(Only if 4th quarter was Summer: INST23x)
Prerequisite for all INST24x, INST25x, and INST26x courses
INST 200 -- 1 wk
Intro. to Instrumentation
Offered 1st week of Fall, Winter, and Spring quarters
Summer quarter
INST 233 -- 4 cr
Protective Relays (elective)
Jobshadow and/or Internship strongly recommended
Fall quarter
INST 240 -- 6 cr
Pressure/Level Measurement
INST 241 -- 6 cr
Temp./Flow Measurement
INST 242 -- 5 cr
Analytical Measurement
Winter quarter
INST 250 -- 5 cr
Final Control Elements
INST 251 -- 5 cr
PID Control
INST 252 -- 4 cr
Loop Tuning
Spring quarter
INST 260 -- 4 cr
Data Acquisition Systems
INST 262 -- 5 cr
Digital Control Systems
INST 263 -- 5 cr
Control Strategies
ENGT 134 -- 5 cr
CAD 1: Basics
Prerequisite for INST206
All courses completed?
No
Yes
INST 205 -- 1 cr
Job Prep I
INST 206 -- 1 cr
Job Prep II
Offered 1st week of Fall, Winter, and Spring quarters
Graduate!!!

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.

Methods of instruction (continued)

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.

Methods of instruction (continued)

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.

file `instructional`

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.

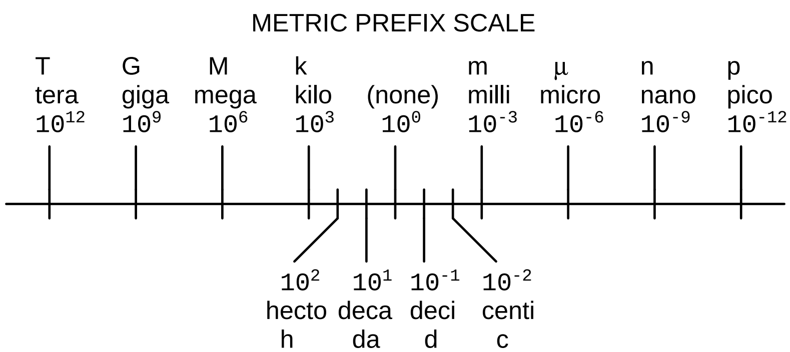
Labwork is perhaps the most difficult portion of the curriculum for a "distance" student to complete, since the equipment used in Instrumentation is typically too large and expensive to leave the school lab facility. "Distance" students must find a way to complete the required lab activities, either 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**
- $^oF = (^oC)(9/5) + 32$
- $^oC = (^oF - 32)(5/9)$
- $^oR = ^oF + 459.67$
- $K = ^oC + 273.15$

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)

Question 0

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.

file `license`

Question 1

Read and outline the "Tube and Tube Fittings" section of the "Instrumentation Connections" chapter in your *Lessons In Industrial Instrumentation* textbook.

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) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

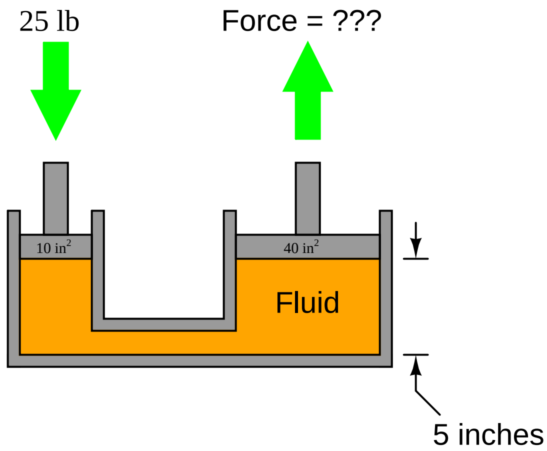
Suggestions for Socratic discussion

- Review the tips listed in Question 0 and apply them to this reading assignment.

  file i03893

Question 2

In this hydraulic system, a force of 25 pounds is applied to the small piston (area = 10 in^2). How much force will be generated at the large piston (area = 40 in^2)? Also, calculate the fluid's pressure.



Finally, explain how *Pascal's Principle* relates to this scenario.

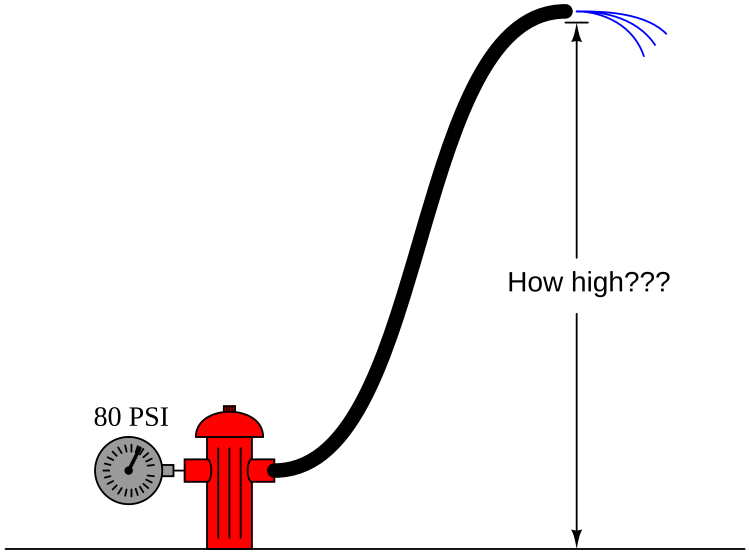
Suggestions for Socratic discussion

- Identify which fundamental principles of science, technology, and/or math apply to each step of your solution to this problem. In other words, be prepared to explain the reason(s) "why" for every step of your solution, rather than merely describing those steps.
- Identify a practical application for a hydraulic system such as this.
- Does the pressure/force/area equation hold true for all piston positions, or only with the pistons in mid-stroke as shown in the illustration?
- Would it matter whether the fluid in this system was a liquid or a gas? Explain in detail how the system's behavior would differ (or not differ) depending on the type of fluid used.
- This mechanism seems to multiply the applied force. How can it do so without violating the Law of Energy Conservation (energy out cannot exceed energy in)?
- Demonstrate how to *estimate* numerical answers for this problem without using a calculator.

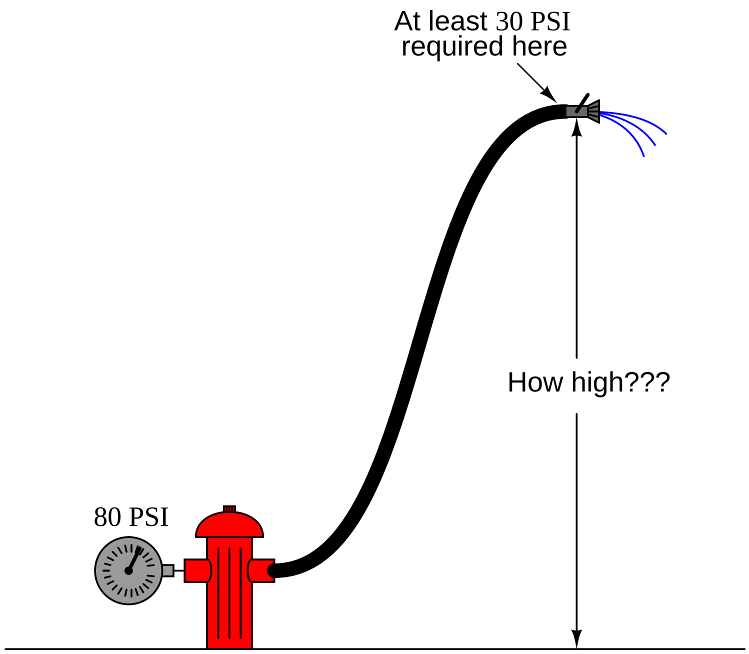
file i00150

Question 3

Water pressure available at a fire hydrant is 80 PSI. If a fire hose is connected to the hydrant and the hydrant valve opened, how high can the end of the hose be raised and still have water flow out the end?



Now, suppose that a spray nozzle attached to the end of the hose requires at least 30 PSI of pressure at the coupling in order to create a proper spray of water. How high can the hose be raised then, and still have enough water pressure at the nozzle to allow for the fighting of a fire?



Suggestions for Socratic discussion

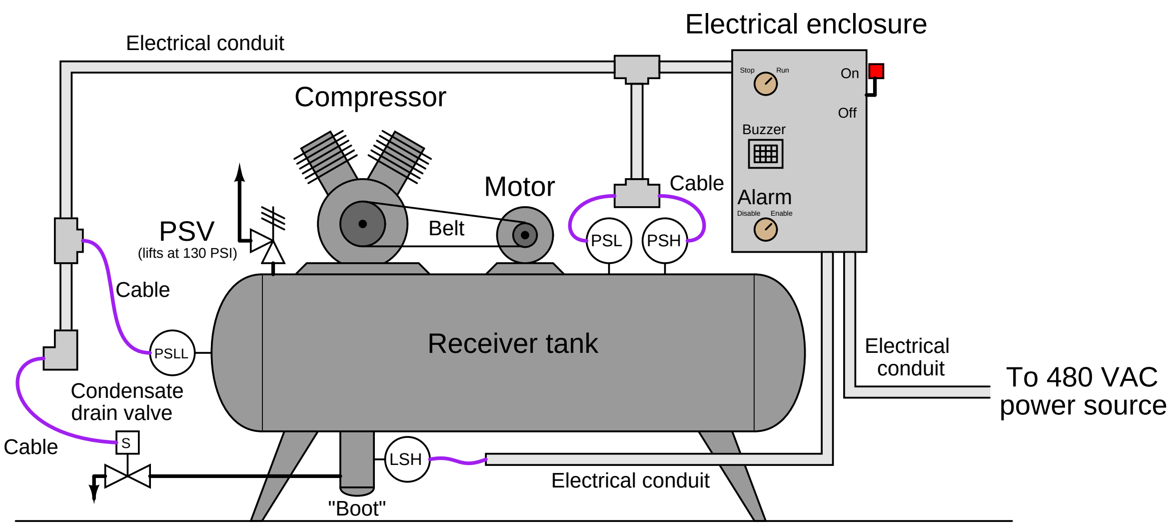
- How may firefighters ensure they are able to spray water high enough to put out tall building fires, if the hydrant pressure is insufficient?

- Describe a scenario with this fire hose that would illustrate *Pascal's Principle*.

file i00148

Question 4

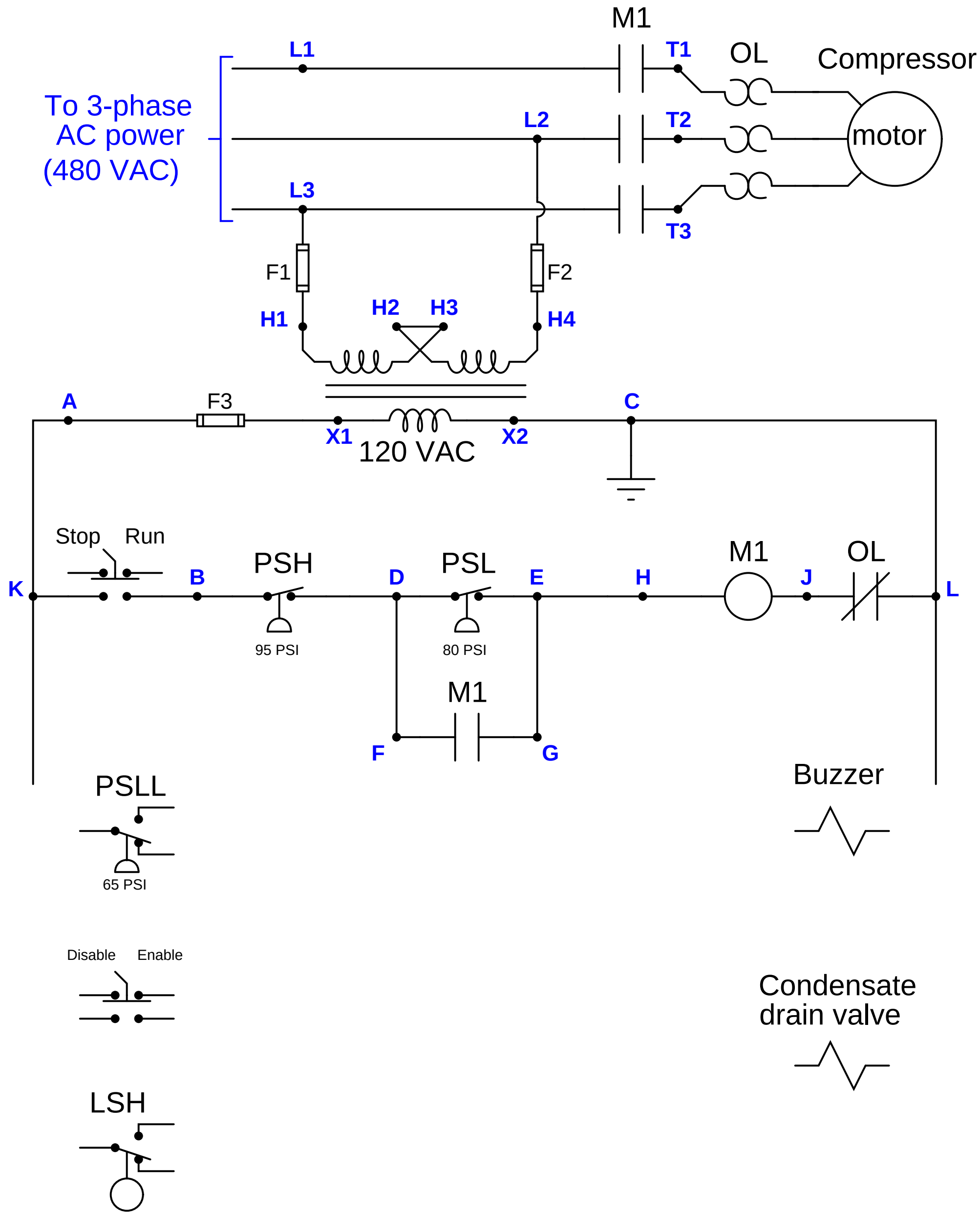
Electrically-powered air compressors are commonly used in many different industries for supplying clean, dry compressed air to machines, instrument systems, and pneumatic tools. A simple compressor system consists of a compressor which works much like a bicycle tire pump (drawing in air, then compressing it using pistons), an electric motor to turn the compressor mechanism via a V-belt, a "receiver tank" to receive the compressed air discharged by the compressor mechanism, and some miscellaneous components installed to control the pressure of the compressed air in the receiver tank and drain any condensed water vapor that enters the receiver:



Electromechanical relay circuitry located inside the electrical enclosure decides when to turn the compressor motor on and off based on the statuses of the high- and low-pressure control switches (PSH = high pressure switch ; PSL = low pressure switch).

Your task is two-fold. First, you must figure out how to wire a new low-low pressure alarm switch (PSLL, shown on the left-hand end of the receiver) so that an alarm buzzer will activate if ever the compressed air pressure falls too low. A newly-installed hand switch located on the front panel of the electrical enclosure must be wired with this PSLL switch in such a way that the buzzer cannot energize if the hand switch is in the "alarm disable" position. Second, you must figure out how to wire a new high-level switch (LSH, shown on the "boot" of the receiver tank) so that the condensate drain valve will energize automatically to open up and drain water out of the receiver boot when the level gets too high, and then automatically shut again when the water in the boot drops down to an acceptable level.

The following schematic diagram shows the basic motor control circuit for this air compressor, with the new switches, buzzer, and drain valve shown unwired:



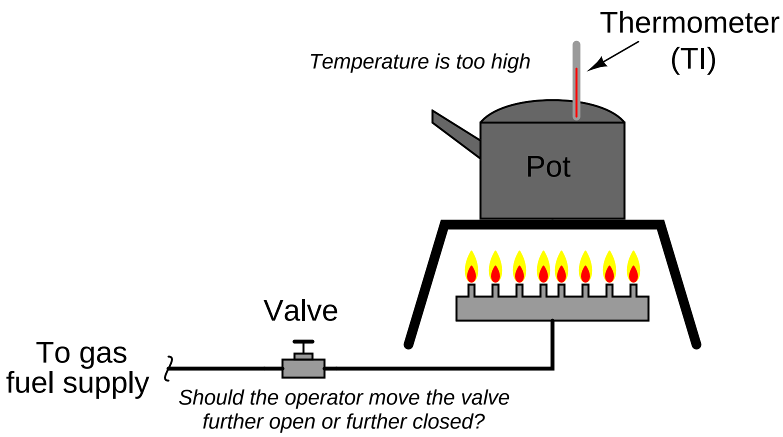
Complete this control circuit by sketching connecting wires between the new switches, buzzer, and drain valve solenoid. Remember that the way all switches are drawn in schematic diagrams is in their "normal" states as defined by the manufacturer: the *state of minimum stimulus* (when the switch is un-actuated). For pressure switches, this "normal" state occurs during a low pressure condition; for liquid level switches, this "normal" state occurs during a low-level (dry) condition. Note that each of the new process switches has SPDT contacts, allowing you to wire each one as normally-open (NO) or as normally-closed (NC) as you see fit.

file i02540

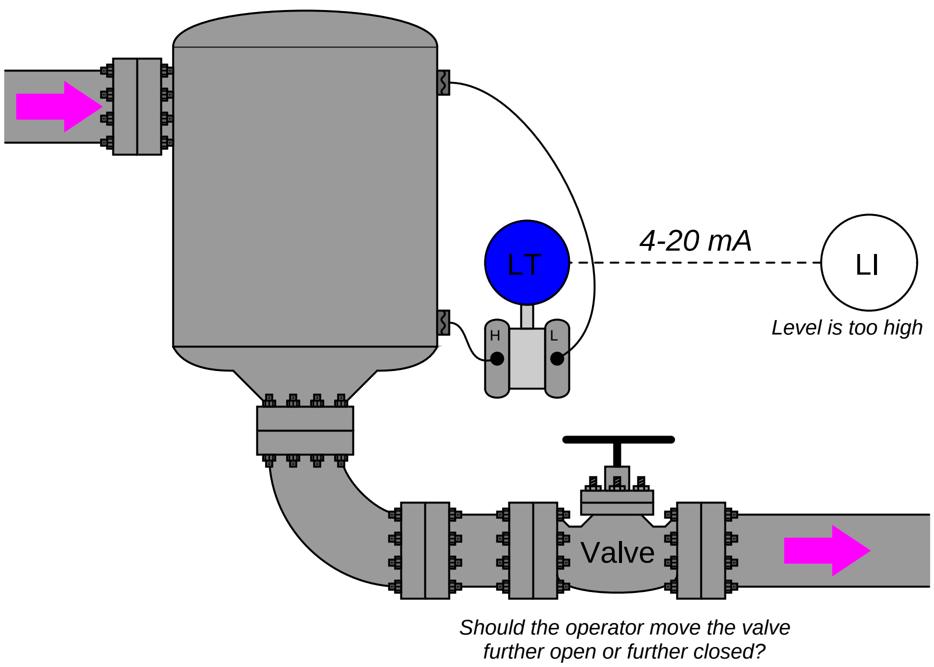
Question 5

Suppose you were giving instructions to a human operator regarding which way to move a hand-operated control valve to maintain a process variable at setpoint. In each of these examples, determine which way the operator should move the valve to *counteract* an increase in the process variable resulting from some independent change in the process:

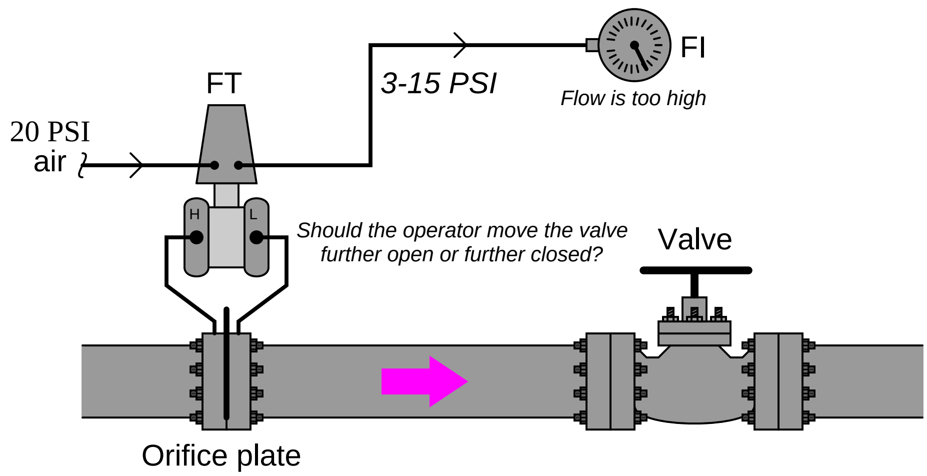
Example 1: Temperature control application



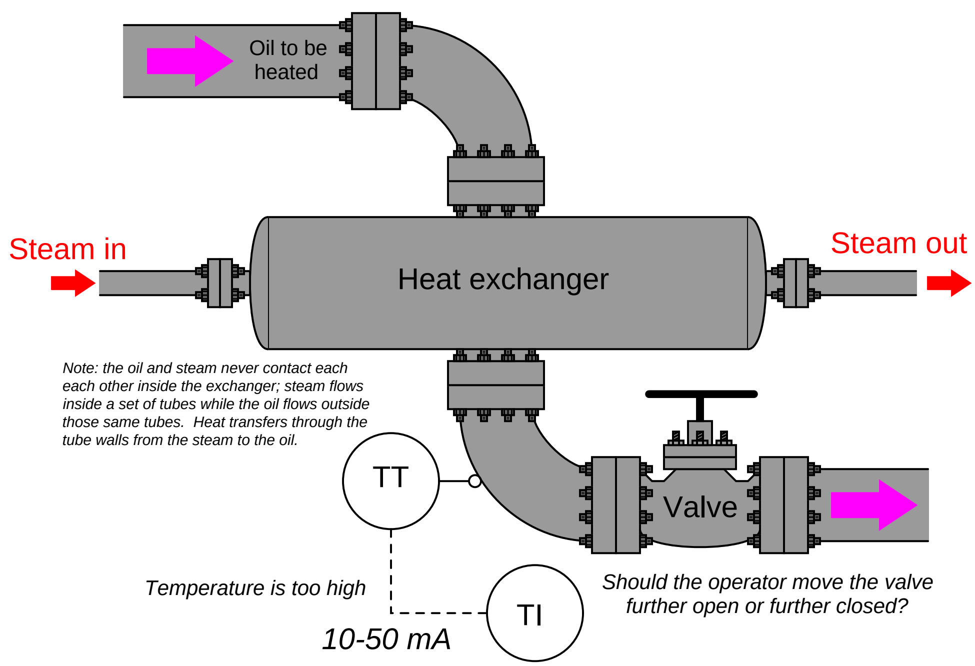
Example 2: Level control application



Example 3: Flow control application



Example 4: Temperature control application



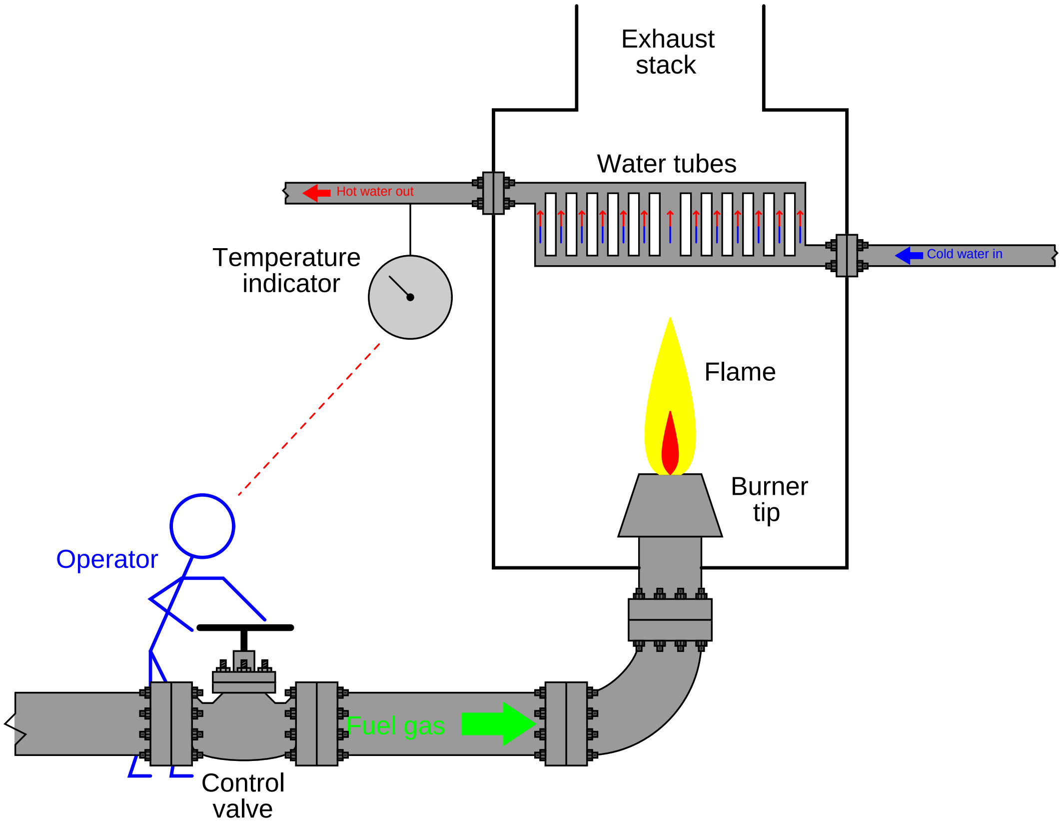
Suggestions for Socratic discussion

- Follow-up question: in which of these examples is the operator functioning as a *direct-action controller* and in which of these examples is the operator functioning as a *reverse-action controller*?

file i00109

Question 6

Suppose a gas-fired water heater is controlled manually, with a human operator observing a temperature indicator on the hot water outlet pipe and actuating a fuel gas control valve:



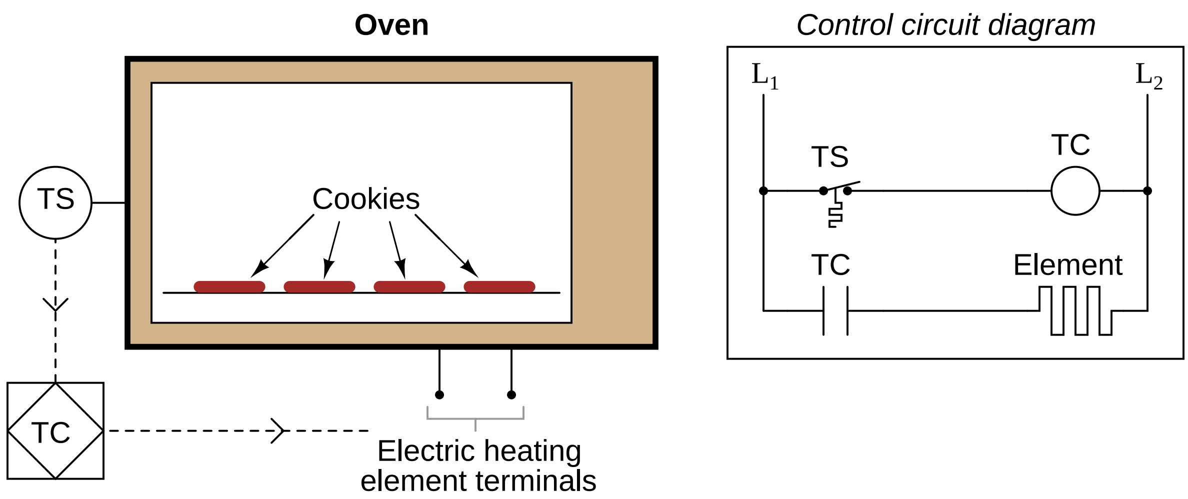
Does the operator play the part of a *direct-acting* controller, or a *reverse-acting* controller, in this process control scenario?

Also, identify the *process variable*, *setpoint*, and *manipulated variable* in this manual control system.

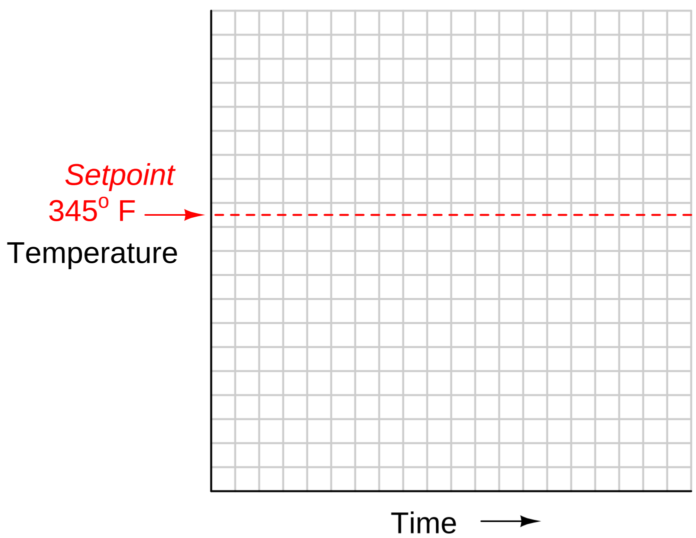
file i01452

Question 7

Suppose an electric oven is equipped with a temperature-sensitive control switch, which is wired to a control relay to send electric power to its heating element:



How would this simple *on-off* control system respond to changes in oven temperature, in its effort to maintain temperature at the setpoint? Be detailed in your explanation of the temperature switch and relay circuit's behavior. Also sketch a graph of the oven temperature over time:

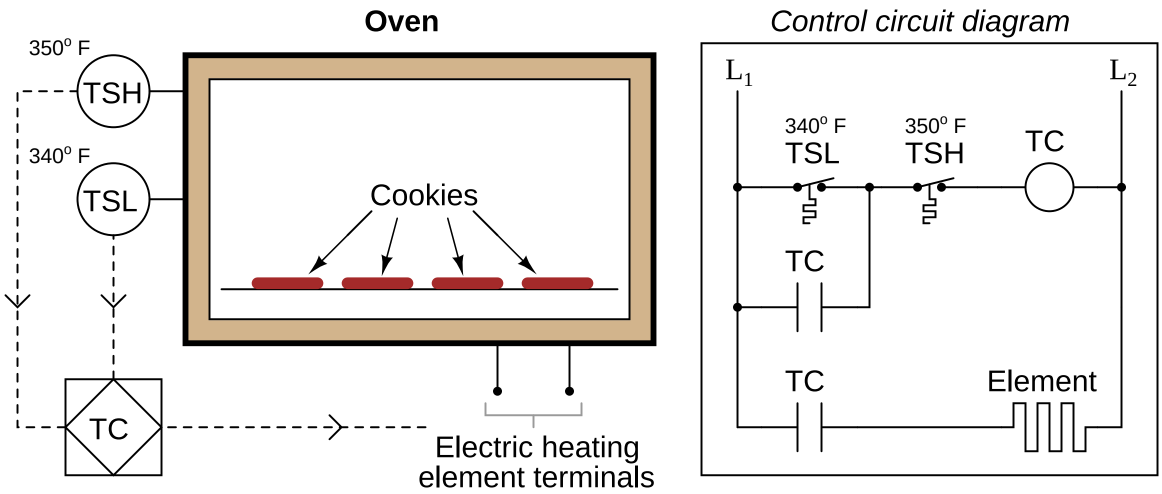


file i01449

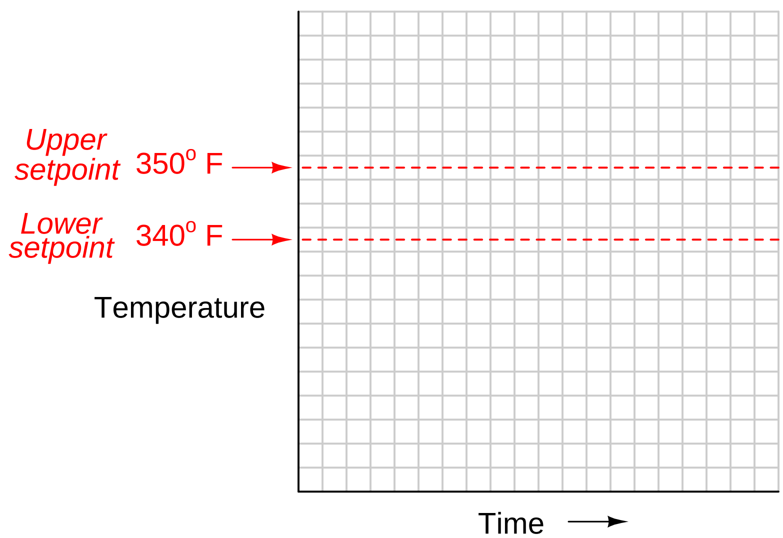
Question 8

One of the problems with simple on-off control is that the final control element "cycles" frequently. In real life, this may be a problem because frequent cycling means more wear and a shortened lifespan for the component.

An answer to this problem of frequent cycling is to design the system to have a "gap" or a "band" of control rather than a single setpoint. In effect, there are two setpoints: an upper and a lower setpoint. This is commonly referred to as *differential gap control*, or alternatively as *on-off control with deadband*. Shown here is a simple switch-and-relay circuit for a differential gap oven temperature control:



In the case of this electric oven, differential gap control means the heating element will not turn on until the temperature falls below the lower setpoint, and will not turn off until the temperature rises above the upper setpoint:



Graph this oven's temperature over time as the control system operates, and contrast its behavior against that of a single-point on-off control system.

file i01450

Question 9

The very simplest style of automatic control is known as *on-off* or more whimsically, *bang-bang* control. This is where the automatic controller only has two output signal modes: fully on and fully off. Your home's heating system is most likely of this sort, where a thermostat can either tell the furnace to turn on or to turn off.

Describe the advantages and disadvantages of "on-off" control, as contrasted against more sophisticated control schemes where a final control element such as a control valve may be proportionately positioned anywhere between fully open and fully closed according to the demands of the process.

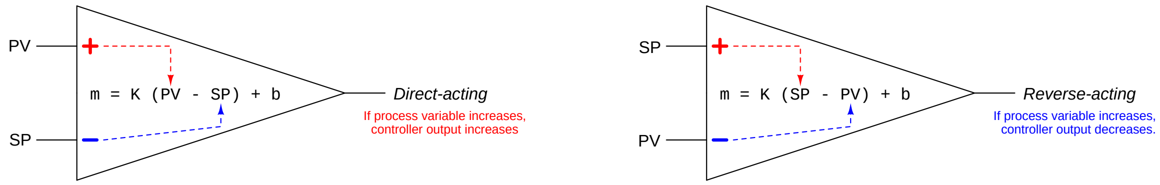
Suggestions for Socratic discussion

- What other control systems in common experience use the "bang-bang" strategy?

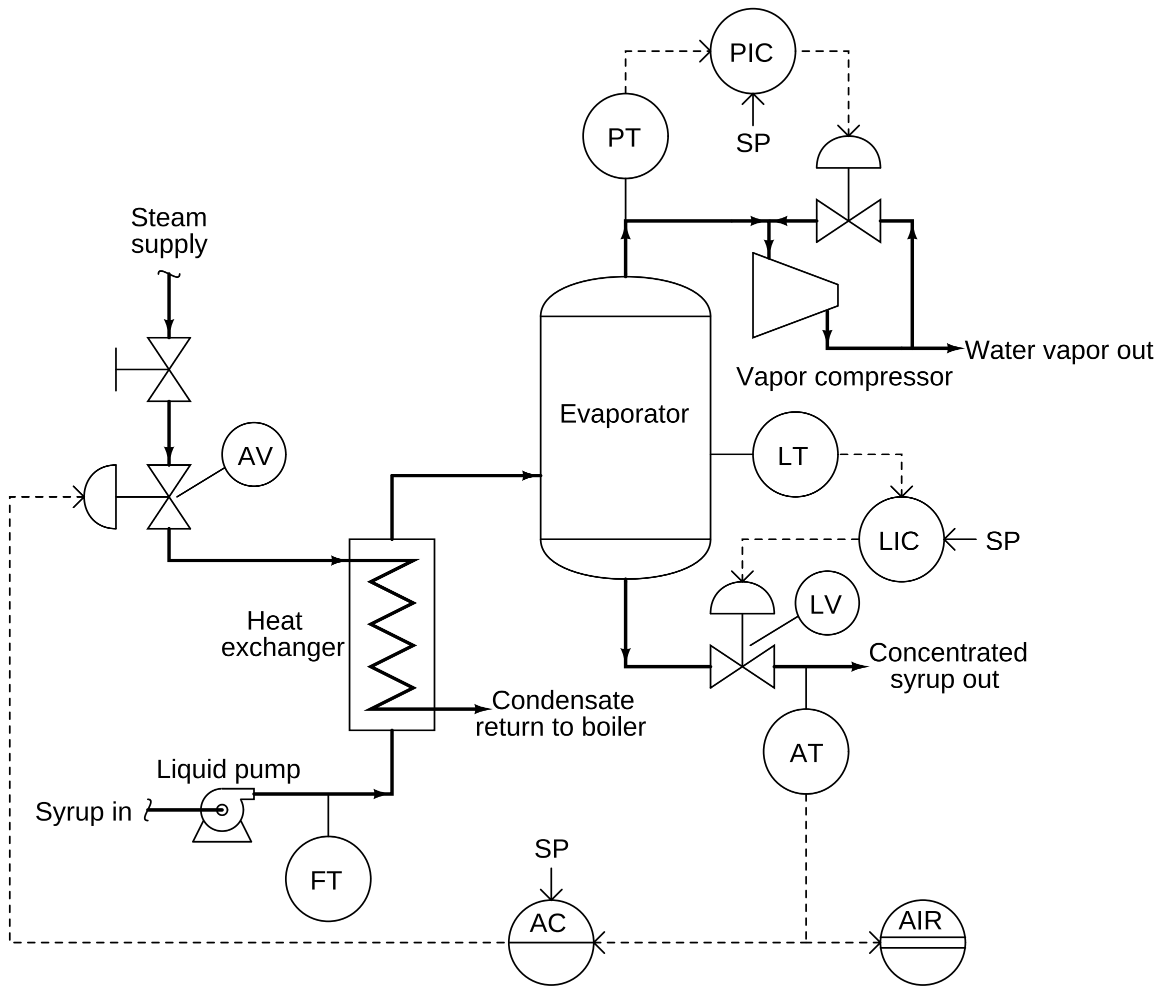
file i00125

Question 10

A helpful strategy for qualitatively analyzing control systems is to mark the inputs of all loop controller bubbles with either "+" or "−" labels to denote the direction of each controller's action. This is the same symbology used to mark the inputs of an operational amplifier, where "+" represents the noninverting input and "−" represents the inverting input. The following illustration shows how the "+" and "−" inputs of an opamp relate to the characteristic equations for direct- and reverse-acting proportional controllers:



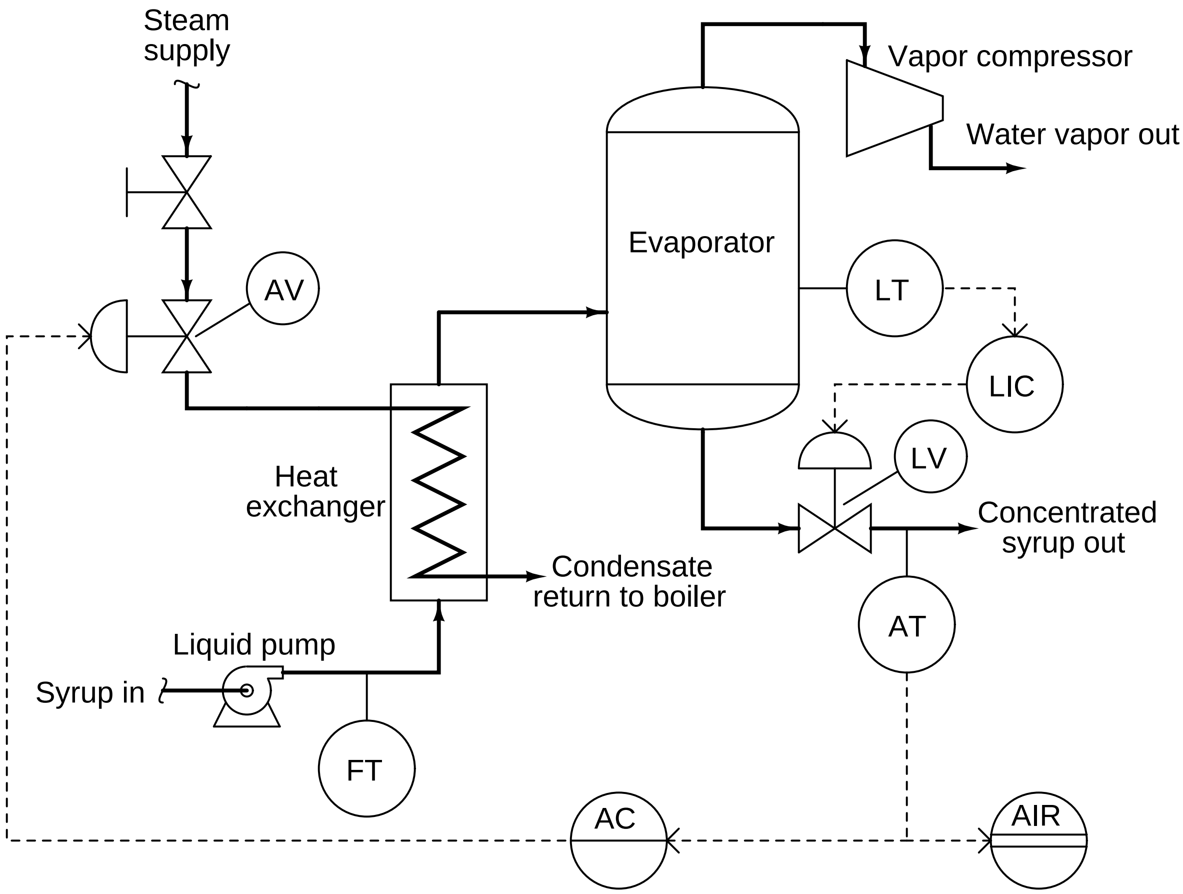
One way to get yourself into this mind-set of marking loop controller inputs with "+" and "−" symbols is to completely replace the ISA-standard "bubble" symbols with triangular opamp symbols. Try doing this in the following PFD, showing the proper direction of action for each controller for the maple syrup evaporator process by the proper orientation of the opamp symbols' inverting and noninverting inputs (PV versus SP):



file i04555

Question 11

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, LIC, and LV) maintains constant syrup level inside the evaporator, while an analytical control system (AT, AIR, AC, and AV) monitors the sugar concentration of the syrup and adjusts steam flow to the heat exchanger accordingly.



Suppose the syrup analyzer (AT) suffers a sudden calibration problem, causing it to register too low (telling the analytical controller that the sugar concentration of the syrup is less than it actually is).

Describe in detail the effect this calibration error will have on the performance of the analytical control system.

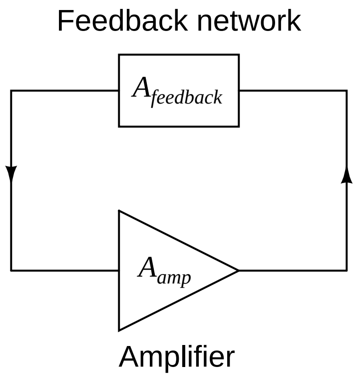
Suggestions for Socratic discussion

- What economic effect will this mis-calibration have on the process? In other words, does the process become more or less profitable as a result of this change?
- Suppose someone shuts the manual block valve on the steam line just a little bit, so that it is about 80% open instead of 100% open. How will this process change affect the control systems in this process?

file i02936

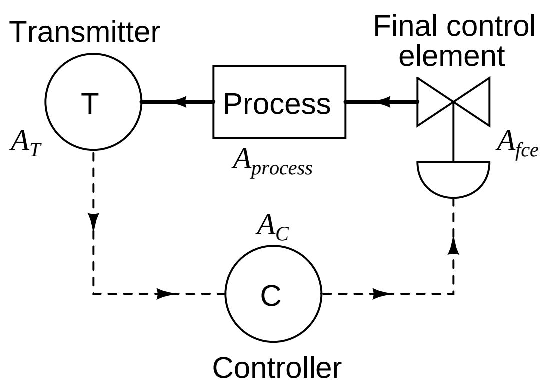
Question 12

In your study of electronics, you probably learned that any amplifier can be turned into an *oscillator* by providing the right amount of phase-shifted feedback from output to input, with a minimum amount of total circuit gain. This principle even had a name: the *Barkhausen criterion*.



So long as the product of the two gains is at least unity ($A_{amp} \cdot A_{feedback} \geq 1$), there will be sufficient amplification to sustain oscillation in the circuit. One key to avoiding oscillation in such a circuit is to limit the total "loop" gain to less than unity.

A process control system using feedback is not much different from this, and it too may oscillate if the total "loop" gain is excessive:



Describe what "gain" represents in each of the four components within the control system shown above (A_C, A_{fce}, $A_{process}$, and A_T), and identify which of these gains is easiest to alter. Finally, explain how that one (easy-to-set) gain should be adjusted. In other words, what criteria should determine its configured value?

file i01459

Question 13

Question 14

Question 15

Question 16

Question 17

Question 18

Question 19

Question 20

Question 21

Read and outline the "Basic Feedback Control Principles" section of the "Closed-Loop Control" chapter in your *Lessons In Industrial Instrumentation* textbook.

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) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

file i04254

Question 22

Read and outline the "On/Off Control" section of the "Closed-Loop Control" chapter in your *Lessons In Industrial Instrumentation* textbook.

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) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

file i04255

Question 23

Read and outline the "Proportional-Only Control" section of the "Closed-Loop Control" chapter in your *Lessons In Industrial Instrumentation* textbook.

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) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

file i04256

Question 24

Read and outline the "Diagnosing Feedback Control Problems" section of the "Closed-Loop Control" chapter in your *Lessons In Industrial Instrumentation* textbook.

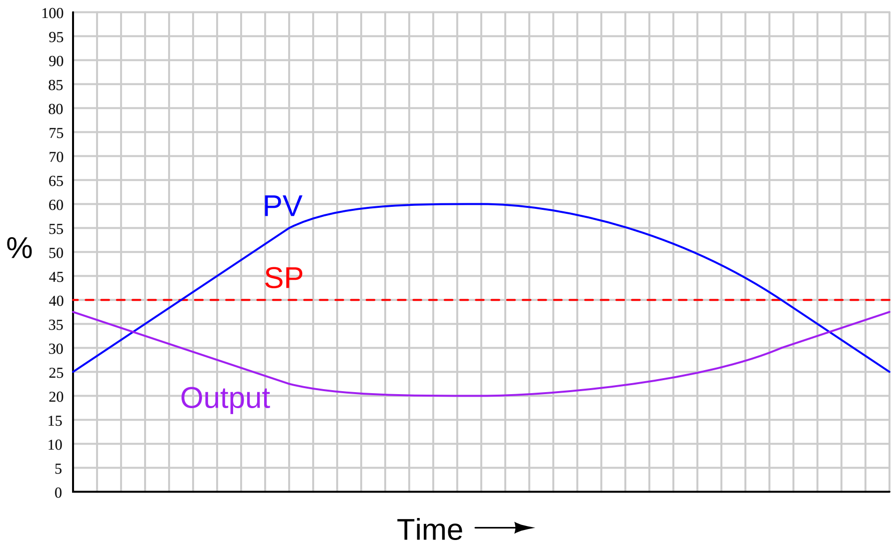
After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(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) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

file i04254

Question 25

An indispensible tool for process operators and instrument technicians alike is the *trend* graph, showing such control loop variables as PV, SP, and controller Output superimposed on the same time-domain plot. The following example shows the process variable, setpoint, and output for a proportional-only controller as it responds to changes in a control loop's PV while the setpoint remains at a constant value of 40%:



Based on an examination of this trend graph, determine the *bias* value of the controller and *gain* value of the controller, as well as its direction of action (*direct* or *reverse*).

A helpful analysis technique when relating trend graphs to controller equations is to sketch a vertical line on the graph to identify some particular point in time, then identify the values of PV, SP, and Output at that point in time. A proper equation for the controller will successfully predict the Output value from the PV and SP values at *any* point in time shown on the trend.

Suggestions for Socratic discussion

- Once you have calculated the gain of this loop controller, calculate its *proportional band* value as well.
- Build a computer spreadsheet program to model the behavior of the proportional controller in this scenario. You will know you are successful when it is able to duplicate any Output value shown on the trend graph at any particular point in time, corresponding to the PV and SP values at that same point in time.
- What would this trend look like if the controller were left in *manual* mode instead of *automatic* mode?

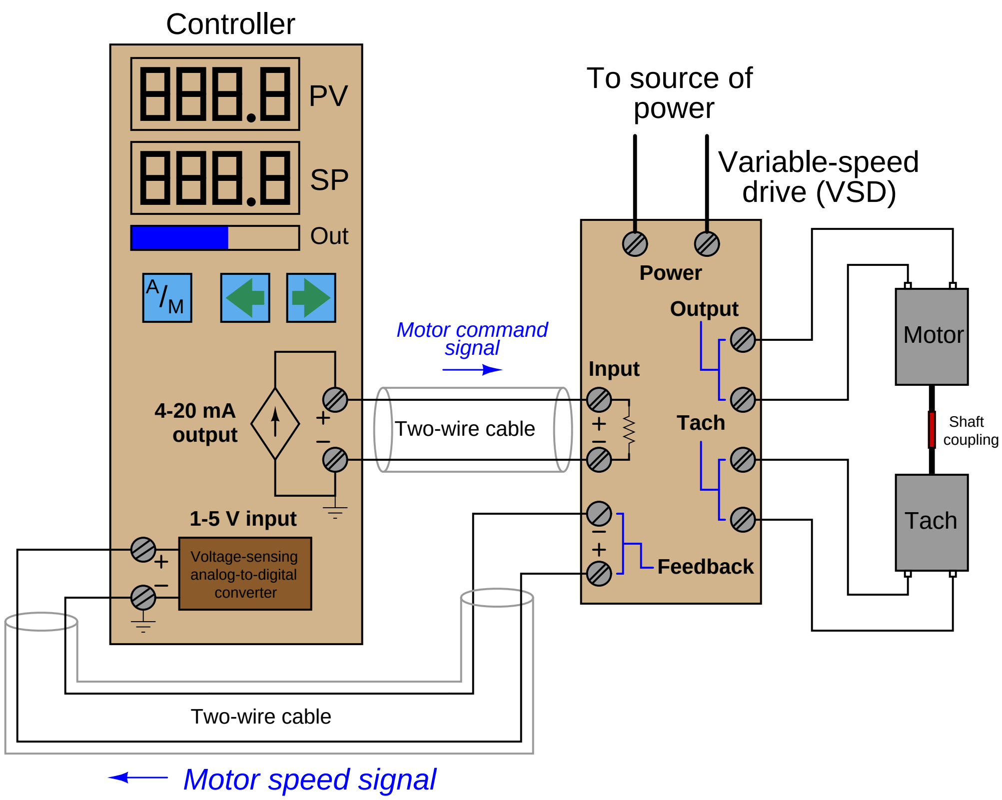
file i00715

Question 26

Desktop Process

PID (Proportional-Integral-Derivative) closed-loop control can be a perplexing subject to master. An essential component of any course of study in PID control is adequate experimental time spent operating and tuning real or simulated PID-controlled processes. In this course, one of the ways you will gain hands-on experience with PID control is to operate a miniature process that easily fits on a desktop.

The following diagram shows one type of "Desktop Process" where a single-loop controller controls the speed of a DC electric motor. The motor receives its power from the Variable-Speed Drive (VSD), and reports shaft speed to the controller by means of a tachogenerator ("tach") which generates a DC voltage proportional to shaft speed:



Alternatively, you could use *PID simulation software* to practice configuring and "tuning" a PID loop controller on a digitally simulated process. One free simulator available to anyone with a computer running the Linux operating system is the `looptune` application which is a part of the `caSCADA` software package available for free download from the same website you download these worksheets and the *Lessons In Industrial Instrumentation* textbook.

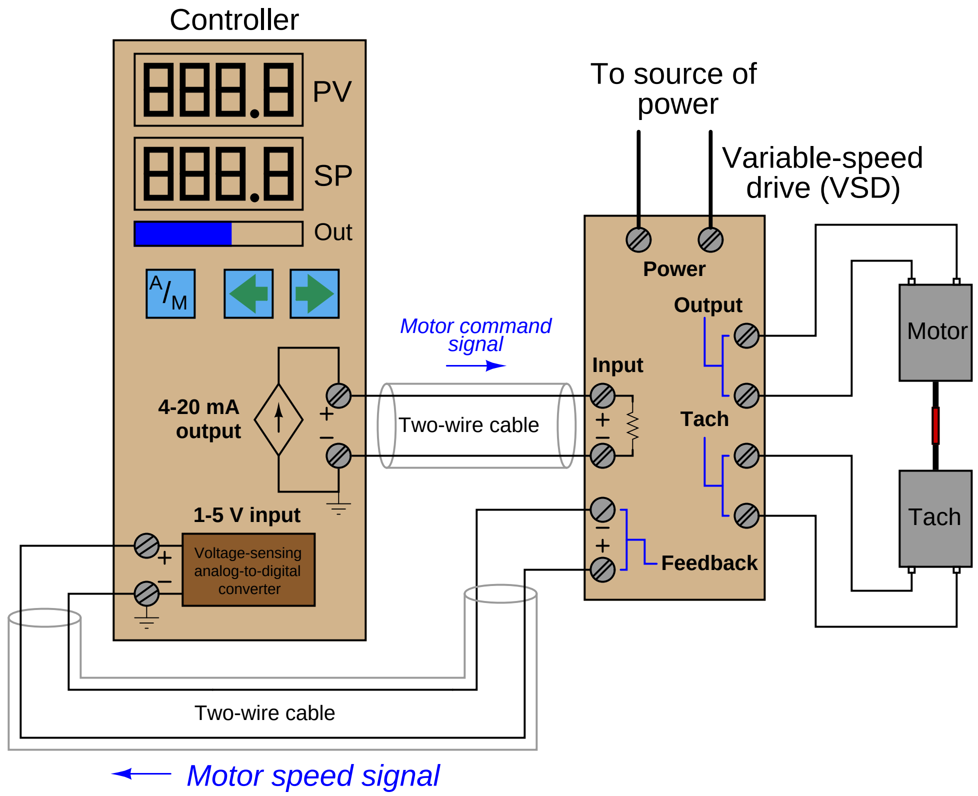
Determine the necessary action of the Desktop Process loop controller (*direct* or *reverse*), assuming that a greater current signal sent to the motor drive causes the motor to spin faster. If you are using PID simulation software, you will need to experiment with the simulated process using the controller's manual mode (adjusting the output value) to determine the necessary controller action for automatic mode.

file i04257

Question 27

Desktop Process exercise

Set up one of the Desktop Process units (or PID simulation software running on a personal computer) to experiment with:



With the controller in manual mode, you should be able to drive the PV to different values, and see those speeds reflected as percentage values on the controller's process variable (PV) display.

Now, configure the controller as follows:

- Control action = *appropriate for the process being controlled*
- Gain = 1 (Proportional Band = 100%)
- Reset (Integral) = *minimum effect* = *100+ minutes/repeat* = *0 repeats/minute*
- Rate (Derivative) = *minimum effect* = *0 minutes*

Adjust the controller's output in manual mode to achieve a PV of approximately 50%, then switch the controller to *automatic* mode and try changing the setpoint (SP) value to see if the motor speed tracks. Experiment with controlling the process in both automatic and manual modes, to better understand the purpose of each controller mode.

Once you have been able to achieve automatic control of the process, try re-configuring the controller for the *opposite* control action. How does this change affect the controller's operation in manual mode (if at all)? How does this change affect the controller's operation in automatic mode (if at all)? Explain why the controller behaves as it does with this new action.

file i04262

Question 28

Desktop Process exercise

Configure the controller as follows (for "proportional-only" control). If you are using PID simulation software instead of a real physical process, select a process that is self-regulating with minimal noise or load changes:

- Control action = *appropriate for the process being controlled*
- Gain = 1 (Proportional Band = 100%)
- Reset (Integral) = *minimum effect = 100+ minutes/repeat = 0 repeats/minute*
- Rate (Derivative) = *minimum effect = 0 minutes*

Check to see that the controller is able to function in automatic mode (regulating the process variable as you adjust the setpoint value). Now, you are set to experiment with the effect of different "gain" values in the PID algorithm. You may access the "gain" parameter by entering the controller's *tuning* function.

Try setting the "gain" value to a number significantly less than 1, then changing the setpoint (SP) value several times to observe the system's response. If you have a data acquisition (DAQ) unit connected to measure controller PV and output signal values, note the relationship between the two graphs plotted on the computer display following each setpoint change.

Now try setting the "gain" value to a number significantly greater than 1, changing the setpoint value again and again to observe the system's response.

Answer the following questions:

- Which gain settings result in the swiftest PV response to SP changes?
- Which gain settings result in the most sluggish PV response to SP changes?
- Are there any gain setting values that result in *oscillation* of the PV?
- Do you notice any *proportional-only offset*?
- Determine the "optimal" gain setting for your process resulting in swift response and minimum offset without too much oscillation.

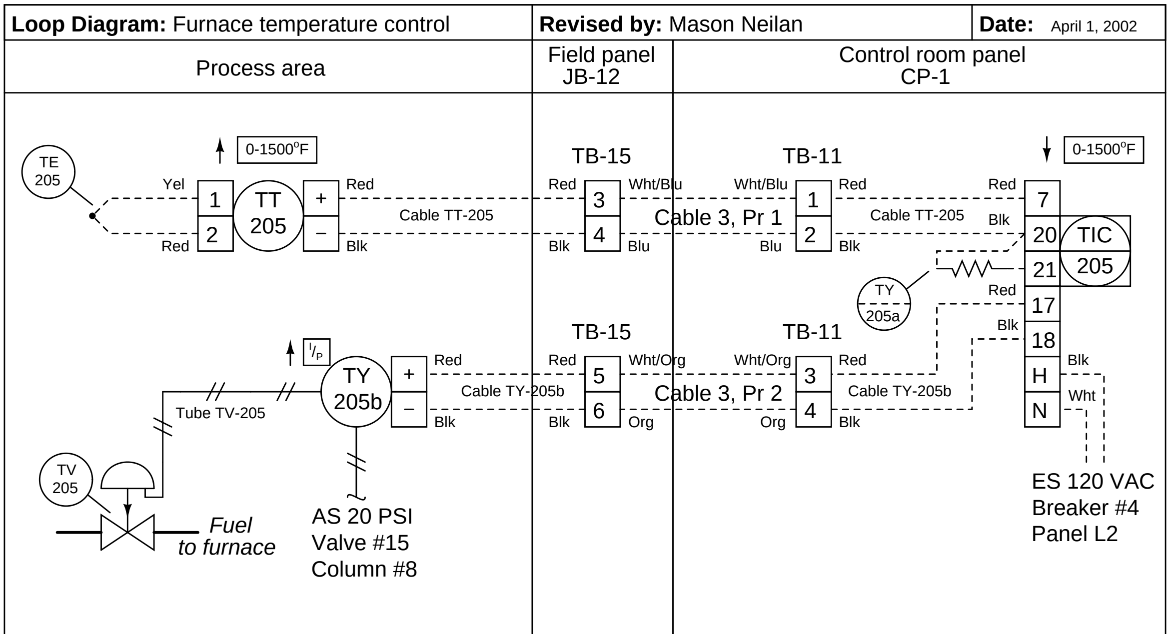
Suggestions for Socratic discussion

- Generalizing to all proportional controllers, explain the effect of decreasing the controller gain value further and further.
- Generalizing to all proportional controllers, explain the effect of increasing the controller gain value further and further.

file i04263

Question 29

This temperature control system has a problem. The process temperature is running above setpoint significantly – the setpoint is 850 ^oF and the temperature (as indicated by TIC-205) is 934 ^oF and showing no signs of cooling off over time:



Tag number	Description	Manufacturer	Model	Calibration	Notes
TE-205	Thermocouple	Omega		Type K	Ungrounded tip
TT-205	Temperature transmitter	Rosemount	444	0-1500° F 4-20 mA	
TY-205a	Resistor	Vishay		250 Ω	
TIC-205	Controller	Siemens	PAC 353	1-5 V 0-1500° F	Reverse-acting control
TY-205b	I/P transducer	Fisher	546	4-20 mA 3-15 PSI	
TV-205	Control valve	Fisher	Easy-E	3-15 PSI	Fail-closed

The operator tells you the process was working just fine yesterday, holding right at the setpoint value of 850 ^oF. Your first step is to examine the faceplate of the controller: it is in automatic mode, and the output is at a value of -5%.

Explain the rationale behind checking the controller's mode and output value. How is this information helpful in troubleshooting the problem? What would be your next step in troubleshooting this problem? What might you do differently if you had seen the controller in a different mode, or with its output at some different (greater) value?

Suggestions for Socratic discussion

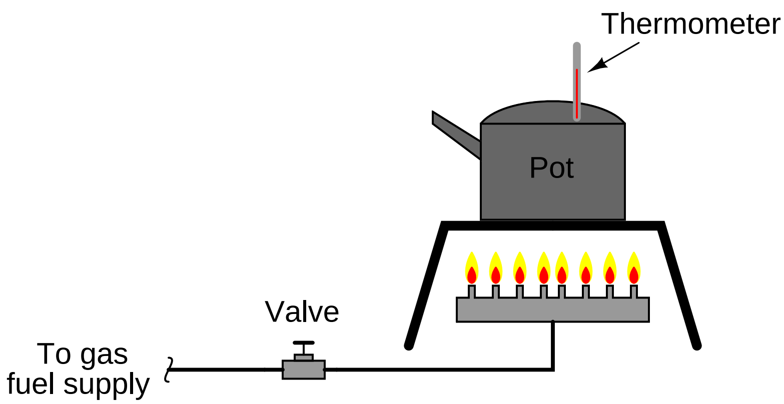
- How significant is the information that this process was working fine just yesterday? Would it make any difference to your diagnosis if you had been told this process has never worked right?
- Suppose this system were functioning perfectly well, and then something pinched Cable 3 Pair 2 and caused it to fail shorted. Explain what would happen as a result of this fault.
- Suppose this system were functioning perfectly well, and then something pinched Cable 3 Pair 1 and caused it to fail shorted. Explain what would happen as a result of this fault.

file i01491

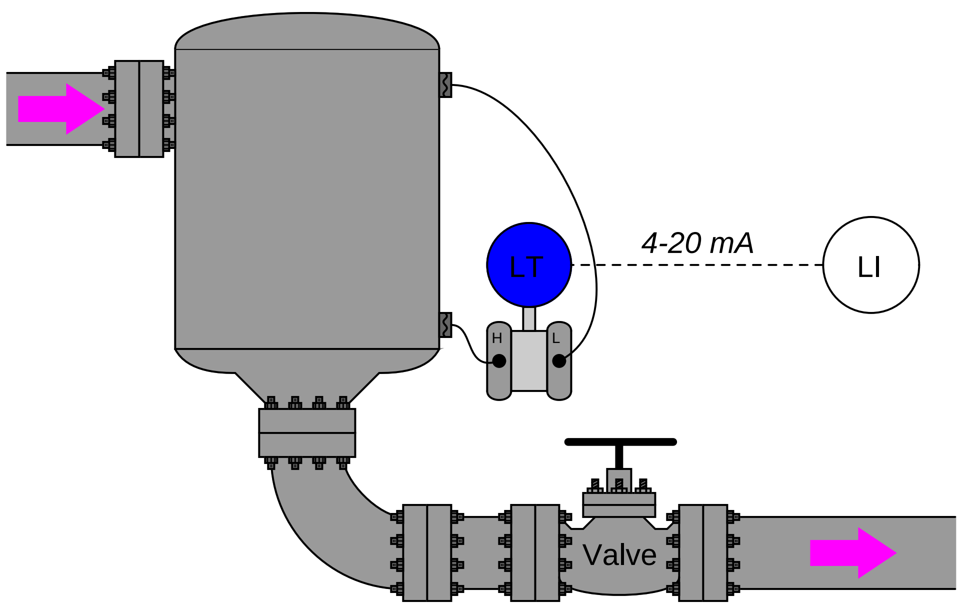
Question 30

In any automated (controlled) system, there is a *process variable*, a *setpoint*, and a *manipulated variable*. There is also something called a *load*, which influences how well the control system is able to maintain setpoint. Provide a general description for a "load," and then identify the load(s) in each of the following manually-controlled processes:

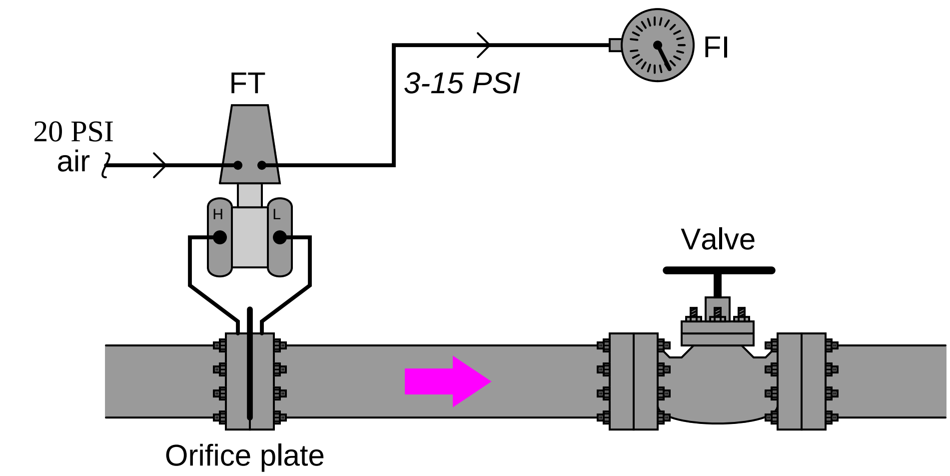
Example 1: Temperature control application



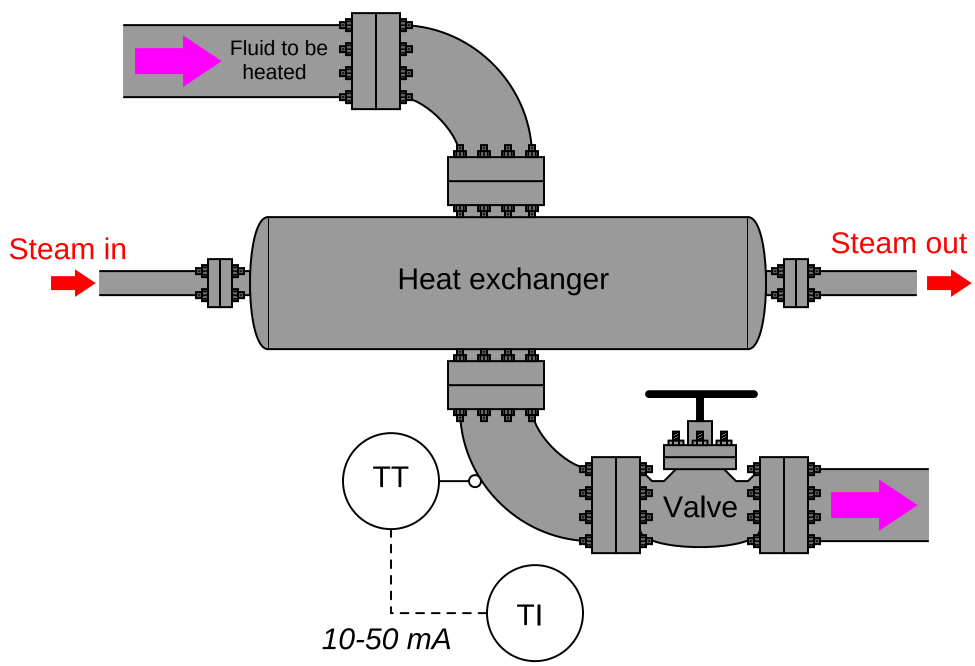
Example 2: Level control application



Example 3: Flow control application



Example 4: Temperature control application



Suggestions for Socratic discussion

- Explain why ambient air temperature is considered a *load* to process example #4, but the insulation thickness on the heat exchanger is not.

  file i01453

Question 31

Convert the following controller gain settings into units of proportional band:

- Gain = 1; P.B. = __________
- Gain = 2; P.B. = __________
- Gain = 3.0; P.B. = __________
- Gain = 0.5; P.B. = __________
- Gain = 0.2; P.B. = __________
- Gain = 0.01; P.B. = __________
- Gain = 5.5; P.B. = __________
- Gain = 10.2; P.B. = __________

file i01462

Question 32

Convert the following controller settings (in units of proportional band) into units of gain (K_p):

- P.B. = 150%; Gain = __________
- P.B. = 300%; Gain = __________
- P.B. = 40%; Gain = __________
- P.B. = 10%; Gain = __________
- P.B. = 730%; Gain = __________
- P.B. = 4%; Gain = __________
- P.B. = 247%; Gain = __________
- P.B. = 9.5%; Gain = __________

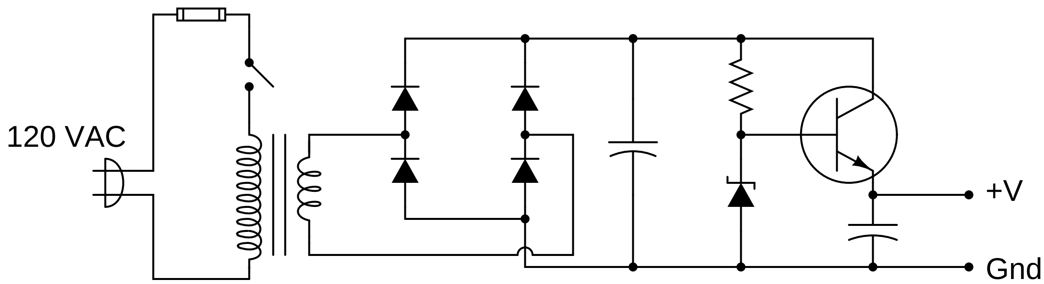
Suggestions for Socratic discussion

- Demonstrate how to estimate answers for these conversions without using a calculator.

file i01463

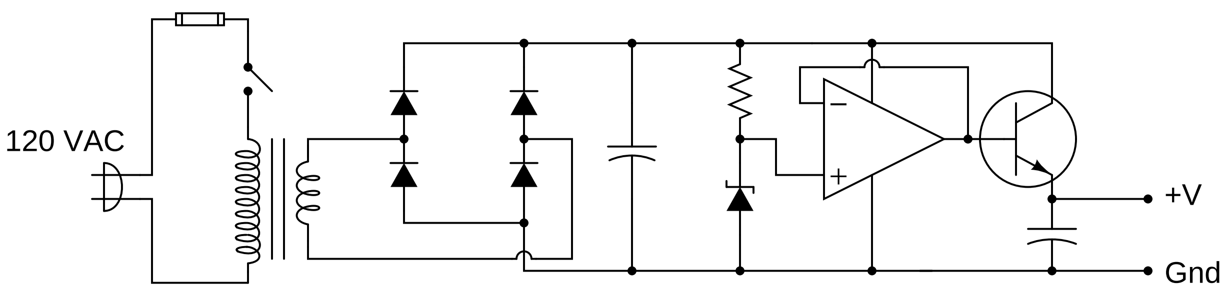
Question 33

A student builds the following regulated AC-DC power supply circuit, but is dissatisfied with its performance:



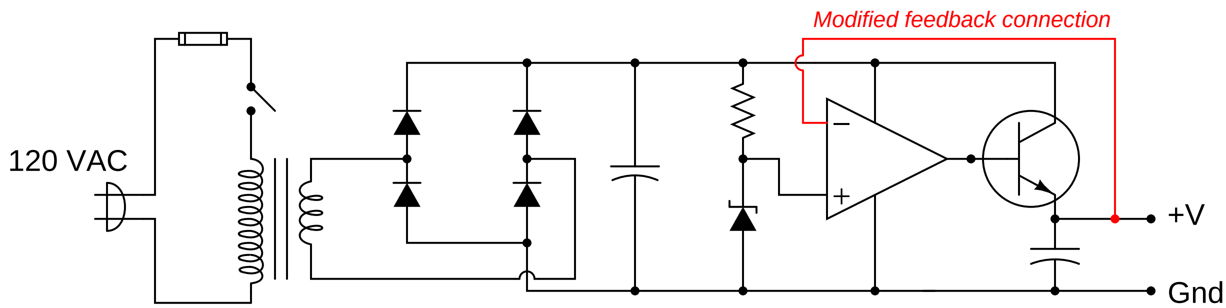
The voltage regulation is not as good as the student hoped. When loaded, the output voltage "sags" more than the student wants. When the zener diode's voltage is measured under the same conditions (unloaded output, versus loaded output), its voltage is noted to sag a bit as well. The student realizes that part of the problem here is loading of the zener diode through the transistor.

In an effort to improve the voltage regulation of this circuit, the student inserts an opamp "voltage follower" circuit between the zener diode and the transistor:



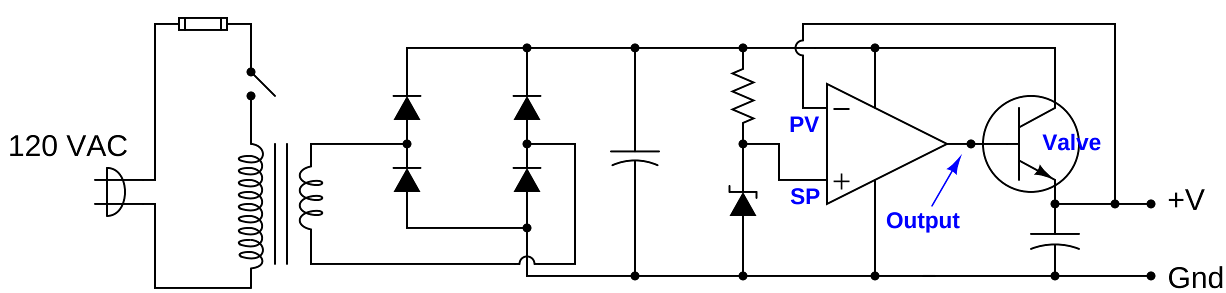
Now the zener diode is effectively isolated from the loading effects of the transistor, and by extension from the output load as well. The opamp simply takes the zener's voltage and reproduces it at the transistor base, delivering as much current to the transistor as necessary without imposing any additional load on the zener diode. While this modification does indeed improve the circuit's ability to hold a steady output voltage under changing load conditions, there is still room for improvement.

Another student looks at the modified circuit, and suggests one small change to dramatically improve the voltage regulation:



Now the output voltage holds steady at the zener diode's voltage with almost no "sag" under load! The second student is pleased with the success, but the first student does not understand why this version of the circuit functions any better than previous version. How would you explain this circuit's improved performance to the first student? How is an understanding of negative feedback essential to being able to comprehend the operation of this circuit?

One hint for explaining the opamp's new role is to relate it to the function of a *loop controller*, representing the input signals as *PV* and *SP*, and the output signal as the *Output*, with the transistor functioning like a *control valve*:



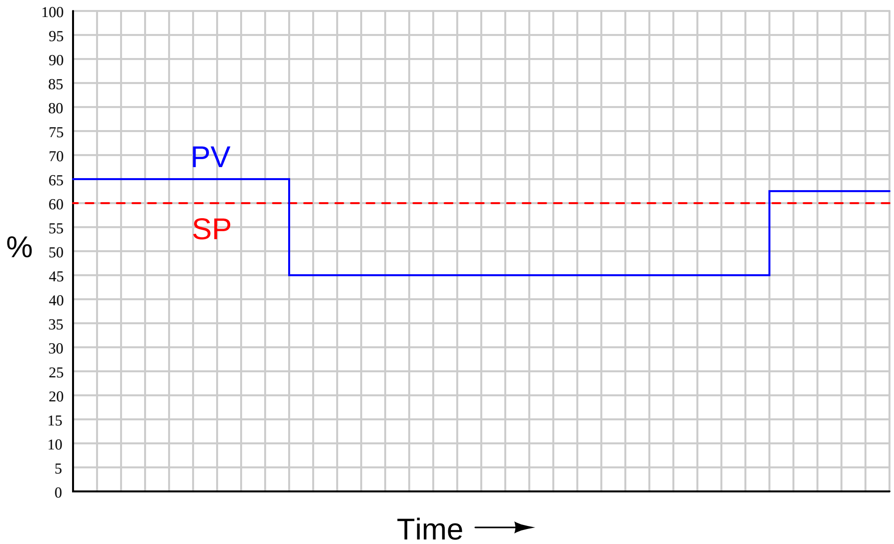
Suggestions for Socratic discussion

- Assuming a zener diode breakdown voltage of 5.0 volts, calculate the output voltage for each version of the power supply circuit.
- Is the opamp "loop controller" functioning with *direct action* or *reverse action*?
- Is the gain of the opamp "loop controller" significant to the regulation of power supply voltage? In other words, will the voltage regulation be any better or worse if the internal (open-loop) voltage gain of the opamp were to change?
- What would happen to this voltage regulator circuit if the resistor in series with the zener diode were to fail open?
- What would happen to this voltage regulator circuit if the feedback wire connecting the opamp's inverting input terminal to the output terminal of the power supply were to fail open?
- What would happen to this voltage regulator circuit if the transistor were to fail open from collector to emitter?

file i01473

Question 34

Graph the output of this proportional-only controller, assuming a gain (K_p) value of 2.0, a bias value of 50%, and a control action that is direct-acting:



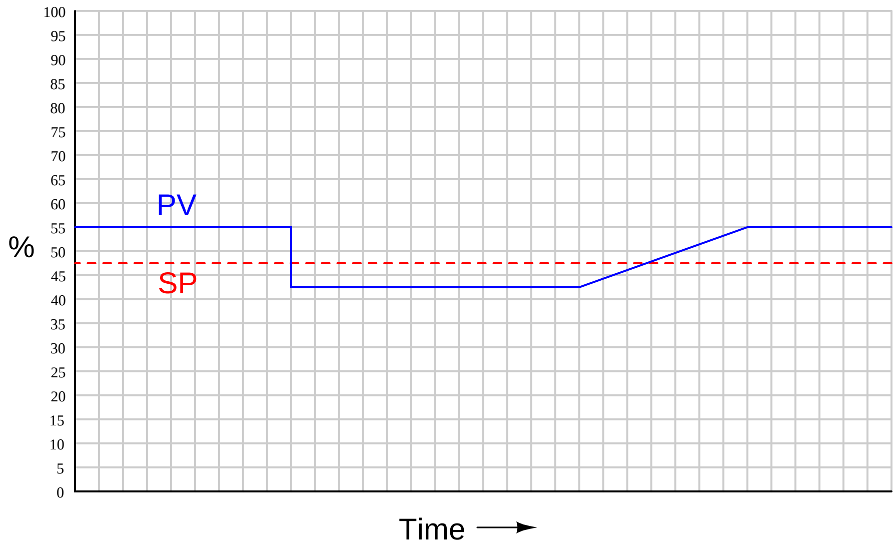
Suggestions for Socratic discussion

- Explain why this trend graph of the PV is unrealistic for a real process, but nevertheless useful for learning how a proportional-only controller is designed to respond to changes in PV.
- How do you suppose the PV would *actually* respond in a real process to the conditions shown (or implied) in this trend? Sketch what you would think would be a more realistic response assuming a properly-tuned proportional-only controller running in automatic mode.

file i01468

Question 35

Graph the output of this proportional-only controller, assuming a proportional band value of 20%, a bias value of 50%, and a control action that is direct-acting:



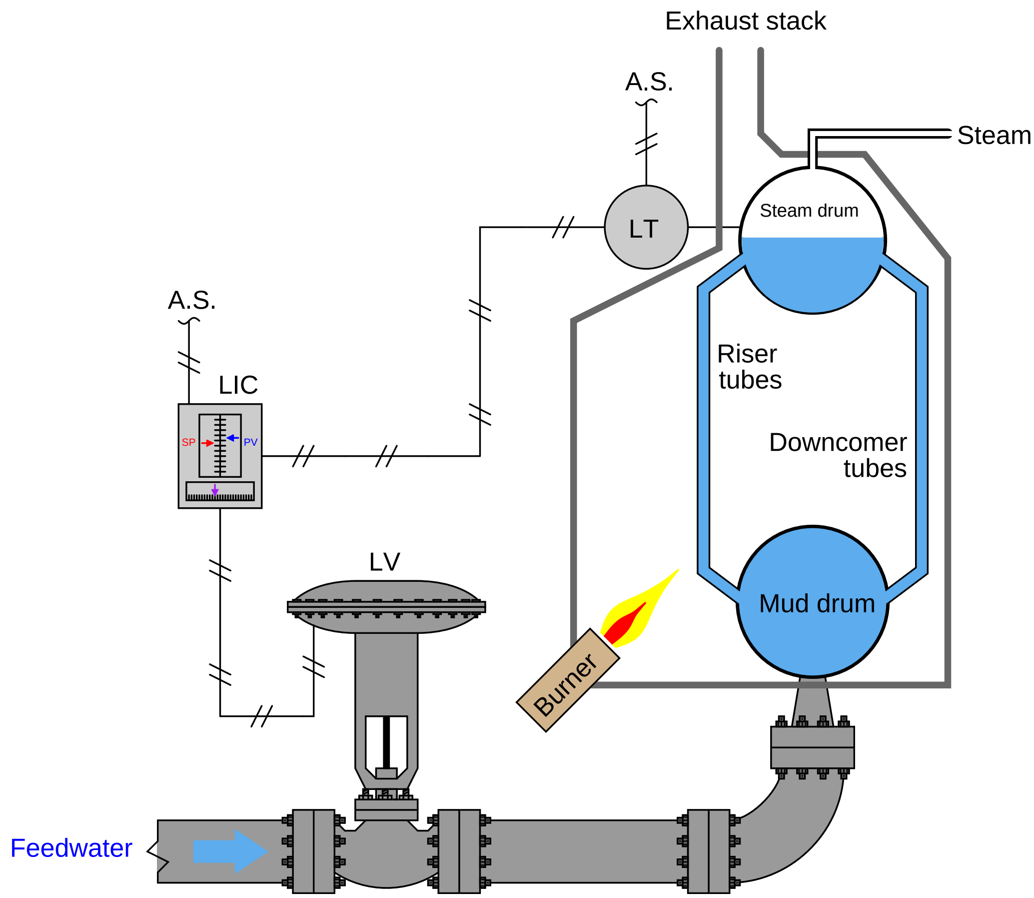
Suggestions for Socratic discussion

- Explain why this trend graph of the PV is unrealistic for a real process, but nevertheless useful for learning how a proportional-only controller is designed to respond to changes in PV.
- How do you suppose the PV would *actually* respond in a real process to the conditions shown (or implied) in this trend? Sketch what you would think would be a more realistic response assuming a properly-tuned proportional-only controller running in automatic mode.
- Identify points on the trend where the PV exhibits a positive rate of change.
- Identify points on the trend where the PV exhibits a negative rate of change.
- Identify points on the trend where the PV exhibits zero change.

file i01469

Question 36

The following steam boiler is automated with a pneumatic water level transmitter, controller, and control valve. This system ensures the water level in the steam drum remains approximately constant regardless of changes in steam demand or burner firing rate, and it is called a *single-element feedwater control* because it bases the feedwater valve position on a single variable (steam drum level):

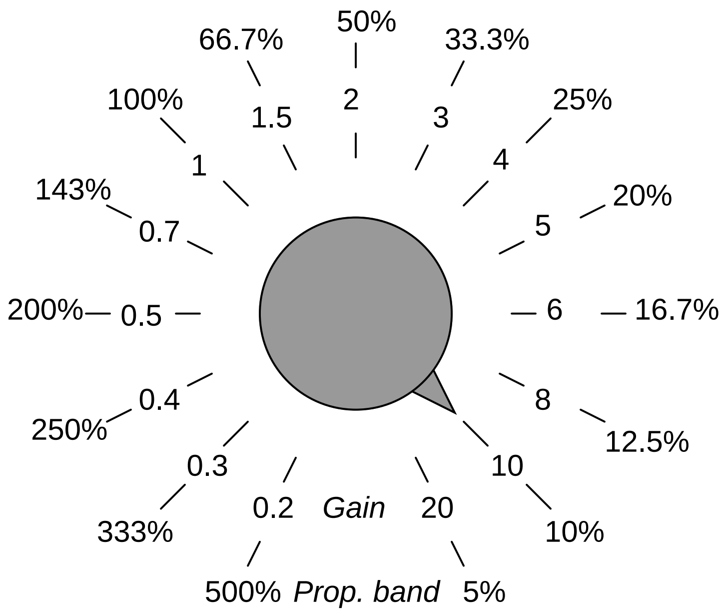


The process variable (PV), setpoint (SP), and output signals (manipulated variable, or MV) of the controller are recorded in a table at random time intervals:

PV (Process Variable)	SP (Setpoint)	MV (Output)
50%	50%	50%
48%	50%	70%
45%	50%	100%
49%	50%	60%
52%	50%	30%
51%	50%	40%
55%	50%	0%

Based on an examination of the values in this table, is the level controller configured for *direct* or *reverse* action?

Examining the controller, you notice there is a knob on its side for setting its gain. This knob is labeled "Gain / Prop. Band," and it has two sets of numbers describing its range of adjustment:



Explain how the two values shown for the knob's setting (Gain = 10 ; Prop. Band = 10%) relate to the percentages you see in the table. Particularly, define *proportional band* in a way that makes sense looking at the controller's behavior over time.

Suggestions for Socratic discussion

- Build a computer spreadsheet program to model the behavior of the proportional controller in this scenario. You will know you are successful when it is able to duplicate the table of values presented in the question (i.e. your spreadsheet will be able to exactly calculate each Output value corresponding to the PV and SP values given in different rows of the table.

file i01461

Question 37

Desktop Process exercise

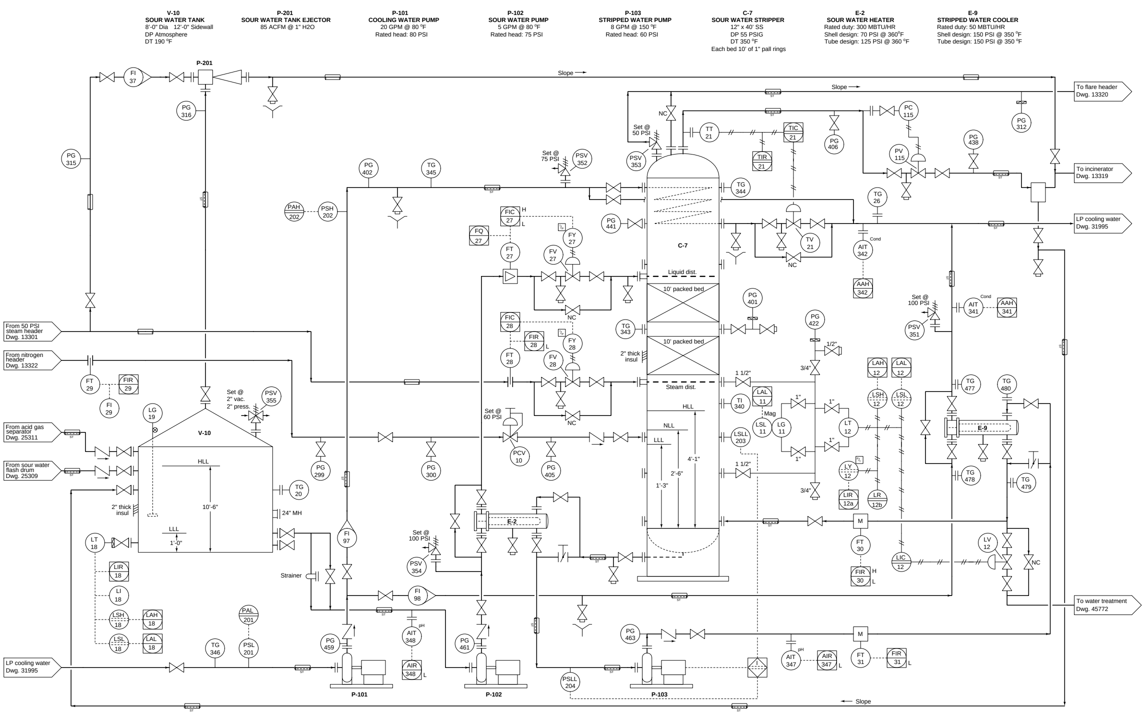
An important feature in any process controller is something called *output tracking*. This feature eases the transition from "Auto" mode to "Manual" mode. Using a Desktop Process, demonstrate this feature in action.

Another important feature in any process controller is something called *setpoint tracking*. This feature eases the transition from "Manual" mode to "Auto" mode. Using a Desktop Process, demonstrate this feature in action.

file i01490

Question 38

In this process, hot steam is used to "strip" volatile sulfur compounds from process water, inside a vessel called a *stripping tower*. A flow control system (loop #28) regulates the amount of stripping steam admitted to the tower:



Suppose the last instrument technician to calibrate the steam flow transmitter (FT-28) made a mistake, and the transmitter consistently reads 1.2 pound per minute more steam flow than there actually is going through the pipe. For example, if the actual steam flow is 6.9 pounds per minute, the transmitter outputs a current signal corresponding to 8.1 pounds per minute.

Describe in detail the effect this mis-calibration will have on the performance of the steam flow control system.

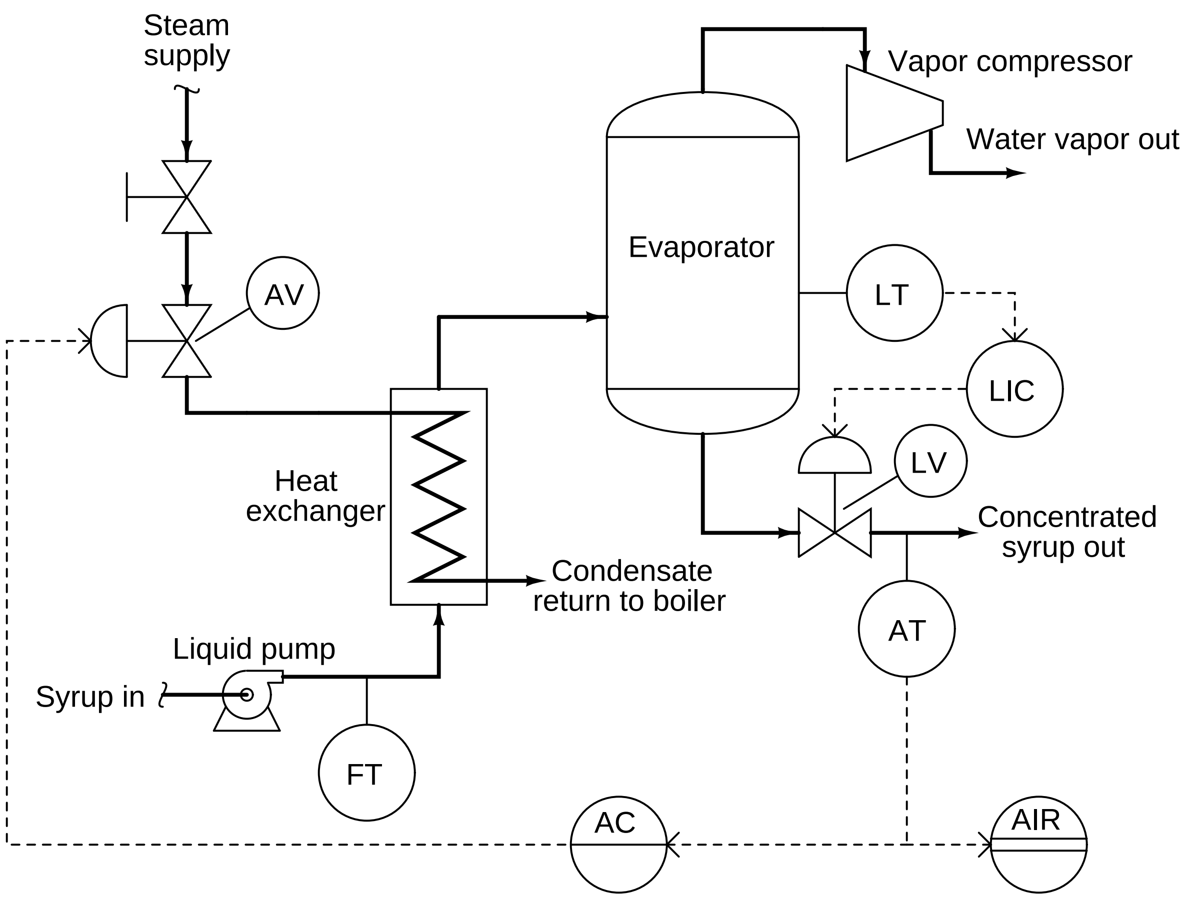
Suggestions for Socratic discussion

- Perform a "thought experiment" where you borrow a friend's car to drive, not knowing the this car's speedometer reads faster than you are actually traveling. What speed will you actually be driving as you attempt to obey the speed limit?
- How do you suppose this miscalibration will affect the performance of the sour water stripping unit?
- Would this miscalibration be evident to an operator looking at the "faceplate" (graphic display) of FIC-28? Why or why not?
- For those who have studied calibration errors, would you characterize this error as a *zero shift*, a *span shift*, a *non-linearity*, or *hysteresis*?
- Explain why nearly every automatic control valve in this process is flanked by two "block" hand valves (one upstream and one downstream) and paralleled by a "bypass" hand valve.

file i02928

Question 39

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, LIC, and LV) maintains constant syrup level inside the evaporator, while an analytical control system (AT, AIR, AC, and AV) monitors the sugar concentration of the syrup and adjusts steam flow to the heat exchanger accordingly.



Suppose a process operator accidently leaves the manual block valve *locked* and *tagged* shut following an overhaul of the process, so that no steam can enter the heat exchanger. Describe how both control systems will respond over time to this process condition.

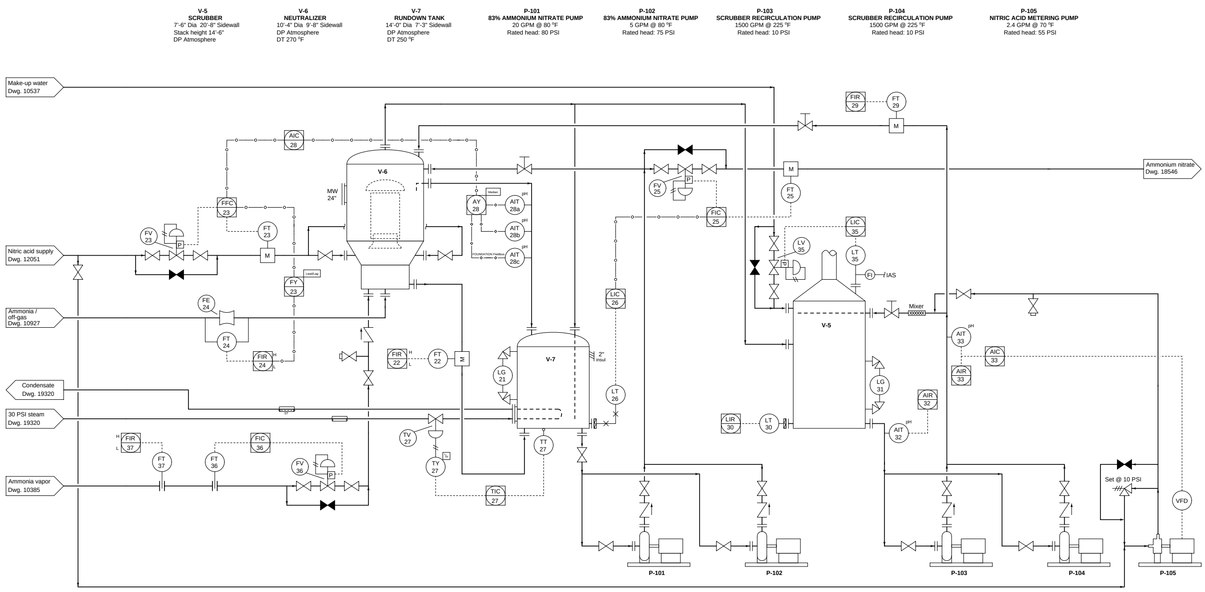
Suggestions for Socratic discussion

- Explain the function of a *heat exchanger*, describing its construction as well.
- Why do you think it is important to monitor and control the level of syrup inside the evaporator?
- How realistic do you think it is that a person might accidently leave their lock and tag on a closed valve following a long period of down-time?

file i02935

Question 40

In this process, nitric acid and ammonia vapor are combined to form a chemical called *ammonium nitrate*, a key ingredient in synthetic fertilizer. The "scrubber" vessel (V-5) uses a liquid spray to remove volatile chemical compounds from vapors before they exit out of an exhaust stack and into the atmosphere. As water evaporates from this liquid solution due to the heat of the vapors, a "make-up" system (loop #35) must add water to maintain a constant liquid level at the bottom of the scrubber vessel:



Suppose the last instrument technician to calibrate the positioner on the level control valve (LV-35) made a mistake, and the valve position is consistently open 10% more than it should be. For example, if controller LIC-35 sends a 50% (12 mA) control signal to the valve, the valve stem will settle at a position of 60% open instead.

Describe in detail the effect this mis-calibration will have on the performance of the level control system for the scrubber vessel.

Suggestions for Socratic discussion

- Perform a "thought experiment" where you put on a pair of shoes with much thicker soles than you are accustomed to before driving a car. The extra thickness of your shoes' soles results in the accelerator pedal being pressed down further than it would normally be for any given foot position. How will this affect your actual driving speed as you attempt to obey the speed limit?
- Is the scrubber vessel in danger of over- or under-filling from the valve's mis-calibration?
- Which would be more dangerous or destructive in this process: an over-filled scrubber or an under-filled scrubber?
- What purpose does a "positioner" serve on a control valve?

file i02929

Question 41

Read and outline the "Proportional Control Action" subsection of the "Pneumatic PID Controllers" section of the "Closed-Loop Control" chapter in your *Lessons In Industrial Instrumentation* textbook.

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) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

file i04264

Question 42

Read and outline the "Automatic and Manual Modes" subsection of the "Pneumatic PID Controllers" section of the "Closed-Loop Control" chapter in your *Lessons In Industrial Instrumentation* textbook.

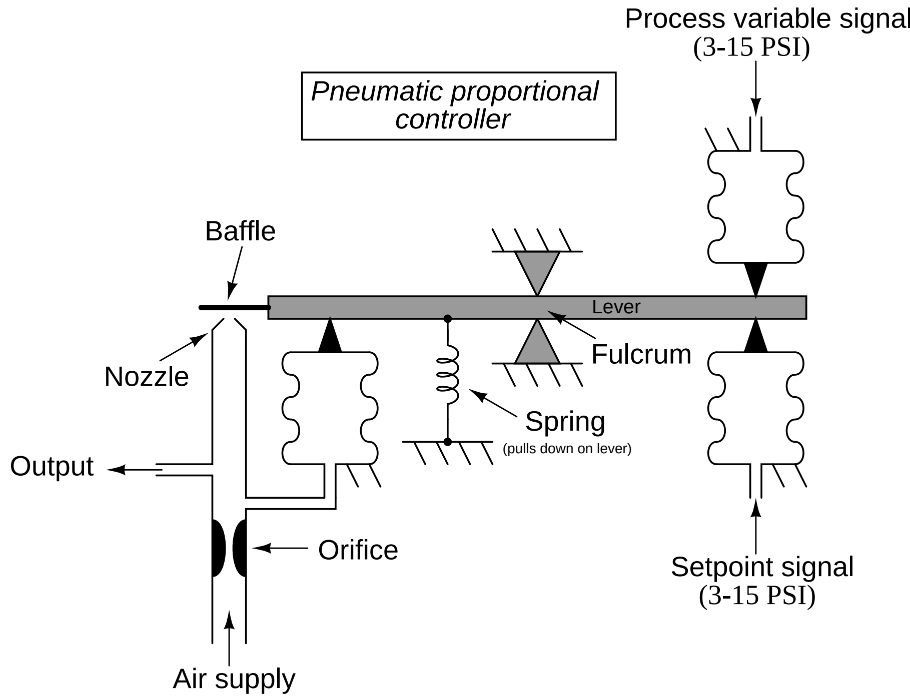
After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(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) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

file i04265

Question 43

Study this illustration of a simple pneumatic proportional controller:



Answer the following questions about this controller mechanism:

- Is it *direct* or *reverse* acting? Annotate the input bellows with "+" and "−" symbols to designate their respective influences on the output signal, just like the input terminals on an operational amplifier.
- Does it work on the *force-balance* or *motion-balance* principle?
- Explain (step-by-step) what happens when the process variable input signal increases and the setpoint remains the same.
- How could the gain of this controller be increased?
- How could the gain of this controller be decreased?
- How could the bias of this controller be adjusted?
- How could the direction of action (direct vs. reverse) be changed?

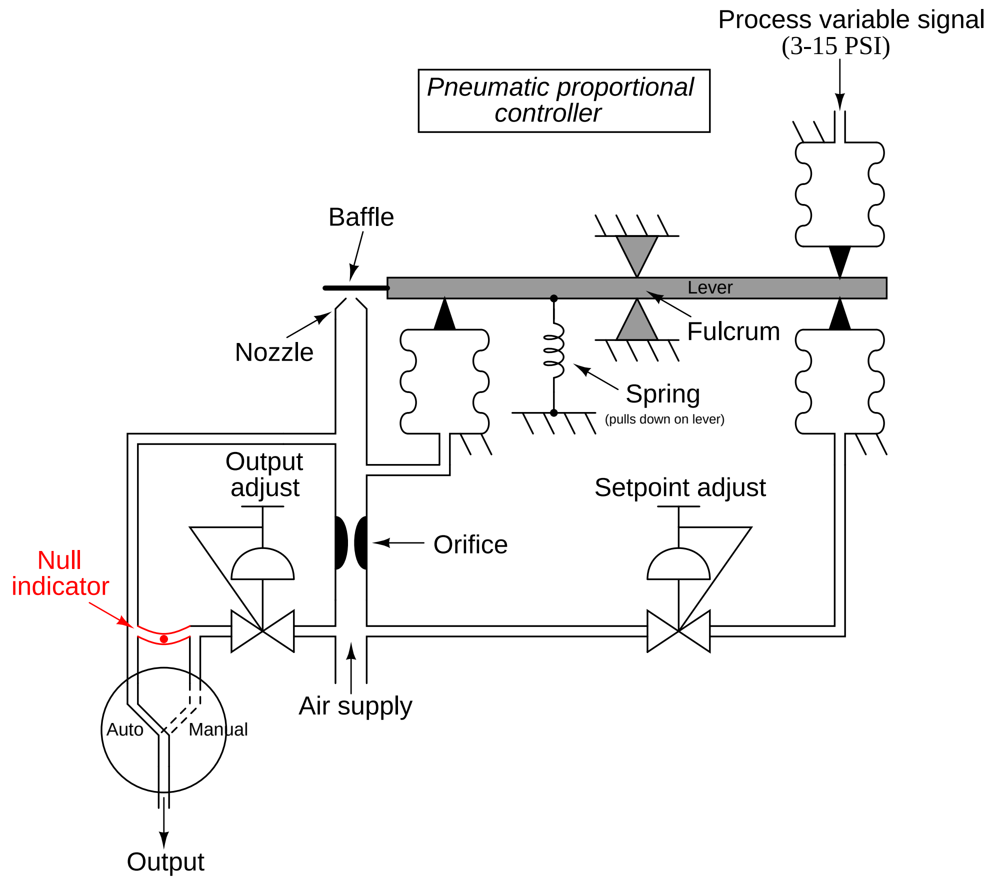
Suggestions for Socratic discussion

- The distinction between force-balance and motion-balance is one that tends to confuse students. A common tactical error students make is to attempt to memorize distinguishing characteristics in order to identify what type of balancing a particular mechanism employs. A better approach is to *think through* the operation of such pneumatic mechanisms using "thought experiments" to identify which balance principle they employ. Why do you think it is bad to go with the memorization approach instead of the "thought experiment" approach?
- What difference does it make to us (as technicians) to know whether a mechanism is force- or motion-balance? In other words, who cares???

file i01476

Question 44

The Foxboro model 43 pneumatic controller used a curved, clear plastic tube with a plastic ball inside as a "null" indicator to help the operator make "bumpless" transfers between auto and manual modes:



Give a step-by-step set of instructions to an operator for making an auto-to-manual mode transfer, using this null indicator to ensure a smooth transition between modes.

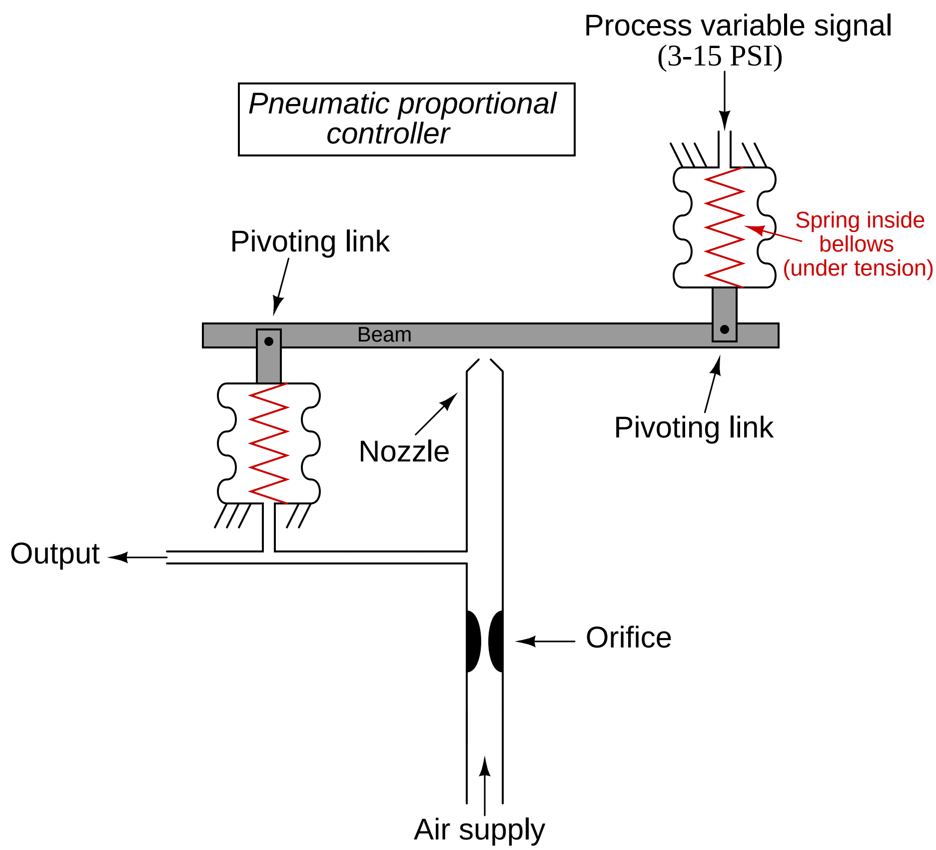
Suggestions for Socratic discussion

- Explain the rationale for an operator making a "bumpless" transfer with a controller such as this.
- Describe a realistic process control scenario where a non-bumpless switch between automatic and manual modes (or vice-versa) could cause problems for the process. If you find it helpful, make reference to a P&ID diagram found somewhere in your homework or in your textbook.
- Suppose the bias spring in this mechanism were to suddenly break. Explain what effect(s) this fault would have on the operation of the pneumatic controller mechanism.
- Suppose the controller is in automatic mode and the balance indicator ball is all the way to the left. Describe the steps necessary to switch this controller to manual mode "bumplessly".
- Suppose the controller is in manual mode and the balance indicator ball is all the way to the left. Describe the steps necessary to switch this controller to automatic mode "bumplessly".

file i01479

Question 45

Study this illustration of a simple pneumatic proportional controller (the beam serves as a baffle, or flapper, for the nozzle to sense):



Answer the following questions about this controller mechanism:

- Is it *direct* or *reverse* acting?
- What would be required to invert the action of the controller, from direct to reverse action or vice-versa?
- Does it work on the *force-balance* or *motion-balance* principle?
- How could the setpoint of this controller be adjusted?
- How could the gain (proportional band) of this controller be adjusted? How about the bias?

Suggestions for Socratic discussion

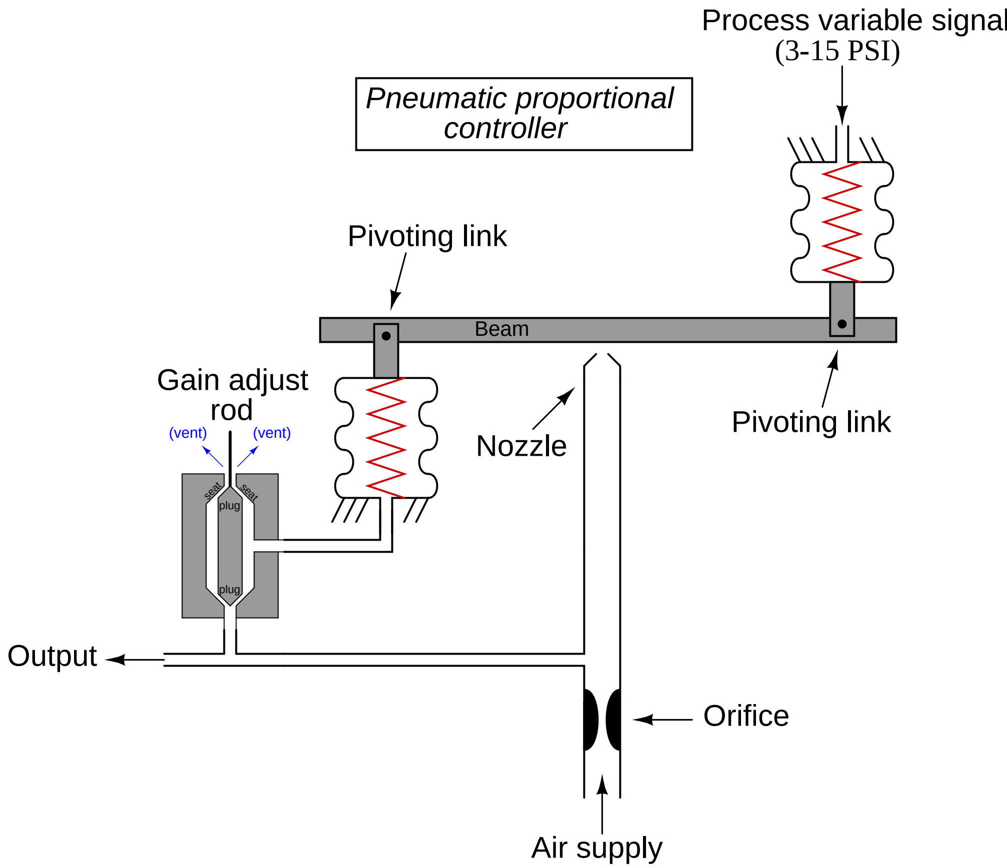
- The distinction between force-balance and motion-balance is one that tends to confuse students. A common tactical error students make is to attempt to memorize distinguishing characteristics in order to identify what type of balancing a particular mechanism employs. A better approach is to *think through* the operation of such pneumatic mechanisms using "thought experiments" to identify which balance principle they employ. Why do you think it is bad to go with the memorization approach instead of the "thought experiment" approach?
- What difference does it make to us (as technicians) to know whether a mechanism is force- or motion-balance? In other words, who cares???

- Identify what would need to be modified and/or added to this mechanism to equip it with a *manual* mode.

file i01481

Question 46

Explain how the gain adjustment works in this pneumatic proportional controller mechanism:



By moving the "gain adjust rod" up and down, the controller gain may be varied. Identify which direction of motion will result in *more* gain.

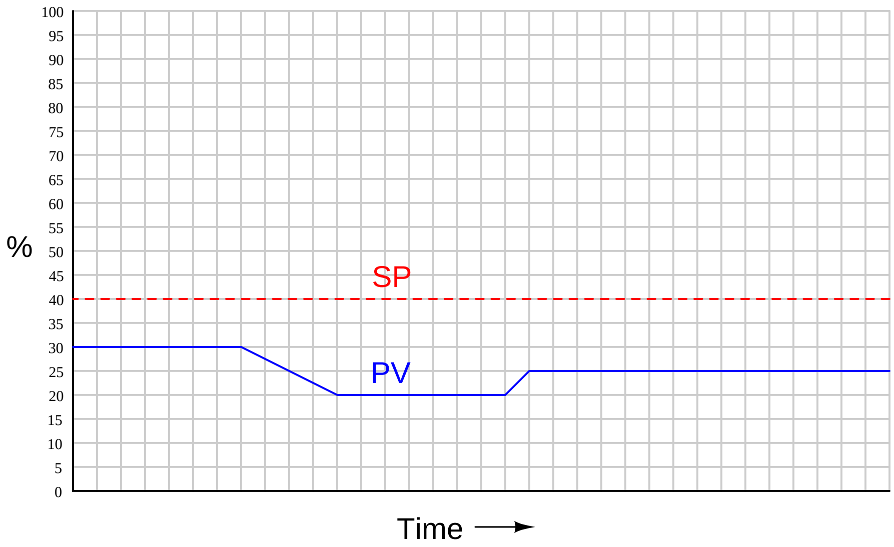
Suggestions for Socratic discussion

- Identify at least one advantage this method of gain adjustment enjoys over other methods of gain adjustment you have seen in pneumatic controller mechanisms.
- Suppose this pneumatic control mechanism were augmented with an *amplifying relay* to improve its performance. Where exactly would the new relay be placed within the mechanism?
- How would this controller mechanism act if the orifice were relocated to a position between the output tube and the nozzle, rather than between the air supply and the output tube where it should be?
- Sketch an electronic opamp circuit with an adjustable gain that works analogously to this pneumatic controller mechanism.

file i01482

Question 47

Graph the output of this proportional-only controller, assuming a proportional band of 50%, a bias value of 30%, and a control action that is reverse-acting:



A direct method of solving for the output graph is to re-calculate the output value using the proportional controller equation ($m = K_p e + b$), at every point where there is a unique PV and/or SP value. For example, you could use the equation to calculate the output value at PV=30%, PV=20%, and PV=25%. This involves repeated calculations, which may be tedious for a complex graph.

As an aid to doing these repeated calculations, try setting up a computer spreadsheet (e.g. Microsoft Excel) to evaluate the proportional control equation for you, and then see if you can configure the spreadsheet to produce a graph of the same PV, SP, and Output trends as well!

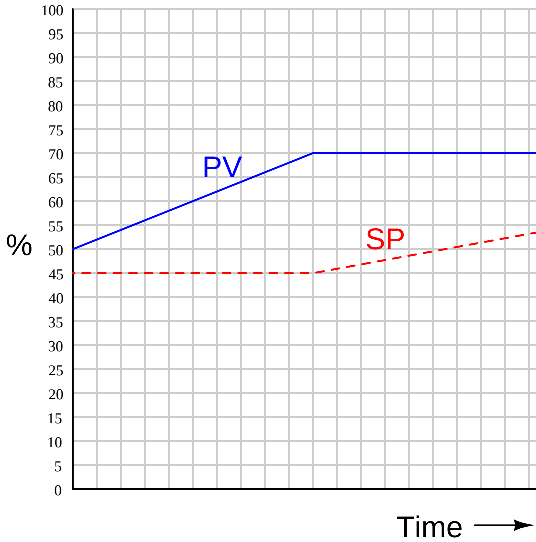
Suggestions for Socratic discussion

- How would the output signal trend be altered if the *proportional band* of this controller were increased?
- How would the output signal trend be altered if the *bias* of this controller were increased?
- How would the output signal trend be altered if the *action* of this controller were switched from reverse to direct?

file i03273

Question 48

Graph the output of this proportional-only controller, assuming a gain (K_p) value of 0.5, a bias value of 40%, and a control action that is reverse-acting:



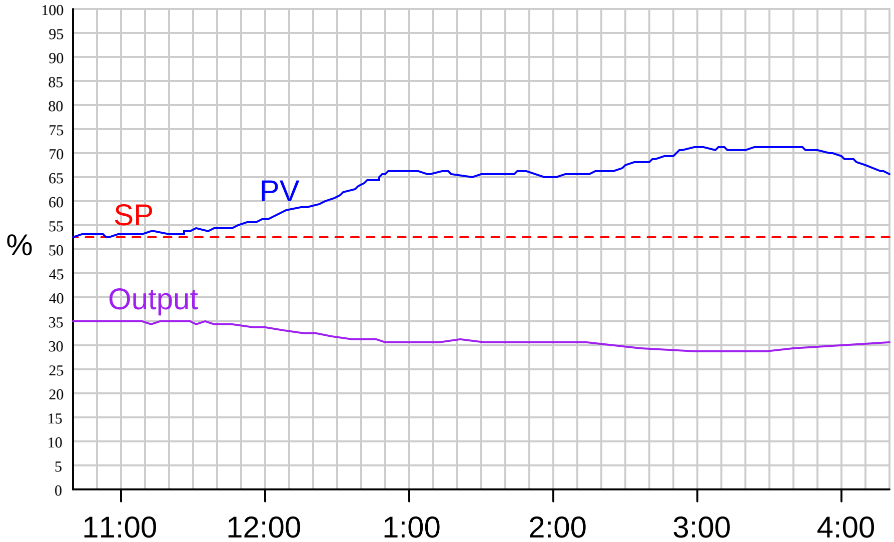
Suggestions for Socratic discussion

- Identify points on the trend where the PV exhibits a positive rate of change.
- Identify points on the trend where the PV exhibits a negative rate of change.
- Identify points on the trend where the PV exhibits zero change.
- How would the output signal trend be altered if the *gain* of this controller were decreased?
- How would the output signal trend be altered if the *bias* of this controller were decreased?
- How would the output signal trend be altered if the *action* of this controller were switched from reverse to direct?

file i01485

Question 49

Suppose you are summoned to diagnose a process control problem, and are shown this trend graph of the PV, SP, and Output for a particular loop:



We see the process variable clearly deviating from setpoint, which it should not do if the control system is doing its job as it should.

Determine the most likely cause of the problem, based on the data you see in this trend.

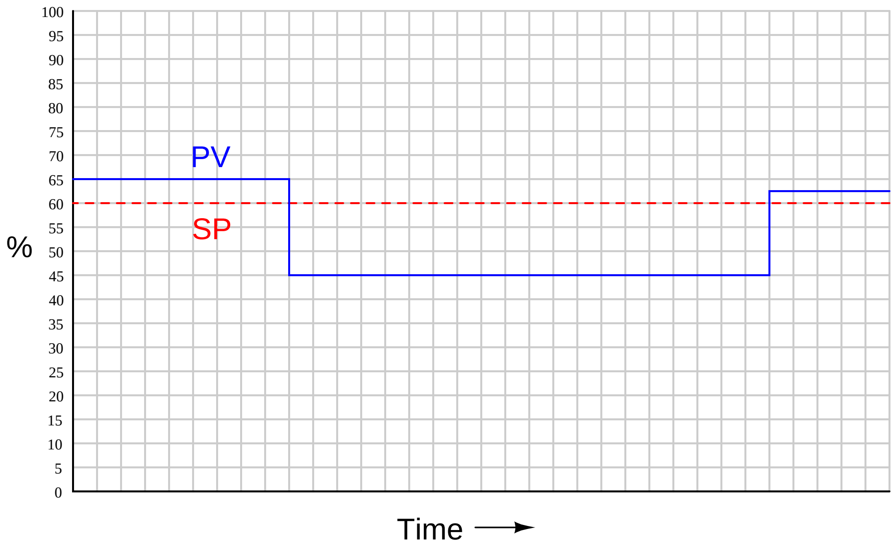
Suggestions for Socratic discussion

- Explain why viewing the *output* trend in addition to the PV trend is critically important to being able to diagnose the problem here.
- Examine this trend graph and explain how we can tell which mode (*automatic* or *manual*) the loop controller is in.
- Examine this trend graph and explain how we can tell which direction of action (*direct* or *reverse*) the loop controller is configured for.
- Identify as best you can the *proportional band* and *bias* values of this controller based on the data shown in the trend.
- Suppose the control valve in a process loop were to fail shut and thereby become unresponsive to the controller's output signal. How do you think this would affect the trend graph of PV, SP, and Output for the loop?
- Suppose the paper chart recorder displaying this trend graph were to fail in such a way that the PV pen drops all the way down to zero and becomes unresponsive to the transmitter's signal. Could an operator extrapolate the value of the PV just by examining the SP and Output trends? Explain why or why not.

file i01388

Question 50

Graph the output of this proportional-only controller, assuming a gain (K_p) value of 2.0, a bias value of 50%, and a control action that is direct-acting:



Suggestions for Socratic discussion

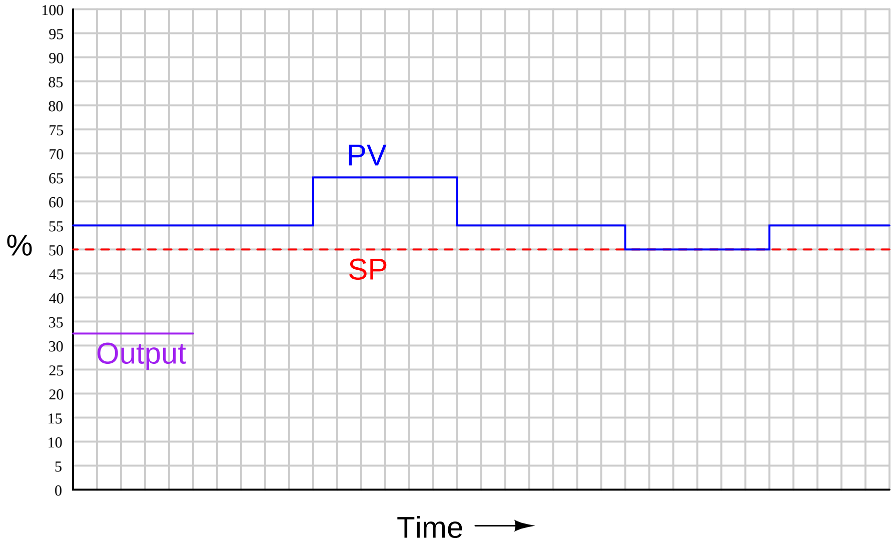
- Explain why this trend graph of the PV is unrealistic for a real process, but nevertheless useful for learning how a proportional-only controller is designed to respond to changes in PV.
- How do you suppose the PV would *actually* respond in a real process to the conditions shown (or implied) in this trend? Sketch what you would think would be a more realistic response assuming a properly-tuned proportional-only controller running in automatic mode.

file i01468

Question 51

Proportional control action is where the output signal of a controller shifts in direct proportion to any shift in *error* (the difference between process variable and setpoint).

Given this definition, identify how a proportional-acting controller would respond to the following process variable (PV) and setpoint (SP) values over time:

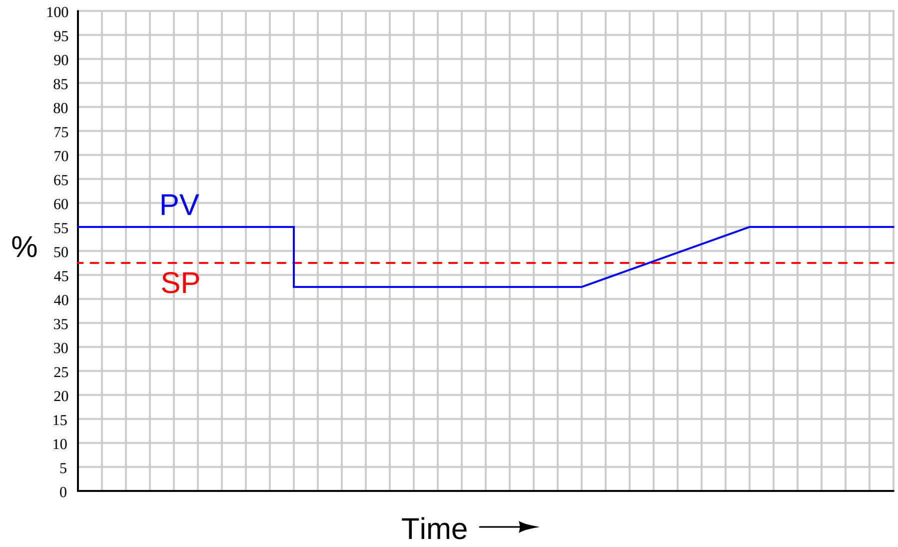


Assume *direct* control action.

file i02417

Question 52

Graph the output of this proportional-only controller, assuming a proportional band value of 20%, a bias value of 50%, and a control action that is direct-acting:



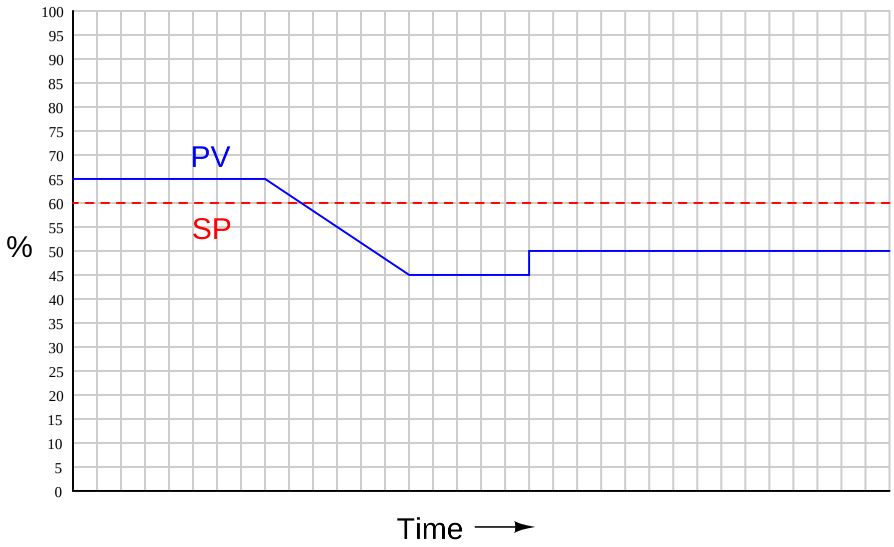
Suggestions for Socratic discussion

- Explain why this trend graph of the PV is unrealistic for a real process, but nevertheless useful for learning how a proportional-only controller is designed to respond to changes in PV.
- How do you suppose the PV would *actually* respond in a real process to the conditions shown (or implied) in this trend? Sketch what you would think would be a more realistic response assuming a properly-tuned proportional-only controller running in automatic mode.
- Identify points on the trend where the PV exhibits a positive rate of change.
- Identify points on the trend where the PV exhibits a negative rate of change.
- Identify points on the trend where the PV exhibits zero change.

file i01469

Question 53

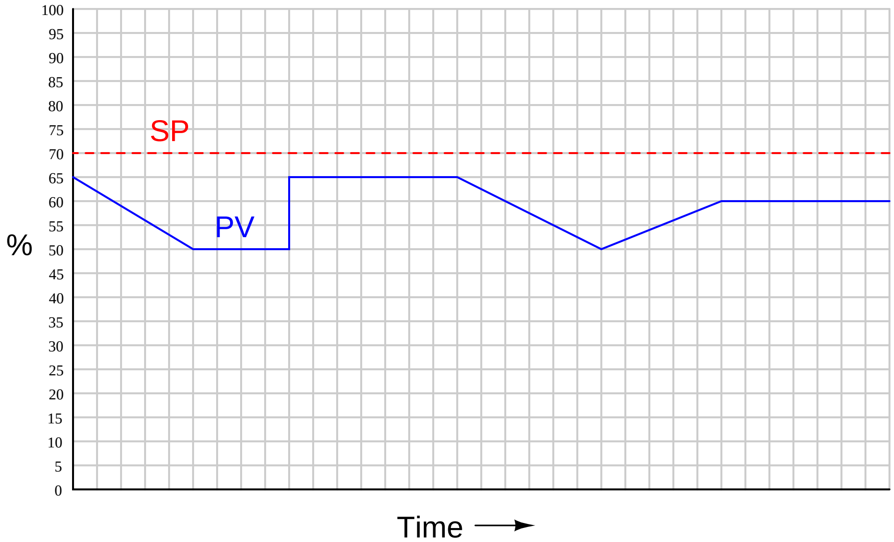
Graph the output of this proportional-only controller, assuming a gain (K_p) value of 1.0, a bias value of 50%, and a control action that is reverse-acting:



file i03272

Question 54

Graph the output of this proportional-only controller, assuming a proportional band value of 125%, a bias value of 30%, and a control action that is reverse-acting:



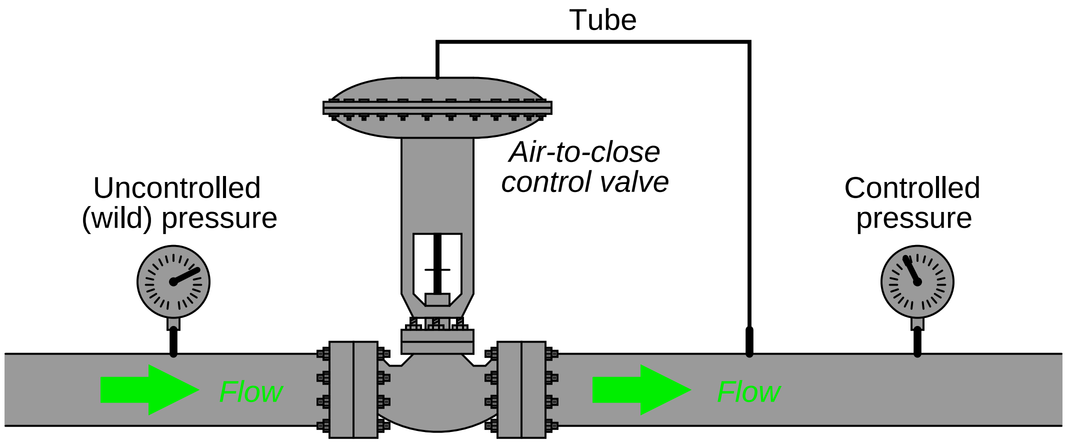
Suggestions for Socratic discussion

- Identify points on the trend where the PV exhibits a positive rate of change.
- Identify points on the trend where the PV exhibits a negative rate of change.
- Identify points on the trend where the PV exhibits zero change.
- How would the output signal trend be altered if the *gain* of this controller were increased?
- How would the output signal trend be altered if the *bias* of this controller were increased?
- How would the output signal trend be altered if the *action* of this controller were switched from reverse to direct?

file i01470

Question 55

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

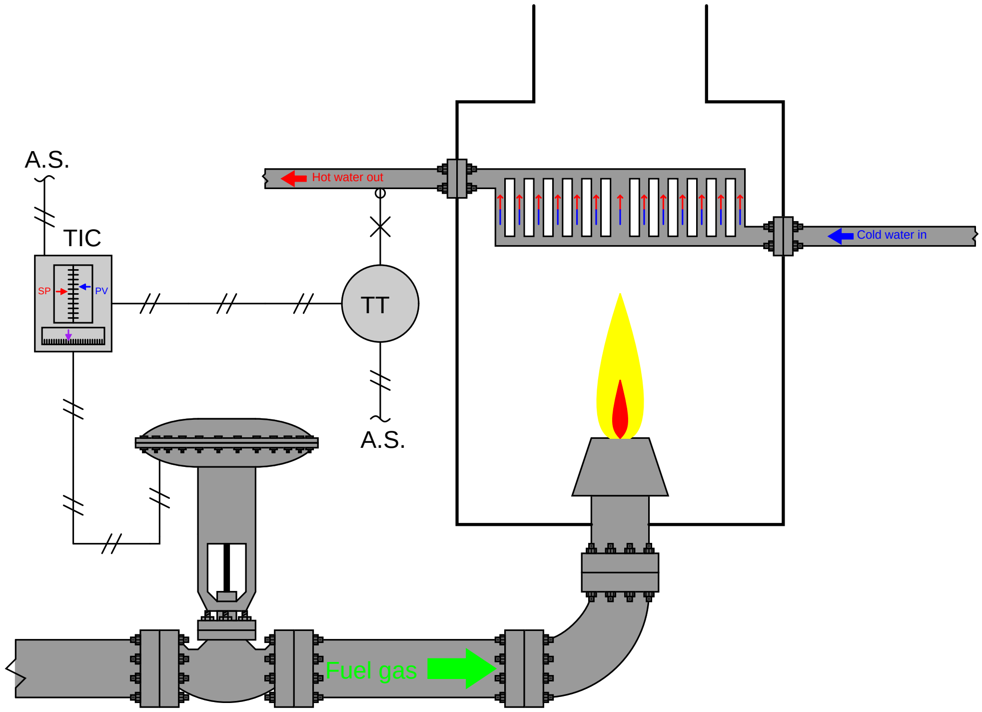


Identify how this constitutes a negative feedback system, and explain how it works to regulate downstream pressure. Then, identify what things you would have to change in this system to alter its gain (proportional band) and setpoint.

file i01483

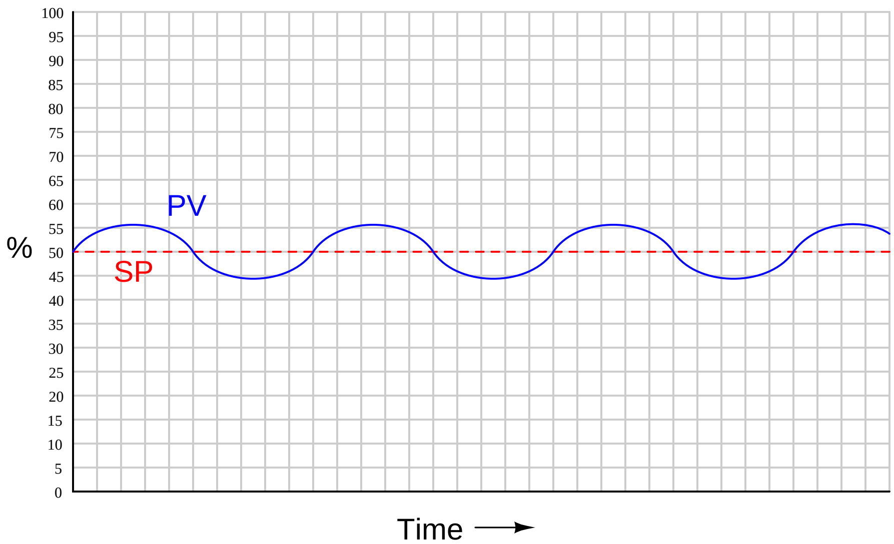
Question 56

A pneumatic water heater control system uses a temperature transmitter calibrated to a range of 0 to 180^o F. The control system has worked adequately for many years:



It is then decided that the temperature range is too wide, since the water temperature never falls below 100^o F. A narrower calibrated range will make better use of the 3-15 PSI signal's dynamic range, and also make it easier to see changes in temperature on 3-15 PSI (input) indicators and chart recorders. An instrument technician re-calibrates the temperature transmitter to a narrower range: 100 to 180^o F, then re-labels all the indicators and chart recorders to reflect the new range. After doing this work, the operator places the control system back in service.

However, it quickly becomes evident that something is wrong. Instead of a smooth line on the chart recorder, the temperature is seen to cycle continuously:

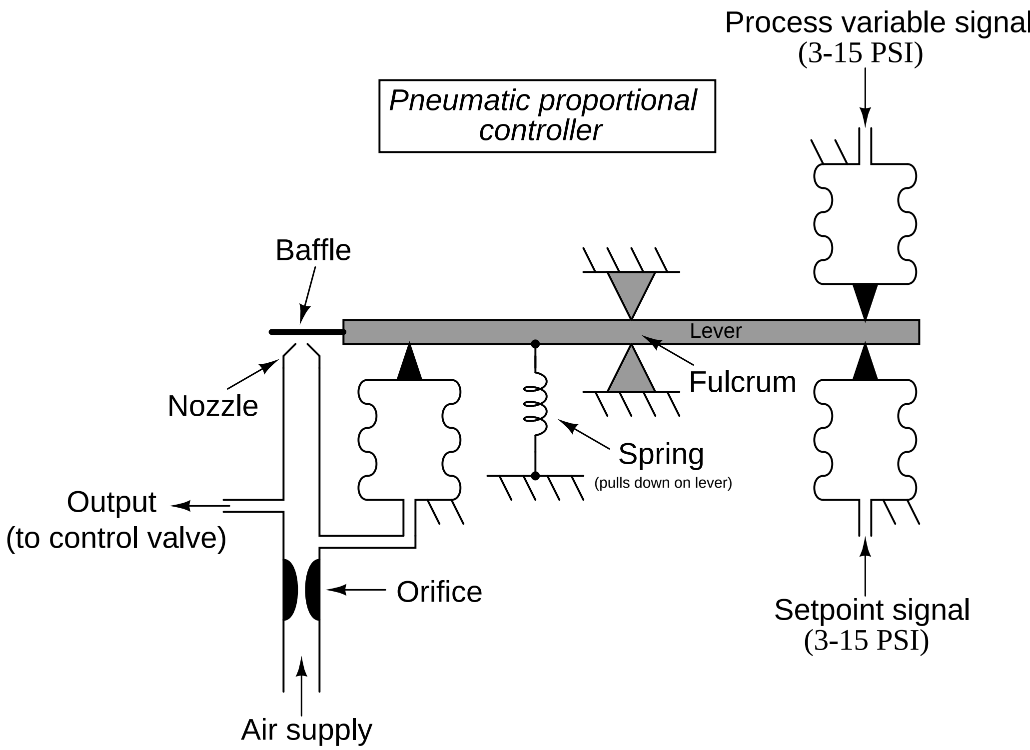


Why is this now happening, when the control used to be stable before the re-calibration? Of course, we could fix the problem by returning the transmitter's calibration back to the way it was (0 to 180^o F), but is there any way we can maintain the narrower transmitter range (100 to 180^o F) *and* yet still have stable control, or are these two goals mutually exclusive?

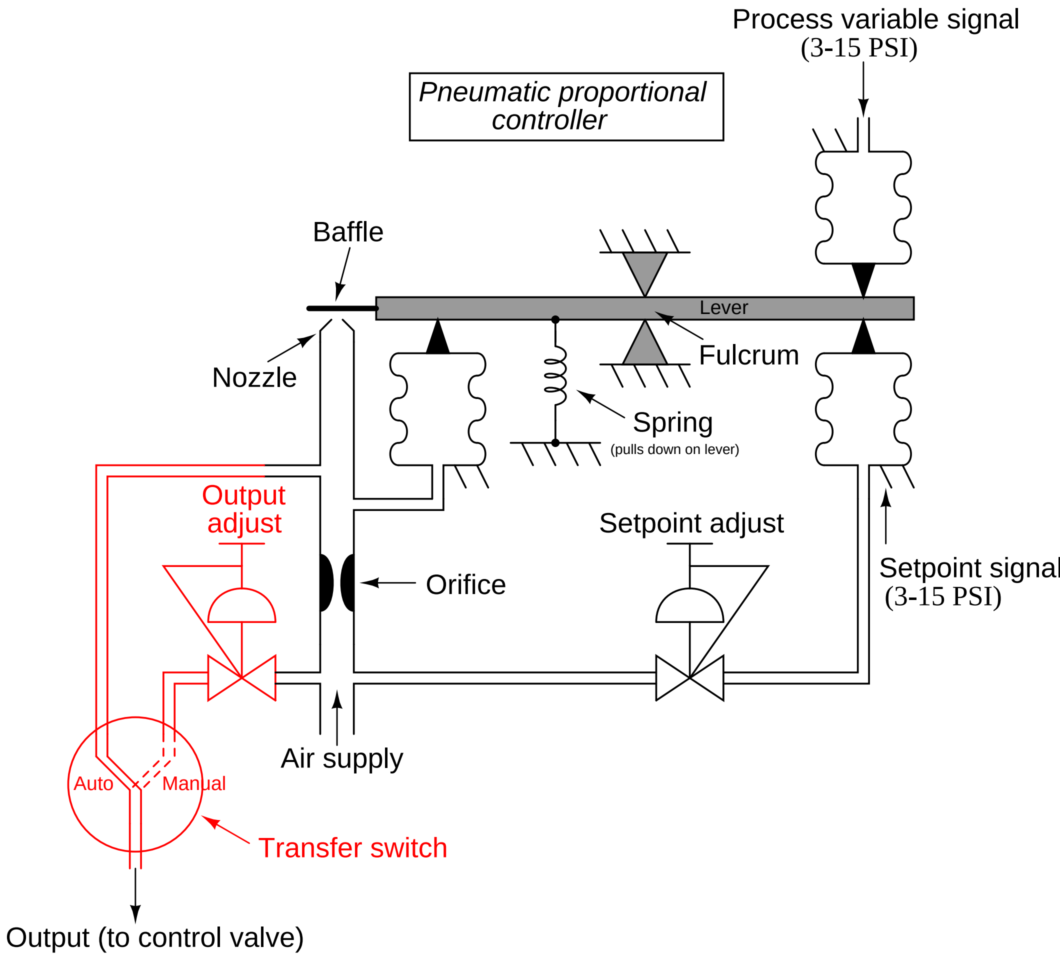
file i01477

Question 57

A simple proportional-only pneumatic controller such as the one shown below has a serious shortcoming. There is no way for an operator to "manually" take control of the process! The controller, as built, will always be in the "automatic" mode of operation:



We can give this controller manual-mode capability by adding a hand pressure regulator and a "transfer" valve:

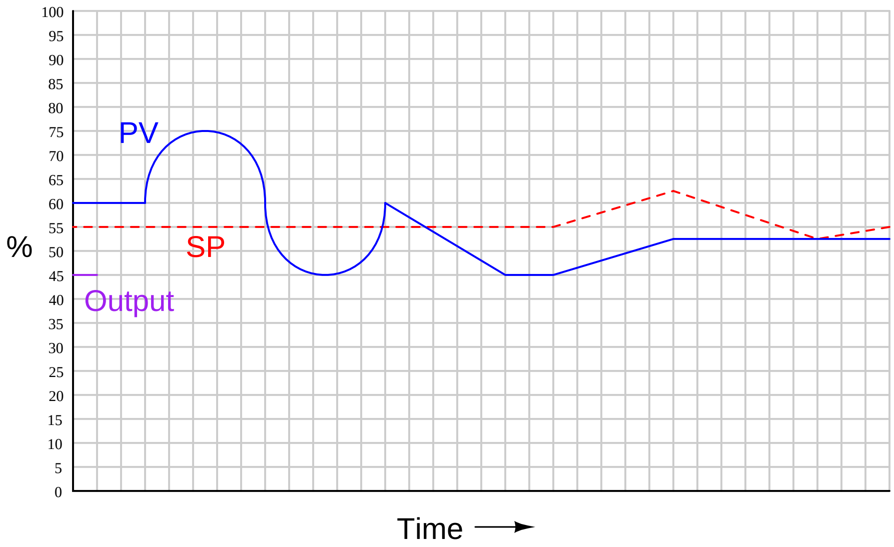


There is still a problem, though. Imagine if you were an operator, about to switch the controller from "Auto" to "Manual" mode or vice-versa. What problem would you encounter as you did this?

file i01478

Question 58

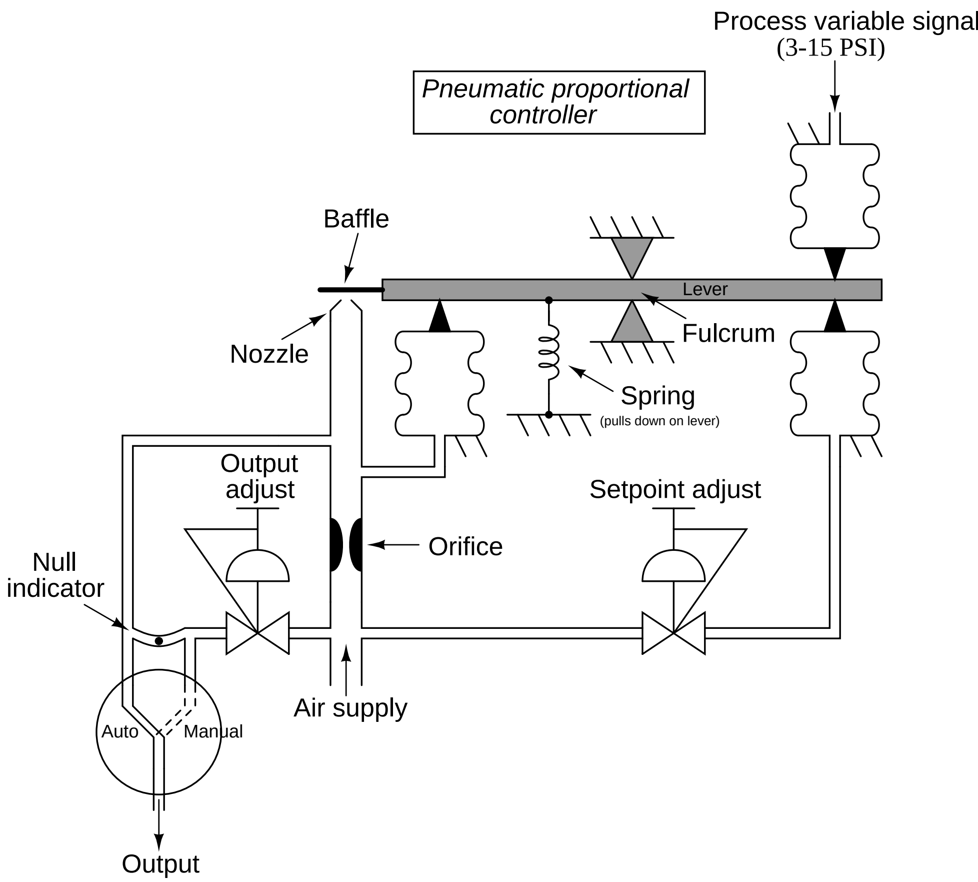
Graph the output of this proportional-only controller, assuming a proportional band value of 100% and a control action that is direct-acting:



file i01484

Question 59

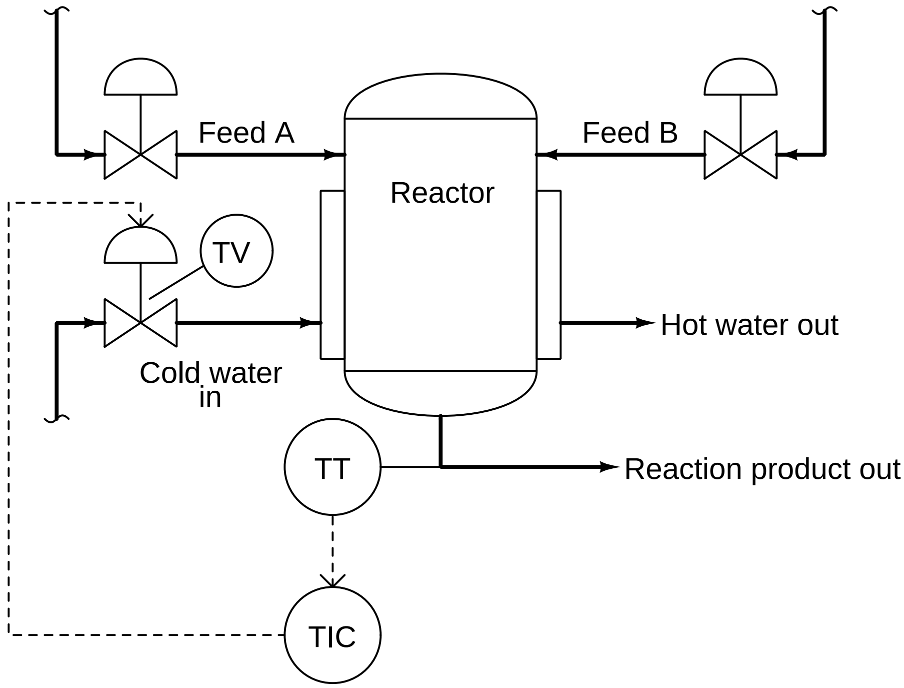
How could the following pneumatic controller mechanism be altered to make the "bias" term adjustable?



file i01480

Question 60

In this process, two chemical streams are mixed together in a reactor vessel. The ensuing chemical reaction is exothermic (heat-producing) and must be cooled by a water cooling system to prevent overheating of the vessel and piping. A temperature transmitter (TT) senses the reaction product temperature and sends a 4-20 mA signal to a temperature indicating controller (TIC). The controller then sends a 4-20 mA control signal to the temperature valve (TV) to throttle cooling water flow:



Suppose the temperature of the incoming cooling water suddenly increases. That is, the cool water available to cool the exothermic process is not as cool as it used to be. Describe in detail the effect this change in conditions will have on the performance of the cooling system.

Suggestions for Socratic discussion

- Is this process in danger of over- or under-heating from this change in cooling water temperature?
- How hot do you think the cooling water can get before the control system simply fails to function?
- If the control valve is signal-to-open, and the transmitter is direct-acting, does the controller need to be direct-acting or reverse-acting?

file i02930

Question 61

Read and outline the introduction to the "Analog Electronic PID Controllers" section of the "Closed-Loop Control" chapter in your *Lessons In Industrial Instrumentation* textbook.

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) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

file i04266

Question 62

Read and outline the "Proportional Control Action" subsection of the "Analog Electronic PID Controllers" section of the "Closed-Loop Control" chapter in your *Lessons In Industrial Instrumentation* textbook.

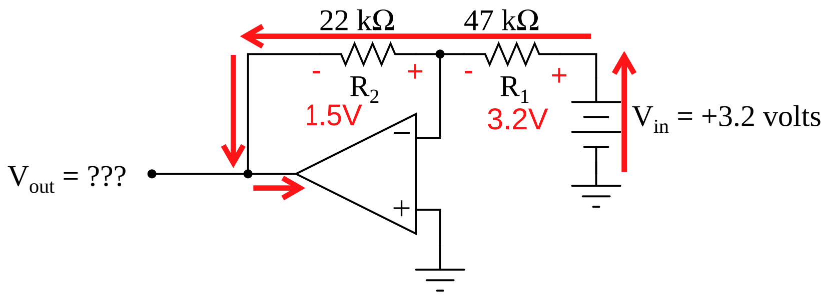
After closely reading and outlining a text, you should be ready to share the following with your classmates and instructor:

(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) Questions of your own you would pose to another reader, to challenge their understanding.
(5) Ideas for experiments that could be used to either demonstrate some concept applied in the text, or disprove a related misconception.
(6) Any points of confusion, and precisely why you found the text confusing.

file i04267

Question 63

Calculate all voltage drops and currents in this circuit, complete with arrows for current direction and polarity markings for voltage polarity. Then, calculate the overall voltage gain of this amplifier circuit (A_V), both as a ratio and as a figure in units of decibels (dB):



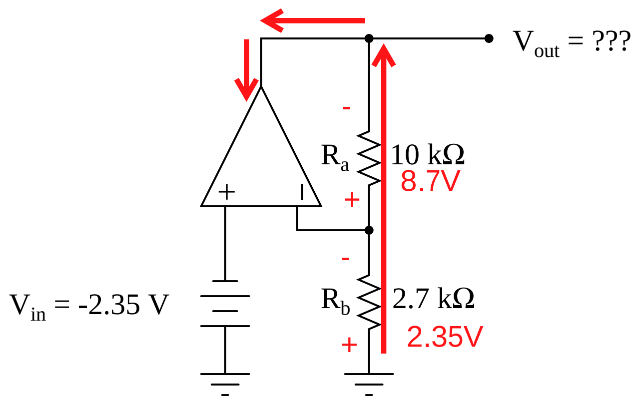
Suggestions for Socratic discussion

- Identify the "simplifying assumptions" we generally use when analyzing DC opamp circuits. Hint: one has to do with the effect of negative feedback on the input voltages, and another has to do with the input terminal currents.
- Trace the direction of current at the opamp's output terminal, and determine whether the opamp is *sourcing* current or *sinking* current.
- Explain how this circuit would respond if the 22 kΩ resistor failed open.
- Explain how this circuit would respond if the 22 kΩ resistor failed shorted.
- Explain how this circuit would respond if the 47 kΩ resistor failed open.
- Explain how this circuit would respond if the 47 kΩ resistor failed shorted.
- Explain how this circuit would respond if the (+) and (−) opamp inputs were swapped.
- Explain how this circuit would respond if the 3.2 volt battery's polarity were reversed.

file i01475

Question 64

Calculate all voltage drops and currents in this circuit, complete with arrows for current direction and polarity markings for voltage polarity. Then, calculate the overall voltage gain of this amplifier circuit (A_V), both as a ratio and as a figure in units of decibels (dB):



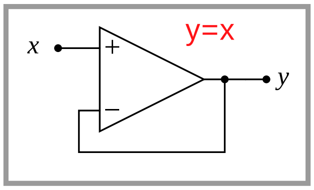
Suggestions for Socratic discussion

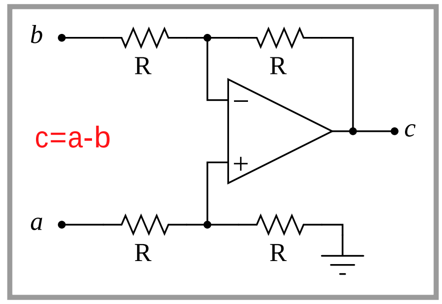
- Identify the "simplifying assumptions" we generally use when analyzing DC opamp circuits. Hint: one has to do with the effect of negative feedback on the input voltages, and another has to do with the input terminal currents.
- Trace the direction of current at the opamp's output terminal, and determine whether the opamp is *sourcing* current or *sinking* current.
- Explain how this circuit would respond if the 10 kΩ resistor failed open.
- Explain how this circuit would respond if the 10 kΩ resistor failed shorted.
- Explain how this circuit would respond if the 2.7 kΩ resistor failed open.
- Explain how this circuit would respond if the 2.7 kΩ resistor failed shorted.
- Explain how this circuit would respond if the (+) and (−) opamp inputs were swapped.

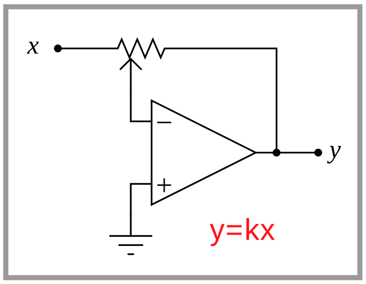
file i03261

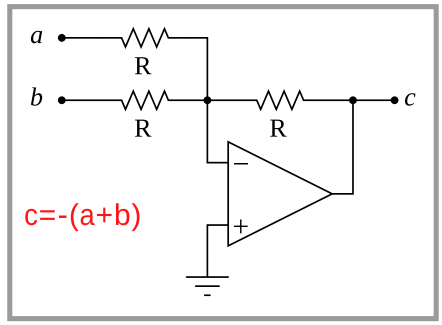
Question 65

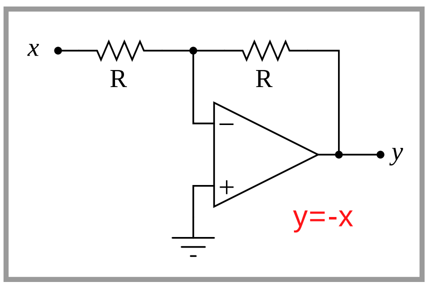
Match the following operational amplifier circuits with their respective transfer functions from the list below (note that more than six functions are listed, just to make it more challenging!):

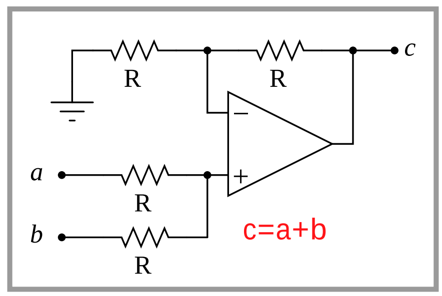












Note – all the resistors labeled R are the exact same value. The k appearing in some of the equations represents a "programmable" constant:

$y = -kx$	$c = -(a + b)$	$y = 2x$	$y = x$	$y = -x$
$c = a + b$	$y = kx$	$c = 2(a + b)$	$y = x \div k$	$c = a - b$

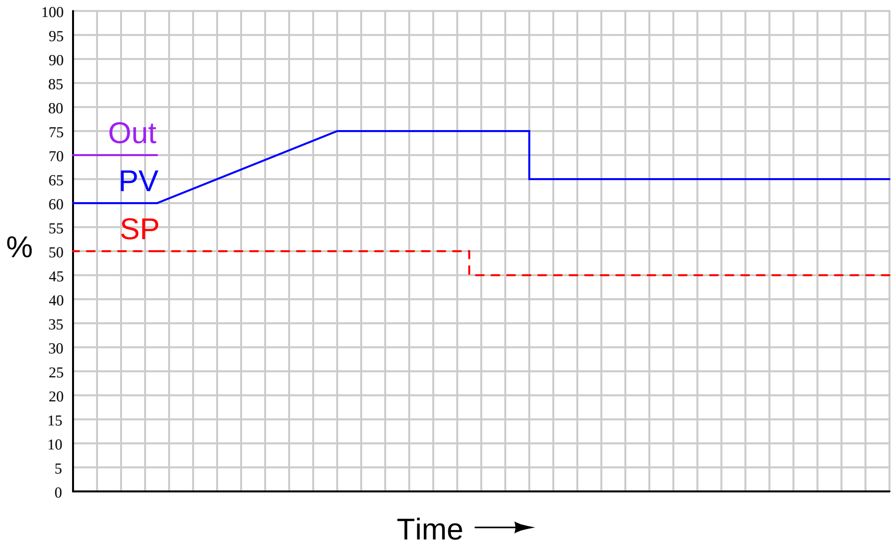
Suggestions for Socratic discussion

- Identify the "simplifying assumptions" we generally use when analyzing DC opamp circuits. Hint: one has to do with the effect of negative feedback on the input voltages, and another has to do with the input terminal currents.
- Explain **why** each circuit perform its respective mathematical function!
- Explain where the negative sign comes from in some of the circuits' equations.

file i01466

Question 66

Complete the output graph for this proportional-only controller, assuming a gain (K_p) value of 3 and a control action that is reverse-acting:



A direct method of solving for the output graph is to re-calculate the output value using the proportional controller equation ($m = K_p e + b$), at every point where there is a unique PV and/or SP value. For example, you could use the equation to calculate the output value at PV=75% and PV=65%. This involves repeated calculations, which may be tedious for a complex graph.

As an aid to doing these repeated calculations, try setting up a computer spreadsheet (e.g. Microsoft Excel) to evaluate the proportional control equation for you, and then see if you can configure the spreadsheet to produce a graph of the same PV, SP, and Output trends as well!

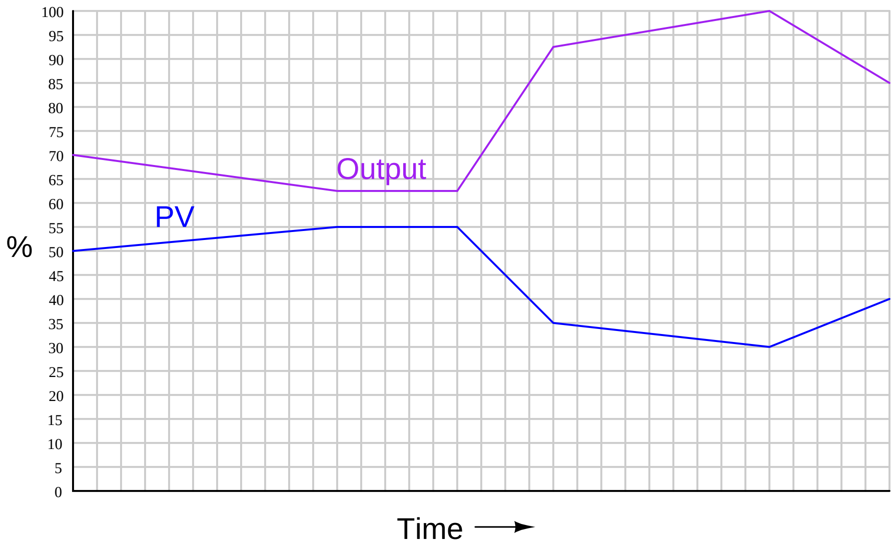
Suggestions for Socratic discussion

- Identify a way we could calculate the output trend without re-evaluating the reverse-acting controller formula, but just knowing the *gain* value of this controller.

file i03271

Question 67

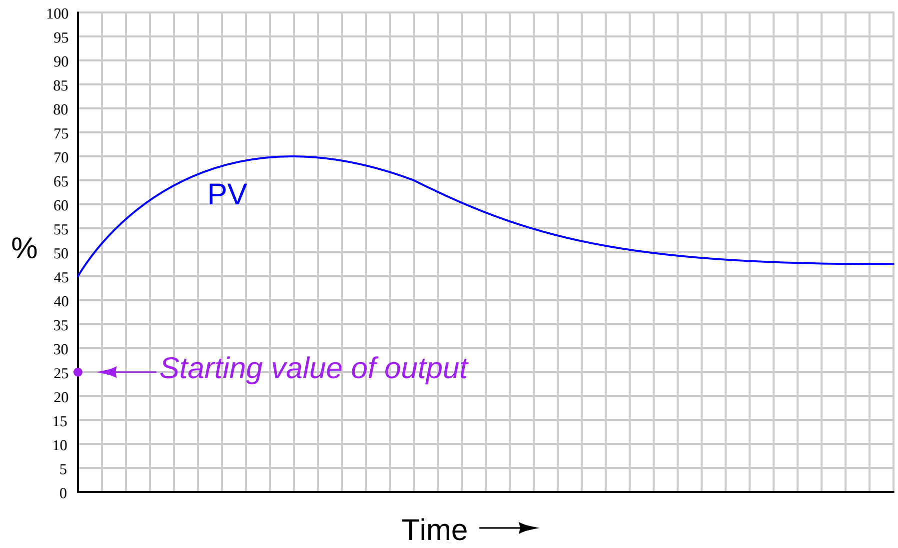
Assuming a constant setpoint, determine the proportional band setting of the proportional-only controller, as well as its control action (either *direct* or *reverse*) based on this chart recording of its behavior:



file i01499

Question 68

Graph the output of this proportional-only controller, assuming a proportional band value of 40%, a constant setpoint, and a control action that is direct-acting:



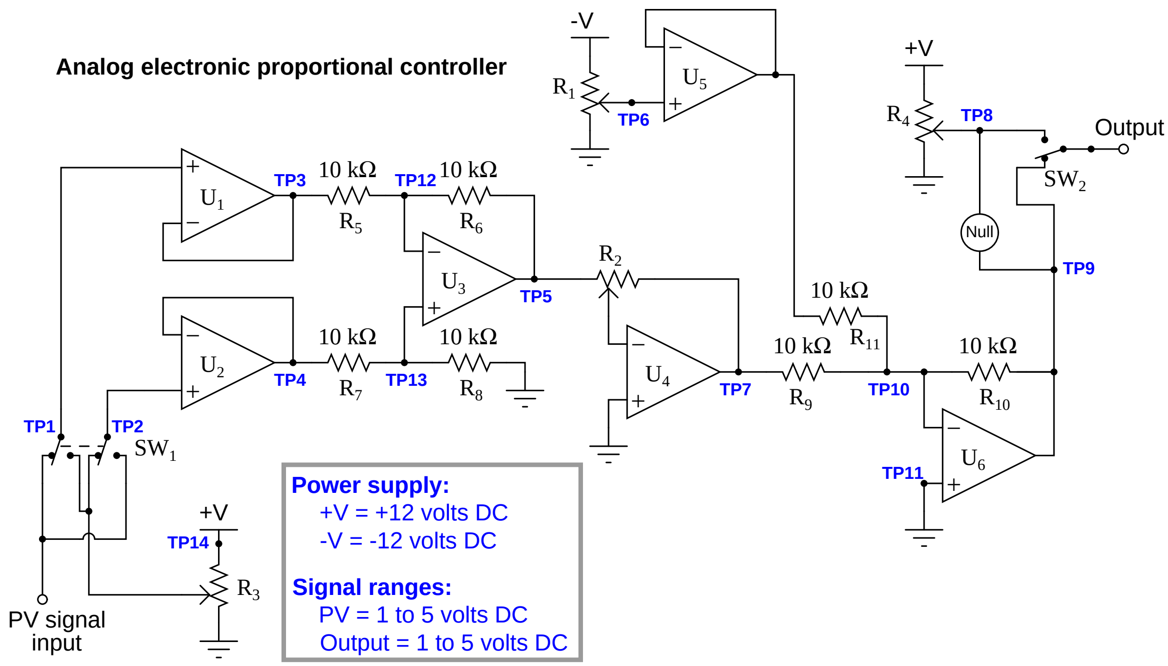
Suggestions for Socratic discussion

- Explain how it is possible to sketch an output trend without knowing the setpoint or bias values for this controller.

file i01500

Question 69

This analog electronic controller circuit has a problem. The output signal is saturated over 100% no matter what signals are input to the PV terminal, and no matter where the SP is adjusted to:



With the PV input signal at +3.00 volts and the setpoint signal at +2.58 volts, a technician measures −0.42 volts DC at test point TP5. 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
Opamp U_1 output failed to low rail		
Opamp U_4 output failed to high rail		
Opamp U_5 output failed to low rail		
R_1 connection to ground failed open		
R_3 connection to +V failed open		
Resistor R_8 failed open		
Resistor R_9 failed open		
Resistor R_{10} failed open		
Resistor R_{11} failed open		

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.

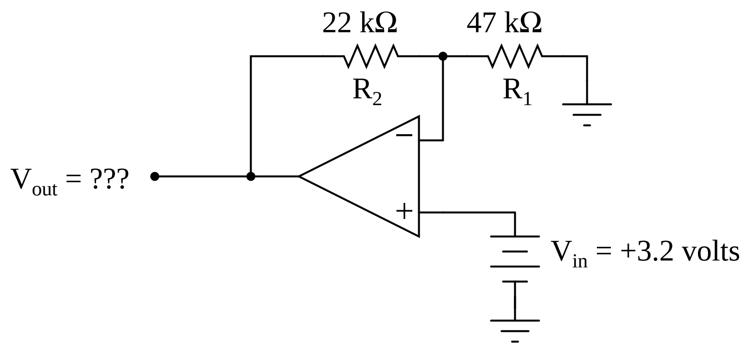
Suggestions for Socratic discussion

- Calculate the appropriate position for potentiometer R_1 in order to set the bias value of this controller to 50%.

file i01416

Question 70

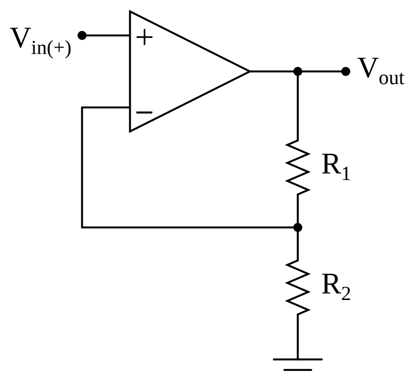
Calculate all voltage drops and currents in this circuit, complete with arrows for current direction and polarity markings for voltage polarity. Then, calculate the overall voltage gain of this amplifier circuit (A_V), both as a ratio and as a figure in units of decibels (dB):



file i01474

Question 71

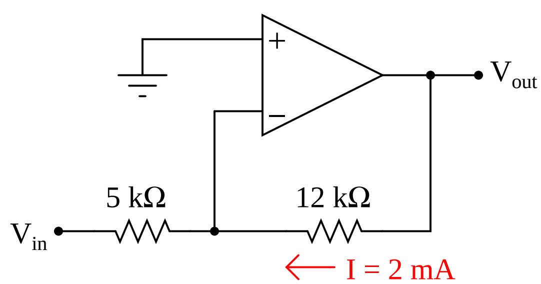
What would have to be altered in this circuit to increase its overall voltage gain?



file i03263

Question 72

Determine both the input and output voltage in this circuit:



file i03267

Question 73

The equation for voltage gain (A_V) in a typical inverting, single-ended opamp circuit is as follows:

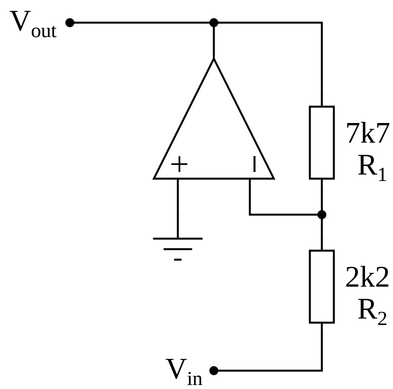
$$A_V = \frac{R_1}{R_2}$$

Where,

R_1 is the feedback resistor (connecting the output to the inverting input)

R_2 is the other resistor (connecting the inverting input to voltage signal input terminal)

Suppose we wished to change the voltage gain in the following circuit from 3.5 to 4.9, but only had the freedom to alter the resistance of R_2:



Algebraically manipulate the gain equation to solve for R_2, then determine the necessary value of R_2 in this circuit to give it a voltage gain of 4.9.

file i03268

Question 74

The equation for voltage gain (A_V) in a typical noninverting, single-ended opamp circuit is as follows:

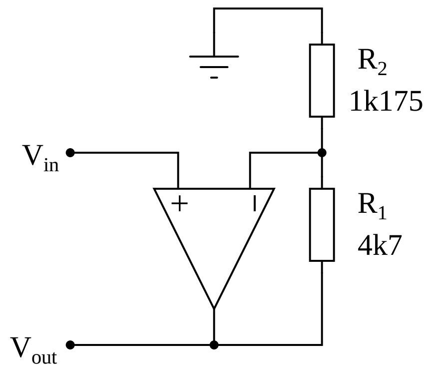
$$A_V = \frac{R_1}{R_2} + 1$$

Where,

R_1 is the feedback resistor (connecting the output to the inverting input)

R_2 is the other resistor (connecting the inverting input to ground)

Suppose we wished to change the voltage gain in the following circuit from 5 to 6.8, but only had the freedom to alter the resistance of R_2:

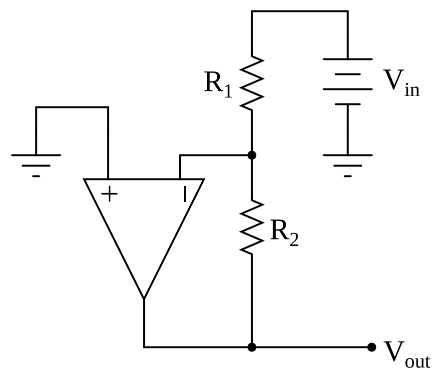


Algebraically manipulate the gain equation to solve for R_2, then determine the necessary value of R_2 in this circuit to give it a voltage gain of 6.8.

file i03264

Question 75

Predict how the operation of this operational amplifier circuit will be affected as a result of the following faults. Consider each fault independently (i.e. one at a time, no coincidental faults):



- Resistor R_1 fails open:
- Solder bridge (short) across resistor R_1:
- Resistor R_2 fails open:
- Solder bridge (short) across resistor R_2:
- Broken wire between R_1/R_2 junction and inverting opamp input:

For each of these conditions, explain *why* the resulting effects will occur.

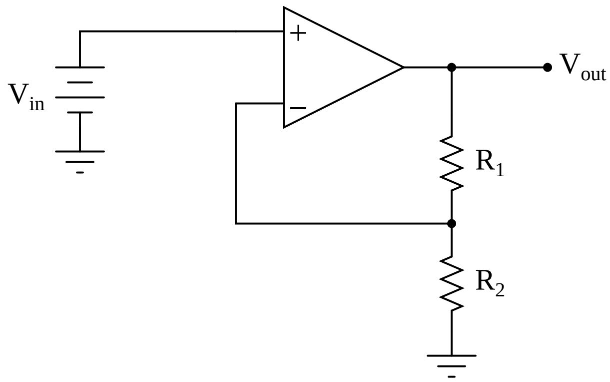
Suggestions for Socratic discussion

- When performing fault analyses of 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.

file i03269

Question 76

Predict how the operation of this operational amplifier circuit will be affected as a result of the following faults. Consider each fault independently (i.e. one at a time, no coincidental faults):

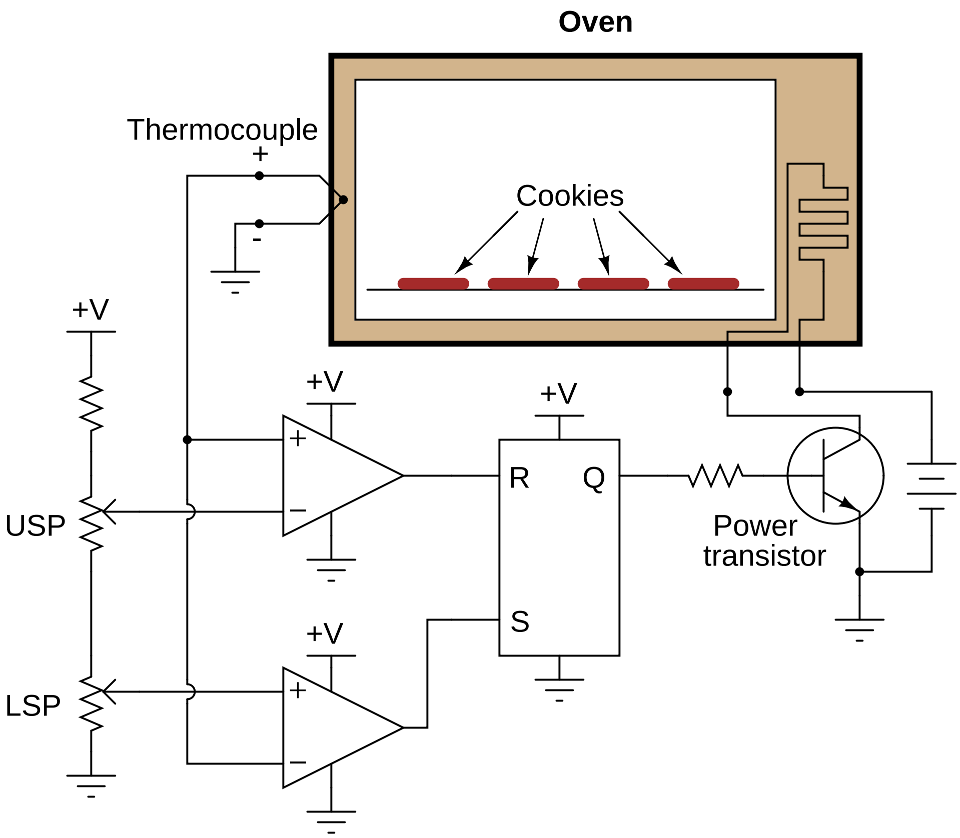


- Resistor R_1 fails open:
- Solder bridge (short) across resistor R_1:
- Resistor R_2 fails open:
- Solder bridge (short) across resistor R_2:
- Broken wire between R_1/R_2 junction and inverting opamp input:

For each of these conditions, explain *why* the resulting effects will occur.
file i03265

Question 77

Explain the operation of this control circuit, including the functions of both potentiometers, and a determination of where those potentiometers should be set to achieve the "tightest" temperature control (resulting in the closest adherence to a setpoint temperature over time). Recall that a *thermocouple* generates a small voltage proportional to temperature:



file i01451

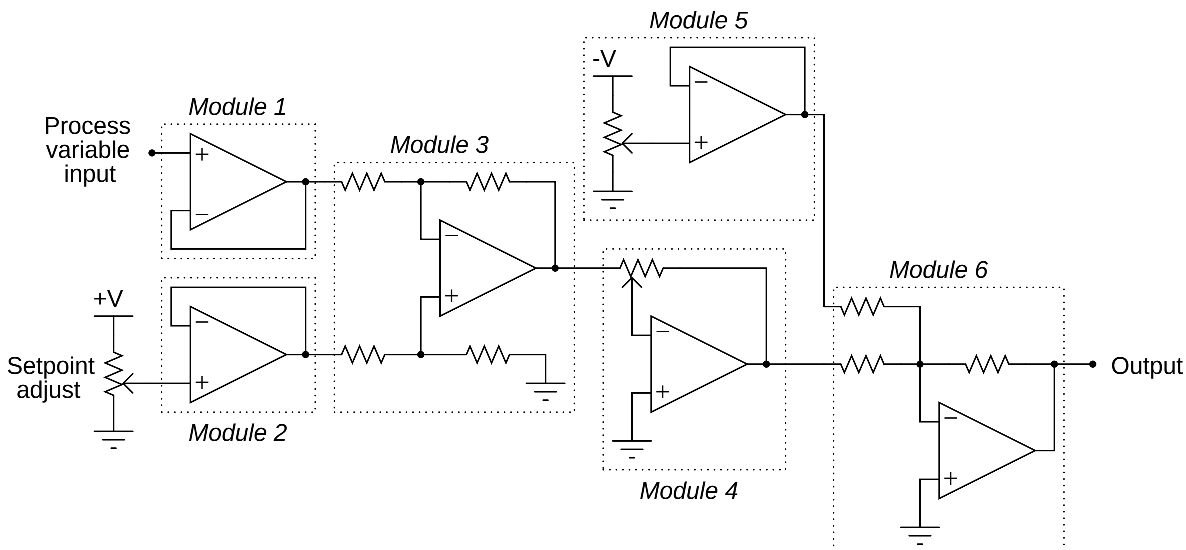
Question 78

A collection of operational amplifiers may be used to implement the following equation for a proportional controller, with each variable represented by a DC voltage:

$$m = K_p(\mathrm{SP} - \mathrm{PV}) + b$$

Where,

m = Manipulated variable (output)
K_p = Controller gain
SP = Setpoint
PV = Process variable
b = Bias



Identify which module or modules implement each portion of the proportional control equation.

- Module 1:
- Module 2:
- Module 3:
- Module 4:
- Module 5:
- Module 6:

Also, identify whether this is a *direct-acting* or a *reverse-acting* controller.

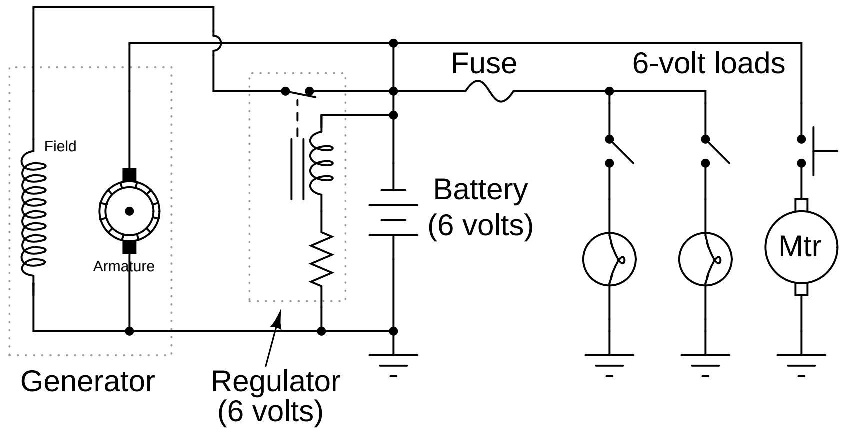
Suggestions for Socratic discussion

- Demonstrate how you may apply the problem-solving technique of using a *thought experiment* to determine whether this controller is direct or reverse acting.
- Randomly choose any one resistor in this controller circuit and imagine that resistor failing either *open* or *shorted*. Then, explain the effects of that fault on the output signal of the controller.

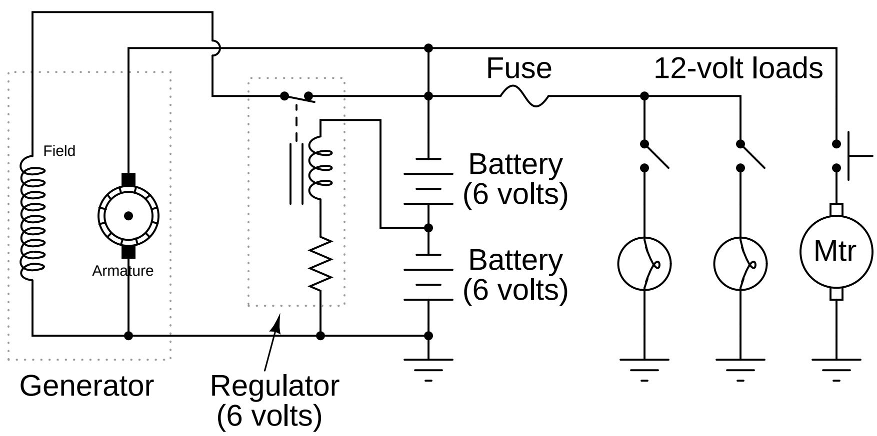
file i01465

Question 79

A mechanic has an idea for upgrading the electrical system in an automobile originally designed for 6 volt operation. He wants to upgrade the 6 volt headlights, starter motor, battery, etc, to 12 volts, but wishes to retain the original 6-volt generator and regulator. Shown here is the original 6-volt electrical system:



The mechanic's plan is to replace all the 6-volt loads with 12-volt loads, and use two 6-volt batteries connected in series, with the original (6-volt) regulator sensing voltage across only one of those batteries:

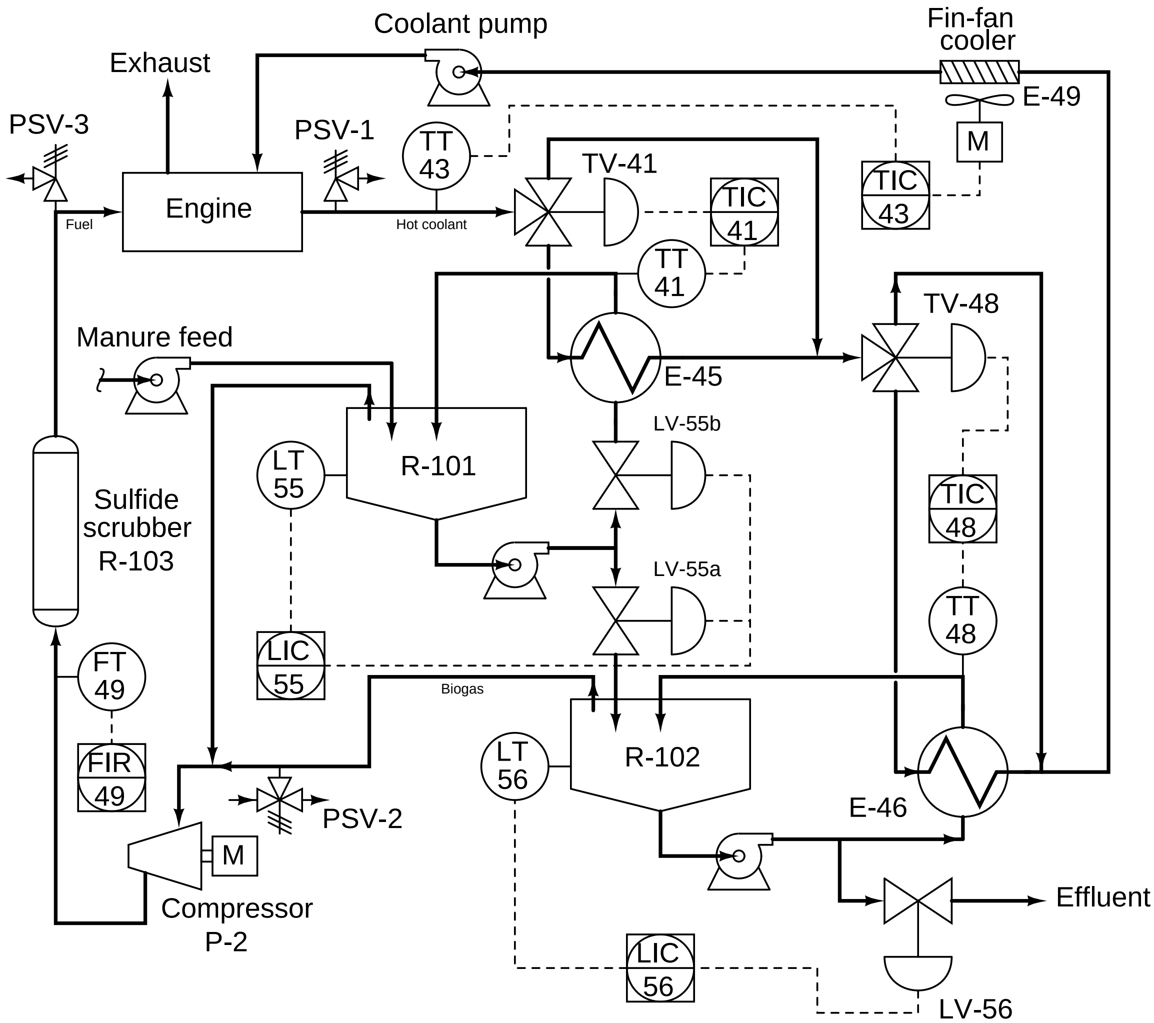


Explain how this system is supposed to work. Do you think the mechanic's plan is practical, or are there any problems with it?

file i02651

Question 80

In this biogas generation system, cow manure is used as a feedstock to produce methane gas (CH_4), which is then used to fuel an engine to turn a generator and make electricity. The waste heat from the engine is used to maintain the cascaded digesters ("reactors" R-101 and R-102) at optimal temperatures for anaerobic bacteria to digest the manure and produce biogas (approximately 105 ^{o}F):



Suppose digester R-102 is found to be at only 97 ^{o}F as indicated by a thermometer placed inside R-102 by an operator, even though temperature indicating controller TIC-48 shows the temperature at the outlet of the heat exchanger to be right at setpoint: 105 ^{o} F. An instrument technician checks the calibration of TT-48 and finds it to be within ± 1% of range (50 to 150 ^{o}F). Identify a probable cause for low temperature in R-102, and also how you would proceed to diagnose the process problem.

Suggestions for Socratic discussion

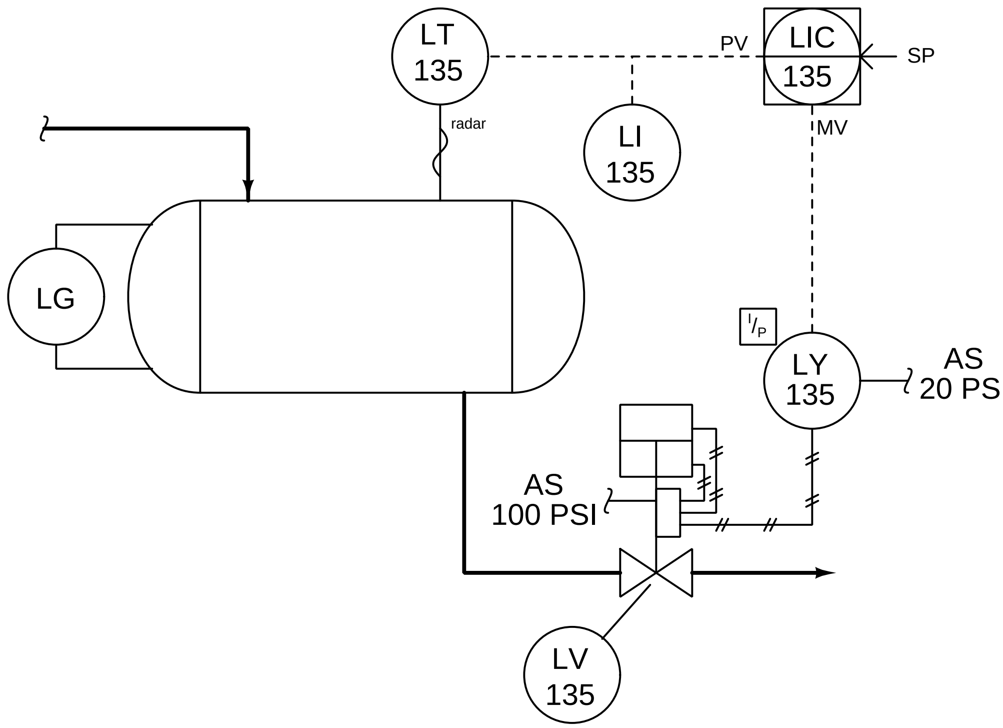
- Is there enough information provided in this P&ID to determine the proper direction of action for temperature controller TIC-48? Why or why not?
- Is there enough information provided in this P&ID to determine the proper direction of action for temperature controller TIC-43? Why or why not?

- Suppose an engineer suggested the reactor vessels be heated by electric heating elements, powered by an electric generator turned by the engine. Do you think this is a better or worse idea than using heat from the engine's coolant loop? Explain why or why not.
- For those who have studied control valve sequencing, identify the proper form of split-ranging for control valves LV-55a and LV-55b.

file i01432

Question 81

An operator calls you (the instrument technician) over to look at a liquid receiver tank. She says the tank is empty, as indicated by the sightglass level gauge (LG) on the side of the tank. This is a problem, because the level control system is supposed to maintain liquid level at the half-way (50% full) point:



The first thing you do is look at the position of the control valve, because it is located very close to the level gauge where you and the operator are standing. You can see that the control valve is wide open.

This is not a new control system. In fact, it was operating just fine a few days ago. Identify two different instrument faults that could cause this problem to occur, and explain *why* each of those faults would cause this to happen.

file i01492

Question 82

A proportional-only controller in automatic mode has the following input and output values:

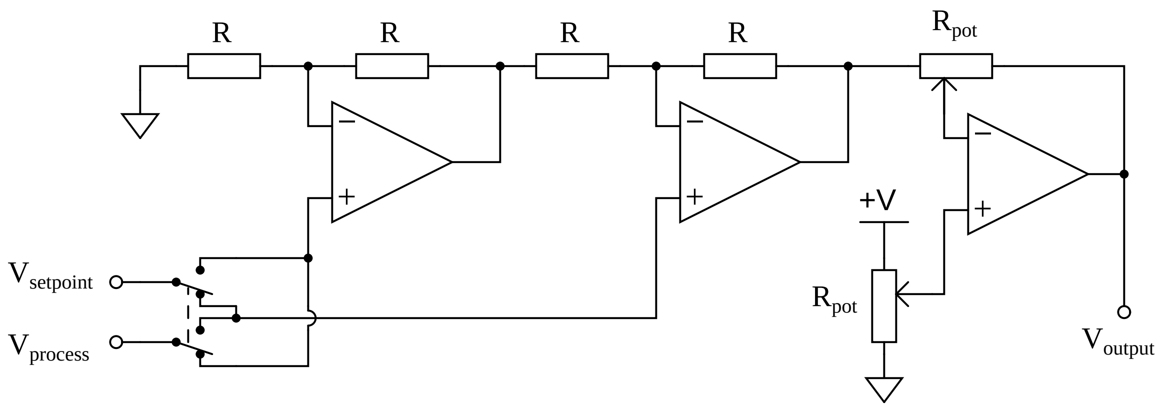
- PV = 65%
- SP = 62%
- Output = 48%

Suddenly, the operator changes the setpoint from a value of 62% to a value of 55%. The controller output immediately goes from 48% to 31%. Calculate the proportional band and the gain for this controller, and show all your work. Also, determine if this controller is *direct* or *reverse* acting.

file i01493

Question 83

Answer the following questions about this analog proportional controller circuit:

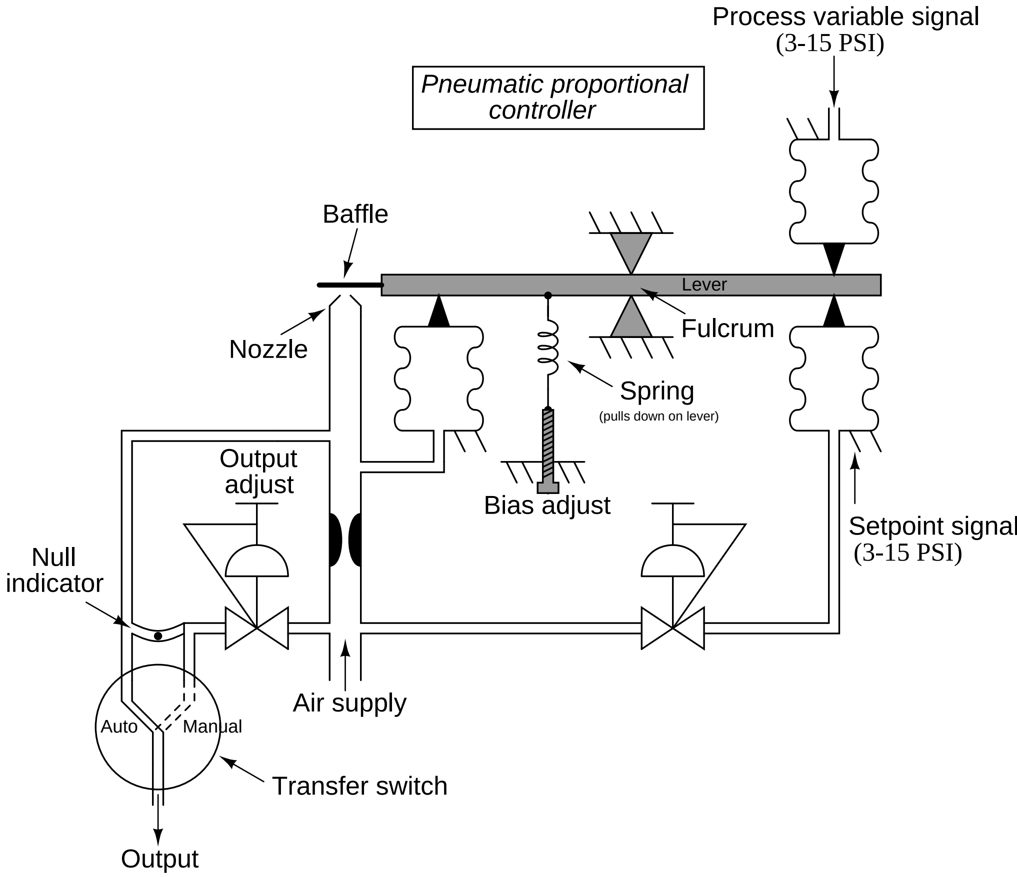


- How is the proportional band setting adjusted?
- How is the bias setting adjusted?
- Which switch position is for *direct* action and which is for *reverse* action?
- Calculate the proportional band for this circuit if all R values are precisely equal, and if both potentiometers are set in mid-position.

file i01494

Question 84

Explain what will happen (and why!) in this pneumatic proportional controller if the bias spring breaks in half:



Furthermore, explain what effect this fault would have on the process being controlled by this pneumatic controller. In other words, what will happen to the value of the process variable as a result of the bias spring breaking, assuming no adjustments are made to the controller by any person?

file i01496

Question 85

An instrument technician is troubleshooting a faulty control loop, in which the control valve does not seem to respond at all to changes in the controller's output (with the controller in manual mode). The controller is part of a distributed control system (DCS), and the control valve is a pneumatically-actuated ball valve with an electro-pneumatic positioner (Fisher model 3582i).

The technician decides to go to the control valve and test the pneumatic valve positioner by pressing the baffle (flapper) toward the nozzle with his finger. The valve does nothing, remaining in its "fail" position.

A second technician assisting the first suggests taking a measurement of loop current, to see if the controller's output signal is arriving at the electro-pneumatic positioner.

Do you agree with the second technician's suggestion? Explain your reasoning, whether for or against this next step in diagnosing the problem.

file i04269

Question 86

Examine the bulletin for the Fisher "Wizard" model 4196 pneumatic temperature indicating controller (Bulletin 34.6:4196, February 1997), especially the diagrams on page 5 showing the proportional-only control option, and answer the following questions about this controller:

- Is this controller's mechanism *force-balance* or is it *motion-balance*?

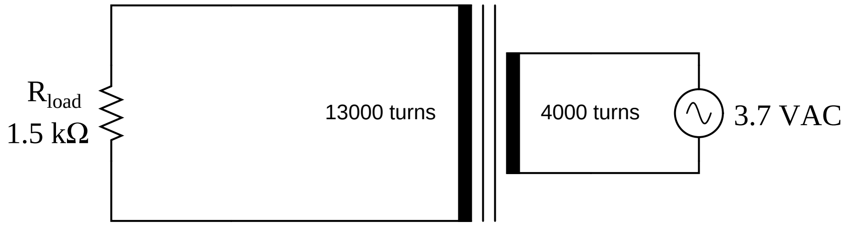
- How is "bumpless" transfer between automatic and manual modes achieved?

- The model 4196S is called a "Differential Gap" controller. Explain what this means, and how the model 4196S controller's behavior differs from that of a normal proportional-only 4196 controller.

file i03615

Question 87

Calculate all listed values for this transformer circuit:



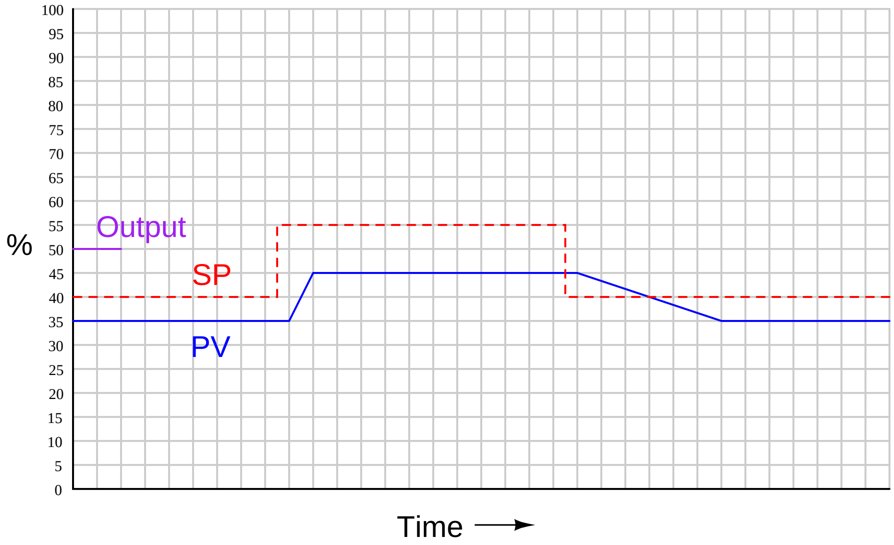
- $V_{primary}$ =
- $V_{secondary}$ =
- $I_{primary}$ =
- $I_{secondary}$ =

Explain whether this is a *step-up*, *step-down*, or *isolation* transformer, and also explain what distinguishes the "primary" winding from the "secondary" winding in any transformer.

file i01257

Question 88

Graph the output of this proportional-only controller, assuming a proportional band of 25% and a control action that is direct-acting:

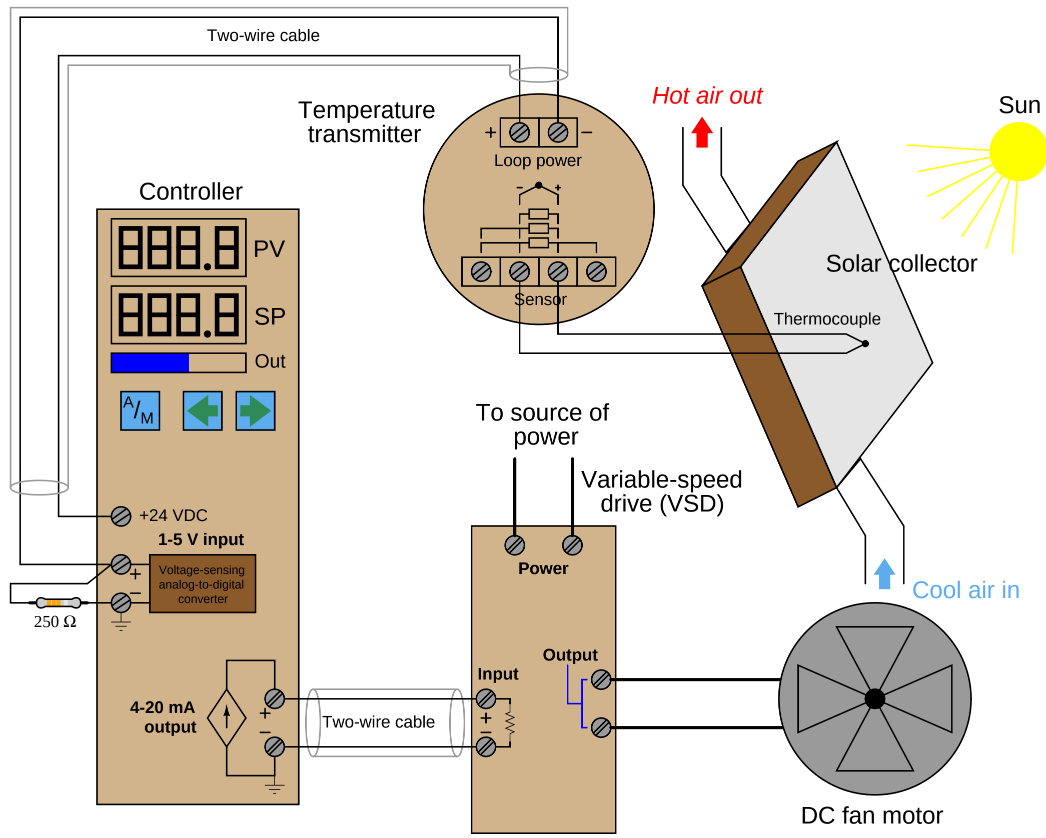


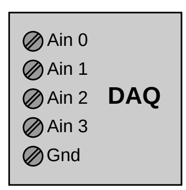
Also, calculate the *bias* value for this proportional-only controller, based on the data shown in the trend.

file i03274

Question 89

A researcher builds an experimental hot-air solar collector with a loop controller to maintain a constant interior temperature regardless of solar input:





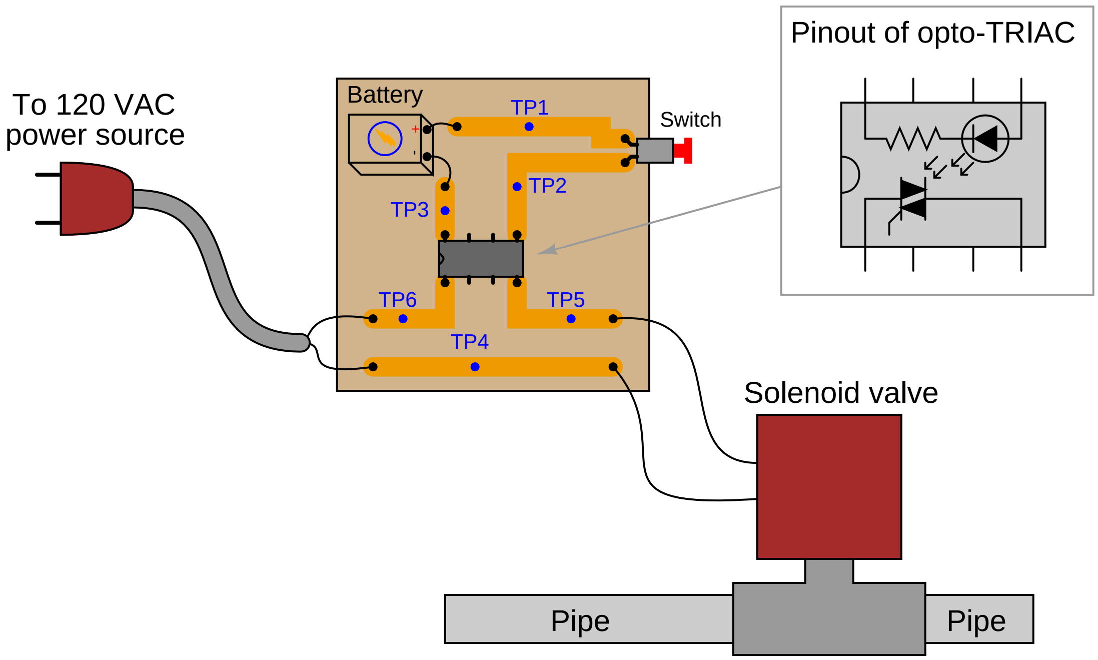
The researcher also wishes to graph the temperature and fan command signals (PV and Output) using a data acquisition module (DAQ) connecting to a personal computer. The DAQ is capable of measuring DC voltage signals ranging from 0 to +7.5 volts (single-ended), like a four-channel DC voltmeter sharing a common negative terminal.

Sketch the necessary connecting wires to allow this DAQ unit to measure the temperature signal on input Ain2 and the fan command signal on input Ain0.

file i01417

Question 90

A technician is troubleshooting a faulty optically-isolated TRIAC power switching circuit. The solenoid valve is supposed to open up and pass liquid through it whenever the pushbutton switch is pressed, but it remains shut no matter what state the switch is in:



Holding the switch in the "pressed" position with a piece of tape, the technician measures 0 volts AC between test points TP4 and TP5, and 9 volts DC (normal for the battery) between test points TP1 and TP3. Based on these voltage measurements, identify two possible faults (either one of which could account for the problem and all measured values in this circuit), and also identify two circuit elements that could not possibly be to blame (i.e. two things that you know *must* be functioning properly, no matter what else may be faulted). The circuit elements you identify as either possibly faulted or properly functioning can be wires, traces, and connections as well as components. Be as specific as you can in your answers, identifying both the circuit element and the type of fault.

- Circuit elements that are possibly faulted

1.
2.

- Circuit elements that must be functioning properly

1.
2.

file i03179

Question 91

Lab Exercise – introduction

Your task is to build, document, and calibrate a *split range* valve system with another team, where a pair of control valves are controlled by the output of a single pneumatic controller in its "manual" mode. Each control valve will use a pneumatic positioner (not an electronic positioner!) to implement the split-ranges. Each instrument in the loop should be labeled with a proper tag name (e.g. "HV-78a" and "HV-78b" for two split-ranged, hand-controlled valves), with all instruments in each loop sharing the same loop number. Write on pieces of masking tape to make simple labels for all the instruments and signal lines.

An additional objective of this lab is to properly cut, bend, and fit metal instrument tubing. Each student is to bend a length of copper or stainless-steel tubing somewhere in their pneumatic controller/valve system and demonstrate to the instructor that the tubes all fit neatly (right-angle corners, proper offsets, level and plumb). Instrument tube bending is something of an art, and requires practice to master.

The following table of objectives show what you and your team must complete within the scheduled time for this lab exercise. Note how some of these objectives are individual, while others are for the team as a whole:

Objective completion table:

Performance objective	**Grading**	**1**	**2**	**3**	**4**	**Team**
Team meeting and prototype sketch (do *first!*)	mastery	–	–	–	–	
Circuit design challenge	mastery					– – – –
Alignment of positioner to valve	mastery					– – – –
Split-range calibration (with saturation)	mastery					– – – –
Final loop diagram and system inspection	mastery					– – – –
Metal tubing properly fitted	mastery					– – – –
Demonstration of working system	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.

It is essential that your team plans ahead what to accomplish each day. A short (10 minute) team meeting at the beginning of each lab session is a good way to do this, reviewing what's already been done, what's left to do, and what assessments you should be ready for. There is a lot of work involved with building, documenting, and troubleshooting these working instrument systems!

As you and your team work on this system, you will invariably encounter problems. You should always attempt to solve these problems as a team before requesting instructor assistance. If you still require instructor assistance, write your team's color on the lab whiteboard with a brief description of what you need help on. The instructor will meet with each team in order they appear on the whiteboard to address these problems.

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.

Team meeting and prototype sketch

Read the lab exercise documentation and discuss with your teammates the objectives to be achieved and the time allotted to do so. Formulate a plan to achieve these objectives and draft a prototype design for the system you intend to build. Then, meet with your instructor to present your team's action plan and prototype design. *This prototype sketch should be annotated with all expected physical parameters (e.g. voltage polarities, current directions, fluid pressures, etc.).* Be prepared to answer all manner of questions about your team's goals, planned schedule of work, available resources, and prototype design, including analysis of the design for specific faults and condition changes. Do not begin construction until your design has been analyzed and approved! Note that multiple meetings may be required if the instructor's assistance is needed to select components influencing your design.

Circuit design challenge

Wire a VFD to a single-phase power source and a three-phase electric motor, then configure the VFD to control the starting and stopping of that motor according to criteria randomly chosen by the instructor.

Final loop diagram and system inspection

Create a complete loop diagram of your team's completed system according to the ISA 5.1 standard, then show that the constructed system meets or exceed all standards described in the lab exercise documentation.

Alignment of positioner to valve

Correctly mount, connect, and mechanically align a positioner to the control valve following all instructions given in the manufacturer's documentation.

Split-range calibration

Calibrate the positioner to fulfill its portion of the split-range scheme agreed upon by all participating teams. The positioner should be fully "saturated" at its signal end-points to ensure full valve stem travel and seat loading.

Metal tube fitting

Bent and fit a short length of metal tubing to connect two devices together, as randomly chosen by the instructor.

Demonstration of working system

Show that the control valve operates correctly over its portion of the split range, using the controller's manual mode to set the 4-20 mA "manipulated variable" signal value.

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 – team meeting, prototype sketch, and instrument selection

An important first step in completing this lab exercise is to **meet with your instructor** as a team to discuss safety concerns, team performance, and specific roles for team members. If you would like to emphasize exposure to certain equipment (e.g. use a particular type of control system, certain power tools), techniques (e.g. fabrication), or tasks to improve your skill set, this is the time to make requests of your team so that your learning during this project will be maximized.

An absolutely essential step in completing this lab exercise is to work together as a team to **sketch a prototype diagram** showing what you intend to build. This usually takes the form of a simple diagram showing all tubing used to connect pneumatic instruments together. This prototype sketch need not be exhaustive in detail, but it does need to show enough detail for the instructor to determine if all components will be correctly connected for their safe function.

You should practice good problem-solving techniques when creating your prototype sketch, such as consulting equipment manuals for information on component functions and marking directions of air flow. Use this task as an opportunity to strengthen your analytical skills! Remember that you will be challenged in this program to do all of this on your own (during "capstone" assessments), so do not make the mistake of relying on your teammates to figure this out for you – instead, treat this as a problem *you* must solve and compare your results with those of your teammates.

You team will need to install a pneumatic positioner on a control valve, and then split-range this positioner in conjunction with another team's valve. While valves lacking positioners can be split-ranged, the task of split-ranging is greatly simplified by using a positioner because it is relatively easy to change zero and span settings. The Fisher model 3582 valve positioner is highly recommended for this lab exercise. Consult documentation from the manufacturer's website to identify how to properly mount, align, and tube the valve positioner.

The control valve should have mounting holes on its actuator assembly for receiving a positioner bracket. This metal bracket will serve as the mounting "platform" for the positioner once attached to the valve actuator. Brackets and positioners are not universal in design – that is, they are made to match each other.

Positioners act as "position controllers" for control valves, sending enough air pressure as necessary to move the valve to match the signal given by the controller's output. As controllers in their own right, positioners require a supply of compressed air to "power" them. This air supply often needs to be of a different (greater) pressure than the air supply of an I/P signal converter. For piston-actuated valves, the positioner often runs on 100 PSI compressed air, while a typical I/P converter typically runs on only 20 PSI. As always, consult the manufacturer's manual for air supply specifications.

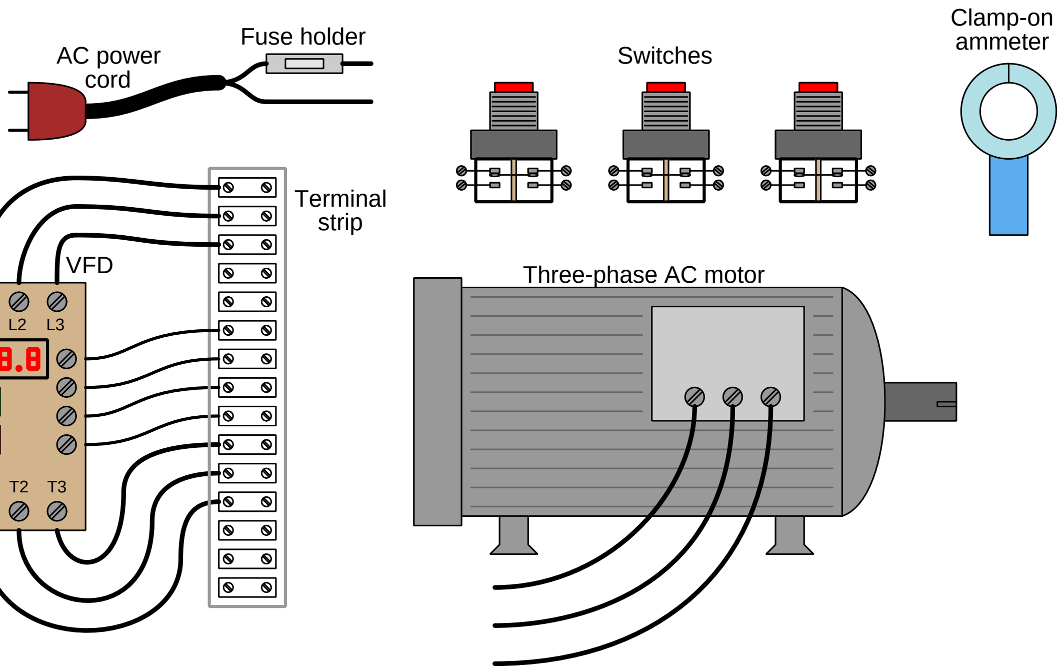
Common mistakes:

- Not checking valve stroke length for proper configuration before installing the positioner.
- Improper pipe/tube fitting installation (e.g. trying to thread tube fittings into pipe fittings and vice-versa).
- Applying Teflon tape to tube fitting threads; failing to apply Teflon tape to pipe fitting threads.

Lab Exercise – circuit design challenge

Connect a variable-frequency motor drive (VFD) to a source of single-phase 120 VAC power and a three-phase electric motor, then demonstrate remote start and stop control over that motor using two or more switches. The motor's speed control will be set by the knob or buttons (keypad) on the VFD, and the motor's acceleration/deceleration rates will be configured for gentle starts and stops. All electrical connections must be made using a terminal strip (no twisted wires, crimp splices, wire nuts, spring clips, or "alligator" clips permitted). The 120 VAC portion of the circuit must be fused for overcurrent protection.

This exercise tests your ability to correctly wire a VFD to a power source and to a three-phase induction motor, reset VFD parameters to their default values, program correct parameters in a VFD to control it per specified criteria, and to use a clamp-on ammeter to measure motor line current.



The following components and materials will be available to you: **variable-frequency motor drive**, with input, control, and motor power wires pre-wired to a terminal strip (this reduces wear and tear on the drive's screw terminals) ; 120 VAC **power cord** with **fuse assembly** ; **three-phase electric motor** ; lengths of **hook-up wire** ; assorted **switches**, and a **clamp-on ammeter** or adapter for use with a multimeter.. You must provide your own tools and digital multimeter (DMM) as well as a copy of this page for your instructor to mark objectives.

You are not allowed to apply power to the VFD, nor start the motor. The instructor will do both, following inspections of your work.

SEQUENCE: (1) Instructor chooses control parameters; (2) You wire and test while unpowered; (3) Instructor verifies wiring is safe for energization; (4) Instructor energizes VFD for the first time and observes you resetting VFD parameters; (5) You program VFD with all necessary parameters; (6) Instructor verifies safe parameters programmed in VFD; (7) Instructor starts and stops motor; (8) You demonstrate correct use of clamp-on ammeter to measure motor line current.

Control options (instructor chooses): ____ SW1 = Forward/Stop, SW2 = Reverse/Stop
____ SW1 = Start, SW2 = Stop, SW3 = Forward/Reverse

Acceleration/Deceleration rate (instructor chooses): ____ seconds (*5 seconds minimum!*)

Maximum motor speed (instructor chooses): __________ RPM

How to reset the VFD to factory defaults (you research and describe):

Instructor inspects wiring and powers up VFD, you reset VFD ____ (completed)

Base motor parameters (from nameplate): V_{line} = __________ Volts
I_{line} = __________ Amps @ full load
Speed = __________ RPM @ 60 Hz

Instructor inspects critical VFD parameters and starts motor, you measure I_{line} ____ (completed)

Study reference: the "Variable Frequency AC Motor Drives" learning module in the *Modular Electronics Learning Project* (ModEL) collection provides general information on VFD parameters. The manual for your specific model of VFD will be absolutely necessary to reference!

Lab Exercise – aligning the positioner

Perhaps the most tedious detail in this lab exercise is properly aligning the mechanical components of the positioner such that the positioner receives accurate and linear feedback of the valve stem's position throughout the range of the control valve. Improper linkage alignment will result in non-linear valve travel (i.e. if 0% and 100% is accurate, 25%, 50% and/or 75% will not be). The manufacturer's documentation is your ultimate guide to proper alignment of the positioner-to-stem linkage.

Additionally, your positioner will likely need to have its internal components aligned with each other. For example, on the Fisher model 3582 positioner, there is a full "beam alignment" procedure which must be followed in order to ensure consistent positioning behavior throughout the range of the valve stem's travel and also throughout the range of the positioner's span adjustment.

For rotary control valves where the positioner receives its feedback from a cam follower, there is less to align than on a sliding-stem control valve. However, other internal alignments to the positioner such as the "crossover" adjustment must still be checked and adjusted. Once again, the manufacturer's documentation will step you through any and all procedures necessary.

After successful alignment, the instructor will mis-adjust the alignment to make the positioner ready for the next person to re-align it.

A detail important for both safety and time management is to make sure you do not disturb the coupling of the valve body and actuator stems when connecting the positioner to the stem. On Fisher sliding-stem valves, particularly, the stem connector bolts must be un-done to attach the positioner's feedback linkage. If the stem connector is loosened with full spring force applied to the valve seat (as is the case with any sliding-stem, air-to-open valve when no air pressure is applied), the actuator stem will slip loose and suddenly shift. This will not only hurt your fingers if they are in the way of the actuator stem when it slips, but it will also necessitate a re-setting of the coupling between the valve body and actuator stems which can be time-consuming.

To avoid this problem on air-to-open valves, first apply enough air pressure to the actuator to raise the plug off the seat and relieve the seating force before loosening the stem coupling! With the valve plug held off the seat by air pressure, you may loosen the stem coupling with no risk of harm to yourself and little risk of disturbing the coupling position.

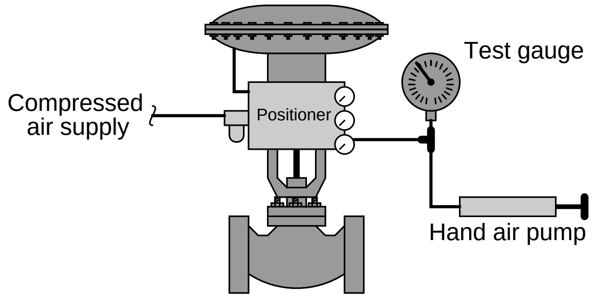
Another important safety tip is that the positioner's feedback linkage must not be adjusted while the positioner is powered and active. Remember that the positioner's function is to apply as much or as little force to the valve stem as needed to achieve the desired stem position, and the only way the positioner "knows" what that stem position is, is via the feedback linkage assembly. If you make adjustments to this feedback linkage while the positioner is powered, it will "think" the valve stem is moving when it should not, and rapidly act to re-position the valve. This is dangerous when your fingers are touching the feedback linkage, because the valve's rapid movement may pinch your fingers. Furthermore, any such adjustments will be counter-productive because the valve stem will not remain still as you are attempting to make those adjustments.

Common mistakes:

- Disturbing the valve body/actuator stem coupling by disassembling the coupling when the actuator spring pressure is still seating the plug.
- Incorrect installation and/or alignment of the linkage coupling the positioner to the valve stem: *consult the manual when installing your team's positioner to see exactly how it should attach!*
- Failing to follow all manufacturer instructions *precisely*, failing to reference figures on different pages than the text, etc.
- Attempting to adjust the feedback linkage while the positioner is powered, which is both futile and dangerous.

Lab Exercise – calibrating the positioner

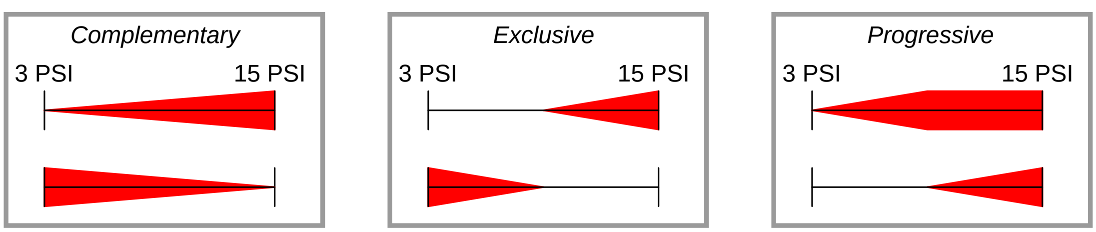
When finished installing the positioner, you should test it prior to building the rest of the loop system. Simply simulate the output signal of a pneumatic loop controller by using a hand air pump and a test gauge indicating the 3-15 PSI signal pressure:



One of the criteria for a successful positioner calibration is that the positioner must "saturate" its output pressure(s) when the valve reaches full stroke. For example, on a simple air-to-open valve calibration (i.e. 3 PSI = valve at 0% position ; 15 PSI = valve at 100% position), the positioner should saturate beyond bench-set pressure at full signal (15 PSI) and saturate at 0 PSI at minimum signal (3 PSI) to ensure full seat loading. Note that the valve's bench-set range may be completely different from the positioner's input signal range of 3-15 PSI, for example 10-30 PSI. In such applications the positioner will automatically adapt to the valve's bench set because that is what positioners do: apply as much or as little actuating pressure to the valve as necessary to move the stem to where it needs to be (as directed by the 3-15 PSI input signal). The requirement of full saturation at 3 and 15 PSI input is in addition to accurate positioning at all points between 0% and 100%.

Mechanical positioners have interactive "zero" and "span" calibration adjustments much like analog transmitters, requiring multiple adjustments to get right. Calibrating a mechanical positioner for a given range is therefore more tedious than doing so with a digital electronic "smart" positioner. As always, you should consult the manufacturer's documentation to determine the proper calibration procedure for your valve's positioner.

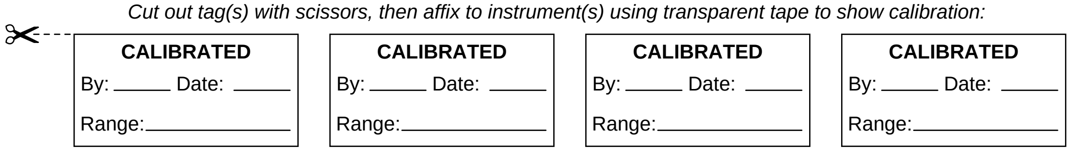
You will need to agree with the other team on a particular split-ranging scheme (e.g. complementary, exclusive, or progressive), then calibrate each valve accordingly:



Be sure to note the limitations of your team's valve when deciding on a split range: some positioners are limited in the ranges they can handle (e.g. some positioner models cannot be configured for reverse action)!

When you are done calibrating the positioner, attach a calibration tag to it:

Cut out tag(s) with scissors, then affix to instrument(s) using transparent tape to show calibration:



Common mistakes:

- Not learning about the *other* positioner (different model) in your split-range loop, but rather focusing exclusively on your team's positioner
- Incorrect supply pressure given to positioner
- Assuming the positioner's input signal pressure needs to match the actuating pressure

Installing and roughly calibrating a positioner should take no more than one full lab session (3 hours) if all components are readily available and the student is working efficiently!

Lab Exercise – building the system

The Instrumentation lab is set up to facilitate the construction of working instrument "loops," with over a dozen junction boxes, pre-pulled signal cables, and "racks" set up with 2-inch vertical pipes for mounting instruments.

After getting your prototype sketch approved by the instructor, you are cleared to begin building the split-ranged valve system. This will consist of a pneumatic loop controller placed into "manual" mode to allow direct control over the position of your team's valve as well as the valve of one more team.

There will be no transmitter installed in this loop. Feel free to use 1/4 inch plastic tubing for all pneumatic signal connections, and be sure not to exceed the rated supply pressure for any instrument.

Select a specific loop controller to act as a "hand control" station for the valves. This may be a rack-mounted pneumatic controller (e.g. Foxboro model 130) or a field-mounted pneumatic controller (e.g. Foxboro model 43AP or Fisher Multi-Trol). The controller itself should be labeled "HC-" or "HIC-" because it is a "hand" controller, allowing a human operator manual control over the valve's position.

Finally, your split-range valve system needs to have a loop number, so all instruments may be properly labeled. This loop number needs to be unique, so that another team does not label their instruments and cables the same as yours. One way to make your loop number unique is to form a two-digit number from the equivalent resistor color-code values for your teams' colors. For example, if you are the "Red" team, and the partnering team is "Blue," your loop number could be "26". The two valves will then be distinguished by suffix letters (e.g. HV-26a and HV-26b).

Common mistakes:

- Applying Teflon tape to tube fitting threads.
- Failing to apply Teflon tape to pipe fitting threads.
- Failing to properly tighten each tube connection.
- Students working on portions of the system in isolation, not sharing with their teammates what they did and how. It is important that the whole team learns all aspects of their system!

Building a functioning system from two working valves should take no more than one full lab session (3 hours) if all components are readily available and the team is working efficiently!

Lab Exercise – loop diagram and system inspection

Each team's system will undergo an inspection simulaneous with inspection of each team member's loop diagram. Team members will exchange diagrams with each other and then verify from those diagrams what the instructor sees when inspecting each and every panel and connection. *Please note that the "Lessons In Industrial Instrumentation" textbook describes good practices for construction and documentation.*

Construction Standards

- All construction must be *safe* (i.e. must not pose any unnecessary hazard to students or visitors). This includes electrical, chemical, thermal, pressure, and general safety hazards (e.g. trip hazards, cut hazards). *Unsafe construction will be dismantled upon discovery.*
- All electrical sources greater than 30 volts must be overcurrent-protected and all related wire connections must be guarded against accidental contact (e.g. use recessed terminals with no exposed metal).
- Proper use of colors for electrical power source wiring (e.g. red and black for DC + and −, black and white for AC "hot" and "neutral", green for earth ground).
- All metallic electrical enclosures must be bonded to earth ground for safety.
- Proper wire types and attachment to terminals (e.g. appropriate wire gauge for the expected current, use of stranded wire wherever possible, correct terminals crimped to ends of wires, no stray wire strands at any point).
- Attached wires must withstand being lightly pulled with fingers.
- Wire insulation must be intact (i.e. no bare wires anywhere).
- Panel wiring must be neat in appearance (e.g. all cables run directly from terminal block to nearest wire duct, with all excess wire length tucked inside wire duct).
- Wiring outside of panels should be run through conduit wherever possible.
- Correct tools must be used at all times. This includes the use of fixed-size wrenches rather than adjustable wrenches whenever possible, box-end over open-end wrenches whenever possible, and the correct type and size of screwdriver used to turn screw heads.
- All electrical components must be located to avoid exposure to liquids.
- All tube and pipe connections must be properly made (e.g. correct "swaging" of tube ends, no over- or under-tightened fittings, Teflon tape or pipe sealant used on all NPT threads).
- All manual controls (e.g. buttons, handles, knobs) must be accessible and function without undue effort.

Documentation Standards

- Loop diagrams must be drawn in accordance with ISA standard 5.1.
- Each instrument must have an appropriate ISA-standard tag name, and this tag name must be visible on the actual instrument (e.g. written on masking tape and attached to the instrument).
- Each signal cable and each signal tube must have an identifying label documented and attached. Long cables must be labeled at each end, as close to the termination points as practical.
- Each team must have its own unique loop number.
- Each instrument's (final) calibrated range must be shown.
- Each control valve's fail mode (e.g. fail-open, fail-closed) or action must be shown.
- All writing must be legible (i.e. easy for anyone to read). *Hint: large-format paper helps!*
- All instrument symbols must be appropriate to the device, function, and location. The large white-colored control panel and the DCS operator stations constitute the *main control room*. All electrical enclosures in the lab room are *auxiliary* locations, and everything else is considered a *field* location.
- Instrument functions shared within a common device must be represented by the "shared" symbol on the diagram (e.g. a controller that is part of a multi-loop control system such as a DCS). Shared controllers must have their identifying loop noted on the diagram (e.g. DCS South Loop #23).
- Any controller I/O cards must be labeled with slot number and channel number in addition to terminal numbers.

- Each location (e.g. field, junction box, control room) must be clearly delineated with vertical seperation lines on the diagram.
- Each diagram must be sufficiently detailed so that no other student will have difficulty locating components (e.g. *"Where is the controller for this loop?"*) or determining important configuration parameters (e.g. range settings).

Sample diagrams are provided in this worksheet (immediately following the lab exercise documentation), and each student is urged to use these sample diagrams as references when drafting their own. The "Lessons In Industrial Instrumentation" textbook also describes ISA-standard documentation practices.

Common mistakes:

- Incorrect tag name format, using letters that do not conform to the ISA 5.1 standard (e.g. including "PLC" or "DCS" in a controller's tag name).
- Forgetting that every instrument's tag name in a loop must begin with the same letter, and that this first letter represents the process variable being measured/controlled.
- Forgetting to label all field instruments with their own tag names (e.g. AT-83).
- Failing to label termination points (e.g. terminal block screws) *exactly* as they are labeled in real life.
- Poor use of space on the diagram paper, causing some portions of the diagram to become "crowded" rather than all components being evenly spaced. *Hint: begin your diagram by sketching the field instrument at the far left of the paper and the control room instrument at the far right of the paper, then draw all other instruments and connections in between!*
- Forgetting to label all signal wires (see example loop diagrams).
- Forgetting to note all wire colors.
- Forgetting to put your name on the loop diagram!
- Leaving junction box cables outside of wire duct, looking messy.
- Leaving wire duct covers off.
- Basing your diagram off of a team-mate's diagram, rather than closely inspecting the system for yourself.
- Not placing loop sheet instruments in the correct orientation (field instruments on the left, control room instruments on the right).

Creating and inspecting accurate loop diagrams should take no more than one full lab session (3 hours) if the team is working efficiently!

Lab Exercise – instrument tube fitting

An additional objective of this lab is learn how to properly bend instrument tubing. Each student is to bend a length of copper or stainless-steel tubing somewhere in their pneumatic controller/valve system and demonstrate to the instructor that the tubes all fit neatly (right-angle corners, proper offsets, no gradual bends, all straight sections level and plumb). Instrument tube bending is something of an art, and requires practice to master!

An ideal application for tube bending are the lines to and from a valve positioner. Alternatively, you may bend and fit tubes for the pneumatic controller's air supply line, the line connecting controller to positioner, etc. Which ever run of tubing you plan to bend, the work should be coordinated with those team members aligning and calibrating the positioner, so as to not create interference in the work schedule.

Rolls of soft copper tubing will be provided by the instructor to use in this lab exercise. Each student's tube run should be relatively short (less than 2 feet) in order to conserve the amount of tubing used. Expect to make at least two attempts when fitting your tube run!

Videos are available on the BTC Instrumentation YouTube channel showing some of the basic procedures of tube cutting, bending, and compression fitting make-up. Each team has a professional-quality 1/4-inch tube bender in their locker, to be used for this exercise. Your Instrumentation Reference also contains manuals from both Swagelok and Parker describing how instrument tube fittings work, and how to properly fit tubing.

Common mistakes:

- Applying Teflon tape or other sealant to tube fitting threads (not necessary!).
- Forgetting to apply Teflon tape or other sealant to pipe fitting threads (necessary!).
- Throwing away used tube fittings when done with the job. Remember than although tube *ferrules* cannot be re-used, the nuts and fitting bodies can!
- Over-tightening compression fittings (only 1-1/4 turns past initial contact are necessary when *first* "making-up" the tube connection!). When re-making tube connections, you need only "snug" the nut, not re-swage with another 1-1/4 turns!
- Trying to straighten a piece of tubing that has already been bent.

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:

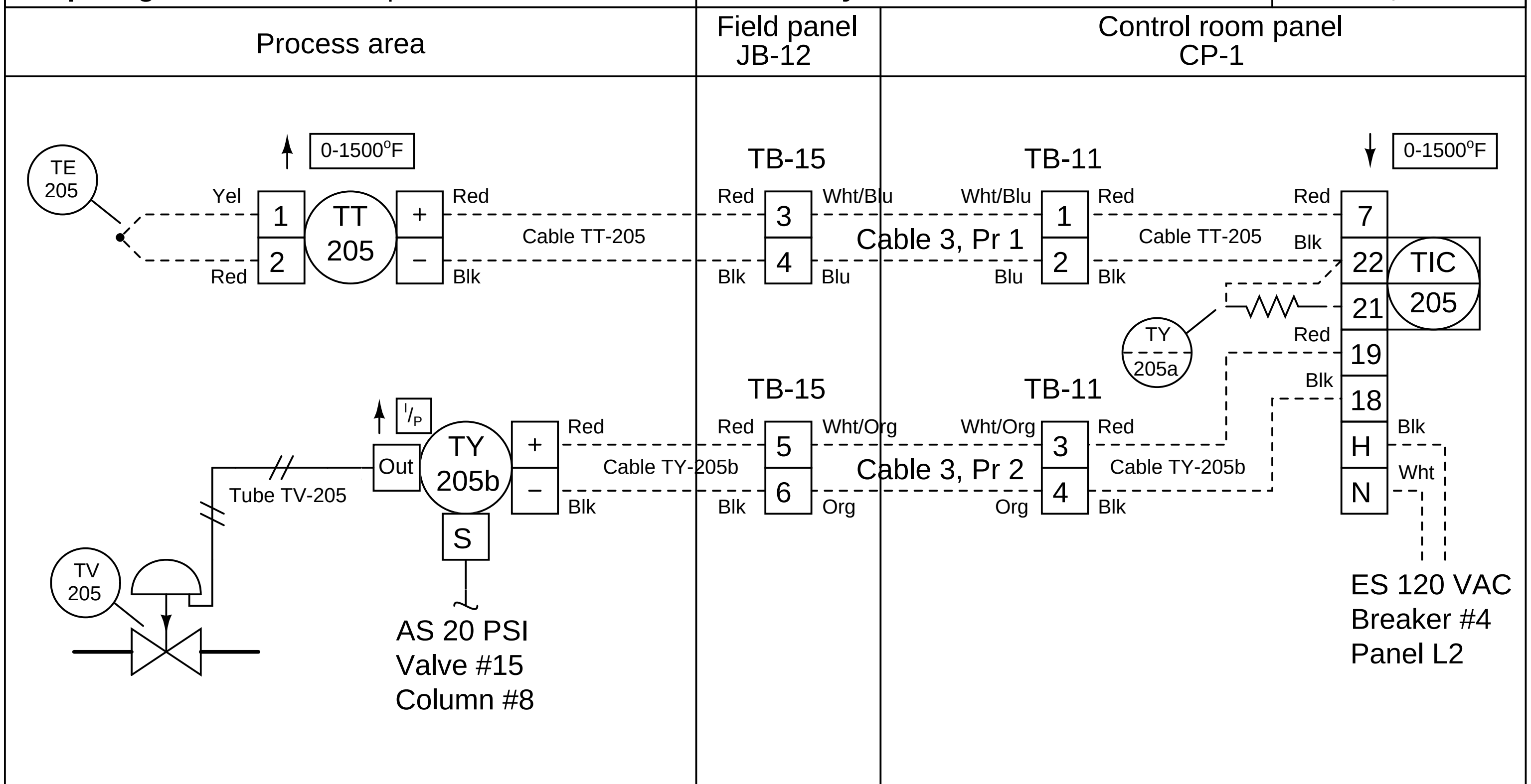
- Sensing elements (e.g. thermocouples, pH probes, etc.)
- Process transmitters
- "Jumper" cables used to connect terminal blocks within a single junction box
- Plastic tubing and tube fittings (disconnect compression-style tube fittings)
- Power cables and extension cords
- Adjustment (loading station)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

file i02584

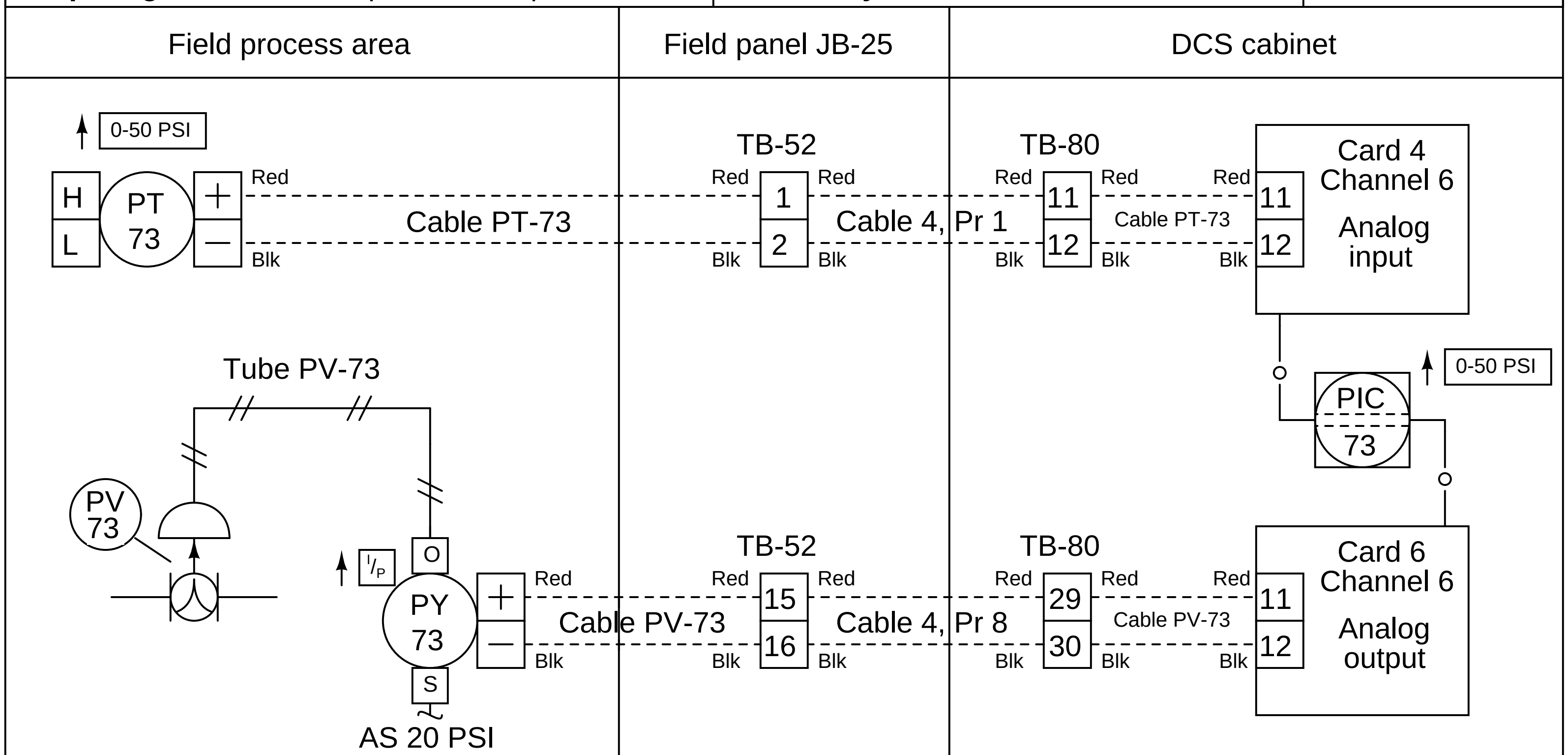
Sample Loop Diagram (using a single-loop controller)

Loop Diagram: Furnace temperature control | **Revised by:** Mason Neilan | **Date:** April 1, 2007



Tag #	Description	Manufacturer	Model	Input range	Output range	Notes
TE-205	Thermocouple	Omega			Type K	Ungrounded tip
TT-205	Temperature transmitter	Rosemount	444	0-1500° F	4-20 mA	Upscale burnout
TY-205a	Resistor	Vishay			250 Ω	
TIC-205	Controller	Siemens	PAC 353	1-5 V	0-1500° F	Reverse-acting control
TY-205b	I/P transducer	Fisher	546	4-20 mA	3-15 PSI	
TV-205	Control valve	Fisher	Easy-E	3-15 PSI	0-100%	Fail-closed

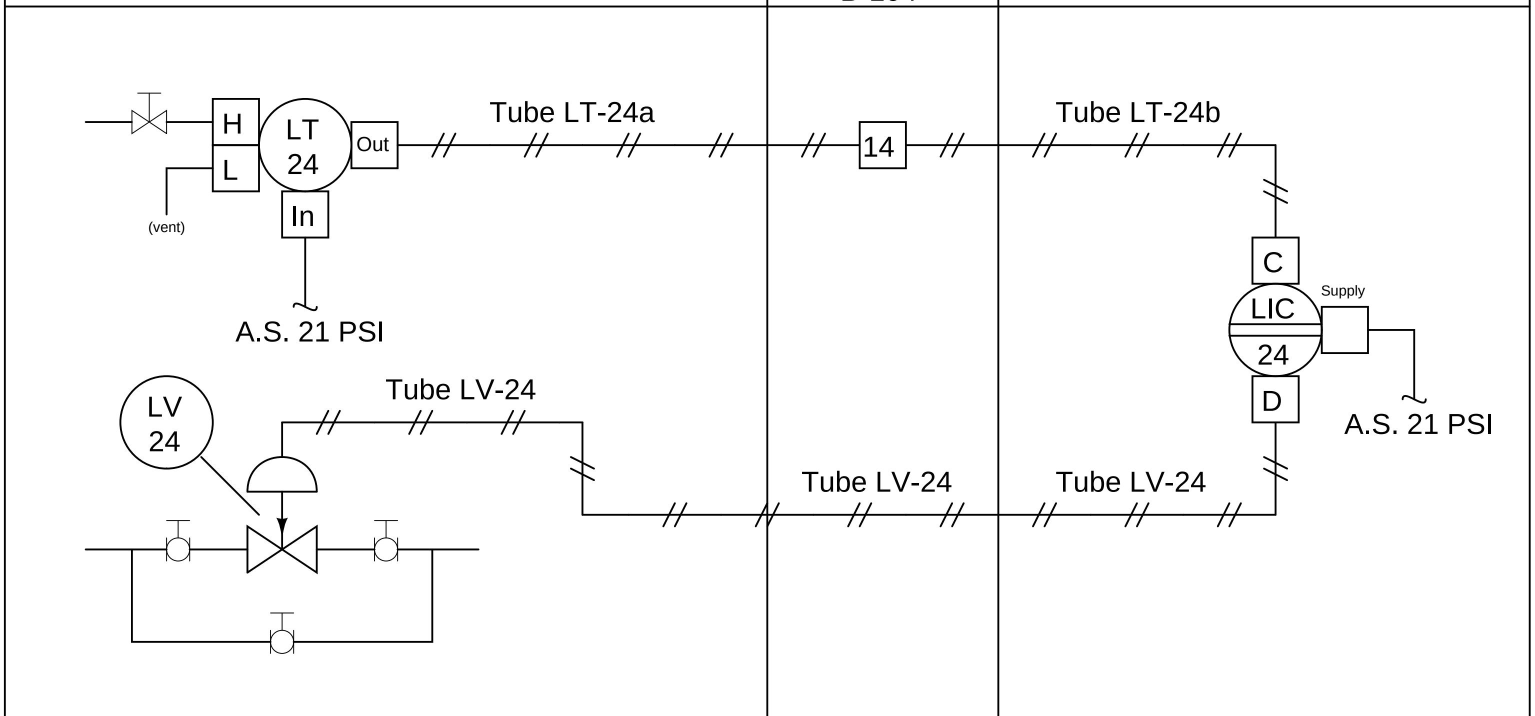
Loop Diagram: Blue team pressure loop	**Revised by:** Duncan D.V.	**Date:** April 1, 2009



Tag #	Description	Manufacturer	Model	Input range	Output range	Notes
PT-73	Pressure transmitter	Rosemount	3051CD	0-50 PSI	4-20 mA	
PIC-73	Controller	Emerson	DeltaV	4-20 mA	4-20 mA	HART-enabled input Direct-acting control
PY-73	I/P transducer	Fisher	846	4-20 mA	3-15 PSI	
PV-73	Control valve	Fisher	Vee-ball	3-15 PSI	0-100%	Fail-open

Loop Diagram: Sludge tank level control | **Revised by:** I. Leaky | **Date:** April 1, 2008

Process area	Bulkhead panel B-104	Control panel CP-11

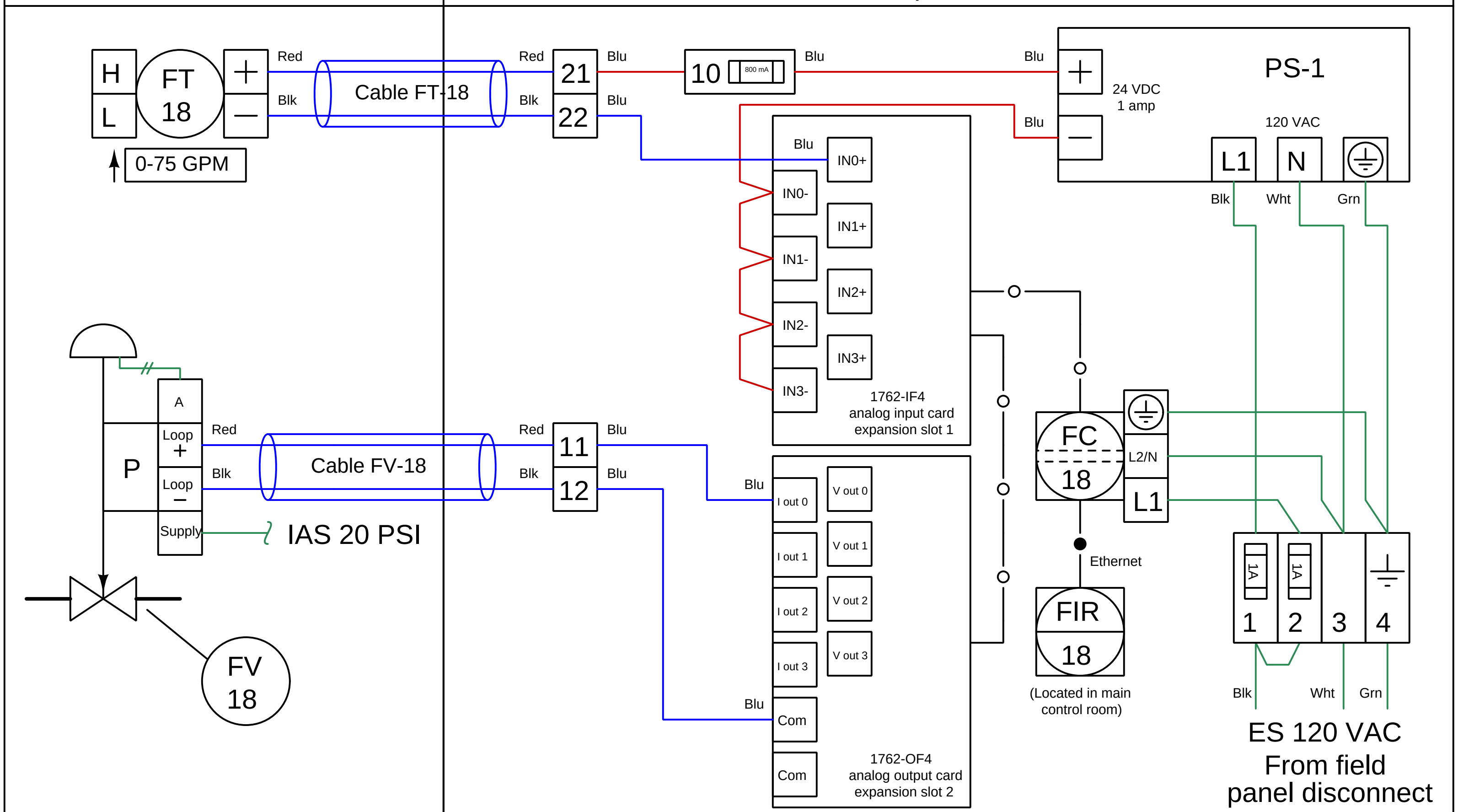


Tag #	Description	Manufacturer	Model	Input range	Output range	Notes
LT-24	Level transmitter	Foxboro	13A	25-150 "H_2O	3-15 PSI	
LIC-24	Controller	Foxboro	130	3-15 PSI	3-15 PSI	
LV-24	Control valve	Fisher	Easy-E / 667	3-15 PSI	0-100%	Fail closed

Sample Loop Diagram (using PLC, with electronic positioner installed on valve)

Loop Diagram: Unit feed flow control	**Revised by:** A. Bradley	**Date:** April 1, 2013

Process area	Field panel FP-25



Tag number	Description	Manufacturer	Model	Calibration	Notes
FT-18	Flow transmitter	Rosemount	3051S	0-100" WC input 4-20 mA output	Square-root characterization
FC-18	PLC	Allen-Bradley	ML1100	1762-IF4 input 4-20 mA 1762-OF4 output 4-20 mA	IP = 169.254.10.9 Mask = 255.255.0.0
FIR-18	HMI touch-panel	AutomationDirect	C-More		
FV-18	Flow valve with positioner	Fisher	ED / 667 DVC6010	4 mA = fully closed 20 mA = fully open	Fail-closed

Lab Exercise – loop diagram and system inspection

Each team's system will undergo an inspection simulaneous with inspection of each team member's loop diagram. Team members will exchange diagrams with each other and then verify from those diagrams what the instructor sees when inspecting each and every panel and connection. *Please note that the "Lessons In Industrial Instrumentation" textbook describes good practices for construction and documentation.*

Construction Standards

- All construction must be *safe* (i.e. must not pose any unnecessary hazard to students or visitors). This includes electrical, chemical, thermal, pressure, and general safety hazards (e.g. trip hazards, cut hazards). *Unsafe construction will be dismantled upon discovery.*
- All electrical sources greater than 30 volts must be overcurrent-protected and all related wire connections must be guarded against accidental contact (e.g. use recessed terminals with no exposed metal).
- Proper use of colors for electrical power source wiring (e.g. red and black for DC + and −, black and white for AC "hot" and "neutral", green for earth ground).
- All metallic electrical enclosures must be bonded to earth ground for safety.
- Proper wire types and attachment to terminals (e.g. appropriate wire gauge for the expected current, use of stranded wire wherever possible, correct terminals crimped to ends of wires, no stray wire strands at any point).
- Attached wires must withstand being lightly pulled with fingers.
- Wire insulation must be intact (i.e. no bare wires anywhere).
- Panel wiring must be neat in appearance (e.g. all cables run directly from terminal block to nearest wire duct, with all excess wire length tucked inside wire duct).
- Wiring outside of panels should be run through conduit wherever possible.
- Correct tools must be used at all times. This includes the use of fixed-size wrenches rather than adjustable wrenches whenever possible, box-end over open-end wrenches whenever possible, and the correct type and size of screwdriver used to turn screw heads.
- All electrical components must be located to avoid exposure to liquids.
- All tube and pipe connections must be properly made (e.g. correct "swaging" of tube ends, no over- or under-tightened fittings, Teflon tape or pipe sealant used on all NPT threads).
- All manual controls (e.g. buttons, handles, knobs) must be accessible and function without undue effort.

Documentation Standards

- Loop diagrams must be drawn in accordance with ISA standard 5.1.
- Each instrument must have an appropriate ISA-standard tag name, and this tag name must be visible on the actual instrument (e.g. written on masking tape and attached to the instrument).
- Each signal cable and each signal tube must have an identifying label documented and attached. Long cables must be labeled at each end, as close to the termination points as practical.
- Each team must have its own unique loop number.
- Each instrument's (final) calibrated range must be shown.
- Each control valve's fail mode (e.g. fail-open, fail-closed) or action must be shown.
- All writing must be legible (i.e. easy for anyone to read). *Hint: large-format paper helps!*
- All instrument symbols must be appropriate to the device, function, and location. The large white-colored control panel and the DCS operator stations constitute the *main control room*. All electrical enclosures in the lab room are *auxiliary* locations, and everything else is considered a *field* location.
- Instrument functions shared within a common device must be represented by the "shared" symbol on the diagram (e.g. a controller that is part of a multi-loop control system such as a DCS). Shared controllers must have their identifying loop noted on the diagram (e.g. DCS South Loop #23).
- Any controller I/O cards must be labeled with slot number and channel number in addition to terminal numbers.

- Each location (e.g. field, junction box, control room) must be clearly delineated with vertical seperation lines on the diagram.
- Each diagram must be sufficiently detailed so that no other student will have difficulty locating components (e.g. *"Where is the controller for this loop?"*) or determining important configuration parameters (e.g. range settings).

Sample diagrams are provided in this worksheet (immediately following the lab exercise documentation), and each student is urged to use these sample diagrams as references when drafting their own. The "Lessons In Industrial Instrumentation" textbook also describes ISA-standard documentation practices.

Common mistakes:

- Incorrect tag name format, using letters that do not conform to the ISA 5.1 standard (e.g. including "PLC" or "DCS" in a controller's tag name).
- Forgetting that every instrument's tag name in a loop must begin with the same letter, and that this first letter represents the process variable being measured/controlled.
- Forgetting to label all field instruments with their own tag names (e.g. AT-83).
- Failing to label termination points (e.g. terminal block screws) *exactly* as they are labeled in real life.
- Poor use of space on the diagram paper, causing some portions of the diagram to become "crowded" rather than all components being evenly spaced. *Hint: begin your diagram by sketching the field instrument at the far left of the paper and the control room instrument at the far right of the paper, then draw all other instruments and connections in between!*
- Forgetting to label all signal wires (see example loop diagrams).
- Forgetting to note all wire colors.
- Forgetting to put your name on the loop diagram!
- Leaving junction box cables outside of wire duct, looking messy.
- Leaving wire duct covers off.
- Basing your diagram off of a team-mate's diagram, rather than closely inspecting the system for yourself.
- Not placing loop sheet instruments in the correct orientation (field instruments on the left, control room instruments on the right).

Creating and inspecting accurate loop diagrams should take no more than one full lab session (3 hours) if the team is working efficiently!

file i00654

Answer 1

Answer 2

Force at large piston = 100 pounds. Fluid pressure = 2.5 PSI.

Pascal's principle states that any pressure applied to a contained fluid will be experienced at all points throughout that fluid. Thus, pressure generated by the 25 lb of force on the small piston creates a pressure (2.5 PSI) distributed throughout the fluid's volume which is experienced in full at the large piston to create the 100 lb force there.

The 5 inch dimension is extraneous information, included for the purpose of challenging students to identify whether or not information is relevant to solving a particular problem.

Answer 3

With no nozzle on the end of the hose, the end may be raised a maximum of 184.54 feet. With a nozzle in place, the hose end may be raised only 115.33 feet.

Essentially, this is just another pressure unit conversion problem: in this case, PSI-to-feet of water column. 80 PSI is equivalent to 184.54 feet, so that is how high 80 PSI can force a column of water.

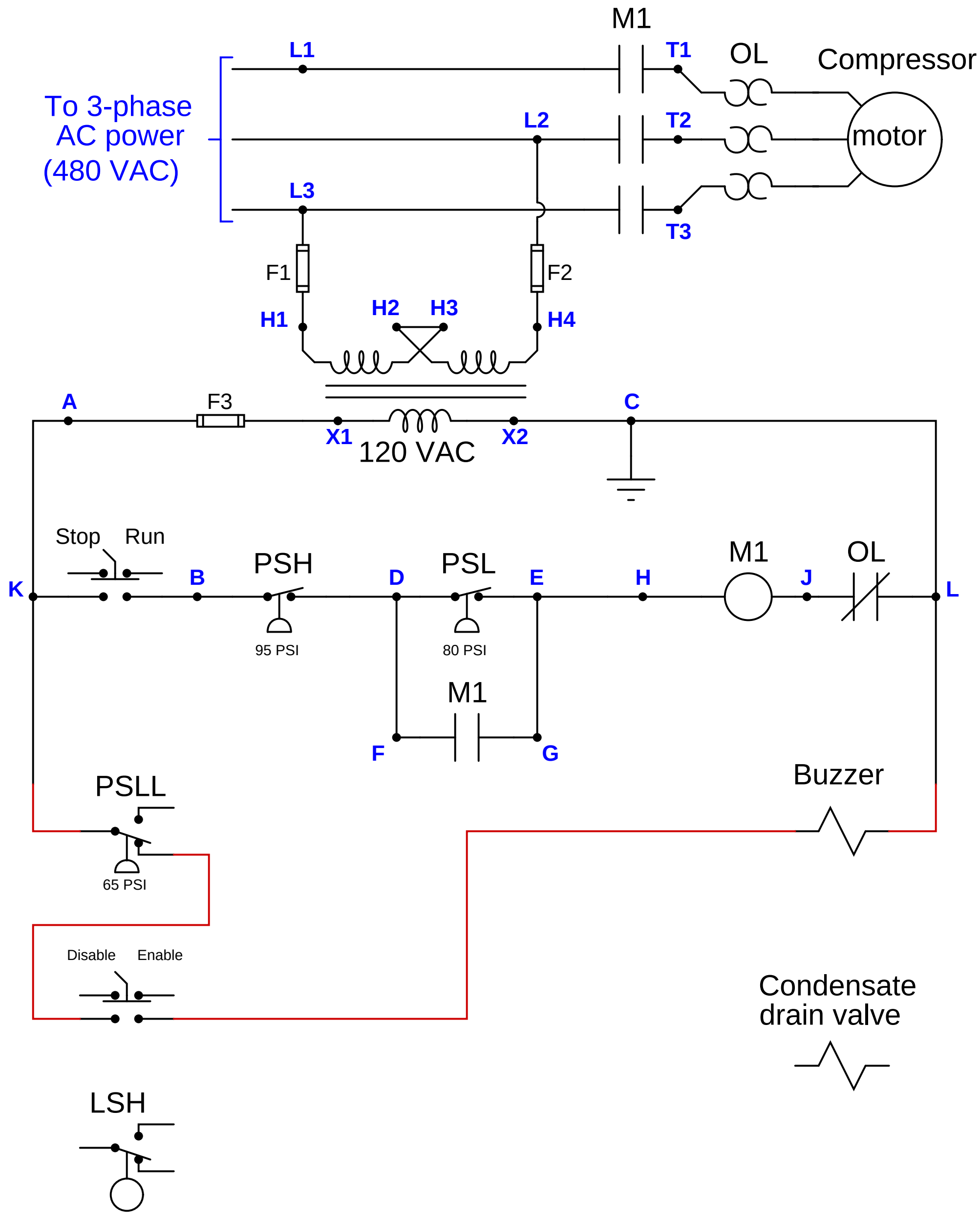
With a nozzle attached to the end of the hose, though, we are only allowed to "drop" 50 feet of hydrostatic pressure, in order to leave 30 PSI remaining at the nozzle coupling for proper operation. 50 PSI is equivalent to 115.33 feet, so this is how high we may raise the hose end with a nozzle on it.

It must be understood that the first calculation is not a very practical one. 80 PSI of pressure at the hydrant will *just* push water 184.54 feet high. If the hose were 190 feet and poised vertically, there would be a column of water inside 184.54 feet tall, with no water at all coming out the end. If the hose end were brought exactly to a height of 184.54 feet, water would be right at the lip of the hose, not even trickling out. Obviously, some pressure is needed at the hose end in order to push water out onto a fire, so the *practical*, no-hose height for 80 PSI will be somewhat lower than 184.54 feet.

The hose-with-nozzle scenario is more realistic, because an actual figure for minimum hose-end pressure is given for us to incorporate into our calculations.

Answer 4

Partial answer: (this is just one possible solution to the wiring of the pressure switch):



Answer 5

- Example 1: increasing temperature, operator should close the valve more
- Example 2: increasing level, operator should open the valve more
- Example 3: increasing flow, operator should close the valve more
- Example 4: increasing temperature, operator should open the valve more

The goal with these questions is to think like an operator, in order to have a clear understanding of the process's needs. Only when one recognizes the required direction of valve operation to correct for an upset (off-setpoint) condition is it possible to properly and confidently configure an automatic controller to do the same. This is something every instrument professional needs to consider when designing and/or commissioning a control system: *which way does the final control element need to go, in order to stabilize the process variable if it deviates too high?*

In the first example, we would need to move the fuel gas valve further closed (toward the shutoff position) if ever the temperature got too high.

In the second example, we would need to move the drain valve further open to correct for a too-high liquid level in the vessel.

In the third example, we would need to move the flow control valve further closed (toward shutoff) if ever the flow rate measured too high.

In the fourth example, we would need to open the control valve further in order to reduce a too-high oil temperature exiting the heat exchanger. The rationale for this direction of valve motion is to increase the flow rate of the oil so that each molecule spends less time in the heat exchanger absorbing heat from steam and increasing in temperature.

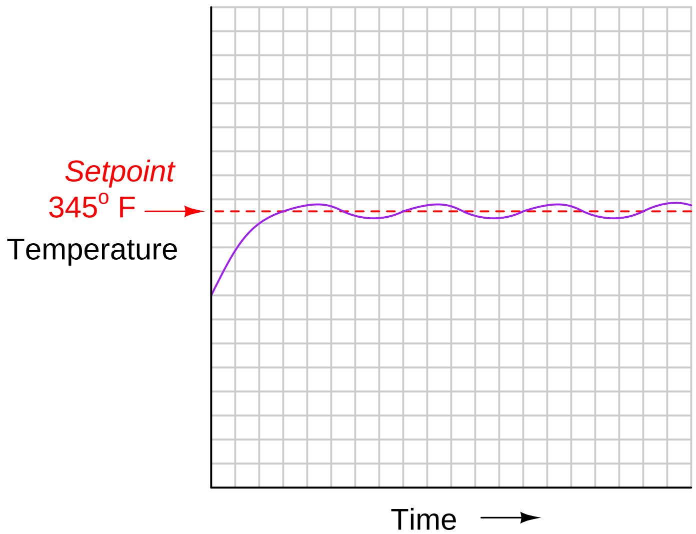
Answer 6

The human operator plays the part of a *reverse-acting* controller, because the valve action must be opposite of any changes in process variable. For example, if the water temperature increases, then the operator should move the control valve further closed.

- PV = water temperature
- SP = ideal (target) water temperature, in operator's mind
- MV = Fuel gas control valve position

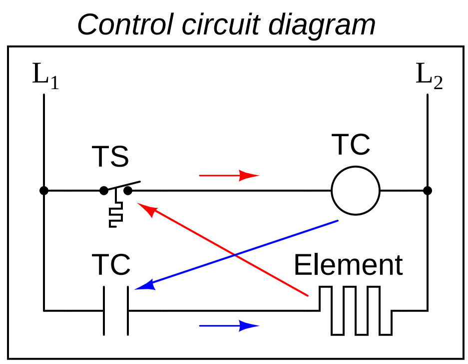
Answer 7

A simple *on-off* control system will apply full power to the heating element if the temperature is less than the setpoint, and will completely shut off power to the heating element if the temperature is greater than the setpoint. The result is a temperature graph that oscillates around the setpoint value over time.

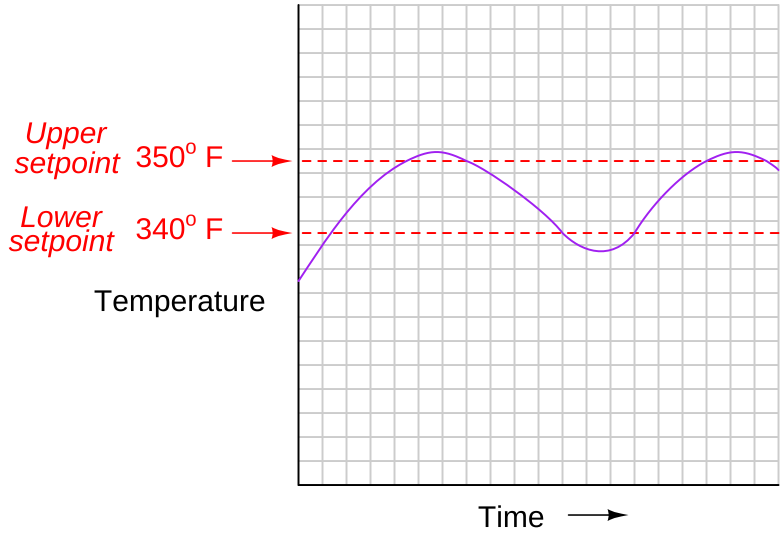


As you can see, the temperature can never settle at any one temperature, since the control action is all-or-nothing, and changes based on a simple "greater-than" or "less-than" relationship between the process variable and the setpoint.

This is an example of a *closed-loop* control system. The control "loop" may be represented in the ladder logic schematic by means of causal arrows:

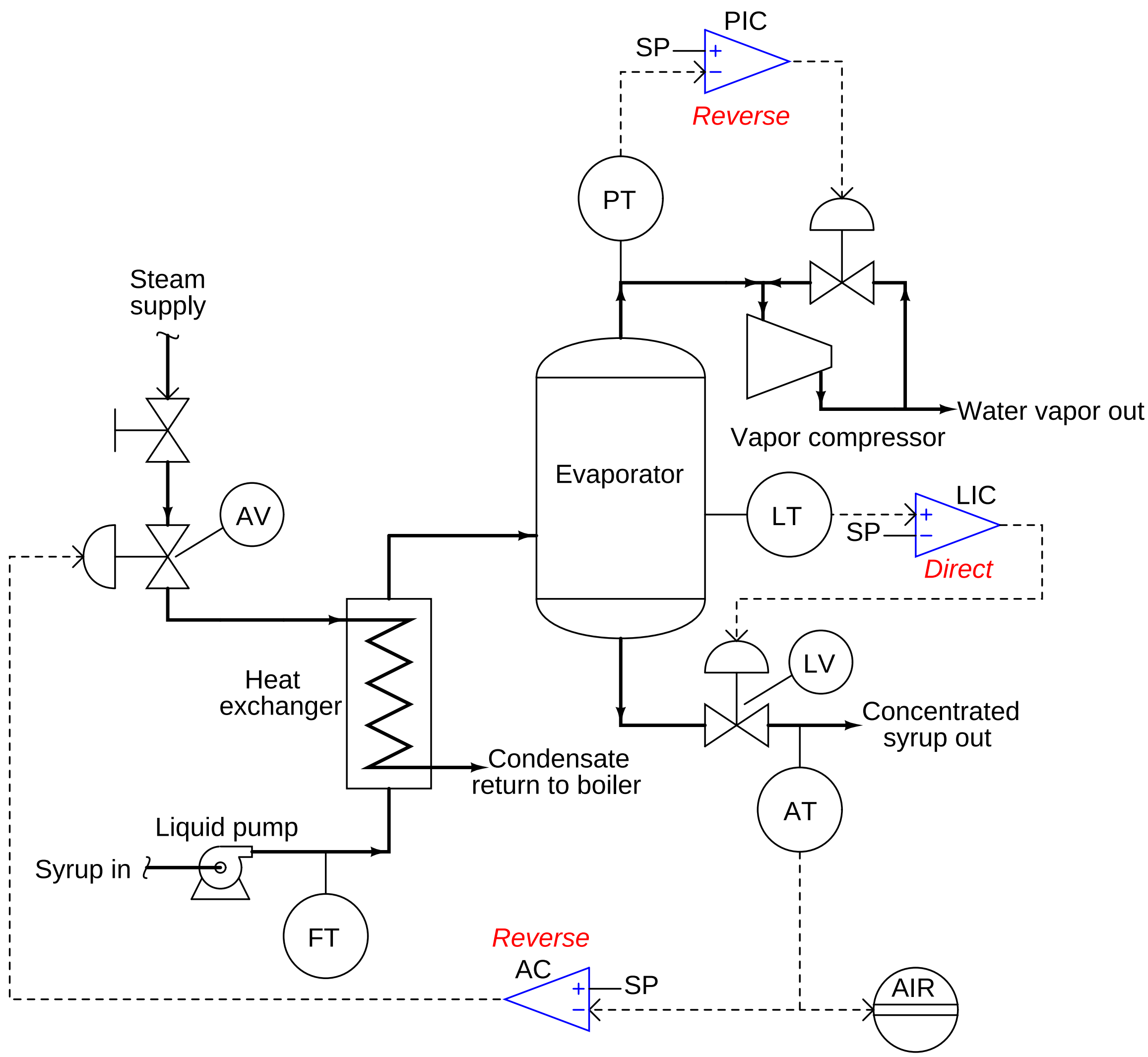


Answer 8



Answer 9

Answer 10



The analytical controller (AC) is reverse-acting in order to close off the steam valve if the sugar concentration of the syrup increases.

The level indicating controller (LIC) is direct-acting in order to open up the discharge valve if the evaporator level increases.

The pressure indicating controller (PIC) is reverse-acting in order to open up the compressor recycle valve if the pressure inside the evaporator decreases (i.e. if the vacuum becomes too strong).

Answer 11

The syrup's sugar concentration will eventually become *excessive* as the analytical controller (AC) attempts to maintain setpoint.

Answer 12

For each component in the control system, "gain" is defined in the same terms that gain is defined for any electronic component – the ratio of output change to input change:

$$\text{Gain } = \frac{\Delta \text{Out}}{\Delta \text{In}}$$

We may be more precise in our definition if we use calculus notation and express this ratio as a *derivative*:

$$\text{Gain } = \frac{d\text{Out}}{d\text{In}}$$

As for how and why to set the controller gain at a particular value, I will let you discuss this with your classmates and arrive at your own answer! I will say this, though: we do *not* want the system to break into oscillations!

Challenge question: as you may (should!) recall, a necessary condition for oscillation in a feedback system is that the feedback be *positive*. In other words, the phase shift from amplifier output to amplifier input needs to be 360^o, or else any oscillation will quickly die out due to interference, regardless of gain. This being said, how can a control system ever oscillate, because we know the feedback is normally *negative* in nature, not positive? Even if the controller gain were huge, shouldn't the inherently negative feedback of the system naturally prevent oscillation?

Answer 13

Answer 14

Answer 15

Answer 16

Answer 17

Answer 18

Answer 19

Answer 20

Answer 21

Answer 22

Answer 23

Answer 24

Answer 25

Gain = 0.5 and bias = 30%

Answer 26

To use caSCADA as a PID simulator in BTC's Instrumentation lab, simply log in to one of the caSCADA development systems in the BTC lab and type ./looptune at the command-line prompt:

- First, connect to the "Instrumentation" wireless network with your personal computer.

- Use SSH client software (e.g. BitVise) to log into any one of the caSCADA RTU computers (e.g. 169.254.8.103 for the one located in cabinet DCS-02). The user name is btc and the password is btc.

- Type ./looptune at the terminal command prompt and press Enter.

- Follow the instructions as the program launches!

Alternatively, you could install caSCADA on your own computer and be able to run the looptune simulator anywhere you wish. Here are some options:

- Install free Cygwin software on your Windows-based PC, under which you may compile and run looptune. Cygwin is a Unix emulation program providing a POSIX-compliant environment on any Windows operating system in which Unix software may be installed, compiled, and executed. *This is perhaps the easiest option for someone with a Windows-based computer who does not wish to purchase anything or alter the operating system on their computer.*
- Purchase your own single-board Linux-based PC such as a Raspberry Pi and run it natively on that platform.
- Install and compile and run looptune natively on an Apple PC with Unix-based operating system.
- Install the Linux operating system on your own PC, then install and compile and run looptune natively.

caSCADA is downloaded as a single "tar" file with a name such as cascada_3v5.tar. The two numbers and the "v" represent the version of that software (e.g. cascada_3v5.tar is version 3.5 of the caSCADA software). Obtain the latest version of the software, download it to a directory on your computer accessible via a command-line "terminal" environment, and then enter the following commands to compile this software:

```
tar xvf cascada*tar

make looptune
```

After running these commands, looptune should be ready to use. Simply enter the following command to begin execution:

```
./looptune
```

Answer 27

Answer 28

Proportional-only offset is the phenomenon that occurs with a controller lacking any integral ("reset") action, whereby the process variable cannot perfectly achieve most setpoint values, but rather will settle at some stable value that is offset from setpoint. The degree of offset between PV and SP is a function of the controller's bias value and process load(s).

Answer 29

The "automatic" mode is proper, and the low output signal value tells us the controller is doing all it can to bring the temperature down. The problem, therefore, is *not* in the controller's automatic response!

Answer 30

A *load* is any variable in a process (besides the manipulated variable) that has influence over the process variable being controlled.

Note: the following answers are not exhaustive. In other words, there may be more loads than what is listed here for each process!

- Example 1: ambient air temperature
- Example 2: incoming flow rate
- Example 3: upstream and downstream pressures
- Example 4: steam flow rate, steam temperature

Answer 31

- Gain = 1; P.B. = 100%
- Gain = 2; P.B. = 50%
- Gain = 3.0; P.B. = 33.3%
- Gain = 0.5; P.B. = 200%
- Gain = 0.2; P.B. = 500%
- Gain = 0.01; P.B. = 10,000%
- Gain = 5.5; P.B. = 18.18%
- Gain = 10.2; P.B. = 9.804%

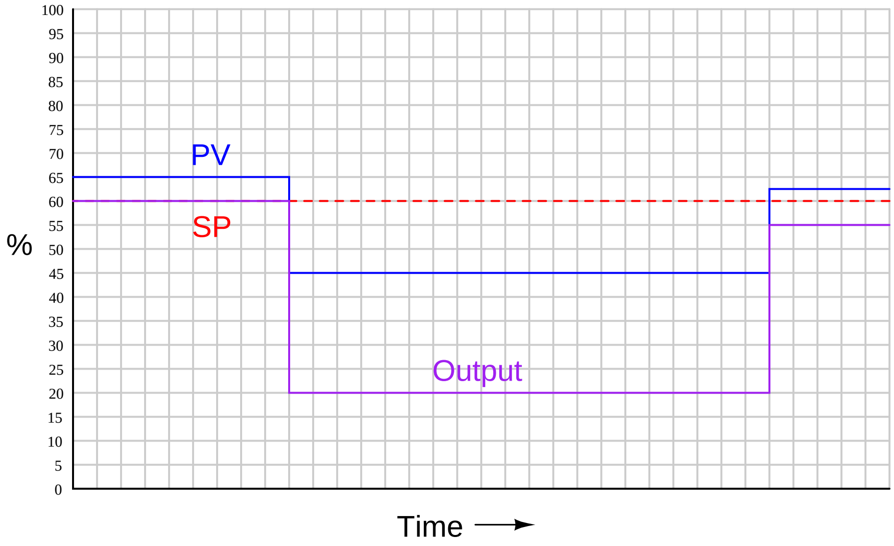
Answer 32

- P.B. = 150%; Gain = 0.667
- P.B. = 300%; Gain = 0.333
- P.B. = 40%; Gain = 2.5
- P.B. = 10%; Gain = 10
- P.B. = 730%; Gain = 0.137
- P.B. = 4%; Gain = 25
- P.B. = 247%; Gain = 0.4049
- P.B. = 9.5%; Gain = 10.53

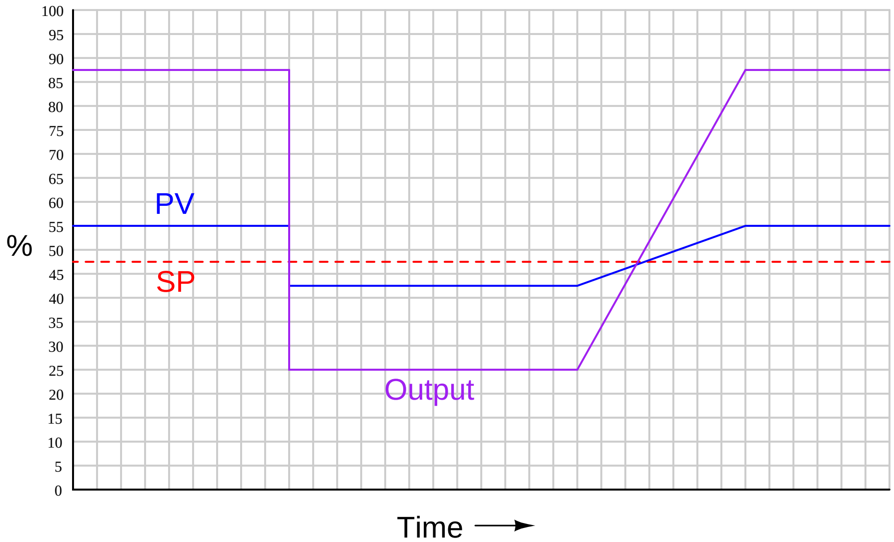
Answer 33

With the relocated feedback connection, the opamp now "senses" the load voltage at the output terminals, and is able to correct for *any* voltage losses in the power transistor. With the previous feedback connection (from the output terminal of the opamp), the opamp was only able to regulate voltage at the base of the transistor, not at the load itself.

Answer 34



Answer 35



Answer 36

This is a *reverse-acting* level controller: the output rises when the PV input falls, and vice-versa.

"Proportional band" is the percentage that the controller input (SP − PV) must deviate in order to swing from 0% to 100% on the output. As you may have noticed, proportional band is the mathematical reciprocal of gain.

Answer 37

When a controller is in the automatic mode, output tracking means the manual output value follows along ("tracks") the automatic output value so that when the controller is switched to manual mode, the transition will be bumpless.

When a controller is in the manual mode, setpoint tracking means the setpoint value follows along ("tracks") the process variable value so that when the controller is switched to automatic mode, the setpoint will begin at the same value as the process variable, and control starts with no error.

In other words, setpoint tracking means the controller assumes the process is where you want it to be at the moment you switch to automatic mode.

Answer 38

Answer 39

Answer 40

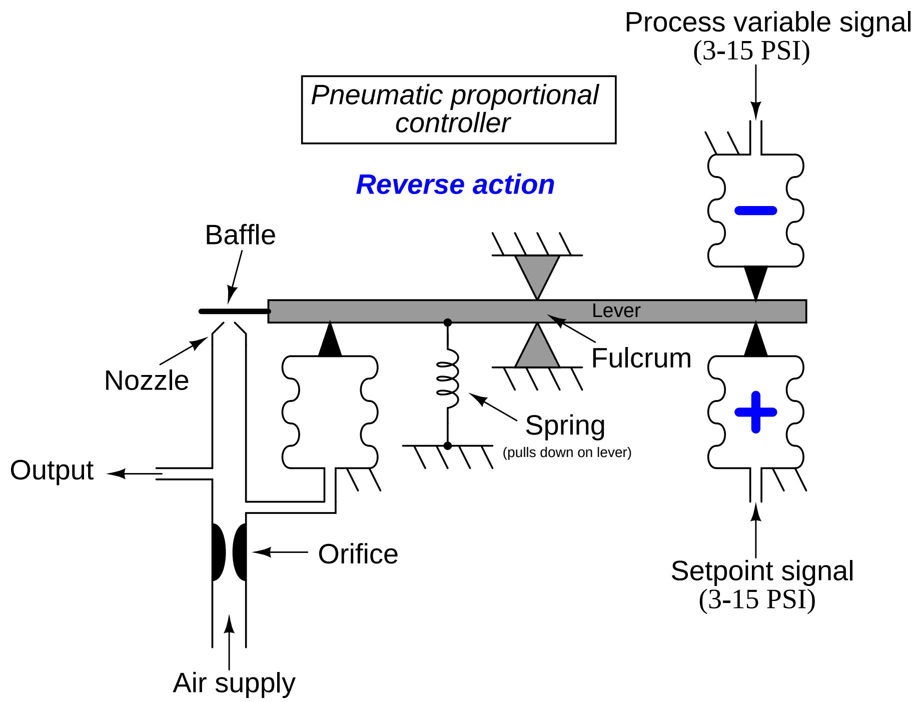
Answer 41

Answer 42

Answer 43

Partial answer:

- Does it work on the *force-balance* or *motion-balance* principle? **Force-balance** (actually, it is a *moment-balance* mechanism, to be precise).
- Explain (step-by-step) what happens when the process variable input signal increases and the setpoint remains the same. **First, the baffle moves away from the nozzle, decreasing backpressure, decreasing force exerted by the feedback bellows, returning the system to equilibrium with a lesser output pressure**.
- How could the bias of this controller be adjusted? **Change the spring tension**.



Answer 44

Hint: the ball should be exactly centered in the tube before moving the transfer valve.

Answer 45

Partial answer:

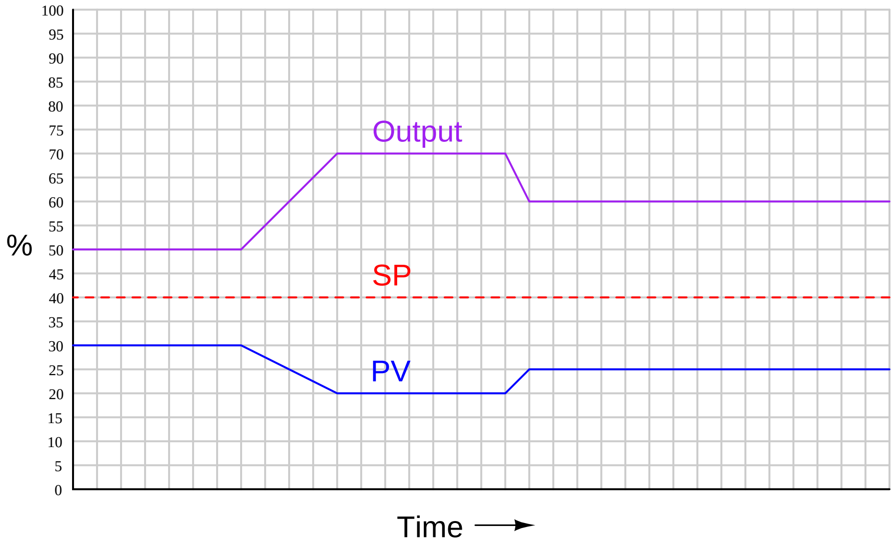
- What would be required to invert the action of the controller, from direct to reverse action or vice-versa? **Flip the process variable bellows from the top side of the beam to the bottom side of the beam**.
- How could the setpoint of this controller be adjusted? **Moving the nozzle closer to or further away from the beam**.

Answer 46

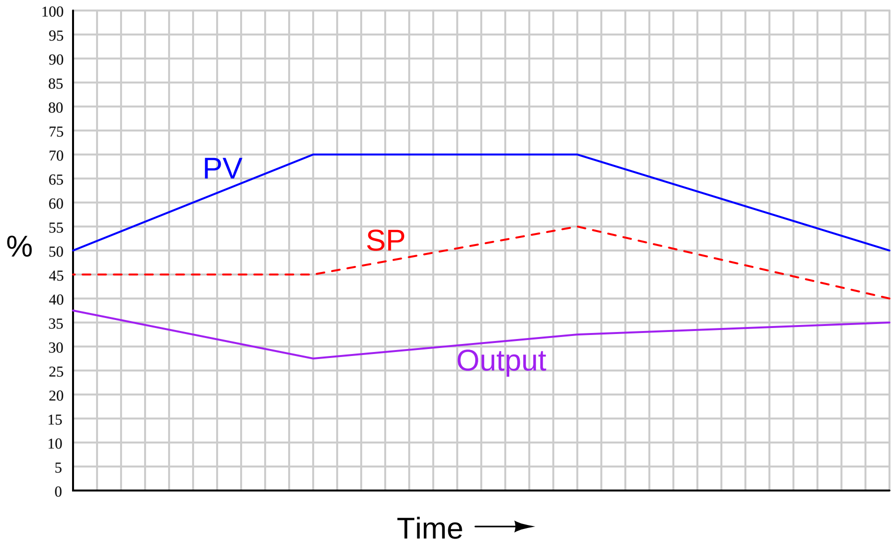
Hint: the pneumatic *pilot* mechanism is analogous to an electrical potentiometer when wired as a voltage divider.

To see an electrical analogue of this mechanism, sketch a negative-feedback opamp circuit where the inverting input of the opamp receives a fraction of the output voltage through a potentiometer.

Answer 47



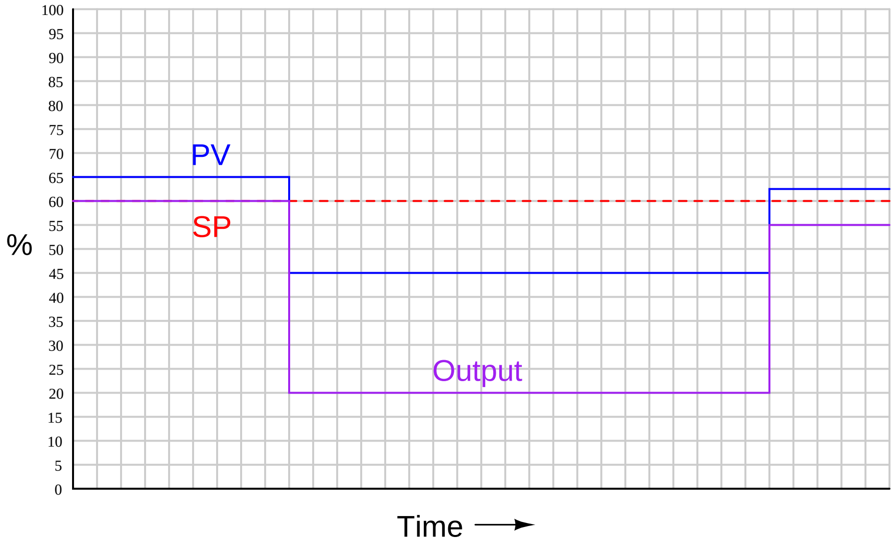
Answer 48



Answer 49

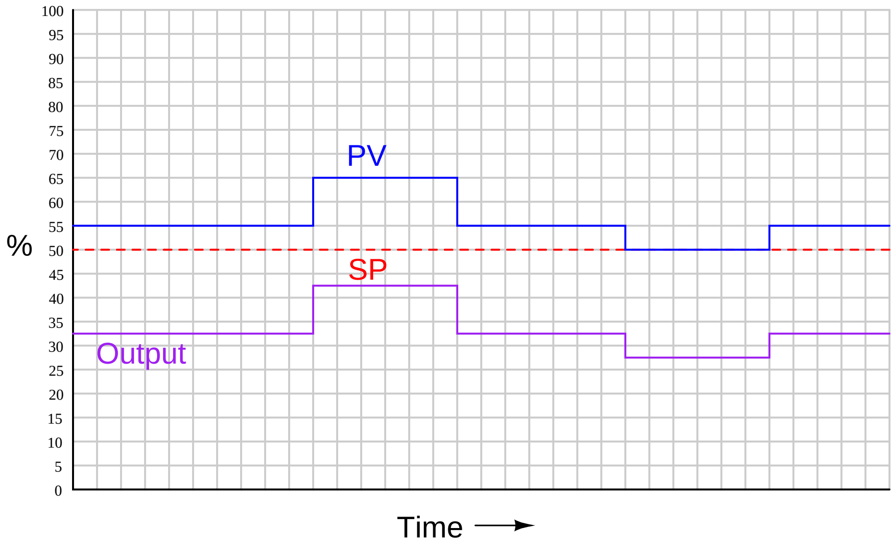
The problem is most likely the controller, but I will let you determine the nature of the problem!

Answer 50

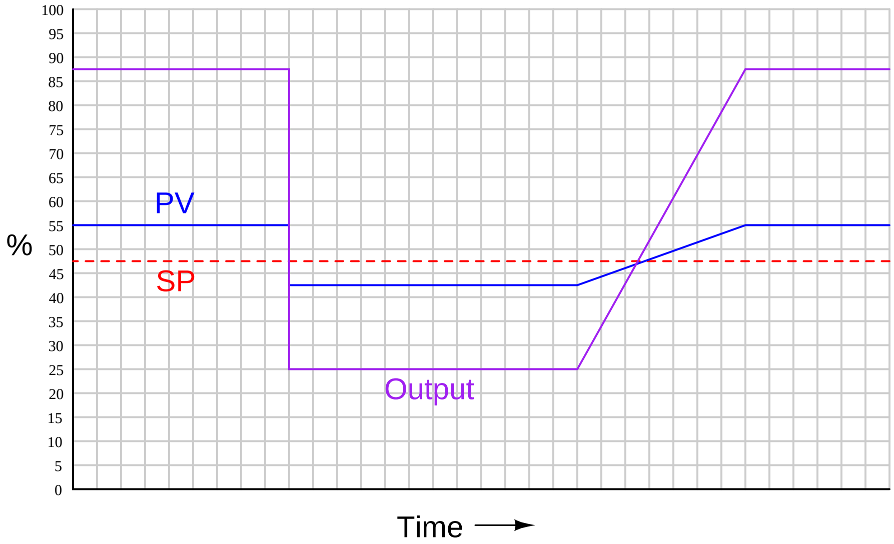


Answer 51

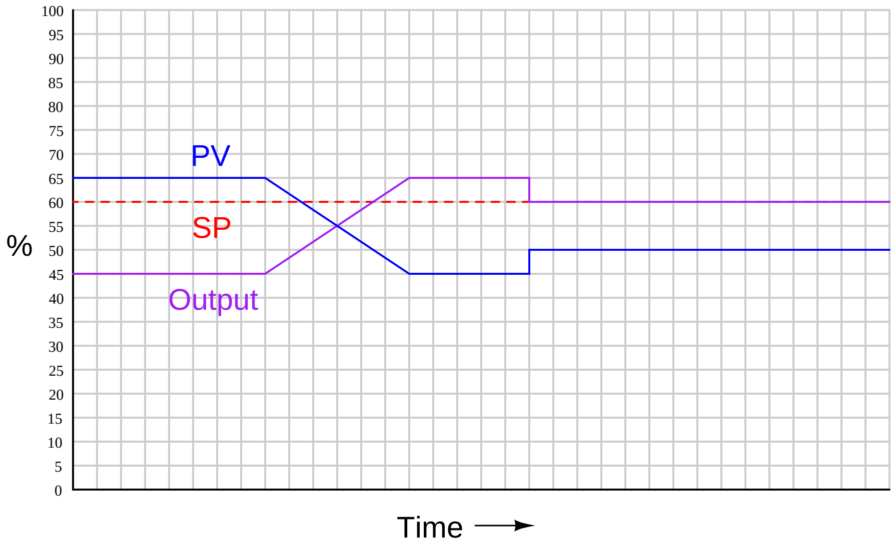
With proportional action, the amount of error tells the output how **far** to go:



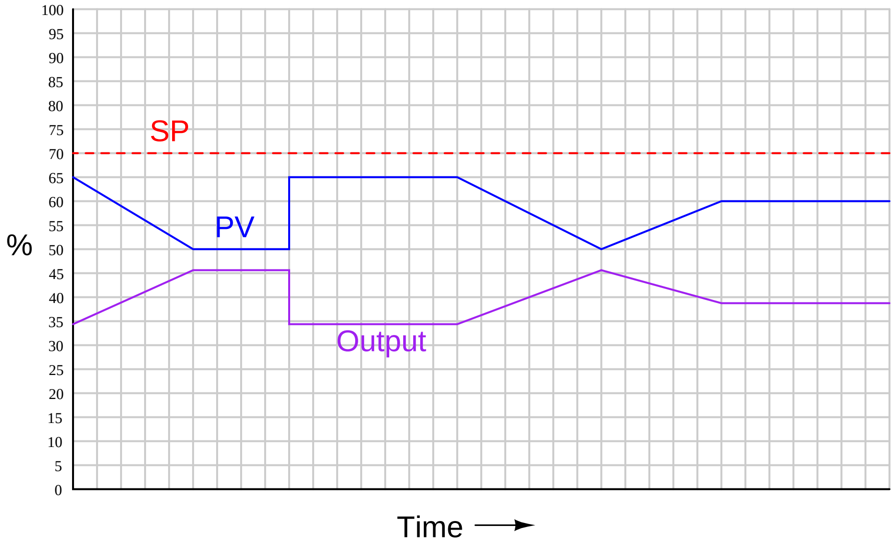
Answer 52



Answer 53



Answer 54



With a proportional band value of 125%, the gain will be equal to 0.8.

$$m = 0.8(\mathrm{SP} - \mathrm{PV}) + 30$$

PV	**SP**	**Output**
65%	70%	34%
50%	70%	46%
60%	70%	38%

Answer 55

The principle is fairly straightforward to figure out, but gain and setpoint are not as easy. To change gain, you could substitute a different-sized diaphragm in the valve actuator. Setpoint adjustments could be made by changing the *bench set* of the valve.

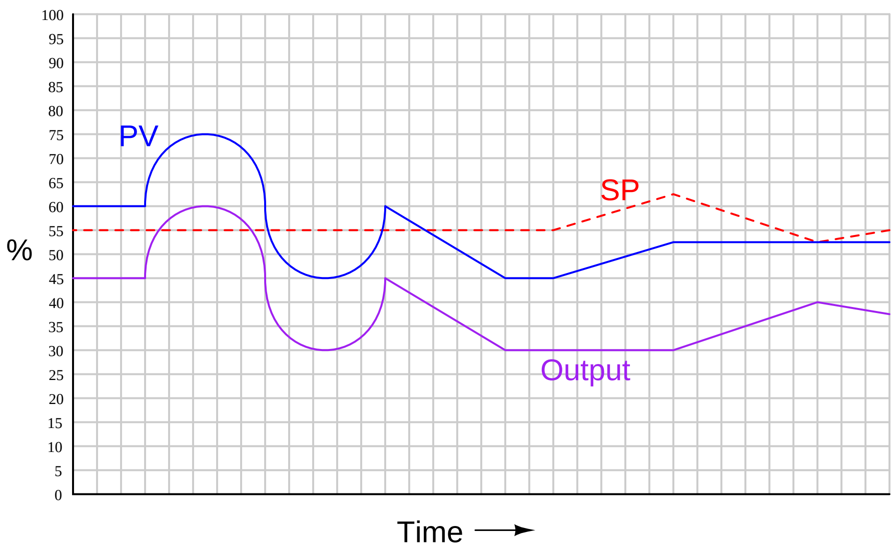
Answer 56

The problem is increased sensor gain with the new calibration range. The solution is to reduce the controller's gain (increase its proportional band) to compensate.

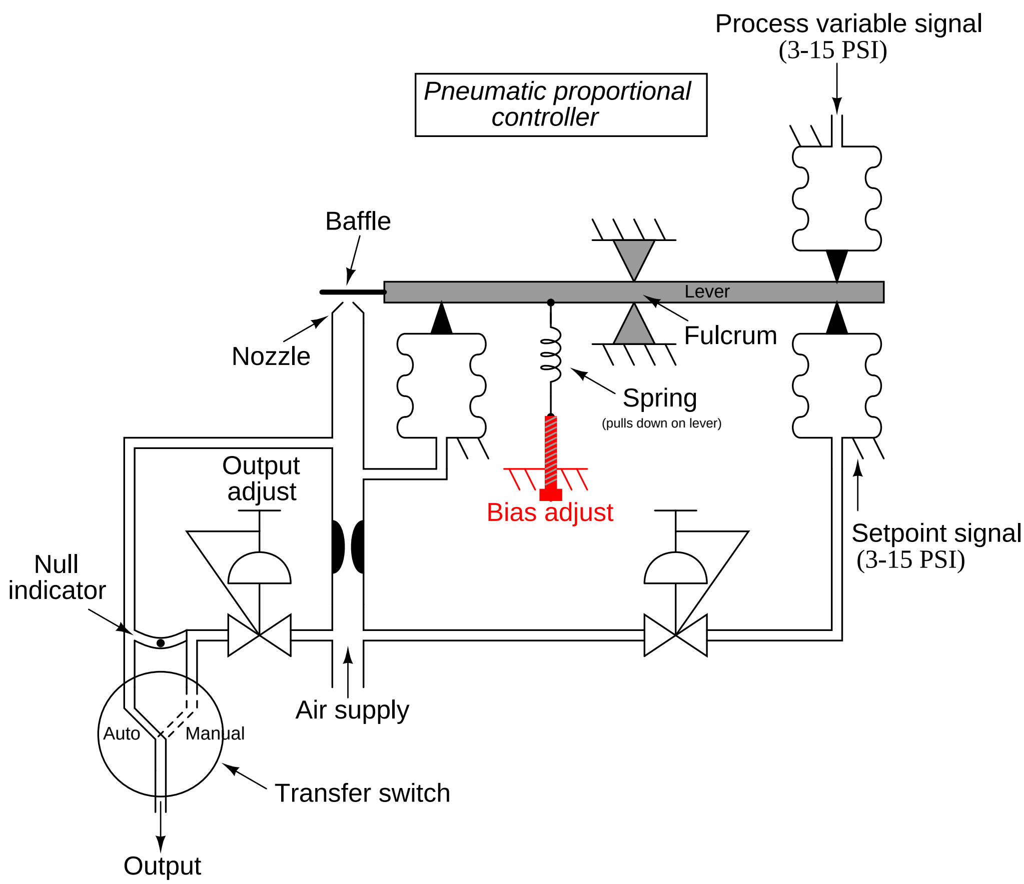
Answer 57

The odds of making a smooth, "bumpless" transfer from one mode to the other will be very slim!

Answer 58



Answer 59

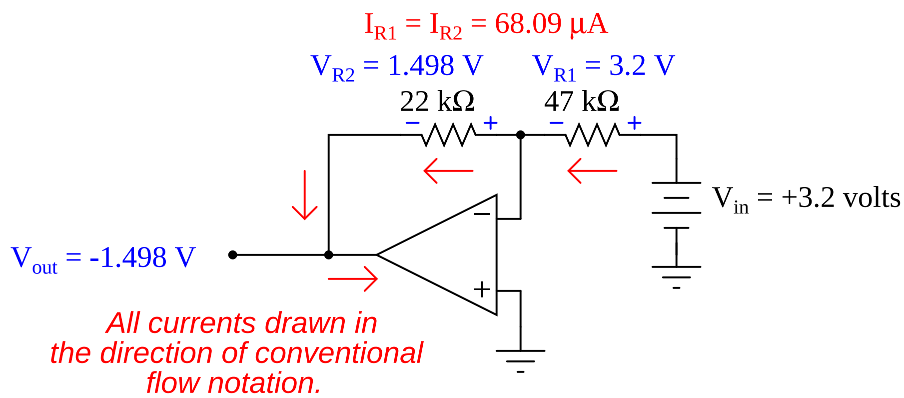


Answer 60

Answer 61

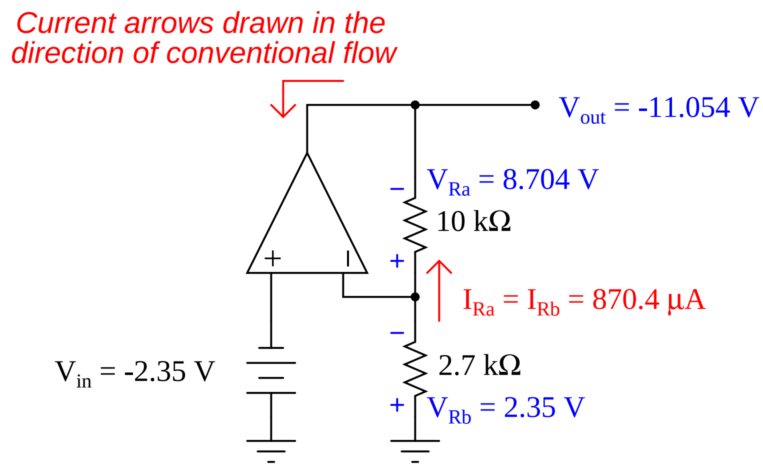
Answer 62

Answer 63



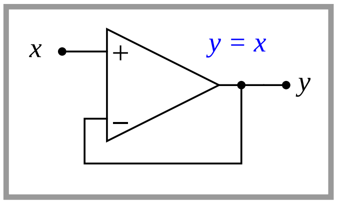
$A_V = 0.468 = -6.594$ dB

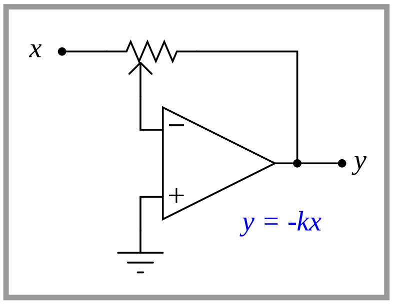
Answer 64

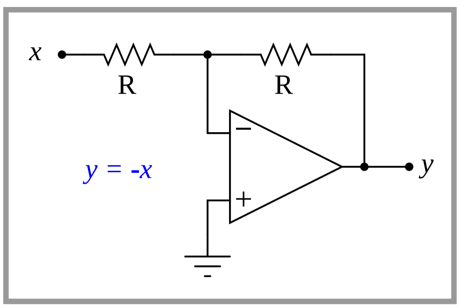


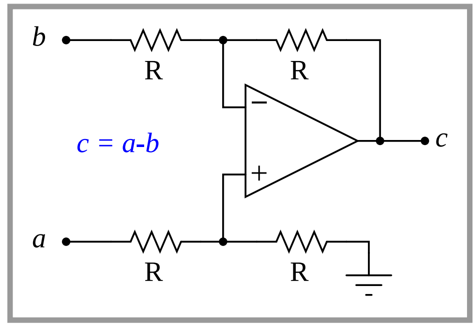
$A_V = 4.704 = 13.449$ dB

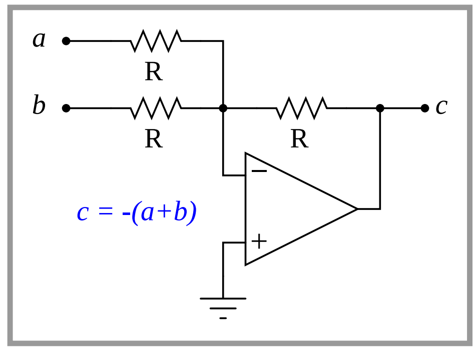
Follow-up question: how much input impedance does the -2.35 volt source "see" as it drives this amplifier circuit?

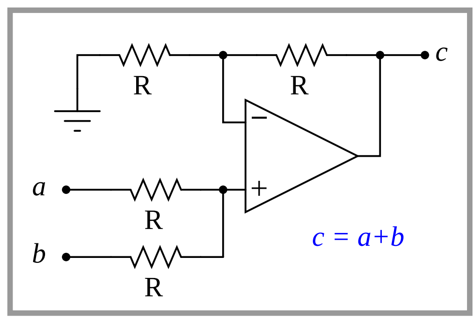

x
y = x
y
+
−


x
y
−
+
y = -kx

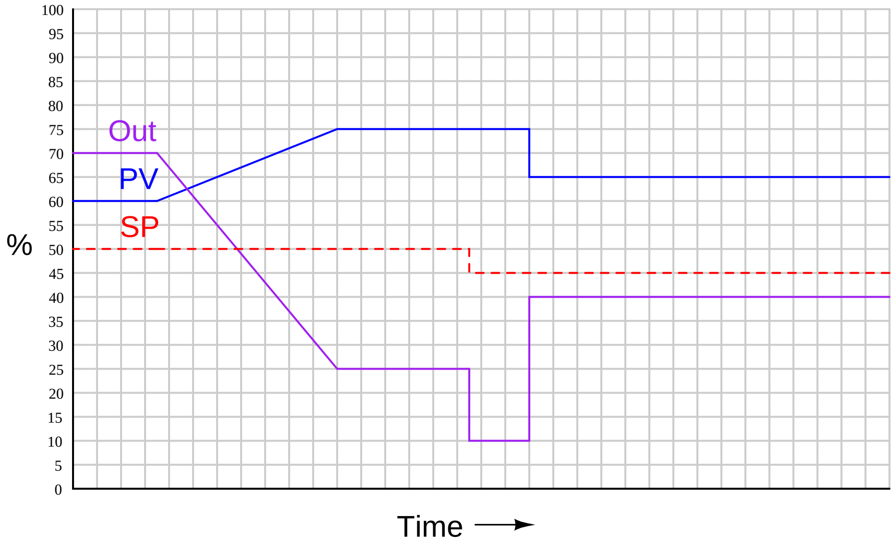

x
R
R
y = -x
y
−
+


b
R
R
c = a-b
c
−
+
a
R
R


a
R
b
R
R
c
c = -(a+b)
−
+


R
R
c
−
+
a
R
b
R
c = a+b

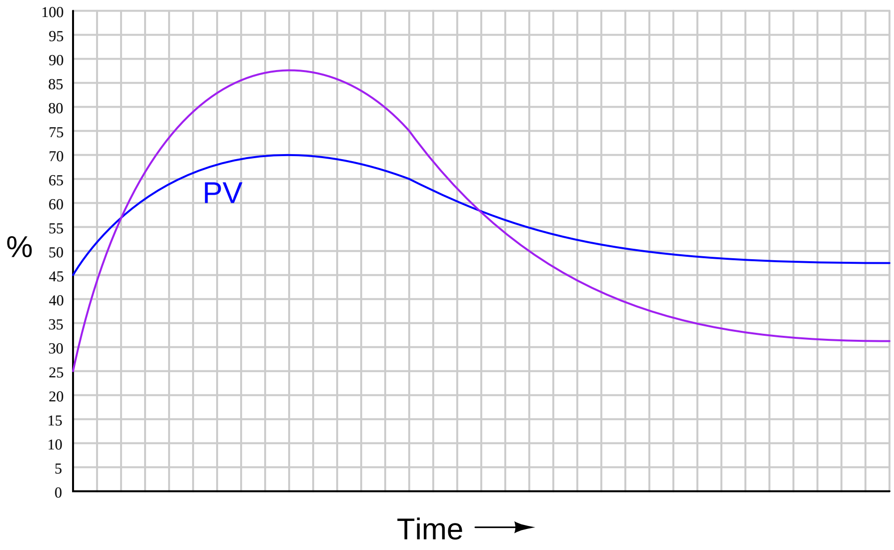
Answer 66



Answer 67

Proportional band = 66.67% ; reverse-acting control

Answer 68



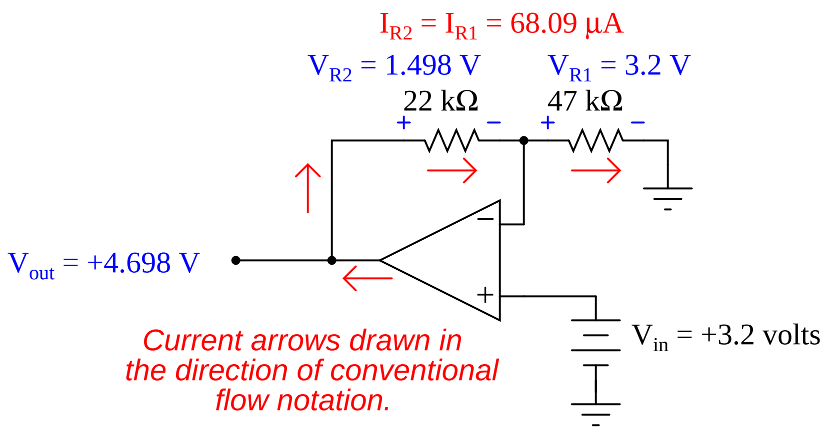
Answer 69

Fault	Possible	Impossible
Opamp U_1 output failed to low rail		$\surd$
Opamp U_4 output failed to high rail		$\surd$
Opamp U_5 output failed to low rail	$\surd$	
R_1 connection to ground failed open	$\surd$	
R_3 connection to +V failed open		$\surd$
Resistor R_8 failed open		$\surd$
Resistor R_9 failed open	?	
Resistor R_{10} failed open	?	
Resistor R_{11} failed open		$\surd$

R_1 connection to ground failed open is possible because that potentiometer connects to the negative power supply rail (-V) and thus an open ground would make the bias signal go fully negative, driving the controller's output fully positive.

An open R_9 or open R_{10} makes sense only for certain (large) values of bias, if the output never deviates from full saturation *no matter what values are input to PV or SP*.

Answer 70



$A_V = 1.468 = 3.335$ dB

Answer 71

The voltage divider would have to altered so as to send a smaller proportion of the output voltage to the inverting input.

Answer 72

V_{in} = -10 V $\qquad$ V_{out} = 24 V

Follow-up question: how do we know that the input voltage in this circuit is negative and the output voltage is positive?

Answer 73

$$R_2 = \frac{R_1}{A_V}$$

For the circuit shown, R_2 would have to be set equal to 1.571 kΩ.

Answer 74

$$R_2 = \frac{R_1}{A_V - 1}$$

For the circuit shown, R_2 would have to be set equal to 810.3 Ω.

Answer 75

Partial answer:

- Solder bridge (short) across resistor R_1: *Output saturates negative.*
- Broken wire between R_1/R_2 junction and inverting opamp input: *Output voltage unpredictable.*

Answer 76

- Resistor R_1 fails open: *Output saturates positive.*
- Solder bridge (short) across resistor R_1: $V_{out} = V_{in}$.
- Resistor R_2 fails open: $V_{out} = V_{in}$.
- Solder bridge (short) across resistor R_2: *Output saturates positive.*
- Broken wire between R_1/R_2 junction and inverting opamp input: *Output voltage unpredictable.*

Answer 77

Two potentiometers provide dual setpoints for the voltage comparators to act upon. If the process variable signal (the thermocouple's output voltage) is less than the lower setpoint, the lower op-amp saturates "high," activating the "Set" input of the S-R latch and engaging power to the heating element.

When the oven temperature is between the two setpoints (LSP < PV < USP), both op-amp outputs will be in the "low" state, and the S-R latch will hold its last output state on Q.

When the process variable exceeds the upper setpoint, the upper op-amp saturates "high," activating the "Reset" input of the S-R latch and disengaging power to the heating element.

In summary, this is a simple *differential-gap* control system for a cookie oven. For tightest temperature control, set the LSP potentiometer to maximum (full *up*) and the USP potentiometer to minimum (full *down*).

Answer 78

- Module 1: Voltage follower (buffer) for PV signal
- Module 2: Voltage follower (buffer) for SP signal
- Module 3: Differential amplifier (calculates error signal)
- Module 4: Variable-gain amplifier (multiplies error signal by K_p, set by potentiometer)
- Module 5: Voltage follower (buffer) for bias signal
- Module 6: Summer, adds bias signal to output of amplifier

This is a *reverse-acting* controller.

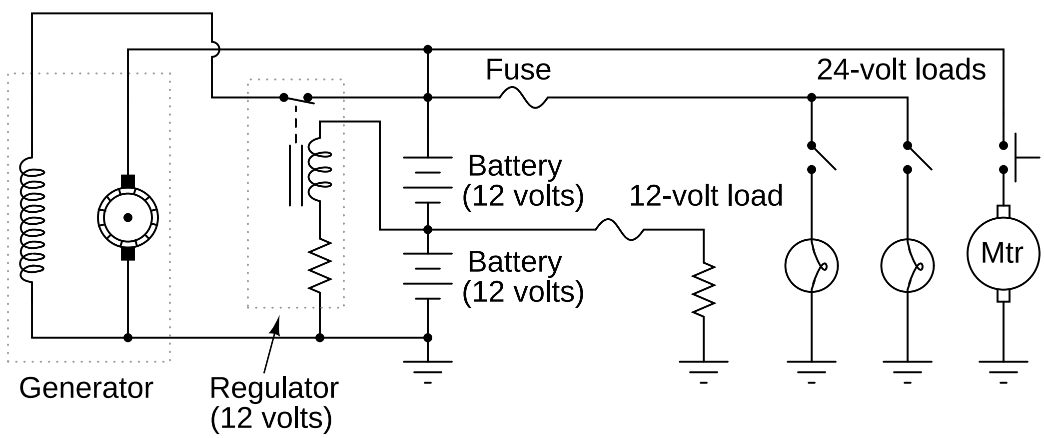
Answer 79

So long as the generator is capable of outputting 12 volts, this system will work!

In this question, we see a foreshadowing of op-amp theory, with the regulator's negative feedback applied to what is essentially a voltage divider (two equal-voltage batteries being charged by the generator). The regulator circuit senses only 6 volts, but the generator outputs 12 volts. Fundamentally, the focus of this question is *negative feedback* and one of its many practical applications in electrical engineering.

This idea actually came from my father, who did this very thing on an International T-4 bulldozer. An important difference is that he used a single 12-volt battery rather than two 6-volt batteries, creating a center-tap connection on the 12-volt battery to make it perform as two 6-volt batteries. To do this, he carefully drilled a hole in the top of the battery to intersect with the lead bus bar between the third and fourth cells, threading a screw into that bus bar as the center-tap terminal. In fact, the entire motivation for this project was that it was far cheaper for him to get a new 12-volt battery than to buy a new 6-volt battery, and he had plenty of 12-volt electrical accessories (headlights, ignition coils, etc.) to upgrade the bulldozer.

One of the readers of my online textbook wished to do something similar, except his plan was to make the vehicle's original 12-volt system output 24 volts so he could power surplus military accessories. An important distinction for this fellow's system is that he planned to have more than a few 12-volt loads remaining in the vehicle, such as a 12-volt radio:



As a challenge for your students, ask them how well they think *this* system would work. It is a bit more complex than the system shown in the question, due to the two different load banks.

Answer 80

One potential cause is digester R-101 running too cold, cooling off the contents of the second digester.

Answer 81

This is a graded question – no answers or hints given!

Answer 82

This is a graded question – no answers or hints given!

Answer 83

This is a graded question – no answers or hints given!

Answer 84

This is a graded question – no answers or hints given!

Answer 85

This is a graded question – no answers or hints given!

Answer 86

This is a graded question – no answers or hints given!

Answer 87

This is a graded question – no answers or hints given!

Answer 88

This is a graded question – no answers or hints given!

Answer 89

This is a graded question – no answers or hints given!

Answer 90

This is a graded question – no answers or hints given!

Answer 91

Answer 92

Your loop diagram will be validated when the instructor inspects the loop with you and the rest of your team.